WTRM 206 BEGINNING WATER TREATMENT PLANT



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WTRM 206 Beginning Water Treatment Plant

by

Catherine Ames

Remixed for Gavilan College

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1.1.1: 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 1.1.1.1: Fraction

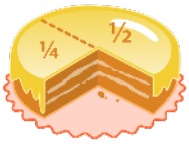


Figure 1.1.1.2: Cake Fractions by Acdx is in the public domain

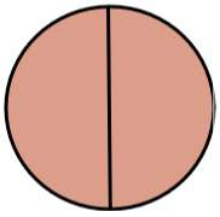


Figure 1.1.1.3: Circle with Proportions by COC OER is licensed under CC BY 4.0

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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1.1.2: 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:

$$\frac{8}{3} \rightarrow 3\overline{)\,8} \;\; \begin{array}{r} 2 \\ \\ -6 \\ \hline 2 \end{array} \quad = 2\frac{2}{3}$$

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

Example:

$$\frac{18}{4} \rightarrow 4\overline{)\,18} \;\; \begin{array}{r} 4 \\ \\ -16 \\ \hline 2 \end{array} \quad = 4\frac{2}{4} = 4\frac{2}{4} \div \frac{2}{2} = 4\frac{1}{2}$$

Exercise 1.2

Reduce the following fractions to their lowest terms.

1. $\frac{7}{2}$
2. $\frac{10}{4}$
3. $\frac{18}{4}$
4. $\frac{20}{4}$
5. $\frac{6}{5}$
6. $\frac{100}{3}$
7. $\frac{39}{6}$
8. $1\frac{8}{12}$
9. $2\frac{9}{4}$
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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1.1.3: 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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1.1.4: 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 x 3 = 6 and 1 x 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 1.1.4.1

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

Example 1.1.4.2

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

In the first Example **1.1.4.1**, if you multiply the numbers across as before, you would multiply 1 times 1 and then 2 x 2. The resulting answer would be 1 over 4 or one forth. In the next Example **1.1.4.2** 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 1.1.4.3

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

In the Example **1.1.4.3**, 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 1.1.4.4

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

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 1.1.4.5

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

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

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

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

$\frac{-32}{1}$

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. $5\frac{9}{3} \times 7\frac{3}{5}$
6. $\frac{21}{24} \times \frac{4}{7} \times \frac{6}{3}$
7. $\frac{1}{100} \times \frac{10}{20}$
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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1.1.5: 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 1.1.5.1

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

Example 1.1.5.2

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

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 1.1.5.3

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

In the Example **1.1.5.3** 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 1.1.5.4

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

Exercise 1.5

Divide the following and reduce if necessary.

1. $\frac{1}{2} \div \frac{2}{4}$
2. $\frac{5}{22} \div 7\frac{2}{4}$
3. $\frac{6}{8} \div \frac{9}{12}$
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. $\frac{9}{13} \div 9$
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. $\frac{13}{33} \div \frac{39}{3}$
16. $100\frac{1}{2} \div 10\frac{5}{6}$

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SECTION OVERVIEW

1.2: Decimals

1.2.1: Understanding Decimals

1.2.2: Multiplying and Dividing Decimals

1.2.3: Rounding

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1.2.1: 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 1.2.1.1

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 1.2.1.2

$0.1 \rightarrow \frac{1}{10}$ 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 = Twelve and three tenths = $\mathbf{12\frac{3}{10}}$

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

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

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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1.2.2: 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 1.2.2.1

0.255 × 0.23 = 0.05865

25 × 35 = 875

100.5 × 12.75 = 1,281.375

Exercise 2.2

Multiply the following problems

1. $\begin{array}{r} 5 \\ \times 0.35 \\ \hline \end{array}$
2. $\begin{array}{r} 65 \\ \times 0.2 \\ \hline \end{array}$
3. $\begin{array}{r} 0.515 \\ \times 0.15 \\ \hline \end{array}$
4. $\begin{array}{r} 20.54 \\ \times 5.01 \\ \hline \end{array}$
5. $\begin{array}{r} 0.002 \\ \times 1.07 \\ \hline \end{array}$
6. $\begin{array}{r} 0.9 \\ \times 0.8 \\ \hline \end{array}$
7. $\begin{array}{r} 8.5 \\ \times 0.2 \\ \hline \end{array}$
8. $\begin{array}{r} 52 \\ \times 0.11 \\ \hline \end{array}$
9. $\begin{array}{r} 0.4 \\ \times 0.04 \\ \hline \end{array}$
10. $\begin{array}{r} 4.23 \\ \times 2 \\ \hline \end{array}$
11. $\begin{array}{r} 0.2 \\ \times 0.45 \\ \hline \end{array}$
12. $\begin{array}{r} 2.68 \\ \times 0.298 \\ \hline \end{array}$

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 1.2.2.2

$$\frac{125}{25} = 5$$
$$\frac{1.25}{25} = 0.05$$
$$\frac{1.25}{0.25} = 5$$

Exercise 2.2.1

Divide the following problems.

1. $0.6 \div 5 =$
2. $28 \div 7 =$

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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1.2.3: 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 1.2.3.1

2 × 2 = 4	Since both numbers you are multiplying are whole numbers, then you would leave the answer as a whole number.
2.0 × 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 × 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 1.2.3.2

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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SECTION OVERVIEW

1.3: Percentages

1.3.1: Expressing Numbers as Percentages

1.3.2: Word Problems

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1.3.1: 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 1.3.1.1

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.

$1.4 \times 100 = 40\%$

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 1.3.1.2

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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1.3.2: 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 (x) sign. You must also remember to convert the percent to a decimal prior to solving.

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SECTION OVERVIEW

1.4: Equations and Word Problems

1.4.1: Solving Equations

1.4.2: Ratios and Proportions

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1.4.1: 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 1.4.1.1

$3+1=4$ 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 1.4.1.2

$3+X=4$

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 1.4.1.3

$2N=10$	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 1.4.1.4

$\frac{2}{3}N = 14$	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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1.4.2: 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 1.4.2.1

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

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.

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

Exercise 4.2

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

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 1.4.2.2

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.

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

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 × 6 hours = 5 employees x W hours

$$18 = 5W$$
$$W = \frac{18}{5}$$
$$W = 3.6 \text{ hours}$$

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 1.4.2.3

10% of 100 is

10% × 100 =

0.10 × 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 ½ 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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SECTION OVERVIEW

1.5: Unit Dimensional Analysis

1.5.1: Units

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1.5.1: 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 1.5.1.1

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.

$$\frac{\not{\text{sec}}}{1} \times \frac{\text{min}}{\not{\text{sec}}} = \text{min}$$

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.

$$\frac{\not{\text{sec}}}{1} \times \frac{\not{\text{min}}}{\not{\text{sec}}} = \frac{\not{\text{hour}}}{\not{\text{min}}} \times \frac{\text{day}}{\not{\text{hour}}} = \text{day}$$

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 1.5.1.2

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.

$$\frac{1cf}{\not{sec}} \times \frac{60\ \not{sec}}{min} = \frac{60cf}{min}$$

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.

$$\frac{1cf}{sec} \times \frac{7.48gal}{cf} = \frac{1\ \not{cf}}{sec} \times \frac{7.48gal}{\not{cf}} = \frac{7.48gal}{sec}$$

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

$$\frac{1\ \not{cf}}{\not{sec}} \times \frac{60\ \not{sec}}{min} \times \frac{7.48gal}{\not{cf}} = \frac{448.8gal}{min}$$

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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SECTION OVERVIEW

1.6: 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 ft^2). 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.

1.6.1: Areas

1.6.2: Volumes

1.6.3: Circumference

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1.6.1: Areas

Circle

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

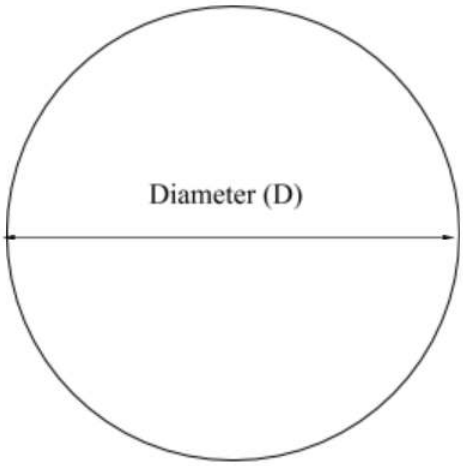


Figure **1.6.1.1**: Area of a circle = $0.785 \times D^2$

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 1.6.1.1

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

Area of a rectangle = $L \times W$

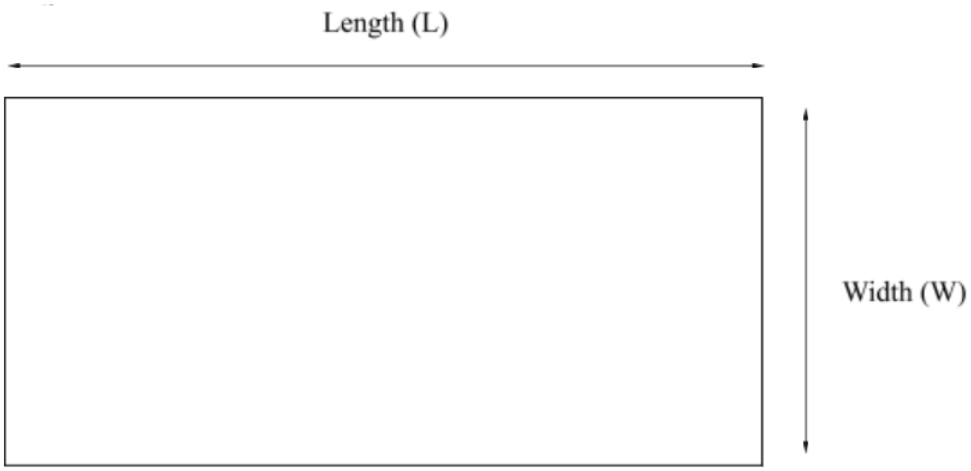


Figure **1.6.1.2**: Area of a rectangle = $L \times W$

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

$$\text{Area of a trapezoid} = \frac{b1 + b2}{2} \times H$$

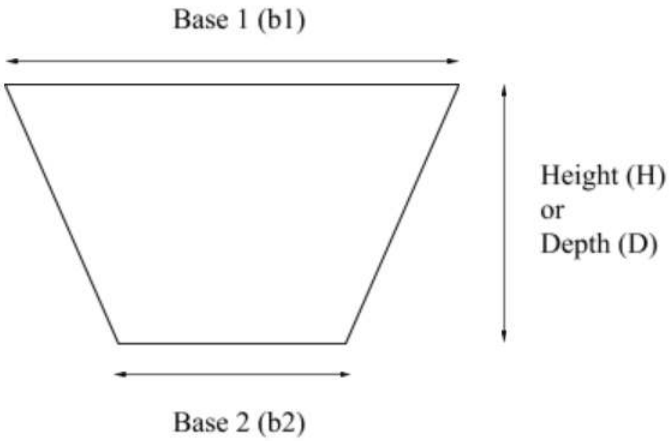


Figure **1.6.1.3**: Area of a trapezoid = $\frac{b1 + b2}{2} \times H$

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.

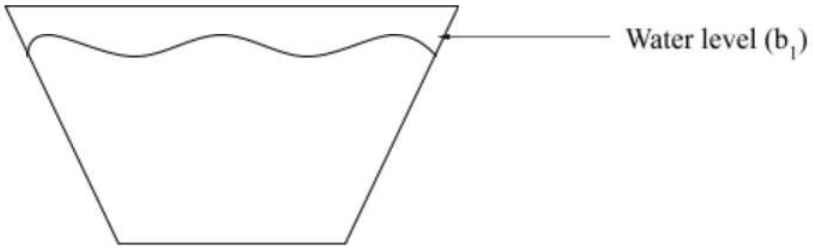


Figure 1.6.1.3: Example of the base 1

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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1.6.2: Volumes

Cylinder

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

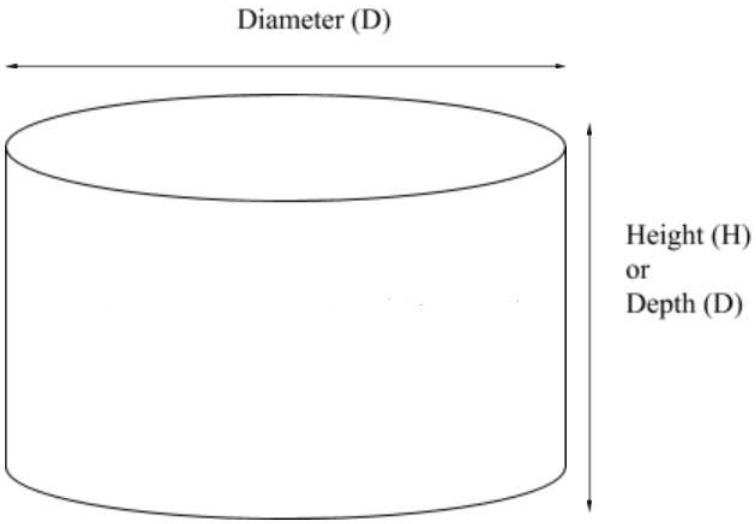


Figure **1.6.2.1**: Volume of a cylinder = $0.785 \times D^2 \times H$

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

Volume of a rectangle = $L \times W \times H$

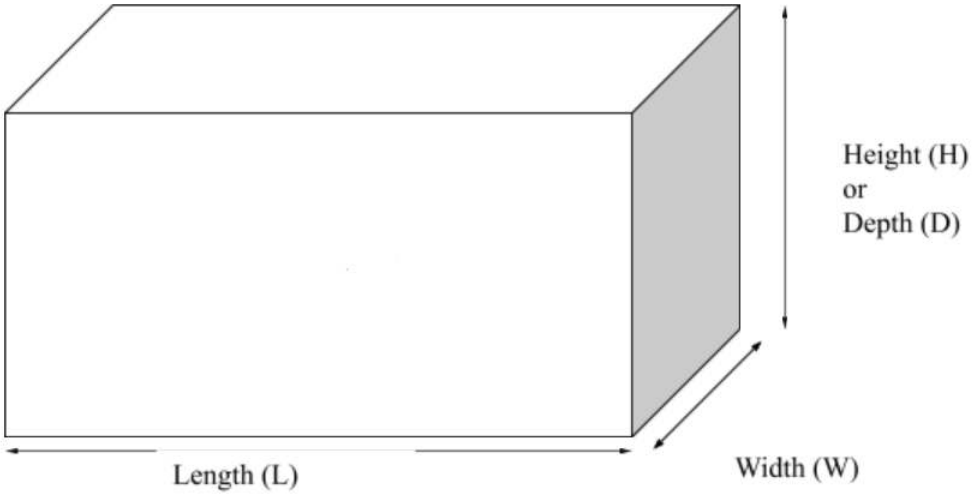


Figure **1.6.2.2**: Volume of a rectangle = $L \times W \times H$

Trapezoid

Volume of a trapezoid = $\frac{b1 + b2}{2} \times H \times L$

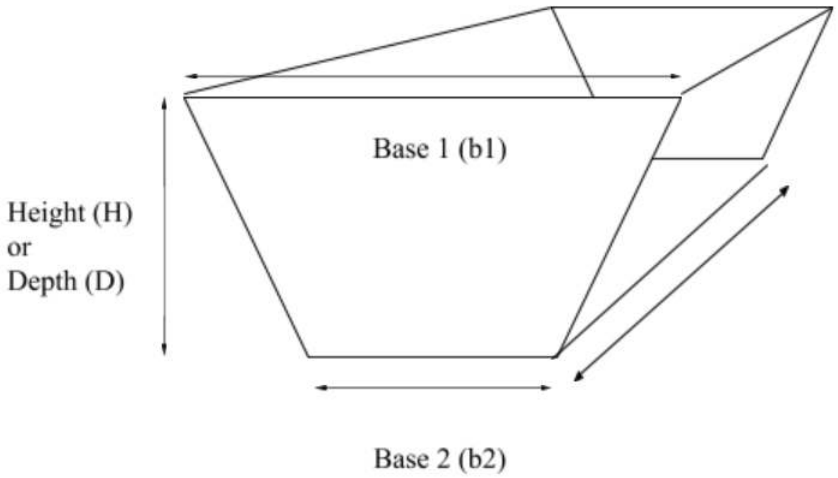


Figure **1.6.2.3**: Volume of a trapezoid = $\frac{b1 + b2}{2} \times H \times L$

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 ¾ 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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1.6.3: 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.

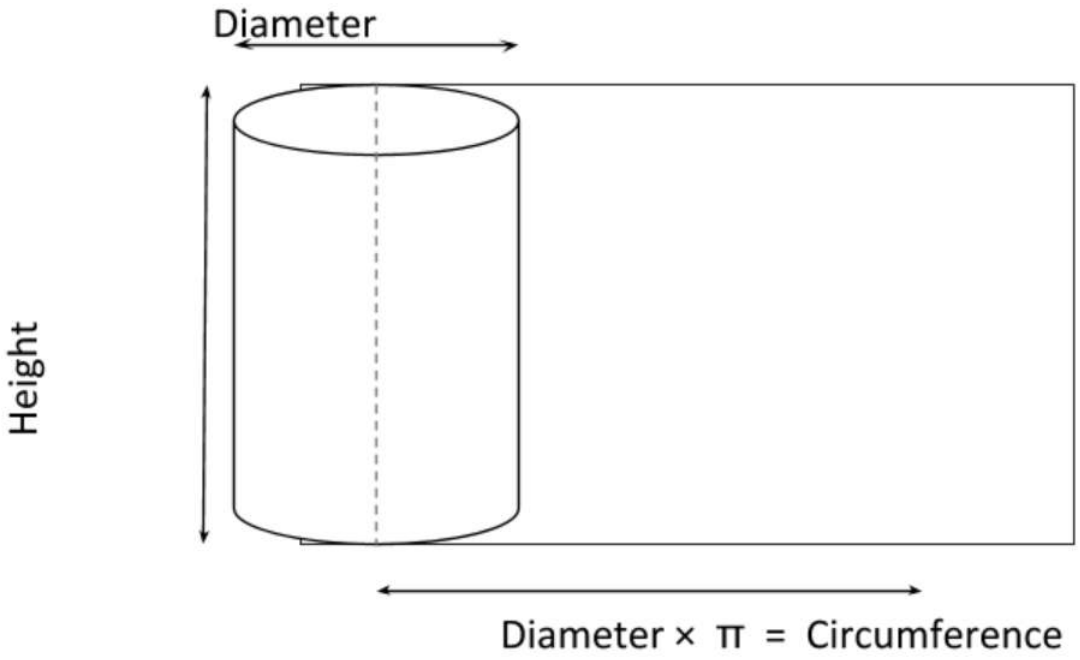


Figure 1.6.3.1: Circumference of a cylinder

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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SECTION OVERVIEW

1.7: 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.

1.7.1: Pressure

1.7.2: Force

1.7.3: Flow Rate

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1.7.1: 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 1.7.1.1

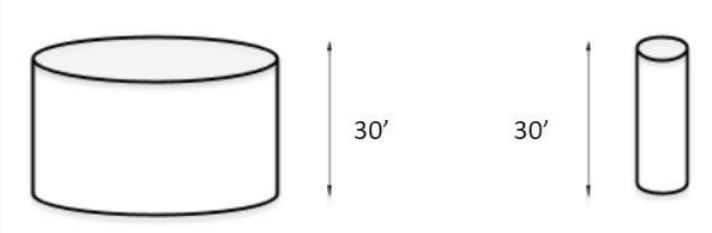


Figure **1.7.1.1**

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

Solution

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

Exercise 7.1

Calculate the following pressure problems

1. What is the pressure in psi at the bottom of a 30 foot tall tank if it is full?
2. What is the pressure in feet if the psi is 130?
3. A storage tank is 45 feet tall and half full. What is the pressure in psi?
4. 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?
5. A fire hydrant was hit and water is spraying up approximately 75 feet. What is the approximate pressure in psi?

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1.7.2: 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 (in^2). 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 psi = 1 foot and 1 psi = 2.31 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 in^2?

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 in^2 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 water 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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1.7.3: 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 UNTIS – CUBIC FEET PER SECOND, where Q represents Flow Rate.

Expressed as

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

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

$$\text{Q} = \text{A} \times \text{V}$$

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

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

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

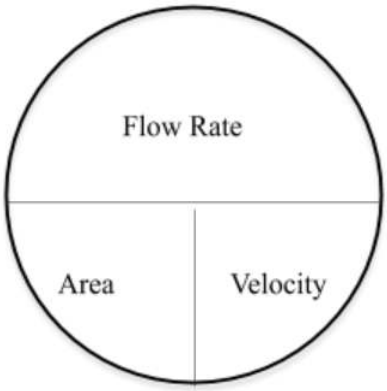


Figure **1.7.3.1**: Pie Wheel

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 ¾ 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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SECTION OVERVIEW

1.8: 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 chorine 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.

1.8.1: The “Pound Formula”

1.8.2: Food to Microorganism Ratio

1.8.3: Mean Cell Residence Time (MCRT)

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1.8.1: 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 1.8.1.1

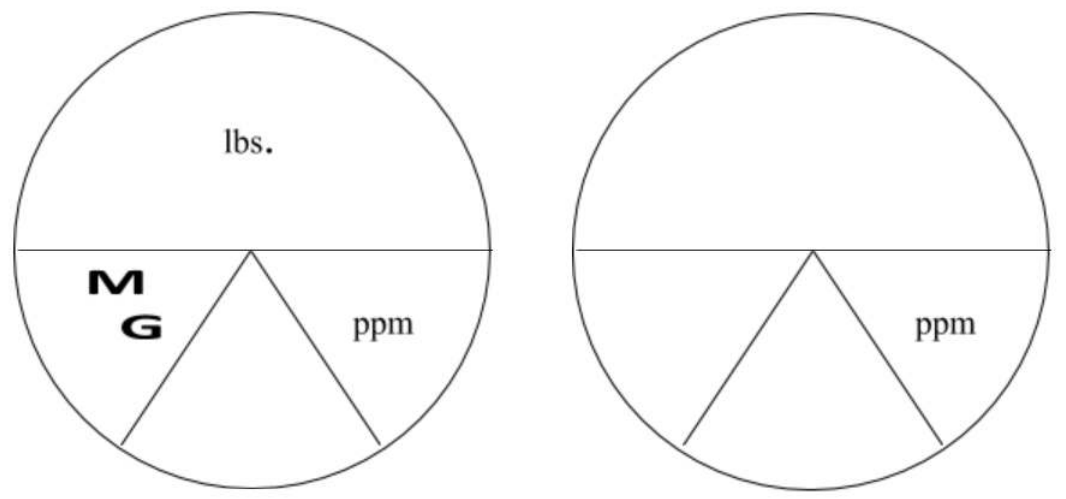


Figure 1.8.1.1

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 Biochemcial 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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1.8.2: 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:

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

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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1.8.3: 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 to 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:

MCRT = Lbs under aeration/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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SECTION OVERVIEW

1.9: Water Treatment Mathematics

1.9.1: Detention Time

1.9.2: Weir Overflow Rate

1.9.3: Filtration Rate

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1.9.1: 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.

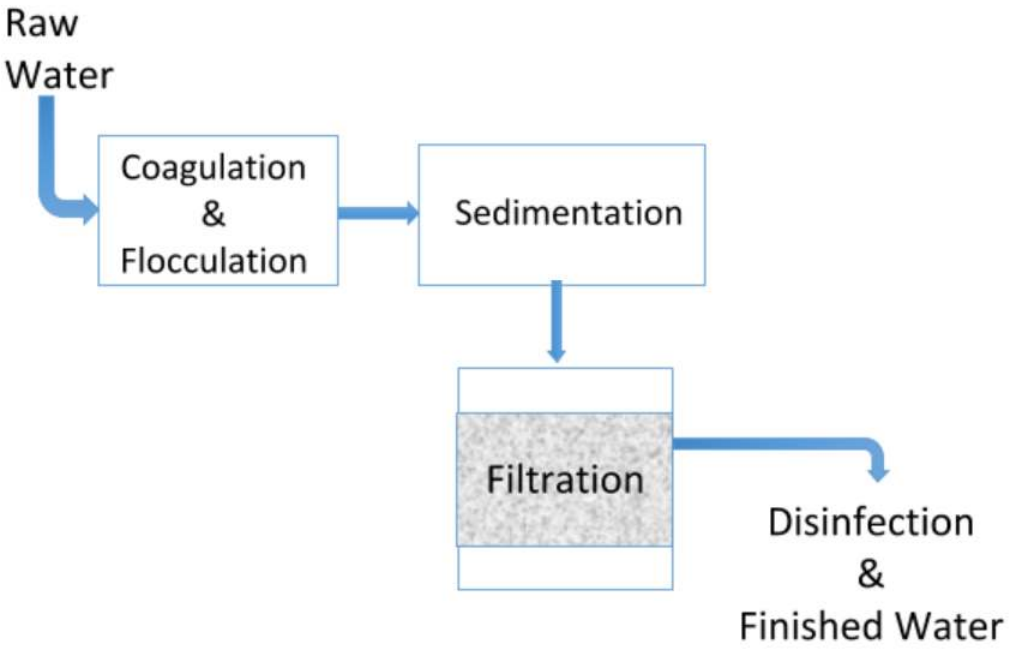


Figure **1.9.1.1**: Treatment Process Example

The following formula is used for calculating detention times.

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

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

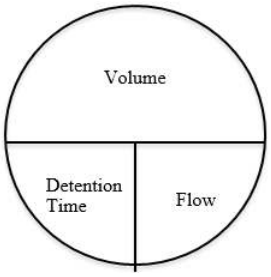


Figure **1.9.1.2**: Pie Wheel

“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 ¾ 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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1.9.2: 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.

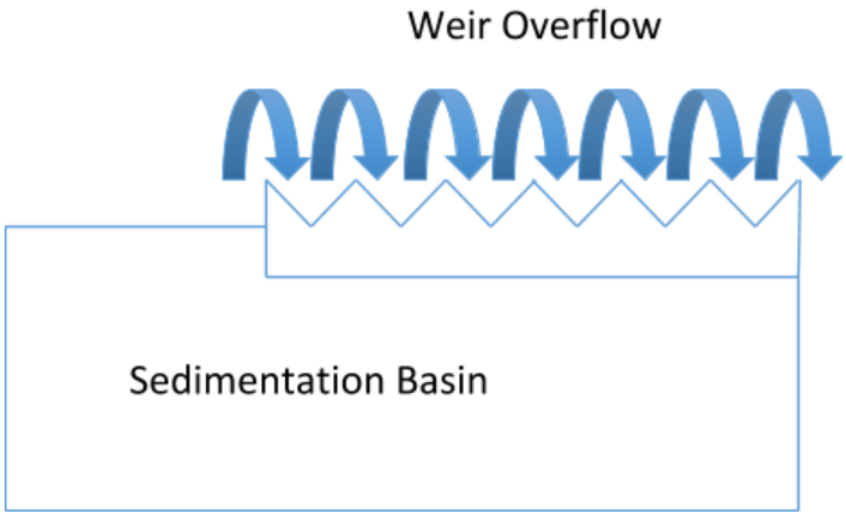


Figure **1.9.2.1**: Overflow

This formula is used:

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

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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1.9.3: 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/ft^2). 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 ft^2 sections).

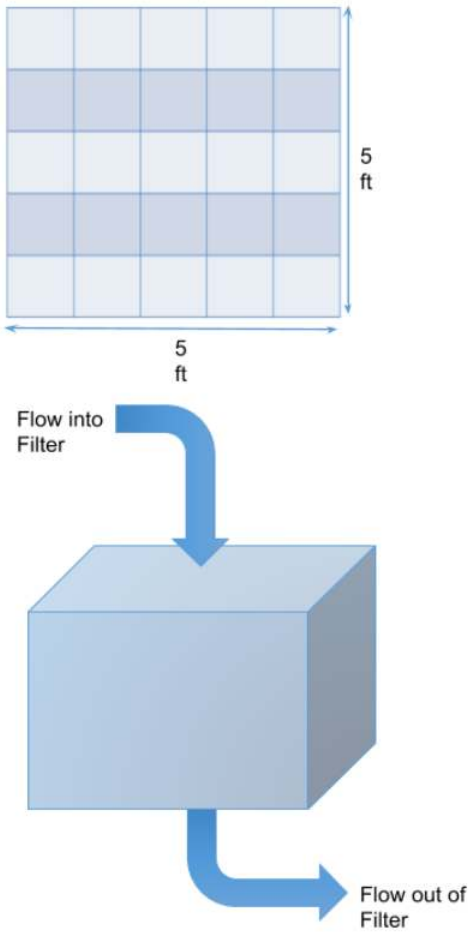


Figure **1.9.3.1**: Demonstration of how filtration rates are expressed

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:

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

Since Filtration Rates are expressed as gpm/ft^2 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:

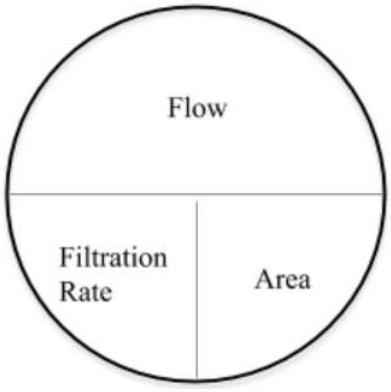


Figure **1.9.3.2**: Pie wheel for Filtration Rates

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

Example 1.9.3.1

A water treatment plant with a 100 ft2 filter has a flow of 1,650 gpm. What is the filtration rate expressed in gpm/ft^2.

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 1.9.3.2

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/ft^2?

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/ft^2.

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

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/ft^2)

1. A water treatment plant has a typical flow through a 175 ft^2 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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SECTION OVERVIEW

1.10: 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.

1.10.1: Planning

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1.10.1: Planning

Planning is important in many aspects of ones 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 protect 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 1.10.1.1

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 1.10.1.2

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 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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SECTION OVERVIEW

1.11: 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.

1.11.1: Examples

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1.11.1: Examples

Let's start with a simple question:

Example 1.11.1.1

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.

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

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 1.11.1.2

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 1.11.1.3

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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SECTION OVERVIEW

2.1: Source Water

2.1.1: Water Resources and the Origin of Contaminants

2.1.2: Source Water Quality

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2.1.1: Water Resources and the Origin of Contaminants

Learning Objectives

After reading this section, you should be able to:

- Understand and describe water sources
- Describe the water cycle
- Compare the term water contaminants with water pollutants

This chapter presents a brief introduction to the water sources that are available for potable supply; detailed information is presented in Water 132 (Water Supply). Understanding drinking water sources is important to assess the variety of contaminants that can be present in water.

Water Sources

According to the United States Geological Survey (USGS), 71% of the Earth's surface is covered in water, and of that 97% are the oceans. The Earth's water can be broken into two different categories: freshwater and salt water. Fresh water is simply water that is not salty and can be found in the planet's surface water such as streams, lakes, and frozen as ice, but also underground in aquifers. Fresh water is stored on the surface as **surface water** or stored underground in aquifers as **groundwater**. Salt water can be found in the world's oceans.

Figure 1.1.1 shows that our planet's water sources are limited. Freshwater is much easier to use for potable (drinkable) applications because it requires simpler treatment. However, it represents only a small fraction of the Earth's water portfolio. A large proportion of the freshwater is locked in glaciers and is not accessible. As a result, less than 1% of the water present on the planet is groundwater and surface water that can be more easily used as potable water source. Although desalination plants have become more prevalent, they are very costly, and their overall environmental impacts are unknown.

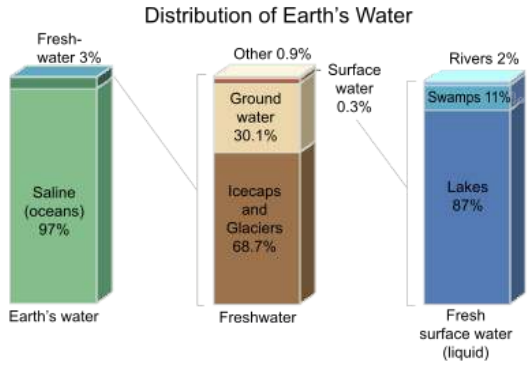


Figure 1.1.1: Distribution of Earth's Water.

The origin of a water source determines its characteristics and the presence of specific contaminants. The concentration and composition of contaminants in water is also influenced by the movements of water, which is illustrated by the water hydrologic cycle (Figure 1.1.2). The Water Cycle is both driven by gravity (i.e., water flows downhill) and sunlight (i.e., water evaporates and condenses).

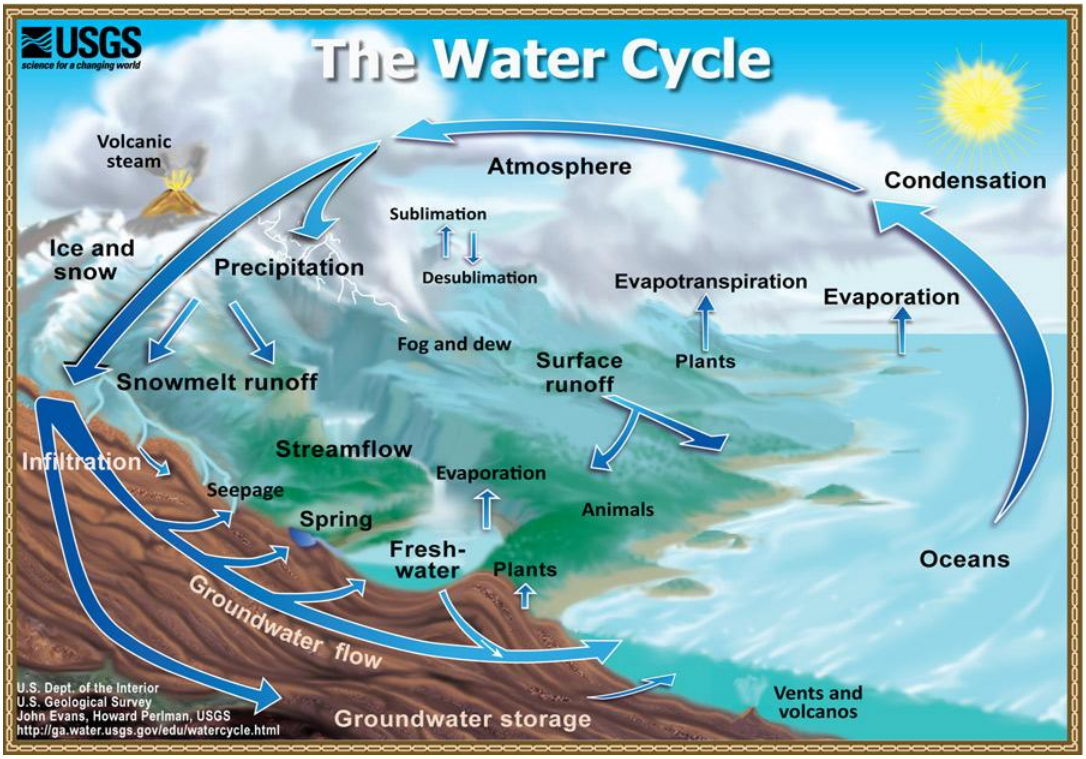


Figure 1.1.2: Water Hydrologic Cycle

Classifications of Contaminants

According to the Safe Drinking Water Act, a contaminant is any physical, chemical, biological, or radiological substance in water. While some contaminants are harmless, others are deadly. Contaminants can even mix with water molecules in the atmosphere. Technically, any compound that is not a water molecule is a contaminant when it comes to water.

Pin It! Misconception Alert

Many people think that all contaminants are manmade. They are not! Some have natural sources in the soil, such as arsenic and uranium. These can be expensive to remove because they occur naturally in the rocks around the water source.

Water can be contaminated by various human-caused (**anthropogenic**) activities or by existing natural features (**natural contaminants**) like mineral-rich geologic formations. It is not uncommon to find naturally occurring fluoride or arsenic in water.

Agricultural activities, industrial operations, landfills, animal operations, and small and large scale sewage treatment processes, among many other things, all can potentially contribute to contamination. As water runs over the land or infiltrates into the soil and **groundwater**, it dissolves material left behind by these potential contaminant sources.

There are three major groups of contamination: inorganic chemicals, organic chemicals, and biological agents. The risks and type of remediation for a contaminant depend on the type of chemicals present.

Pin It! Misconception Alert

People use the words contaminants and pollutants interchangeably. What is the difference between a contaminant and a pollutant?

- A contaminant is a substance that is not normally expected.
- A pollutant is a substance found at a concentration that has reached a level that adversely affects the suitability of the water for its intended purpose.

Key Terms

- **anthropogenic contaminants** – human-caused (manmade) contaminants
- **contaminant** – a substance that is not normally expected
- **groundwater** – water stored in the ground
- **natural contaminants** – contaminants in soil geology, erosion of soils, etc. Examples of contaminants include fluoride and arsenic
- **pollutant** – a substance found at a concentration that has reached a level that adversely affects the suitability of the water for its intended purpose
- **surface water** – water on the surface of the earth

Review Questions

1. **Outline the water cycle highlighting water sources.**

2. **List the major contaminants of water in the environment.**

Chapter Quiz

1. How much water on planet earth is easily treated for drinking water?
    1. 96%
    2. 20.9%
    3. 32%
    4. < 1.0%
2. Most of the water on earth is found in the _____.
    1. atmosphere
    2. ocean
    3. ground
    4. rivers
3. Which of the following is a natural contaminant?
    1. Pesticides
    2. Nitrates
    3. Phosphates
    4. Fluoride
4. Anthropogenic contaminants refers to _____.
    1. turbidity
    2. geological contaminants
    3. inorganic contaminants
    4. manmade contamination
5. The _____ is(are) essential for the maintenance of most life and ecosystems on the planet.
    1. climate
    2. water cycle
    3. aesthetic characteristic of water
    4. atmospheric circulation
6. The _____ drive(s) the water cycle.
    1. types of precipitation
    2. oxygen concentration
    3. nutrient levels
    4. sun

7. What portion of surface water is found in the permafrost and ice?
    1. 69%
    2. 68.7%
    3. 96.5%
    4. 30.1%

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2.1.2: Source Water Quality

Learning Objectives

After reading this chapter you should be able to identify and explain the following:

- The Earth's Hydrologic Cycle
- Sources of groundwater
- Sources of Surface Water
- Water math: Area and Unit Conversions

A very finite amount of water on our planet (0.34%) is available to treat for human consumption. Knowing where the water comes from assists certified operators in treating raw source water to make it potable. Newer technology has been developed to treat salinized or salty water found in the ocean. These treatment methods are still extremely expensive and not widely accessible. Supplying water to the public is an extremely important function in society as water is the basic building block of life. Because water quality is of the utmost importance new regulations and water quality standards are continually changing and evolving to make sure the public has safe sources of drinking water. The first drinking water standards were written in the Safe Drinking Water Act (SDWA), which was signed into law by President Ford in 1974. Throughout the text, new concepts will be introduced and an acronym will be given and used subsequently. You are going to learn to love acronyms if you become a certified operator. We use them quite frequently!

The Hydrologic Cycle

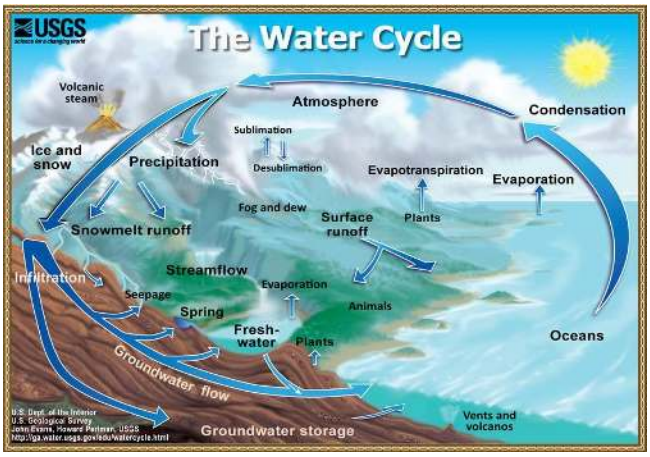


Figure **2.1.2.1**: The Water Cycle by the USGS is in the public domain

The Hydrologic cycle is the continual movement of water on the surface of the planet. The water moves above, below, and across the Earth's surface as a liquid, gas, or solid. The 12 elements of the hydrologic cycle are defined as follows:

- Evaporation—Water moves in the gas state from the Earth's surface to the atmosphere
- Transpiration—Water moves in the gas state from plants to the atmosphere.
- Advection—Water in the gas state moves through air currents in the atmosphere
- Condensation—Water vapor converts from gas to liquid state in the form of water droplets.
- Precipitation—Water as a liquid and/or solid falls from the atmosphere. We commonly refer to this as rain, snow, sleet, and hail.
- Interception—Water in the liquid state that is captured by plants
- Infiltration—Water in the liquid state that soaks into the surface of the ground. This will be what is known as groundwater which will be detailed later in this chapter.
- Subsurface Flow—Water in the liquid state flows below the Earth's surface. The movement is generated by gravity and obstructions below the surface of the Earth.
- Runoff—Water in the liquid form travels to bodies of water. This would include the ocean, lakes, rivers, and streams. This is also known as surface water which will be detailed more later in this chapter.
- Channel flow—Water in the liquid form that flows from small channels into rivers and streams

- Storage—Water is naturally stored in liquid form in lakes, ponds, wetlands, and groundwater aquifers. In solid form, water is naturally stored in ice, snow, and glaciers. This natural storage provides much of the water treated for human consumption.
- Snowmelt—Water in the solid form converts to water in the liquid form and is returned to the hydrologic cycle. Note: In California, snowpack is a critical water supply indicator as it is the melting snowpack that recharges rivers and the general supply of water

There are other important terms to note in regard to the hydrologic cycle. The surface to atmosphere movement of water is known as evapotranspiration. This is the combination of evaporation and transpiration from plant life to the atmosphere. The most widely known movement of water is precipitation which is when water in various physical states falls from the atmosphere to the surface of the Earth. The movement of water from the surface to subsurface is known as percolation. Percolation might also be referred to as infiltration or recharge. These terms are commonly associated with underground aquifers. Finally, surface to surface flow is called runoff.

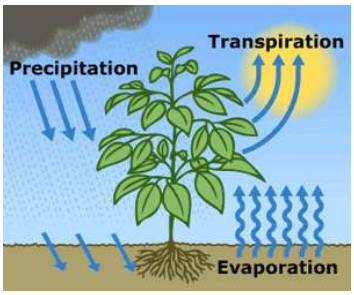


Figure **2.1.2.2**: Hydrologic Cycle Image by the USGS is in the public domain - Evapotranspiration is the sum of evaporation from the land surface plus transpiration from plants. Precipitation is the source of all water

Groundwater

Groundwater is one of the two main sources of storage used by municipalities to produce potable water. It is formed by the **percolation** (infiltration and/or recharge) of water from the surface of the earth to the subsurface. Water moves through holes and cracks in the subsurface and collects in an underground aquifer. An aquifer is a geologic formation that accumulates water due to its porousness. Important characteristics of groundwater include consistent water quality and the ability to remain safe from surface contamination. With greater technology and testing methods chemicals and constituents known to be harmful to humans have been found in numerous well sites throughout the United States. Wells close to industrial areas have been contaminated with harmful chemicals and substances. New regulations are continually being updated to ensure source groundwater is safe to drink. In normal circumstances, very little treatment is required to yield groundwater.

The **Groundwater Treatment Rule** (GWTR) was enacted in 2006 to prevent microbial contamination from underground water supplies. The purpose of the new rule was to classify water systems that were at a greater risk for fecal contamination. These systems must employ a multiple-barrier protection similar to the surface water treatment rule which will be covered in more detail in the next section.

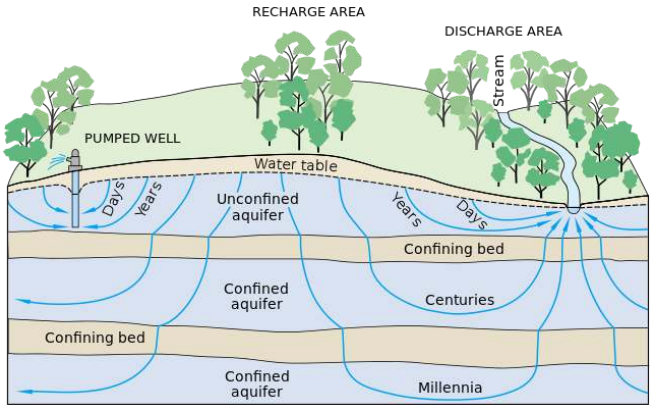


Figure **2.1.2.3**: Groundwater Image by the USGS is in the public domain

There are two kinds of aquifers, confined and unconfined. In an unconfined or water table aquifer the water table is free to rise and fall. The water table in unconfined aquifers rise and fall depending on the amount of precipitation that recharges the aquifer. Confined aquifers, also known as artesian wells, contain water that is confined due to layers of low permeability. These layers, which restrict movement, are comprised of rock or hard clay and are referred to as confining beds, aquitards, or aquicludes. Artesian wells are generally under pressure when drilled. Once drilled the water level at which the column of water will rise is known as the piezometric surface. Sometimes, the water will rise to the surface or past the surface but in the instance, the water remains below it is known as a non-flowing artesian well.

Wells

The construction of wells is critical in the extraction of water from underground water supplies. The placement of wells is very important because proper location will produce the greatest yield. Important terms related to underground wells:

- Static Water Level—The level in the well when no water is being removed from the aquifer. This level can be measured in feet or elevation.
- Pumping water level—The level when water is being removed from the aquifer. This level can vary depending on the rate of flow from the well.
- Drawdown—The difference between the pumping water level and the static water level
- Cone of depression—The shape or “cone” created by the movement of water in all directions during pumping.
- Zone of influence—The area of water affected by the drawdown of water during pumping. It is important to note that wells cannot be placed too closely together because their zones of influence may affect each other.
- Well yield—The amount of water drawn from an aquifer over a specific period of time
- Specific capacity—The amount of water produced per drawdown expressed in gpm/ft
- Safe Yield/Perennial yield—The amount of water that can be pulled from an aquifer per year without a drop in the water table
- Overdraft—Too much water removed. Greater than the safe yield of a well
- Subsidence—The permanent drop in the water table due to overdraft

Specific Capacity Calculation

$$\text{Specific capacity} = \text{Flow (GPM)} \div \text{Drawdown (ft)} \tag{2.1.2.1}$$

Example 2.1.2.1

A well has a yield of 600gpm and the drawdown is 50 ft. What is the specific capacity of the well?

Solution

This is a direct application of Equation 2.1.2.1

\[\text{Specific Capacity = 600\, \text{GPM} ÷ 50\, \text{ft} = 12\]

Surface Water

Throughout the United States, surface water is the most widely used source of water for large cities and other municipalities. Groundwater is not as widely available so is not a sufficient water supply for major cities. Surface water includes lakes, ponds, rivers, and streams. California is unique as the southern half of the state has 2/3 of the population but only 1/3 of the available water and the northern half of the state has 1/3 of the population but 2/3 of the water. Snowpack in northern California is critical to the state’s water supply. Most of Southern California is very arid and densely populated so water travels from Northern California through the State Water Project to Southern California.

Surface runoff supplies water for all surface water sources. Influences of surface runoff include intensity of rainfall, duration of rainfall, composition of soil, amount of moisture in soil, slope of the ground, vegetation coverage, and human influences. One would think that a lot of rain would be ideal. However, if the rainfall density is too great, more water can be lost because the ground will no longer absorb the water. The same applies to the duration of rainfall. A prolonged rain even makes the soil too moist and unable to capture water. Vegetation coverage and the slope of the ground are very important to stopping runoff. If the slope of the ground is steep, the speed of runoff is increased. Vegetation slows the speed of runoff and allows more water to absorb or

infiltrate into the ground. Human influences have a great impact on water runoff. Impervious surfaces like concrete entirely prevent infiltration.

Natural Watercourses

Key Terms

Natural water courses include rivers, creeks, streams, washes, and arroyos. They flow in one of three ways:

- Perennial streams—Watercourses which flow continuously throughout the year
  - EX: Colorado River
- Ephemeral streams—Watercourses that flow sporadically, generally after rainfall
  - EX: Santa Clara River which runs through Santa Clarita and Ventura County
- Intermittent—Watercourses which flow somewhere between ephemeral and perennial streams. Rainfall and high groundwater levels will affect how often these streams flow.

Rivers and Streams are a good water supply source but are not necessarily the best source for public water supplies.



Figure **2.1.2.4**: Image of the Colorado River by Paul Hermans is licensed under CC BY-SA 3.0



Figure **2.1.2.5**: Santa Clara River Map by Shannon1 is in the public domain

Lakes

Lakes are the most widely used public water supply source. However, very few “natural” lakes exist. Most lakes used for public water supply are man-made and use a dam to create the lake and contain the water. This is known as an impoundment. Water from these lakes is piped to treatment facilities. Due to variances in temperature lakes develop “layers” also known as stratification. Denser, colder water will drop to the bottom (Benthic zone) of a lake during the summer. There are three layers:

- Epilimnion—The strata closest to the surface
- Hypolimnion—The strata near the bottom
- Thermocline—Middle strata with the greatest variance in temperature

Lake turnover will occur during seasonal temperature changes. When the temperature of a lake is uniform it is known as isothermal. Algae growth is a serious problem that causes taste and odor issues in treated water. Copper sulfate can be added to a lake to help remedy algae blooms. In severe cases, the water undergoes eutrophication which is the loss of oxygen. Complete or extreme oxygen depletion can kill all living creatures in the water including animals and fish.



Figure **2.1.2.6**: Image of Castaic Lake by Rehman is in the public domain

Introduction to Water Math

Mathematics is a key component of water treatment. Operators use conversion tables and basic algebra to complete many daily tasks. Charts are available on the State Water Resources Control Board website that assist operators with most calculations you would find on the state exams or while on the job. Below is a list of basic units and their respective conversion factors:

Table 1.1: Units and Conversion Factors

Measurement	Equivalent
1 cubic foot of water	62.3832lbs
1 gallon of water	8.34lbs
1 liter of water	1,000 grams
1 mg/L	1 part per million (ppm)
1 ug/L	1 part per billion (ppb)
1 mile	5,280 feet
1 yard	3 feet
1 yard3	27ft3
1 acre	43,560 square feet or ft2
1 cubic foot or ft3	7.48 gallons
1 gallon	3.785 Liters or L
1 L	1,000 milliliters (ml)
1 pound	454 grams

Working with Fractions

NumeratorDenominator

44=11 or =1 42=21 or =1

Rounding

Rounding the number 324.179	
3 = Hundreds	The above number (324.179) rounded to the nearest tenth would be 324.2. Since the number in the hundredth place is at or above 5, the number in the tenth place is rounded up. If you were rounding this number to the nearest whole number it would be 323 since the number in the tenth place is below 5.
4 = Tens	
9 = Units	
1 = Tenth	
7 = Hundredth	
9 = Thousandth	

Unit Dimensional Analysis

This is the most important function in most water math problems. Make sure to always place your factors in the proper place or the equation will be impossible to solve correctly. The example below will use unit measurements. Water operators will commonly convert between different units of measurement.

Example 1

Convert 48 inches into feet. (There are 12 inches in a foot.)

48 inches11 foot12 inches=4 ft1

Drop the one from the denominator and the answer is 4 ft.

The same process will be to convert between gallons and cubic feet.

Example 2

Convert 22.44 gallons into cubic ft. or ft3 (There are 7.48 gallons in one cubic foot.)

22.44 gallons11 $ft^3$7.48 gallons=3 $ft^3$1

Drop the 1 from the denominator and your answer is 3 ft^3

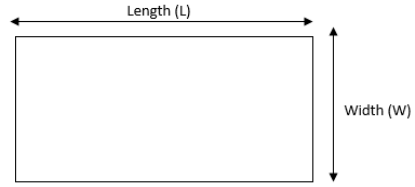
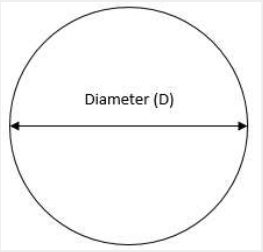
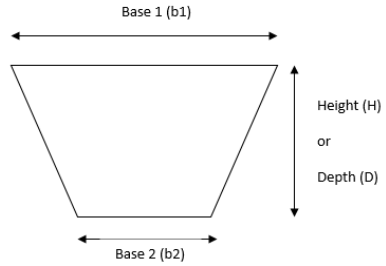
Example 3

How many gallons are there in a tank which holds 300ft^3 of water?

300ft317.48 gal1ft3=2,244 gallons

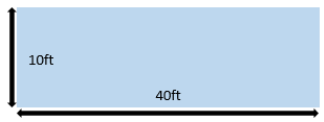
Area

Area will be important for many applications in water math. It may be necessary to calculate the area of a tank that requires painting or an area of ground cover near equipment.

Rectangles 	Area = L × W
Circle 	Area = $0.785 \times D^2$
Trapezoid 	Area = $\frac{b1 + b2}{2} \times H$

Example 1

A wall that is 10ft wide and 40ft in length needs to be painted. What is the total square feet of the wall?

	Area = Length x Width Area = 10ft x 40ft Area = $400ft^2$

Example 2

What is the area of the top of a circular storage tank that is 100 feet in diameter? (Note: Use the formula .785 x d2. In most cases in water math, we will always be dealing with the diameter and not the radius. These short cuts will help as the problems become more difficult. In this problem I will demonstrate why we will use this formula and not the standard mathematical equation for solving area problems.)

Equation #1 Area= π (3.14) x r^2 (100ft ÷ 2 = 50 to find radius)

Area = 3.14 x 50 x 50

Area = 7,850 ft^2

Equation #2 Area= .785 x d^2

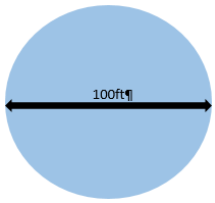
Area = .785 x 100 x 100

Area = 7,850 ft^2

In this example, the first equation was easy to solve because we were working with a pretty friendly number. As the equations become more difficult we do not want to take the extra step to divide the diameter by two to solve for the radius. If the diameter of the tank was 357ft, this problem would have been slightly more difficult using the first equation.

Example 3

The top of a circular storage tank needs to be painted. It is 100 ft. in diameter. Each gallon of paint covers approximately 200 square feet. How many gallons of paint will you need to buy?



Area= .785 x d^2
Area= .785 x 100ft x 100ft
Area= 7,850 ft^2
7850 $ft^2$1x1 gal200 ft^2=39.25 gal

Chapter Review

1. What is the middle layer of a stratified lake called?
    1. Thermocline
    2. Benthic Zone
    3. Epilimnion
    4. Hypolimnion
2. What is the conversion of liquid water to gaseous water known as?
    1. Advection
    2. Condensation
    3. Precipitation
    4. Evaporation
3. Water weighs _____.
    1. 7.48 lbs/gal
    2. 8.34 lbs/gal
    3. 62.4 lbs/ft^3
    4. Both 2 and 3
4. What is the static level of an unconfined aquifer also known as?
    1. Drawdown
    2. Water Table
    3. Pumping Water Level
    4. Aquitard
5. What is the cause of taste and odor problems in raw surface water?
    1. Copper sulfate
    2. Blue-green algae
    3. Oxygen
    4. Lake turnover
6. What chemical reduces blue-green algae growth?
    1. Chlorine
    2. Caustic Soda
    3. Copper Sulfate
    4. Alum

7. A water-bearing geologic formation that accumulates water due to its porousness.
    1. Aquifer
    2. Lake
    3. Aquiclude
    4. Well
8. What kind of stream flows continuously throughout the year?
    1. Ephemeral
    2. Perennial
    3. Intermittent
    4. Stratified
9. The surface to atmosphere movement of water is known as _____.
    1. Precipitation
    2. Percolation
    3. Stratification
    4. Evapotranspiration
10. An aquifer that is underneath a layer of low permeability is known as _____.
    1. Confined aquifer
    2. Water Table aquifer
    3. Unconfined aquifer
    4. Unreachable groundwater
11. What is the middle layer of a stratified lake known as?
    1. Hypolimnion
    2. Benthic Zone
    3. Thermocline
    4. Epilimnion
12. The amount of water that can be pulled from an aquifer without depleting.
    1. Drawdown
    2. Safe yield
    3. Overdraft
    4. Subsidence

Math Questions

Please show all work. On the State exams, you will not get credit if work is not shown.

1. What is the area of the top of a storage tank that is 75 feet in diameter?
    1. 4,000 ft^2
    2. 4416 ft^2
    3. 1104 ft^2
    4. 17,663 ft^2
2. What is the area of a wall 175 ft. in length and 20 ft. wide?
    1. 3,000 ft^2
    2. 2,500 ft^2
    3. 3,500 ft^2
    4. 4,000 ft^2
3. You are tasked with filling an area with rock near some of your equipment. One (1) bag of rock covers 250 square feet. The area that needs rock cover is 400 feet in length and 30 feet wide. How many bags do you need to purchase?
    1. 40 Bags
    2. 42 Bags

3. 45 Bags
4. 48 Bags

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SECTION OVERVIEW

2.2: Surface Water Regulations

2.2.1: Microbiology Regulations

2.2.2: Water Chemistry and Standards

2.2.3: Microorganisms

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2.2.1: Microbiology Regulations

Learning Objectives

After reading this section, you should be able to:

- Explain the Total Coliform Rule
- Compare the Groundwater Treatment Rule and Surface Water Treatment Rule
- Describe the concern with Cryptosporidium

Total Coliform Rule

The **Total Coliform Rule** (TCR), a National Primary Drinking Water Regulation (NPDWR), was published in 1989 and became effective in 1990. The rule sets a health goal (Maximum Contaminant Level Goal (MCLG)) and legal limits (Maximum Contaminant Levels, MCLs)) for the presence of total coliforms in drinking water.

The Environmental Protection Agency (EPA) published the Revised Total Coliform Rule (RTCR) in the Federal Register (FR) in February 2013 (78 FR 10269) and minor corrections in February 2014 (79 FR 10665). The RTCR is the revision to the 1989 Total Coliform Rule (TCR) and is intended to improve public health protection. All public water systems (PWSs), except aircraft PWSs subject to the Aircraft Drinking Water Rule (ADWR) (40 CFR 141 Subpart X), must comply with the RTCR starting April 2016, or an earlier state effective date.

Total coliforms are a group of related bacteria that are, with few exceptions, not harmful to humans. This is very important to note. The EPA considers total coliforms a useful indicator of other pathogens for drinking water. Total coliforms are used to determine the adequacy of water treatment and the integrity of the distribution system.

Key provisions of the RTCR include:

1. Setting a maximum contaminant level goal (MCLG) and maximum contaminant level (MCL) for E. coli for protection against potential fecal contamination.
2. Setting a total coliform treatment technique (TT) requirement.
3. Requirements for monitoring total coliforms and E. coli according to a sample siting plan and schedule specific to the PWS.
4. Provisions allowing PWSs to transition to the RTCR using their existing Total Coliform Rule(TCR) monitoring frequency, including PWSs on reduced monitoring under the existing TCR.
5. Requirements for seasonal systems (such as, Non-Community Water Systems not operated on a year-round basis) to monitor and certify the completion of a state-approved start-up procedure.
6. Requirements for assessments and corrective action when monitoring results show that PWSs may be vulnerable to contamination.
7. Public notification (PN) requirements for violations.
8. Specific language for CWSs to include in their Consumer Confidence Reports (CCRs) when they must conduct an assessment or if they incur an E. coli MCL violation.

Revised Total Coliform Rule

Overview of the Rule

Revised Total Coliform Rule (RTCR) 78 FR 10269, February 2013, Vol. 78, No. 30

Purpose: Increase public health protection through the reduction of potential pathways of entry for fecal contamination into distribution systems.

General Description

The rule establishes a maximum contaminant level (MCL) for E. coli and uses E. coli and total coliforms to initiate a find and fix approach to address fecal contamination that could enter into the distribution system. It requires public water systems (PWSs) to perform assessments to identify sanitary defects and subsequently take action to correct them.

The Total Coliform Rule applies to all Public Water Systems.

Implementation of the Total Coliform Rule will result in:

1. A decrease in the pathways by which fecal contamination can enter the drinking water distribution system.
2. Reduction in fecal contamination should reduce the potential risk from all waterborne pathogens including bacteria, viruses, parasitic protozoa, and their associated illnesses.

Requirements:

1. Public Water Systems must develop a written sample siting plan that identifies the system's sample collection schedule and all sample sites, including sites for routine and repeat monitoring.
2. PWSs monitoring quarterly or annually must also identify additional routine monitoring sites in their sample siting plans.
3. Sample siting plans are subject to state review and revision.

Routine Sampling Requirements

1. Total coliform samples must be collected by Public Water Systems at sites which are representative of water quality throughout the distribution system according to a written sample siting plan subject to state review and revision.
2. For Public Water Systems collecting more than one sample per month, collect total coliform samples at regular intervals throughout the month, except that ground water systems serving 4,900 or fewer people may collect all required samples on a single day if the samples are taken from different sites.

Repeat Sampling Requirements

Within 24 hours of learning of a Total Coliform positive routine sample result, at least 3 repeat samples must be collected and analyzed for total coliform:

1. One repeat sample must be collected from the same tap as the original sample.
2. One repeat sample must be collected from within five service connections upstream.
3. One repeat sample must be collected from within five service connections downstream.
4. The PWS may propose alternative repeat monitoring locations that are expected to better represent pathways of contamination into the distribution system.

If one or more repeat sample is Total Coliform Positive:

1. The TC+ sample must be analyzed for the presence of E. coli.
2. If any repeat TC+ sample is also EC+, then the EC+ sample result must be reported to the state by the end of the day that the PWS is notified.
3. The PWS must collect another set of repeat samples, unless an assessment has been triggered and the PWS has notified the state.

Routine Sampling Requirements

1. Each total coliform-positive (TC+) routine sample must be tested for the presence of E. coli.
2. If any coliform-positive (TC+) sample is also E. coli-positive (EC+), then the EC+ sample result must be reported to the state by the end of the day that the PWS is notified.
3. If any routine sample is TC+, repeat samples are required.
4. Public Water Systems on quarterly or annual monitoring must take a minimum of three additional routine samples (known as additional routine monitoring) the month following a TC+ routine or repeat sample.
5. Reduced monitoring may be available for Public Water Systems using only ground water and serving 1,000 or fewer persons that meet certain additional Public Water System criteria.

Assessments and Corrective Action

The RTCR requires PWSs that have an indication of coliform contamination (e.g., as a result of TC+ samples, E. coli MCL violations, performance failure) to assess the problem and take corrective action. Two levels of assessments exist (i.e., Level 1 and Level 2) based on the severity or frequency of the problem.

Purpose of Level 1 and Level 2 Assessments

To find sanitary defects at the Public Water System including:

1. Sanitary defects that could provide a pathway of entry for microbial contamination
2. Sanitary defects that indicate failure (existing or potential) of protective barriers against microbial contamination.

Deadline for Completing Corrective Actions

When sanitary defects are identified during a Level 1 or Level 2 Assessment, they should be corrected as soon as possible to protect public health. The Public Water System must complete corrective actions by one of the following timeframes:

1. No later than the time the assessment form is submitted to the state, which must be within 30 days of triggering the assessment, or
2. Within state-approved timeframe which was proposed in the assessment form.

Level 1 Assessments

Conducting Level 1 Assessments

1. Performed by the PWS owner or operator each time a Level 1 Assessment is triggered.
2. Upon trigger of a Level 1 Assessment, the Level 1 Assessment form must be submitted within 30 days to the state.

Level 1 Assessment Triggers

Level 1 Assessment is triggered if any one of the following occurs:

1. A Public Water System collecting fewer than 40 samples per month has 2 or more TC+ routine/ repeat samples in the same month.
2. A PWS collecting at least 40 samples per month has greater than 5.0 percent of the routine/repeat samples in the same month that are TC+.
3. A PWS fails to take every required repeat sample after any single TC+ sample.

Level 2 Assessments

Conducting Level 2 Assessments

Performed by the state or state-approved entity each time a Level 2 Assessment is triggered.

1. The Public Water System is responsible for ensuring that the Level 2 Assessment is conducted regardless of the entity conducting the Level 2 Assessment.
2. (3)Upon trigger of a Level 2 Assessment, the Level 2 Assessment form must be submitted within 30 days to the state.

Level 2 Assessment Triggers

Level 2 Assessment is triggered if any one of the following occurs:

1. A Public Water System incurs an E. coli MCL violation.
2. A Public Water System has a second Level 1 Assessment within a rolling 12-month period.
3. A Public Water System on state-approved annual monitoring has a Level 1 Assessment trigger in 2 consecutive years.

Seasonal System Provisions

The Total Coliform Rule defines seasonal systems and specifies additional requirements for these types of PWSs:

1. A seasonal system is defined as a non-community water system that is not operated as a PWS on a year round basis and starts up and shuts down at the beginning and end of each operating season.

Start-up Procedures for Seasonal Systems

At the beginning of each operating period, before serving water to the public, seasonal water systems must:

1. Conduct state-approved start-up procedures.
2. Certify completion of state-approved start-up procedures.

3. An exemption from conducting state-approved start-up procedures may be available for seasonal systems that maintain pressure throughout the distribution system during non-operating periods.

Examples of state-approved start-up procedures, which need to be completed prior to serving water to the public, may include one or more of the following:

1. Disinfection.
2. Distribution system flushing.
3. Sampling for total coliform and E. coli.
4. Site visit by state.
5. Verification that any current or historical sanitary defects have been corrected.

Routine Monitoring for Seasonal Systems

1. The baseline monitoring frequency for seasonal systems is monthly.
2. A reduced monitoring frequency may be available for seasonal systems that use ground water only and serve fewer than 1,000 persons.

Other Provisions for the State Drinking Water Agency Special Monitoring Evaluation

The state must perform a special monitoring evaluation at all ground water systems serving 1,000 or fewer persons during each sanitary survey to review the status of the Public Water System and to determine whether the sample sites and monitoring schedule need to be modified.

Major Violations

E. coli MCL Violation

A Public Water System will receive an E. coli MCL violation when there is any combination of an E.coli positive sample result with a routine/repeat Total Coliform positive or E. coli positive sample result:

E. coli MCL Violation Occurs with the Following Sample Result Combination

Routine Repeat

EC+ TC+

EC+ Any missing sample

EC+ EC+

TC+ EC+

TC+ TC+ (but no E. coli analysis)

Treatment Technique Violation

A PWS will receive a Treatment Technique violation when any of the following occur:

1. Failure to conduct a Level 1 or Level 2 Assessment within 30 days of a trigger.
2. Failure to correct all sanitary defects from a Level 1 or Level 2 Assessment within 30 days of a trigger or in accordance with the state-approved timeframe.
3. Failure of a seasonal system to complete state-approved start-up procedures prior to serving water to the public.

Key Points for Public Water Systems to Remember

Find and correct sanitary defects as soon as you become aware of them. This can help reduce E. coli MCL violations, which trigger a Level 2 Assessment. This can help reduce TC+ sample results, which may trigger a Level 1 Assessment.

Make sure to collect all routine and repeat samples as required. Timely and correct monitoring can help reduce triggering a Level 1 or Level 2 Assessment because:

1. Failure to conduct repeat monitoring triggers a Level 1 Assessment.
2. A Level 1 Assessment triggered twice within a certain timeframe triggers a Level 2 Assessment.

Surface Water Treatment Rule

The purpose of the **Surface Water Treatment Rules (SWTRs)** is to reduce illnesses caused by pathogens in drinking water. The disease-causing pathogens include *Legionella*, *Giardia lamblia*, and *Cryptosporidium*.

The SWTRs requires water systems to filter and disinfect surface water sources. Some water systems are allowed to use disinfection only for surface water sources that meet criteria for water quality and watershed protection. This combination of rules is designed to provide protection from microbial pathogens.

Simultaneously, the rules minimize health risks to the population from disinfection byproducts.

For PWSs that use surface water sources and are not required to filter, existing regulations do not require any treatment for Cryptosporidium. New survey data suggest that typical Cryptosporidium levels in the treated water of unfiltered PWSs are higher than in the treated water of filtered PWSs. Thus, Cryptosporidium treatment by unfiltered PWSs is needed to achieve comparable public health protection.

Further, results from recent treatment studies has allowed EPA to develop standards for the inactivation of Cryptosporidium by ozone, ultraviolet (UV) light, and chlorine dioxide. Based on these developments, the EPA has established requirements for all unfiltered PWSs to treat for Cryptosporidium, with the required degree of treatment depending on the source water contamination level. Additionally, the long-term rule addresses risks in uncovered finished water storage facilities, in which treated water can be subject to significant contamination as a result of runoff, bird and animal wastes, human activity, algal growth, insects, fish, and airborne deposition. Existing regulations prohibit the building of new uncovered finished water storage facilities. Under the long-term rule, PWSs must limit potential risks by covering or treating the discharge of such storage facilities. The requirements in the Surface Water Treatment Rule reflect consensus recommendations from the Stage 2 Microbial and Disinfection Byproducts (M–DBP) Federal Advisory Committee. These recommendations are set forth in the Stage 2 M–DBP Agreement in Principle.

Long-Term Surface Water Treatment Rule

Source Water Monitoring. The rule requires PWSs using surface water or groundwater under the direct influence (GWUDI) of surface water to monitor their source water (the influent water entering the treatment plant) to determine an average Cryptosporidium level. Monitoring results determine the extent of Cryptosporidium treatment requirements.

Large PWSs (serving at least 10,000 people) must monitor for Cryptosporidium (plus E. coli and turbidity in filtered PWSs) for a period of two years. To reduce monitoring costs, small filtered PWSs (serving fewer than 10,000 people) initially monitor just for E. coli for one year as a screening analysis and are required to monitor for Cryptosporidium only if their E. coli levels exceed specified trigger values. Small filtered PWSs that exceed the E. coli trigger, as well as all small unfiltered PWSs, must monitor for Cryptosporidium for one or two years, depending on the sampling frequency.

Under the long-term rule, specific criteria are set for sampling frequency and schedule, sampling location, using previously collected data, providing treatment instead of monitoring, sampling by PWSs that use surface water for only part of the year, and monitoring of new plants and sources. The long-term rule also establishes requirements for reporting of monitoring results, using analytical methods, and using approved laboratories. The rule also requires a second round of monitoring to begin approximately 6.5 years after the first round concludes in order to determine if source water quality has changed to a degree that should affect treatment requirements.

The long-term rule establishes risk-targeted treatment technique requirements to control *Cryptosporidium* in PWSs using surface water or GWUDI. These treatment requirements supplement those established by existing regulations. Filtered PWSs are classified in one of four treatment categories (or bins) based on the results of the source water *Cryptosporidium* monitoring. This bin classification determines the degree of additional *Cryptosporidium* treatment, if any, that filtered PWS must provide. PWSs classified in Bins 2, 3, or 4 must achieve 1.0 to 2.5-log of treatment (90 to 99.7 percent reduction) for *Cryptosporidium* over and above that provided with conventional treatment. Different additional treatment requirements may apply to PWSs using other than conventional treatment, such as direct filtration, membranes, or cartridge filters.

Filtered PWSs must meet the additional *Cryptosporidium* treatment required in Bins 2, 3, or 4 by using one or more treatment or control processes from a microbial toolbox of options. The long-term rule requires all unfiltered PWSs to provide at least 2-log (99 percent) inactivation of *Cryptosporidium*. If the average source water *Cryptosporidium* level exceeds 0.01 oocysts/L, the unfiltered PWS must provide at least 3-log (99.9 percent) inactivation of *Cryptosporidium*. Further, under the long-term rule, unfiltered PWSs

must achieve their overall inactivation requirements (including *Giardia lamblia* and virus inactivation) using a minimum of two disinfectants.

PWSs with uncovered finished water storage facilities must take steps to address contamination risks. Existing regulations require PWSs to cover all new storage facilities for finished water but do not address existing uncovered finished water storage facilities. Under the long-term rule, PWSs using uncovered finished water storage facilities must cover the storage facility or treat the storage facility discharge to achieve inactivation and/or removal of 4-log virus, 3-log *Giardia lamblia*, and 2-log *Cryptosporidium* on a state-approved schedule.

The rule applies to all PWSs using surface water or GWUDI, including large and small PWSs, community and non-community PWSs, and non-transient and transient PWSs. Wholesale PWSs must comply with the requirements of the rule based on the population of the largest PWS in the combined distribution system.

Consecutive PWSs that purchase treated water from wholesale PWSs that fully comply with the monitoring and treatment requirements of the rule are not required to take additional steps for that water.

Existing Regulations for Microbial Pathogens in Drinking Water

1. The Surface Water Treatment Rule (SWTR) (54 FR 27486, June 1989) applies to all PWSs using surface water or ground water under the direct influence (GWUDI) of surface water as sources (Subpart H PWSs). It established MCLGs of zero for *Giardia lamblia*, viruses, and *Legionella*, and includes the following treatment technique requirements to reduce exposure to pathogenic microorganisms:
    1. Filtration, unless specific avoidance criteria are met
    2. Maintenance of a disinfectant residual in the distribution system
    3. Removal and/or inactivation of 3-log (99.9%) of *Giardia lamblia* and 4-log (99.99%) of viruses
    4. Maximum allowable turbidity in the combined filter effluent (CFE) of 5 nephelometric turbidity units
    5. (NTU) and 95th percentile CFE turbidity of 0.5 NTU or less for plants using conventional treatment or direct filtration
    6. Watershed protection and source water quality requirements for unfiltered PWSs
2. The Total Coliform Rule (TCR) (54 FR 27544, June 1989) applies to all PWSs. It established an MCLG of zero for total and fecal coliform bacteria and an MCL based on the percentage of positive samples collected. Coliforms are used as an indicator of fecal contamination and to determine the integrity of the water treatment process and distribution system. Under the Total Coliform Rule, no more than 5 percent of distribution system samples collected in any month may contain coliform bacteria (no more than 1 sample per month may be coliform positive in those PWSs that collect fewer than 40 samples per month). The number of samples to be collected in a month is based on the number of people served by the PWS.
3. Interim Enhanced Surface Water Treatment Rule (63 FR 69478, December 16, 1998) (USEPA 1998a) applies to PWSs serving at least 10,000 people and using surface water or GWUDI sources. Key provisions established by the interim rule include the following:
    1. An MCLG of zero for *Cryptosporidium*
    2. *Cryptosporidium* removal requirements of 2-log (99 percent) for PWSs that filter
    3. More stringent turbidity performance standards of 1.0 NTU as a maximum and 0.3 NTU or less at the 95th percentile monthly for treatment plants using conventional treatment or direct filtration
    4. Requirements for individual filter turbidity monitoring
    5. Disinfection benchmark provisions to assess the level of microbial protection that PWSs provide as they take steps to comply with new disinfection by-products standards
    6. Inclusion of Cryptosporidium in the definition of GWUDI and in the watershed control requirements for unfiltered PWSs
    7. Requirements for covers on new finished water storage facilities
    8. Sanitary surveys for all surface water systems regardless of size

The interim surface water treatment rule was developed in conjunction with the Stage 1 Disinfectants and Disinfection Byproducts Rule (Stage 1 DBPR) (63 FR 69389, December 1998), which reduced allowable levels of certain DBPs, including trihalomethanes, haloacetic acids, chlorite, and bromate.

4. Long Term 1 Enhanced Surface Water Treatment Rule (67 FR 1812, January 2002) builds on the microbial control provisions established by the interim rule for large PWSs through extending similar requirements to small PWSs. The long-term interim rule applies to PWSs that use surface water or GWUDI as sources and that serve fewer than 10,000 people. Like the interim rule, the long-term rule established the following:
    1. 2- log (99 percent) *Cryptosporidium* removal requirements by PWSs that filter
    2. Individual filter turbidity monitoring and more stringent combined filter effluent turbidity standards for conventional and direct filtration plants
    3. Disinfection profiling and benchmarking; inclusion of *Cryptosporidium* in the definition of GWUDI and in the watershed control requirements for unfiltered PWSs
    4. The requirement that new finished water storage facilities be covered.
5. Filter Backwash Recycle Rule (66 FR 31085, June 2001) requires PWSs to consider the potential risks associated with recycling contaminants removed during the filtration process. The provisions of the filter backwash rule apply to all PWSs that recycle, regardless of population served. In general, the provisions include the following:
    1. PWSs must return certain recycle streams to a point in the treatment process that is prior to primary coagulant addition unless the State specifies an alternative location
    2. Direct filtration PWSs recycling to the treatment process must provide detailed recycle treatment information to the State
    3. Certain conventional PWSs that practice direct recycling must perform a one-month, one-time recycling self-assessment

Introduction to Cryptosporidium

Concern with Cryptosporidium in Drinking Water

EPA is promulgating the Long-Term Surface Water Treatment Rule to reduce the public health risk associated with *Cryptosporidium* in drinking water.

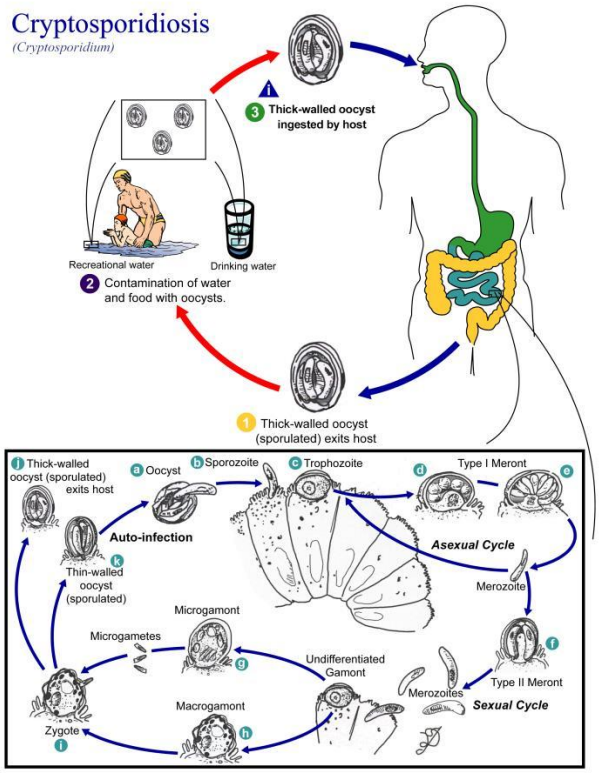


Figure 2.1.1: Cryptosporidiosis.

Cryptosporidium is a protozoan parasite that lives and reproduces entirely in one host. Ingestion of *Cryptosporidium* can cause cryptosporidiosis, a gastrointestinal (GI) illness. Cryptosporidium is excreted in feces. Transmission of cryptosporidiosis occurs

through consumption of water or food contaminated with feces or by direct or indirect contact with infected persons or animals. In the environment, Cryptosporidium is present as a thick-walled oocyst containing four organisms (sporozoites).

The oocyst wall insulates the sporozoites from harsh environmental conditions. Oocysts are 4–5 microns in length and width. Upon a host's ingestion of oocysts, enzymes and chemicals produced by the host's digestive system cause the oocyst to excyst, or break open. The excysted sporozoites embed themselves in the surfaces of the epithelial cells of the lower small intestine. The organisms then begin absorbing nutrients from their host cells. When these organisms sexually reproduce, they produce thick and thin-walled oocysts. The host excretes the thick-walled oocysts in its feces. The thin-walled oocysts excyst within the host and contribute to further host infection.

The exact mechanism by which *Cryptosporidium* causes GI illness is not known. Factors may include damage to intestinal structure and cells, changes in the absorption/secretion processes of the intestine, toxins produced by *Cryptosporidium* or the host, and proteins that allow *Cryptosporidium* to adhere to host cell surfaces. Upon excretion, *Cryptosporidium* oocysts may survive for months in various environmental media, including soil, river water, seawater, and human and cattle feces at ambient temperatures. *Cryptosporidium* can also withstand temperatures as low as 20 °C for periods of a few hours, but they are susceptible to desiccation.

Cryptosporidium is a widespread contaminant in surface water used as drinking water supplies. *Cryptosporidium* contamination can come from animal agriculture, wastewater treatment plant discharges, slaughterhouses, birds, wild animals, and other sources of fecal matter. *Cryptosporidium parvum* (C. *parvum*) has been the primary species of concern to humans.

Cryptosporidium infection is characterized by mild to severe diarrhea, dehydration, stomach cramps, and/or a slight fever. Incubation is thought to range from 2 to 10 days. Symptoms typically last from several days to 2 weeks. In a small percentage of cases, the symptoms may persist for months or longer in healthy individuals. Symptoms may be more severe in immunocompromised persons. Such persons include those with AIDS, cancer patients undergoing chemotherapy, organ transplant recipients treated with drugs that suppress the immune system, and patients with autoimmune disorders.

Cryptosporidium oocysts are highly resistant to standard disinfectants like chlorine and chloramines. Consequently, control of *Cryptosporidium* in most treatment plants is dependent on physical removal processes. However, due to their size (4–5 microns), oocysts can sometimes pass through filters. Monitoring data on finished water show that *Cryptosporidium* is sometimes present in filtered, treated drinking water.

Certain alternative disinfectants can be more effective in treating for *Cryptosporidium*. Ozone and chlorine dioxide have been shown to inactivate *Cryptosporidium* at doses higher than those required to inactivate *Giardia*, which has typically been used to set disinfectant doses. Studies have also demonstrated a synergistic effect of treatment using ozone followed by chlorine or monochloramine. UV light has recently been shown to achieve high levels of *Cryptosporidium* inactivation at feasible doses. Other processes that can help reduce *Cryptosporidium* levels in finished water include watershed management programs, pretreatment processes like bank filtration, and additional clarification and filtration processes during water treatment. Further, optimizing treatment performance and achieving very low levels of turbidity in the finished water has been shown to improve *Cryptosporidium* removal in treatment plants.

Cryptosporidium has caused a number of waterborne disease outbreaks since 1984 when the first was reported in the United States. Data from the Centers for Disease Control and Prevention include ten outbreaks caused by *Cryptosporidium* in drinking water between 1984 and 2000, with approximately 421,000 cases of illness. The most serious outbreak occurred in 1993 in Milwaukee; an estimated 403,000 people became sick, and at least 50 *Cryptosporidium*-associated deaths occurred among the severely immunocompromised.

A PWS that begins using a new surface water source after the date the PWS is required to conduct source water monitoring under the Long-Term 2 Surface Water Treatment Rule must monitor the new source on a schedule approved by the State. This applies to new plants that begin operation and previously operating plants that bring a new source on-line after the required monitoring date for the PWS. The State may determine that monitoring should be conducted before a new plant or source is brought on-line or initiated within some time period afterward.

The new source monitoring must meet all long-term rule requirements. The PWS must also determine its treatment bin classification and comply with any additional *Cryptosporidium* treatment requirements based on the monitoring results on a

schedule approved by the State.

Background and Analysis Monitoring requirements in the rule are designed to ascertain *Cryptosporidium* levels with suitable accuracy for making treatment bin classifications and in a time frame that does not delay the installation of *Cryptosporidium* treatment where needed. A mean *Cryptosporidium* concentration of 0.01 oocysts/L determines whether unfiltered PWSs are required to provide 2 or 3-log *Cryptosporidium* inactivation. No *E. coli* concentration was effective in determining whether PWSs were likely to fall above or below this level. Consequently, the rule requires all unfiltered PWSs to monitor for *Cryptosporidium*, unless they choose to provide 3-log *Cryptosporidium* inactivation.

Sampling location

The requirements in the rule for the source water sample collection location are designed to achieve two objectives:

1. Characterize the influent water to the treatment plant at the time each sample is collected.
2. Ensure that samples are not affected by treatment chemicals that could interfere with *Cryptosporidium* analysis.

The first objective is the basis for requiring PWSs that use multiple sources to analyze a blended source sample or calculate a weighted average of sources that reflects the influent at the time of sample collection. It is also the reason that PWSs are required to sample after certain pretreatment processes like bank filtration that do not involve chemical addition.

The second objective is why PWSs are generally required to sample upstream of chemical addition and prior to backwash addition (for PWSs that recycle filter backwash). However, EPA recognizes that in some situations, sampling prior to chemical addition will not be feasible and discontinuing chemical addition for a period of time prior to sampling will not be advisable. This situation could occur when a treatment chemical is added at an intake that is difficult to access. Further, some treatment chemicals may not interfere with *Cryptosporidium* analyses when present at very low levels. Consequently, the rule allows States to approve PWSs sampling after chemical addition when the State determines that collection prior to chemical treatment is not feasible, and the treatment chemical is not expected to interfere with the analysis of the sample. EPA believes that States should review source water monitoring locations for their PWSs.

Sampling Schedule

The requirement will help to ensure that monitoring determines the mean concentration of *Cryptosporidium* in the treatment plant influent. To achieve this objective, the timing of sample collection must not be adjusted in response to fluctuations in water quality, such as the avoidance of sampling when the influent water is expected to be of poor quality. EPA believes that the 5-day window for sample collection and associated allowances for sampling outside this window provide sufficient flexibility. If circumstances arise that prevent the PWS from sampling within the scheduled 5-day window, such as a weather event or plant emergency, the PWS must collect a sample as soon as feasible. In this case, feasibility includes the ability of the PWS to safely collect a sample and the availability of an approved laboratory to conduct the analysis within method specifications. In addition, the rule allows States to authorize a different date for collecting the delayed sample.

Failing to Monitor

For most monitoring and testing procedure violations under the Long-Term Rule 2, PWSs must provide a Tier 3 public notification, which is standard for this type of violation under an NPDWR. However, if a PWS fails to collect three or more *Cryptosporidium* samples, the violation is elevated to a Tier 2 special public notice. The reason for elevating the public notice at this point is the persistence of the violation and the difficulty the PWS will have in collecting the required number of samples for bin classification by the compliance date. The rule requires bin classification within six months following the end of the monitoring period specified for the PWS. This six-month period provides some opportunity for collecting and analyzing missed samples. The number of samples that can be made up in this period is limited, though, due to the need for samples to be evenly distributed throughout the year, as well as for PWSs and States to spend time during this period evaluating monitoring results to determine bin classification.

Failure by a PWS to collect the required number of *Cryptosporidium* samples for bin classification by the compliance date is a treatment technique violation with a required Tier 2 public notice. This violation reflects the inability of the PWS to determine and comply with its *Cryptosporidium* treatment requirements under the rule and provide the appropriate level of public health protection. The violation ends when the State determines that the PWS is carrying out a monitoring plan that will lead to bin classification.

A PWS that has already provided a Tier 2 public notice for missing three sampling dates and is successfully meeting a State-approved sampling schedule is not required to issue another public notice for missing the bin classification date. Alternatively, the PWS can choose to provide the highest level of *Cryptosporidium* treatment required under the rule, which is 5.5-log for filtered PWSs and 3-log for unfiltered PWSs.

Requirements for grandfathering previously collected monitoring data in the rule based on the principle that to be eligible for grandfathering, previously collected data must be equivalent in quality to data that will be collected under the rule.

The Stage 2 M–DBP Advisory Committee recommended that EPA accept previously collected *Cryptosporidium* data that are equivalent in sample number, frequency, and data quality (volume analyzed, percent recovery) to data that would be collected under the long-term rule to determine bin classification in lieu of further monitoring.

Ongoing watershed assessment treatment requirements under the rule are based on source water quality. Consequently, the rule requires watershed assessment and, a second round of monitoring following initial bin classification to determine if source water quality has changed to the degree that the treatment level should be modified. States are allowed to use programs other than the sanitary survey to assess changes in the watershed. The rule leverages the existing requirement for States to perform sanitary surveys on surface water PWSs. During the source water review in the sanitary survey, the rule requires States to determine if significant changes have occurred in the watershed that could lead to increased contamination by *Cryptosporidium*. The State can also choose to make this determination through an equivalent review of the source water under a program other than the sanitary survey, such as a Source Water Protection Assessment. If the State determines that significant changes have occurred, the State may specify that the PWS conduct additional source water monitoring or treat the potential contamination. This approach allows the PWS and State to respond to a significant change in source water quality prior to initiating a second round of monitoring or any time thereafter.

Second Round of Monitoring

A more rigorous reassessment of the source water occurs through a second round of monitoring that begins six years after initial bin classification. If EPA does not develop and finalize modifications to the rule prior to the date when PWSs must begin the second round of monitoring, then this second round must conform to the same requirements that applied to the initial round of monitoring. PWSs may be classified in a different treatment bin, depending on the results of the second round of monitoring.

Process Summary

Source water monitoring to determine additional treatment requirements for *Cryptosporidium.*

1. Sampling parameters and frequency, sampling location, sampling schedule, monitoring plants that operate only part-year, failing to monitor, providing treatment instead of monitoring, grandfathering previously collected data, ongoing source water assessment, second round of monitoring, and new source monitoring.

The Rule requires filtered PWSs using surface water or GWUDI sources to provide greater levels of treatment if their source waters have higher concentrations of *Cryptosporidium*. Filtered PWSs are classified in one of four treatment bins based on results from the source water monitoring. PWSs classified in the lowest concentration bin are subject to no additional treatment requirements, while PWSs assigned to higher concentration bins must reduce *Cryptosporidium* levels. All PWSs must continue to comply with the requirements of the SWTR, IESWTR, and LT1ESWTR, as applicable. This section addresses procedures for classifying filtered PWSs in *Cryptosporidium* treatment bins and the treatment requirements associated with each bin. Microbial toolbox that PWSs must use to meet additional Cryptosporidium treatment requirements.

- Bin classification-after completing initial source water monitoring, filtered PWSs must calculate a *Cryptosporidium* bin concentration for each treatment plant where *Cryptosporidium* monitoring is required. This *Cryptosporidium* bin concentration is used to classify filtration plants in one of the four treatment bins.

In general, the *Cryptosporidium* bin concentration is calculated by averaging individual sample results from one or more years of monitoring. Specific procedures vary, however, depending on the frequency and duration of monitoring. These procedures are as follows:

1. For PWSs that collect a total of at least 24 but not more than 47 *Cryptosporidium* samples over two or more years, the *Cryptosporidium* bin concentration is equal to the highest arithmetic mean of all sample concentrations in any 12

consecutive months of *Cryptosporidium* monitoring.

2. For PWSs that collect a total of at least 48 samples, the *Cryptosporidium* bin concentration is equal to the arithmetic mean of all sample concentrations.
3. For PWSs that serve fewer than 10,000 people and monitor for *Cryptosporidium* for only one year (collect 24 samples in 12 months), the *Cryptosporidium* bin concentration is equal to the arithmetic mean of all sample concentrations.
4. For PWSs with plants that operate only part-year that monitor for less than 12 months per year, the *Cryptosporidium* bin concentration is equal to the highest arithmetic mean of all sample concentrations during any year of *Cryptosporidium* monitoring.

In data sets with variable sampling frequency, PWSs must first calculate an arithmetic mean for each month of sampling and then apply one of these four procedures using the monthly mean concentrations. PWSs may grandfather previously collected *Cryptosporidium* data where the sampling frequency varies (one year of monthly sampling and one year of twice-per- month sampling). Filtered PWSs serving fewer than 10,000 people are not required to monitor for *Cryptosporidium* if they demonstrate a mean E. *coli* concentration less than or equal to 10/ 100 mL for lake/reservoir sources or 50/ 100 mL for flowing stream sources or do not exceed an alternative State-approved indicator trigger. PWSs that meet this criterion are classified in Bin 1.

When determining the *Cryptosporidium* bin concentration, PWSs must calculate individual sample concentrations as the total number of oocysts counted, divided by the volume as saved. In samples where no oocysts are detected, the result is assigned a value of zero for the purpose of calculating the bin concentration. Sample analysis results are not adjusted for analytical method recovery or the percent of *Cryptosporidium* oocysts that are infectious. PWSs must report their treatment bin classification to the State for approval following initial source water monitoring. The report must include a summary of the data and calculation procedure used to determine the bin concentration. PWSs must recalculate their bin classification after completing the second round of monitoring and report the results to the State for approval. If the State does not respond to a PWS regarding its bin classification after either report, the PWS must comply with the *Cryptosporidium* treatment requirements of the rule based on the reported bin classification.

- Bin treatment requirements. All filtered PWSs must comply with the treatment requirements based on their bin classification.

The total *Cryptosporidium* treatment required for plants in Bins 2, 3, and 4 is 4.0-log, 5.0-log, and 5.5-log, respectively. Conventional treatment (including softening), slow sand, and diatomaceous earth filtration plants in compliance with the IESWTR or LT1ESWTR, as applicable, receive a prescribed 3.0-log *Cryptosporidium* treatment credit toward these total bin treatment requirements. Accordingly, these plant types must provide 1.0 to 2.5-log of additional treatment when classified in Bins 2–4, respectively. Direct filtration plants in compliance with existing regulations receive a prescribed 2.5-log treatment credit and, consequently, must achieve 0.5-log greater treatment to comply with Bins 2–4.

For PWSs using alternative filtration technologies, such as membranes, bag filters, or cartridge filters, no prescribed treatment credit is available because the performance of these processes is specific to individual products. Consequently, when PWSs using these processes are classified in Bins 2–4, the State must determine additional treatment requirements based on the credit the State awards to a particular technology. The additional treatment requirements must ensure that plants classified in Bins 2–4 achieve total *Cryptosporidium* reductions of 4.0- to 5.5-log, respectively. PWSs can achieve additional *Cryptosporidium* treatment credit through implementing pretreatment processes like pre-sedimentation or bank filtration, by developing a watershed control program, and by applying additional treatment steps like ozone, chlorine dioxide, UV, and membranes. In addition, PWSs can receive a higher level of credit for existing treatment processes through achieving very low filter effluent turbidity or through a demonstration of performance.

A combination of options from the microbial toolbox can be used to gather additional credit. PWSs in Bin 2 can meet additional *Cryptosporidium* treatment requirements by using any option or combination of options from the microbial toolbox. For Bins 3 and 4, PWSs must achieve at least 1-log of the additional treatment requirement by using ozone, chlorine dioxide, UV, membranes, bag filtration, cartridge filtration, or bank filtration.

- The rule increases protection against *Cryptosporidium* and other pathogens in PWSs with the highest source water contamination levels. This targeted approach builds upon existing regulations under which all filtered PWSs must provide the same level of treatment regardless of source water quality. The rule is to ensure that PWSs with higher risk source waters achieve public health protection commensurate with PWSs with less contaminated sources.

The rule establishes risk-targeted *Cryptosporidium* treatment requirements and sets specific bin concentration ranges and treatment requirements that apply to filtered PWSs. The IESWTR established a *Cryptosporidium* MCLG of zero and requires large filtered PWSs to achieve 2-log *Cryptosporidium* removal. The LT1ESWTR extended this requirement to small PWSs. After these rules were promulgated, advances were made in analytical methods and treatment for Cryptosporidium, and EPA collected new information on *Cryptosporidium* occurrence and infectivity. Consequently, EPA assessed the implications of these developments for further controlling Cryptosporidium to approach the zero MCLG. The risk-targeted approach for filtered PWSs in the rule stems from four general findings based on new information on *Cryptosporidium*:

1. New data on *Cryptosporidium* infectivity suggest that the risk associated with a particular level of *Cryptosporidium* is most likely higher than EPA estimated at the time of earlier rules.
2. New data on *Cryptosporidium* occurrence indicate that levels are relatively low in most water sources, but a subset of sources has substantially higher concentrations.
3. The finding that UV light can readily inactivate *Cryptosporidium*, as well as other technology developments, makes achieving high levels of treatment for *Cryptosporidium* feasible for PWSs of all sizes.
4. EPA Methods 1622 and 1623 are capable of assessing annual mean levels of *Cryptosporidium* in drinking water sources.

These findings led EPA to conclude that most filtered PWSs currently provide sufficient treatment for *Cryptosporidium*, but additional treatment is needed in those PWSs with the highest source water Cryptosporidium levels to protect public health. Further, PWSs can characterize *Cryptosporidium* levels in their source waters with available analytical methods and can provide higher levels of treatment with available technologies. Consequently, risk-targeted treatment requirements for *Cryptosporidium* based on source water contamination levels are appropriate and feasible to implement.

Basis for bin concentration ranges and treatment requirements. To establish the risk-targeted treatment requirements in today's rule, EPA had to determine the degree of treatment that should be required for different source water *Cryptosporidium* levels to protect public health. This determination involved addressing several questions:

1. What is the risk associated with *Cryptosporidium* in a drinking water source?
2. How much *Cryptosporidium* removal do filtration plants achieve?
3. What is the appropriate statistical measure for classifying PWSs into treatment bins?
4. What degree of additional treatment is needed for higher source water *Cryptosporidium* levels?
5. How should PWSs calculate their treatment bin classification?

The risk of infection from *Cryptosporidium* in drinking water is a function of exposure (the dose of oocysts ingested) and infectivity (likelihood of infection as a function of ingested dose). Primary (direct) exposure to *Cryptosporidium* depends on the concentration of oocysts in the source water, the fraction removed by the treatment plant, and the volume of water consumed (secondary exposure occurs through interactions with infected individuals). Thus, the daily risk of infection (DR) is as follows:

DR = (oocysts/L in source water) × (fraction remaining after treatment) × (liters consumed per day) × (likelihood of infection per oocyst dose). Assuming 350 days of consumption per year for people served by community water systems (CWSs), the annual risk (AR) of infection is as follows: AR = 1 ¥ (1 ¥ DR)350.

EPA has estimated the mean likelihood of infection from ingesting one *Cryptosporidium* oocyst to range from 4 to 16 percent. Median individual daily water consumption is estimated as 1.07 L/day.

Key Terms

- ***Cryptosporidium*** - a protozoan parasite that lives and reproduces entirely in one host; ingestion of *Cryptosporidium* can cause cryptosporidiosis, a gastrointestinal (GI) illness; cryptosporidium is excreted in feces.
- **Ground Water Rule (GWR)** – the purpose is to improve drinking water quality and provide protection from disease-causing microorganisms; water systems that have groundwater sources may be susceptible to fecal contamination; applies to public water systems that use ground water as a source of drinking water
- **Surface Water Treatment Rules (SWTRs)** – the purpose is to reduce illnesses caused by pathogens in drinking water, including *Legionella*, *Giardia lamblia*, and *Cryptosporidium*; the SWTRs requires water systems to filter and disinfect surface water sources.

- **Total Coliform Rule** (TCR) - a National Primary Drinking Water Regulation (NPDWR), published in 1989 and became effective in 1990; sets a health goal (Maximum Contaminant Level Goal (MCLG)) and legal limits (Maximum Contaminant Levels, MCLs)) for the presence of total coliforms in drinking water

Review Questions

1. **What are the primary components of the Total Coliform Rule?**

2. **What is the basis of the Total Coliform Rule?**

3. **What is the primary requirement in the Groundwater Rule?**

4. **List four EAP approved laboratory methods for testing for coliforms.**

5. **What are the major provisions of the Long-Term Surface Water Treatment Rule?**

Chapter Quiz

1. Total coliforms are used as a(n) _____ of the possible presence of pathogens in drinking water. Total coliforms are used to determine the adequacy of water treatment and the integrity of the distribution system.
    1. indicator
    2. model
    3. log removal
    4. alternative
2. The Revised Total Coliform Rule establishes _____for E. coli and uses E. coli and total coliforms to initiate a find and fix approach to address fecal contamination that could enter into the distribution system.
    1. a log removal
    2. a maximum contaminant level (MCL)
    3. a secondary maximum contaminant level (SMCL)
    4. a model
3. Within 24 hours of learning of a Total Coliform positive routine sample result, at least ____ repeat samples must be collected and analyzed for total coliform.
    1. 1
    2. 2
    3. 3
    4. 4
4. States are required to conduct _____ of all groundwater systems in order to identify significant deficiencies, including deficiencies which may make a system susceptible to microbial contamination.
    1. hydrologic studies
    2. microbial examinations
    3. a sanitary survey
    4. laboratory studies
5. The Surface Water Treatment Rule requires water systems to _____ surface water sources.

1. filter and disinfect
2. conserve
3. aerate
4. disinfect

6. In order not to be subject to triggered source water monitoring under the Groundwater Rule, a groundwater system can notify the state that it provides at least _____ treatment of viruses using virus inactivation, or removal, before or at the first customer.
    1. 2-log
    2. 3-log
    3. 4-log
    4. 6-log
7. The Long-Term Surface Water Rule establishes risk-targeted treatment technique requirements to control _____ in PWSs using surface water or groundwater under the influence of surface water.
    1. *E.coli*
    2. *Giardiasis lambdia*
    3. *Cryptosporidium*
    4. Coliforms
8. What is the maximum allowable turbidity in the combined filter effluent?
    1. 0.5 NTU
    2. 1.0 NTU
    3. 3.0 NTU
    4. 5.0 NTU
9. EPA promulgated the Long-Term Surface Water Treatment Rule to reduce the public health risk associated with _____ in drinking water.
    1. *Giardiasis lambdia*
    2. *Cryptosporidium*
    3. Coliforms
    4. *E. coli*
10. _____ is a protozoan parasite that lives and reproduces entirely in one host,
    1. *E. coli*
    2. Coliforms
    3. *Cryptosporidium*
    4. Fecal streptococcus

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2.2.2: Water Chemistry and Standards

Learning Objectives

After reading the chapter the student should be able to identify:

- Matter, elements, and compounds
- Public water systems: community and non-community
- Primary and secondary standards
- Water treatment violations
- Volume math problems

Water treatment is a complex process that involves parts that the human eye cannot see. In this chapter, you will learn about the basic scientific principals related to the water treatment. We will also discuss drinking water standards in the United States and different community standards.

Matter, Elements, and Compounds

Matter

The smallest parts of an element are comprised of particles known as atoms. Even though they are so small, atoms still retain the characteristics of the element. Even with technological advancements, microscopes are still unable to capture atoms. The multiple arrangements of atoms make each element unique. The atom ever so small, is comprised of three particles known as the proton, neutron, and electron. Each particle is associated by different charges.

- Proton-positive
- Neutron-no charge
- Electron- Negative charge

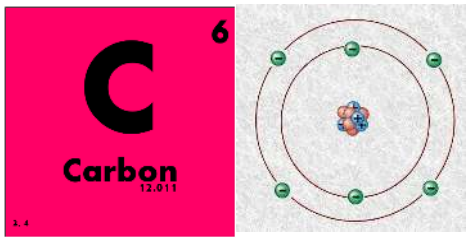


Figure **2.2.2.1**: (left) Carbon by Science Activism is licensed under CC BY 2.0. Figure **2.2.2.2**: (right) Carbon atom by Alejandro Porto is licensed under CC BY-SA 3.0

The defining characteristic of an atom is identified by the proton. The proton, located in the nucleus, has a distinctive number. For example, carbon has six protons located in the nucleus. No other element has six protons in the nucleus. The number of protons is represented as the atomic number. The atomic weight is the number of protons and neutrons. The number of protons that exist for a given element is always the same, but the number of neutrons can vary. When there is a varying number of neutrons of a given element, it is known as an isotope. When an atom has a difference in electrons, it is called an ion. When the charges of the atom are not balanced, they become unstable. An atom that has more protons than neutrons is called a cation. An atom that has more electrons than protons is called an anion.

Most common elements in the water treatment profession:

- Aluminum (Al)
- Antimony (Sb)
- Arsenic (As)
- Barium (Ba)
- Beryllium (Be)
- Boron (B)

- Bromine (Br)
- Cadmium (Cd)
- Calcium (Ca)
- Carbon (C)
- Chlorine (Cl)
- Chromium (Cr)
- Copper (Cu)
- Fluorine (F)
- Hydrogen (H)
- Iodine (I)
- Iron (I)
- Lead (Pb)
- Magnesium (Mg)
- Manganese (Mn)
- Mercury (Mn)
- Nickel (Ni)
- Nitrogen (N)
- Oxygen (O)
- Phosphorus (P)
- Potassium (K)
- Radium (Ra)
- Selenium (Se)
- Silicon (Si)
- Silver (Ag)
- Sodium (Na)
- Strontium (Sr)
- Sulfur (S)
- Thallium (Tl)

There are elements that are pure in form, such as oxygen. Since elements are unstable, they often combine with other elements to form compounds. Water (H_2O), for example, is a compound. It is a combination of two hydrogen atoms and one oxygen atom. A compound is two or more elements that are bonded together due to their attraction by reverse charges. The combining elements form a molecule. When two chemicals are mixed together without a chemical reaction it is called a mixture. The difference between a mixture and a compound is bonded together by a chemical reaction. A good example of a mixture is saltwater. The salt can be removed from the water through distillation. Water chemistry will be covered in greater detail in the Water Quality text and course.

Drinking Water Standards

The first drinking water standards created in the United States occurred in 1974 and were called the Safe Drinking Water Act (SDWA). The US EPA sets drinking Water Standards that all Water Municipalities must adhere to. Although States are able to come up with their own Standards, they must meet the minimum requirements set forth by the federal EPA. In California, drinking water standards are much more stringent than the federal requirements and therefore have primacy. As of 2014, the State regulatory group responsible for drinking water is the State Water Resources Control Board. Revisions to the safe drinking water act include approval techniques for treatment plants, specifying criteria for filtration of public water supplies, distinguishing different treatment techniques for surface and groundwater, and prohibiting lead products in drinking water systems. There are two sets of drinking water Standards identified as primary standards and secondary standards. Primary Standards affect human health and are mandated with **Maximum Contaminant Levels** (MCL). The MCL is the official safe level at which a human can consume the given contaminant without adverse health effects. Secondary Standards do not affect human health and are controlled with **Maximum Contaminant Level Goals** (MCLG). When a contaminant is reported, there is no such thing as zero. Levels are set to protect human health but are also set based on the best available technology. As technology improves MCL's may be reexamined.

Instrumentation to measure contaminant levels are not always capable of reading to absolute zero. Because of this, a Detection level for reporting is required.

Public Water Systems

There are three different categories of public water systems:

- Community Public Water System: A community public water system has 15 or more service connections and serves at least 25 or more people year-round. These would include municipalities, mobile home parks, condos, and apartment buildings.
- Nontransient, NonCommunity System: A nontransient, NonCommunity public water system owns its own system and serves an average of 25 people for at least six months. Schools, hospitals, and office buildings are included in this category.
- Transient, NonCommunity System: A transient, NonCommunity public water system owns their own water system and serves an average of 25 people per day. In this category people consume the water for a short period of time. This category includes churches, parks, restaurants, and motels.

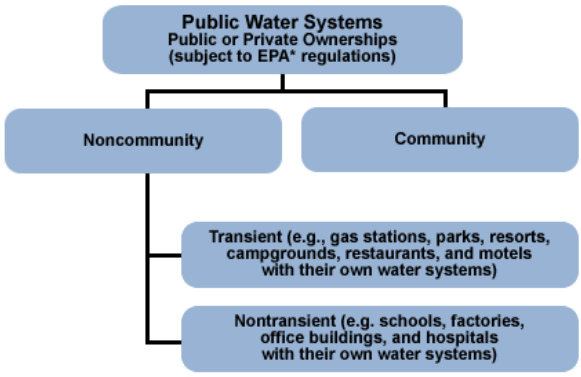


Figure **2.2.2.2**: Image by the CDC is in the public domain

Primary Drinking Water Standards are split into five categories. The categories include Inorganics, Organics, Turbidity, Microbiological, and Radiological.

- Inorganics: Metals, Nitrate, and Fluoride
- Organics: Pesticides, solvents, and Disinfectant byproducts (DBP's)—The combination of Chlorine and natural organic material. This topic will be discussed in greater detail later in the text.
- Turbidity: The cloudiness of the water. Turbidity has the ability to shield microbiological material.
- Microbiological: Coliform testing (This will be covered in greater detail later in the text. Water operators do not test for specific microbiological agents. We test for the indicator organism coliform. They colonize in greater numbers so if a sample comes back positive there is a greater likelihood of fecal contamination.)
- Radiological: Gross alpha, beta, and radon

Secondary drinking water standards are solely based on the aesthetic quality of drinking water. The main focus of secondary standards is taste, odor, and color. A glass of water that smells like fish and is orange in color may be "safe" to drink but wouldn't be well received or readily consumed. California, as well as some other states, has endorsable secondary standards.

Table 2.1: Recommended Levels for Contaminants and Characteristics

Contaminant/characteristic	Recommended level
Aluminum	0.05 to 0.2 mg/L
Chloride	250 mg/L
Color	15 color units
Copper	1 mg/L
Corrosivity	Non-corrosive
Fluoride	2 mg/L
Foaming agents	0.5 mg/L
Iron	0.3 mg/L
Manganese	0.05 mg/L
Odor	3 threshold odor number
pH	6.5 to 8.5
Silver	0.10 mg/L
Sulfate	250 mg/L
Total dissolved solids	500 mg/L
Zinc	5 mg/L

Source: Graph by the EPA is in the public domain

Public Notification

In the event that a treatment plant does not meet requirements of the SDWA, the public must be notified. There are three different tiers of notification with tier I being the worst of violations and tier III being the least. The EPA provides very specific language for public notifications in the event of a violation. Violating a SDWA compliance is bad enough, but failing to report violations brings even stiffer penalties and fines. In 2014 in Flint Michigan 15 people were criminally charged due to their negligence in the water treatment profession. It all started when the city of Flint changed their source water without properly testing. Officials knew the water was not safe to drink and numerous violations had been made. The public was not properly informed of these violations which resulted in 10 deaths and 77 others becoming severely ill. It is something that is rarely discussed because people in industrialized countries never really worry about the quality of their drinking water. The most important thing you can do as an operator is say something if there appears to be a problem with the quality of the drinking water. Otherwise, you may end up in jail. Notification options include radio or television announcements, newspapers, hand delivery, posting in public places, loudspeakers, texting, and reverse 911. The notification will vary based on the severity of the violation.

Violations

Tier I

- Any positive fecal coliform positive test and failure to sample after an initial positive test
- Nitrate or Nitrite violation
- Chlorine Dioxide Maximum residual disinfection limit
- Exceed treatment plants allowable turbidity level. Can be a tier II if the primacy agency does not elevate violation.
- Waterborne emergency or outbreak of waterborne illness

Tier II

- MCL, MRDL and, Treatment Technique (TT) violations if treatment plant does not perform corrective actions to fix issues in treatment plant or fails to inform public.
- Water quality monitoring violation—not taking required water quality samples. Can also be a tier III violation but can be elevated for gross negligence
- Noncompliance of a variance or an exemption

Tier III

- Water testing and monitoring violation
- Any time the treatment system is running under a variance or exception. Primacy agency may give a treatment plant a variance or exemption for a short period of time. The public notification is to inform the public that a water agency is not running in accordance with an approved treatment technique. It doesn't mean the water is unsafe to drink, but the operating manuals are very specific.

Water Quality monitoring

Continuous monitoring of drinking water ensures quality; reliable drinking water is being delivered to the public. The number of samples taken, frequency of sampling, sampling location, testing procedures, and requirements for record-keeping are all specified by state and federal requirements. If sampling requirements are not met, it can lead to public notification. The tier violation is based on the contaminant and whether or not the contaminant causes acute health effects.

The type of monitoring is based on the source of the water, the treatment technique, and the size of the system. Reporting and record keeping is based on the primacy agency's regulations. The state regulations must meet federal requirements at a minimum but may be more stringent as is the case in California.

Record Keeping

Below is a list of records that must be kept and the amount of time the records must be retained on file.

- Bacteriological and Turbidity—5 years
- Chemical analysis—10 years
- Corrective actions from violations—3 years
- Sanitary surveys—10 years
- Exemptions—5 years after expiration

Variances and Exemptions

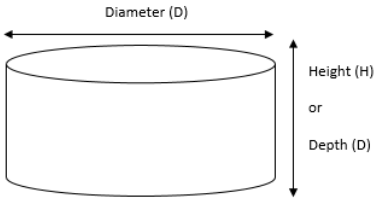
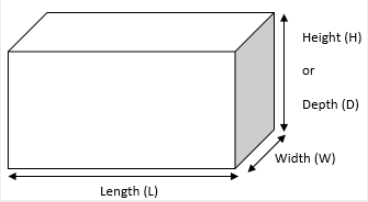
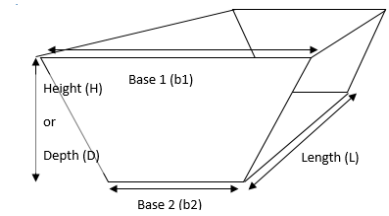
In the event a water system is unable to meet a MCL because of the source water, a primacy agency can grant a variance or exemption. The variance is only given when the agency has incorporated the best available technology and there is zero risk to public health. In the case of Flint Michigan, the new source water was not properly tested before it was used in the system. Flint Water plant was unable to properly treat the source water which had elevated levels of lead and the City was not using the best available technology. Even if the City of Flint would have applied for a variance or exemption, it would not have been granted because the lead levels in the water create a significant risk to public health.

In future chapters of the text, we will examine regulations added to the SDWA. Several changes and enhancements have been made since the exception of the original legislation. We will discuss in greater detail the Total Coliform Rule, Surface Treatment Water Rule, Long Term 2 Enhanced Surface Water Treatment Rule, Lead and Copper Rule, Ground Water Rule, and Stage 1 &2 Disinfectant Bi-Product Rule.

Volume

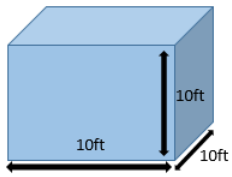
Volume calculations will become very common for water treatment operators. Operators use volume calculations to solve math questions with circles, triangles, and rectangles. If you look around a water treatment facility, it is full of geometric shapes. Tanks

can be cylindrical or rectangular in nature. Settling ponds may have a triangular nature to them. The basic volume questions will become more involved later on in the text as you may have to solve a volume question first, and then solve a flow-related question.

Cylinder  	Volume = 0.785 × D2 × H
Rectangle  	Volume = L × W × H
Trapezoid  	Volume = $\frac{b1 + b2}{2}$ × H × L

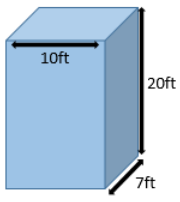
Example 2.2.2.1

What is the volume of a cubed tank that is 10 feet high? (Remember cubes have the same unit of length on all three sides. This is the easiest problem to solve.)

 	Volume = Length × Width × Height Volume (ft^3) = 10ft × 10ft × 10ft Answer is 1,000 ft^3

Example 2.2.2.1

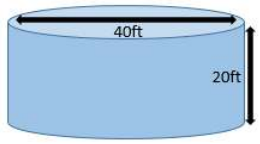
What is the volume of a rectangular tank that is 20 ft. high, 10 ft wide, and 7ft in length?

 	Volume= Length × Width × Height Volume= 7ft × 10ft × 20ft Answer is 1,400ft^3

There are two different ways to solve cylindrical math problems. The easiest formula to use is volume= .785 d^2 H. This formula is easiest because in water math we are generally looking at the diameter of a cylindrical shape and not the radius. The radius of a circle is half the diameter. It is a straight line measured from the center of the circle to the edge of the circle. The diameter is a straight line that passes through the center of the circle with endpoints on the circle.

Example 2.2.2.2

What is the volume of a storage tank that measures 40 ft. in diameter and is 20 ft. deep?



Volume= .785 × d^2 × H
Volume= .785× 40ft × 40ft × 20ft
Answer is 25,120ft^3

Often the water math word problems will require multiple steps to solve. Typically, we want to know how many gallons a given tank will hold. Once we find the volume of the tank in cubic feet, we will then convert the cubic feet into gallons.

Example 2.2.2.3

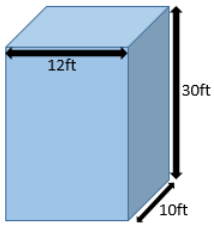
Convert the answer from Example **2.2.2.3** into gallons.

25,120 ft^3 x 17.48 gal x 1 ft^3 = 187,898 gal x 1

Answer: 187,898 gallons

Example 2.2.2.4

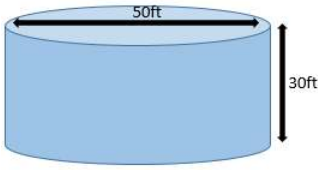
A rectangular water tank is full. The dimensions are 30ft high 12ft wide and a length of 10 ft. Convert to gallons.



Volume= 10ft x 12ft x 30 ft
Volume= 3,600ft^3
3,600 ft^3 x 17.48 gal x 1 ft^3 = 26,928 gal x 1
Answer: 26,928 gallons

Example 2.2.2.5

A cylindrical storage tank has a diameter of 50ft and a height of 30ft. The tank is half full. How many gallons are in the tank?



Volume= .785 x 50ft x 50ft x 15ft
Volume= 29,437.5 rounded to 29,438ft^3
29,438 ft^3 x 17.48 gal x 1 ft^3 = 220,196 gal x 1
Answer: 220,196 gallons

Chapter Review

1. The smallest part of an element is known as _____.
    1. Proton

2. Neutron
3. Atom
4. Nucleus

2. The atomic weight is comprised of _____.
    1. Neutrons and electrons
    2. Protons and neutrons
    3. Nucleus and neutrons
    4. Atom and nucleus
3. An atom with a negative charge is known as _____.
    1. Proton
    2. Neutron
    3. Nucleus
    4. Electron
4. What does the symbol mg/L stand for?
    1. Micrograms per liter
    2. Milligrams per/L
    3. parts per million
    4. Both 2 and 3
5. What does the acronym MCL stand for?
    1. Minimum contaminant level
    2. Micron contaminant level
    3. Maximum contaminant Level
    4. Milligrams counted last
6. How long do sanitary surveys have to be retained for records?
    1. 3 years
    2. 5 years
    3. 7 years
    4. 10 years
7. The most severe water system violation that requires the fastest public notification is _____.
    1. Tier I
    2. Tier II
    3. Tier III
    4. Tier IV
8. The primacy agency may grant a variance or exemption as long as _____.
    1. The agency is using the Best Available Technology
    2. There is no threat to public health
    3. There is never a scenario for a variance or exemption
    4. Both 1 and 2
9. A public water system that serves at least 25 people six months out of the year is known as _____.
    1. Nontransient noncommunity
    2. Transient noncommunity
    3. Community public water system
    4. None of the above
10. Regulations based on the aesthetic quality of drinking water are known as _____.
    1. Primary Standards
    2. Secondary Standards
    3. Microbiological Standards

4. Radiological Standards

11. The lowest reportable limit for a water sample is _____.
    1. 0.5 mg/L
    2. Zero
    3. Public health goal
    4. Detection Level for reporting
12. Primary Standards are based on _____
    1. Color and Taste
    2. Aesthetic quality
    3. Public Health
    4. Odor
13. A circular clearwell is 150 feet in diameter and 40 feet tall. The Clearwell has an overflow at 35 feet. What is the maximum amount of water the clearwell can hold in Million gallons rounded to the nearest hundredth?
    1. MG
    2. 4.62 MG
    3. 18.50 MG
    4. 7.50 MG
14. A sedimentation basin is 400 feet length, 50 feet in width, and 15 feet deep. What is the volume expressed in cubic feet?
    1. 100,000 ft^3
    2. 200,000 ft^3
    3. 300,000 ft^3
    4. 400,000 ft^3
15. A clearwell holds 314,000 ft^3 of water. It is 100 ft in diameter. What is the height of the clearwell?
    1. 25 ft
    2. 30 ft
    3. 35 ft
    4. 40 ft

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2.2.3: Microorganisms

The most important job of a Water Treatment Operator is providing reliable and quality water to the public. This is accomplished through chemical deactivation or physical removal of disease-causing microorganisms in the water. Microorganisms are deactivated by the addition of a chemical such as Chlorine or Ozone while physical removal is accomplished with the use of a filtration system.

Surface Water Treatment Rule

The **Surface Water Treatment Rule** (SWTR) was created in 1990 to further protect the public from waterborne illness. The specific diseases the SWTR seeks to prevent are those caused by viruses, legionella, and *Giardia* lamblia. Disease-causing microorganisms are also known as pathogens. The microbes that cause most waterborne illnesses are found in most surface water in the United States. Every public agency that uses surface water as source water must adhere to the SWTR. Surface Water is defined as any open body of water that is susceptible to surface runoff. Rainfall and snowmelt that enter open bodies of water such as lakes, rivers, and man-made reservoirs are susceptible to contamination from sewage treatment plants and animal feces.

At this time there are no simple inexpensive tests for viruses, legionella, and *Giardia* lamblia; therefore, other protective measures are used to test the source water and treated water. Water regulations provide detailed inactivation and removal regulations for Protozoa, also known as *Giardia*, and viruses. Bacteria fall somewhere in the middle of both microorganisms so there is no need to "regulate" them. Bacteria will be removed and/or deactivated within the parameters or regulations that are in place. *Giardia* and *Cryptosporidium* form hard cysts that are very difficult to deactivate chemically with Chlorine. They are larger than viruses so they or more easily removed through filtration. Newer technological advances such as ozone addition are excellent ways to deactivate *Giardia*.

Treatment plants must use a combination of disinfectant (chemical deactivation) and filtration and must achieve 99.9% removal or inactivation of *Giardia* cysts and 99.99% of viruses. You might also see the percentages expressed as 3 Log and 4 Log. 99.9% will be expressed as 3 Log and 99.99% will be expressed as 4 Log. Treatment plants, which use filtration, achieve their removal factor by monitoring the combined filter effluent turbidity. Turbidity is the measurement of the cloudiness in water. The reason it is important to measure turbidity is because microorganisms can hide behind the very small particles and render treatment techniques ineffective. Turbidity readings are expressed as nephelometric turbidity units (NTU). Most surface source water will not meet standards that would enable a treatment plant to refrain from using approved filtration techniques. The approved treatment techniques currently used by water operators are conventional treatment, direct filtration, slow sand, diatomaceous earth, reverse osmosis, and alternate treatment technologies approved on a case by case basis by the primacy regulating board. Newer technologies such as membrane filtration and UV treatment are being employed by some water agencies.

Table 2.3.1: Waterborne Pathogens

Bacteria	Viruses	Protozoa
• Campylobacter • Escherichia coli (E-coli) • Salmonella • Yersinia • Vibrio • Legionella • Aermmonas • Mycobacterium • Shigella • Pseudomonas	• Hepatitis A • Reovirus • Calicivirus • Enterovirus • Coxsackievirus • Adenovirus • Echovirus • Poliovirus	• *Giardia Lamblia* • *Cryptosporidium* • Entameoba • *Microsporidium*

A continuous disinfectant residual must always be in the distribution system to prevent waterborne illness. A disinfectant residual of .2 mg/L must be present at all times in the distribution system, however, most water operators will maintain somewhere between 2.5 mg/L-3.0 mg/L. The CT calculation is used to make sure proper disinfectant levels are being used during the treatment and distribution process. The effectiveness of the treatment process is calculated with the CT formula and uses data such as disinfectant

used, residual of disinfectant, length of time disinfectant is in contact with water, water temperature, and pH of the water. It is important to note that during the treatment process the goal is to disinfect the water (kill all pathogens) and not to sterilize (kill all organisms).

The “C” is the concentration of disinfectant while the “T” is the amount of time the disinfectant is in contact with water. On days with higher effluent plant rates, an operator may need to raise chlorine doses as the disinfectant will be in contact with the water for less time. Conversely, if plant flow rates are lower, a lower chlorine dose can be used because the disinfectant is in contact with the water for a greater time.

Case Study: Milwaukee April 1993

In April of 1993, the largest outbreak of *Cryptosporidium* on record occurred in Milwaukee, Wisconsin. Over 400,000 people reported illness and 100 people died. All of the people who died after drinking the tainted water had the AIDS virus. It can’t be for certain that the *Cryptosporidium* was the cause of each of their deaths, but as will be discussed later in this chapter, people with weakened immune systems are much more susceptible to death if they drink tainted water.

The Milwaukee incident was the catalyst for enhancements to the SWTR. Since *Cryptosporidium* creates cysts and is not killed by chlorine, the “double barrier” treatment approach was created. Treatment plants were then required to monitor turbidity effluent levels and use alternative treatment techniques, such as ozone or ultraviolet light, that would deactivate the *Cryptosporidium*. An effective filtration plant using coagulation, flocculation, sedimentation, and filtration, should have been able to handle the outbreak, thus turbidity levels were not within standards.

The source of the *Cryptosporidium* was believed to be a sewage spill that was very close to the intake of the Southern Milwaukee treatment plant where the outbreak occurred. Others believe that the operators of the treatment plant were using higher quantities of waste stream water in the treatment process. Recycling washed filter water is a common practice, but after this event, it was established that only 10% of the sourced raw water can come from the wastewater.

The lesson everybody learned here is water quality is ever-changing and evolving. Mother Nature throws curve balls at us that change the quality of the source water. If something is wrong, it is your duty as an operator to say something. Regulations are all well and good but if they are not being followed, people can become very ill or possibly even die.

Total Coliform Rule

The **total coliform rule** was published in 1989 and was revised in 2014. It set up minimum requirements for the frequency and amount of coliform tests that would be taken by water agencies. As discussed earlier, the coliform bacteria exist in larger quantities than other bacteria. If there is a positive coliform test, there is a greater chance the treatment process is not functioning properly and there is an increased chance of pathogens in the water. Bacterial outbreaks in water cause gastroenteritis with the associated symptoms of nausea, diarrhea, vomiting, and cramps. Very young people, elderly, and people with weakened immune systems are at an even greater danger should there be waterborne illnesses in water. Each water agency is required to have an approved sampling site map approved by the primacy agency.

The Total Coliform Rule goal is zero positive coliform samples. Water systems that take less than 40 samples per month are only allowed one positive sample while systems that take greater than 40 samples must not find positive results in more than 5% of the coliform samples taken. If a positive coliform sample is found, it is not necessarily an indicator of a problem. Human sampling error could be the culprit. Once a positive is found the coliform sample is retaken within 24 hours at the positive sampling site and two additional samples are taken, one upstream and one downstream of the initial positive site. If there is a second positive coliform result, the water is then tested for E-Coli. If E-Coli is present in the sample, it is an immediate public health risk and is deemed an acute MCL violation. This would be considered a Tier I violation and public notification would have to occur within 24 hours.

Long-Term 1 Enhanced Surface Water Treatment Rule

The Long-Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR) applies to water systems that serve less than 10,000 people. Below is a list of requirements for water agencies that fall under this category:

- Must achieve 99% or 2 log removal of *Cryptosporidium*

- Most systems are required to meet turbidity standards of 0.5 NTU from 95% of combined filter effluent turbidity readings. Smaller systems will get 2 log removal credit of *Giardia* with a stricter .03 NTU combined filter effluent.
- Monitoring of individual filter is required. Higher turbidity reading from individual filters will require corrective action.
- Some states might require a disinfectant byproduct profile
- Any change in primary disinfectant must be profiled and approved
- All treated water clearwells must be covered and not open to atmosphere

Long-Term 2 Enhanced Surface Water Treatment Rule

The Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) covers all water systems which serve more than 10,000 customers.

- This rule added enhancements to the SWTR. Water providers are required to test the source raw water for *Cryptosporidium* and E-coli for a 2 year period. This step was put in to ensure all treatment plant equipment was capable of properly deactivating and removing pathogens from water.
- After testing, systems were given a bin number which determined how susceptible the system was to contamination.
- If systems were susceptible, a time frame was given to correct deficiencies
- Continuous monitoring of the distribution system influent and maintaining at least .02 mg/L chlorine residual is required

Filter Back Wash Recycling Rule

As noted in the Milwaukee case study, water systems are able to use recycled wastewater as a raw water source. Many treatment plants utilize waste ponds, waste lagoons, and waste basins to capture recycled wash water and water from drains throughout treatment plant. In order for plants to use the recycled water, plants must put the wastewater through the same treatment process as raw untreated water. The amount of water that can be returned is based on the plants size and maximum plant flows.

Lead and Copper Rule

The lead and copper rule differs from most other water guidelines because these two constituents are usually found in water after it has gone through the treatment cycle. Most raw water has very low levels of lead and copper. Lead and copper are found in drinking water after a chemical reaction takes place in distribution pipes. Water that is more acidic can erode lead and copper pipes causing them to leach into water. The use of lead pipes in drinking water systems was banned in 1986 and they can no longer be used. Lead is known to cause several health problems in fetuses and young children. It can cause developmental problems. Lead can also have effects on the kidney, brain, red blood cells, and is known to cause anemia.

With optimal corrosion control, the ability of water to chemically react with lead and copper pipes is lowered. Many treatment plants add chemicals such as caustic soda to raise the pH of the water. Treated water with a pH around 8 will keep a thin layer of calcium on the inside of a distribution pipe which protects the pipe from corrosion. Corrosion control is tested by monitoring the conductivity, testing pH of water, water temperature, testing for calcium, testing for alkalinity, and testing for phosphate or silica corrosion inhibiter if used to control corrosion.

The Lead and Copper rule also differs from other rules because it bases its parameters on action levels. If 10 percent of the customers' water tests in the 90th percentile of the action level for lead and copper, then further preventative actions must be met. Most customers do not have to worry about this due to advances in corrosion control in the past few decades.



Figure **2.2.3.1**: Image of lead pipes by Borsi112 is licensed under CC BY-SA 3.0

Stage 1 and 2 Disinfectant Bi-Product Rule

When natural organic matter mixes with chemical disinfectants, it is possible for disinfectant byproduct formation (DBP). Chemical disinfectants used in water treatment that form DBP's are chlorine, chlorine dioxide, chloramines, and ozone. The Stage 1 disinfectant byproduct rule established MCL's for trihalomethane (TTHM), haloacitic acid (HAA5), chlorite, and bromate. Compliance is set up on a running annual average for TTHM, HAA5, and Bromate and on a monthly average for chlorite. The rule also set up maximum disinfection levels for chlorine, chloramines, and chlorine dioxide.

The Stage 2 disinfectant byproduct rule applies to all community and nontransient noncommunity water systems that add a chemical disinfectant or purchase treated water that has a chemical disinfectant. The purpose of the Stage 2 rule is to monitor local sampling of individual connections. Some parts of the water system have less movement, therefore they are more susceptible to DBP formation. The Stage 2 rule covers TTHM and HAA5 and has the same MCL as the Stage 1 rule. See the chart below:

Disinfectant Residual	MRDL* as mg/L	Compliance Based On
Chlorine	4.0 mg/L	Running annual average RAA
Chloramines	4.0 mg/L	Running annual average RAA
Chlorine Dioxide	0.8 mg/L	Daily samples

*Maximum residual disinfectant level

Disinfection Byproduct	Maximum Contaminant Level	Compliance Based On
Trihalomethane	.080 mg/L (80 ppb)	Running annual average
Haloacetic acid	.060 mg/L (60 ppb)	Running annual average
bromate	.010 mg/L (10 ppb)	Running annual average
chlorite	1.0 mg/L (1 ppm)	Monthly average

*ppb- parts per billion ppm- parts per million

Consumer Confidence Reports

The public has a right to know what is in their drinking water. As you continue to read through the text you will notice that a lot of the terminology is quite a mouthful. In 1998 consumer confidence reports were made available to the public for transparency. Eight groups of information were added to the report:

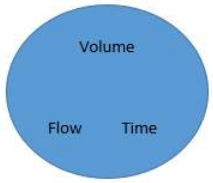
- System information including contact info
- Different sources of water (i.e. lakes, wells, rivers)
- Definitions non-water personnel can understand including MCL's, MCLG's and treatment techniques
- Any detected contaminants in the system along with a listing of the possible health effects if limits and goals are not met

- Non-regulated contaminants found
- List of violations if they occurred
- Variances and exemptions
- Educational tools for contaminants and affected populations

The internet has made it possible for water treatment facilities to post information monthly on company websites; however, a consumer confidence report will be mailed/electronically delivered to its customers on a yearly basis.

Flow Rate Calculation

The flow rate calculation will be one of the most frequently used in water math. This calculation tells us a lot about what is going on in our water system. Common flow rates you will see are Gallons per Minute (GPM), Cubic Feet Per Second (CFS), Million Gallons a Day (MGD), and Acre Feet per Year (AFY). Water operators use flow rates for different purposes. If you were running a small treatment plant, you might use GPM or CFS in your day to day operations but when looking at water produced throughout the entire month or year, calculating in Acre Feet may be more appropriate. Like any algebraic formula, there will be an unknown factor you are solving for. In the case of a flow question, there will be 3 values, two known and one unknown.

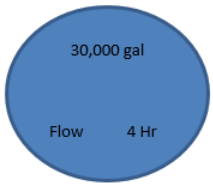


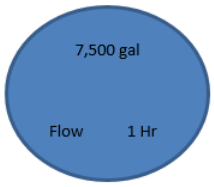
Flow Rate Equation
Flow Rate = Volume ÷ Time
The algebraic "Wheel" is a very effective way to solve many water math problems. Those students with more "mechanical" minds may find this way of solving math problems easier. Below is an example of how to solve a flow rate equation with both methods.

Example 1

In 4 hours, a water tank's volume increases by 30,000 gallons. What was the flow rate of the water entering the tank? Express in gallons per minute.

Flow Rate = Volume/Time
Flow Rate = 30,000 gallons/4 hours
7,500 gallons/1 hour
7,500 gallons/1 hour = 1 hour/60 min
= 125 gallons/minute





We can also use the Flow Rate calculation to solve for volume or time.

Example 2 - Solve for Time

How long will it take to drain a 100,000-gallon storage tank where the water is exiting at 2,500 Gallons per minute?

Time = 100,000 gal/2,500 GPM = 40 minutes

Always put the unknown in the left part of the formula so your factors cancel out properly.

Example 3 - Solve for Volume

Your water tank pump is set to run for 90 minutes. Your pump output is 3,000 GPM. How many gallons of water will enter the tank?

Volume = 3,000 GPM x 90 min

Volume = 270,000 gallons

Example 4

A water tank's full capacity is 500,000 gallons. The operator will bring the tank down to half full in an 8-hour period. What is the flow rate of the water exiting the tank?

(Note: The state gets very creative with their test questions. Remember to read the question multiple times before solving it. Don't be the test taker that uses 500,000 gallons in the equation instead of 250,000 gallons!)

Flow Rate = 250,000 gallons/8 hours

Flow Rate = 31,250 gallons/1 hour

31,250 gal/1 hour = 1 hour/60 min = 520.83 GPM

Chapter Review

1. A disease-causing microorganism:
    1. Pathogen
    2. Colilert
    3. Pathological
    4. Turbidity
2. According to the Surface Water Treatment Rule, what is the combined inactivation and removal for *Giardia*?
    1. 1.0 Logs
    2. 2.0 Logs
    3. 3.0 Logs
    4. 4.0 Logs
3. What is the equivalency expressed as a percentage for the SWTR inactivation and removal of viruses?
    1. 99.9%
    2. 99.99%
    3. 99.0%
    4. 99.999%
4. A water agency that takes more than 40 coliform samples must fall under what percentile?
    1. 10%
    2. 7%
    3. 5%
    4. No positive samples allowable
5. The multiple barrier treatment approach includes _____.
    1. Sterilization and filtration
    2. Disinfection and filtration
    3. Disinfection and sterilization
    4. Infection and filtration
6. The maximum disinfectant residual allowed for chlorine in a water system is _____.
    1. .02 mg/L
    2. 2.0 mg/L
    3. 3.0 mg/L
    4. 4.0 mg/L
7. How do water agencies monitor the effectiveness of their filtration process?
    1. Alkalinity
    2. Conductivity
    3. Turbidity
    4. pH
8. What is the disinfectant byproduct caused by ozonation?
    1. Trihalomethanes
    2. Bromate
    3. Chlorite

4. No DBP formation

9. Haloacitic Acids are also known as _____.
    1. TTHM
    2. HOCL
    3. Chlorite
    4. HAA5
10. What is the MCL for trihalomethanes?
    1. .10 mg/L
    2. .06 mg/L
    3. .08 mg/L
    4. .12 mg/L
11. What is the MCL for Haloacitic Acids?
    1. 100 ppb
    2. 60 ppb
    3. 80 ppb
    4. 120 ppb
12. What is the MCL for bromate?
    1. .010 mg/L
    2. .020 mg/L
    3. .030 mg/L
    4. .040 mg/L
13. A treatment plant operator must fill a clearwell with 10,000 ft3 of water in 90 minutes. What is the rate of flow expressed in GPM?
    1. 111 GPM
    2. 831 GPM
    3. 181 GPM
    4. 900 GPM
14. A water tank has a capacity of 6MG. It is currently half full. It will take 6 hours to fill. What is the flow rate of the pump?
    1. 3,333 GPM
    2. 6,333 GPM
    3. 8,333 GPM
    4. 16,666 GPM
15. A clearwell with a capacity of 2.5 MG is being filled after a maintenance period. The flow rate is 2,500 GPM. The operator begins filling at 7 AM. At what time will the clearwell be full?
    1. 10:00 PM
    2. 10:40 PM
    3. 11:00 PM
    4. 11:40 PM

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00: Front Matter

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SECTION OVERVIEW

3.1: Groundwater Sources

3.1.1: Water Resources and the Origin of Contaminants

3.1.2: Source Water Quality

3.1.3: Sources and Characteristics of Water

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3.1.1: Water Resources and the Origin of Contaminants

Learning Objectives

After reading this section, you should be able to:

- Understand and describe water sources
- Describe the water cycle
- Compare the term water contaminants with water pollutants

This chapter presents a brief introduction to the water sources that are available for potable supply; detailed information is presented in Water 132 (Water Supply). Understanding drinking water sources is important to assess the variety of contaminants that can be present in water.

Water Sources

According to the United States Geological Survey (USGS), 71% of the Earth's surface is covered in water, and of that 97% are the oceans. The Earth's water can be broken into two different categories: freshwater and salt water. Fresh water is simply water that is not salty and can be found in the planet's surface water such as streams, lakes, and frozen as ice, but also underground in aquifers. Fresh water is stored on the surface as **surface water** or stored underground in aquifers as **groundwater**. Salt water can be found in the world's oceans.

Figure 1.1.1 shows that our planet's water sources are limited. Freshwater is much easier to use for potable (drinkable) applications because it requires simpler treatment. However, it represents only a small fraction of the Earth's water portfolio. A large proportion of the freshwater is locked in glaciers and is not accessible. As a result, less than 1% of the water present on the planet is groundwater and surface water that can be more easily used as potable water source. Although desalination plants have become more prevalent, they are very costly, and their overall environmental impacts are unknown.

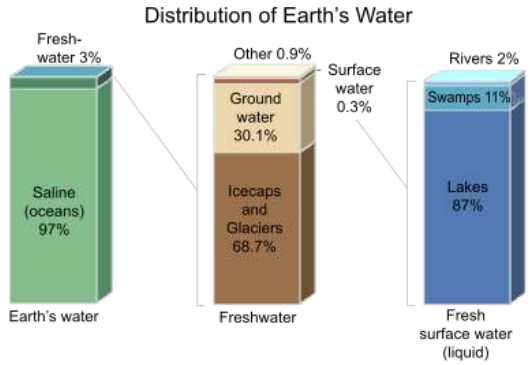


Figure 1.1.1: Distribution of Earth's Water.

The origin of a water source determines its characteristics and the presence of specific contaminants. The concentration and composition of contaminants in water is also influenced by the movements of water, which is illustrated by the water hydrologic cycle (Figure 1.1.2). The Water Cycle is both driven by gravity (i.e., water flows downhill) and sunlight (i.e., water evaporates and condenses).

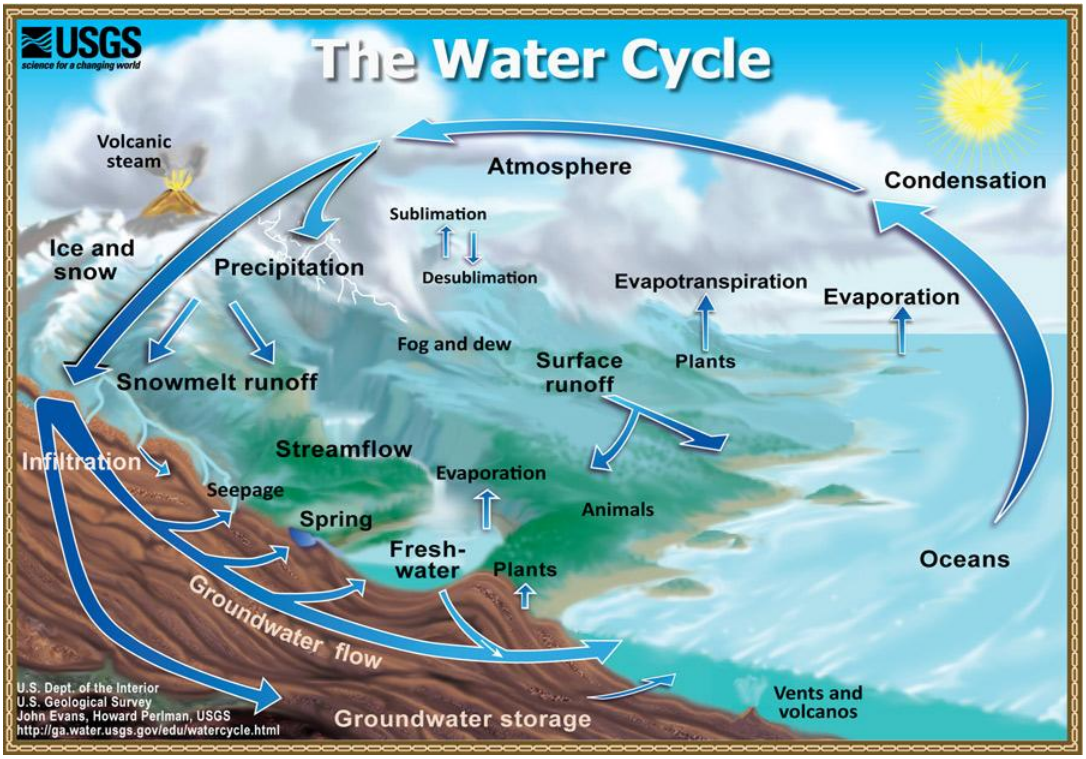


Figure 1.1.2: Water Hydrologic Cycle

Classifications of Contaminants

According to the Safe Drinking Water Act, a contaminant is any physical, chemical, biological, or radiological substance in water. While some contaminants are harmless, others are deadly. Contaminants can even mix with water molecules in the atmosphere. Technically, any compound that is not a water molecule is a contaminant when it comes to water.

Pin It! Misconception Alert

Many people think that all contaminants are manmade. They are not! Some have natural sources in the soil, such as arsenic and uranium. These can be expensive to remove because they occur naturally in the rocks around the water source.

Water can be contaminated by various human-caused (**anthropogenic**) activities or by existing natural features (**natural contaminants**) like mineral-rich geologic formations. It is not uncommon to find naturally occurring fluoride or arsenic in water.

Agricultural activities, industrial operations, landfills, animal operations, and small and large scale sewage treatment processes, among many other things, all can potentially contribute to contamination. As water runs over the land or infiltrates into the soil and **groundwater**, it dissolves material left behind by these potential contaminant sources.

There are three major groups of contamination: inorganic chemicals, organic chemicals, and biological agents. The risks and type of remediation for a contaminant depend on the type of chemicals present.

Pin It! Misconception Alert

People use the words contaminants and pollutants interchangeably. What is the difference between a contaminant and a pollutant?

- A contaminant is a substance that is not normally expected.
- A pollutant is a substance found at a concentration that has reached a level that adversely affects the suitability of the water for its intended purpose.

Key Terms

- **anthropogenic contaminants** – human-caused (manmade) contaminants
- **contaminant** – a substance that is not normally expected
- **groundwater** – water stored in the ground
- **natural contaminants** – contaminants in soil geology, erosion of soils, etc. Examples of contaminants include fluoride and arsenic
- **pollutant** – a substance found at a concentration that has reached a level that adversely affects the suitability of the water for its intended purpose
- **surface water** – water on the surface of the earth

Review Questions

1. **Outline the water cycle highlighting water sources.**

2. **List the major contaminants of water in the environment.**

Chapter Quiz

1. How much water on planet earth is easily treated for drinking water?
    1. 96%
    2. 20.9%
    3. 32%
    4. < 1.0%
2. Most of the water on earth is found in the _____.
    1. atmosphere
    2. ocean
    3. ground
    4. rivers
3. Which of the following is a natural contaminant?
    1. Pesticides
    2. Nitrates
    3. Phosphates
    4. Fluoride
4. Anthropogenic contaminants refers to _____.
    1. turbidity
    2. geological contaminants
    3. inorganic contaminants
    4. manmade contamination
5. The _____ is(are) essential for the maintenance of most life and ecosystems on the planet.
    1. climate
    2. water cycle
    3. aesthetic characteristic of water
    4. atmospheric circulation
6. The _____ drive(s) the water cycle.
    1. types of precipitation
    2. oxygen concentration
    3. nutrient levels

4. sun

7. What portion of surface water is found in the permafrost and ice?
    1. 69%
    2. 68.7%
    3. 96.5%
    4. 30.1%

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3.1.2: Source Water Quality

Learning Objectives

After reading this chapter you should be able to identify and explain the following:

- The Earth's Hydrologic Cycle
- Sources of groundwater
- Sources of Surface Water
- Water math: Area and Unit Conversions

A very finite amount of water on our planet (0.34%) is available to treat for human consumption. Knowing where the water comes from assists certified operators in treating raw source water to make it potable. Newer technology has been developed to treat salinized or salty water found in the ocean. These treatment methods are still extremely expensive and not widely accessible. Supplying water to the public is an extremely important function in society as water is the basic building block of life. Because water quality is of the utmost importance new regulations and water quality standards are continually changing and evolving to make sure the public has safe sources of drinking water. The first drinking water standards were written in the Safe Drinking Water Act (SDWA), which was signed into law by President Ford in 1974. Throughout the text, new concepts will be introduced and an acronym will be given and used subsequently. You are going to learn to love acronyms if you become a certified operator. We use them quite frequently!

The Hydrologic Cycle

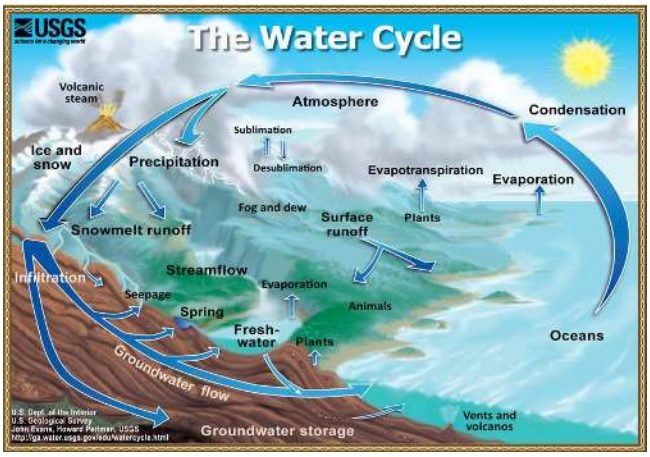


Figure **3.1.2.1**: The Water Cycle by the USGS is in the public domain

The Hydrologic cycle is the continual movement of water on the surface of the planet. The water moves above, below, and across the Earth's surface as a liquid, gas, or solid. The 12 elements of the hydrologic cycle are defined as follows:

- Evaporation—Water moves in the gas state from the Earth's surface to the atmosphere
- Transpiration—Water moves in the gas state from plants to the atmosphere.
- Advection—Water in the gas state moves through air currents in the atmosphere
- Condensation—Water vapor converts from gas to liquid state in the form of water droplets.
- Precipitation—Water as a liquid and/or solid falls from the atmosphere. We commonly refer to this as rain, snow, sleet, and hail.
- Interception—Water in the liquid state that is captured by plants
- Infiltration—Water in the liquid state that soaks into the surface of the ground. This will be what is known as groundwater which will be detailed later in this chapter.
- Subsurface Flow—Water in the liquid state flows below the Earth's surface. The movement is generated by gravity and obstructions below the surface of the Earth.
- Runoff—Water in the liquid form travels to bodies of water. This would include the ocean, lakes, rivers, and streams. This is also known as surface water which will be detailed more later in this chapter.
- Channel flow—Water in the liquid form that flows from small channels into rivers and streams

- Storage—Water is naturally stored in liquid form in lakes, ponds, wetlands, and groundwater aquifers. In solid form, water is naturally stored in ice, snow, and glaciers. This natural storage provides much of the water treated for human consumption.
- Snowmelt—Water in the solid form converts to water in the liquid form and is returned to the hydrologic cycle. Note: In California, snowpack is a critical water supply indicator as it is the melting snowpack that recharges rivers and the general supply of water

There are other important terms to note in regard to the hydrologic cycle. The surface to atmosphere movement of water is known as evapotranspiration. This is the combination of evaporation and transpiration from plant life to the atmosphere. The most widely known movement of water is precipitation which is when water in various physical states falls from the atmosphere to the surface of the Earth. The movement of water from the surface to subsurface is known as percolation. Percolation might also be referred to as infiltration or recharge. These terms are commonly associated with underground aquifers. Finally, surface to surface flow is called runoff.

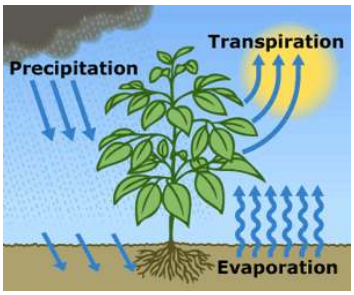


Figure **3.1.2.2**: Water Cycle Image Source by the USGS is in the public domain - Evapotranspiration is the sum of evaporation from the land surface plus transpiration from plants. Precipitation is the source of all water

Groundwater

Groundwater is one of the two main sources of storage used by municipalities to produce potable water. It is formed by the **percolation** (infiltration and/or recharge) of water from the surface of the earth to the subsurface. Water moves through holes and cracks in the subsurface and collects in an underground aquifer. An aquifer is a geologic formation that accumulates water due to its porousness. Important characteristics of groundwater include consistent water quality and the ability to remain safe from surface contamination. With greater technology and testing methods chemicals and constituents known to be harmful to humans have been found in numerous well sites throughout the United States. Wells close to industrial areas have been contaminated with harmful chemicals and substances. New regulations are continually being updated to ensure source groundwater is safe to drink. In normal circumstances, very little treatment is required to yield groundwater.

The **Groundwater Treatment Rule** (GWTR) was enacted in 2006 to prevent microbial contamination from underground water supplies. The purpose of the new rule was to classify water systems that were at a greater risk for fecal contamination. These systems must employ a multiple-barrier protection similar to the surface water treatment rule which will be covered in more detail in the next section.

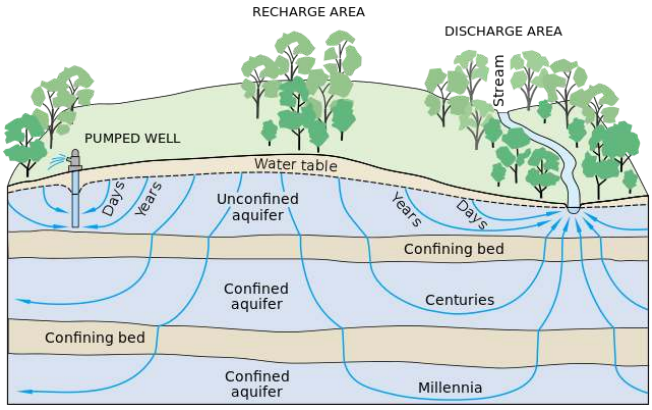


Figure **3.1.2.3**: Groundwater Image Source by the USGS is in the public domain

There are two kinds of aquifers, confined and unconfined. In an unconfined or water table aquifer the water table is free to rise and fall. The water table in unconfined aquifers rise and fall depending on the amount of precipitation that recharges the aquifer. Confined aquifers, also known as artesian wells, contain water that is confined due to layers of low permeability. These layers, which restrict movement, are comprised of rock or hard clay and are referred to as confining beds, aquitards, or aquicludes. Artesian wells are generally under pressure when drilled. Once drilled the water level at which the column of water will rise is known as the piezometric surface. Sometimes, the water will rise to the surface or past the surface but in the instance, the water remains below it is known as a non-flowing artesian well.

Wells

The construction of wells is critical in the extraction of water from underground water supplies. The placement of wells is very important because proper location will produce the greatest yield. Important terms related to underground wells:

- Static Water Level—The level in the well when no water is being removed from the aquifer. This level can be measured in feet or elevation.
- Pumping water level—The level when water is being removed from the aquifer. This level can vary depending on the rate of flow from the well.
- Drawdown—The difference between the pumping water level and the static water level
- Cone of depression—The shape or “cone” created by the movement of water in all directions during pumping.
- Zone of influence—The area of water affected by the drawdown of water during pumping. It is important to note that wells cannot be placed too closely together because their zones of influence may affect each other.
- Well yield—The amount of water drawn from an aquifer over a specific period of time
- Specific capacity—The amount of water produced per drawdown expressed in gpm/ft
- Safe Yield/Perennial yield—The amount of water that can be pulled from an aquifer per year without a drop in the water table
- Overdraft—Too much water removed. Greater than the safe yield of a well
- Subsidence—The permanent drop in the water table due to overdraft

Specific Capacity Calculation

$$\textbf{Specific capacity} = \textbf{Flow (GPM)} \div \textbf{Drawdown (ft)} \tag{3.1.2.1}$$

Example 3.1.2.1

A well has a yield of 600gpm and the drawdown is 50 ft. What is the specific capacity of the well?

Solution

This is a direct application of Equation 3.1.2.1

\[\text{Specific Capacity = 600\, \text{GPM} ÷ 50\, \text{ft} = 12\]

Surface Water

Throughout the United States, surface water is the most widely used source of water for large cities and other municipalities. Groundwater is not as widely available so is not a sufficient water supply for major cities. Surface water includes lakes, ponds, rivers, and streams. California is unique as the southern half of the state has 2/3 of the population but only 1/3 of the available water and the northern half of the state has 1/3 of the population but 2/3 of the water. Snowpack in northern California is critical to the state’s water supply. Most of Southern California is very arid and densely populated so water travels from Northern California through the State Water Project to Southern California.

Surface runoff supplies water for all surface water sources. Influences of surface runoff include intensity of rainfall, duration of rainfall, composition of soil, amount of moisture in soil, slope of the ground, vegetation coverage, and human influences. One would think that a lot of rain would be ideal. However, if the rainfall density is too great, more water can be lost because the ground will no longer absorb the water. The same applies to the duration of rainfall. A prolonged rain even makes the soil too moist and unable to capture water. Vegetation coverage and the slope of the ground are very important to stopping runoff. If the slope of the ground is steep, the speed of runoff is increased. Vegetation slows the speed of runoff and allows more water to absorb or

infiltrate into the ground. Human influences have a great impact on water runoff. Impervious surfaces like concrete entirely prevent infiltration.

Natural Watercourses

Key Terms

Natural water courses include rivers, creeks, streams, washes, and arroyos. They flow in one of three ways:

- Perennial streams—Watercourses which flow continuously throughout the year
  - EX: Colorado River
- Ephemeral streams—Watercourses that flow sporadically, generally after rainfall
  - EX: Santa Clara River which runs through Santa Clarita and Ventura County
- Intermittent—Watercourses which flow somewhere between ephemeral and perennial streams. Rainfall and high groundwater levels will affect how often these streams flow.

Rivers and Streams are a good water supply source but are not necessarily the best source for public water supplies.



Figure **3.1.2.4**: Image of the Colorado River by Paul Hermans is licensed under CC BY-SA 3.0



Figure **3.1.2.5**: Santa Clara River Map by Shannon1 is in the public domain

Lakes

Lakes are the most widely used public water supply source. However, very few “natural” lakes exist. Most lakes used for public water supply are man-made and use a dam to create the lake and contain the water. This is known as an impoundment. Water from these lakes is piped to treatment facilities. Due to variances in temperature lakes develop “layers” also known as stratification. Denser, colder water will drop to the bottom (Benthic zone) of a lake during the summer. There are three layers:

- Epilimnion—The strata closest to the surface
- Hypolimnion—The strata near the bottom
- Thermocline—Middle strata with the greatest variance in temperature

Lake turnover will occur during seasonal temperature changes. When the temperature of a lake is uniform it is known as isothermal. Algae growth is a serious problem that causes taste and odor issues in treated water. Copper sulfate can be added to a lake to help remedy algae blooms. In severe cases, the water undergoes eutrophication which is the loss of oxygen. Complete or extreme oxygen depletion can kill all living creatures in the water including animals and fish.



Figure **3.1.2.6**: Image of Castaic Lake by Rehman is in the public domain

Introduction to Water Math

Mathematics is a key component of water treatment. Operators use conversion tables and basic algebra to complete many daily tasks. Charts are available on the State Water Resources Control Board website that assist operators with most calculations you would find on the state exams or while on the job. Below is a list of basic units and their respective conversion factors:

Table 1.1: Units and Conversion Factors

Measurement	Equivalent
1 cubic foot of water	62.3832lbs
1 gallon of water	8.34lbs
1 liter of water	1,000 grams
1 mg/L	1 part per million (ppm)
1 ug/L	1 part per billion (ppb)
1 mile	5,280 feet
1 yard	3 feet
1 yard3	27ft3
1 acre	43,560 square feet or ft2
1 cubic foot or ft3	7.48 gallons
1 gallon	3.785 Liters or L
1 L	1,000 milliliters (ml)
1 pound	454 grams

Working with Fractions

NumeratorDenominator

44=11 or =1 42=21 or =1

Rounding

Rounding the number 324.179

The above number (324.179) rounded to the nearest tenth would be 324.2. Since the number in the hundredth place is at or above 5, the number in the tenth place is rounded up. If you were rounding this number to the nearest whole number it would be 323 since the number in the tenth place is below 5.

Placement of Digits
3 = Hundreds
4 = Tens
9 = Units
1 = Tenth
7 = Hundredth
9 = Thousandth

Unit Dimensional Analysis

This is the most important function in most water math problems. Make sure to always place your factors in the proper place or the equation will be impossible to solve correctly. The example below will use unit measurements. Water operators will commonly convert between different units of measurement.

Example 1

Convert 48 inches into feet. (There are 12 inches in a foot.)

48 inches11 foot12 inches=4 ft1

Drop the one from the denominator and the answer is 4 ft.

The same process will be to convert between gallons and cubic feet.

Example 2

Convert 22.44 gallons into cubic ft. or ft3 (There are 7.48 gallons in one cubic foot.)

22.44 gallons11 $ft^3$7.48 gallons=3 $ft^3$1

Drop the 1 from the denominator and your answer is 3 ft^3

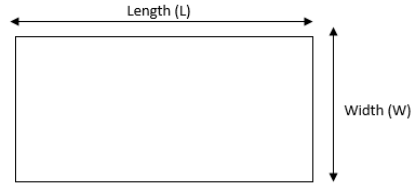
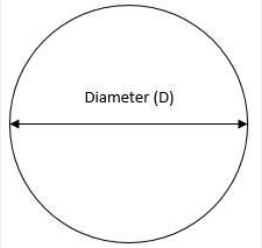
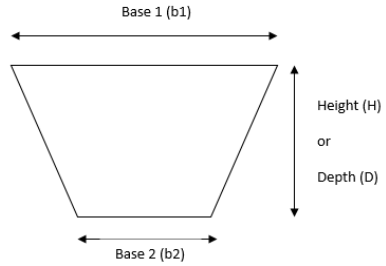
Example 3

How many gallons are there in a tank which holds 300ft^3 of water?

300ft317.48 gal1ft3=2,244 gallons

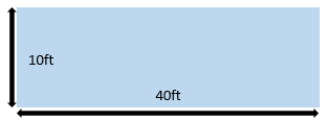
Area

Area will be important for many applications in water math. It may be necessary to calculate the area of a tank that requires painting or an area of ground cover near equipment.

Rectangles 	Area = L × W
Circle 	Area = $0.785 \times D^2$
Trapezoid 	Area = $\frac{b1 + b2}{2} \times H$

Example 1

A wall that is 10ft wide and 40ft in length needs to be painted. What is the total square feet of the wall?

	Area = Length x Width Area = 10ft x 40ft Area = $400ft^2$

Example 2

What is the area of the top of a circular storage tank that is 100 feet in diameter? (Note: Use the formula .785 x d2. In most cases in water math, we will always be dealing with the diameter and not the radius. These short cuts will help as the problems become more difficult. In this problem I will demonstrate why we will use this formula and not the standard mathematical equation for solving area problems.)

Equation #1 Area= π (3.14) x r^2 (100ft ÷ 2 = 50 to find radius)

Area = 3.14 x 50 x 50

Area = 7,850 ft^2

Equation #2 Area= .785 x d^2

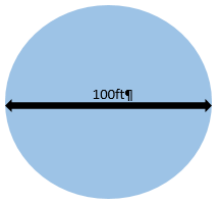
Area = .785 x 100 x 100

Area = 7,850 ft^2

In this example, the first equation was easy to solve because we were working with a pretty friendly number. As the equations become more difficult we do not want to take the extra step to divide the diameter by two to solve for the radius. If the diameter of the tank was 357ft, this problem would have been slightly more difficult using the first equation.

Example 3

The top of a circular storage tank needs to be painted. It is 100 ft. in diameter. Each gallon of paint covers approximately 200 square feet. How many gallons of paint will you need to buy?



Area= .785 x d^2
Area= .785 x 100ft x 100ft
Area= 7,850 ft^2
7850 $ft^2$1x1 gal200 ft^2=39.25 gal

Chapter Review

1. What is the middle layer of a stratified lake called?
    1. Thermocline
    2. Benthic Zone
    3. Epilimnion
    4. Hypolimnion
2. What is the conversion of liquid water to gaseous water known as?
    1. Advection
    2. Condensation
    3. Precipitation
    4. Evaporation
3. Water weighs _____.
    1. 7.48 lbs/gal
    2. 8.34 lbs/gal
    3. 62.4 lbs/ft^3
    4. Both 2 and 3
4. What is the static level of an unconfined aquifer also known as?
    1. Drawdown
    2. Water Table
    3. Pumping Water Level
    4. Aquitard
5. What is the cause of taste and odor problems in raw surface water?
    1. Copper sulfate
    2. Blue-green algae
    3. Oxygen
    4. Lake turnover
6. What chemical reduces blue-green algae growth?
    1. Chlorine
    2. Caustic Soda
    3. Copper Sulfate
    4. Alum

7. A water-bearing geologic formation that accumulates water due to its porousness.
    1. Aquifer
    2. Lake
    3. Aquiclude
    4. Well
8. What kind of stream flows continuously throughout the year?
    1. Ephemeral
    2. Perennial
    3. Intermittent
    4. Stratified
9. The surface to atmosphere movement of water is known as _____.
    1. Precipitation
    2. Percolation
    3. Stratification
    4. Evapotranspiration
10. An aquifer that is underneath a layer of low permeability is known as _____.
    1. Confined aquifer
    2. Water Table aquifer
    3. Unconfined aquifer
    4. Unreachable groundwater
11. What is the middle layer of a stratified lake known as?
    1. Hypolimnion
    2. Benthic Zone
    3. Thermocline
    4. Epilimnion
12. The amount of water that can be pulled from an aquifer without depleting.
    1. Drawdown
    2. Safe yield
    3. Overdraft
    4. Subsidence

Math Questions

Please show all work. On the State exams, you will not get credit if work is not shown.

1. What is the area of the top of a storage tank that is 75 feet in diameter?
    1. 4,000 ft^2
    2. 4416 ft^2
    3. 1104 ft^2
    4. 17,663 ft^2
2. What is the area of a wall 175 ft. in length and 20 ft. wide?
    1. 3,000 ft^2
    2. 2,500 ft^2
    3. 3,500 ft^2
    4. 4,000 ft^2
3. You are tasked with filling an area with rock near some of your equipment. One (1) bag of rock covers 250 square feet. The area that needs rock cover is 400 feet in length and 30 feet wide. How many bags do you need to purchase?
    1. 40 Bags
    2. 42 Bags

3. 45 Bags
4. 48 Bags

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3.1.3: Sources and Characteristics of Water

This chapter will discuss the sources of water in California and the characteristics of water.

Student Learning Outcomes

After reading this chapter, you should be able to:

- Explain the different stages of the hydrologic cycle
- Identify the various sources of supply
- List the primary sources of supply for the Southern California area
- Discuss the physical, chemical, and biological aspects of water

Hydrologic Water Cycle

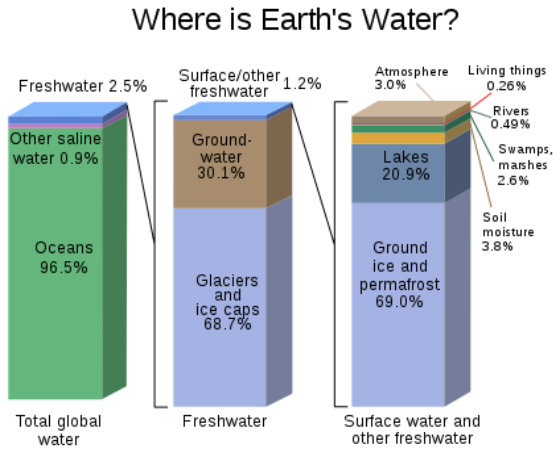


Figure **3.1.3.1**: Water Location Image Source by the USGS is in the public domain

Where does our water come from? One of the most unique aspects of our planet is the vast amount of water covering it. About seventy-one (71) percent of the earth's surface is water. The very thing that is essential to sustain life covers almost three-quarters of our planet. However, approximately ninety-seven and a half (97.5) percent of all the water on earth is saltwater. This equates to about three hundred twenty-six (326) million trillion gallons of water, which is not suitable for drinking. This means two and a half (2.5) percent of the planet's water is freshwater, or water not containing salt. While this is still a lot of water, almost seventy (70) percent of it is inaccessible. This water is in the form of glaciers or permanent snow cover. Approximately thirty-one (31) percent of this water is groundwater and less than one (1) percent is considered surface water.

Does this mean we will eventually run out of freshwater? If the majority of the earth's water is either saltwater or inaccessible, does it mean we have a limited supply to sustain life? The short answer is no, we will not run out of freshwater and we do not have a limited supply. However, access to freshwater is an issue that needs to be addressed, and there are places on our planet that lack safe and adequate supplies of drinking water. In this section, we will address the "short answer". The reason we have access to freshwater in most areas on earth has to do with something known as the hydrologic cycle. The hydrologic cycle is the continuous movement of water throughout the earth. It is the physical process of evaporation, condensation, precipitation, infiltration, and surface runoff. Water changes from one form to another and then another. The three phases that water passes through are liquid, gas, and solid. We understand and encounter water in these three phases on a daily basis. Water in its most common form is liquid. However, we can freeze it to make ice (solid) or boil it to encounter steam (gas). Throughout the hydrologic cycle, water also transfers through these phases.

The image below (courtesy of the United States Geological Survey - USGS) shows a lot of detail regarding the hydrologic cycle. First, try to focus on the three phases we just discussed (liquid, gas, and solid). Precipitation is the liquid state, ice and snow the solid state, and evaporation represents the gas or vapor state. As you can see from this diagram, it is a little more complicated, but water passes through these three phases (states) in a continuous movement on, above, and below the surface of the earth. There are

three (3) other terms you should become familiar with in this process. The terms are evapotranspiration, infiltration, and sublimation.

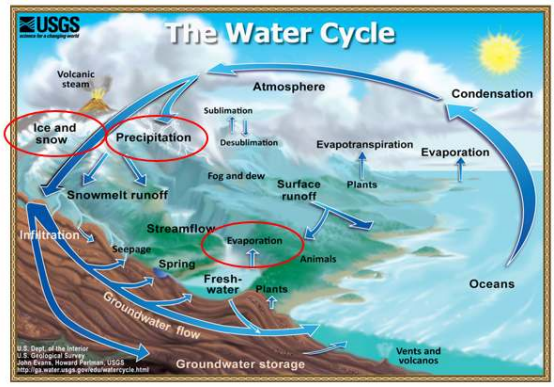


Figure 3.1.3.2: Water Cycle Image Source by the USGS is in the public domain

Evapotranspiration is the process of water transferring from the land to the atmosphere from the soil and other surfaces and by transpiration from plants. Transpiration is the evaporation from plant leaves. Think of it as plants sweating. Sublimation is the process by which a substance (water in this case) passes directly from the solid phase to the vapor or gaseous phase. This typically happens in the atmosphere. The third term is infiltration. Infiltration is the process of water entering the ground surface. If geological conditions are right, the water will continue transferring deeper into the earth's surface until it becomes groundwater. This deeper transferring process is known as percolation. The only other process in the hydrological cycle you should take note of is the process of condensation. This is when water vapors transition from the gas phase to the liquid phase. Now that we have a general understanding of the hydrologic cycle, it's time to turn our attention to the various sources of water supply.

Water Sources

Surface Water

As water leaves the oceans and other areas on land, it evaporates into the atmosphere and eventually comes back down through some form of precipitation. As snow and ice melt or rain falls on land it becomes runoff. This runoff will enter streams, rivers, or lakes. These are considered surface water. There are three (3) main surface water sources of supply in southern California, State Water Project, Colorado River Aqueduct, and Los Angeles Aqueduct. Each of these surface water sources serve specific areas and are owned and operated by different water agencies.

- Los Angeles Aqueduct – The LA Aqueduct is owned and operated by Los Angeles Department of Water and Power (LADWP). The only users of this water are the customers of LADWP. The aqueduct took approximately five (5) years to construct and originates in the Owen's Valley, bringing water to LADWP customers through an all gravity system.
- Colorado River Aqueduct – The Colorado River Aqueduct brings water from the Colorado River at Lake Havasu to Southern California. It is operated by Metropolitan Water District. The water flows through two (2) reservoirs and five (5) pumping stations and delivers water as far south as San Diego County.
- State Water Project – The State Water Project is one of the largest public water utilities in the world. It brings water from Northern California and distributes it to areas in and around San Francisco and to the major metropolitan areas of Southern California. It is maintained by the California Department of Water Resources and has twenty-nine different contractors pulling water from this system. There are more than a dozen water storage reservoirs and pumping plants within this system.

According to the USGS, approximately eighty (80) percent of all water used in the United States comes from surface water sources. Surface water is an important natural resource used for many purposes, especially irrigation and public drinking water supply.

Groundwater

Groundwater is water on the surface, which infiltrates and eventually percolates deep enough into underground systems known as aquifers. An aquifer is an underground system of permeable soil (sand, gravel, rock), which can contain and transmit water underground or groundwater. Groundwater exists for two main reasons, gravity and geologic formation.

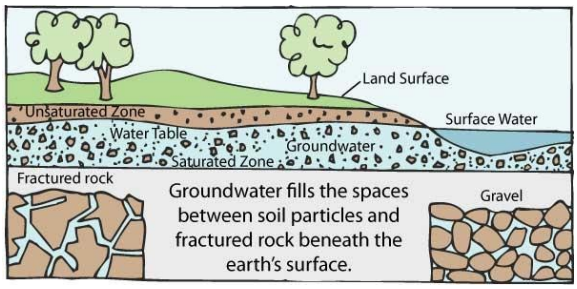


Figure **3.1.3.3**: This material was reproduced from groundwater.org with the permission of The Groundwater Foundation. © The Groundwater Foundation. All Rights Reserved.

Gravity pulls the water into the earth and if the geologic formation is conducive to holding water, aquifers will form. Water accumulates in the voids and spaces within the underground geology. Some examples of these formations consist of sandstone, limestone, and even granite. There are three (3) main types of aquifers, unconfined, confined, and fractured rock. Each of these has unique characteristics and properties.

- Unconfined Aquifer – An unconfined aquifer has the upper surface open to the atmosphere through permeable material such as sand and gravel. This type of aquifer is typically more susceptible to contamination from spills or discharges on the ground surface.
- Confined Aquifer – A confined aquifer has a similar composition as unconfined aquifers. They consist of porous materials such as sand and gravel. The main distinction is there is an overlying impervious rock or clay layer separating it from the atmosphere. Commonly, this impervious layer consists of clays. Because of this impervious layer, confined aquifers are generally less susceptible to contamination.

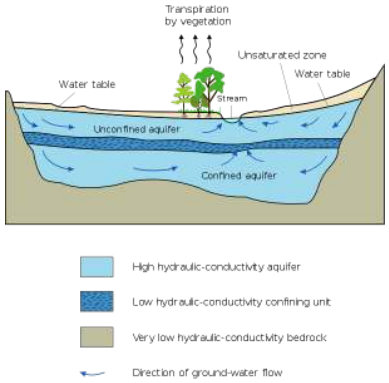


Figure **3.1.3.4**: Groundwater Image Source by Hans Hillewaert is licensed under CC BY-SA 3.0

- Fractured Rock – An underground fractured rock aquifer system is much different than unconfined and confined aquifers. In some areas, there are rock formations, which have little to no permeability, but they still can contain water. The water is stored in complex fractures (cracks) within the rock formation. This water can be withdrawn, but the variability of the fractures makes it more difficult to locate the areas with water.

Both unconfined and confined aquifers can yield large quantities of water for domestic and agricultural use. Many communities rely solely on groundwater from these types of aquifers. While fractured rock can store water underground, these types of aquifer are not as common and do not produce nearly as much water. In the Southern California area, there are many different aquifers systems. According to the California Department of Water Resources (DWR), there are seventy-seven (77) groundwater basins and subbasins in the South Coast Hydrologic Region. This includes the counties of Ventura, Los Angeles, San Bernardino, Riverside, Orange, and San Diego.

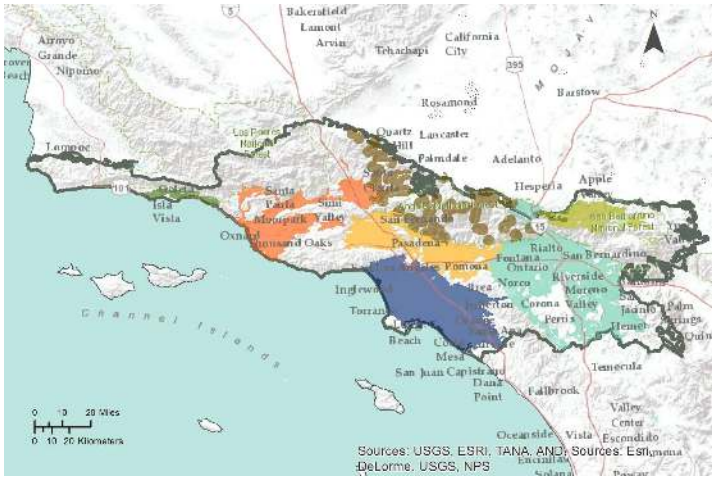


Figure **3.1.3.5.1**: Map by the USGS is in the public domain

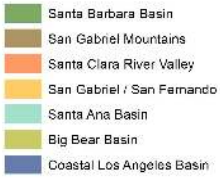


Figure **3.1.3.5.2**: The Transverse Ranges and Selected Peninsular Ranges Province consists of the following Study Units

Recycled Water

Another source of supply, which is becoming more prominent and needed is recycled water. In the past, the term “reclaimed” water was used more frequently. This was due in part to the source of the water, water reclamation plants. However, as the use became more prevalent, the term recycled became more common. They are interchangeable.

Recycled water is treated wastewater. All wastewater travels through a network system of sewer pipelines. This network is primarily a gravity flow system, but at times when elevations change, pumps are required to “lift” the wastewater. Once the wastewater arrives at a wastewater reclamation plant (wastewater treatment plant is also commonly used), it must go through a treatment process. The treatment requirements for ultimate discharge vary depending on where the treated wastewater will be released. Sometimes these treatment plants are located along the coast and the water is discharged to the ocean. While other times, plants are located in inland communities and the water is discharged in local river systems.

In order for treated wastewater to be used as recycled water, it must at least go through tertiary treatment. The first two stages of wastewater treatment (primary and secondary) are designed to remove the debris and solids through a sedimentation process and then a process to remove the biological content. The tertiary treatment process is usually the last stage of treatment unless some form of advanced treatment is used. Typically this process involves some form of filtration, which includes sand. Additional nutrients can also be removed.

While recycled water typically meets all state and federal drinking water standards, it is not allowed for human consumption. The primary use of recycled water is irrigation. Parks, playgrounds, sports fields, street and freeway landscaping, and golf courses are some of the more common uses of recycled water. Recycled water can also be used for industrial and commercial cooling systems.

Water Characteristics

Water is an amazing compound and has some very unique properties. Because of the molecular structure of water, it has an affinity for other molecules. Water is considered a “polar” compound. This means there is an uneven distribution of the electron density. The bonds between the oxygen atom and two hydrogen atoms are at an angle (see below).

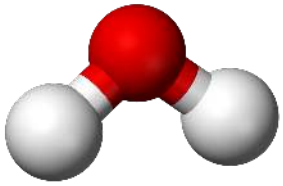


Figure **3.1.3.6**: Water-3D-balls by Benjah-bmm27 is in the public domain

The red dot above represents the oxygen atom in water and the two white dots represent the hydrogen atoms, which equates to the molecular formula “H2O”. The structure of water has a partial negative charge near the oxygen and partial positive charge near the hydrogen atoms. This structure allows water to have both cohesion and adhesion properties. Cohesion is the ability of water to be attracted to other water molecules. This cohesive property is what gives water surface tension and allows insects such as a Water Strider to walk on water. This polarity also allows water to dissolve many different compounds.



Figure **3.1.3.7**: Gerris by webrunner is licensed under CC BY-SA 3.0

Water also has an attraction between molecules. This property is referred to as adhesion. When you fill a glass with water the water around the glass “adheres” to the glass causing the water to “climb” the glass wall. This results in the water having a meniscus a concave appearance.

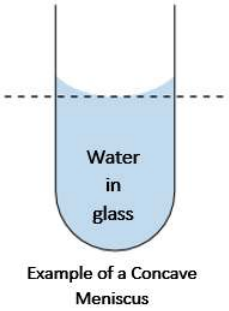


Figure **3.1.3.8**: Water in Glass Image Source by Jleedev is licensed under CC BY-SA 3.0 (image modified by COC OER)

Water is also the only common substance on the earth’s surface, which exists as a gas, liquid, and solid. Temperature effects water by causing it to persist in each one of these phases. It is typically a colorless and odorless substance.

Physical Characteristics

Water is generally colorless. This is one of the most important aesthetic qualities of water, which customers care about. No one wants to drink water that has a color. However, this is also a common problem water quality professionals have to monitor. There are several things in the distribution system, which can cause water to have a color. Some examples include air (white), iron (yellow or brown), manganese (causing black stains). There are solutions to these examples, but it is important for water utility professionals to monitor their water quality within the distribution system in order to keep water in its natural colorless state.

In addition to being colorless, water typically doesn’t have a taste. However, much like color, certain things in the water supply can give water an unpleasant taste. Chlorine is a chemical commonly used to disinfect water in order to make it safe to drink. However, this can also give water an unpleasant taste to customers.

The final physical property of water we will discuss in this text is temperature. As the temperature of water changes, the physical nature of water also changes. For example, as water approaches 0°C it changes form from a liquid to a solid. Conversely, as water

approaches 100°C, it starts to boil and transitions from a liquid to a gas.

Sample Questions

1. Which one is not one of the phases of water throughout the hydrologic cycle?
    1. Liquid
    2. Gas
    3. Solid
    4. Sublimation
2. Treated wastewater used for irrigation is termed _____.
    1. Non-potable water
    2. Irrigated supply water
    3. Agriculture water
    4. Recycled water
3. Water is generally _____.
    1. Colorless
    2. Unsafe to drink
    3. Abundant in all areas
    4. All of the above
4. Which of the following would not be considered an aquifer?
    1. Confined
    2. Unconfined
    3. Aqueduct
    4. Fractured rock
5. The three main surface water sources of Los Angeles include all of the following except _____.
    1. Los Angeles Aqueduct
    2. Columbia River
    3. Colorado River
    4. State Water Project

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3.2: Wells

Student Learning Outcomes

After reading this chapter, you should be able to:

- Explain the different groundwater systems
- Identify the above ground and below ground components of a well
- Describe the different methods of drilling wells

Groundwater Sources of Supply

Groundwater is one of the most important sources of supply of fresh drinking water throughout the United States. Beneath the earth's surface, there are soil formations where water can be extracted in large volumes. These underground soil formations are referred to as aquifers. An aquifer is an underground layer of water-bearing permeable rock formations or unconsolidated materials such as sand and gravel.

Aquifers

There are two main types of underground systems (called **aquifers**) where water is stored and can be extracted. These are called:

- **Unconfined Aquifer** – A natural underground layer of porous, water-bearing (strata) materials (sand, gravel) usually capable of yielding a large amount of supply of water
- **Confined Aquifer** – A natural underground layer of porous, water-bearing materials (sand, gravel) separated by impermeable layers of materials (clay)

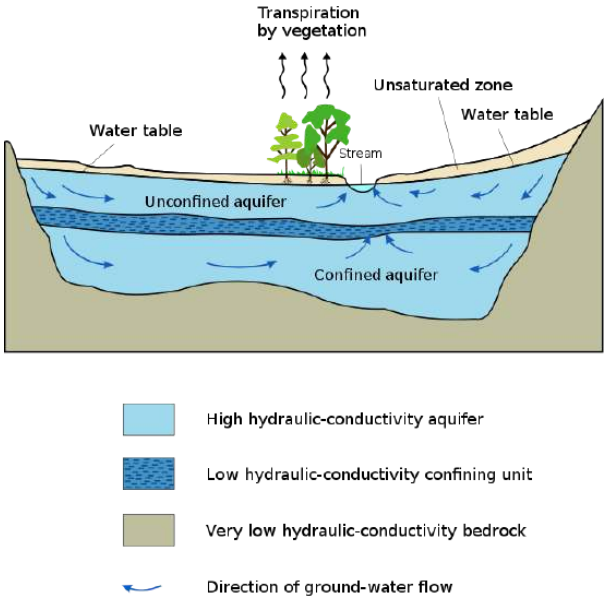


Figure 3.2.1: Image by the USGS is in the public domain

The spaces and fractures in the geologic materials underground store water which can be extracted. This material can be classified as consolidated or unconsolidated. Consolidated aquifer systems are less common and consist of materials such as sandstone, shale, granite, and basalt. The more common underground geologic material contains unconsolidated sediment containing granular material such as sand, gravel, silt, and clay. Alluvium aquifers (sand, gravel, and silt deposits by rivers are some of the more common unconfined aquifers. Since these aquifer systems generally lie within river beds, they have a direct connection to the ground surface and therefore are more susceptible to contamination. Any contamination deposited on the ground surface has the potential to percolate ("trickle through") the sediments into the aquifer.

Wells

In order to extract water out of the ground, a well must be drilled. A groundwater well is a structure constructed in the ground through various methods in order to extract or pump water from underground aquifers. They can be as simple as a deep hole with supports to keep the hole from collapsing and the water is withdrawn using a bucket. Or, they can be thousands of feet deep and constructed with steel reinforcement columns and use pumps to extract the water. Regardless of the type of well, this source is an important resource for communities throughout the world. In this section, we will focus on water utility groundwater wells.



Figure **3.2.2**: Image by Didiervberghe is in the public domain



Figure **3.2.3**: Image Source by SuSanA Secretariat is licensed under CC BY 2.0

There are three (3) main types of groundwater wells. These can be described as:

- **Bored or shallow wells**: These are usually bored into an unconfined water source, generally found at depths of one hundred (100) feet or less.
- **Consolidated or rock wells**: These are drilled into a formation consisting entirely of a natural rock formation that contains no soil and does not collapse. These are typically around two hundred (250) feet.
- **Unconsolidated or sand wells**: These are the most common type of drinking water wells and are drilled into a formation of soil, sand, gravel, and clay material. If not supported, these wells will collapse upon themselves.

Well Components

There are both underground and above ground components to a well. These components channel the water into a pipe, lift the water up from below the ground, and allow the water to flow above ground and into a distribution system. First, we will look at the above-ground surface features of a well, these are:

- Well casing vent
- Gravel tube
- Sounding tube
- Pump pedestal
- Pump motor base
- Sampling taps
- Air release vacuum breaker valve
- Drain line (Discharge to waste)

Well Casing Vent

When a well is in operation, the water in the well starts to rise in the column pipe of the well. However, there is an air space between the water and where the water is being pumped. This “air” needs to be released from the column pipe. The well casing vent provides this release. It prevents vacuum conditions inside a well by admitting air during the *drawdown* period when the well pump is first started and it prevents pressure buildup inside a well casing during by allowing excess air to escape during the well recovery period after the well pump shuts off.

Gravel Tube

When a well is drilled, a pipe is lowered into the ground. Water enters into this pipe from the surrounding soil. We want water to enter the well, but we do not want the surrounding soil (sand) to enter the well. Gravel is used as a barrier between the surrounding

soil outside of the casing and the water entering the casing. A gravel tube is installed to monitor the level of gravel within the well and to add additional gravel as necessary.

Sounding Tube

A sounding tube is a tube (pipe) that is installed into the well casing to allow for the measurement of groundwater levels within a well. There are several methods of measuring the depth to groundwater, which include automatic measuring devices and manual methods. The simplest means of measuring the level of groundwater below ground surface (bgs) is with a cable lowered into a sounding tube, which has markings identifying distances in various increments (inches.) The cable is connected to a light or signal and when the bottom of the cable touches the water a sound or light signal will occur. Other means of measuring the depth to groundwater include electronic transducers and airline water level measuring. Airline tube measuring is accomplished by lowering a tube into the well, supplying air pressure to the tube and measuring the pressure with a gauge. Each pound per square inch of pressure equates to 2.31 feet. In addition to measuring groundwater levels, sounding tubes can be used to add chlorine or other disinfecting or treatment chemical agents into a well.

Pump Pedestal

The well casing vent, gravel tube, and sounding tube are encased within a concrete pump pedestal. A pump pedestal is designed to support the entire weight of the pumping unit. The concrete should be continuously poured with steel reinforcement in order to minimize cracks and breaches in the concrete. Fractures in the concrete could expose the inside of the well to surface water and other potential contaminants. A pump pedestal must also be a minimum of 18 inches above the finished elevations of the well pad.

Pump Motor Base

At the point where the motor rests on the pedestal, it must have a watertight seal. This seal is commonly provided by a neoprene rubber gasket. This establishes a barrier seal between the motor base and the concrete pump pedestal.

Sampling Taps

Drain Line (Discharge to waste)

These are only some of the more common above-ground components of a well. There are other features, but they will not be covered in this text. The following items are a list of some below-ground features of a well.

Casing

A casing is an impervious durable pipe placed in a well to prevent the walls of the surrounding soil from caving in on the well. A casing is also designed to seal off water from draining into a well from specific depths.

Conductor casing

When a well is drilled the upper portions of the surrounding soil tends to be loose and a conductor casing is used to support the drilling operations. It is a tubular structure between the drilled hole and the inner casing completed in the upper portion of a well.

Annular seal

Another means to prevent surface water from entering a well is the annular seal. An annular or sanitary seal is a cement grout installed between the well casing and the conductor casing, the space between the conductor casing and the borehole, or the space between the well casing and the borehole depending on the well. This seal also protects the well casing or conductor casing against exterior corrosion. Three (3) types of grout are used; neat cement grout, sand-cement grout, and bentonite clay.

Intake section

Water enters a well through an intake section. This portion of a well is designed to allow water to enter the well casing and prevent the surrounding soil from entering. The following items are general characteristics of a properly designed intake section:

- Non clogging slots/screen
- Resistant to corrosion
- Sufficient collapse strength

- Resistant to encrusting
- Low head loss
- Prevent sand from entering

There are five (5) common types of intake sections of a well. These include:

- Well screens
- Mill-cut slots
- Formed louvers
- Torch-cut/chisel-cut slots
- Mechanical slots

Well screens are generally constructed of stainless steel, monel metal, special nickel alloy, silicon red brass, red brass, special alloy steel, and plastic. They are broken into three (3) main categories which include continuous slots, bar, and wire-wound screens.

Mill-cut slots are commonly made of the same type and diameter as the casing. The openings are machine milled (cut) into the wall of the casing pipe parallel to the axis of the casing and uniformly spaced around the casing pipe.

Formed louvers are machined horizontal to the axis of the casing with the openings facing downward. They are shaped to create an upward flow as the water enters a well and they are placed together in vertical rows.

Torch-cut slots are not very common. They are relatively simple to create, but very difficult to control the size of the openings. This has a tendency to produce excessive quantities of sand.

Mechanical slots are usually slotted after the well has been drilled. The openings are made opposite the water-bearing formations by means of a casing perforator tool lowered into the well and activated from the drill rig. One main downside of this process is the openings cannot be closely spaced.

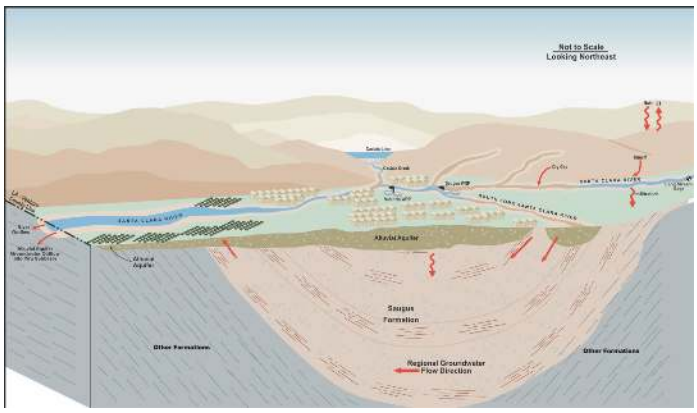


Figure 3.2.4: Source: Adapted by LACSD from the Task 2A - Conceptual Model Development East and Piru Subbasins Final Report by CH2M HILL 2006

Well Drilling

In order for water to be extracted from an aquifer, a well must be constructed (drilled). There are several methods of well drilling. The more common methods include:

- Cable Tool
- California Stovepipe
- Direct Rotary
- Reverse Circulation Rotary
- Air Rotary

Cable Tool Method

The cable tool method of drilling wells is also referred to as the “percussion” method. This method involves the lifting and dropping of a heavy string of drilling tools into the borehole. The cable tools can weigh in excess of one (1) ton and the drill bit

breaks or crushes consolidated rock into smaller and smaller fragments. In unconsolidated rock the bit loosens and breaks apart the material. The reciprocating action of the tools mixes the crushed and loosened materials with water to form a slurry at the bottom of the borehole. The slurry needs to be removed and is done so with the use of a sand pump or bailer. The cable tool drilling equipment consists of five (5) components; drill bit, drill stem, drilling jars, swivel socket, and cable.

California Stovepipe

This method is similar to the cable tool method. The difference is a heavy bailer is used as both a drill bit and bailer. This heavy bailer is referred to as a mud scow. The stovepipe casing is what also distinguishes this method from others. It uses laminated steel in short lengths providing added strength, as opposed to using standard steel. Hydraulics jacks are used to force the casing downward as opposed to driving the casing with impact tools. Once the casing is at the desired depth, a perforator is used to puncture holes in the pipe opposite the water-bearing formation.

Direct Rotary

As drilling technologies progressed, the desire for faster drilling speeds and greater drilling depths increased. The direct rotary method uses a rotating drill bit. The cuttings are removed by the continuous circulation motion of a drilling fluid as the bit penetrates the formation. The bit is attached to a lower end of a string drill pipe, which transmits the rotating action from the rig to the bit. The drilling fluid is pumped down through the drill pipe and out through the ports or jets in the bit. The fluid flows upward in the annular space between the hole and the drill pipe, carrying the cuttings in suspension to the surface.

Reverse Circulation Rotary

The reverse circulation rotary drilling method was designed to overcome limitations in borehole diameter and drilling depths. In this method, both water and air are used as the drilling fluid and the direction of the drilling rotation is reversed. As a result of this direction, the drilling fluid and the load of cuttings move upward inside the drill pipe and are discharged by the pump into a settling pit.

Air Rotary

In solid consolidated materials, standard drilling practices are more difficult. Therefore, an air rotary method is often employed. This process uses compressed air as the drilling fluid as opposed to drilling mud. Air is circulated through the center of the drill pipe out through ports in the drill bit. In order to break through consolidated material, pressures from 100 to 250 pounds per square inch (psi) are needed. The process of removing the cuttings requires ascending air velocities of at least 3,000 feet per minute are necessary.

Shallow Wells

In some areas, groundwater levels are very shallow. These are usually in areas adjacent to running riverbeds and lakes. In these areas, the surface river and lake water could be used as drinking supplies. However, surface waters require a significant amount of treatment in order to remove turbidity (sediment). This can be quite costly. One of the benefits of groundwater is the natural filtration the geological formations provide. In these areas, shallow collector wells are often used. Trenches are dug around ten (10) to twenty (20) feet deep and screened pipe is laid horizontally to the river or lake bank. Depending on the type of surrounding soil, these pipes are often radially driven. Caissons (watertight retaining structures) are used to gain access to the bottom of a stream or other water body. A common shallow collector type is a Ranney.

Here is an animation of a well being constructed.

Well Pumps

A few terms should be defined before discussing the classification and types of pumps used for wells. These terms are general terms relating to the inlet and outlet side of all pumps. Pressure is the concept of a continuous force being exerted on or against an object, while “head” is commonly used because it evaluates a pump’s capacity to do a job. For this discussion, both pressure and head will be considered interchangeable. Pressure is expressed as pounds per square inch (psi) and head expressed in feet.

Suction Head, Suction Lift, and Discharge Head

The inlet side of a pump is referred to as suction head or suction lift. Suction, referring to the “sucking” or pulling aspect of a fluid entering a pump. If the fluid is above the inlet side of a pump it is referred to as suction head. This is because the fluid is providing pressure to the inlet or suction side of a pump. In essence, it is helping the pump push water through the pump and to the discharge side of the pump. If the fluid being pumped is below the suction side, then the pump has to “suck” or lift the water up to the pump. This is referred to as suction lift. Discharge head refers to the outlet side of a pump, which is “pushing” the fluid out.

There are two major pump classifications for wells: positive displacement and variable displacement. The common types of each include:

- Piston (positive displacement)
- Rotary (positive displacement)
- Centrifugal (variable displacement)
- Turbine (variable displacement)
- Jet (variable displacement)

Positive displacement well pumps deliver the same volume or flow of water against any head pressure within the operating capacity. Typical types are piston (reciprocating) pumps and screw or squeeze displacement (diaphragm) pumps.

Variable displacement well pumps deliver water with the volume or flow varying inversely with the head (the greater the head, the less the volume or flow) against which they are operating. The major types are centrifugal, jet, and airlift pumps.

There are various uses for each type of pump throughout the water utility industry. However, turbine pumps are predominately used for groundwater wells. Since groundwater is found at different depths below the ground, it only stands to reason there might be different types of “turbine” pumps to lift this water out of the ground.

- Shallow Well Pumps – When a well is constructed in shallow aquifer systems. Shallow can be a relative term, but in this context let’s assume it is within fifty (50) feet below ground surface. Under these circumstances, a shallow well pump would be installed above a well. It would take water from the well by suction lift. The critical issue is the water level must be within the “lift” capacity of the pump
- Deep Well Pumps – Since many wells are drilled deeper than fifty (50) feet, most pumps cannot “lift” the water above these depths when they are installed above a well. Therefore, deep well pumps are used. These types of turbine pumps have a series of pump bowls installed in a well with the inlet (suction) section of the pump submerged below the pumping level in a well.

Since pressures can be expressed in both units of psi and feet, there needs to be a way to convert between the two. One pound per square inch equates to just over two feet. See the example below.

- 1 psi = 2.31 feet (head)

If a pump has a discharge head of 100 psi, how many feet does this equal?

- 100 psi12.31 feet1 psi=231 feet

While this text discusses aspects of water-related mathematical computations, it is advised to take specific coursework in waterworks mathematics.

Measuring Groundwater Levels

An important set of data associated with groundwater wells is the measurement of water below the ground surface. There are two common measurements in a groundwater well: static and pumping. The static water level within a well is the depth of water below the ground surface when a well is not running. In contrast, the pumping level is the measure below the ground surface when a well is running. The diagram below illustrates these two terms.

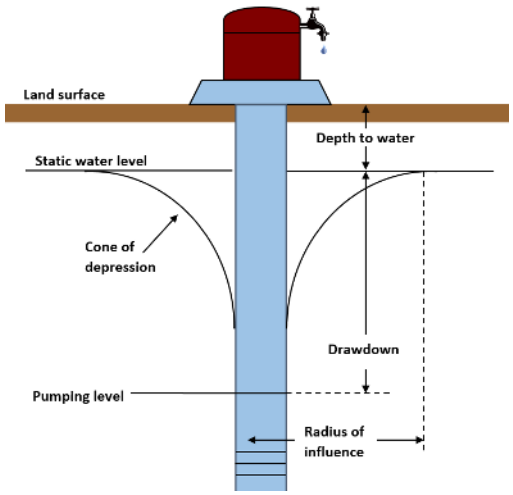


Figure **3.2.5**: Image by COC OER is licensed under CC BY 4.0

In this diagram, there are several other important terms. Drawdown is the difference between the pumping and static water levels. This level identifies the distance the water level drops when a well is off and when it is running. Also depicted in the diagram is something referred to as the cone of depression. The water level in an aquifer is only affected by a well running within a certain area around the well. This area of "depression" pulls the water down deeper closer to the well and the further away from the well the effect is less. Hence, a "cone" shaped effect occurs. The distance from the center of a well to the farthest area where the depression effect occurs is referred to as the radius of influence. These measurements help in the analysis of the health of the underlying aquifer and the efficiency of a well.

Sample Questions

1. If an airline measuring device is used to measure the depth to groundwater displays a pressure of 125 psi, what is the depth in feet?
    1. 125 feet
    2. 289 feet
    3. 54 feet
    4. None of the above
2. An unconfined aquifer is _____.
    1. More susceptible to contamination than a confined aquifer
    2. Less susceptible to contamination than a confined aquifer
    3. Typically deep within the earth's crust
    4. Not a common source of water for a water utility
3. A sounding tube is used _____.
    1. To hear if a motor is running correctly
    2. To test the flow of a well
    3. To measure the depth to groundwater within a well
    4. To see if a well works properly
4. Which of the following materials is not a common well screen?
    1. Stainless steel
    2. Iron
    3. Monel metal
    4. Special nickel alloy
5. The annular seal is commonly made of _____.
    1. Plastic

2. Steel
3. Bentonite clay
4. All of the above

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3.3: Water Treatment Overview

Learning Objectives

After reading this section, you should be able to:

- Describe water quality characteristics
- Describe disinfection processes
- Describe the classes of water quality
- Explain water quality characteristics

Water Quality Characteristics

Water functions as a solvent due to its polarity and small molecular size. It has the ability to form hydrogen bonds which allows it to dissolve many types of molecules. It is often referred to as a "universal solvent". Microorganisms rely on water in order to grow. As such, pathogens which cause human illness are found in untreated surface water and groundwater. Waterborne diseases include typhoid fever, cholera, giardia, dysentery, E coli., hepatitis A, cryptosporidium, and Salmonella.

Public water system treatment plants use a combination of different treatment methods to remove or inactivate all disease-causing organisms and viruses. The process is referred to as a **multi-barrier treatment** approach. The final step in this approach involves chemical disinfection using chlorine or chloramines. Complete sterilization like the process used in hospitals is not necessary in water treatment.

Factors Influencing Disinfection

Several physical characteristics of a microorganism and chemical factors can influence the disinfection of water and include:

pH

Worldwide, many agencies have historically limited the range of pH values of distributed water between 6.5 and 8.5. Although this range is not a regulatory limit, many jurisdictions have used it as one. The antimicrobial activity of chlorine is optimal at a neutral pH of 7.0. But an increase in pH will reduce its efficacy (pH over 8.0).

Temperature

The activity of most disinfectants will increase as the temperature increases. Chlorine is very effective at temperatures above 65 ℉. Temperature measurements for calculating treatment contact times is important.

Turbidity

Turbidity is the measure of the relative clarity of a liquid. Cloudy (turbid) water would be due

To the presence of clay, silt, tiny inorganic and organic matter and other microorganisms. This would definitely interfere with the disinfection process and is why a multi-barrier treatment approach with filtration precedes disinfection.

Organic Matter

A disinfectant like chlorine or bromine will react with natural organic residue found in water. This reduces the amount of disinfectant available. But more importantly the formation of chemical disinfection by-products called trihalomethanes (THMs) also occurs. These compounds are regulated by the EPA. Consequently, most water agencies in California now use chloramines instead of chlorine as a primary disinfectant.

Inorganic Matter

Inorganic compounds found in residual silts or a compound such as ammonia (NH_3) in water will reduce the amount of disinfectant.

Reducing Agents

A **reducing agent** loses electrons and is oxidized in a chemical reaction. Examples of reducing agents include earth metals, formic acid, and sulfite compounds. Chlorine combines with reducing agents, thereby affecting the amount of chlorine available to disinfect. Examples of reducing agents in water include hydrogen sulfide (H2S), ferrous ion (Fe+2), manganous ion (Mn+2), ammonia (NH3), and nitrite (NO2-).

Microorganisms

The physical characteristics of a microorganism can influence the disinfection process for example, spores are resistant to disinfectants because the spore coat and cortex act as a barrier. But most microorganisms can be filtered or settled out prior to disinfection.

Removal Processes

A multi-barrier approach is used to remove pathogens before they are killed or inactivated (if a virus) by chemical disinfection.

1. **Coagulation.** Coagulation is often the first step in water treatment. During coagulation, chemicals with a positive charge are added to the water (floc). The positive charge neutralizes the negative charge of dirt and other dissolved particles in the water. When this occurs, the particles bind with the chemicals to form slightly larger particles. Common chemicals used in this step include specific types of salts, aluminum, or iron. In an international report published in 1998, it was found that coagulation and sedimentation alone can remove between 27 and 84 percent of viruses and between 32 and 87 percent of bacteria. Usually, the pathogens that are removed from the water are removed because they are attached to the dissolved substances that are removed by coagulation.
2. **Sedimentation.** This refers to one of the steps water treatment plants use to separate out solids from the water. During sedimentation, flocs settle to the bottom because they are heavier than water.
3. **Filtration.** Once the flocs have settled to the bottom of the water, the clear water on top is filtered to separate additional solids from the water. During filtration, the clear water passes through filters that have different pore sizes and are made of different materials (such as sand, gravel, and charcoal). These filters remove dissolved particles and germs, such as dust, chemicals, parasites, bacteria, and viruses. Activated carbon filters also remove any bad odors.

Disinfection Process

After the water has been filtered, water treatment plants may add one or more chemical disinfectants (such as chlorine, chloramine, or chlorine dioxide) to kill any remaining parasites, bacteria, or viruses. To help keep water safe as it travels to homes and businesses, water treatment plants will make sure the water has low levels of the chemical disinfectant when it leaves the treatment plant. This remaining disinfectant kills pathogens living in the pipes between the water treatment plant and your tap.

In addition to or instead of adding chlorine, chloramine, or chlorine dioxide, water treatment plants can also disinfect water using UV light and ozone. They work well to disinfect water in the treatment plant, but these disinfection methods do not continue killing germs as water travels through the pipes between the treatment plant and your tap (no disinfection residual).

Ultraviolet Rays

Advances in UV disinfection have been made in recent years. An Ultraviolet (UV) disinfection system transfers electromagnetic energy from a mercury arc lamp to an organism's genetic material (DNA and RNA). When UV radiation penetrates the cell wall of an organism, it destroys the cell's ability to reproduce. UV radiation, generated by an electrical discharge through mercury vapor, penetrates the genetic material of microorganisms and retards their ability to reproduce. Unfortunately, this method leaves no disinfectant residual and is expensive.

Heat

Primarily used in emergencies, heating water to a boil for 5 minutes will kill all microorganisms which may have breached the distribution system. From a practical perspective, it is an expensive and inefficient way to disinfect water for a public water system.

Chemical Disinfection

Iodine

Iodine is a good disinfectant and has been utilized for potable water treatment since the early 1900's in concentrations between 2.5 – 7 ppm. The US Army continues to issue iodine-based tablets to field soldiers and other personnel to disinfect water in emergencies. It is expensive and is also not recommended for use as a primary disinfectant due to lack of knowledge on long-term toxic effects**.**

Bromine

Bromine is primarily used as an alternative disinfectant for swimming pools, spas and cooling tower water, but not for municipal drinking-water, partly due to cost and partly to concerns about the formation of brominated DBPs.

Ozone

Ozone is used to disinfect water along with reducing taste and odors. Drawbacks of ozone for disinfection include a high cost, big physical footprint, lack of residual, difficulty in storing, and maintenance requirements.

Ozone has its advantages and disadvantages. Ozone treatment has the ability to achieve higher levels of disinfection than chlorine or UV, however, the capital costs as well as maintenance expenditures are not competitive with available alternatives.

Chlorine

At room temperature, chlorine is a yellow-green gas that is heavier than air and has a strong irritating odor. It can be converted to a liquid under pressure or cold temperatures. Chlorine is mainly used as bleach in the manufacture of paper and cloth and to make a wide variety of products. Chlorine appears as a greenish yellow gas with a pungent suffocating odor. Chlorine does not burn but, like oxygen, supports combustion. Long-term inhalation of low concentrations or short-term inhalation of high concentrations has ill effects. Vapors are much heavier than air and tend to settle in low areas.

Disinfection Action

Chlorine destroys organisms by oxidizing their cellular material. It is extremely effective for inactivating pathogens with one exception, Cryptosporidium. Leaving chemistry out of this discussion, let's consider what happens if 1 mg of chlorine gas is added to 1 liter of pure distilled water. Chemical reactions will occur to form two chlorine species which are referred to as free chlorine. That free chlorine "residual" is 1 mg/liter and has the ability to disinfect. Now consider 1 liter of water as it exists in nature. Let's also say there are no pathogens in the water. It will still contain natural organic compounds, non-organic elements like iron and manganese, and other compounds found in nature like nitrites, ammonia, and hydrogen sulfide. Chlorine will also react with them to form other compounds but won't have the ability to disinfect. Consequently, you won't have 1mg/liter of free chlorine residual. It will be less. You would need to add more chlorine gas to get back to 1mg/liter.

Chlorine Reactions in Water

Chlorine and water will react to form hypochlorous acid HOCL and hydrochloric acid HCl. These are weak compounds and HOCL will dissociate further into the hypochlorite ion OCL^-. Hypochlorous acid and the hypochlorite ion are what make up the free chlorine residual. As a disinfectant, the hypochlorite ion is only 1% as effective as hypochlorous acid.

These reactions are reversible and pH dependent.

- between pH 3.5 and 5.5, HOCl is the predominant species.
- between about pH 5.5 and 9.5, both HOCl and OCl^- species exist in various proportions.
- above pH 8, OCl^- predominates.

Reactions with Substances in Water

Chlorine will react with natural organic and inorganic compounds. This will reduce the free chlorine residual for disinfection purposes and necessitate the addition of additional chlorine gas. Hydrogen sulfide is a common compound found in groundwater. It has an unpleasant smell and is responsible for many taste and odor complaints from retail customers who may be served with groundwater sources of supply. Chlorine is very effective at removing it.

When chlorine reacts with natural organic matter, a group of disinfection byproducts, known as THM's or trihalomethanes may form. They may be harmful to certain segments of the population and are listed as a contaminant and regulated by the EPA.

Consequently, many water agencies have switched from using the direct use of chlorine gas as a primary disinfectant.

Chloramination

Chloramines have been used as a disinfectant in water systems for many years, primarily to control taste and odor. They can maintain a detectable disinfectant residual in a distribution system. But chloramine is a weaker disinfectant than chlorine. Consequently, higher chloramine doses and longer contact times are required to achieve the same level of disinfectant effectiveness as chlorine. A big advantage of using chloramines is to significantly reduce trihalomethane (THM) levels in order to meet the regulatory requirements of the Surface Water Treatment Rule.

Chloramines are formed when chlorine reacts with ammonia. They will form when natural untreated water contains ammonia. To maintain very low THM levels but maintain effective disinfection residuals, treatment plant operators will apply chlorine gas with ammonia concurrently in the treatment plant influent, or sequentially at a different downstream location in order to create a high chorine residual in part of the treatment process.

Hypochlorite

Rather than use chlorine gas, hypochlorite is available as calcium hypochlorite or sodium hypochlorite. They are a good alternative to supplying chlorine. Calcium hypochlorite is available as a solid. Sodium hypochlorite is available in solution.

Chlorine Dioxide

Chlorine dioxide (ClO2) is an effective disinfectant. Chlorine dioxide does not form THM's like chlorine gas. It is more costly, and more hazardous to use. Chlorine dioxide is highly reactive and flammable.

UV Disinfection and Treatment of Water

Ultraviolet (UV) rays are part of the light that comes from the sun. The UV spectrum is higher in frequency than visible light and lower in frequency compared to x-rays. The UV spectrum has a larger wavelength than x-rays and a smaller wavelength than visible light and the order of energy, from low to high, is visible light, UV, and x-rays.

UV is known to be an effective disinfectant due to its strong germicidal (inactivating) ability. UV disinfects water containing bacteria and viruses and can be effective against protozoans, such as *Giardia lamblia* cysts or *Cryptosporidium* oocysts. UV is used in the pharmaceutical, cosmetic, beverage, and electronics industries. In the United States, it is used for drinking water disinfection; however, high operating costs compared to disinfection by chlorination has limited its usage.

Because of safety issues associated with the reliance of chlorination and improvements in UV technology, UV has experienced increased acceptance in municipal water systems. Two classes of disinfection systems are certified and classified by the NSF under Standard 55, Class A and Class B Units.

1. Class A These ultraviolet water treatment systems must have an intensity and saturation rating of at least 40,000 uw-sec/cm2 and possess designs that will allow them to disinfect and/or remove microorganisms from contaminated water. Affected contaminants should include bacteria and viruses. Class A point-of-entry and point-of-use systems covered by this standard are designed to inactivate and/or remove microorganisms, including bacteria, viruses, and *Cryptosporidium* oocyst and *Giardia* cysts from contaminated water. Systems covered by this standard are not intended for the treatment of water that has obvious contamination or intentional source contamination, such as raw sewage, nor are these systems intended to convert wastewater to drinking water. These systems are intended to be installed on visually clear water.
2. Class B These ultraviolet water treatment systems must have an intensity and saturation rating of at least 16,000 uw-sec/cm2 and possess designs that will allow them to provide supplemental bactericidal treatment of water already deemed safe, such that no elevated levels of *E. coli* or a standard plate count of less than 500 colonies per 1 ml exists. NSF Standard 55 suggests Class B UV systems are designed to operate at a minimum dosage and are intended to reduce normally occurring non-pathogenic or nuisance microorganisms only. The Class B or similar non-rated UV systems are not intended for the disinfection of microbiologically unsafe water.

The type of unit depends on the situation for use, source of water, and water quality. Transmitted UV light dosage is affected by water clarity. Water treatment devices are dependent on the quality of the raw water. When turbidity is 5 NTU or greater and/or

total suspended solids are greater than 10 ppm, pre-filtration of the water is highly recommended. Normally, it is advisable to install a 5 to 20 micron filter prior to a UV disinfection system.

UV disinfection is based on the principles associated with wave lengths of light that damage the nucleic acids of water borne pathogens. UV radiation has three wavelength zones, UV-A, UV-B, and UV-C, and it is the last region, the shortwave UV-C, that has germicidal properties for disinfection. A low-pressure mercury arc lamp resembling a fluorescent lamp produces the UV light in the range of 254 manometers (nm). These lamps contain elemental mercury and an inert gas, such as argon, in a UV-transmitting tube, usually quartz. Traditionally, most mercury arc UV lamps have been the low-pressure type because they operate at a relatively low partial pressure of mercury, low overall vapor pressure (about 2 mbar), low external temperature (50-100o C), and low power. These lamps emit nearly monochromatic UV radiation at a wavelength of 254 nm, which is in the optimum range for UV energy absorption by nucleic acids (about 240-280 nm).

In recent years, medium pressure UV lamps that operate at much higher pressures, temperatures, and power levels have been installed. They emit a broad spectrum of higher UV energy between 200 and 320 nm.

An essential requirement for UV disinfection with lamp systems is an available and reliable source of electricity. While the power requirements of low-pressure mercury UV lamp disinfection systems are modest, they are essential for lamp operation to disinfect water. Since most microorganisms are affected by radiation around 260 nm, UV radiation is in the appropriate range for germicidal activity. UV lamps are available that produce radiation in the range of 185 nm, and they are effective in reducing microorganisms as well. They will also reduce the total organic carbon (TOC) content of the water.

For typical UV systems, approximately 95-percent of the radiation passes through a quartz glass sleeve and into the untreated water. The water is flowing as a thin film over the lamp. The glass sleeve is designed to keep the lamp at an ideal temperature of approximately 104° F.

UV radiation affects microorganisms by altering the DNA in the cells and impeding reproduction. UV treatment does not remove organisms from the water. It inactivates them. The effectiveness of this process is related to exposure time and lamp intensity, as well as general water quality parameters.

The exposure time is reported as microwatt-seconds per square centimeter (uwatt-sec/cm2), and the U.S. Department of Health and Human Services has established a minimum exposure of 16,000 µwatt-sec/cm2 for UV disinfection systems. Most manufacturers provide a lamp intensity of 30,000-50,000µwatt-sec/cm2. In general, coliform bacteria are destroyed at 7,000 µwatt-sec/cm2.

Since lamp intensity decreases over time with use, lamp replacement and proper pretreatment are key to the success of UV disinfection. In addition, UV systems should be equipped with a warning device to alert operators when lamp intensity falls below the germicidal range.

Used alone, UV radiation does not improve the taste, odor, or clarity of water. UV light is a very effective disinfectant, although the disinfection can only occur inside the unit. No residual disinfection in the water exists to inactivate bacteria that may survive or may be introduced after the water passes by the light source. The percentage of microorganisms destroyed depends on the intensity of the UV light, the contact time, raw water quality, and proper maintenance of the equipment.

If material builds up on the glass sleeve or the particle load is high, the light intensity and the effectiveness of treatment are reduced. At sufficiently high doses, all waterborne enteric pathogens are inactivated by UV radiation. The general order of microbial resistance (from least to most) and corresponding UV doses for extensive (>99.9%) inactivation are vegetative bacteria and the protozoan parasites *Cryptosporidium parvum* and *Giardia lamblia* at low doses (1-10 mJ/cm2) and enteric viruses and bacterial spores at high doses (30-150 mJ/cm2).

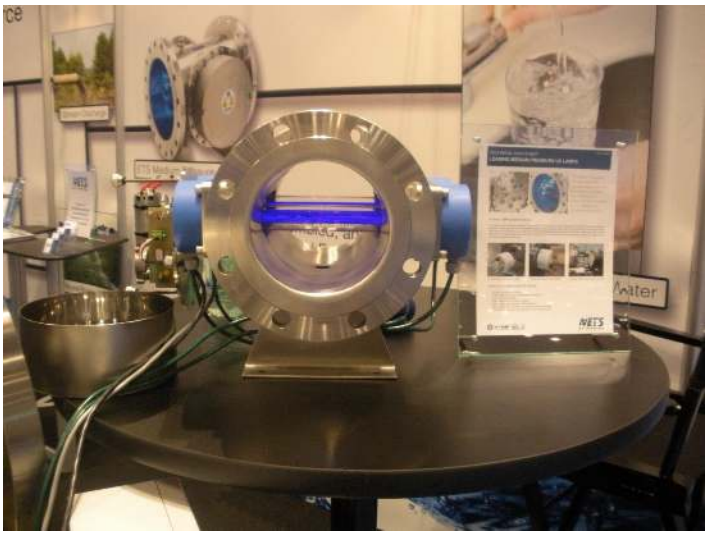


Figure **3.3.1**: UV light used for disinfection in water treatment.

Most low-pressure mercury lamp UV disinfection systems can readily achieve UV radiation doses of 50-150 mJ/cm2 in high quality water; and therefore, efficiently disinfect waterborne pathogens. However, dissolved organic matter, such as natural organic matter, certain inorganic solutes such as iron, sulfites and nitrites, and suspended matter (particulates or turbidity) will absorb UV radiation or shield microbes from UV radiation, resulting in lower delivered UV doses and reduced microbial disinfection. Another concern surrounding disinfecting microbes with lower doses of UV radiation is the ability of bacteria and other cellular microbes to repair UV-induced damage and restore pathogenicity, which is a phenomenon known as reactivation.

UV inactivates microbes primarily by chemically altering nucleic acids. However, the UV-induced chemical lesions can be repaired by cellular enzymatic mechanisms, some enzymes act independent of light (dark repair) and other enzymes require visible light (photo-repair or photo-reactivation). Therefore, achieving optimum UV disinfection of water requires delivering a sufficient UV dose to induce greater levels of nucleic acid damage; and thereby, overcome DNA repair mechanisms.

UV units have a maximum flowrate capacity and some equipment have minimum flowrates. If the flow is too high, water will pass through without enough UV exposure. If the flow is too low, heat may build up which can damage the UV lamp. A UV unit with minimum flow requirements should not be placed on the water line supplying pressure stations in a non-recirculating system. UV units are most often used in constant flow systems.

UV lamps do not burn out as normal florescent lamps do. Instead, the UV lamps will solarize, which reduce their intensity to about 60% of a new lamp after about one year of continuous use. When lamps are new, they will generate a dosage level near 60,000 µW-s/cm2. When the dosage drops to 30,000 µW-s/cm2, the minimum dosage needed to effectively kill bacteria, lamps should be replaced. Lamp life will be shortened significantly if the lamp is turned on and off more frequently than once every eight hours.

Water should be sampled and tested for bacteria counts regularly. Sample before and after the UV unit to test its performance. Water should also be sampled in the distribution since bacterial regrowth can occur downstream of the UV unit.

As water passes through the UV unit, minerals, debris, and other material in the water will deposit onto the quartz or Teflon sleeve. This activity will limit the penetration of UV rays through the sleeve and into the water. To maintain high clarity, the glass around the lamp must be cleaned regularly. Cleaning frequency depends on the water quality and will be minimal with RO treatment upstream.

UV light intensity meters are available which indicate the penetration of UV light through the glass sleeve and the water. Low intensity means the UV dose is too low to provide adequate disinfection. This meter will indicate when cleaning or lamp replacement is needed.

Ozone

Ozone is one of the most powerful water treatment compounds available to system managers today. It is a technology that has been in continual commercial use for over 100 years and has distinct properties that allow disinfection of even heavily compromised

water streams. With the 1996 reauthorization of the Safe Drinking Water Act, ozone was named as among the best available technologies for water system compliance with National Primary Drinking Water Regulations as overseen by the US Environmental Protection Agency.

Ozone (O3) is formed when oxygen molecules are exposed to electron flow. Ozone molecules are unstable and will lose the third oxygen atom over time. Ozone is formation characterization:

1. Ozone generators provide an electron flow between dielectric and SS tubes.
2. Oxygen is passed through the gap between dielectrics resulting in ozone generation.
3. Oxygen feed gas must be dry and free of particles.
4. Ozone generators must be cooled, and cooling water removes .90 percent of the heat that is generated.

Ozone is a powerful oxidant with high disinfectant capacity. Ozone residuals between 0.3 to 2.0 mg/L inactivate viruses. Inactivation rates range from >3.9-log to >6-log, and occur within very short contact periods, 5 seconds. Microorganisms in natural waters are very sensitive to ozone. *Giardia* and enteric viruses are inactivated by ozone, as a primary disinfectant, with 5 minutes of contact time. Ozone residuals of 0.5 to 0.6 mg/L result in 3-log and 4-log removals, respectively. When ozone is used as a primary treatment, the criterion for its use is based on ozone residuals, competing ozone demands, and a minimum contact time to meet the required cyst and viral inactivation requirements.

Ozone is the strongest oxidant and strongest disinfectant available for potable water treatment. This unique material can be utilized for a number of specific water treatment applications, including disinfection, taste and odor control, color removal, iron and manganese oxidation, hydrogen sulfide removal, nitrite and cyanide destruction, oxidation of organics such as phenols, pesticides, and some detergents, algae destruction and removal, and as a coagulant aid. Even though ozone is the strongest chemical disinfectant available for water treatment, some refractory organics are not oxidized, or oxidize too slowly. In such cases, ozone can be combined with UV radiation and/or hydrogen peroxide to produce hydroxyl free radicals, HO-, which is a stronger oxidant than molecular ozone, O3. Deliberate production of hydroxyl free radicals starting with ozone has been termed ozone advanced oxidation. Groundwater that is contaminated with chlorinated organic solvents and some refractory hydrocarbons are being treated successfully with ozone advanced oxidation techniques.

At ambient temperatures, ozone is an unstable gas, partially soluble in water; generally, more soluble than oxygen. Due to its instability, ozone quickly reverts to oxygen. Ozone cannot be produced at a central manufacturing site, bottled, shipped, and stored prior to use. It must be generated and applied on-site. The installation of an ozone production plant requires storage of pure oxygen on-site as the feed gas. Ozone is generated for commercial uses using corona discharge or ultraviolet radiation. The UV technique produces low concentrations of ozone, whereas corona discharge produces ozone concentrations in the range of 1 – 4.5 % when dry air is fed to the ozone generator. When concentrated oxygen is used as the feed gas, gas phase ozone concentrations of up to 14 to 18% can be produced. Since ozone is only partially soluble in water, once it has been generated it must be contacted with the water to be treated in such a manner as to maximize the transfer of ozone from the gas phase into water. For this purpose, many types of ozone contactors have been developed. However, as higher concentrations of ozone gas are employed, contacting system designs become more critical because of the lower gas to liquid ratios.

The use of oxygen as the feed gas can result in oxygen super saturation of the treated water causing operational problems and corrosion in the distribution system. Ozone contacting system options include atmospheric tall towers or pressurized gas to liquid mass transfer processes. Fine bubble diffusers, static mixers, or venturi injectors can be used to mix the gas with the water to be treated in full flow or side stream configurations. Once dissolved in water, ozone is available to act on water contaminants to accomplish its intended purposes of disinfection and/or oxidation. At pH levels of 3-6, ozone is present primarily in its molecular form (O3). However, as the pH rises, the decomposition of ozone to produce the hydroxyl free radical (HO-) becomes increasingly rapid. At pH 7 about 50% of the ozone transferred into water produces HO-. At pH >10, the conversion of molecular O3 to HO- is virtually instantaneous.

Because ozone is such a powerful oxidant/disinfectant, the trick to applying it to solve water treatment problems is to do so in a manner that is effective for water treatment, yet at the same safe for the people in the vicinity. Ozone safety issues are handled easily by using proper ambient ozone monitoring, tank venting, and ozone destruction. In the case of systems driven solely by a pumping/injector system, ozone may be produced under vacuum, which ensures no leakage of ozone into the operating environment.

The five basic components of an ozone system include:

1. Gas preparation–either drying gas to a suitable dew point or using oxygen concentrators
2. A suitable electrical power supply
3. A properly sized ozone generator(s)
4. An ozone contacting system
5. Ozone off-gas destruction or suitable venting system

Moisture in the feed gas causes two operating problems:

1. The amount of ozone produced by application of a given electrical energy level is lowered as relative humidity rises. Consequently, it is usually cost-effective to dry the air to a recommended dew point of minus 65’C (-65’C or -76’F) or lower.
2. Ozone generated using air in the presence of moisture allows small amounts of nitrogen oxides to react with the moisture to produce nitric acid. In this instance, gas condensation at the cooling/heat transfer surfaces produces a corrosive compound which can cause corrosion problems in the ozone generation equipment with concomitant increases in equipment maintenance requirements.

Because of the high oxidative qualities of gas-phase ozone and the chance of moisture from a failing feed gas unit, system managers must take extra care to make certain that all components in the ozone generator, ozone supply line, ozone gas to liquid mass transfer equipment and the contact vessel are ozone-compatible.

For large scale ozone systems, the equipment for cleaning and drying feed gases can become quite complex. For example, effective air drying can involve multiple treatment steps including air filtration, compression, cooling, desiccation, and final filtration prior to passage into an operating corona discharge ozone generator.

A need exists for efficient ozone contacting and destruction of excess ozone in contactor off-gases. Absent an effective ozone off-gas destruct unit, excess ozone would be present for people in the vicinity to breathe, which is not recommended because of its strong oxidizing nature. Additionally, ozone is heavier than ambient air, and can settle in the vicinity, and attack oxidizable materials. Destruction of contactor off-gas ozone is readily accomplished thermally (370’C), catalytically, thermal-catalytically, and by passing the off-gas through granular activated carbon. Care should be exercised in selecting an ozone destruct method whenever very high concentrations of ozone are encountered.

Ozone is a critical process for non-reverse osmosis purification. It is usually coupled with biologic activated carbon filtration. The process reduces TOC and trace chemical pollutants, removes protozoans, kills viruses, and is a flocculation aid. Ozone treatment is an oxidation process used as a disinfection and oxidant prior to biologic activated carbon filtration.

Instrumentation and controls for ensuring effective and safe operation of ozone systems are concerned with applying ozone effectively and affordably. System processes control ozone generation, oxygen usage, drying, ozone injection and diffusing, and ozone destruction.

The instrumentation monitors each step, and each step has an alarm associated with the process.

Key Terms

- **Coagulation –** a process that is followed by sedimentation and filtration will remove 90 to 95-percent of the pathogenic organisms depending on which chemicals are used; alum usage in coagulation can increase virus removals up to 99-percent.
- **Disinfection –** a process that destroys harmful organisms physically or chemically
- **Filtration** – a process through granular filters is an effective means of removing pathogenic and other organisms form water; removal rates vary from 20 to 99-percent, depending on the coarseness of the filter media and the type of effectiveness of pretreatment.
- **Sedimentation** – a process through which pathogenic organisms settle out by gravity, assisted by chemical floc; proper design of sedimentation processes can effectively remove 20 to 70-percent of the pathogenic microorganisms

Review Questions

1. **List the factors that affect chlorination of drinking water?**
2. **Describe disinfection as a process in drinking water treatment.**

3. **What is the purpose of chloramination in drinking water?**
4. **What is ozonation of drinking water?**
5. **How does UV light effect microorganisms?**
6. **Describe the primary reason that chlorine may not be used for drinking water disinfection at a particular drinking water facility.**

Chapter Quiz

1. _____ is the process designed to kill or inactivate most microorganisms in water, including essentially all pathogenic (disease-causing) bacteria.
    1. Sterilization
    2. UV treatment
    3. Application of chlorine
    4. Disinfection
2. Which of the diseases listed is not caused by a waterborne pathogenic organism?
    1. Gastrointestinal anthrax
    2. Shigellosis
    3. Polio
    4. All of these are water borne diseases
3. Hypochlorous Acid and hypochlorite when considered together are also known as the _____.
    1. chlorine dose
    2. chlorine demand
    3. free chlorine
    4. chlorine residual
4. _____ is a gas that does not form carcinogenic compounds like those compounds formed by chlorine disinfection. It also is not affected by ammonia, and it is a very effective disinfectant at higher pH levels. It is also used to diminish taste and odor problems in the distribution system. It is especially useful in inhibiting *Legionella*.
    1. Chloramination
    2. Chlorine dioxide
    3. Hydrogen peroxide
    4. Potassium permanganate
5. Because of safety issues associated with the reliance of chlorination and improvements in _____ technology, it has experienced increased acceptance in municipal water systems. Two systems are certified and classified by the NSF under Standard 55. The type of unit depends on the situation for use, source of water, and water quality. The dosage is affected by water clarity. When turbidity is 5 NTU or greater and/or total suspended solids are greater than 10 ppm, pre-filtration of the water is highly recommended. It is advisable to install a 5 to 20 micron filter prior to the disinfection system.
    1. ozone
    2. chloramination
    3. ultraviolet light
    4. chlorine dioxide
6. _____ is the strongest oxidant and strongest disinfectant available for potable water treatment. This unique material can be utilized for specific water treatment applications, including disinfection, taste and odor control, color removal, iron and manganese oxidation, hydrogen sulfide removal, nitrite and cyanide destruction, oxidation of organics such as phenols, pesticides, and some detergents, algae destruction and removal, and as a coagulant aid.
    1. Ozone
    2. Chloramination
    3. Ultraviolet light
    4. Chlorine dioxide

7. A major problem with disinfection using _____ is that bacterial regrowth can occur downstream of the application site in the distribution.
    1. Ozone
    2. Chloramination
    3. Ultraviolet light
    4. b and c are correct
8. An alternative used by many water agencies to manage the formation of DBP's would be _____ disinfection.
    1. Ozone
    2. Chloramination
    3. Ultraviolet light
    4. Chlorine dioxide
9. _____ is a critical process for non-reverse osmosis purification. It is usually coupled with biologic activated carbon filtration. The process reduces TOC and trace chemical pollutants, removes protozoans, kills viruses, and is a flocculation aid. It is an oxidation process used as a disinfection and oxidant prior to biologic activated carbon filtration.
    1. Ozone
    2. Chloramination
    3. Ultraviolet light
    4. Chlorine dioxide
10. Which of the listed factors does not have an influence on the disinfection of water with chlorine?
    1. pH,
    2. Reducing agents
    3. Hardness
    4. Temperature

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SECTION OVERVIEW

3.4: Distribution System Design

3.4.1: System Design

3.4.2: Water Storage

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3.4.1: System Design

Student Learning Outcomes

After reading this chapter, you should be able to:

- Explain how source water availability and reliability affects distribution system design
- Describe the three main distribution system configurations
- Evaluate the main requirements, which affect the quantity of distribution system storage
- Analyze and describe the main types of distribution system maps

When designing a water distribution system a lot of different things need to be considered. For example, the following questions are some which might be considered:

- What will the water be used for?
- Is it a small rural farming community or a large industrial metropolitan city?
- Will the community grow in size?
- Are there other sources of supply available?

Planning is an important step in the design of a water distribution system. Most early communities were built around a water source, some place where water was available. This obviously made planning and design much easier. However, as villages grew into towns and as communities began to spread out well beyond the original sources of supply, planning and design became more difficult and more important. Below is a list of a few things that should be considered prior to or during the design of distribution systems.

1. Water availability – Is there an available supply of water to meet current and future demands?
2. Source reliability – How reliable is the source or sources of supplies?
3. Water quality – Does the current water quality meet regulatory standards?
4. Location – What is the location of the community in relation to the sources of supply? What is the topography of the community?
5. Local, state, and federal requirements – In addition to water quality regulations, there are other local, state, and federal regulations

Let's break down each one of these items in a little more detail.

Water Availability

It is not by coincidence that early settlers and homesteads were in close proximity to rivers and lakes. These water bodies provided a source of freshwater for drinking and bathing. In addition, it provided a good source of food. In addition to fish, other animals would gather around water sources. As communities began to grow, the availability of water became more and more important. In the late 1800s and early 1900s, Los Angeles relied mostly on local groundwater supplies. However, as the population began expanding rapidly, the need for another source of supply became evident. At the time, William Mulholland was the Los Angeles Water Company Superintendent and was instrumental in bringing water from the Owens Valley area in the north, making it available so Los Angeles could continue to expand.

Bringing water from the north to southern California required an extensive transmission pipeline system. Once the water reached Los Angeles, a distribution system network allowed people to reside and spread out all across the area. A water transmission system is typically composed of large diameter pipelines bringing water to areas, which lack available water supplies. In contrast, a water distribution system disperses water throughout a given area through smaller diameter pipelines. Pipeline diameters and types will be discussed in more detail later in this text.

Water Reliability

Accessing water from different sources and locations, such as in the case of Los Angeles, allowed for cities to grow at a rapid rate. In the early 1900s, William Mulholland realized the local groundwater serving the city of Los Angeles would not sustain the growing population and discovered another source of supply to the north. In this case, the Owens Valley not only provided an

additional supply (availability) for Los Angeles, it also increased the supply reliability for the region. Multiple supplies of water increase reliability. For example, if an area relies on a surface water supply as their main source and there is not enough precipitation one year to sustain the surface supply, a local groundwater system can supplement the demand.

In a distribution system having pipelines, which interconnect, can provide a more reliable supply in the event of pipeline breaks or system failures. For example, a grid pipeline network (discussed later in this chapter) provides water service from multiple directions allowing water to be served to customers from more than one location. Having a reliable supply of water and a redundant system of pipelines is critical to an efficiently run water distribution system. In addition, having back up sources of power to operate pumps in the event of power outages also provides increased reliability.

Water Quality

In addition to having an available and reliable supply of water, it is important to have a supply, which meets water quality standards. A safe water supply is equally as important as any other consideration when designing a water distribution system. In instances where source water quality does not meet drinking water regulations, treatment can be implemented. However, if sources of supply are not in centralized locations, the cost of treatment can be prohibitive. For example, if a water utility has multiple drinking water groundwater wells and these wells are spread throughout the distribution system or several miles, centralized treatment would be difficult. If each of these wells were contaminated, it might mean individual treatment systems would need to be installed at each location. The cost for individual treatment systems is typically more costly than a centralized treatment system. In contrast, if these wells are located within close proximity to each other, a centralized treatment system could be installed. This could significantly reduce the cost of treatment.

The cost of treatment is paid for by each customer through water rates. Therefore, in smaller communities, any type of treatment could be costly causing devastating consequences for the residents. This is purely an “economy of scale” issue. For example, if the Los Angeles Department of Water and Power (LADWP) had to provide treatment on a groundwater well, the cost of this treatment would be spread out among their rate base (total number of paying customers). LADWP has hundreds of thousands of paying customers. However, if a small rural water utility with only a few hundred or even thousand customers needed the same type of treatment, it might end up being cost-prohibitive.

Location

The next area which needs to be considered is location. When it comes to real estate, the common mantra is “location, location, location”. Well, this sort of speaks true to a water distribution system too. Location provides for water availability, reliability, and quality. This is not to say water cannot be brought in to areas where it does not naturally exist, but it does come at an additional cost. Water that is of good quality, readily available, and reliable will be considerably cheaper than if clean and reliable water needs to be imported over long distances.

Location also has to be considered when it comes to the actual design of a water system. For example, is the water distribution going to be built in an area, which is subject to freezing temperatures? If so, this will affect the depth of water distribution system infrastructure as well as above-ground appurtenances such as fire hydrants. If a fire hydrant is filled with water and the ambient temperature is below freezing for long periods of time, the water within the hydrant can freeze rendering the hydrant inoperable. Topography will also affect system design. Are there wide ranges of elevation of the proposed water distribution system or is the topography relatively flat and uniform? If there is a wide variation in elevations, additional pumping might be required, as well as other appurtenances compared to an area where the terrain is flat. Other things that may affect distribution system design based on location are things like soil corrosivity and local geology. This can affect the types of material used for things such as piping as well as the installation process.

Local, State, and Federal Requirements

Regulations will dictate minimum water quality and some system design standards and details. These standards and details can range from permitting the installation of facilities to very specific drinking water quality regulations. Each state, county, and city can have different criteria that can affect the design and installation of a water distribution system.

At a minimum, all public water utilities must meet federal drinking water quality regulations. These regulations however, can vary from state to state. State drinking water quality regulations must be at least as strict as the federal standards, but they can be more

stringent. An example of this is with the constituent chromium. There are several valance levels of chromium, with chromium VI being the most common. However, the federal **Safe Drinking Water Act (SDWA)** and California (SDWA) have a **maximum contaminant level (MCL)** for "total" chromium. This is the maximum level of all valances of chromium allowed in drinking water. In the federal SDWA, the MCL for total chromium is 100 micrograms per liter (ug/L) and in California, the level is 50 ug/L. This is an example where the state water quality regulation is more stringent than the federal requirement.

When it comes to design and installation criteria, there can be a number of local requirements, which include excavation permits, offset distances from other facilities, as well as other conditions. It is important for the design team to understand these requirements and help plan for them before and during the installation of distribution facilities.

In addition to these considerations when it comes to the design of a distribution system, there are a variety of other criteria that should be considered. Below is not an exhaustive list, but it covers various items that should also be considered.

- Future growth – In many areas, there are or will be plans for future growth. Some of these growth projections are understood through local planning documents, while other areas might not have as much detail. Regardless, it is always prudent to work with local agencies on the potential for future development plans and growth. This is particularly important when it comes to the sizing of facilities. For example, if a pipeline for an existing number of homes only needs to be six (6) inches in diameter, but will need to supply many more homes in the future, it might be prudent to increase the size of the pipeline in anticipation of this future growth. This is also true for pumping and storage facilities. It is important for water utilities to understand the projected population growth of their area, understand the existing and future projected water demands, and what sort of fire protection requirements are needed for each type of customer class.
- Cost and Funding – Cost is another important item to consider when designing and building a new or expanding an existing distribution system. Who benefits from the work being done? Is the distribution system expansion for a new development or is it to improve the service for existing customers. Many times if a new development is being planned, the owner (developer) of the property will be responsible for paying the costs associated with expanding the distribution system. However, the developer should also be responsible for paying some portion of the cost for the existing water system too. Why you might ask? Well, while the existing water system is benefitting the existing customers, a portion of the existing system will provide some benefit to the new development as well. Understanding this proportional cost is beyond the scope of this chapter and would be covered in more detail in a text related to water rates. However, it is important to understand that building a new distribution system or expanding an existing distribution system is quite costly and this cost needs to be shared by the customers receiving benefit. Sometimes a developer will pay for some or all of a distribution system project while other times the utility may carry debt to fund certain projects and then spread the cost to their customers over time.

Distribution System Layout

Planning is an important step in designing the layout of a water distribution system. While all the items discussed above should be considered before and during the planning stages, there are other "nuts and bolts" related planning items in order to layout the design of a distribution system.

Distribution systems are commonly designed by the utilities engineering department while other times engineering consultants are used. Regardless of who the engineer is, planning the design layout is a critical step in any distribution system. Calculations need to be completed in order to properly size facilities, pipelines, and the various appurtenances of a distribution system. Some of the items which are considered are the following:

- Water demands
- Flow rates
- Flow velocity
- Fire flow requirements
- Topography
- Pressure
- Power requirements
- Material selection
- Land ownership

This is by no means an exhaustive list. However, it should provide some insight into things, which are considered when planning and designing a distribution system. These and other items help determine what materials are selected, the size of facilities needed, and how things are designed and ultimately installed.

While most of the planning and design of distribution systems is conducted in the office with professional engineers, distribution operators should also be consulted. Unfortunately, this step of discussing the planning and design of a distribution system with field operators is sometimes overlooked. Many times, the steps of planning and design happen without the input from the very people who will be installing and operating the systems being designed. It might seem obvious to consult distribution operators, but why then is it often overlooked? A lot of information is gathered during the planning and design phase. One of the more important things to review are plans called as-built drawings. An as-built drawing is simply that, it is a plan that is modified after it was installed and "as it was built". Even after everything is considered during the planning and design stage, when the design plans make it to the field and the facilities are actually installed, things are often adjusted and changed during installation. These changes and adjustments are the result of conflicts that were not identified on the design plans and can end up costing significantly more than what was initially proposed. While the idea of being able to avoid all conflicts is not conceivable, consulting with field employees before the design plans are complete can help reduce some of these unforeseen conflicts.

Distribution Design Configurations

One of the more important things behind the functionality of a distribution system is the layout or configuration. There are three (3) common distribution system configurations. These are arterial loop, gird, and tree systems. Each one will be explained below. While some of these may be a more preferred and ideal installation configuration, sometimes less desirable designs cannot be avoided. The primary goal of a well-designed water distribution system is to provide good water quality at acceptable pressures to the utility's customers. In order to meet these and other objectives such as meeting the required customer water demands, which include flows to fight fires and limiting the number of customers out of water during outages, the design of a water distribution system is extremely important.

Arterial Loop System

The idea behind an arterial loop system is to provide flexibility by supplying water to the distribution system from multiple locations. This system attempts to surround the distribution system with larger diameter water mains. This provides adequate flows (volumes of water) to the interconnecting distribution system from different locations. Arterial mains are constructed on the perimeter of a distribution system bringing a main flow of water supply from various branches. An arterial loop system typically has very large diameter pipes (referred to as transmission mains) providing water to smaller but still large diameter mains (referred to as arterial mains), which then feed water to smaller mains (referred to as distribution mains), and finally, these mains distribute water to the customers. See the example diagram below.

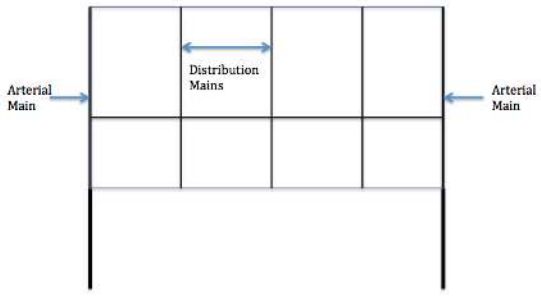


Figure **3.4.1.1**: Arterial Loop Distribution System by Mike Alvord is licensed under CC BY 4.0

Grid System

A grid system is one of the more desirable distribution system layouts. They can provide water to all customers from multiple areas. This configuration allows water to circulate throughout the entire system providing better water quality, pressures, and flow rates. Another positive benefit to a grid system is the ability to limit the number of customers who are out of water during outages

from things such as water main breaks. The main difference between an arterial loop and a simple grid system is the grid system shown below is typically fed by a single transmission and/or arterial main.

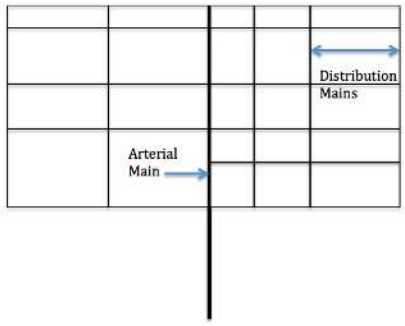


Figure 3.4.1.2: Grid System by Mike Alvord is licensed under CC BY 4.0

Tree System

This type of distribution system is the least desirable design. A tree system is typically fed by one larger main and then branches off to smaller distribution mains. However, as shown below, a tree system's distribution mains end in something referred to as "dead ends". Dead ends are where a water main terminates at the end of a cul-de-sac or other area where it cannot connect to another distribution main. Dead ends can result in reduced water quality, pressure, and flow. If a dead end distribution main is too large, the water in the main can become stagnant and cause undesirable taste, odor, and color water quality problems. Therefore, dead-end water mains are sometimes undersized and then can result in reduced pressures and flows.

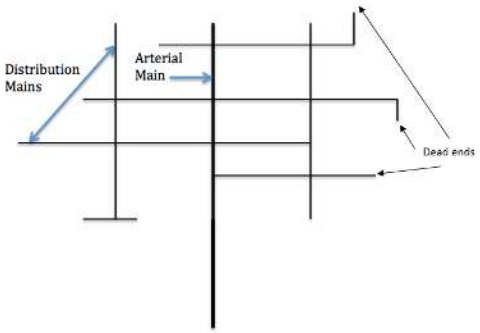


Figure 3.4.1.3: Tree System by Mike Alvord is licensed under CC BY 4.0

Appurtenances

An appurtenance is a generic term for accessories associated with a functioning distribution system. In this chapter, we will only focus on the last two appurtenances in the list below. Most of the others on the list below will be discussed in more detail later in this text.

- Valves
- Fire hydrants
- Elbow and angles
- Fittings
- Blow offs
- Air and vacuum valves (airvac)

In water distribution systems where there are high and low points (topographic elevation changes) blow offs and airvacs are commonly used. When you have low points in water pipelines, debris (sand, dirt) can accumulate at the bottom of the pipes. Also, as previously mentioned, water can become stagnant at the end of pipelines (dead ends). In these situations, blows are installed. Blow offs allow distribution system operators to flush water in order to remove any stagnant water or debris. In contrast, air can

accumulate in high points of a pipeline. In order to remove air, air and vacuum valves are installed to automatically release air from the distribution system. Below are some examples of these appurtenances.



Figure **3.4.1.4**: Fire Hydrant Image Source by the Anderson Air Force Base is in the public domain

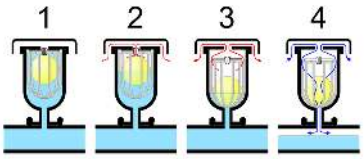


Figure **3.4.1.5**: Air Valve Image Source by Shigeru23 is licensed under CC BY-SA 3.0



Figure **3.4.1.6**: Elbow pipe fitting – Image by Cschirp is licensed under CC BY-SA 3.0



Figure **3.4.1.7**: Downtown Charlottesville Fire Hydrant by Ben Schumin is licensed under CC BY-SA 2.5

Water System Demands

As mentioned previously in this chapter, water demand is an important parameter, which is reviewed when planning and designing a water distribution system. Water demand includes a number of things including the demand of all customers within a distribution system (residential, commercial, industrial) and the demand to fight fires. It is important to identify not just the average demand of a distribution system, but also the maximum amount of water demanded on any given day and the peak demand during any given hour of the day. These three (3) demand factors are critical in the design of a distribution system and are defined below.

- Average Day Demand (ADD) – The average day demand is the total distribution system water use over one (1) year, which is then divided by 365 days. In the design of a new distribution system without any existing users, land use projections are commonly used to estimate the amount of water, which will be used by future users.
- Maximum Day Demand (MDD) – The maximum day demand is determined by looking at the entire demand over one (1) year and determining the day with the highest (maximum) usage over one twenty-four (24) hour period. Daily demands are typically calculated using production meters from supply facilities bringing water into a distribution system.

- Peak Hour Demand (PHD) – The peak hour demand is the highest water usage over a one (1) hour period. This demand number can be measured by production meters, but can also be estimated through calculations.

Fire Flow Demands

Residential, commercial, and industrial water demands are important for designing a distribution system. However, fire flows are a critical component, especially when sizing storage and pumping facilities. Fire flows are commonly the determining factor when sizing water systems in smaller communities serving a population of less than 50,000 people. Fire flows are determined through a variety of fire and building code criteria determined by the Insurance Services Office (ISO). Local fire departments and organizations are typically responsible for providing this information and guidance to water utilities. Among other criteria, the ISO identifies minimum pipe diameters for specific uses, as well as pressure and flow requirements. Most areas have a requirement that pressures do not drop below twenty (20) pounds per square inch (psi). The flow requirements will vary based on the type of use, such as schools, commercial buildings, and residential areas.

Network Analysis

Engineers use a variety of tools when planning and designing a water system to determine the size of facilities, which will dictate the pressure, and velocity of the water flowing through the pipes. The pressure within a distribution system is determined primarily by the elevation of the storage facilities within the system. Pressure is commonly measured in pounds per square inch (psi). One (1) pound per square inch equates to 2.31 feet of elevation, referred to as “head pressure”. Therefore, if a water storage tank sits one hundred (100) feet above a water service, the subsequent pressure would be 43.3 psi. Mathematically, this is accomplished by dividing 100 feet by 2.31 (see below).

- 100 Feet x 1 psi2.31 feet=43.3psi

This pressure is a theoretical pressure in a water distribution system. As the water moves through pipes and the various appurtenances throughout a distribution system, the pressure is reduced due to friction. The roughness of the interior of the pipe, the diameter of the pipe, the changes in direction of the piping, and valves, all have an effect on the velocity and pressure of the flow of water. A standard calculation used by engineers to determine this head loss due to friction is the Hazen-Williams equation. Another commonly used formula is the Darcy-Weisbach equation. These equations are beyond the scope of this text and beyond the necessary knowledge for distribution system operators to perform their jobs appropriately. Therefore, they are discussed in this chapter, but will not be used or explained beyond the general nature of their use by engineers. Since the Hazen-Williams equation is ideal for fluids such as water flowing at ordinary temperatures (40°to 75°F) it is the more commonly used formula. This equation is used to identify the smoothness (roughness) of the interior of a water main. The rougher the pipe interior, the more friction loss will be observed. This equation relates the flow of water in a pipe with the physical properties of the pipe and the pressure drop caused by friction. The resulting value is referred to as the C-Factor. The higher the C-Factor the smoother the pipe interior and the less head loss from friction. The lower the C-Factor, the rougher the pipe interior, which results in greater head loss from friction. The table below shows some typical pipe materials and corresponding C-Factors.

Material	Hazen-Williams C-Factor
Asbestos Cement	140
Cast-Iron 20 years old	89-100
Cast-Iron 40 years old	64-83
Steel	140-150
Ductile Iron (cement-lined)	120
Ductile Iron	140
PVC (C900/905)	150

Another tool engineers use to determine the various parameters of a water distribution system is a hydraulic water model. Water models can help determine expected flows and pressures throughout a distribution system network and can sometimes accurately

mirror what is occurring in the distribution system. While these models can be accurate in predicting pressures and flows, it is also helpful to calibrate these computer models with actual field data. Pressure recorders can be placed throughout a distribution system on things such as fire hydrants to measure and record the pressure in a distribution system over a period of time. Some pumping equipment can also be equipped with devices to measure the pressure on the suction and discharge side of a pump.

Pressure is an important parameter to measure and monitor within a distribution system. Some systems can have excessive water pressures or very low pressures. This presents a problem for utility operators and customers alike. If pressures are too low, customers may not be able to operate things like irrigation sprinkler systems. If pressures are too high, things may prematurely fail due to the excessive pressure. Under normal flow conditions, acceptable pressures are commonly within the range of forty (40) psi to one hundred fifty (150) psi. However, at times certain areas within a distribution system, pressures can exceed even these relatively high values or drop below acceptable levels. Therefore, understanding what the pressures are going to be will dictate what types of materials (especially pipes) are acceptable. Pipeline strength is commonly expressed in terms of tensile and flexural strength. In addition to the internal loads expressed on pipes, there are also external loads such as traffic driving over pipes buried below ground or the amount pipe can bend or flex.

- Tensile Strength – This is the measure of the resistance a pipe has to the longitudinal or lengthwise pull it has before it will fail. When the flow of water changes direction within a distribution system network, it can put these types of forces against the pipe. Therefore the material chosen can be critical.
- Flexural Strength – This characteristic is the ability of a pipe to bend or flex without breaking. If the trench bedding (dirt) is not flat or if the pipe being installed needs to bend slightly as the road meanders left or right, different pipe materials have different abilities to bend or flex.

If a pipe does not have the adequate strength, then the possibility of a water pipe (main) break can occur. If the earth shifts during an earthquake for example, a pipe may rupture in what is referred to as a shear break. If a buried pipe is unevenly supported, a beam break may occur. In addition, if the internal pressures exceed the acceptable operating pressure of a pipeline, it may also rupture. Therefore, understanding the pressures within a distribution system and the appropriate materials to use under different circumstances is an important aspect of planning and design.



Figure **3.4.1.8**: Pipe Rupture Image Source by Los Angeles Fire Department is licensed under CC BY-ND 2.0



Figure **3.4.1.9**: Image by Mike Alvord is licensed under CC BY 4.0

Mapping (Plans)

Once all the planning is finished and the design criteria is selected, engineers get to work on creating design drawings (or plans) for the construction crews to use during the installation (construction) phase. These “construction plans” and accompanying specifications are not only important for the crews to properly build and install the distribution system facilities, but they are also used in the budgeting (estimating) process. Once a set of plans is complete, contractors can provide bids or cost estimates. The estimates will include the cost for materials, labor, and equipment needed for construction.

There are various types of plans for a distribution system. These typically include piping plans, pump station plans, source of supply plans (i.e., groundwater wells), and storage facility plans (above ground storage tanks). Each set of plans will have the pertinent information for constructing and the material needed. For example, a set of pump station plans will have all the required mechanical and electrical equipment needed. These plans will detail the facility housing this equipment. The facility might be as simple as a chain-linked fence or as elaborate as a block walled building with a roof. Specifications will be detailed enough so the contractor performing the work will know what pumping equipment, valves, piping, motors, and any other items required to construct a full functioning pump station.

After facilities are constructed, plans are updated to reflect any changes that have occurred during the construction process. Even on the most thoroughly prepared design plans, things often change when they are actually constructed. Therefore, it is the responsibility of the construction contractor to make up the plans for the engineer to modify and update. These updated plans are referred to as as-built drawings. Once the as-built drawings have been prepared, they need to be provided to the distribution operators for future reference. These maps give the distribution operators information regarding all the existing facilities for locating and operating purposes. Each water utility will have its own standards and mapping styles, but typically, there are three (3) main types of maps. These are comprehensive, sectional, and valve and hydrant maps.

- Comprehensive Maps outline the entire distribution system. They are useful in understanding the various pressure zones, general locations of pipelines and larger facilities, and commonly outline the entire service area boundary of the utility.
- Sectional Maps provide a more detailed picture of the distribution system on a larger scale. While these maps are similar to comprehensive maps, they have more details. For example, sectional maps will show distances between water main pipes and other buried utilities such as sewer and storm drain pipes. These maps help distribution operators identify which side of the street pipelines are located and provide the size and material as well.
- Valve and Hydrant Maps show the precise location of distribution system valves and fire hydrants. This information is extremely important so distribution operators can quickly identify which valves need to be isolated (closed) when there is a water main break. These maps are commonly used by distribution operators for valve and hydrant maintenance activities. Many times the local fire department will request copies of these maps so they have a clearer understanding of fire hydrant locations.

The designing of a water distribution system is an important process in order for a water utility to be able to provide their customers with a reliable and high-quality supply of water. Multiple departments are typically involved as well as outside consultants in order to properly plan, design, and construct a distribution system, which complies with all the required laws and regulations and operates in an efficient and functional manner.

Sample Questions

1. Which of the following is the most desirable system configuration?
    1. Arterial loop
    2. Tree
    3. Grid
    4. Depends on the system
2. Dead-ends cause _____.
    1. Restricted flow
    2. Stagnant water
    3. Water outages during breaks
    4. All of the above
3. Blow offs should be installed _____.

1. At high points
2. Low points
3. Regular intervals
4. Only on large main lines

4. Air and vacuum valves should be installed _____.
    1. At high points
    2. Low points
    3. Regular intervals
    4. Only on large main lines
5. ISO stands for _____.
    1. Insurance Services Organization
    2. Insurance Services Office
    3. Insurance Standards Organization
    4. Insurance Standards Office

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3.4.2: Water Storage

Student Learning Outcomes

After reading this chapter, you should be able to:

- Explain the uses and requirements of water storage
- List the various types of water storage facilities
- List water storage facility equipment
- Describe the operations and maintenance of water storage facilities

Water storage is an important component of a distribution system. The main purpose is to provide sufficient amounts of water to average or equalize the daily demands on the system. Storage provides increased operating conveniences by providing sources of supply throughout the day and at night when utility employees are not typically at work. It levels out pumping requirements, can decrease power costs from pumping, provides a supply of water during power outages, fire storage, and other benefits. This chapter of the text will examine water storage systems, the various types of water storage, how water storage affects water quality, and a general overview of the operation and maintenance of water storage structures.

Why Water Storage Is Needed

Water demand is highest in the early more and evening hours of the day. In the morning, customers are showering, using toilets, and preparing meals, which require water. In addition, most irrigation systems are in use in the early morning hours before temperatures get too hot. In the evening hours, people are returning from work and school and water demand typically increases during these times. There is low use midday and during overnight hours. Without storage, the pumping capacity would be approximately two times the average requirement. Adequate storage allows for uniform pumping. Storage also allows minimal operator involvement during non-working hours. Without storage, workers would need to be available to operate the system if unexpected increases in demand occur. A utility would require various different size pumps to match changes in demand. Frequent on-off cycling of pumps causes increased wear on pumps and motors and higher costs for electricity.

Another benefit of water storage is the ability to store and supply water during emergencies and power outages. If a water utility solely relied on pumps to meet demands, anytime there is a power outage, water service would be interrupted. Having water stored in tanks allows for uninterrupted service during these times. Some distribution systems have long transmission water mains bringing the water supply into the community being served. Under these circumstances, any repairs made to these pipes requiring the water main to be isolated, would disrupt water supply to customers.

Fire fighting is another critical need of community water systems. Water utilities not only need to meet operational demands, they must also meet the demands to extinguish fires. Fire fighting may account for as much as fifty (50) percent of total storage. In addition, fire-fighting demands must be met during main line breaks, power outages, and maximum customer demands. Adequate pressure must also be maintained during fire flows.

Water Storage and Water Quality

Water storage can help with water quality and it can also contribute to water quality problems. As part of the Safe Drinking Water Act, a set of regulations called Surface Water Treatment Rule (SWTR), requires specific times that chlorine must be in contact with the water before the water reaches the first customer. Water storage tanks can provide detention time to allow the chlorine to remain in contact with the water long enough provide the required time. Water storage can also be an area where blending multiple sources of supply can take place. If an impaired source of supply is pumped into a storage tank, unimpaired sources can also be pumped into the tank providing adequate blending of the impaired source.

Water quality can also degrade in water storage tanks. While water storage tanks provide various benefits, storing too much water can lead to water quality degradation. Chlorine residuals can diminish and water can become stagnant if the water within storage tanks is not changed. Cycling tanks (allowing the level in a tank to rise and fall) can help avoid stagnation and water quality degradation.

What Type and Size of Storage Is Needed?

Water storage tanks come in various sizes and styles. Some of the factors to determine the type and capacity of storage in a distribution system depend on the size of the system, the topography of the distribution system, and how the distribution system is laid out (is the system spread out or concentrated in a small area). These and other criteria are used to design the water storage needs.

Several terms related to water storage should be understood.

- Average Day Demand (ADD)—This is the total demand for water during a period of time divided by the number of days in that time period. This is also called the average daily demand.
- Maximum Day Demand (MDD)—This is the highest total demand over a 24 hour period within a given year
- Peak Hour Demand (PHD)—This is the maximum demand over a one hour period within a given year
- Float on the System—This is a method of operating a storage facility. Daily flow into the system is approximately equal to the average day demand. When customer demands are low, the storage facility will be filling and when demands are high the storage facility will be emptying.

System hydraulics are directly related to the location of water storage facilities within a distribution system. If a water storage tank is located in close proximity to a pumping station, the head loss (pressure) to the farthest portion of the distribution system may be excessive through normal size piping. Additional transmission mains can help alleviate this type of pressure loss. If a storage tank is placed at the farthest end of a service area adequate pressure is typically received at the far ends and near the pumping stations. This type of set up avoids the need for increased main sizes. However, there must be enough capacity to the remote location to refill the tank during off-peak periods. In addition, if there is a great separation between the pumping facility and storage, lower pressures might occur in the middle of the distribution system. If possible, locating storage structures adjacent to the area with the lowest pressure is ideal. This typically provides enough available pressure to the entire service area and smaller diameter water mains can be used because flow from the tank is split into two directions.

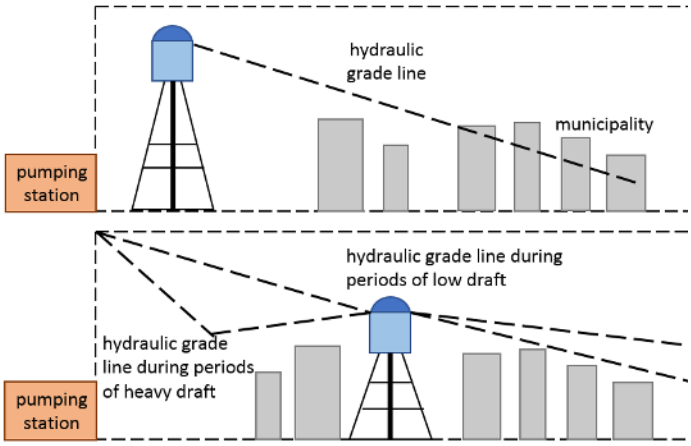


Figure 3.4.2.1: Images by COC OER is licensed under CC BY

For hydraulic purposes, it is more ideal to have multiple smaller tanks instead of one larger tank. This allows for more stabilized and equal pressures throughout the distribution system. Head losses also increase whenever pumping is required over long distances and during peak demand conditions. Locating storage tanks near the center of a distribution system allows pumping stations to operate at or near average day demand conditions most of the time.

Types of Water Storage Structures

There are various types of water storage facilities. They are made of different types of materials and are designed in different shapes to serve various needs. While there are various storage structures storing raw water and within a treatment plant, this section only discusses storage structures found in distribution systems. The following are some of the more common water storage facilities within a distribution system:

- Elevated Storage Tanks—In regions with relatively flat topography, elevated storage tanks are commonly used. They are above ground tanks supported by a steel or concrete tower or pedestal. Most are made of steel and designed to float on the system. If they are not constructed tall enough, they can overflow and provide inadequate pressures.



Figure **3.4.2.2**: Image by McGhiever is licensed under CC BY-SA 4.0

- Hydroneumatic Storage Tanks—These tanks are used in very small systems with in adequate pressure. They are kept partially full with compressed air to provide water in excess of the pump capacity when required. These types of systems will also provide water for a limited time if a pump fails.
- Standpipes—These tanks are constructed directly on the ground and have a height greater than the diameter. They are commonly used to equalize storage near a source of supply like a well field. They can also be used to provide additional fire protection.



Figure **3.4.2.3**: Image by Necraig is licensed under CC BY-SA 3.0

- Above Ground Storage Tanks—These are the most commonly used forms of storage tanks along the west coast of the United States. They can store large quantities of water and are located where the topography is such that they can be constructed on hillsides. The main downside is that they require a fairly large area of land.



Figure **3.4.2.4**: Image Source by the U.S. Air Force is in the public domain

Components of Elevated and Above Ground Storage Tanks

These tanks have very similar components. This section will review the major components and address any differences between the two styles of storage structures.

Inlet and Outlet Pipes

Elevated storage tanks generally have a common inlet and outlet pipe, while above ground storage tanks can have either common or separate inlet and outlet pipes. The purpose of these pipes is to bring water in and allow water to exit the tank. The purpose of having a separate inlet and outlet-piping configuration is to help water circulate inside the tank. The common pipe (called a riser) for an elevated storage tank typically runs up the middle of the support structure holding the tank. The inlet and outlet piping of an above-ground storage tank typically enters the tank along the bottom portion of the tank. In the separate inlet/outlet configuration, the location of the inlet and outlet connection is typically at opposite ends of the tank.

Overflow Pipe

Each type of tank is equipped with an overflow pipe. It is designed to allow water to exit the tank to the atmosphere in the event the water-level controls fail. They are commonly constructed to discharge into a catch basin and should never be directly connected to a sewer or storm drain. They should have a proper air gap separation from the area they are discharging into and should be screened or have a weighted flap to prevent animals from entering the pipe.

Drain Connection

All tanks need to be inspected periodically. While some inspections can occur with water in the tank, it is common to drain a tank for inspection, cleaning, and repairs. Water in a tank can be lowered by preventing pumps from turning on to fill the tank. However, they can only be lowered to a level the height of the outlet pipe and at no time should a tank be drained completely while in service. Once the water is brought down as far as in can while in service, a separate drain pipe can be opened to drain the rest of the water.

Monitoring Devices

Water storage tanks, just like other water distribution facilities are commonly equipped with monitoring devices. Details about these monitoring devices are covered in another chapter. However, the will also be discussed here briefly. One of the most important things to monitor on storage tanks is the water level. Therefore, most are equipped with either a physical site gauge mounted on the outside of the tank and/or level sensors which can transmit tank levels to remote locations. These devices are commonly furnished with high and low water level alarms.

Valves

In order to isolate a tank from the distribution system, a valve must be furnished along the inlet/outlet piping coming in to the tank. This valve can then be closed to take the tank out of service for maintenance and repairs. Sometimes a tank will be furnished with a valve referred to as an altitude valve. This valve is designed to close preventing the tank from overflowing.

Vents

Air ventilation is usually provided at the tops of tanks to allow air to escape as the tank is filling and air to enter and the level in the tank drops. These air vents must be large enough to prevent the tank from collapsing and they must be properly screened with a minimum mesh size of ¼”.

Access Hatches

Access inside a tank also needs to be provided. There are at least and sometimes multiple access hatches on the top of storage tanks. These allow works to enter the tank for inspection and maintenance. These hatches must be properly constructed with rims under the cover to prevent surface water runoff from getting into the tank. There are also manways at the bottom of the tank for access when a tank has been drained and taken out of service for maintenance and inspection.

Ladders

Access needs to be provided to the tops of tanks and inside tanks. Ladders usually provide this access. Some above ground water storage tanks use spiral staircases as opposed to ladders. Elevated storage tanks are usually equipped with three (3) different ladders. The first one runs up the leg of the tower from the ground to the balcony around the tank. The second ladder runs from the balcony to the top of the tank roof. The third ladder runs along the inside of the tank for inside access. Outside ladders should be installed six (6) to eight (8) feet off the ground or have a locked metal shield around the bottom to prevent unauthorized access.

Cathodic Protection

Interior tank walls are subject to corrosion, especially in the upper portions, which are not constantly submerged in water. Cathodic protection can reduce this interior corrosion in coated steel tanks. Cathodic protection reverse the flow of current that tends to dissolve iron from the tank surface causing rust and corrosion. Electrodes with a direct current (DC) are used and will corrode instead of the tank walls. In warm climates, the electrodes can be suspended from the tank roof. In cold climates, the electrodes must be submerged. The anodes can last up to ten (10) years, but should also be inspected annually.

Tank Coatings

Since steel can oxidize and deteriorate and since water is considered the “universal solvent”, it is important to properly coat the interior and exterior of tanks. Interior coatings must be able to withstand constant emersion in water, varying water temperatures, alternate wetting and drying periods, ice abrasion, high humidity, heat, chlorine, and mineral content in the water. Exterior coatings must endure similar conditions and maintain a good appearance. All interior coatings must be NSF approved.

Operation and Maintenance

The American Water Works Association recommends that all water storage structures be completely inspected every three (3) to five (5) years. Elevated and above ground storage tanks should be periodically drained, cleaned, inspected, repaired, and painted. The interior surfaces should be cleaned thoroughly with a high-pressure water jet or by sweeping and scrubbing. All dirt and debris should be removed from the tank and a complete or spot re-coating should also occur.

All tanks need to be disinfected before being placed in service. This includes new construction and tanks taken out of service for maintenance. There are three (3) basic methods for disinfecting storage tanks:

- The first method involves filling the entire tank with water and held at a disinfectant residual level of 10 mg/L. If the water is disinfected before entering the tank the detention time is six (6) hours and is the tank is filled and then disinfected, the detention time is twenty-four (24) hours.
- The second method involves spraying the interior walls with a disinfectant solution concentration of 200 mg/L
- The third method requires six (6) percent of the tank to be filled and disinfected to a residual of 50 mg/L. The tank is then completely filled and held for twenty-four (24) hours.

The tank must then be sampled and analyzed for total coliform bacteria. If the results come back positive, additional disinfection is required until two (2) consecutive samples are negative. New and recoated tanks must also be sampled and analyzed for volatile organic compounds.

Routine inspections should also be conducted at water storage tanks. The overflow piping, vents, hatches, ladders, and locks should be monitored frequently for damage and vandalism. Ladders should be in good condition and replaced if deemed unsafe. The roof and access points should also be checked for cracks and holes to prevent surface water leaking into the tank.

Sample Questions

1. An altitude valve is used to _____.

    1. Prevent storage tanks from filling too fast
    2. Prevent storage tanks from overflowing
    3. Separate the inlet and out let flows
    4. None of the above

2. Water storage reservoirs should be completely inspected?

1. Every year
2. Every other year
3. Every 3 to 5 years
4. Every 5 to 10 years

3. Without storage, pumping capacity would be approximately _____.

1. Twice the average requirement
2. Three times the average requirement
3. Less than the average requirement
4. None of the above

4. Fire demand may account for as much as _____.

1. 10% of storage
2. 25% of storage
3. 50% of storage
4. 100% of storage

5. It is recommended that storage tanks have _____.

1. Separate inlet and outlet piping
2. Common inlet and outlet piping
3. Outlets twice as large as inlet piping
4. There are no recommendations

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SECTION OVERVIEW

3.5: Sampling and Regulations

3.5.1: Microbiology Regulations

3.5.2: Regulations

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3.5.1: Microbiology Regulations

Learning Objectives

After reading this section, you should be able to:

- Explain the Total Coliform Rule
- Compare the Groundwater Treatment Rule and Surface Water Treatment Rule
- Describe the concern with Cryptosporidium

Total Coliform Rule

The **Total Coliform Rule** (TCR), a National Primary Drinking Water Regulation (NPDWR), was published in 1989 and became effective in 1990. The rule sets a health goal (Maximum Contaminant Level Goal (MCLG)) and legal limits (Maximum Contaminant Levels, MCLs)) for the presence of total coliforms in drinking water.

The Environmental Protection Agency (EPA) published the Revised Total Coliform Rule (RTCR) in the Federal Register (FR) in February 2013 (78 FR 10269) and minor corrections in February 2014 (79 FR 10665). The RTCR is the revision to the 1989 Total Coliform Rule (TCR) and is intended to improve public health protection. All public water systems (PWSs), except aircraft PWSs subject to the Aircraft Drinking Water Rule (ADWR) (40 CFR 141 Subpart X), must comply with the RTCR starting April 2016, or an earlier state effective date.

Total coliforms are a group of related bacteria that are, with few exceptions, not harmful to humans. This is very important to note. The EPA considers total coliforms a useful indicator of other pathogens for drinking water. Total coliforms are used to determine the adequacy of water treatment and the integrity of the distribution system.

Key provisions of the RTCR include:

1. Setting a maximum contaminant level goal (MCLG) and maximum contaminant level (MCL) for E. coli for protection against potential fecal contamination.
2. Setting a total coliform treatment technique (TT) requirement.
3. Requirements for monitoring total coliforms and E. coli according to a sample siting plan and schedule specific to the PWS.
4. Provisions allowing PWSs to transition to the RTCR using their existing Total Coliform Rule(TCR) monitoring frequency, including PWSs on reduced monitoring under the existing TCR.
5. Requirements for seasonal systems (such as, Non-Community Water Systems not operated on a year-round basis) to monitor and certify the completion of a state-approved start-up procedure.
6. Requirements for assessments and corrective action when monitoring results show that PWSs may be vulnerable to contamination.
7. Public notification (PN) requirements for violations.
8. Specific language for CWSs to include in their Consumer Confidence Reports (CCRs) when they must conduct an assessment or if they incur an E. coli MCL violation.

Revised Total Coliform Rule

Overview of the Rule

Revised Total Coliform Rule (RTCR) 78 FR 10269, February 2013, Vol. 78, No. 30

Purpose: Increase public health protection through the reduction of potential pathways of entry for fecal contamination into distribution systems.

General Description

The rule establishes a maximum contaminant level (MCL) for E. coli and uses E. coli and total coliforms to initiate a find and fix approach to address fecal contamination that could enter into the distribution system. It requires public water systems (PWSs) to perform assessments to identify sanitary defects and subsequently take action to correct them.

The Total Coliform Rule applies to all Public Water Systems.

Implementation of the Total Coliform Rule will result in:

1. A decrease in the pathways by which fecal contamination can enter the drinking water distribution system.
2. Reduction in fecal contamination should reduce the potential risk from all waterborne pathogens including bacteria, viruses, parasitic protozoa, and their associated illnesses.

Requirements:

1. Public Water Systems must develop a written sample siting plan that identifies the system's sample collection schedule and all sample sites, including sites for routine and repeat monitoring.
2. PWSs monitoring quarterly or annually must also identify additional routine monitoring sites in their sample siting plans.
3. Sample siting plans are subject to state review and revision.

Routine Sampling Requirements

1. Total coliform samples must be collected by Public Water Systems at sites which are representative of water quality throughout the distribution system according to a written sample siting plan subject to state review and revision.
2. For Public Water Systems collecting more than one sample per month, collect total coliform samples at regular intervals throughout the month, except that ground water systems serving 4,900 or fewer people may collect all required samples on a single day if the samples are taken from different sites.

Repeat Sampling Requirements

Within 24 hours of learning of a Total Coliform positive routine sample result, at least 3 repeat samples must be collected and analyzed for total coliform:

1. One repeat sample must be collected from the same tap as the original sample.
2. One repeat sample must be collected from within five service connections upstream.
3. One repeat sample must be collected from within five service connections downstream.
4. The PWS may propose alternative repeat monitoring locations that are expected to better represent pathways of contamination into the distribution system.

If one or more repeat sample is Total Coliform Positive:

1. The TC+ sample must be analyzed for the presence of E. coli.
2. If any repeat TC+ sample is also EC+, then the EC+ sample result must be reported to the state by the end of the day that the PWS is notified.
3. The PWS must collect another set of repeat samples, unless an assessment has been triggered and the PWS has notified the state.

Routine Sampling Requirements

1. Each total coliform-positive (TC+) routine sample must be tested for the presence of E. coli.
2. If any coliform-positive (TC+) sample is also E. coli-positive (EC+), then the EC+ sample result must be reported to the state by the end of the day that the PWS is notified.
3. If any routine sample is TC+, repeat samples are required.
4. Public Water Systems on quarterly or annual monitoring must take a minimum of three additional routine samples (known as additional routine monitoring) the month following a TC+ routine or repeat sample.
5. Reduced monitoring may be available for Public Water Systems using only ground water and serving 1,000 or fewer persons that meet certain additional Public Water System criteria.

Assessments and Corrective Action

The RTCR requires PWSs that have an indication of coliform contamination (e.g., as a result of TC+ samples, E. coli MCL violations, performance failure) to assess the problem and take corrective action. Two levels of assessments exist (i.e., Level 1 and Level 2) based on the severity or frequency of the problem.

Purpose of Level 1 and Level 2 Assessments

To find sanitary defects at the Public Water System including:

1. Sanitary defects that could provide a pathway of entry for microbial contamination
2. Sanitary defects that indicate failure (existing or potential) of protective barriers against microbial contamination.

Deadline for Completing Corrective Actions

When sanitary defects are identified during a Level 1 or Level 2 Assessment, they should be corrected as soon as possible to protect public health. The Public Water System must complete corrective actions by one of the following timeframes:

1. No later than the time the assessment form is submitted to the state, which must be within 30 days of triggering the assessment, or
2. Within state-approved timeframe which was proposed in the assessment form.

Level 1 Assessments

Conducting Level 1 Assessments

1. Performed by the PWS owner or operator each time a Level 1 Assessment is triggered.
2. Upon trigger of a Level 1 Assessment, the Level 1 Assessment form must be submitted within 30 days to the state.

Level 1 Assessment Triggers

Level 1 Assessment is triggered if any one of the following occurs:

1. A Public Water System collecting fewer than 40 samples per month has 2 or more TC+ routine/ repeat samples in the same month.
2. A PWS collecting at least 40 samples per month has greater than 5.0 percent of the routine/repeat samples in the same month that are TC+.
3. A PWS fails to take every required repeat sample after any single TC+ sample.

Level 2 Assessments

Conducting Level 2 Assessments

Performed by the state or state-approved entity each time a Level 2 Assessment is triggered.

1. The Public Water System is responsible for ensuring that the Level 2 Assessment is conducted regardless of the entity conducting the Level 2 Assessment.
2. (3)Upon trigger of a Level 2 Assessment, the Level 2 Assessment form must be submitted within 30 days to the state.

Level 2 Assessment Triggers

Level 2 Assessment is triggered if any one of the following occurs:

1. A Public Water System incurs an E. coli MCL violation.
2. A Public Water System has a second Level 1 Assessment within a rolling 12-month period.
3. A Public Water System on state-approved annual monitoring has a Level 1 Assessment trigger in 2 consecutive years.

Seasonal System Provisions

The Total Coliform Rule defines seasonal systems and specifies additional requirements for these types of PWSs:

1. A seasonal system is defined as a non-community water system that is not operated as a PWS on a year round basis and starts up and shuts down at the beginning and end of each operating season.

Start-up Procedures for Seasonal Systems

At the beginning of each operating period, before serving water to the public, seasonal water systems must:

1. Conduct state-approved start-up procedures.
2. Certify completion of state-approved start-up procedures.

3. An exemption from conducting state-approved start-up procedures may be available for seasonal systems that maintain pressure throughout the distribution system during non-operating periods.

Examples of state-approved start-up procedures, which need to be completed prior to serving water to the public, may include one or more of the following:

1. Disinfection.
2. Distribution system flushing.
3. Sampling for total coliform and E. coli.
4. Site visit by state.
5. Verification that any current or historical sanitary defects have been corrected.

Routine Monitoring for Seasonal Systems

1. The baseline monitoring frequency for seasonal systems is monthly.
2. A reduced monitoring frequency may be available for seasonal systems that use ground water only and serve fewer than 1,000 persons.

Other Provisions for the State Drinking Water Agency Special Monitoring Evaluation

The state must perform a special monitoring evaluation at all ground water systems serving 1,000 or fewer persons during each sanitary survey to review the status of the Public Water System and to determine whether the sample sites and monitoring schedule need to be modified.

Major Violations

E. coli MCL Violation

A Public Water System will receive an E. coli MCL violation when there is any combination of an E.coli positive sample result with a routine/repeat Total Coliform positive or E. coli positive sample result:

E. coli MCL Violation Occurs with the Following Sample Result Combination

Routine Repeat

EC+ TC+

EC+ Any missing sample

EC+ EC+

TC+ EC+

TC+ TC+ (but no E. coli analysis)

Treatment Technique Violation

A PWS will receive a Treatment Technique violation when any of the following occur:

1. Failure to conduct a Level 1 or Level 2 Assessment within 30 days of a trigger.
2. Failure to correct all sanitary defects from a Level 1 or Level 2 Assessment within 30 days of a trigger or in accordance with the state-approved timeframe.
3. Failure of a seasonal system to complete state-approved start-up procedures prior to serving water to the public.

Key Points for Public Water Systems to Remember

Find and correct sanitary defects as soon as you become aware of them. This can help reduce E. coli MCL violations, which trigger a Level 2 Assessment. This can help reduce TC+ sample results, which may trigger a Level 1 Assessment.

Make sure to collect all routine and repeat samples as required. Timely and correct monitoring can help reduce triggering a Level 1 or Level 2 Assessment because:

1. Failure to conduct repeat monitoring triggers a Level 1 Assessment.
2. A Level 1 Assessment triggered twice within a certain timeframe triggers a Level 2 Assessment.

Ground Water Treatment Rule

EPA issued the **Ground Water Rule (GWR)** to improve drinking water quality and provide protection from disease-causing microorganisms. Water systems that have groundwater sources may be susceptible to fecal contamination. In many cases, fecal contamination can contain disease-causing pathogens.

The purpose of the Ground Water Rule (GWR) is to reduce disease incidence associated with harmful microorganisms in drinking water.

The Ground Water Rule applies to public water systems that use ground water as a source of drinking water. The rule also applies to any system that delivers surface and ground water to consumers where the ground water is added to the distribution system without treatment. The Ground Water Rule was published in the Federal Register in November 2006.

Overview of the Rule

Ground Water Rule (GWR)

71 FR 65574, November 2006, Vol. 71, No. 216

Correction 71 FR 67427, November 2006, Vol. 71, No. 224

Purpose

The rule should reduce the risk of illness caused by microbial contamination in public ground water systems (GWSs).

General Description

The Groundwater Rule establishes a risk-targeted approach to identify groundwater systems susceptible to fecal contamination, and the rule requires corrective action to correct significant deficiencies and source water fecal contamination in all public groundwater systems.

Utilities Covered

The Ground Water Rule applies to all public water systems that use groundwater, including consecutive systems, except that it does not apply to public water systems that combine their groundwater with surface water or with groundwater under the direct influence of surface water prior to treatment.

Public Health Benefits

Targeted protection for over 70 million people served by groundwater sources that are not disinfected or receive less than 4-log treatment or reduction in 99.99% harmful microorganisms. Implementation created an avoidance of 42,000 viral illnesses and 1 related death annually.

Requirements for Drinking Water Systems

New groundwater sources must meet triggered source water monitoring requirements or conduct compliance monitoring. Groundwater systems must conduct triggered source water monitoring if the system does not provide at least 4-log virus inactivation, removal, or a state-approved combination of these technologies before or at the first customer and the system is notified that a sample collected for the Total Coliform Rule (TCR) is total coliform-positive.

Groundwater systems identified as a significant deficiency and systems that have had at least one of the five additional groundwater source samples that has tested positive for fecal contamination must comply with the treatment technique requirements.

Analytical Methods for Source Water Monitoring

Fecal Indicator Methodology Method

1. E. coli Colilert
2. Colisure
3. Membrane Filter Method with MI Agar
4. m-ColiBlue24 Test

5. E*Colite Test
6. EC-MUG
7. NA-MUG
8. 9223 B
9. 9223 B
10. EPA Method 1604
11. 9221 F
12. 9222 G
13. Enterococci Multiple-Tube Technique
14. Membrane Filter Technique
15. Enterolert
16. 9230 B
17. 9230 C
18. EPA Method 1600.
19. Coliphage Two-Step, Enrichment, Presence-Absence Procedure
20. Single Agar Layer Procedure
21. EPA Method 1601
22. EPA Method 1602

Major Provisions of Rule

1. Compliance Monitoring
2. Treatment
3. Technique
4. Compliance
5. Monitoring

In order not to be subject to triggered source water monitoring, a groundwater system can notify the state that it provides at least 4-log treatment of viruses using virus inactivation, removal, or a state-approved combination of 4-log virus inactivation and removal before or at the first customer. The groundwater system must then begin compliance monitoring designed to show the effectiveness of their treatment processes.

Groundwater systems that use chemical disinfection and serve more than 3,300 people must continuously monitor their disinfectant concentration. These systems must maintain the minimum disinfectant residual concentration determined by the state.

Groundwater systems that use chemical disinfection and serve 3,300 people or fewer must take daily grab samples or meet the continuous monitoring requirements described for public groundwater systems serving more than 3,300 people.

Groundwater systems using membrane filtration for 4-log treatment of viruses must monitor the membrane filtration process according to state-specified monitoring requirements.

Groundwater systems may use alternative treatment technologies (e.g., ultraviolet radiation [UV]) approved by the state. Groundwater systems must monitor the alternative treatment according to state specified monitoring requirements and must operate the alternative treatment according to compliance requirements established by the state.

Source Water Monitoring

Triggered Source Water Monitoring

Groundwater systems that do not conduct compliance monitoring and are notified of a total coliform-positive routine sample collected in compliance with the Total Coliform Rule (40 CFR 141.21) must conduct triggered source water monitoring.

Groundwater systems must collect at least one ground water source sample from each source in use at the time the total coliform-positive sample was collected. The triggered source water sample must be analyzed for the presence of a fecal indicator as specified in the rule.

If the triggered source water sample is fecal indicator-positive, the Groundwater system must either take corrective action, as directed by the state, or if corrective action is not required by the state and the sample is not invalided by the state, the Groundwater system must conduct additional source water sampling.

States may waive the triggered source water monitoring requirement if the state determines and documents, in writing, that the total coliform-positive routine sample is the result of a documented distribution system deficiency.

States may develop criteria for distribution system conditions that cause total coliform positive samples. A Groundwater system can document to the state that it met the state criteria within 30 days of the total coliform-positive sample and be exempt from collecting triggered source water sample(s).

States may invalidate a fecal indicator-positive groundwater source sample under specific conditions. If a fecal indicator-positive source sample is invalidated, the Groundwater system must collect another source water sample within 24 hours of being notified by the state of its invalidation decision.

Additional Source Water Sampling

If the state does not require corrective action in response to a fecal indicator-positive triggered source water sample, the Groundwater system must collect five additional source water samples (from the same source), using the same indicator as used in triggered source water monitoring, within 24 hours of being notified of the fecal indicator-positive sample.

Assessment Source Water Monitoring

States have the opportunity to target higher risk GWSs for additional testing. States independently can determine on a case by case basis whether monitoring is necessary and when corrective action needs to be taken.

Treatment Technique Requirements

Groundwater Systems with Significant Deficiencies or Source Water Fecal Contamination

Groundwater systems must take corrective action if a significant deficiency is identified, or if the initial source samples (if required by the state) or one of the five additional groundwater source samples tests positive for fecal contamination. The Groundwater systems must implement at least one of the following corrective actions:

1. Correct all significant deficiencies
2. Provide an alternate source of water
3. Eliminate the source of contamination
4. Provide treatment that reliably achieves at least 4-log treatment of viruses (using inactivation, removal, or a state-approved combination of 4-log virus inactivation and removal) before or at the first customer for the groundwater source.

New Sources

New Ground Water Sources

New sources which come online after November 2009 are required either to conduct triggered source water monitoring as required by the Groundwater Rule, or provide at least 4-log inactivation, removal, or a state-approved combination of these technologies and conduct compliance monitoring within 30 days of the source being put in service.

Sanitary Surveys

All Ground Water Systems

States are required to conduct sanitary surveys of all Groundwater systems in order to identify significant deficiencies, including deficiencies which may make a system susceptible to microbial contamination.

Following the initial sanitary survey, states must conduct sanitary surveys every 3 years for most Community Water Systems and every 5 years for Non-community Water Systems that provide at least 4-log treatment of viruses or have outstanding performance records, as determined by the state.

Existing Regulations for Microbial Pathogens in Drinking Water

1. The Surface Water Treatment Rule (SWTR) (54 FR 27486, June 1989) applies to all PWSs using surface water or ground water under the direct influence (GWUDI) of surface water as sources (Subpart H PWSs). It established MCLGs of zero for *Giardia lamblia*, viruses, and *Legionella*, and includes the following treatment technique requirements to reduce exposure to pathogenic microorganisms:
    1. Filtration, unless specific avoidance criteria are met
    2. Maintenance of a disinfectant residual in the distribution system
    3. Removal and/or inactivation of 3-log (99.9%) of *Giardia lamblia* and 4-log (99.99%) of viruses
    4. Maximum allowable turbidity in the combined filter effluent (CFE) of 5 nephelometric turbidity units
    5. (NTU) and 95th percentile CFE turbidity of 0.5 NTU or less for plants using conventional treatment or direct filtration
    6. Watershed protection and source water quality requirements for unfiltered PWSs
2. The Total Coliform Rule (TCR) (54 FR 27544, June 1989) applies to all PWSs. It established an MCLG of zero for total and fecal coliform bacteria and an MCL based on the percentage of positive samples collected. Coliforms are used as an indicator of fecal contamination and to determine the integrity of the water treatment process and distribution system. Under the Total Coliform Rule, no more than 5 percent of distribution system samples collected in any month may contain coliform bacteria (no more than 1 sample per month may be coliform positive in those PWSs that collect fewer than 40 samples per month). The number of samples to be collected in a month is based on the number of people served by the PWS.
3. Interim Enhanced Surface Water Treatment Rule (63 FR 69478, December 16, 1998) (USEPA 1998a) applies to PWSs serving at least 10,000 people and using surface water or GWUDI sources. Key provisions established by the interim rule include the following:
    1. An MCLG of zero for *Cryptosporidium*
    2. *Cryptosporidium* removal requirements of 2-log (99 percent) for PWSs that filter
    3. More stringent turbidity performance standards of 1.0 NTU as a maximum and 0.3 NTU or less at the 95th percentile monthly for treatment plants using conventional treatment or direct filtration
    4. Requirements for individual filter turbidity monitoring
    5. Disinfection benchmark provisions to assess the level of microbial protection that PWSs provide as they take steps to comply with new disinfection by-products standards
    6. Inclusion of Cryptosporidium in the definition of GWUDI and in the watershed control requirements for unfiltered PWSs
    7. Requirements for covers on new finished water storage facilities
    8. Sanitary surveys for all surface water systems regardless of size

The interim surface water treatment rule was developed in conjunction with the Stage 1 Disinfectants and Disinfection Byproducts Rule (Stage 1 DBPR) (63 FR 69389, December 1998), which reduced allowable levels of certain DBPs, including trihalomethanes, haloacetic acids, chlorite, and bromate.

4. Long Term 1 Enhanced Surface Water Treatment Rule (67 FR 1812, January 2002) builds on the microbial control provisions established by the interim rule for large PWSs through extending similar requirements to small PWSs. The long-term interim rule applies to PWSs that use surface water or GWUDI as sources and that serve fewer than 10,000 people. Like the interim rule, the long-term rule established the following:
    1. 2- log (99 percent) *Cryptosporidium* removal requirements by PWSs that filter
    2. Individual filter turbidity monitoring and more stringent combined filter effluent turbidity standards for conventional and direct filtration plants
    3. Disinfection profiling and benchmarking; inclusion of *Cryptosporidium* in the definition of GWUDI and in the watershed control requirements for unfiltered PWSs
    4. The requirement that new finished water storage facilities be covered.
5. Filter Backwash Recycle Rule (66 FR 31085, June 2001) requires PWSs to consider the potential risks associated with recycling contaminants removed during the filtration process. The provisions of the filter backwash rule apply to all PWSs that recycle, regardless of population served. In general, the provisions include the following:

1. PWSs must return certain recycle streams to a point in the treatment process that is prior to primary coagulant addition unless the State specifies an alternative location
2. Direct filtration PWSs recycling to the treatment process must provide detailed recycle treatment information to the State
3. Certain conventional PWSs that practice direct recycling must perform a one-month, one-time recycling self-assessment

Introduction to Cryptosporidium

Concern with Cryptosporidium in Drinking Water

EPA is promulgating the Long-Term Surface Water Treatment Rule to reduce the public health risk associated with *Cryptosporidium* in drinking water.

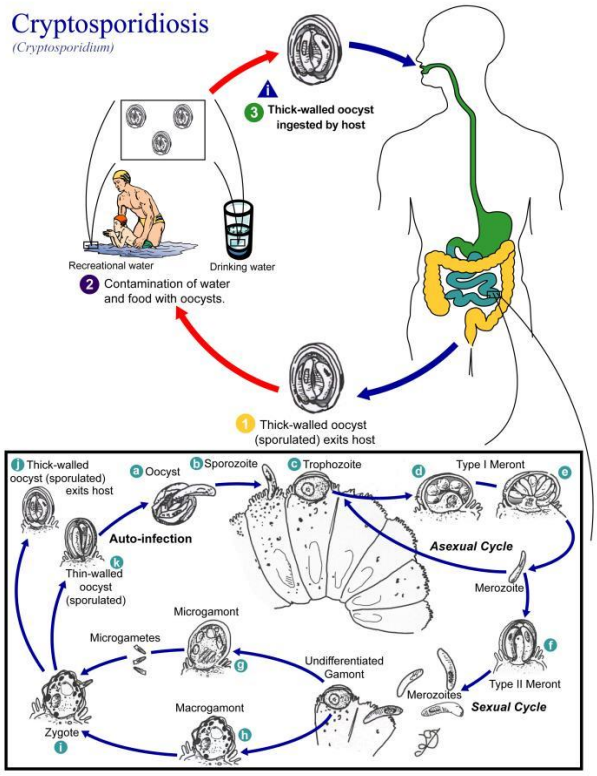


Figure 3.5.1.1: Cryptosporidiosis.

Cryptosporidium is a protozoan parasite that lives and reproduces entirely in one host. Ingestion of *Cryptosporidium* can cause cryptosporidiosis, a gastrointestinal (GI) illness. Cryptosporidium is excreted in feces. Transmission of cryptosporidiosis occurs through consumption of water or food contaminated with feces or by direct or indirect contact with infected persons or animals. In the environment, Cryptosporidium is present as a thick-walled oocyst containing four organisms (sporozoites).

The oocyst wall insulates the sporozoites from harsh environmental conditions. Oocysts are 4–5 microns in length and width. Upon a host's ingestion of oocysts, enzymes and chemicals produced by the host's digestive system cause the oocyst to excyst, or break open. The excysted sporozoites embed themselves in the surfaces of the epithelial cells of the lower small intestine. The organisms then begin absorbing nutrients from their host cells. When these organisms sexually reproduce, they produce thick and thin-walled oocysts. The host excretes the thick-walled oocysts in its feces. The thin-walled oocysts excyst within the host and contribute to further host infection.

The exact mechanism by which *Cryptosporidium* causes GI illness is not known. Factors may include damage to intestinal structure and cells, changes in the absorption/secretion processes of the intestine, toxins produced by *Cryptosporidium* or the host, and proteins that allow *Cryptosporidium* to adhere to host cell surfaces. Upon excretion, *Cryptosporidium* oocysts may survive for months in various environmental media, including soil, river water, seawater, and human and cattle feces at ambient temperatures. *Cryptosporidium* can also withstand temperatures as low as 20 °C for periods of a few hours, but they are susceptible to desiccation.

Cryptosporidium is a widespread contaminant in surface water used as drinking water supplies. *Cryptosporidium* contamination can come from animal agriculture, wastewater treatment plant discharges, slaughterhouses, birds, wild animals, and other sources of fecal matter. *Cryptosporidium parvum* (C. *parvum*) has been the primary species of concern to humans.

Cryptosporidium infection is characterized by mild to severe diarrhea, dehydration, stomach cramps, and/or a slight fever. Incubation is thought to range from 2 to 10 days. Symptoms typically last from several days to 2 weeks. In a small percentage of cases, the symptoms may persist for months or longer in healthy individuals. Symptoms may be more severe in immunocompromised persons. Such persons include those with AIDS, cancer patients undergoing chemotherapy, organ transplant recipients treated with drugs that suppress the immune system, and patients with autoimmune disorders.

Cryptosporidium oocysts are highly resistant to standard disinfectants like chlorine and chloramines. Consequently, control of *Cryptosporidium* in most treatment plants is dependent on physical removal processes. However, due to their size (4–5 microns), oocysts can sometimes pass through filters. Monitoring data on finished water show that *Cryptosporidium* is sometimes present in filtered, treated drinking water.

Certain alternative disinfectants can be more effective in treating for *Cryptosporidium*. Ozone and chlorine dioxide have been shown to inactivate *Cryptosporidium* at doses higher than those required to inactivate *Giardia*, which has typically been used to set disinfectant doses. Studies have also demonstrated a synergistic effect of treatment using ozone followed by chlorine or monochloramine. UV light has recently been shown to achieve high levels of *Cryptosporidium* inactivation at feasible doses. Other processes that can help reduce *Cryptosporidium* levels in finished water include watershed management programs, pretreatment processes like bank filtration, and additional clarification and filtration processes during water treatment. Further, optimizing treatment performance and achieving very low levels of turbidity in the finished water has been shown to improve *Cryptosporidium* removal in treatment plants.

Cryptosporidium has caused a number of waterborne disease outbreaks since 1984 when the first was reported in the United States. Data from the Centers for Disease Control and Prevention include ten outbreaks caused by *Cryptosporidium* in drinking water between 1984 and 2000, with approximately 421,000 cases of illness. The most serious outbreak occurred in 1993 in Milwaukee; an estimated 403,000 people became sick, and at least 50 *Cryptosporidium*-associated deaths occurred among the severely immunocompromised.

A PWS that begins using a new surface water source after the date the PWS is required to conduct source water monitoring under the Long-Term 2 Surface Water Treatment Rule must monitor the new source on a schedule approved by the State. This applies to new plants that begin operation and previously operating plants that bring a new source on-line after the required monitoring date for the PWS. The State may determine that monitoring should be conducted before a new plant or source is brought on-line or initiated within some time period afterward.

The new source monitoring must meet all long-term rule requirements. The PWS must also determine its treatment bin classification and comply with any additional *Cryptosporidium* treatment requirements based on the monitoring results on a schedule approved by the State.

Background and Analysis Monitoring requirements in the rule are designed to ascertain *Cryptosporidium* levels with suitable accuracy for making treatment bin classifications and in a time frame that does not delay the installation of *Cryptosporidium* treatment where needed. A mean *Cryptosporidium* concentration of 0.01 oocysts/L determines whether unfiltered PWSs are required to provide 2 or 3-log *Cryptosporidium* inactivation. No *E. coli* concentration was effective in determining whether PWSs were likely to fall above or below this level. Consequently, the rule requires all unfiltered PWSs to monitor for *Cryptosporidium*, unless they choose to provide 3-log *Cryptosporidium* inactivation.

Sampling location

The requirements in the rule for the source water sample collection location are designed to achieve two objectives:

1. Characterize the influent water to the treatment plant at the time each sample is collected.
2. Ensure that samples are not affected by treatment chemicals that could interfere with *Cryptosporidium* analysis.

The first objective is the basis for requiring PWSs that use multiple sources to analyze a blended source sample or calculate a weighted average of sources that reflects the influent at the time of sample collection. It is also the reason that PWSs are required to sample after certain pretreatment processes like bank filtration that do not involve chemical addition.

The second objective is why PWSs are generally required to sample upstream of chemical addition and prior to backwash addition (for PWSs that recycle filter backwash). However, EPA recognizes that in some situations, sampling prior to chemical addition will not be feasible and discontinuing chemical addition for a period of time prior to sampling will not be advisable. This situation could occur when a treatment chemical is added at an intake that is difficult to access. Further, some treatment chemicals may not interfere with *Cryptosporidium* analyses when present at very low levels. Consequently, the rule allows States to approve PWSs sampling after chemical addition when the State determines that collection prior to chemical treatment is not feasible, and the treatment chemical is not expected to interfere with the analysis of the sample. EPA believes that States should review source water monitoring locations for their PWSs.

Sampling Schedule

The requirement will help to ensure that monitoring determines the mean concentration of *Cryptosporidium* in the treatment plant influent. To achieve this objective, the timing of sample collection must not be adjusted in response to fluctuations in water quality, such as the avoidance of sampling when the influent water is expected to be of poor quality. EPA believes that the 5-day window for sample collection and associated allowances for sampling outside this window provide sufficient flexibility. If circumstances arise that prevent the PWS from sampling within the scheduled 5-day window, such as a weather event or plant emergency, the PWS must collect a sample as soon as feasible. In this case, feasibility includes the ability of the PWS to safely collect a sample and the availability of an approved laboratory to conduct the analysis within method specifications. In addition, the rule allows States to authorize a different date for collecting the delayed sample.

Failing to Monitor

For most monitoring and testing procedure violations under the Long-Term Rule 2, PWSs must provide a Tier 3 public notification, which is standard for this type of violation under an NPDWR. However, if a PWS fails to collect three or more *Cryptosporidium* samples, the violation is elevated to a Tier 2 special public notice. The reason for elevating the public notice at this point is the persistence of the violation and the difficulty the PWS will have in collecting the required number of samples for bin classification by the compliance date. The rule requires bin classification within six months following the end of the monitoring period specified for the PWS. This six-month period provides some opportunity for collecting and analyzing missed samples. The number of samples that can be made up in this period is limited, though, due to the need for samples to be evenly distributed throughout the year, as well as for PWSs and States to spend time during this period evaluating monitoring results to determine bin classification.

Failure by a PWS to collect the required number of *Cryptosporidium* samples for bin classification by the compliance date is a treatment technique violation with a required Tier 2 public notice. This violation reflects the inability of the PWS to determine and comply with its *Cryptosporidium* treatment requirements under the rule and provide the appropriate level of public health protection. The violation ends when the State determines that the PWS is carrying out a monitoring plan that will lead to bin classification.

A PWS that has already provided a Tier 2 public notice for missing three sampling dates and is successfully meeting a State-approved sampling schedule is not required to issue another public notice for missing the bin classification date. Alternatively, the PWS can choose to provide the highest level of *Cryptosporidium* treatment required under the rule, which is 5.5-log for filtered PWSs and 3-log for unfiltered PWSs.

Requirements for grandfathering previously collected monitoring data in the rule based on the principle that to be eligible for grandfathering, previously collected data must be equivalent in quality to data that will be collected under the rule.

The Stage 2 M–DBP Advisory Committee recommended that EPA accept previously collected *Cryptosporidium* data that are equivalent in sample number, frequency, and data quality (volume analyzed, percent recovery) to data that would be collected under the long-term rule to determine bin classification in lieu of further monitoring.

Ongoing watershed assessment treatment requirements under the rule are based on source water quality. Consequently, the rule requires watershed assessment and, a second round of monitoring following initial bin classification to determine if source water quality has changed to the degree that the treatment level should be modified. States are allowed to use programs other than the sanitary survey to assess changes in the watershed. The rule leverages the existing requirement for States to perform sanitary surveys on surface water PWSs. During the source water review in the sanitary survey, the rule requires States to determine if significant changes have occurred in the watershed that could lead to increased contamination by *Cryptosporidium*. The State can

also choose to make this determination through an equivalent review of the source water under a program other than the sanitary survey, such as a Source Water Protection Assessment. If the State determines that significant changes have occurred, the State may specify that the PWS conduct additional source water monitoring or treat the potential contamination. This approach allows the PWS and State to respond to a significant change in source water quality prior to initiating a second round of monitoring or any time thereafter.

Second Round of Monitoring

A more rigorous reassessment of the source water occurs through a second round of monitoring that begins six years after initial bin classification. If EPA does not develop and finalize modifications to the rule prior to the date when PWSs must begin the second round of monitoring, then this second round must conform to the same requirements that applied to the initial round of monitoring. PWSs may be classified in a different treatment bin, depending on the results of the second round of monitoring.

Process Summary

Source water monitoring to determine additional treatment requirements for *Cryptosporidium.*

1. Sampling parameters and frequency, sampling location, sampling schedule, monitoring plants that operate only part-year, failing to monitor, providing treatment instead of monitoring, grandfathering previously collected data, ongoing source water assessment, second round of monitoring, and new source monitoring.

The Rule requires filtered PWSs using surface water or GWUDI sources to provide greater levels of treatment if their source waters have higher concentrations of *Cryptosporidium*. Filtered PWSs are classified in one of four treatment bins based on results from the source water monitoring. PWSs classified in the lowest concentration bin are subject to no additional treatment requirements, while PWSs assigned to higher concentration bins must reduce *Cryptosporidium* levels. All PWSs must continue to comply with the requirements of the SWTR, IESWTR, and LT1ESWTR, as applicable. This section addresses procedures for classifying filtered PWSs in *Cryptosporidium* treatment bins and the treatment requirements associated with each bin. Microbial toolbox that PWSs must use to meet additional Cryptosporidium treatment requirements.

- Bin classification-after completing initial source water monitoring, filtered PWSs must calculate a *Cryptosporidium* bin concentration for each treatment plant where *Cryptosporidium* monitoring is required. This *Cryptosporidium* bin concentration is used to classify filtration plants in one of the four treatment bins.

In general, the *Cryptosporidium* bin concentration is calculated by averaging individual sample results from one or more years of monitoring. Specific procedures vary, however, depending on the frequency and duration of monitoring. These procedures are as follows:

1. For PWSs that collect a total of at least 24 but not more than 47 *Cryptosporidium* samples over two or more years, the *Cryptosporidium* bin concentration is equal to the highest arithmetic mean of all sample concentrations in any 12 consecutive months of *Cryptosporidium* monitoring.
2. For PWSs that collect a total of at least 48 samples, the *Cryptosporidium* bin concentration is equal to the arithmetic mean of all sample concentrations.
3. For PWSs that serve fewer than 10,000 people and monitor for *Cryptosporidium* for only one year (collect 24 samples in 12 months), the *Cryptosporidium* bin concentration is equal to the arithmetic mean of all sample concentrations.
4. For PWSs with plants that operate only part-year that monitor for less than 12 months per year, the *Cryptosporidium* bin concentration is equal to the highest arithmetic mean of all sample concentrations during any year of *Cryptosporidium* monitoring.

In data sets with variable sampling frequency, PWSs must first calculate an arithmetic mean for each month of sampling and then apply one of these four procedures using the monthly mean concentrations. PWSs may grandfather previously collected *Cryptosporidium* data where the sampling frequency varies (one year of monthly sampling and one year of twice-per- month sampling). Filtered PWSs serving fewer than 10,000 people are not required to monitor for *Cryptosporidium* if they demonstrate a mean E. *coli* concentration less than or equal to 10/ 100 mL for lake/reservoir sources or 50/ 100 mL for flowing stream sources or do not exceed an alternative State-approved indicator trigger. PWSs that meet this criterion are classified in Bin 1.

When determining the *Cryptosporidium* bin concentration, PWSs must calculate individual sample concentrations as the total number of oocysts counted, divided by the volume as saved. In samples where no oocysts are detected, the result is assigned a

value of zero for the purpose of calculating the bin concentration. Sample analysis results are not adjusted for analytical method recovery or the percent of *Cryptosporidium* oocysts that are infectious. PWSs must report their treatment bin classification to the State for approval following initial source water monitoring. The report must include a summary of the data and calculation procedure used to determine the bin concentration. PWSs must recalculate their bin classification after completing the second round of monitoring and report the results to the State for approval. If the State does not respond to a PWS regarding its bin classification after either report, the PWS must comply with the *Cryptosporidium* treatment requirements of the rule based on the reported bin classification.

- Bin treatment requirements. All filtered PWSs must comply with the treatment requirements based on their bin classification.

The total *Cryptosporidium* treatment required for plants in Bins 2, 3, and 4 is 4.0-log, 5.0-log, and 5.5-log, respectively. Conventional treatment (including softening), slow sand, and diatomaceous earth filtration plants in compliance with the IESWTR or LT1ESWTR, as applicable, receive a prescribed 3.0-log *Cryptosporidium* treatment credit toward these total bin treatment requirements. Accordingly, these plant types must provide 1.0 to 2.5-log of additional treatment when classified in Bins 2–4, respectively. Direct filtration plants in compliance with existing regulations receive a prescribed 2.5-log treatment credit and, consequently, must achieve 0.5-log greater treatment to comply with Bins 2–4.

For PWSs using alternative filtration technologies, such as membranes, bag filters, or cartridge filters, no prescribed treatment credit is available because the performance of these processes is specific to individual products. Consequently, when PWSs using these processes are classified in Bins 2–4, the State must determine additional treatment requirements based on the credit the State awards to a particular technology. The additional treatment requirements must ensure that plants classified in Bins 2–4 achieve total *Cryptosporidium* reductions of 4.0- to 5.5-log, respectively. PWSs can achieve additional *Cryptosporidium* treatment credit through implementing pretreatment processes like pre-sedimentation or bank filtration, by developing a watershed control program, and by applying additional treatment steps like ozone, chlorine dioxide, UV, and membranes. In addition, PWSs can receive a higher level of credit for existing treatment processes through achieving very low filter effluent turbidity or through a demonstration of performance.

A combination of options from the microbial toolbox can be used to gather additional credit. PWSs in Bin 2 can meet additional *Cryptosporidium* treatment requirements by using any option or combination of options from the microbial toolbox. For Bins 3 and 4, PWSs must achieve at least 1-log of the additional treatment requirement by using ozone, chlorine dioxide, UV, membranes, bag filtration, cartridge filtration, or bank filtration.

- The rule increases protection against *Cryptosporidium* and other pathogens in PWSs with the highest source water contamination levels. This targeted approach builds upon existing regulations under which all filtered PWSs must provide the same level of treatment regardless of source water quality. The rule is to ensure that PWSs with higher risk source waters achieve public health protection commensurate with PWSs with less contaminated sources.

The rule establishes risk-targeted *Cryptosporidium* treatment requirements and sets specific bin concentration ranges and treatment requirements that apply to filtered PWSs. The IESWTR established a *Cryptosporidium* MCLG of zero and requires large filtered PWSs to achieve 2-log *Cryptosporidium* removal. The LT1ESWTR extended this requirement to small PWSs. After these rules were promulgated, advances were made in analytical methods and treatment for Cryptosporidium, and EPA collected new information on *Cryptosporidium* occurrence and infectivity. Consequently, EPA assessed the implications of these developments for further controlling Cryptosporidium to approach the zero MCLG. The risk-targeted approach for filtered PWSs in the rule stems from four general findings based on new information on *Cryptosporidium*:

1. New data on *Cryptosporidium* infectivity suggest that the risk associated with a particular level of *Cryptosporidium* is most likely higher than EPA estimated at the time of earlier rules.
2. New data on *Cryptosporidium* occurrence indicate that levels are relatively low in most water sources, but a subset of sources has substantially higher concentrations.
3. The finding that UV light can readily inactivate *Cryptosporidium*, as well as other technology developments, makes achieving high levels of treatment for *Cryptosporidium* feasible for PWSs of all sizes.
4. EPA Methods 1622 and 1623 are capable of assessing annual mean levels of *Cryptosporidium* in drinking water sources.

These findings led EPA to conclude that most filtered PWSs currently provide sufficient treatment for *Cryptosporidium*, but additional treatment is needed in those PWSs with the highest source water Cryptosporidium levels to protect public health.

Further, PWSs can characterize *Cryptosporidium* levels in their source waters with available analytical methods and can provide higher levels of treatment with available technologies. Consequently, risk-targeted treatment requirements for *Cryptosporidium* based on source water contamination levels are appropriate and feasible to implement.

Basis for bin concentration ranges and treatment requirements. To establish the risk-targeted treatment requirements in today's rule, EPA had to determine the degree of treatment that should be required for different source water *Cryptosporidium* levels to protect public health. This determination involved addressing several questions:

1. What is the risk associated with *Cryptosporidium* in a drinking water source?
2. How much *Cryptosporidium* removal do filtration plants achieve?
3. What is the appropriate statistical measure for classifying PWSs into treatment bins?
4. What degree of additional treatment is needed for higher source water *Cryptosporidium* levels?
5. How should PWSs calculate their treatment bin classification?

The risk of infection from *Cryptosporidium* in drinking water is a function of exposure (the dose of oocysts ingested) and infectivity (likelihood of infection as a function of ingested dose). Primary (direct) exposure to *Cryptosporidium* depends on the concentration of oocysts in the source water, the fraction removed by the treatment plant, and the volume of water consumed (secondary exposure occurs through interactions with infected individuals). Thus, the daily risk of infection (DR) is as follows:

DR = (oocysts/L in source water) × (fraction remaining after treatment) × (liters consumed per day) × (likelihood of infection per oocyst dose). Assuming 350 days of consumption per year for people served by community water systems (CWSs), the annual risk (AR) of infection is as follows: AR = 1 ¥ (1 ¥ DR)350.

EPA has estimated the mean likelihood of infection from ingesting one *Cryptosporidium* oocyst to range from 4 to 16 percent. Median individual daily water consumption is estimated as 1.07 L/day.

Key Terms

- ***Cryptosporidium*** - a protozoan parasite that lives and reproduces entirely in one host; ingestion of *Cryptosporidium* can cause cryptosporidiosis, a gastrointestinal (GI) illness; cryptosporidium is excreted in feces.
- **Ground Water Rule (GWR)** – the purpose is to improve drinking water quality and provide protection from disease-causing microorganisms; water systems that have groundwater sources may be susceptible to fecal contamination; applies to public water systems that use ground water as a source of drinking water
- **Surface Water Treatment Rules (SWTRs)** – the purpose is to reduce illnesses caused by pathogens in drinking water, including *Legionella*, *Giardia lamblia*, and *Cryptosporidium*; the SWTRs requires water systems to filter and disinfect surface water sources.
- **Total Coliform Rule** (TCR) - a National Primary Drinking Water Regulation (NPDWR), published in 1989 and became effective in 1990; sets a health goal (Maximum Contaminant Level Goal (MCLG)) and legal limits (Maximum Contaminant Levels, MCLs)) for the presence of total coliforms in drinking water

Review Questions

1. **What are the primary components of the Total Coliform Rule?**

2. **What is the basis of the Total Coliform Rule?**

3. **What is the primary requirement in the Groundwater Rule?**

4. **List four EAP approved laboratory methods for testing for coliforms.**

5. **What are the major provisions of the Long-Term Surface Water Treatment Rule?**

Chapter Quiz

1. Total coliforms are used as a(n) _____ of the possible presence of pathogens in drinking water. Total coliforms are used to determine the adequacy of water treatment and the integrity of the distribution system.
    1. indicator
    2. model
    3. log removal
    4. alternative
2. The Revised Total Coliform Rule establishes _____for E. coli and uses E. coli and total coliforms to initiate a find and fix approach to address fecal contamination that could enter into the distribution system.
    1. a log removal
    2. a maximum contaminant level (MCL)
    3. a secondary maximum contaminant level (SMCL)
    4. a model
3. Within 24 hours of learning of a Total Coliform positive routine sample result, at least ____ repeat samples must be collected and analyzed for total coliform.
    1. 1
    2. 2
    3. 3
    4. 4
4. States are required to conduct _____ of all groundwater systems in order to identify significant deficiencies, including deficiencies which may make a system susceptible to microbial contamination.
    1. hydrologic studies
    2. microbial examinations
    3. a sanitary survey
    4. laboratory studies
5. The Surface Water Treatment Rule requires water systems to _____ surface water sources.
    1. filter and disinfect
    2. conserve
    3. aerate
    4. disinfect
6. In order not to be subject to triggered source water monitoring under the Groundwater Rule, a groundwater system can notify the state that it provides at least _____ treatment of viruses using virus inactivation, or removal, before or at the first customer.
    1. 2-log
    2. 3-log
    3. 4-log
    4. 6-log
7. The Long-Term Surface Water Rule establishes risk-targeted treatment technique requirements to control _____ in PWSs using surface water or groundwater under the influence of surface water.
    1. *E.coli*
    2. *Giardiasis lambdia*
    3. *Cryptosporidium*
    4. Coliforms

8. What is the maximum allowable turbidity in the combined filter effluent?
    1. 0.5 NTU
    2. 1.0 NTU
    3. 3.0 NTU
    4. 5.0 NTU
9. EPA promulgated the Long-Term Surface Water Treatment Rule to reduce the public health risk associated with _____ in drinking water.
    1. *Giardiasis lambdia*
    2. *Cryptosporidium*
    3. Coliforms
    4. *E. coli*
10. _____ is a protozoan parasite that lives and reproduces entirely in one host,
    1. *E. coli*
    2. Coliforms
    3. *Cryptosporidium*
    4. Fecal streptococcus

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3.5.2: Regulations

Student Learning Outcomes

After reading this chapter, you should be able to:

- Differentiate between the primary sources of drinking water contamination
- Evaluate the water quality sampling requirements within a distribution system
- Summarize the main federal and state water quality regulatory citations
- Explain the role the American Waterworks association plays in terms of water quality standards

Is My Water Safe to Drink?

One of the biggest questions and concerns people have is whether or not their tap water is safe to drink. However, sometimes there is confusion between the taste, odor, and appearance of the water and the actual "safety" of the water. Many times these two things are not one and the same. Tap water can be discolored, smell strange, and have an odd taste, but from a health and safety standpoint, the water might be perfectly fine. Explaining this to a customer can be a very challenging task. Conversely, a glass of water might be crystal clear and have no apparent taste or odor and could be potentially unsafe (non-potable) for human consumption.

So, how does a water quality professional handle variability in the quality of drinking water? There are several things (tools in a toolbox) water treatment and distribution operators use to make sure the water they are providing to millions of people is safe and to a certain extent "pleasant" to drink. The word pleasant is placed in quotes because things like taste, odor, and color can be very subjective characteristics in terms of drinking water quality.

The tools water utility professionals use can be explained in four main categories; regulations, treatment, testing, and maintenance. Each one of these will be explained throughout this chapter, but below is a concise explanation of each one.

- Regulations – Drinking water quality regulations might be the number one component to ensure a safe drinking water supply is being provided to water utility customers. The United States Environmental Protection Agency (USEPA) is tasked with providing minimum drinking water standards for water utilities throughout the United States to adhere to. These drinking water regulations are found in the Safe Drinking Water Act (SDWA). Among other things, the SDWA sets minimum levels for a variety of contaminants in drinking water.
  - USEPA Safe Drinking Water Act
  - California Safe Drinking Water Act
- Treatment – Within the SDWA, there are rules and regulations regarding the treatment requirements at drinking water treatment plants. Along with the minimum contaminant levels, there are various treatment technologies for drinking water treatment plants.
- Testing – The SDWA also spells out testing requirements for water utilities at treatment plants, at the various sources of supply, and within distribution systems. Additional sampling is also common for a variety of other reasons not spelled out in the regulations. Collecting and analyzing water quality samples is not only a regulatory requirement, it is used by treatment and distribution operators for monitoring and predicting water quality.
- Maintenance – Maintenance (especially within distribution systems) goes a long way with improving and maintaining good water quality. Some of the more common distribution maintenance tasks associated with improving and maintaining good water quality are flushing of water mains and cycling the level of water in storage tanks.

Providing and maintaining a safe supply of drinking water to customers is a primary responsibility of all water utilities. This is achieved through the items discussed above as well as a collaborative and coordinated effort between water utility staff, regulators, and the public receiving this vital resource.

In addition to the regulatory requirements, the American Water Association (AWWA) provides a variety of standards and guidance to water utilities. AWWA is an international, nonprofit, scientific, and educational organization. It was established in 1881 and is the largest Association of water supply professionals in the world. The recent State Water Resources Control Board Division of

Drinking Water's (DDW) waterworks standards were revised in 2008 and most were based on AWWA recommendations and standards.

Sources of Contamination

There are a number of naturally occurring and manmade contaminants, which can be found in water supplies. These contaminants can be broken down into four (4) main categories; physical, biological, chemical, and radiological. Because the sources of drinking water supply vary from region to region, the contaminants present in one part of the world are not necessarily found in other parts of the world. For example, a constituent, such as fluoride, is temperature-dependent and therefore is not typically found in groundwater supplies in cooler regions but may be found in warmer climate regions.

Physical Contamination

Most physical contaminants do not pose a direct health effect. They primarily impact the appearance of drinking water. Physical contamination is more commonly found in surface water supplies and often results from soil erosion. Sediments and organic material can wash off surrounding hillsides along lakes, rivers, and streams. These contaminants mostly affect the aesthetic quality of drinking water, such as taste, odor, and color. However, these types of contaminants can also impede the drinking water treatment process and can act as a barrier, protecting biological contaminants.

Biological Contamination

One of the most common contaminants water utilities collect samples and analyze are part of the biological class of contaminants. While only a few bacteriological organisms are pathogenic, this entire class of organisms can wreak havoc on a water system. From a public health standpoint, we are mainly concerned with the bacteriological and viral disease-causing (pathogenic) organisms. Since it can be difficult and costly to try and analyze all the different strands of viruses and bacterial organisms, which might find their way into a water system, an "indicator" organism is preferred. In drinking water supplies and systems, the indicator of choice is the total coliform group.

Pathogenic organisms include those derived from fecal contamination and viruses, which typically use bacteria as a host for replication. These disease-causing organisms that can be found in drinking water include, but are not limited to *Escherichia coli (E. coli*) and various strains of *Vibrio* and *Enterococcus*, various enteroviruses, and parasites such as *Cryptosporidium* and *Giardia*. Most of these organisms find their way into a drinking water system through some type of contamination with fecal matter. Perhaps an animal feed lot is upstream from a water supply or an underground sewer collection system is leaking next to a drinking water underground well. Therefore, the main source for these contaminants is human or animal feces.

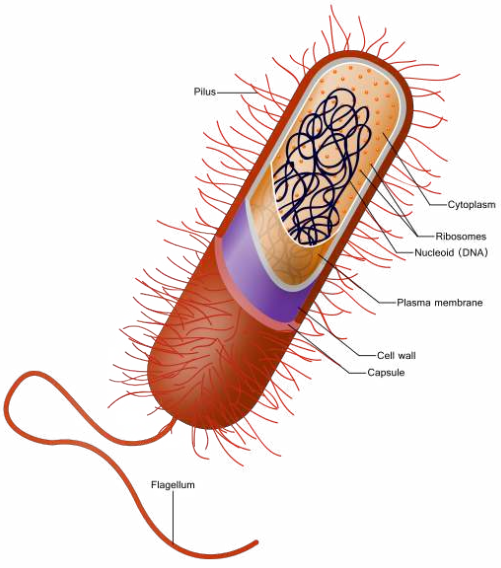


Figure **3.5.2.1**: Contamination Image Source by Ali Zifan is licensed under CC BY-SA 3.0

All of these potential contaminants are routinely monitored through a regulation called the Total Coliform Rule (TCR). In 2013 and 2014, revisions to the 1989 TCR were implemented in order to improve public health. The TCR is now referred to as the Revised Total Coliform Rule (RTCR). Total coliforms are a group of related bacteria, which are (with few exceptions) not harmful to humans. Therefore, the USEPA has identified this group of organisms to represent an indicator for a variety of bacteria, viruses, and parasites which are known pathogens and can cause health problems in humans if they are ingested.

Revised Total Coliform Rule

The USEPA published the Revised Total Coliform Rule (RTCR) in the Federal Register on February 13, 2013 (78 FR 10269) and minor corrections on February 26, 2014 (79 FR 10665). Promulgation of the RTCR began on April 1, 2016.

Most of the major provisions of the TCR stay in place and include:

- Collecting total coliform (TC) samples at representative locations throughout the distribution system.
- Samples must be collected at regular intervals.
- Numbers of samples collected are based on the size of the population the water utility serves.
- Repeat sampling is required for positive results, which include analysis of *E. coli*.

Details of the TCR can be found in the USEPA's Total Coliform Rule: A Quick Reference Guide.

The main changes to the RTCR include the following:

- Setting a maximum contaminant level goal (MCLG) and maximum contaminant level (MCL) for *E. coli*.
- Setting a TC treatment technique (TT).
- Requirements for assessments and corrective actions.
- Specific language in the annual Consumer Confidence Reports (CCR) for violations.

Details of the RTCR can be found in the USEPA's Revised Total Coliform Rule: A Quick Reference Guide.

There are a number of different provisions within each rule and depending on the size of the utility, there are different requirements. In general, every TC positive sample must be followed up with analysis of *E. coli* and repeat samples are also required. At least three (3) repeat samples are required for every TC positive sample. The repeat samples must be collected within 24 hours of learning about the positive TC result. The repeat samples must be collected from the same sample location and within five (5) service connections upstream and downstream of the original sample location. There are additional requirements, but more detail is beyond the scope of this text.

Chemical Contamination

There are many different chemicals used in the world for a variety of different things. For example, arsenic is used to preserve wood and prevent rotting and chromium is used in chrome plating processes. While chemicals are commonly used in various manmade processes, they are also found naturally occurring in the environment. Regardless of the source of contamination (naturally occurring or manmade), if they pose a threat to public health they also need to be regulated if they are found in drinking water supplies. Within this group of contaminants, there are two main categories; inorganic and organic. The main difference between these two categories is the absence of carbon with inorganic chemicals and the presence of carbon with organic chemicals. Below is a short list of common contaminants found in drinking water supplies within both categories.

- Common Inorganic Chemicals – While most of these inorganic chemicals can be found naturally occurring in water supplies, with the exception of arsenic, most are the result of contamination from human activities.
  - Arsenic (As) – As previously mentioned, one of the main uses of arsenic is preserving wood. Arsenic is also commonly found naturally in groundwater supplies, especially in the southwest.
  - Nitrate (NO3) – While nitrate can be found naturally occurring, these levels are relatively harmless. The primary sources of nitrate in drinking water are from fertilizers and contamination from sewage.
  - Chromium (Cr) – Chromium is used in plating processes and can also be found naturally in the environment. One of the unique things about chromium is it is found in two common oxidative states, Cr III and Cr VI.
  - Lead – Lead is most commonly found in plumbing systems, although the allowable levels are being reduced because of the significant health effects. The main reason lead was used in plumbing supplies is because of its malleability.
  - Copper – Copper is also most commonly found in plumbing supplies

- Common Organic Chemicals – The organic chemicals found in drinking water supplies are referred to as volatile organic compounds (VOCs) and synthetic organic compounds (SOCs). While they can be found naturally occurring, the majority of the VOCs and SOCs found in drinking water supplies are from manmade chemicals.
  - Trichloroethylene (TCE) – TCE is a common solvent used as a degreaser
  - Tetrachloroethylene (PCE) – PCE is a common solvent used in dry cleaning
  - Methyl tertiary-butyl ether (MTBE) – A gasoline additive to help improve air quality

Drinking Water Standards

In order to make sure contaminants are limited or kept at levels below those which would pose health effects to consumers, there are a number of regulatory standards in the SDWA. In addition to the federal SDWA, some states have their own set of standards water utilities must adhere to. In California under Title of the California Code of Regulations, there is the California Safe Drinking Water Act (CSDWA). The difference between federal and state drinking water regulations is the ability of state regulations to be more stringent than federal regulations. This means that the CSDWA can have regulatory levels for contaminants set at a lower level than the federal SDWA. They cannot be set higher. Within the SDWA, contaminants are separated into two main categories, primary drinking water standards and secondary drinking water standards. Primary standards are for those chemicals which pose a public health threat. Secondary standards are for contaminants, which have aesthetic effects on the water supply.

The USEPA goes through an extensive process in order to determine if a contaminant needs to be regulated under the SDWA. There are three (3) main criteria the USEPA considers in order to make a regulatory determination. They determine whether or not the contaminant meets the following criteria:

- The contaminant may have an adverse effect on the health of persons
- The contaminant is known to occur or there is a substantial likelihood the contaminant will occur in public water systems with a frequency and at levels of public health concern
- In the sole judgment of the Administrator, regulation of the contaminant presents a meaningful opportunity for health risk reductions for persons served by public water systems

Once the USEPA identifies whether or not a contaminant needs to be regulated, further evaluation is required to determine the technical and economical feasibility of regulating the contaminant. During this process, a non-enforceable level is usually established. This non-enforceable level is referred to as a Maximum Contaminant Level Goal (MCLG). MCLGs are set at levels which no known or anticipated adverse health effect would occur. The next step is to develop an enforceable standard referred to as a Maximum Contaminant Level (MCL). MCLs are set as close to the MCLG as is feasible. The SDWA defines “feasible” as the level that may be achieved with the use of the best available technology or treatment techniques the USEPA finds available (under field conditions and not solely under laboratory conditions), taking cost into consideration. The USEPA can establish a regulatory treatment technique when there is no reliable method that is economically and technically feasible to measure a contaminant.

In addition to MCLs and MCLGs, there are other acronyms related to drinking water quality regulations. These include the following:

- PHG – Public Health Goals are similar to MCLGs. They are California non-enforceable standards where an MCL does not exist.
- AL – Action Levels are set for certain contaminants where an MCL does not exist and some type of response (action) is required by the water utility if an AL is exceeded
- DLR – Laboratories are tasked with analyzing contaminants. As laboratory techniques improve, these levels become smaller (lower) over time. The Detection Limit for Reporting is set at a level laboratories can accurately reproduce with the current method of analysis.

The level of a contaminant is expressed using a ratio of units. The most common units used to express levels of contaminants are the following:

- Milligram per liter (mg/L)
- Microgram per liter (ug/L)
- Nanogram per liter (ng/L)

The above examples express the weight of the contaminant in a liter of water. Therefore, a level of 10 mg/L means that for every liter of water there are 10 mg of a substance. Sometimes, alternative units of measure are used. These alternatives are the following:

- Parts per million (ppm) = mg/L
- Parts per billion (ppb) = ug/L
- Parts per trillion (ppt) = ng/L

These units mean for every part of a contaminant there are a million, billion, or trillion parts of water. For example, a level of 10 ppm (same as 10 mg/L) means that for every million parts of water, there are 10 parts of the substance.

While it is not required for water distribution operators to memorize drinking water quality standards (MCLs), it is important for them and especially the water quality professionals to have a general understanding of the main contaminants within their water supply. In addition, it is important for water quality professionals such as water quality technicians, specialists, supervisors, and managers to understand the health effects associated with common contaminants. Some of the more commonly found primary contaminants in drinking include the following:

Nitrate

Nitrate – MCL = 45 mg/L as NO3 or 10 mg/L as N – The reason there are two MCLs for nitrate is because the value can be expressed as actual amount of nitrate (NO3) or expressed as the total amount of nitrogen (N).



Figure **3.5.2.2**: Nitrogren Image Source by OpenStax is licensed under CC BY 4.0 (image modified by COC OER)

- Source – The primary source of nitrate in drinking water is from fertilizers. This is especially present in areas where there is or was agriculture present. Nitrate can also occur as a result of contamination from animal or human sewage waste.
- Health Effects – The primary health effect associated with elevated levels of nitrate in drinking water is something referred to as “blue baby syndrome”. The medical diagnosis is methemoglobinemia. It is a condition, which effects the body’s ability to release oxygen to tissues. Infants six (6) months old and younger are particularly susceptible.

Arsenic

Arsenic – MCL = 10 ug/L

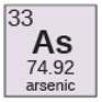


Figure **3.5.2.3**: Arsenic Image Source by OpenStax is licensed under CC BY 4.0 (image modified by COC OER)

- Source – Arsenic is found naturally in certain geologic formations and is also used in some industries. One common use is a preservative for wood products.
- Health Effects – Studies have linked long-term exposure to arsenic in drinking water to cancer of the bladder, lungs, skin, kidney, nasal passages, liver, and prostate. Non-cancer effects of ingesting arsenic include cardiovascular, pulmonary, immunological, neurological, and endocrine effects.

Radiological Compounds

There are several types of radiological compounds found in drinking water supplies and include; uranium, strontium, total alpha, and total beta.

- Source – The primary source of radiological compounds in drinking water is naturally occurring geologic formations. Accidental or intentional releases from human activities is a rare occurrence.
- Health Effects – Elevated levels of radiological compounds in drinking water can increase the risk of kidney damage.

Lead and Copper

Lead and Copper – AL = 15 ug/L for Lead (Pb) and 1,300 ug/L for Copper (Cu) – Lead and copper contamination does not typically occur in the source water or even in the distribution system of drinking water systems. The primary source of lead and

copper contamination occurs in internal plumbing systems. Lead and copper are commonly used in the manufacturing of plumbing supplies and can leach out into drinking water. Therefore in 1991, the Lead and Copper Rule (LCR) was passed. The LCR requires water utilities to collect samples for lead and copper within customer homes. While lead and copper is not as common within distribution systems, it is an issue in older communities where lead service laterals and other materials were commonly used. The most recent discovery of lead contamination within a distribution system was in 2014 in Flint, Michigan. As a result, the LCR is going through a number of different revisions.

- Health Effects – The primary effects of copper in drinking water are related to gastrointestinal issues. However, the effects of lead in drinking water are far worse and include damage to the brain, red blood cells, and kidney.

As previously mentioned, secondary drinking water contaminants are not health related. The problems associated with secondary contaminants can be grouped into three categories:

- Aesthetic effects – undesirable tastes or odors
- Cosmetics effects – effects which do not damage the body but are still undesirable
- Technical effects – damage to water equipment or reduced effectiveness of treatment for other contaminants

The periodic table lists the various chemical substances that can be found in water supplies. Below is an image of the periodic table with many of the ions mentioned below circled for reference.

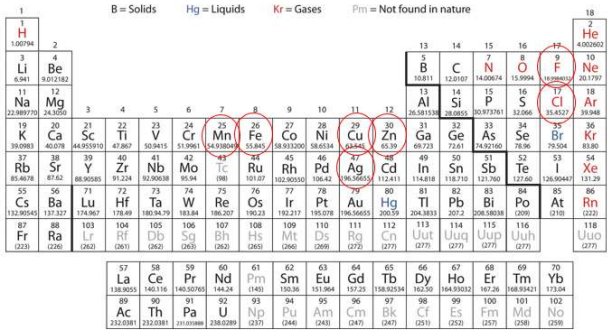


Figure **3.5.2.4**: Periodic Table Image Source by Saylor Academy is licensed under CC BY-NC-SA 3.0 (image modified by COC OER)

Contaminants related to color, odor and taste (aesthetic) include, Chloride (Cl), Copper (Cu), Foaming Agents, Iron (Fe), pH, Sulfate (SO4), Manganese (Mn), Total Dissolved Solids (TDS), and Zinc (Zn).

Contaminants related to cosmetic effects include, Silver (Ag) and Fluoride (F).

Contaminants related to technical effects include, Chloride, Copper, Corrosivity, Iron, Manganese, pH, and Total Dissolved Solids.

Some of the chemical contaminants listed above are compounds or in the case of TDS, are a combination of ions. Sulfate for example is a sulfur ion combined with four (4) oxygen atoms. TDS represents a number of different constituents which include but are not limited to calcium, magnesium, sulfate, chloride, as well as others.

Disinfection

One of the most critical processes in the area of water quality is the ability to control the growth and regrowth of pathogenic organisms throughout the distribution system. This process is commonly handled through disinfection. By definition, disinfection is the process of cleaning something, especially with a chemical, in order to destroy bacteria. Disinfection should not be confused with other processes such as sanitation or sterilization. Sanitation is the process to make something clean, but it doesn't necessarily target disease causing organisms and sterilization is the process of ridding something of all bacteria. The goal of drinking water disinfection is to destroy pathogenic organisms in order to make it safe for human consumption. This process is commonly achieved through the use of chlorine and chlorine related compounds or other oxidants.

Physical Disinfectants

While not common, microorganisms can be inactivated in water supplies through physical means. These include, but are not limited to ultraviolent rays, heat, and ultra-sonic waves. While all of these are physical means of inactivating harmful organisms,

they lack something chlorine and chlorine related compounds provide. These processes are good at the time of use but provide no long term protection from regrowth.

Non-chlorine Disinfectants

Chemicals such as iodine, bromine, various bases (alkaline chemicals), and ozone are good oxidizing agents, but each one has limitations when it comes to drinking water disinfection. Iodine has been used for years to disinfect cuts and skin abrasions and in low doses it can be used to disinfect drinking water. However, because of the high costs and potential physiological effects on pregnant women, it is not used in drinking water. Bromine is commonly used in swimming pools and spas, but because of safety related issues with handling the chemical it is not used in drinking water. An example of a base that can be used as a disinfectant is sodium hydroxide. It is also commonly used to disinfect cuts and skin abrasions, but it leaves a bitter taste if it is ingested and is not suitable for drinking water disinfection. Ozone is a great disinfectant for drinking water under certain instances. It is primarily used in the drinking water treatment process to control taste and odor and to reduce the amount of total organic carbon prior to treatment. The main problem with ozone is it does not leave a residual, is difficult to store, and is expensive.

Chlorine and Chlorine Related Compounds

Chlorine has been used in the United States to disinfect drinking water for over 100 years. It does a great job at inactivating pathogenic organisms and leaves a residual preventing regrowth throughout the distribution system. In its natural state, chlorine is a gas with a greenish-yellow color. There are other chlorine related compounds such as calcium hypochlorite (solid) and sodium hypochlorite (liquid) commonly used to disinfect drinking water. In addition to chlorine and these related compounds, chlorine is often combined with ammonia to create chloramine. Chloramine is also an efficient disinfectant. One of the major drawbacks to using chlorine as a disinfectant is the potential creation of disinfection by-products such as total tri-halomethanes and halo-acetic acids

Distribution System Water Quality

As water makes its way through the distribution system, distribution operators need to be able to maintain the quality of the water. Water quality can degrade within a distribution system for a number of reasons, including but not limited to age of water, temperature of water, lack of a disinfectant residual, pH, various reducing agents, and microorganisms. Maintaining a disinfectant residual within distribution systems is an important responsibility for distribution operators. Sampling, monitoring, and various maintenance activities can help with maintaining a disinfectant residual.

Distribution Sampling

The SDWA states how many and where water quality samples need to be collected. In addition, state regulators such as DDW may also require additional sampling based on vulnerabilities and other water quality related issues.

All sources of supply must be sampled routinely for bacteriological, inorganic chemicals, organic chemicals, and radiological contaminants. Each group of contaminants and some individual contaminants have different sampling intervals and procedures. For example, VOCs are required to be sampled at each source annually unless there is a positive detection, in which case they need to be sampled quarterly.

Sampling within the distribution system is also required. However, there are far fewer constituents, which need to be sampled in distributions systems. The main contaminants which are required to be sampled for in distribution systems are bacteriological as part of the TCR and disinfection by-products. If you think about this, it makes sense. If you sample source water for VOCs for example, you would not need to sample for VOCs again in the distribution system. The reason for this is because VOCs do not develop in the distribution system. In contrast, in the absence of a disinfectant residual, bacteria can regrow in a distribution system and disinfection by-products may form in a distribution system under certain conditions.

As part of the TCR, water utilities prepare sample siting plans. These plans identify the number of customers the utility serves, which in turn determines how many samples must be collected for total coliform bacteria. The sample locations and sampling frequency are also identified in these plans. Larger utilities can be required to sample dozens of locations on a weekly basis for total coliform bacteria as part of the TCR, while smaller utilities may just have to sample a few locations a month. At each location the disinfectant residual is also analyzed. This data can help determine if there is the potential for a problem within the distribution

system. Let's take a look at a hypothetical example. Suppose ten (10) locations per week are being sampled for total coliform bacteria and a chlorine disinfectant residual. Over three weeks, all the total coliform results come back negative (absent of total coliform bacteria), but the sampler has noticed a downward trend in the chlorine residual level at one of the sample locations. This sort of information can indicate a potential problem and maybe the next total coliform sample at this site will come back positive. This scenario doesn't necessarily mean something is wrong, but the sampler at least has data, which can be presented to other operators and may trigger some type of maintenance.

Distribution System Maintenance

Maintaining an efficient distribution system can help maintain good water quality. Water entering a distribution system from a source is routinely disinfected with a chemical such as chlorine. While the water travels through the distribution system the disinfectant will do its job by inactivating pathogenic organisms. As this occurs, the amount of chlorine in the system (residual) will reduce. The further the water travels, the lower the residual level. The water also becomes older as it travels through the distribution system and the water can become stagnant, resulting in discoloration, odors, and low chlorine residuals. One way to help keep a disinfectant level at acceptable levels is to help move the water through the system by flushing dead ends and areas furthest away from sources. By flushing and helping to move water through the distribution system, the water and with it the disinfectant residual travels faster through the distribution system and the water does not become stagnant



Figure **3.5.2.5**: Image by Daniel Case is licensed under CC BY-SA 3.0

Sometimes, residuals drop very rapidly or cannot be maintained within a distribution system. This typically occurs when the initial dose of the disinfectant is not high enough at the source water, the water stays in the distribution system too long because of low use, or there is some other problem within the distribution system. When this occurs, distribution operators may choose to add a disinfectant in water storage tanks. Since disinfectants are added at the sources of supply they are typically found at higher levels in the distribution system around these sources. Storage tanks are commonly placed on the outer edges of distribution systems and if water demands (usage) are low, disinfectant residuals can drop below acceptable levels. This is when distribution operators can add disinfectants, such as calcium hypochlorite granules or liquid sodium hypochlorite to storage tanks. This will help improve disinfectant residuals within the tank and then in the distribution system as water is taken out of the tanks during times of usage.



Figure **3.5.2.6**: Image by Barksdale Air Force Base is in the public domain

Water Quality Violations

When a water utility does not comply with drinking water quality regulations a violation occurs. Since many states (including California) have their own set of regulations, the states are the primacy agency for enforcing drinking water quality regulations. This means the enforcement comes from the state instead of the USEPA. However, since some regulations are specifically promulgated by the USEPA, they would be the primacy agency for those regulations.

Included in the SDWA is something referred to as the Public Notification Rule (PN). This rule ensures consumers will know if there is a problem with their drinking water. These notices are intended to alert customers if there is a risk to public health. Customers are notified when:

- The water does not meet drinking water standards;
- If the system fails to test its water;
- If the system has been granted a variance (use of less costly technology); or
- If the system has been granted an exemption (more time to comply with a new regulation).

If a water utility cannot meet a drinking water standard, that is they exceed an MCL for a contaminant, in addition to notifying their customers, several things are commonly triggered:

- Resampling the water must occur. Depending on the contaminant, several resamples may be required.
- If these results confirm an MCL has been exceeded, then the source is usually taken out of service. There are some exceptions. Depending on the health effect, the primacy agency may allow the source to be blended in order to bring the level of the contaminant below the MCL.
- Depending on the health effect of the contaminant, the utility may be required to notify the public immediately. Other times if the health risk is minimal, the utility would be required to notify their customers in an annual consumer confidence report.
- Depending on the level and the health effect of the contaminant, the utility may be required to install some form of treatment in order to remove or lower the level of the contaminant

With some contaminants where a positive result occurs, but the level is below an MCL, additional monitoring is sometimes required. For example, nitrate has one of the more complex additional sampling requirements.



Figure **3.5.2.7**: Sampling Image Source by Shaw Air Force Base is in the public domain

Nitrate Sampling Requirements

The SDWA states that nitrate must be sampled annually at each source entering the distribution system. If the result is more than half the MCL (>22.5 mg/L as NO3 or >5 mg/L as N) then quarterly sampling is required. Quarterly must continue until four (4) consecutive quarters yield results less than half the MCL.

Consumer Confidence Report (CCR)

The CCR is an annual report sent to all customers receiving water from a utility. This report provides information on the sources of supply, updates on new or emerging water quality regulations, health effects from contaminants found in their drinking water, levels for all contaminants found in the drinking water supply, and any violations which may have occurred. This CCR is very helpful in communicating to the public the safety of their water supply. The information within the report is from the prior calendar

year and must be sent to all customers by July 1 of the following year. The report also must be provided in each language spoken within the utility service area if the population speaking that language is greater than ten (10%) percent of the total population.



Figure 3.5.2.8: Sample CCR – Photo by Tim Marshall on Unsplash (modified by COC OER)



Figure 3.5.2.9: Sample CCR – Photo by rawpixel on Unsplash (modified by COC OER)

Sample Questions

1. CCR stands for _____ and is provided to _____.
    1. Consumer Confidence Regulations/all water utilities
    2. Customer Certification Requirements/all customers
    3. Consumer Confidence Report/only select customers
    4. Consumer Confidence Report/all customers
2. Stagnant water in a distribution system can have the following qualities _____.
    1. Discoloration
    2. Odor
    3. Low chlorine residual
    4. All of the above
3. Tri-halomethane are considered _____.
    1. Surface water contaminants
    2. By-products of the disinfection process
    3. Groundwater contaminants
    4. All of the above
4. AWWA stands for _____.
    1. American Water Workers Agency
    2. American Water Wage Association
    3. American Water Works Association
    4. None of the above
5. Primary drinking water standards are considered _____.
    1. Health-related
    2. Aesthetic-related
    3. Not enforceable
    4. Less important than secondary standards

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3.6: Safety

Student Learning Outcomes

After reading this chapter, you should be able to:

- Describe the difference between acute and chronic health effects as they relate to safety
- List the various types of safety practices of a water utility
- Explain the importance of proper record keeping related to safety

Safety in the workplace is something that transcends all industries. Each profession has their own set of safe work practices as it pertains to their specific job functions. For example, construction workers might be exposed to excessive heat. Therefore, these employees should be given the proper training and equipment to help prevent things like heat stroke. People working on an assembly line might be exposed to repetitive motions, which can lead to things like carpal tunnel syndrome. Their employer must provide the right work conditions in order to protect against strains and conditions associated with this type of activity. Another example might be someone working on a loading dock and is required to lift heavy objects. In this case, they must receive the proper instructions on how to lift properly and provided about what to do in the case where something is too heavy to lift.

These are just a few examples of safety-related items workers encounter in various industries. The water utility industry is no different. In fact, a professional water worker might be exposed to many different safety-related issues compared to employees in other industries. In addition, since many water utility operators are required to work around the public, there is an aspect of protecting the public from injuries related to the work they do. This text will attempt to analyze and address many of the safety items water workers might encounter.

Various Types of Safety

We will break the different types of safety into three (3) main categories. These are organizational safety, fleet safety, and public safety. Each of these categories is defined below:

- Organizational Safety—This is the most universal type of safety businesses (organizations) are faced with. It is the overall prevention of injury to employees. This prevention of injury is for employees both on and off the job. You might ask why an employer should be concerned with an employee's personal safety when they are not working. The main reason organizations should instill the value of safety for employees both on and off the job is two-fold. First, any injury can result in lost time. This means if an employee gets injured at home, they may not be able to report to work. This results in inefficiency in the workplace and sometimes results in a loss of revenue for the employer. The second reason and maybe more importantly is creating a culture where safety is a value within the organization. Valuing safe work practices both on and off the job will result in a safer work environment and less loss time and money for organizations.
- Fleet Safety—Water utility workers work within a community. They are required to operate equipment and drive vehicles. This can result in traffic accidents and equipment-related accidents. Fleet safety is designed to help prevent these types of accidents.
- Public Safety—Put simply, public safety is the prevention of injury to the general public. Water utilities have facilities throughout a community and it is important these facilities do not pose a safety hazard to the general public. An example of this might be something simple like a meter box lid. If the lid is missing or broken, it could present a tripping hazard to someone walking along a sidewalk. Water utility workers also work in public streets. This not only presents a safety hazard to the employee but blocking off portions of a street can lead to traffic accidents and exposes the public to potential safety hazards.

Organizing a Safety Program

Each utility should designate an individual responsible for safety. Unfortunately in smaller agencies this is usually someone in middle management. A full-time safety officer is important in order to have one single person looking after health and safety for the entire organization. When safety is assigned to someone with other responsibilities, safety sometimes gets overlooked. Regardless who is tasked with overseeing the program, it is important that staff, management, and the entire organization look at safety as a core value. Each individual is ultimately responsible for their own safety, but they also need the correct tools and equipment to do their job safely.

A designated safety's main responsibility is to help staff and primarily supervisors. They are not tasked with providing all the training and equipment. They are to assess safety work practices and help implement safety programs. They determine the safety needs of an organization. They plan, develop, and recommend safety plans and programs. A safety officer should evaluate the effectiveness of safety plans and programs and make adjustments and corrections as necessary. Generating safety information and conducting meetings with employees and supervisors is also a function of a safety officer. Investigating accidents and injuries is also part of the responsibility of a safety officer as well as maintain records and reports covering all aspects of the safety program. These are some of the more critical responsibilities and additional tasks may be required as necessary.

Management also plays a large role in regards to safety. Without management's "buy-in", staff sometimes feels disenfranchised. Management needs to establish an overall safety policy for the organization. They appoint the safety officer (or coordinator) and assign responsibility for accident prevention. Management establishes goals, revises as needed, and evaluates results of the overall program.

Supervisors set the patterns for safety and should lead by example. No employee likes the "do as I say, not as I do" attitude. Since supervisors have direct control over employees, they should instill safety as a core value and provide the proper tools, equipment, and safety items needed to do tasks in a safe manner. They should instruct and council staff on safe work habits and review work for compliance with the safety program and regulations.

Employees are the front line workers of an organization. Therefore they are typically exposed to the majority of safety hazards. They must perform their work in accordance with the appropriate safety procedures and actively participate in the safety program. All injuries and hazards should be reported. At no time should an employee work in an unsafe manner or condition. If an employee feels a job is unsafe they are to report these findings to a supervisor.

The following is an example policy safety statement:

- The organization's recognition of the need for safety in order to stimulate efficiency, improve service, build employee morale, and promote better public relations
- The organization's interest in the employee - to provide proper equipment and working conditions, and to promote safety and the expectation that the individual employee will maintain safe work practices
- The fact that the human factor rather than the mechanical is most significant cause of accidents, thus emphasizing the employee's responsibility to perform the job safely
- That an essential part of the supervisor's job is responsibility for development of safe work practices and their environment

Safety Regulatory Requirements

The federal Occupational Safety and Health Administration (OSHA) is responsible for assuring safe and healthful working conditions by setting and enforcing standards and by providing training, outreach, education, and assistance. OSHA is part of the United States Department of Labor. Safe work practices can eliminate and reduce suffering, injury, and death. Safe work practices also reduce lost time, medical costs, and legal judgments. Proper safe work practices save time and money for companies too.

OSHA has established minimum health and safety standards that are applicable to every industry. The mandate that every employer furnish employees with a workplace that is free from recognized hazards that are likely to cause death or serious physical harm.

Causes of Accidents

Unsafe acts and unsafe conditions are two of the most common results in accidents and injuries. Lack of experience or improper training commonly results in unsafe acts. Some employees have an indifference to safety and can result in excess accidents and injuries. Poor work habits or cutting corners, working too fast and impatience results in unnecessary accidents and injuries. It is also important for employees to be well-rested and in good physical condition. There are usually specific condition requirements for some jobs. For example, a job requiring the operation of heavy equipment or strenuous labor may require certain licenses and regular physical fitness testing. Drug and alcohol testing may also be required for certain jobs. Impaired employees pose a danger to themselves and to other co-workers. Below are examples of unsafe acts:

- Ignorance—It is not that employees are ignorant. It is when they lack the experience or training to do their job safely
- Indifference—Some employees and in some instances employers are "indifferent" or do not care about safe work practices

- Poor work habits—Many times employees develop bad habits if they don't understand how to perform task correctly in the first place
- Laziness—Sometimes employees do not want to or are unable to provide the required effort
- Haste—Working too fast can contribute to unsafe work conditions
- Poor physical condition—Employees need to have proper rest and for some tasks must be physically fit
- Temper—Impatience and anger can cloud judgment and result in accidents

Reading through the list above you might have thought that most if not all of these are preventable. If so, you would be right. Most unsafe acts and conditions are preventable. That is not to say all accidents can be avoided, but many can by simply avoiding the list above.

Safety Training Topics

One of the most important aspects of a safety program is training the workforce. Some training topics are required to be completed by employees on a routine basis. Standard training requirements are found in Occupational Safety and Health Administration (OSHA) regulations. Some safety requirements are under General Industry standards while others are specific based on the type of industry. The following safety training topics are general in nature, required throughout the water industry, and provide a high level of understanding.

Hazard Communication

Any industry where chemicals are used, annual training explaining the hazards associated with exposure to these chemicals in the workplace must be conducted. Employers should provide employees with training prior to initial assignment to their work area. Hazard communication (HazComm) training should identify the activities and locations of the chemicals in the workplace and the health hazards associated with exposure to the chemicals. Additional topics covered in the training include but are not limited to steps employees can take to protect themselves, labeling criteria of the chemicals. And clean up procedures.

As part of hazard communication training, an inventory list of chemicals needs to be provided and available to all employees. The details of which chemicals are required to be covered in training are beyond the details provided in this text. The example we will use is one of the more common chemicals used in the water industry. Chlorine is one of the most widespread chemicals used in drinking water distribution and treatment. In addition, chlorine is hazardous to health.

Several different types of chlorine related compounds are used in the disinfection of drinking water. Calcium hypochlorite is corrosive in water and can support combustion. Sodium hypochlorite is a very strong base on its own and becomes an acid in water. Operators should wear goggles and gloves when working with hypochlorites.

The most common disinfectant in drinking water is chlorine, which is a greenish/yellow gas. Since chlorine gas is two and half times heavier than air, ventilation is required in chlorine rooms. The ventilation vents should be twelve (12) inches above the floor. Since chlorine is a compressed gas and stored in cylinders, it should not be filled more than eighty-five (85) percent to allow for expansion. Another safety feature of chlorine gas cylinders is a fusible plug. One (1) ton cylinders have two (2) valves for removing either gas or liquid and six (6) fusible plugs. A one hundred fifty (150) pound cylinder has one of each. Fusible plugs are designed to melt between the temperatures of one hundred fifty-eight (158) and one hundred sixty-five (165) degrees Fahrenheit. If there are chlorine leaks in a cylinder, an ammonia-soaked rag can be used to help detect the leak. By waving an ammonia-soaked rag a white cloud would appear. High levels of chlorine in the air affect respiration and the immediately dangerous to life and health (IDLH) level is 10 parts per million (ppm).

This example is just one of many where chemicals are used in the workplace and employees need to be properly trained on the hazards associated with working with and around these chemicals. In 2003, the United Nations adopted the Globally Harmonized System of Classification and Labeling of Chemicals (GHS). In 2009, OSHA published regulations to align their Hazard Communication standard (HCS) with the GHS. There are five (5) mandatory components of OSHA's HCS, one of which includes an update to what was previously known as Material Safety Data S, which sheets. The revised standard refers to Safety Data Sheets (STS) and sixteen (16) required sections with information about each chemical. If there is no relevant information under one of the subject headings, then the SDS must clearly indicate that no applicable information is available.

Personal Protective Equipment

One of the sections on an SDS must reference personal protection from exposure to chemicals. In addition, personal protective equipment (PPE) has its own regulatory standards regarding training, what types of working conditions might require PPE, and how to Don, Doff, and care for PPE.

Each employee is responsible to maintain their own PPE and notify their supervisor whenever it needs replacing. It is the management's responsibility to provide the training and required PPE needed by the employees. The following PPE examples are just some common types of personal protective equipment.

- Hard hats—Any time there is a potential for head injuries including low headroom working conditions or overhead items, which can fall on an employee, hard hats are required. Metal or plastic hard hats can be used, but metal hard hats should not be used where there are electrical hazards.
- Gloves—If there are pinching, cutting, crushing, or other hand-related injuries, then gloves should be worn. In addition, gloves may also be required when working with or around chemicals.
- Respiratory—When surrounding air contains dust, fumes, mists, or any other particulates, which can be inhaled, then respiratory protection is required. Respiratory protection can be as simple as a dust mask or as complex as a self-contained breathing apparatus.
- Eye Protection—Goggles, face shields, safety glasses are all forms of eye protection. Dust and debris can cause irritation is they get into someone's eyes. Any kind of object, including chemicals, can all cause damage to the eye.
- Steel-toed boats—It is prudent to wear foot protection in any construction-related industry. Therefore, steel-toed boats are often required.
- Hearing Protection—Earplugs provide ear protection from loud noises and sounds. Earmuffs can also be used to protect ears.

Understanding how to don and doff PPE is an important aspect of PPE training and all employees should understand the proper way to wear the appropriate equipment.

Slips Trips and Falls

Sometimes, the simplest and most common hazards can result in personal injury. Slips, trips, and falls should always be avoidable. Often times, it is a matter of good housekeeping. Making sure floors and walking surfaces are clear of debris and any kind of slipping or tripping hazards. Walking areas should have slip-resistant surfaces and proper handrails should be provided on stairways, catwalks, and areas where walking can be difficult. Fall protection also needs to be provided on elevated surfaces.

Back Safety

Back injuries are one of the most common injuries in the workplace. Improper lifting, twisting, pulling, and pushing are all aspects of back safety. Whenever lifting something heavy, workers should always bend at the knees and keep their back straight. One person should never lift large and heavy loads. When carrying something heavy, you should always turn with your legs and not at your waist. Equipment should also be used when appropriate to help lift and/or move heavy objects.

Trench Safety

Trenching is a method of digging into the ground to install things such as pipes. Whenever work is done inside a trench, special precautions need to be made in order to protect workers from the possibility of a cave-in. There are specific requirements based on the depth of the trench. If trenches are shallow (less than five (5) feet) then the danger is not as great as it is with deeper trenches. However, workers can still get trapped in shallow trenches. When trenches are five (5) feet or deeper, special protection is required. This protection is referred to as shoring, shielding, or sloping. If there is enough room, then sloping is allowed. Sloping is the process of reducing the depth of a trench by removing soil and opening the width of a trench to prevent the trench walls from collapsing. Shoring and shielding is the process of using equipment placed up against trench walls. The dirt being excavated (referred to as spoils) should be placed at least two (2) feet away from the trench edge and on the side opposite of the pipe being installed. If trenches are long, then ladders should be placed within twenty-five (25) feet of workers. Another important aspect of trench safety is proper supervision. Special training must be provided to individuals overseeing trenching activities. These individuals providing supervision are referred to as a "Competent Person".

Confined Spaces

A confined space is defined, as a workspace, which has limited or restricted means of entry or exit, is large enough for an employee to enter and perform work, and is not designed for continuous work or occupancy. Confined spaces are defined as “permit-required” and “non-permit required” confined spaces. In order for a confined space to be classified as a permit-required confined space, it must meet the following conditions:

- Contains or has the potential to contain a hazardous atmosphere
- Contains a material that has the potential for engulfing an entrant
- Has an internal configuration such that an entrant could be trapped or asphyxiated by inwardly converging walls or by a floor that slopes downward and tapers to a smaller cross-section
- Contains any other recognized serious safety or health hazard

The internal atmosphere of a confined space must be tested for oxygen content, flammable gases, and vapors, potentially toxic air contaminants, hydrogen sulfide, and methane. Ventilation equipment should be used to provide acceptable air conditions. Three (3) or more workers should be involved with permit-required confined spaces. One (1) or more workers inside the confined space, one (1) worker in communication with the worker(s), and one (1) worker to respond and retrieve emergency personnel if needed.

Respiratory Safety

As previously mentioned, it is important to provide workers with respiratory protection if the surrounding atmosphere is not adequate for a working environment. Respiratory hazards include, but are not limited:

- Dust from rock, cement, coal, and wood
- Dust from toxic materials such as lead, arsenic, and asbestos
- Mists and fumes from chemicals and heated materials
- Vapors and gases from chemicals such as chlorine, ammonia, and carbon monoxide
- Oxygen deficient environments

Respiratory problems can range from very mild irritation causing coughing and wheezing, to death. Respirators can be broken down into two main types, air purifying and atmosphere supplying.

Air-purifying—These types of respirators use cartridges, filters, or canisters to remove contaminants from the air. In order to remove vapors and gases, a granular porous material referred to as an absorbent needs to be used. The type of filter, cartridge, or canister is dependent on the type and amount of the airborne contaminate. For example, a particulate filter would not necessarily remove vapors or gases. Therefore the employer must identify the contaminant(s) and provide employees the proper protection against dust, fumes, mists, and solid particulate matter.

Atmosphere-supplying—In certain circumstances, the surrounding atmosphere is not suitable for breathing and purifying the air may not be sufficient. Therefore, a respirator where clean air is provided should be used. A common situation where this might occur is when the surrounding atmosphere lacks adequate oxygen levels or is considered oxygen deficient. At this point, atmosphere-supplying respirators are required.

There are a number of various other safety topics, which should be considered if potential hazards exist. Some of these topics include, but are not limited to hand and power tool safety, electrical, head, body, and extremity protection.

Traffic Control

Utility workers often work in roadways. Whenever work is performed in traffic areas, the Manual on Uniform Traffic Control Devices for Streets and Highways should be used. This manual is published by the US Department of Transportation (USDOT) and specifies approved traffic control devices and procedures. Some states have their own traffic control reference manuals and those should also be reviewed before working in the street. If improper traffic control is set up, the utility can be held liable for damage from accidents. Often times special permits, such as encroachment permits are required as well as special traffic control plans need to be submitted to the governing agency. Traffic control devices such as cones, pylons, and other systems are used to channel the flow of traffic to designated areas. There are five (5) zones within a construction worksite in roadways:

- Advanced Warning Zone—This area is a warning to drivers letting them know what to expect. This advanced warning can be as simple as a single flashing light to a series of signs and notifications prior to the temporary construction work and change in the flow of traffic.
- Transition Zone—Whenever the redirection of the normal flow of traffic is required, a transition area is needed. Traffic must be channelized from the normal flow to the new path in order to avoid the construction area.
- Buffer Zone—While not required, it is an important area for the protection of workers. It is an area between the flow of oncoming traffic and the area where employees are working.
- Work Zone—This is the area where the work is being performed. Workers and equipment are within this area. By the time traffic reaches this area, it should be completely redirected out of this zone.
- Termination Zone—As with the transition zone, the termination zone is redirecting traffic. Except in this zone, traffic is being returned to its normal flow path.

The taper lengths and buffer zones have specific distances in relation to traffic speed. More traffic control devices, longer taper lengths, and larger buffer zones are needed as the speed of traffic increases.

Occupational Injuries

All injuries in the workplace should be reported immediately. This early reporting not only helps the utility determine if the injury occurred at work and it also speeds up the process for the employee to start any type of worker's compensation. An occupation injury is defined as any personal injury sustained by an employee during the course of work. Employees should report their injury to their supervisor or to the organization's safety representative. Utilities typically have injury report forms. These forms should be simple but informative. They should contain information from both the employee and supervisor. The employee is responsible for reporting the injury and the supervisor and safety representative are responsible for making sure the report form is completed correctly.

All injuries should be investigated. Accident and injury investigations provide an opportunity for the safety professional to speak with the employee and any witnesses. It allows for feedback on the cause of the incident and give the safety professional the opportunity to provide feedback on the necessity of exercising care and caution. It also presents the opportunity to identify any unsafe work practices or conditions and allows for recommendations on workplace improvements.

Safety professionals should prepare and review a variety of reports associated with workplace accidents and injuries. These include, but are not limited:

- Number of lost-time injuries—any injuries resulting employees missing time from work
- Number of injuries requiring first aid—first aid kits should be provided at each workplace and with workers who work in remote locations
- Number of injuries requiring medical attention—any injury where an employee receives assistance from a medical professional
- Number of lost time days—when employees miss work due to an injury, this is referred to as lost time

There are also OSHA related performance measures safety professionals use to track and interpret the prevalence of workplace-related injuries. These include:

- Incidence Rate—This is based on the number of injuries requiring more than first aid per 200,000 hours worked
- Frequency Rate—This is the number of lost time accidents per million employee hours worked
- Severity Rate—This is the number of days lost or charged per million employee hours worked

OSHA has specific reporting requirements related to workplace injuries. Most organizations are required to maintain an OSHA Form 300 Log. This log lists all recordable workplace injury and illness. OSHA defines a recordable injury or illness as:

- Any work-related fatality
- Any work-related injury or illness that results in loss of consciousness, days away from work, restricted work, or transfer to another job
- Any work-related injury or illness requiring medical treatment beyond first aid
- Any work-related diagnosed case of cancer, chronic irreversible diseases, fractured or cracked bones or teeth, and punctured eardrums

In addition to these definitions, there are also special recording criteria for work-related cases involving: needle sticks and sharps injuries; medical removal; hearing loss; and tuberculosis. In general, minor injuries and injuries requiring first aid treatment do not need to be recorded. All employers are also required to notify OSHA directly when an employee is killed on the job or suffers a work-related hospitalization, amputation, or loss of an eye. Fatalities must be reported within eight (8) hours and in-patient hospitalization, amputation, or eye loss must be reported within twenty-four (24) hours.

Safety is a very important aspect for all occupations. Water utility operations are no exception. It is important for safety to be supported from the top executives all the way down throughout the organization. Ultimately, the primary person responsible for safety is…YOU!

Sample Questions

1. When symptoms develop rapidly within a person it is considered _____.
    1. A chronic health effect
    2. An acute health effect
    3. A disease
    4. Both 1 and 3
2. What is the primary responsibility of the safety officer?
    1. Should be a line function
    2. Should be a staff function
    3. Should provide all the training
    4. All of the above
3. Traffic control should be set up in the following order:
    1. Buffer Zone, Transition Zone, Work Zone, Termination Zone, Advanced Warning
    2. Advanced Warning, Buffer Zone, Work Zone, Transition Zone, Termination Zone
    3. Advanced Warning, Transition Zone, Buffer Zone, Termination Zone, Work Zone
    4. Advanced Warning, Transition Zone, Buffer Zone, Work Zone, Termination Zone
4. Fusible plugs are designed to _____.
    1. Melt, preventing combustion
    2. Melt between 158°F - 165°F
    3. Fuse the valve connection to the hose
    4. Only 1 and 2
5. A 1-ton chlorine cylinder has _____.
    1. 2 fusible plugs and 6 valves
    2. 2 valves and 6 fusible plugs
    3. 1 valve and 5 fusible plugs
    4. 5 valves and 1 fusible plug
6. The IDLH for chlorine gas is _____.
    1. 5 ppm
    2. 10 ppm
    3. 20 ppm
    4. 100 ppm
7. All fatalities, serious injuries and illnesses must be reported to Cal/OSHA within _____.
    1. 8 hours
    2. 16 hours
    3. 24 hours
    4. 48 hours
8. A chronic health effect is _____.
    1. An adverse effect developing rapidly

2. An adverse effect resulting in cancer
3. An adverse effect developing over a long period of time
4. A disease with little or no symptoms

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SECTION OVERVIEW

3.7: Water Customers

3.7.1: Water Rates

3.7.2: Public Relations

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3.7.1: Water Rates

Student Learning Outcomes

After reading this chapter, you should be able to:

- Evaluate different rate structures
- Understand why water rates are needed
- Analyze water rights and utility ownership

Why Are There Water Rates?

Water must be sold in order for a utility to be able to treat, distribute, and deliver water. There are chemical, electrical, infrastructure, labor, and a variety of expenses a water utility must cover. In order to pay for all these expenses, they must receive revenue to cover all the costs associated with operating and maintaining a water utility. This required revenue is referred to as revenue requirements.

Revenue requirements can be explained, as the total revenue required to ensure proper operations and maintenance, development, and perpetuation of a distribution system, and preservation of the utilities' financial integrity. Most of the revenue received by a water utility comes from the sale of water. However, some utilities receive supplemental revenue from renting property, merchandising, services related to other utilities, taxes, capacity, and impact fees.

Utilities must properly budget based on projections of water sales and all associated expenses for proper water rates are assigned in order to generate enough revenue. Sometimes budgets and associated projections extend out multiple years. Regardless of budgetary projections, they should be reviewed annually and adjusted accordingly.

Water rates studies and analysis usually accompanying any rate changes. Budget projections aid this process of rate-making. Additional studies can also include financial and budgetary planning, support for issuance of debt, and evaluation of past and future adequacy of contractual, litigation, rate proceeding or other requirements.

When a utility is calculating the adequacy of revenue in order to recover costs. Budgeting may require projections into the future. Projections beyond ten (10) years tend to be quite speculative, while five (5) projections are usually considered adequate. Historical water usage and other data is used to help determine appropriate water rates. However, the data must be normalized or adjusted to reflect conditions that may not continue in the future. For example, if there will be no future growth of additional customers, the need for additional sources of supply and storage may not be needed.

Below is a list of some factors affecting revenues:

- Number of customers served
- Customer water use
- Rate changes
- Non-recurring sales
- Weather
- Conservation
- Use restrictions
- Price elasticity

Below is a list of factors affecting revenue requirements:

- Number of customers served
- Customer water use
- Non-recurring sales
- Weather
- Conservation
- Use restrictions
- Inflation

- Interest rates on debt
- Capital financing needs
- Changes to tax laws
- Other changes in operating
- Economic conditions

There are two general approaches for projecting revenue requirements. They are cash-needs approach and utility approach.

Cash-Needs Approach

The cash-needs approach ensures revenues are sufficient to recover all the utility cash needs for a given projected time period. This approach simply means the total amount of revenue needed to meet cash expenditures. The cash-needs approach usually relies on debt financing. Debt indentures usually specify sufficient cash to meet cash expenditures, deposits are made to reserve account(s), and debt-service coverage requirements are met.

The accounting term “cash” refers to revenues being recognized as earned when cash is received and expenses charge when cash is disbursed. The term “accrual” refers to revenues being recorded when earned and expenditures are recorded when the become liabilities for benefits received and are not dependent on what period of time they are received.

The cash-needs approach is usually followed by public (government-owned) water utilities. Elected officials of public water utilities are tasked with approving water rates.

Utility Approach

The utility approach of projecting revenue requirements is mandated for all investor-owned (private) water utilities. This approach is also referred to as “utility basis” approach. This approach is similar to the cash-needs approach. However, the governing regulatory body assigns a “rate payer advocate”. In California, this rate payer advocate group is referred to as the Division of Rate Payer Advocate (DRA) and the governing body is the California Public Utility Commission (PUC).

This approach involves measuring revenue requirements with or without concern for allocating revenue requirements among classes of customers served. This means assigning or not assigning specific revenue requirements to specific classes of customers.

Revenue Requirement Components

In order to determine the revenue requirements, a utility must determine all the operating expenses. In other words, what does it cost the utility to provide service. On the surface, this might seem like an easy and straightforward task. However, there are a lot of aspects to operating a water utility and it is important to capture all these expenses. The following list is not exhaustive, but it is fairly comprehensive.

- Administrative costs
- Salaries
- Benefits
- Energy costs
- Chemicals
- Supplies
- Fuel
- Equipment costs
- Equipment replacements
- Principal and interest payments on debt
- Miscellaneous

The paragraphs below will provide additional detail for some of these operating costs.

Operations and Maintenance

These expenses are usually based on actual expenditures and adjusted to reflect anticipated changes. Operations and maintenance (O & M) costs include employee salaries, wage, benefits, purchased power to operate pumps and equipment, purchased water from

other utilities, chemicals for treatment, supplies, tools, equipment, vehicles, fuel, outside services, and general overhead. Some outside services can include, billing services, construction contractors, engineering and other consultants, other utility services. This list is not exhaustive but should provide a good general understanding of the various O & M expenses.

Some utility expenses are considered fixed costs while others are referred to as variable costs. Fixed costs are the costs the utility most cover to keep the utility in operation and are independent on the amount of water the utility sells. For example, if the water utility does not experience the anticipated water demand (this could be due to water use restrictions during a drought) the amount of revenue recovered would be lower than expected. However, the utility would still need to out salaries, benefits, and administrative costs. The staffing requirements are not directly proportional to the amount of water sold. Water meters would still need to be read, infrastructure, equipment, and vehicles would also need to be maintained. These costs would be considered fixed costs. Whereas, the amount of chemicals needed to treat the water might be less if the utility is producing less water. Therefore, the cost for chemicals would be less and this would be considered a variable cost. Regardless of the type of cost, the utility would still need to recover these revenue requirements.

Debt Service

Sometimes utilities require large amounts of funds in order to pay for large capital improvement projects. Some of these projects consist of new sources of supply such as groundwater wells, large storage facilities, and other major infrastructure improvements. If a utility had to spend several millions of dollars in a given year and tried to collect these expenditures in the same year, water rates would be unusually high. Therefore, a utility acquires debt in order to spread out these costs over multiple years. Debt service is the annual cost to pay the debt back. It includes both principal and interest.

Reserves

Water utilities commonly maintain reserve accounts. Reserve accounts are savings accounts. They are usually set aside for emergencies or unexpected needs. For example, if a utility has earthquake insurance, a specific reserve account can be set aside to cover the deductible costs and start making payments to begin the immediate process for repairs to the system. Another example might be a reserve account to replace a large expensive facility if there is an unexpected failure.

Capital Expenditures

Water utilities will typically have normal routine replacement of existing facilities. All equipment and infrastructure have reasonably expected operating lives. For example, groundwater might last fifty (50) years. The utility would have to plan for the replacement of these facilities. Another example is the piping infrastructure. A utility might have two hundred (200) miles of underground pipelines. Let’s assume the average lifespan of this pipe is seventy-five (75) years. This would mean the utility would need to replace on average 2.7 miles or 14,256 feet a pipe per year to keep up on the replacement schedule. Capital improvement projects (CIP) would also include annual extensions and other improvements. Often times, large CIP is financed through debt, reserves, or some combination. Very rarely are large projects paid for with cash. Issuing debt or using reserve funds prevents the customers from paying 100% of the initial cost of facilities.

Coverage Ratio

A common measurement to help determine the financial health of a utility is the coverage ratio. This is the measure of the ability of the utility to pay the principal and interest on all loans and bonds. It is calculated by subtracting the non-debt expenses from the total revenue divided by debt service expenses. A good financial coverage ration would be above 1.0.

Revenue

Where does a water utility get the money to fulfill revenue requirements? There are typically three (3) classes of revenue; Operating revenues, non-operating revenues, and contributions to capital.

Operating revenues include both metered and unmetered water sales. Most of the time, the sale of water is metered. This means a customer pays for the water, which flows through their meter. Sometimes, utilities sell water at a flat rate or unmetered. If a water utility sells water to another water utility they would be considered a wholesale water provider. The revenue earned from these sales are also considered operating revenue. Any fee for or charge for water service is also considered operating revenue. For example, some utilities have a monthly fee for something referred to as a “readiness to serve” charge. This means if a customer has

a meter service, but does not use any water for a period of time (i.e., month) the utility would still bill the customer for the ability or readiness to serve the customer. Often times this monthly service charge is based on the size of the meter. The larger the meter the higher the monthly charge. If a water utility rents property (i.e., cellular leases) or charges for the use of the utilities operating property, these would also be considered operating revenues.

Non-operating revenues is a smaller amount of revenue most utilities earn, but they still need to be taken into account. Examples of non-operating revenues include merchandising interest, dividends, sale of property, tax revenues, and various other revenues not associated with operating the utility. The last classes of revenue include funds contributed by developers and grant funds. These are considered contributions to capital.

Customer Classes

There are generally four (4) main classes of customers. These are identified as residential, commercial, industrial, public authority, and dedicated landscape. Residential customers consist of single and multi-family dwellings. This would include attached and detached homes, apartment buildings, condominiums, and townhomes. Commercial customers would include businesses such as restaurants, small and large businesses. Industrial customers would include manufacturing and processing establishments. Public authority would be public establishments such as schools, city, and county buildings. Dedicated landscape service connections are commonly separated from other service classes.

There are also some special classes of customers. These would include wholesale service, fire-protection, and service for air conditioning and refrigeration.

Wholesale service is usually defined as a situation in which water is sold to a customer at one or more major points or delivery for resale to individual retail customers within the wholesale customer's service area. This water is typically treated before being sold and is sold to a separate municipality or water district.

Fire protection service is primarily a standby service. There is a readiness to deliver relatively large quantities of water for short periods of time at any of a large number of points within a distribution system. The total quantity of water used is typically small and service costs are based on one of the following two criteria:

1. Cost of service is determined on the basis of the potential demand for water for fire fighting purposes in relationship to the total of all potential demands for water.
2. Cost of service is allocated as an incremental cost to the costs of general water service. It is based on the premise that the prime function of a water utility is to supply general water service.

Air conditioning and refrigeration is water sold for use in water-cooled air conditioning and refrigeration systems. Most units now use water referred to as "make-up" water. This is water recycled within the business.

Water Rates

It is common practice for a water utility to provide water service to all general service customers within a given jurisdiction through a single rate schedule, comprised of a two-part rate. There are three (3) common general classes of customers and these are:

- Residential—This customer class generally comprises of one and two family dwellings, usually physically separate.
- Commercial—This customer class is commonly comprised of multifamily apartment buildings and nonresidential, nonindustrial business enterprises.
- Industrial—This customer class represents manufacturing and processing establishments

Sometimes a utility will subdivide the general classes of customers into more specific groups. Water use characteristics, service requirements, and other various reasons may set certain customer classes apart from one another. Sometimes utilities will create special classes of customers, which can include wholesale, fire-protection, irrigation, and air conditioning/refrigeration services.

The jurisdictional area referred to above is the service area boundary. A governing body of each water utility determines service area boundaries. In the case of investor-owned private utilities in California, the governing body is the California Public Utilities Commission (CPUC). Within the County of Los Angeles, the governing body is the Local Agency Formation Commission (LAFCO). Commonly, a two-part water rate includes an initial charge, which generally recovers customer related and possibly

some volume related costs of the utility, together with a volumetric charge to recover the remaining costs. Some utilities recover their fixed costs with a monthly charge not associated with the amount of water sold. The variable revenue requirements would then be covered by the volumetric charge for water. The volumetric charge is based on the amount (or volume) of water sold.

Why would a utility have a two-part rate versus just charging water based on the actual usage of each customer? This is a common question people sometimes ask. The simple answer is because of the variability in how much water people use. What would happen if every customer only used a small quantity of water? Earlier in this text, we discussed revenue requirements. A utility must sell enough water or more importantly collect enough revenue from the sale of water, to cover all their related "requirements" to operate. If customers use too little water, then the utility would not be able to collect enough revenue, unless they charged an exorbitant amount for each unit of water. An example of this will be presented in the last chapter of this text (Waterworks Mathematics). Therefore, oftentimes, a utility will have a "fixed" charge. This fixed charge is sometimes referred to as a readiness to serve charge. This allows the utility to collect sufficient revenue to keep the utility running regardless of the amount of water sold. It commonly covers meter reading, billing, and day-to-day operational costs. Therefore, a two-part rate, one part fixed and the other part variable is commonly used.

Flat Rates

A fixed charge is different than a flat rate. A flat rate is something utilities sometimes use when the water supply is plentiful. It is the same charge across all customer classes and users. It is an amount, which must cover the revenue requirements of the utility, but is blind to the amount of water each customer uses. This type of rate is becoming less common, especially in California where drought often affects certain parts of the state. It is also not an even or equitable means of charging for water service. It also does not encourage water savings or conservation.

Variable Rates

As previously mentioned, a variable rate is based on the amount of water customers use. Therefore, the more water a customer uses the more revenue the utility collects. Conversely, if a customer uses zero units of water over the billing cycle, then the utility would collect no revenue from this particular customer. Also, as previously mentioned, fixed charges can and are oftentimes included with a variable water rate.

Tiered Rates

Much like variable rates, a fixed charge is usually included with tiered rates. Tiered rates are another type of variable rate structure. However, in a tiered rate the variable price increases with usage. For example, each unit of water would be sold at a specific amount up to a certain unit usage set point. Then after the designated amount, the charged amount is increased until another specific usage amount, and so on. See a simple example below.

- 0 – 9 Units of Water Used = $1.00
- 10 – 19 Units of Water Used = $2.00
- 20 – 29 Units of Water Used = $3.00
- 30 or More Units of Water Used = $4.00

Tiered rates are designed to encourage water conservation. The belief is as water becomes more expensive as usage goes up, usage would be curbed. While tiered rates have been shown to contribute to conservation efforts. However, there are other issues associated with charging more for water based on customer usage. The utility must explain the reason they are charging more for quantities above specific usage amounts. There have been several lawsuits associated with the legality of tiered water rates. One such lawsuit was in 2015 between a group of San Juan Capistrano taxpayers and their local water utility. It is extremely important a utility properly explains and notifies their customers before implanting water rates, especially tiered water rates.

Budget Based Rates

A budget based rate structure is similar to a tiered rate structure. The difference between the two is instead of charging water purely based on the quality of water used. In a water budget based rate structure, water charges are assigned based on customer usage both indoors and outdoors. While most utilities do not measure these (indoor/outdoor) uses separately, under a budget based water rate, a certain volume is often assigned for indoor water use. In addition, a specific amount is assigned for outdoor water use (irrigation).

These assigned amounts are considered a customer's budget. The rate assigned to the budget is a standard volumetric water rate. If customer's stay within their budget, do not use more than the allocated amount, then the rate does not change. However, if a customer uses more water than their allocation, the cost of water increases similar to a tiered structure.

Another difference to a water budget rate structure compared to a standard tiered rate structure is budgets are commonly personalized for each customer. In a tiered system, all customers follow the same tiered rate, whereas budgets can be based on the specific water needs of each customer.

Regardless of the rate structure, the utility must be able to adequately recover its revenue requirements with the chosen rate structure. Rates are designed for specific periods of time known as the rate schedules. Projections of expenses are compared against projections of water use and then a rate can be calculated. During a water rate study, utilities will commonly use something referred to as a test year. A test year is an annualized period for which costs are analyzed and rates are established.

Utility costs for ongoing operations and maintenance of the system as well as past large capital improvements must be incorporated into the water rate. In addition, utilities need to properly account for future replacements and growth of the utility. While existing customers typically cover a large portion of these costs, some of the future expansion of a system should be and often times is paid for through fees to construction developers. These fees are referred to as facility capacity and connection fees. These fees are associated with expanding a system in order to supply water to additional customers.

The concept of recovering costs and expenditures through the sale of water is a fairly simplistic concept. However, determining necessary costs and expenditures and calculating the water rate associated with recovering this money is a difficult and complex process in order to keep the customer of water reasonable to the customer, but also ensuring the utility has enough cash flow to keep operations flowing.

Sample Questions

1. Budget projections beyond 10 years tend to be _____.
    1. Accurate
    2. Speculative
    3. Adequate
    4. Both 1 and 3
2. The "Cash-Needs" approach is typically used by _____.
    1. Private utilities
    2. Public utilities
    3. Agencies with multiple commodities
    4. All of the above
3. Which of the following is not included in O&M expenses?
    1. Salaries
    2. Purchased water
    3. Chemicals
    4. None of the above
4. Investor-owned utilities are governed by _____.
    1. An elected board of directors
    2. A City Council
    3. The California Public Utilities Commission
    4. A Mayor
5. A periodic stated charge for utility service not based on the metered quantity of service defines _____.
    1. Firm service
    2. Flat rate
    3. Rate blocks
    4. Standard rates
6. The annualized period for which costs are to be analyzed and rates established defines _____.

1. Test year
2. Yearly projections
3. Annual analysis
4. None of the above

7. Connection fees are charged to _____.
    1. Create revenue for O&M expenses
    2. New customers for the costs of new facilities needed to apply water
    3. Help establish service area boundaries
    4. All of the above

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3.7.2: Public Relations

Student Learning Outcomes

After reading this chapter, you should be able to:

- Explain the importance of public relations as it pertains to public perception
- Identify the key areas where communicating to the public is important
- List four (4) main areas the public experiences a water utility and their workers

Many times, public relations are looked at as a marketing strategy for businesses selling a product, or, perhaps a government agency disseminating information to a certain constituency or group of voters. Public relations (PR) is nothing more than the spread of information between an individual or an organization to the public. Therefore, PR is just as important for a water utility.

Even though customers do not have a choice who they receive their drinking water from, it is important for a water utility to be open, transparent, and helpful to their customers. Therefore, providing good public relations is important.

A water utility is in the public eye in a variety of ways. Utility vehicles are driving throughout a town performing work. Meter readers often visit customer homes to read a water meter. Every time someone turns on their faucet and the water coming out is unacceptable or when someone receives a high water bill, the water utility is often the one a customer will blame.

Some areas water utility workers are exposed to the general public include, but are not limited to meter reading, operations and maintenance workers, vehicle operation, public meetings, and customer calls and complaints. These are not the only instances where customers can and interact with water utility workers.

Meter Readers

Meter readers have the potential of interacting with customers on a routine basis. Meters are generally located near the property boundary of customers and in some parts of the United States; they can be installed inside customer buildings. Therefore, a customer might approach an employee reading meters. Customers can be in search of specific information about the service they are receiving or perhaps they might have questions about something they heard about in the news. Regardless of what a customer might be asking, it is important for meter readers to be respectful and polite.

Meter readers should maintain a neat appearance. Many utilities provide their employees with uniforms, which clearly display the utility's name. If a meter reader is speaking with a customer they should provide some form of identification letting the customer know who they are and whom they work for. If a customer's meter is inside a customer's residence, a customer may be reluctant to allow them into their home without proper identification or someone who is wearing worn-out clothes, dirty, or unshaven. Meter readers should be properly trained and have a good general understanding of utility operations. However, at no time should any employee, including meters, feel responsible to answer any questions they are unfamiliar with. Sometimes meter readers will carry around brochures with frequently asked questions and they should always provide the customer with a phone number to call, in order to receive additional information. While reading meters, a meter reader should also be aware of any abnormalities with the customer's service. If a leak is detected on the customer's side of the service, they should attempt to contact the customer. If a customer is not home, often times a water service notice tag is left on the customer's door. Whenever dealing with the public a meter reader should stay pleasant and polite.

Operations and Maintenance Workers

This group of workers does not typically have direct contact with customers. Therefore, while they should maintain a neat appearance, it is not as important as with meter readers. Sometimes when workers are working in the public right of way (i.e., streets, sidewalks, etc) a local resident may inquire about the work they are doing. While it may seem obvious to the worker, they need to remember most of the time the public is just curious. Therefore, it is important for the worker to be polite and to refrain from "smart aleck" responses. It is oftentimes best for a worker to refer the inquisitive public to the supervisor in charge of the work instead of trying to answer all the questions they might be asked. It is important for the utility to give the public proper notice whenever service is planned to be disrupted or when streets might be closed. This can be accomplished through mailers, calls, or

signs placed in the work area. During planned shutdowns for repairs or new installs, door hangers are commonly used to provide the local residents notice.

All work zones should be properly marked and kept safe. Safety cones, tape, and other means can be used to block public access in order to protect public safety. Work zones should also be kept as clean as possible and workers should avoid sitting or walking on private property. Customers generally do not like workers taking their breaks on their lawns. Equipment and vehicles should look clean and professional and tools should not be scattered around the worksite. After the work is complete, the workers need to leave the area in the condition (or better) as they found it.

Vehicle Operation

Water utility workers generally drive a significant amount throughout their day. This increases the potential for accidents and citations. Therefore, it is critical that all utility drivers need to be careful, follow all driving rules, and be extremely cautious of their surroundings. Careless driving also makes people angry. If a utility worker is driving too fast or appears to be driving carelessly, residents often take note and many times will call the utility to complain. This generally leads to a situation where it is the worker's word versus the resident's word. Courteous driving leaves a better impression on the public and leads to less potential issues. Utility workers should also use good judgment on where they park their vehicles. It might make a bad impression if someone sees a utility truck parked in front of the local tavern, even if the worker is actually working around the corner.

Water Quality

Water quality throughout the United States is highly regulated and safe to drink. However, that doesn't mean customers like the taste, smell, and look of their water. Even if the water is considered safe to drink, if it is discolored, has an odor, and tastes odd, customers will complain. A good PR strategy for handling water quality complaints is very important in order for customers to be confident in the water they are being served. Typically, there are water quality professionals employed by a water utility to answer questions related to water quality complaints. They are trained to explain the potential causes of these unpleasant aesthetic qualities, offer suggestions to improve the quality, and offer to sample the water if necessary.

Many times, the aesthetic quality of the water is a result of internal home plumbing problems, such as old galvanized plumbing. However, sometimes water can be discolored in the distribution system from flushing or other flow changes in pipes. Other times a utility might change the disinfection practices for various reasons. This can result in taste and odor issues. If the utility is aware of potential changes in water quality from distribution activities, it is advised the utility notify customers ahead of time in order to prevent a large number of complaints.

In accordance with federal and state drinking water quality regulations, annual reports must be provided to customers stating the quality of water they are being served. These reports are referred to as annual water quality reports or consumer confidence reports. These reports typically list the sources of supply, results from water quality samples collected, and health effects data related to constituents found in the water supply. These reports while regulatory requirements are also public relations materials and it provides utilities another avenue for communicating with their customers.

Customer Service

The staff in customer service departments is the first exposure a customer has with a utility. Customers often call with questions or complaints about their service. Some customers pay their water bills in person. Customer service representatives can experience angry and hostile customers who are unhappy with the service provided by the utility. They may receive calls and complaints about high water bills, poor water quality, low or high water pressure, leaks, and a host of other issues customers might experience. These customer service representatives should be trained to be able to appropriately handle customer complaints and when to escalate complaints to their supervisors.

Customer service representatives should remain calm and polite, even if a customer raises their voice and/or gets angry. This is easier said than done. However, it is important to try and diffuse conflict with customers. If a customer is aggressive with an employee of a utility getting angry will only escalate the problem. Instead, it is recommended to listen, listen, and listen. People taking the time to call a utility and complain, want to be heard. Once you have listened to the customer's issue, offer to help. Even if there is not much you can do, the simple offer of wanting to help will go a long way.

Customer service representatives need to be provided with the proper tools to be able to adequately address customer concerns. Access to customer account information is important as well as a list of staff that the representative can refer or transfer customers to. For example, if a customer is complaining or has questions about the quality of their water, there should be staff within the organization that are able to answer questions and provide answers to customers. Therefore, properly trained staff is an important aspect of public relations and good customer service.

Media

The general rule most water utility workers should follow when it comes to talking with anyone from the media is, *don't do it*. There are too many opportunities for being misquoted and it can be embarrassing to see incorrect information in print, on the radio or television. Water utilities should have a designated media spokesperson to handle all questions and interviews from reporters. However, oftentimes, the front line workers are the first people on the scene and might be approached by reporters. If this happens, workers should give very brief and factual information about what they are doing and that is all. For example, if crews are responding to a water main break that is all the information the workers should offer. They can explain what they are doing and why they are at the location. However, they should avoid speculating as to the cause of the problem or how long they will be at the work location. They should let reporters know they are not qualified to go into more detail and that a supervisor or media representative will arrive on site soon.

Larger organizations can have designated public relations departments and spokespeople, commonly public information officers. In smaller utilities, middle or upper management staff is typically the designated spokesperson. Regardless of the spokesperson they should speak in facts only and never speculate.

Communication

It is important for a utility to properly communicate with its customers and the community as a whole. General communication about the service provided by the utility is important to convey to customers. Informing customers about changes in their water rates, conservation information, how to pay or where to pay water bills, or things such as business hours are all important items to communicate. In addition, it is important to properly notify customers and the general public whenever there's going to be work performed or water outages.

Strategic communication planning is also important. It is important to properly plan and relay information about changes in regulations, which can affect customers, changes in water quality or service reliability, and meet the public's expectations. There are four steps to successful communication planning. These include understanding the message, identifying the audience who will receive the communication, deciding on the type of communication, and the strategic planning of the dissemination of the communication.

It is important to establish a good working relationship with the local media. Working directly with reporters and writers for local newspapers and news media who typically write and report on environmental and utility-related issues is suggested. Working with the local media provides a means to open and honest dialog and the ability to help frame the stories they cover.

Public relations representatives should be accessible for comments regardless if the story is positive or negative. Access to subject matter experts should also be provided. Many times a story is about a topic involving issues of a complex nature. The subject matter experts should be available for interviews. However, they should also be able to explain complex subject matter in non-technical and understandable terms.

Public Media Events

Often times a utility will host a variety of public events. These events should be designed to provide valuable information and educate the participants about the event. These events can be joint events with other local agencies and organizations. They are typically intended to create public involvement and participation.

It is important to properly advertise the events and host in a location with ample space. All public events should be held in locations convenient to the public, have plenty of parking, and access to restrooms. A public event is designed to create a positive and informative perception of the local community.

While it is not necessary, utilities often have free items to hand out to the visiting public. If the event is a water conservation event, the utility may offer free low flow showerheads or other water-saving devices. If the event is about drinking water quality, free sample water testing kits are sometimes offered. Regardless of the event, free “trinkets” with the utilities logo or name are good ways to publicize the agency.

Emergency Information

No one looks forward to a crisis or emergency. However, all water utilities should be prepared to properly respond to and notify their customers in the case of one of these events. An emergency can be associated with a large water main break where traffic is disrupted and water service is lost to several customers to a major catastrophe where water service is lost to thousands of customers. Regardless of the extent of the emergency, the utility needs to be properly prepared.

In addition to operational planning of how a utility will respond to water quality and operational issues, a utility needs to have proper public relations planning and preparation. Some media notifications are required by regulations. For example, if a utility has a Tier 1 water quality violation, they must notify all of their customer within twenty-four (24) hours. In these situations, it is important not to waste any time. Therefore, it is important for the public relations team to prepare ahead of time. In these situations, if the utility has developed a good working relationship with the media, disseminating information is easier. It is important to know all the media outlets in the utilities service area, including but not limited to newspapers, radio stations, and television stations.

Interviews

When possible, interviews should be conducted with public relations personnel or by knowledgeable staff. There are things you definitely don’t want to say during an interview and there are strategies for giving a successful interview.

One common mistake by interviewees is not listening to the interviewer’s question. You should always take your time before answering a question and listen carefully to what is being asked. If the interview is live radio or television, be sure to speak clearly and try to avoid using acronyms and too technical details. An interviewee should always assume they are providing information to an uninformed audience. Keeping things to basic grade level responses can be effective. Always look at the person (reporter) interviewing you and try and not look at the camera.

Whether in print, audio, or visual media, the interviewee should try and disseminate information that is factual and stands on its own merit. Sometimes interviewers paraphrase information and you want to avoid any misinterpretation. In any print media, in-depth detailed information is generally acceptable. The reader has the opportunity to reread statements if they do not understand something. However, it is still important to provide facts and not opinions.

Sample Questions

1. Which one of the following is not an example where utility workers are exposed to the public?
    1. Meter reading
    2. Public Meetings
    3. Accounting
    4. Vehicle Operation
2. What would be a common mistake in a public relations interview?
    1. Not listening to the interviewer's question
    2. Answering a question specifically
    3. Looking at the person conducting the interview
    4. Disseminate factual information
3. In larger organizations, it is common to have _____ act as the organization's public spokesperson.
    1. Middle Manager
    2. Public Information Officer
    3. Customer Service Representative
    4. Consultants
4. Operations and Maintenance workers typically have frequent contact with the public.

1. True
2. False

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00: Front Matter

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SECTION OVERVIEW

4.1: Water All Around Us

In Part One of this text, we'll explore the basics of water supply and demand. We'll review the water cycle, explore basic concepts in water management, introduce surface water and groundwater rights, and then introduce the ideas of stakeholders in water projects. Part One is divided into these four sections:

- The Water Cycle
- Water Management Concepts
- Water Rights
- Stakeholder Concepts

For many of you, the Water Cycle will not be a new concept. But now you will need to frame it differently. Rather than considering it as a scientific concept, you'll have to see the interface between science and society and between supply and demand.

Water management concepts will take the water cycle further as you learn how different sources of groundwater and surface water supplies are identified and used both separately and together. There are benefits and drawbacks to each type of source of water.

Water rights are important to all aspects of the water supply. While we can't make you an attorney, you'll understand the basic types of water rights in California by the end of this section.

And lastly, in Part One, you'll finish with an examination of typical stakeholders in different water issues. Stakeholders aren't just a concept from business theory. They are critical to how we get things done in the water industry. You'll look at a few real-life examples of the consequences of working with (or neglecting) stakeholders in the water industry.



Figure **4.1.1**: Hydraulic Gold Mining by Carlton Wakins is in the public domain - *Hydraulic mining in the 1880s in Nevada City, California*

4.1.1: Water Cycle

4.1.2: Water Management Concepts

4.1.3: Water Rights

4.1.4: Stakeholder Concepts

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4.1.1: Water Cycle

Learning Objectives

After reading this section, you should be able to:

- Identify processes in the water cycle that influence the water supply
- Analyze situations in terms of precipitation, condensation, evaporation, and transpiration
- Evaluate yearly data for evapotranspiration

You've probably heard on the news the statewide water supply in California described in terms of snowpack and rainfall. These are critical measures of how much water is available for human use. Water managers in California follow both snowpack measurements and rainfall measurements closely. In the diagram above from the United States Geological Survey (USGS), you can see that precipitation is shown as rainfall and snow.

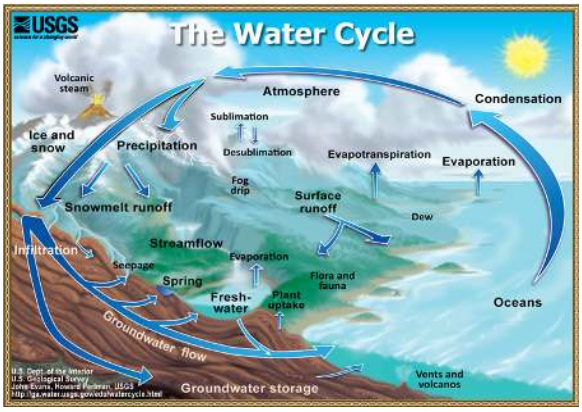


Figure **4.1.1.1**: The Water Cycle by John Evans and Howard Perlman is in the public domain

Precipitation also includes something you don't see too often in California: hail and sleet. All forms of water that fall from the sky, including rain, snow, hail and sleet, are forms of precipitation. Rainfall can provide much needed water in the ground by the process of infiltration, the process by which water seeps into the ground and eventually recharges our groundwater, water stored in the ground. Using the diagram above, you can also trace the flow of groundwater in some cases to both rivers, lakes, and even to the ocean.

Above ground, rainfall can also be stored on earth's surface in lakes. Precipitation in California also provides snow for snowpack, which can be our largest area of storage of water in the winter. In fact, it is common for water managers to view the snowpack in the Sierra as a reservoir; it is simply a seasonal reservoir that melts in the spring. Snowmelt runoff from the snowpack can fill streams and lakes. Runoff from rainfall is also captured in streams and lakes and can serve to recharge aquifers through percolation and infiltration.

The diagram also shows the key process of evaporation, or the process through which liquid water turns into a gas. Evaporation occurs over bodies of water like the ocean or lakes, but also over the land. If you own a home with a pool, you have probably noticed that if you leave the pool without a cover in the summer, you have to add water more often in the summer than in the winter. This is because the rate of evaporation is higher in the summer than the winter, often dramatically so.

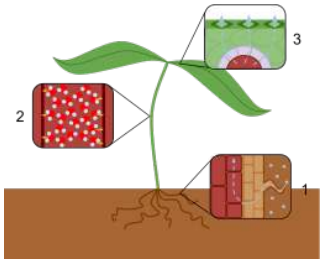


Figure **4.1.1.2**: Transpiration Overview by Laurel Jules is licensed under CC BY-SA 3.0

Transpiration is the process through which plants lose water. This may seem like an inconsequential process, but it is the entire process that drives irrigation. In the diagram below you can follow the transpiration process. In Step 1, plants bring in moisture from the soil with their roots. Then, in Step 2, water travels up through the plant. In Step 3, water leaves through their pores or stomates (plural of stomata) and enters the atmosphere again.

The combination of water loss from liquid water in the ground evaporating and water in plants losing water is called evapotranspiration (ET). Evapotranspiration is frequently used by scientists as a measurement of the plant water needs. If a location has a high ET, then the plant needs are greater than a location with a low ET.

Most locations in the state of California are close to a weather station that is part of the California Irrigation Management Information System (CIMIS) network. A CIMIS station measures a variety of variables in order to calculate the ET including: temperature, solar radiation, humidity, wind speed, and wind direction. With a complicated formula, the CIMIS station will calculate the ET for a specific geographic location. This information is frequently used to make a water budget, an estimate of how much water a location should use, including outdoor watering based on the amount of landscaping, the type of landscaping and the evapotranspiration.



Figure **4.1.1.3**: CIMIS Station #204 (Photo used with permission of Castaic Lake Water Agency)

The monthly inches of ET data in the table for Santa Clarita reflects the water needs in terms of inches of water that grass would need to receive per month. You can see that the highest needs are in summer, primarily July and August, with needs decreasing rapidly in September through December. Even though September is typically almost as hot as August, the days are shorter and the sun is less intense so the evapotranspiration is less in September than August. This means the plant needs for irrigation are significantly less.

CIMIS Station #204 Santa Clarita - 2016 Evapotranspiration Data

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly ET (in)	1.97	4.80	4.51	5.24	5.77	7.77	8.99	8.13	6.30	4.68	3.40	2.69

Knowledge of evapotranspiration has a practical application - in Southern California, many people find they can turn off their irrigation systems for grass in normal years from November through February and that their plants' water needs will be met with rainfall alone.

The opposite process of evaporation is condensation, the process through which water as a gas turns into liquid water again. Condensation is the process through which clouds form. This is also the process through which water beads on the outside of a glass of iced tea on a humid day or on a mirror in a steamy bathroom. In terms of the water supply picture, condensation is the key process that can lead to precipitation, so clouds are carefully monitored by scientists.

What makes the water cycle work? In short, gravity and the sun. Notice that there is always groundwater flow and streamflow from a higher altitude to a lower altitude. Gravity drives this flow of water in the water cycle, and is also a key force in most water distribution systems. If you're not using gravity, you're going to need a pump to go from a lower elevation to a higher elevation. Systems are generally designed to avoid pumps if possible and use the force of gravity. The sun drives the water cycle in a different

way, by heating the water and causing it to evaporate. It also melts the snowpack in the mountains while gravity causes the water to flow into streams, rivers and lakes.

In Section 1.1, you've learned the basic processes in the water cycle: precipitation, infiltration, evaporation, transpiration, and condensation. Next, you'll see how these processes create surface and groundwater supplies and how these supplies are used for water management.

Try It!

Describe a process at work in each scenario and how the process works:

1. Analyze the effect on the water cycle if California had no precipitation for a year.
2. You hang a wet swimsuit out on the balcony to dry overnight. What process is at work? How is water changing states?
3. Using the CIMIS web site (www.cimis.water.ca.gov/), register for an account (free). Then under the Data tab, find the nearest CIMIS station to your home create a monthly web report for 12 consecutive months, which should include ET. When should you water the most? When should you water the least?

Key Terms

Condensation—The process through which water as a gas turns into liquid water again; opposite of evaporation

Evaporation—The process through which liquid water turns into a gas; opposite of condensation

Evapotranspiration—The combination of water loss from liquid water in the ground evaporating and water in plants losing water

Groundwater—Water stored in the ground

Infiltration—The process through which water seeps into the ground

Precipitation—All forms of water that fall from the sky, including rain, snow, hail, and sleet

Transpiration—The process through which plants lose water

Water budget—An estimate of how much water a location should use, including outdoor watering based on the amount of landscaping, the type of landscaping and the evapotranspiration

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4.1.2: Water Management Concepts

Let's engage in a little thought experiment.

If a zombie apocalypse happened right now and you ran for the hills, you would have to find water to survive. How would you go about doing this? In this section, you'll identify sources of water supply. This section is critical to an understanding of water management, both personally as well as regionally and statewide.

Learning Objectives

- After reading this section, you should be able to:
- Describe various sources of surface and groundwater supply
- Give examples of water storage
- Evaluate a situation in terms of conjunctive use

Now back to the zombie apocalypse. If you had to find water, you would probably:

- Try to find a stream or lake
- Start digging a well

Notice that you didn't start with the ocean. This is important because most of us intuitively understand the amount of energy it takes to make ocean water drinkable. Although most of the water on earth is in the oceans, bays, and seas, it's not drinkable without expensive treatment. Who would have time for that level of treatment in the zombie apocalypse? And you also didn't start with the ice caps (too far and too many zombies in the way). What you have intuitively chosen is the right solution—surface water and groundwater. And your strategy reveals another challenge for water managers—most of the water on earth is not accessible or easily potable (drinkable).

Most of the water on earth is in the ocean (97%). For the 3% that remains as freshwater, most of it is trapped in glaciers and ice caps (68.7%). That leaves only groundwater and surface water making up less than 1% of the water on earth. You can see why people refer to water as precious! In fact, 20% of all freshwater on earth is in one enormous lake in Russia, Lake Baikal, which is inaccessible to most of us on earth.

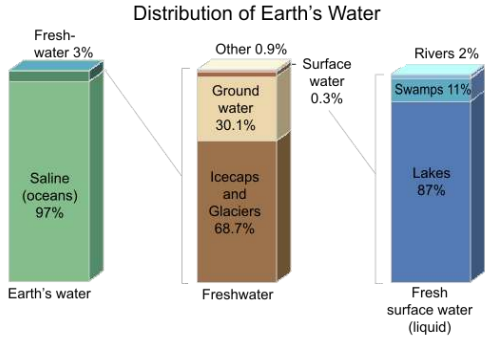


Figure **4.1.2.1**: Distribution of Earth's Water by the U.S. Geological Survey is in the public domain

Surface water can be broken into different types, but it is easiest to think of surface water as either bodies of water and flowing water. Surface water can occur as a lake or pond, both bodies of water at low places in the land where water has accumulated. Most lakes have both inflow and outflow. Some lakes lack inflow and/or outflow and they become salty over time (e.g., Great Salt Lake, Dead Sea, Salton Sea). A reservoir is a lake that is manmade by making a dam across a river.

Surface water can be flowing water, such as a creek, stream, or river. It can also be water stored in a lake or reservoir. People tend to use the terms creek, stream or river interchangeably. Rivers (or streams or creeks) form when water moves from higher ground to lower ground. You'll remember that in the water cycle, gravity is a driving force—all water flows downhill. When water falls from the sky as rain in the water cycle, it may infiltrate into the ground, but it also may run off and form creeks and streams. Eventually, creeks, streams and rivers flow to the ocean.

As a source of water, surface water has both benefits and drawbacks.

Benefits of Surface Water	Drawbacks of Surface Water
Easy to access	Water is lost to evaporation
Lakes and reservoirs can provide flood control in addition to a water supply	Lakes and reservoirs may experience a build-up of sediment, especially after fires
	Distribution requires a network of pipes and/or canals

Well, nothing is perfect in the study of water supply. If surface water isn't the perfect supply, perhaps groundwater is better. In the diagram below, you can see both surface water and groundwater. The water table is the line at which soil becomes saturated with water. The soil above the water table is unsaturated and the water below the water table is saturated. Groundwater is stored in aquifers, which are areas underground of soil or rock that can hold and transmit water beneath the water table.

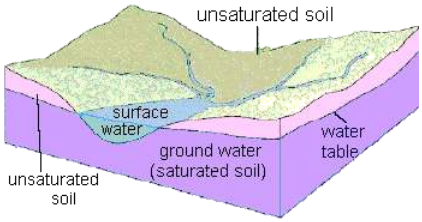


Figure **4.1.2.2**

> *Misconception Alert!*
>
> *Frequently, people will describe an aquifer as an underground swimming pool. While this does illustrate the idea that water is stored underground, it is really misleading. A swimming pool contains water entirely. An aquifer is mostly sediment or rock with water in the pores between grains of rock or sediment.*

Sediment and rock vary in terms of how much water it can store. The ability for rock to transmit media is often referred to as permeability. Sometimes gravel has large pores and rock has large connected fractures that enable water to move through them. Other times, the pores in gravel and the fractures in rock are impermeable.

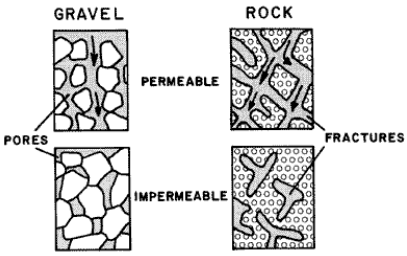


Figure **4.1.2.3**

In order to get water from the aquifer to the surface, you need either the water to come up from the ground naturally because of pressure in the layers confining the aquifer or you need to drill a well, which is much more common. In the diagram below, you can see the difference between a deep well and a shallow well. When the water table is at a normal level, both the shallow and deep well can produce water. However, when it is a drought, only the deep well can reach below the water table. The shallow well would end up being dry.

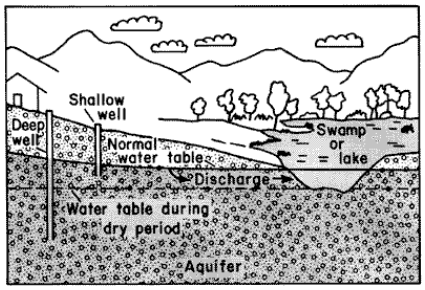


Figure **4.1.2.4**: Rock layers image by the U.S. Geological Survey is in the public domain

Groundwater as a water supply also has benefits and drawbacks that communities consider when they build their water supply portfolios.

Groundwater Benefits	Groundwater Drawbacks
Difficult to pollute	Difficult to clean up
Useful in times of drought when surface supplies are low	Replenishment is slow
Generally, cheaper	Hard to manage as levels dwindle
No need for an expensive network of pipes and canals to transport long distances	Visual inspection is difficult

Some communities use both surface water and groundwater as a supply. In years of heavy snowfall and deep snowpack, there may be abundant surface water available. In this case, surface water would be used for water supply while groundwater supplies could be allowed to replenish naturally through the infiltration of rainfall. In addition, surface water could be stored in groundwater basins to aid in replenishment. In the reverse situation, in years of light rainfall and little snowpack, groundwater would be relied on as a primary source because surface water was not a sufficient supply. The practice of alternating water supplies to meet the needs in a community is called conjunctive use.

Both surface water and groundwater can provide adequate yearly sources of water, but it is best to have water stored for use in dry years or for emergencies. Water can be stored above ground in reservoirs and below ground in banks. Storing water in reservoirs makes it readily accessible in times of drought or emergency, such as fires or if part of a distribution system goes out of service. Storing water in the ground can be done in water banks, such as the banks in Kern County.

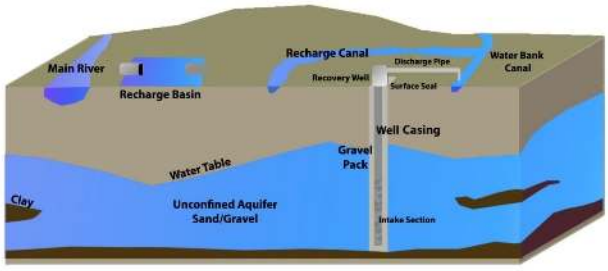


Figure **4.1.2.5**: Water Bank Diagram by Natalie Miller is licensed under CC BY 4.0

In these banks, water is injected or infiltrates directly into an aquifer. It can be retrieved later for a fee during times when groundwater and surface water are not sufficient. Many water districts find that storing water in various water banks can diversify their water supply portfolio, giving them more flexibility in providing water in dry years.

How can you make your water supply more reliable? Think of the last drought. You probably noticed lower levels in surface water at lakes and reservoirs and even in streams. In the photo comparison, you can see the difference in just over a month's time in 2014 in the visible shoreline. In this example, more water has been taken from the reservoir to treatment facilities during the late spring in 2014 with a very visible effect on the appearance of the lake!



Figure 4.1.2.6: Images of Castaic Lake (Photo used with permission of Castaic Lake Water Agency)

In California, typically, it is only through a combination of water supplies that you can have a reliable water supply. The best scenario is that you have a water supply that consists of multiple sources of groundwater and surface water. That way, when one source is dry or less reliable due to a drought or unusable due to a water quality issue, you have a backup. The ultimate scenario for water supply reliability also includes a supply of water in storage.

In Santa Clarita, there are multiple sources of water supply for the water retail companies. Sources of supply include relatively shallow groundwater wells into the alluvium, clay, silt, and gravel, as well as deeper groundwater wells into the Saugus formation. While the shallower alluvial wells provide a source of relatively inexpensive supply, they also tend to be more sensitive to droughts. Imported water from the State Water Project makes up roughly 50% of the water supply in a normal year though the amount in this supply relies entirely on the snowpack in the Sierra Nevada Mountains.

During the last drought in Santa Clarita when water deliveries from the State Water Project were at a minimum, groundwater pumping was increased above normal year levels. When deliveries from the State Water Project returned to pre-drought levels in 2017, groundwater wells were pumped less in order to let the well levels recover. This is a classic example of conjunctive use that brings together what you've learned about groundwater and surface water because of the alternation of supplies in order to achieve greater reliability.

Now that you understand the concepts used to manage groundwater and surface water, let's take a look at water rights in California.

Try It!

1. Identify at least three potential sources of water that you could use during the zombie apocalypse.
2. Describe the drawbacks of surface water and groundwater.
3. Many communities in California rely on groundwater and surface water. Explain how conjunctive use might apply.

Key Terms

Alluvium—Clay, silt, or gravel left from old rivers

Aquifers—Areas underground of soil or rock that can hold and transmit water

Conjunctive use—Use of alternating water supplies to meet the water demands

Permeability—The ability to transmit water

Potable—Drinkable water

Reservoir—A lake that is manmade by making a dam across a river

Surface water—Flowing water, such as a creek, stream, or river; also still river stored in a lake or reservoir

Water table—The line at which soil becomes saturated with water

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4.1.3: Water Rights

In order to understand the types of water rights that you'll find in California, you'll have to take a bit of a trip back in time, not just in California history, but in British history as well. You will be able to apply what you have learned about surface and groundwater.

Learning Objectives

After reading this section, you should be able to:

- Distinguish between surface water and groundwater rights
- Describe types of water rights found in California
- Analyze a situation involving water rights to determine which rights should prevail

You probably recall that California was not always a state within the United States. For many years, it was a settlement of the Spanish government, and later, the Mexican government. Settlements of the Spanish and Mexican governments have pueblo rights to both the surface and groundwater within the settlement limits. These rights are considered to have the highest priority compared to all other right types and cannot be lost.

The City of Los Angeles has exercised pueblo rights several times in its history, illustrating interesting features of pueblo rights:

1. A pueblo water right can increase in quantity as the population increases. As the population of Los Angeles has increased, the pueblo water right to flows of the Los Angeles River as well as to groundwater have increased in terms of quantity;
2. A pueblo water right can be extended to newly annexed areas of the original pueblo, such as when the City of Los Angeles annexed the San Fernando Valley

You can see how pueblo water rights are extremely encompassing and useful.

Pueblo Rights	Riparian Rights
Exist because of historical affiliation with Spain and Mexico	Exist because of streamside location
Can increase in quantity based on population or area annexed	Not quantified
	Only beneficial and reasonable use (not wasteful)

Shifting continents for a moment, we will explore the idea of riparian rights. In English common law, a riparian right (riparian means "streamside") is the right to use surface water because you own property that is adjacent to it. This means that if you bought a home that was adjacent to a stream, you would have the right to use the water from it. You could only use the water that was naturally flowing from the stream, not water from upstream or downstream that you channeled into your land. If you lived one street further away and didn't own any property adjacent to the stream, you would have no riparian rights. Riparian rights are not quantified, so if you owned that house on the stream, you may only use as much water to make reasonable and beneficial use of it.

Now taking what you've learned about pueblo water rights and riparian rights, let's shift back to California to the mid-1800s when gold mining was thriving. An appropriative right stems from mining practices in which miners worked on public land using the water to dislodge soil to expose gold. Often, water had to be channeled a distance from its origin to where it was used. This was considered an appropriation of water. Miners literally posted a notice about their diversion of water to stake a claim to that water. Whereas riparian rights are not quantitative, an appropriative right is a specific amount of water for a specific purpose in a specific place. If there is not enough water for all appropriators, the ones with the older appropriations get their water first.



Figure 4.1.3.1: Hydraulic Gold Mining by Carlton Wakins is in the public domain - *Hydraulic mining in the 1880s in Nevada City, California*

The most famous legal case involving surface water rights is Lux v. Haggin (1886), which established the existence of both riparian rights and appropriative rights and the relationship between the types of rights. In this case, Haggin owned the upstream Kern Valley Land and Water Company, which diverted water for irrigation. Because Haggin did not own land that was adjacent to the water, he was exercising appropriative rights and not riparian rights. Miller-Lux owned downstream land that was adjacent to the Kern River and exercised riparian rights. During a drought, Haggin continued to use upstream water and cattle owned by Miller-Lux died due to lack of available water. Miller-Lux sued Haggin. The primary question, in this case, was whether an upstream appropriator could divert water in a way that hurt a downstream holder of riparian rights. In a surprising outcome, the California Supreme Court ruled that appropriators (Haggin) could have senior rights if the rights were established prior to downstream riparian use.

In Herminghaus v. Southern California Edison (1926), riparian and appropriative rights faced off again. Herminghaus was using riparian rights to irrigate by letting water from the San Joaquin River flood his crops. Southern California Edison wanted to build an upstream power plant using appropriative rights. The California Supreme Court ruled that downstream riparian use had the right to the entire flow of the San Joaquin River for flood irrigation. In other words, the California Supreme Court ruled that the downstream riparian right trumped the appropriative right, which meant Southern California Edison received no water rights.

Currently, appropriative rights are governed by a “first in time, first in right” philosophy and regulated by the State Water Resources Control Board. A “first in time, first in right” philosophy means that if you are using the water first, you have seniority in terms of water use. In times of water shortage, you will get your water first. Much like you saw in the previous court cases, you do not need to own the land in order to have an appropriative right to water. However, you do need to use the water in a reasonable and beneficial way with an appropriative right.

While surface water rights have hundreds of years of history, groundwater rights are relatively recent and currently changing in California. Currently, in California, the Sustainable Groundwater Management Act is driving the management of groundwater in a much more deliberate fashion. Basins in California have been ranked according to their priority for the development of a groundwater management plan into high, medium, and low priority. Basins with high ranking are currently developing plans for agency formation.

Groundwater rights can be overlying or appropriative. Remember your streamside house? It had riparian rights to use water from the stream. You would also own overlying rights and the rights to drill a well and pump water to use water on your own land. If your neighbor behind you wanted to pump water to take the water off of the land, he would be using appropriative rights. Appropriative rights in groundwater are similar to rights in surface water. “First in time, first in right” means that groundwater appropriators are evaluated in terms of when they started using the water.

Although groundwater and surface water rights have some of the same names, it is important to note that they are managed as if they are not related. For surface water rights, you can have pueblo water rights if the land was originally a Spanish or a Mexican settlement, riparian rights if you are using the water streamside and appropriative rights if you are using the water away from the source. For groundwater rights, you can have overlying rights or appropriative rights. From studying the water cycle, you already understand that surface water and groundwater are related. It would make sense if their rights were connected rather than treated as separate entities.

Try It!

1. You own a home and would like to dig a well in the backyard. What type of water rights would be involved?
2. You would like to run a pipe from your neighbor's creek to your home to engage in flood irrigation. What types of rights are involved? What issues might come up?
3. When might you have a surge in water rights disputes?

Key Terms

Appropriative right—Right to move water from its source; quantities for a specific purpose in a specific location; often called "first in time, first in right" rights

Overlying rights—Groundwater rights for water underneath the land

Pueblo rights—Rights that pueblos and settlements of the Spanish and Mexican government have for surface and groundwater rights; pueblo water rights can increase in quantity as population increases and can be extended to newly annexed areas

Riparian right—Streamside right to surface water

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4.1.4: Stakeholder Concepts

Who are stakeholders in your water supply?

While you might immediately think of your water utility, city or county agencies, you are also a stakeholder in the water supply. You are a resident and you use the water in some fashion (e.g., drinking, cooking, cleaning yourself and clothes, irrigating, and swimming).

How much interest do you have in the water supply? And how much power do you wield in critical discussions about water?

Learning Objectives

After reading this section, you should be able to:

- Identify and classify stakeholders
- Differentiate among stakeholders according to the level of interest and the level of power

Stakeholders are people with a “stake” in an idea or project. These could be people who are financially related to the idea or project, interested in the environmental impacts, or just plain curious. In many nationwide issues, like the presidential election, health insurance, or gasoline prices, all residents of the United States have a “stake.” Some issues are much more regional, such as water supply issues or air pollution issues, in which residents in a smaller geographic area have a stake while some issues, such as health care, are nationwide issues

Stakeholders are typically classified as internal or external. An internal stakeholder is a person within an organization, such as a staff person or board member, while an external stakeholder is outside an organization. For example, suppose that staff at a water agency was considering changing the rules for a turf grass removal program, commonly called "Cash for Grass," in order to stop rebating artificial turf. Here is a table of the internal and external stakeholders who have a “stake” in this proposal to remove artificial turf from the Cash for Grass program:

Internal Stakeholders	External Stakeholders
Staff at the water agency	Residents in the area
Management at the water agency	Landscapers (who install plant material)
Board members at the water agency	Contractors (who install artificial turf)

Why is it important to identify stakeholders and categorize them? As you work in the water industry, you will find that reaching out, listening to, and working with stakeholder groups is critical to your success. In the example above, what would happen if staff didn't reach out to contractors who install artificial turf? It's possible that they would become very angry because a potential source of income (installation of artificial turf for rebates) has been taken away from them. They might make phone calls to managers and board members. They might attend board meetings to speak and protest during public comment. Their anger might have been moderated if staff had reached out ahead of time to explain the reason for the rule change and offer some alternative strategies to move ahead.

Let's take another example from the water industry. Let's say the customer service manager decided to implement a new software program that sent work orders to field representatives. The customer service manager bought the software with her own manager's approval, but chose not to introduce customer service and field staff to the new product. Instead, the customer service manager rolled out the product at a meeting after the software was purchased. How do you think the staff felt? They may have had valid concerns about the software, but the entire purchase was presented to them like a done deal. The customer service manager should have identified her stakeholders, including internal stakeholders like customer service and field staff, ahead of time.

Stakeholders are people very specifically interested in an idea or concept whether it's artificial turf or work order software. Stakeholders are specific to the locale as well as the concept. For example, the City of Beverly Hills developed a cultural plan, which included an extensive list of stakeholder groups: residents, businesses, chamber of commerce, entertainment industry, faith-based communities, fashion community, financial sector, gay community, homeowners associations, Iranian community, lawyers

associations, media, private galleries, restaurants, senior community, service clubs, and the tourist industry, including hotels and visitors.

A cultural plan for a different city would have different stakeholder groups and, a stakeholder list for a different issue in the same city would have different stakeholders. Let's look at what would happen if we looked at a different issue, like water supply reliability, and identify internal and external stakeholders in Beverly Hills. Stakeholders who were added to the list are in blue text. Many of the stakeholder groups that were interested in a cultural plan do not appear below because they may not be interested in water supply reliability.

Internal Stakeholders for Water Supply Plan	External Stakeholders for Water Supply Plan
City of Beverly Hills staff	Residents
City of Beverly Hills management	Businesses
Beverly Hills City Manager	Chamber of Commerce
Beverly Hills City Council	Environmental Groups
Metropolitan Water District (wholesale supplier of water)	Homeowners' Associations (HOAs)
	Large Residential Users (A Top 100 List)
	Media
	Restaurants
	Tourism & Hotel Industry
	Visitors

The list is by no means all-inclusive, but shows that there are some groups that will be constant in an area because they are powerful (HOAs, tourism & hotel industry, and restaurants) and some groups that are specific to an issue (e.g., Environmental Groups and Top 100 water users). This list is shorter and more focused on where the water is used.

Once you have identified your stakeholders, you can arrange them according to their level of interest and power.

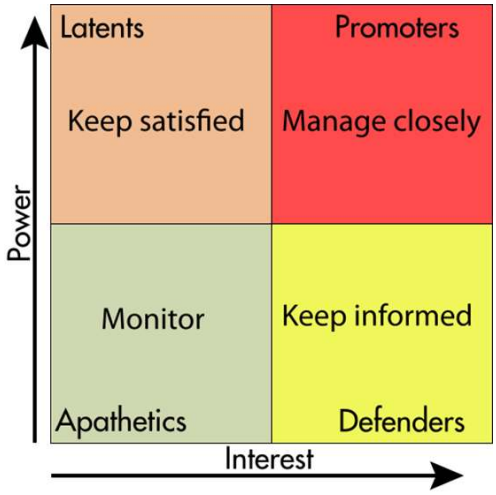


Figure **4.1.4.1**: Stakeholders Matrix by Zirguezi is licensed under CC0 1.0 - *Power vs. Interest Chart*

In terms of water issues, most of the public, most of the time, unfortunately, has a relatively low level of interest and low level of power, which would classify them as Apathetics. But come drought time? You will have a much higher level of interest for most people and they will shift from the Apathetics to the Defenders. They may not have a high level of power, but their interest in water supply reliability is much higher.

Not everyone who is powerful is interested in all issues. For water supply, there are frequently groups that simply do not perceive water supply to be an issue, and choose to focus their energy elsewhere. They would be considered Latents (“latent” means that the interest is lying dormant, but could be expressed with the right circumstances). A Latent stakeholder might become more interested in water supply reliability if he/she were involved in a development that needed water, if there was a drought, or if there were mandatory watering schedules or penalties that affected his/her interests.

One of the most important issues in water supply management in the state of California is the challenge of the Sacramento-San Joaquin Bay Delta. Formed by the confluence of the Sacramento and the San Joaquin Rivers, the Bay Delta, south of Sacramento is the source of continual stakeholder challenges. Who are the stakeholders in the Bay Delta? At first, it seems obvious: there are residents and farmers who live and work in the Delta. While they are the most visible stakeholders, the water supply for much of Southern California flows through the Delta so Central Valley farmers and Southern Californians are also stakeholders (most Southern Californians would be Latents though until a crisis arises). Likewise, Northern Californians are stakeholders, because this is water that is leaving their area. Frequently discussions about the Bay Delta are framed around the strong interest and immense amounts of power that Southern California wields and the high interest, but low amounts of power that the farmers in the Bay Delta hold. We will discuss more about the Bay Delta in the section on the State Water Project.

You've learned about the importance of involving stakeholders and that stakeholders can be classified as internal or external and in terms of power and influence as well as interest. In Part Two of this text, you'll look at four major surface water development projects in terms of stakeholders.

Try It!

1. Identify a water-related issue in your area. Try typing into Google "water issues" and the name of the community. Who are the stakeholders? Classify them as internal or external. Classify each stakeholder on a grid in terms of their interest and power.
2. In the water-related issue you chose above, what are ways (other than the drought) to increase the level of interest of stakeholders in the issue?
3. Add the stakeholders in the conservation program rule change scenario to a chart in terms of interest and power. Who has both a lot of interest and a lot of power? Who has neither interest nor power?

Key Terms

Stakeholders—People or organizations with a “stake” in an idea or concept

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SECTION OVERVIEW

4.2: Supply-Side Management

In Part Two of this text, we'll explore supply-side management. A supply-side management approach to water concentrates on securing more water supplies through engineering feats. Supply-side management was frequently done by building massive engineering projects to move water hundreds of miles. While they were impressive projects at the time, today, there are more significant regulatory hurdles to building supply-side projects, including environmental regulations. The difficulty of building major infrastructure projects has led to more work being done with exploring alternative supplies and reducing demand.

For a long time, human beings have related to nature as if nature was something to be conquered. In the United States, until the 1960s, the natural environment was viewed as mostly inconsequential to expansion and development. The environmental movement, beginning with the publication of Rachel Carson's *Silent Spring* in 1962 and continuing with the Cuyahoga River catching on fire due to pollution in 1969, began to change the way we related to nature. Perhaps nature wasn't something to be vanquished as an enemy. Perhaps nature isn't limitless. As you examine four large public works projects in California, it is important to keep the shifting mentality of these times in mind. Each project was a feat to build at the time, and in some cases seen as a battle of man against nature. With current regulatory requirements, these projects would be just about impossible to build today.

In Part Two, we will cover these topics:

- Water Development Projects
  - Los Angeles Aqueduct
  - Colorado Aqueduct
  - Central Valley Project
  - State Water Project
- Alternative Water Sources
  - Recycled water
  - Gray water
  - Stormwater
  - Desalination

Water Development Projects

The primary challenge in water supply planning in California is usually framed as spatial. Most of the water is in the northern part of the state and most of the people live in the southern part of the state. In other words, the supply does not exist where the demand is. However, there is an additional challenge as well. Much of California receives water during the winter and early spring when the demands are the least, and not during the summer and fall when the demands are the greatest. This creates a temporal (time) challenge because the supply has to be stored until it is needed.

The map below shows the population centers in the Bay Area and Los Angeles Area as well as the volume of storage at various reservoirs throughout California. Notice how storage is concentrated in central and Northern California away from Southern California. This frames many of the water development projects.

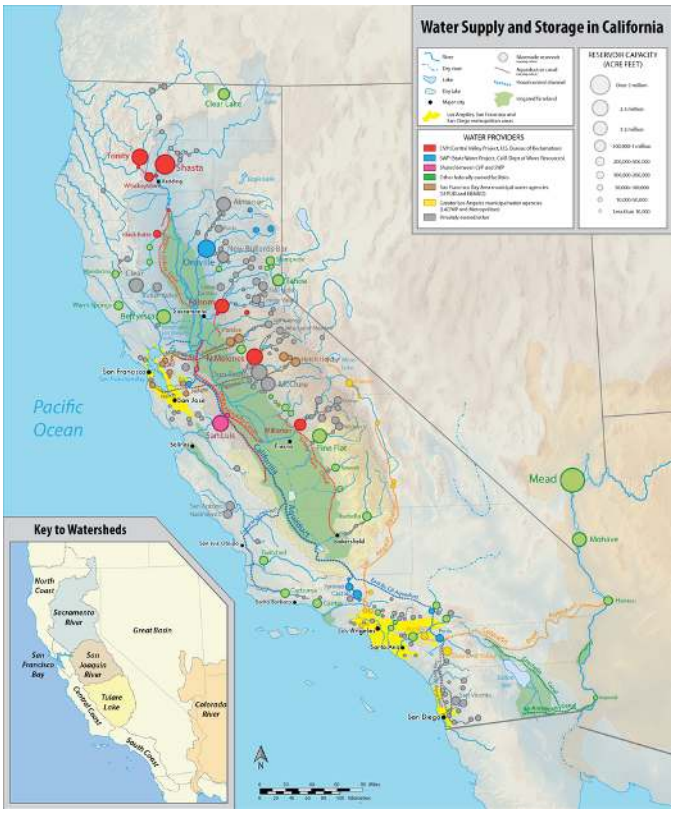


Figure **4.2.1**

4.2.1: Los Angeles Aqueduct

4.2.2: Central Valley Project

4.2.3: Colorado River Aqueduct

4.2.4: State Water Project

4.2.5: Alternative Water Supplies

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4.2.1: Los Angeles Aqueduct

Learning Objectives

After reading this section, you should be able to:

- Identify driving factors in the construction of the Los Angeles Aqueduct
- Classify stakeholders in the construction of the Los Angeles Aqueduct
- Evaluate the impacts of Decision 1631

Year	Population
1850	1,610
1860	4,385
1870	5,728
1880	11,183
1890	50,395
1900	102,479

To understand current day Los Angeles, you need to understand the population explosion in the last two hundred years in the Los Angeles basin. Los Angeles was initially a Spanish pueblo when founded in 1781 and it had a small population. A combination of surface water from the Los Angeles River and groundwater from artesian springs remained sufficient supply for a long time. As you know, Los Angeles was entitled to these supplies of surface water and groundwater because of pueblo water rights. While the supplies were sufficient for the existing population, the introduction of cattle ranching and citrus cultivation in the 1880s coupled with a drought resulted in strained water supplies.

Now, imagine you are the superintendent of this water system within California, which has been reliable under current conditions, but is strained by more and more people.

Ack! Look at those numbers! You're going to run out of water!

In 50 years, the population increased from just over fifteen hundred to over one hundred thousand people. This is the fix William Mulholland found himself in as superintendent of the water system: a burgeoning population and a dwindling water supply. His friend and colleague, former mayor of Los Angeles, Fred Eaton, suggested the Owens River as a potential supply. The Owens River relied on snowmelt from the Sierras. In order to obtain the rights for the water, the land surrounding the river was purchased to obtain water rights.



Figure **4.2.1.1**: Photographic portrait of William Mulholland with a surveyor's scope on a tripod by University of Southern California Libraries and California Historical Society is licensed under CC BY 3.0

Both Eaton and Mulholland were engineers. They were intrigued by the idea that the water could be conveyed entirely by gravity with a slight slope in the aqueduct from more than 3800 feet above sea level to 1400 feet above sea level. The energy from the water was even enough to generate electricity at a number of power plants that were built along the way. In many ways, their

fascination with the engineering aspects of the project may have kept them from fully considering other ethical concerns as they orchestrated purchases of land in the Owens Valley.

Year	Population
1910	319,198
1920	576,673
1930	1,238,048
1940	1,504,277
1950	1,970,358
1960	2,479,015
1970	2,811,801
1980	2,968,579
1990	3,485,398
2000	3,694,742
2010	3,792,621

Eaton and Mulholland certainly seemed to disregard stakeholders in this potential project. For example, the residents of the Owens Valley, including farmers, ranchers and the indigenous Paiute people, were certainly going to be impacted by directing the water to Southern California. These stakeholders, whose lives were dependent on the water, had very little power to mount a protest at the time. And, in fact, they generally were not asked for permission. The purchases of land in the Owens Valley were conducted in ways that seemed underhanded and non-transparent, including agents for the City of Los Angeles representing themselves as from the Bureau of Reclamation. At the point when actual stakeholders in Southern California were brought in to fund and approve the project, the land was already purchased. This is a classic example of stakeholders not being consulted until the project is almost a *fait accompli*.

Even though Mulholland had found enough water for the existing population in Los Angeles, the population continued to grow. By 1923, Mulholland had explored the possibility of bringing water from the Colorado River as well as the second portion of the Los Angeles Aqueduct to Mono Lake. Both projects moved ahead because it was clear that the original Los Angeles Aqueduct was not enough.

And, in the end, even the second addition to the Los Angeles Aqueduct was not enough. The Los Angeles Aqueduct was completed in three parts:

- Part One: 1913 - Los Angeles voted 10 to 1 to authorize $23 million for the first Los Angeles Aqueduct and it is subsequently built.
- Part Two: 1940 - Los Angeles votes to extend the Los Angeles Aqueduct to the Mono Lake watershed for $40 million and the extension is built.
- Part Three: 1963 - Los Angeles begins the construction of the second Los Angeles Aqueduct project



Figure **4.2.1.2**: Los Angeles Aqueduct used with permission of Los Angeles Department of Water and Power

In sum, using only gravity, the Los Angeles Aqueduct encompasses canals from the Mono Lake watershed to Los Angeles stretching over 340 miles in three separate projects.

While the Los Angeles Aqueduct provided a great benefit to the residents in Southern California, it left the Owens Valley a dust bowl, including carcinogenic dust containing cadmium and nickel. After numerous years of protest and litigation, the State Water Resources Control Board in Decision 1631 drastically reduced the amount of water that could be removed from the Owens Valley from 90,000 acre-feet per year (AFY) to 16,000 AFY. How did this happen? This decision applied the public trust doctrine in a new way. The public trust doctrine addresses rights to things that are owned collectively for public use by the government, such as water and air. This interpretation allowed the water in the Owens Valley to be seen as a public resource and not something that could solely benefit Los Angeles.

As a water supply, the Los Angeles Aqueduct provides water that is dependent on local hydrology within Owens Valley. Because of the variability and Decision 1631, Los Angeles has been forced to focus on demand reduction, rely more on alternate sources of water, such as those from Metropolitan Water District of Southern California, and remediation of existing groundwater supplies in the San Fernando Groundwater Basin.

> *Misconception Alert!*
> *Many people think that all of the water supply in Los Angeles comes from the Owens Valley. As you saw in this section, only 16,000 AFY currently come through the Los Angeles Aqueduct. The rest of the supply is a matter of other imported water, including the Colorado River, as well as groundwater in the San Fernando Groundwater Basin.*

Try It!

1. What were some of the drawbacks of removing water from the Owens Valley?
2. What were the effects of Decision 1631?

3. What stakeholders were not consulted in the development of the Los Angeles Aqueduct?

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4.2.2: Central Valley Project



Figure **4.2.2.1**: Central Valley Project by Shannon1 is licensed under CC BY-SA 4.0

California's Central Valley is known as one of the most productive agricultural regions on earth, but it was not always this way. For a long time, the Central Valley was ranching country. And then it was farming country, but was farmed "dry," meaning without supplemental irrigation. It wasn't until the population influx in the 1850s with the gold miners and the development of a pump that there was a drive to make the Central Valley intensively agricultural.

After decades of pumping water for irrigation in the Central Valley and a drought from 1928-1934, the Central Valley Project was conceived as a plan to ensure water supply reliability and protect it from floods.

Learning Objectives

After reading this section, you should be able to:

- Identify and critique the purposes of the Central Valley Project
- Anticipate the future crises for the Central Valley Project

The Central Valley typifies the challenge of California's water supply. Most of the rainfall occurs in five months, from December to April. There is enough rain to regularly produce flooding in these months. But when the needs of the plants are the greatest for food production (spring and summer), there is little natural rainfall. Pumping supplemental water made the groundwater levels drop significantly in the Central Valley causing subsidence. Diverting river flows for irrigation brought in the salt waters to the Sacramento-San Joaquin Bay Delta, which meant saltier water, sometimes unfit for irrigation, came inland.

The state of California authorized the California Central Valley Project Act of 1933 to sell bonds to fund the project. However, due to the Great Depression, the bonds didn't sell. The federal government took control of the project with the Rivers and Harbors Act of 1935 and the project was finally approved in 1935 for construction by the federal Bureau of Reclamation, which eventually took over operation.

The Central Valley Project was authorized with three key elements in its mission: flood control, water for irrigation and power generation. Water quality was added later to the mission as well as recreation and fish and wildlife enhancement.

Although the Central Valley Project is the largest of the federal water reclamation projects and includes reservoirs capable of storing 11 million acre-feet of water, it has a fairly simple structure. Water is stored in Shasta Reservoir and Shasta Dam acts as flood control for the Sacramento River. The Trinity River supplements the Sacramento River. The San Joaquin River supplies areas south of the Delta.

The Central Valley Project shares some facilities including San Luis Reservoir with the State Water Project. The photo below shows Shasta Dam, which is exclusively used by the Central Valley Project.



Figure **4.2.2.2**

> *Misconception Alert!*
>
> *Many people believe that Shasta Lake is part of the State Water Project. As you learned in this section, this is part of the Central Valley Project. The State Water Project has another larger reservoir that stores water in Northern California, Lake Oroville. These reservoirs are typically confused by many people.*

The Central Valley Project Improvement Act in 1992 allocated water for fishery restoration. This is similar to Decision 1631 in that a water development project was re-evaluated with current environmental norms. The allocation for fishery restoration is 800,00 AFY, which is perceived as enormous by some. This was a considerable change in the mission of the Central Valley Project from water supply reliability, irrigation, and power generation to fish and wildlife enhancement.

Try It!

1. Compare and contrast the Los Angeles Aqueduct and Central Valley Project.
2. Investigate potential challenges to the Central Valley Project in the future.

Key Terms

California Central Valley Project Act of 1933—Authorized by the state of California to sell bonds to fund the Central Valley Project. However, due to the Great Depression, the bonds didn't sell.

Central Valley Project Improvement Act in 1992—Allocated water for fishery restoration in the Central Valley Project

Rivers and Harbors Act of 1935—Authorized by the federal government to fund the Central Valley Project in 1935 for construction by the federal Bureau of Reclamation

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4.2.3: Colorado River Aqueduct

Metropolitan Water District was formed in 1928 with the explicit purpose of picking up on where the City of Los Angeles left off with the planning for the use of the Colorado River. The Colorado River Aqueduct was funded by voters three years later in 1931, begun in 1933 and completed in 1935. Water first began to flow in 1939. Even though this time frame is relatively short, the Colorado River Aqueduct was the result of a series of lengthy and heated negotiations, which we will now explore. Collectively the agreements that govern the Colorado River are known as The Law of the River.

Learning Objectives

After reading this section, you should be able to:

- Differentiate among key agreements that are part of The Law of the River
- Conjecture as to possible sources of future disagreement



Figure **4.2.3.1**

The primary tension with all Law of the River negotiations is similar to the tension in California: spatial. The water doesn't exist where the population centers are. But the geography of the Western United States is much more vast than just California. There are seven states considered to be within the Colorado River Basin: Wyoming, Colorado, Utah, New Mexico, Arizona, Nevada, and California. These are all primary stakeholders in the use of the Colorado River. The upper basin states include Wyoming, Colorado, Utah, and New Mexico. Upper basin states were especially sparse in population and anticipated that they might need the Colorado River water at some point as their populations increased or industries like natural gas extraction grew, but they didn't have an immediate need for the water. The lower basin states included California, Arizona, and Nevada, most of whom had burgeoning populations. The upper basin states were originally concerned that if the lower basin states constructed dams, including Hoover Dam, and began to use the Colorado River that under the doctrine of prior appropriation, the upper basin states would not be able to use the Colorado River's water again.

The first important agreement in The Law of the River is the Colorado River Compact of 1922, which divided the basin in half. Each basin had the right to use 7.5 MAF of water based on an average flow of the Colorado River of 18 million acre-feet per year, plus a small allocation to Mexico. While most states ratified this agreement, it took Arizona 22 years to ratify it, which is a window into the contentiousness. Arizona was greatly concerned about not receiving enough water eventually and of California taking water that Arizona was entitled to.

The second important agreement in The Law of the River was the Boulder Canyon Project Act of 1928. Negotiations for this agreement lasted seven years, and including four bills being introduced and a filibuster. In this agreement, the lower basin was apportioned among the states:

- Arizona - 2.8 MAF
- California - 4.4 MAF
- Nevada - 0.3 MAF

The Secretary of the Interior was directed to function as the authority for water use in the lower basin, including the ability to commission studies on feasibility for dams and storage. It is interesting to note how small the apportionment for Nevada is.

As a slightly less important agreement in the Law of the River, the California Seven Party Agreement of 1931 is an agreement for division of water among seven entities. The parties included Palo Verde Irrigation District, Yuma Project, Imperial Irrigation District, Coachella Valley Irrigation District, Metropolitan Water District, and the City and County of San Diego. This agreement temporarily settled longstanding disagreements between agricultural and urban users.

The third important act in The Law of The River is an international treaty. In the Mexican Water Treaty of 1944, 1.5 MAF of the Colorado River flow were committed to be received in Mexico. While the amount was agreed upon, the quality of the water remained undetermined. Due to agricultural and urban use, the quality of the Colorado River becomes worse the further south the river flows. A desalting plant for removing salt was eventually built in Yuma, Arizona to increase the quality of the water released to Mexico.

In the fourth important agreement in The Law of the River, the Upper Colorado River Basin Act of 1948, the upper Colorado River Commission was created and the Upper Basin was apportioned:

- Colorado - 51.75%
- New Mexico - 11.25%
- Utah - 23%
- Wyoming - 14%

During the negotiations, it was noted that the originally agreed upon amount of 18 million acre-feet of normal flow for the Colorado River might be an overestimation and that agreements would be better done by percent rather than flat allocations of water.

The Law of the River is a complicated set of agreements, and the previous pages only covered the major agreements. It should be clear that there will be issues of allocations, water rights, and urban v. agricultural differences for many years to come. Several recent modifications to the Law of the River were made because of droughts. In 2007, interim guidelines for allocating the Colorado River during water shortages through 2026 were signed by the Secretary of the Interior. Water shortages were determined based on the surface elevation of Lake Mead. In 2012, the United States and Mexico signed Minute 319 that addressed how Mexico's allocation of 1.5 MAF would change in drought conditions also based on the surface elevation of Lake Mead.

Try It!

1. What is the difference between the Upper Colorado Basin Act and the Boulder Canyon Project Act?
2. What is a likely source of disagreement in the future?

Key Terms

Boulder Canyon Project Act of 1928—Apportioned the lower Colorado River basin among three states:

- Arizona - 2.8 MAF
- California - 4.4 MAF
- Nevada - 0.3 MAF

Colorado River Compact of 1922—Which divided the basin in half; each basin had the right to use 7.5 MAF of water based on an average flow of the Colorado River of 18 million acre-feet per year, plus a small allocation to Mexico

The Law of the River—Collectively the laws and regulations that govern the Colorado River

Mexican Water Treaty of 1944—Committed 1.5 MAF of the Colorado River flow to Mexico; did not describe the quality of water, just quantity

Minute 319—An international agreement between the United States and Mexico regarding the Colorado River that addressed how Mexico's allocation of 1.5 MAF would change in drought conditions also based on the surface elevation of Lake Mead

Upper Colorado River Basin Act of 1948—Apportioned the Upper Colorado River Basin by percent:

- Colorado - 51.75%
- New Mexico - 11.25%
- Utah - 23%

- Wyoming - 14%

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4.2.4: State Water Project

The last major water infrastructure project undertaken for water supply in California was the State Water Project (SWP) and it still isn't quite finished! The SWP major features were outlined in 1957 in the California Water Plan and it was funded by the Burns-Porter Act in 1960 in $1.75 Billion in general obligation bonds.

Learning Objectives

After reading this section, you should be able to:

- Identify the major stakeholder groups and their needs
- Analyze major threats to the Sacramento-San Joaquin Delta in terms of water supply
- Project future impacts to the State Water Project

The State Water Project is a massive infrastructure project that involves several major stakeholder groups throughout the state of California, all of which have been stakeholders in other water development projects that you've learned about:

- Northern California communities that wanted flood control protection (as a result of devastating floods on the Feather River in 1955)
- San Joaquin-Sacramento River Delta communities that wanted flood protection, but also access to high-quality water for farming
- San Joaquin farmers who wanted access to water for expansion of agriculture, but also because of groundwater overdraft issues
- Southern California residents who wanted water for future growth and for water supply reliability

The State Water Project brought together these stakeholder groups with a combined mission of providing water supply to the San Joaquin Valley farmers as well as Southern California.

The State Water Contract was among 32 public water agencies all over the state, including some agencies that formed specifically to contract for SWP water supplies. The terms of the contract were 75 years minimum or until the bonds were repaid. The State of California was obligated to make reasonable efforts to complete the project. The Contractors were obligated to pay even if the water supplies were reduced or the project was not complete. As you might guess, these aren't great contract terms (paying for a project that is incomplete or reduced in some way).

The State Water Project had several purposes: flood control (specifically at Lake Oroville), recreation (e.g., Pyramid Lake, Castaic Lake) and water supply (including primary reservoirs at Oroville and San Luis and terminal reservoirs at Pyramid and Castaic Lake, Lake Perris and Lake De Val). Facilities to convey water through the Delta and for additional storage were not completed.

The Delta

The Sacramento-San Joaquin Delta (sometimes referred to only as "the Bay-Delta" or "the Delta") is one of the most interesting places in California to study in terms of stakeholders, science, and water supply.

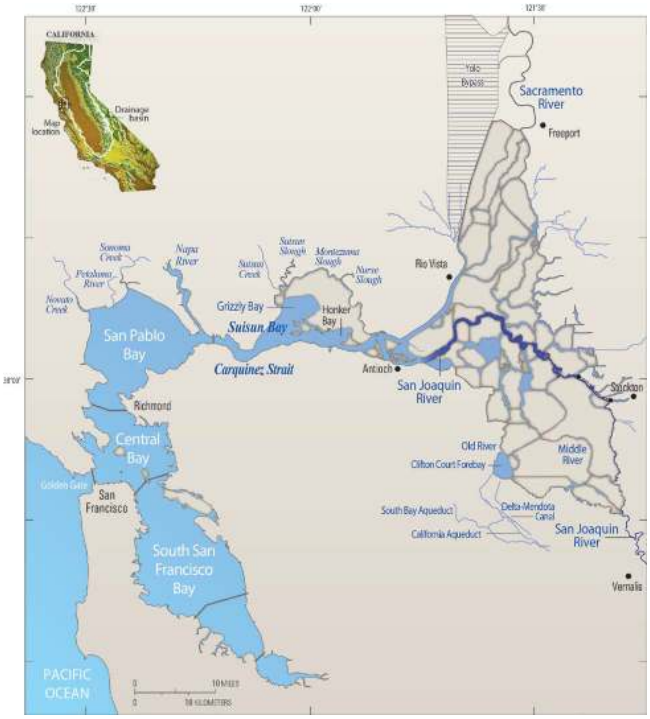


Figure **4.2.4.1**: Image of the Sacramento-San Joaquin Bay-Delta by the U.S. Geological Survey is in the public domain

In terms of stakeholders, the Delta is home to historic towns and family farms. Many farms are under sea level with manmade levees their only protection. The Delta is also fully used for recreation—boating, fishing, sightseeing, bird watching (and duck hunting). There are also millions of stakeholders south of the Delta that rely on the water supply that passes through the Delta. So combine various stakeholders with a location that is literally described as the "heart" of the water supply and you can see how there might be inherent conflicts.

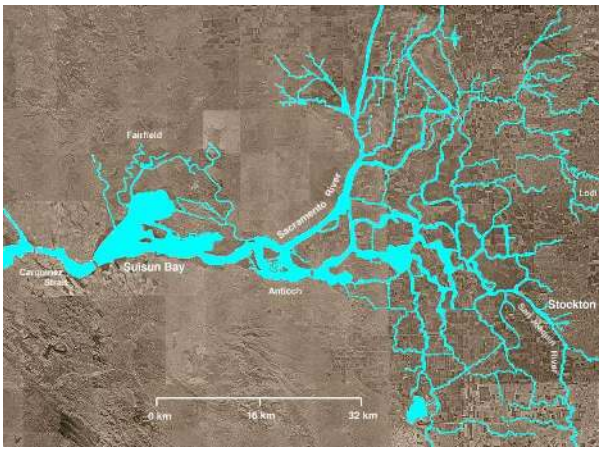


Figure **4.2.4.2**: Sacramento Delta by Matthew Trump is licensed under CC BY-SA 3.0

The Delta has been altered by farmers over the past 150 years and it has also been altered by the operation of the State Water Project and Central Valley Project. It is currently threatened by three primary issues:

Seismic—A large earthquake could break down the manmade levee system, allowing seawater into the Delta, and essentially making the water supply undrinkable for anyone south of the Delta

Subsidence—Land within the Delta is made of peat soil, which is excellent for farming, but compacts and subsides over time, leading to levees sinking and needing to be repaired and strengthened

Sea Level Rise—Sea level rise also threatens the Delta as there is often only a few feet between the top of the water and the top of the levee

The most likely path forward is two twin tunnels under the Delta. This is known as the California Water Fix (formerly known as the Bay Delta Conservation Plan).

Try It!

1. Identify three purposes of the State Water Project.
2. Write a letter advocating a plan to fix the Delta.

Key Terms

Burns-Porter Act—Funded the State Water Project in 1.75 billion in general obligation bonds in 1960

This table summarizes the four major infrastructure projects covered.

	Los Angeles Aqueduct	Central Valley Project	Colorado River Aqueduct	State Water Project
Purpose	Water supply reliability	Flood control Water for irrigation Power	Water supply	Water supply Flood control Irrigation for farms
Stakeholders	Southern California residents Owens Valley ranchers, farmers, Paiute tribe	San Joaquin Valley farmers	Wyoming, Colorado, Utah, New Mexico, Nevada, Arizona, California	Southern California residents San Joaquin Valley farmers Northern California communities with flood protection needs
Legislation		California Central Valley Project Act of 1933 Rivers and Harbors Act of 1935 Central Valley Project Improvement Act in 1992	All under The Law of The River: Colorado River compact of 1922 Boulder Canyon Project Act of 1948 Mexican Water Treaty of 1944 Upper Colorado River Basin Act of 1948 Minute 319	California Water Plan Burns-Porter Act
Major Features	Owens Lake Mono Lake	Lake Shasta San Luis Reservoir	Lake Powell Lake Mead	Lake Oroville San Luis Reservoir

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4.2.5: Alternative Water Supplies

Alternative Water Supplies are supplies other than groundwater and surface water. Frequently, they are “reused” supplies, meaning they were potable water supplies that were captured for use individually or system-wide after being used once.

Here are a few quick definitions to begin:

Recycled Water	Gray water	Storm water	Desalinated Water
Heavily treated wastewater that is used for irrigation, groundwater replenishment and as a subsurface barrier against seawater intrusion; typically in California, recycled water is used for irrigation	Household wastewater, including water from the washing machine, shower, bathroom sinks, that is captured and reused, but excluding blackwater, which is water from toilets and kitchen sinks; commonly referred to as "lightly used" water	Runoff from precipitation (rain or snowmelt) that flows overland; may mobilize pollutants and is better to capture on site to replenish groundwater	Ocean or brackish water that has had the salt removed to make it potable; two primary methods are used worldwide, but in the United States, reverse osmosis is most frequently used

Learning Objectives

After reading this section, you should be able to:

- Analyze the water supply portfolio for several geographic locales in terms of the likelihood of adding an alternative water supply
- Differentiate among types of alternative supplies and their appropriateness, given different situations

Recycled Water

You may hear “recycled water” used in a variety of ways in the United States and abroad. In California, specifically, there is some confusion in terminology. Changes to a variety of codes occurred in 1995 when “recycled water” became the term of choice rather than “reclaimed water.” These are essentially the same thing. Regulations for the level of treatment for various uses are in Title 22 of the California Code of Regulations.

What happens to wastewater when it leaves your house? It travels through a series of larger and larger pipes to a wastewater treatment facility. Alternatively, if you live rurally, your wastewater may be held and separated in a septic tank on your own property. Wastewater that has undergone primary treatment has had the solids removed. Wastewater that has undergone secondary treatment has had organic materials removed through biological processes. Secondary treated wastewater can be used for groundwater recharge and irrigation. Water that has undergone tertiary treatment has undergone sedimentation, chemical flocculation, and filtration. As you might imagine, water that has undergone tertiary treatment has a range of uses, even those involving body contact, such as recreational use in lakes, as well as irrigation.

Recycled water has only system-wide applications in that individual homes are not creating and using recycled water. You may be familiar with recycled water for irrigation of golf courses, medians, but it also can be used for groundwater recharge, including to act as a seawater intrusion barrier. Orange County Water District treats recycled water in a three-step process of microfiltration, reverse osmosis, and ultraviolet treatment. The treated water is then injected into the groundwater basin. The water serves as a barrier against the intrusion of ocean water into the aquifer.

Recycled water seems like an important source to add to a water supply portfolio. After all, what community in California wouldn't want a reliable source of water for irrigation of landscapes? And what coastal community wouldn't want water to inject into the ground as a barrier of seawater intrusion. Overall, recycled water can decrease the demand for potable water by providing an addition to a water supply portfolio. But recycled water is expensive. Next to desalination, it is one of the most expensive options out there (think of the treatment costs!). Like many aspects of infrastructure, recycled water is politically appealing to residents, but the added costs are not.

Gray water

Certainly, the water that you drink, wash your clothes in, and use to bathe needs to be potable. But what about the water that you flush your toilets with? What about the water that you irrigate with? The premise of gray water use is that not all water that we use on a daily basis needs to be potable. Keeping this in mind, you then have to consider what can be reused in your indoor water use.

Wastewater from toilets and wastewater from the kitchen sink both contain bacteria from feces or meats. But wastewater from a washing machine can be reused without many concerns, assuming diapers are not washed or clothes are not highly soiled, greasy or contaminated.

The easiest gray water system to construct is called “Laundry to Landscape.” Wastewater from the washing machine is directed to a drip irrigation system outside the house. Water isn’t stored in any fashion - when you run a load of clothes in the wash, you are irrigating with the wastewater directly afterwards. You can see that you would need to time your laundry - washing everything on Sunday would lead to too much water for irrigation. Doing a load of wash every other day might be enough water for irrigation in the summer.

What do you need in order to have a simple Laundry to Landscape system?

- Your washing machine should be located close to an exterior wall in order to run a pipe to the outside of the house
- Your house should be slightly above the area that you are irrigating so you can use gravity to direct the water to the drip system and the plants without a pump (though pumps that remove water from washing machines can be powerful and enough to move water some distance);
- You need to have plants that can be irrigated with drip irrigation (shrubs or trees); and
- You need to install a diverter valve at the washing machine that would allow especially dirty loads of laundry to drain toward the sewer or septic tank and not into your irrigation system.

There are more complicated gray water systems that involve storing gray water in tanks and using pumps and filters, but most gray water practitioners agree that simple is best.



Figure **4.2.5.1**

Here are some best practices in residential gray water systems:

- Don’t store gray water
- Minimize body contact with gray water
- Allow gray water to infiltrate the soil with drip irrigation, not pool on the surface
- Simple is better. Avoid pumps and filters.
- Install a diverter valve
- Match needs of plants

Please note that these are best practices, but not necessarily rules and regulations. Rules and regulations vary by city and county.

In a recent study of graywater systems in the Bay Area, it was noted that the most common problem in gray water systems was clogs, but this wasn't much of a surprise because most people reported performing no maintenance on the system. Plants were generally just as healthy as with a standard irrigation system and some were overwatered and some were under watered. Overall, people saw an average reduction in water use of 26%. There was at least one unintended consequence - with an abundance of water to irrigate, some people planted more plants and their irrigated area increased in size.

There are a number of institutional hurdles to expanding gray water use. The primary hurdle is one related to the construction of homes: homes are plumbed with intermingled graywater and blackwater. This means that the wastewater from the entire home is treated as blackwater and sent to the sewer or septic tank. Additionally, if you check the city, county and state code related to graywater, they are frequently contradictory. California code, Title 24, Part 6, Chapter 16 a, Part 1 establishes minimum requirements for gray water regulations. Additionally, AB 849 (Gatto) prohibits local jurisdictions from banning gray water. However, a city or county may impose additional regulations so that it becomes too complicated to establish gray water in the home. Furthermore, as you can imagine, setting up a gray water system relies on a knowledge base of basic plumbing and wastewater. It is probably not an overstatement to say that most customers try not to think about this.

> *Misconception Alert!*
>
> *Many people use "graywater" to refer to all sorts of alternative supplies, including recycled water and stormwater. This is simply incorrect, but a common misuse of language. Graywater must be water from indoor use that can be reused, typically for irrigation. It is not wastewater or stormwater.*

Stormwater

Picture the last rain storm that you remember in Southern California. Was there gentle rain for a long time? Or was there a short burst of rainfall? When there is an entire day (or even just an afternoon) of gentle rain, the rain is usually able to infiltrate into the ground, and eventually recharge the aquifers beneath the surface. But much of the rainfall that we receive in California is in bursts with heavy downpours and then days, weeks, and even years of nothing. This type of heavy rain results in a lot of run off. Stormwater is run off that can be captured.

Stormwater becomes a problem when it encounters a lot of impervious surfaces, such as asphalt and concrete. These surfaces may hold visible pollutants (e.g., trash, dog poop) and invisible residues (e.g., pesticides, herbicides). When stormwater encounters impervious surfaces and pollutants, it turns can drain pollutants into storm drains and eventually the ocean.

What slows down stormwater? Vegetation and pervious surfaces. These sorts of textured surfaces allow water to infiltrate the soil. Parkways, the area in between the sidewalk and the street, can slow water from running off properties and into the street. Planter beds near downspouts can let water percolate rather than run into the street. Plants, whether shrubs, or groundcover, or even trees, can slow water down on slopes and hillsides.

What about rain barrels? Aren't they a good way to capture stormwater? Rain barrels are typically used on a residential site to capture water that comes off the roof through the rain gutters. In many parts of the country, rain barrels work well because the water needs of the plant correspond to the times when there are heavy rains. In much of California, the rainfall occurs in the cooler times of the year when the plant water needs are minimal. This means that water in a rain barrel must be stored for lengthy periods of time. And this is where we run into issues with creating the perfect habitat to breed mosquitoes - it's still water available for irrigation, but it may be there for more than 4-7 days, which is all mosquitoes need to breed.

There are other (and better) ways to capture rainfall. On a small scale keeping vegetation on hillsides and parkways, directing downspouts to planter beds, and keeping lots of green plants will decrease stormwater run-off. On a larger scale, stormwater can be captured within a neighborhood. Several neighborhoods within Los Angeles are tackling this. Elmer Avenue in Los Angeles has a stormwater capture area. Catch basins with soft bottoms allow water to percolate into the groundwater rather than re-enter the stormwater system and get flushed into the ocean. There are also bioswales in the yards near the catch basin to slow the water and allow it to infiltrate rather than run off.

Desalination

You may hear desalination or "desal" frequently touted as the solution to all water supply problems. You may wonder why there are not more desalination plants around if it is such the perfect solution. Good question—read on.

There are two primary methods of desalination: thermal and membrane. In thermal desalination, water is heated in a boiling chamber, it then condenses in a dome, and collects in a chamber leaving all the salt behind. In membrane desalination, seawater is screened, filtered, and pushed through a reverse osmosis membrane under high pressure, and then the distilled water is treated to

drinking water standards. These methodologies aren’t that complicated, but they do tend to use large amounts of energy, leading to a high cost.

For both methods of desalination, there are similar hurdles:

Seawater intake—Seawater needs to be removed from the ocean very carefully so as not to hurt plant and animal life. Typically, a speed slower than the ocean current is best.

Power consumption—Typically, the reverse osmosis process uses the most energy, which contributes to the highest costs

Brine—While brine can be returned to the ocean, most plants and animals thrive in a small range of salinities. There may be environmental consequences associated with creating areas of higher than normal salinity.

Santa Barbara, California, provides an interesting case study in desalination work. As a result of the drought in the 1980s, the City of Santa Barbara along with Montecito and Goleta constructed a desalination facility with a capacity of 7,500 acre-feet per year (AFY) with expansion to 10,000 AFY. Construction costs of $34 million were shared based on proportions of water provided for the City of Santa Barbara of 3,181 AFY, Montecito of 1,250 AFY and Goleta of 3,069 AFY.

By the time the desalination facility was built, the drought had ended and a period of heavy rainfall had begun. The plant operated for March, April, May and June of 1992 during and after a time of heavy rainfall. Then the desalination plant was put on standby. After it was paid off over 5 years, Goleta and Montecito decided not to renew the contract and subtracted desalination from their water supply portfolio.

Santa Barbara has recently decided to re-activate the desalination plant as the sole funder of this enterprise. The facility will produce 3,125 acre-feet per year or roughly 30% of Santa Barbara's water supply in a year. In terms of hurdles, the intake is 2,500 feet off shore with openings of 1 millimeter and takes in water at a rate of 0.5 feet per second, which is slower than the existing current. Additionally, the power consumption for reverse osmosis has decreased by 40% since the facility was designed. The brine has twice the salinity of seawater and will be discharged at an outfall shared with the wastewater treatment facility. A study was recently completed with Scripps Institute of Oceanography, which suggested the city can comply with discharge requirements.

It probably goes without saying, but let's say it anyway: desalination is more appropriate for coastal communities, such as Santa Barbara, San Diego or Santa Cruz. For an inland community to fund desalination, the inland community would also be evaluating

an expensive pipeline to transport water or negotiating a water exchange with a coastal community in order to avoid building the pipeline. Proximity to the source is everything in desalination.

Alternative Supply	What is it?	What are the benefits?	What are the drawbacks?	System-wide Opportunities?
Desalinated water	Potable water that was ocean or brackish water that has the salt removed to make it potable	A drought-proof supply	Generally, the most expensive source of supply. Disposal of the brine can be problematic. High energy use.	Yes
Gray water	Non-potable household wastewater, including water from the washing machine, shower, bathroom sinks, that is held and reused; excludes blackwater, which is water from toilets and kitchen sinks	Cost-effective method for residential irrigation	Supply and demand must be balanced. Easy to end up with too much supply Water can contain pathogens.	No
Recycled water	Non-potable water that is treated wastewater that is used for irrigation, groundwater replenishment and as a barrier against seawater intrusion	Non-potable use of water; can recharge groundwater	Expensive; requires separate plumbing system of purple pipes	Yes
Stormwater	Non-potable water that is runoff from precipitation (rain or snowmelt) that flows overland; may mobilize pollutants	Can recharge groundwater	Must be captured, retained and allowed to percolate	Yes

Try It!

1. A coastal community in Southern California is considering diversifying its water supply with an alternative water supply. Which type of water supply is considered “drought-proof”? Why?
2. An inland community is looking for an alternative supply to use for recharge. Which type of supplies make sense to use for recharge? Why?

Key Terms

Desalinated water—Potable water that was ocean or brackish water that has the salt removed to make it potable; considered a drought-proof supply

Gray water—Non-potable household wastewater, including water from the washing machine, shower, bathroom sinks, that is held and reused; excludes blackwater, which is water from toilets and kitchen sinks

Recycled—Non-potable water that is treated wastewater that is used for irrigation, groundwater replenishment and as a barrier against seawater intrusion

Stormwater—Non-potable water that is runoff from precipitation (rain or snowmelt) that flows overland; may mobilize pollutants

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SECTION OVERVIEW

4.3: Demand-Side Management

In Part Three, you will shift from supply-side to demand-side management. When we manage the water demand, which is to say the water “need” or water “consumption” you tend to lessen the need for supply-side management. That is to say, if you can get people to need less water, you do not need to go out and find more water for them to use. In Part Three, we will cover:

- Regulations that affect conservation in California
- Water loss
- Water rates
- Indoor water use and conservation
- Outside water use and conservation
- CII water use and conservation
- Social marketing campaigns

Everything listed above addresses ways of decreasing demand for water, whether it is a regulation that mandates watering schedules, an aggressive leak detection program run by a water district, higher water rates for higher consumption, or toilet rebates.

There are many ways to control the demand for water. One of the most effective ways is with regulation. This frequently isn’t what people expect to or want to hear, but between statewide legislation, statewide mandates from the Water Resources Control Board, and California Building Code requirements, demand was substantially regulated during the drought in California. In this section, you will:

- Analyze potential outcomes of the requirements of SBX7-7
- Identify the prohibited measures by the State Water Resources Control Board
- Interpret requirements of building codes in California for water conservation

4.3.1: Regulations

4.3.2: Water Loss

4.3.3: Water Rates

4.3.4: Indoor Water Use

4.3.5: Outdoor Water Use

4.3.6: CII Water Use

4.3.7: Social Marketing Campaigns

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4.3.1: Regulations

SBX7-7

For many years, water agencies conducted water conservation programs as public outreach. They often set goals of fairly minimal savings over long periods of time—in other words, goals that were easy to achieve. Rebates were intended to help people save water, but also make them feel good and appreciate the water agency at the same time. Meanwhile, water agencies often had their own revenues in mind. They did not want people to be wasteful with water, but they also calculated a certain demand in order to set rates. They did not want too much conservation without planning for a reduction in revenue.

SBX7-7 changed everything. In 2009, Governor Schwarzenegger signed into law SBX7-7, the Water Conservation Act of 2009, which required retail water suppliers to determine their baseline per capita water use and reduce water use by 20% of their baseline by 2020.

What happens if a retail water supplier misses its target? Compliance with SBX7-7 determines eligibility for state water grants and loans. Failure to meet the target establishes a violation of law for administrative or judicial proceedings. This means a supplier wouldn't be eligible for many grants and loans that suppliers rely on to fund infrastructure, and could have legal actions taken against it.

No doubt in 2020 some water suppliers will not meet SBX7-7 goals either intentionally or unintentionally. What will actually happen to them? Sometimes it is worth making a distinction between agencies that are making an effort and those that are deliberately ignoring the law. Some may be penalized with proceedings and some may not be because they made a good faith effort. This will be interesting to see.

State Water Resources Control Board Mandatory Measures

While SBX7-7 set a long-term goal of 20% by 2020, in July of 2014, mandatory measures from the State Water Resources Control Board (SWRCB) were enacted to combat the severity of the drought. The table below walks you through the executive and regulatory decisions about the drought.

January 2014	Governor Brown declared a drought state of emergency.
April 2014	Governor Brown signed an Executive Order (April 2014 Proclamation), which asked for reductions of 20% by all Californians with an emphasis on outdoor conservation. The order prohibited HOAs from punishing homeowners who limit their watering,
July 2014	State Water Resource Control Board (SWRCB) asked for mandatory reductions with an emphasis on outdoor reductions.
March 2015	SWRCB adopted an expanded mandatory emergency conservation regulation, which prohibited: • Non-recirculating fountains • Hosing sidewalks and driveways to clean • Washing a car without a shut-off nozzle • Run-off from over-irrigating Water suppliers are tasked with enforcement and ordered to report data monthly to the SWRCB.
April 2015	Governor Brown directed the SWRCB to implement mandatory water reductions in urban areas to reduce urban use overall by 25% compared to 2013. Instructions to the SWRCB included considering relative per capita water usage of each supplier's service area and requiring areas with higher use to cut consumption more.
May 2015	SWRCB adopted an emergency conservation regulation with residential gallons per capita per day (R-GPCD targets).
January 2016	Mandatory measures are extended through October 2016 with adjustments to R-GPCD possible for suppliers for climate and growth.
May 2016	Prohibited measures described above become permanent. Water suppliers are allowed to "self-certify" their conservation targets by analyzing their water demand (average of 2013 and 2014) and their water supply and using a target for any shortfall.

So while SBX7-7 concentrated on long-term conservation goals compared to a baseline of total water production, the SWRCB mandatory measures concentrated on short-term conservation goals, particularly in the residential sector and particularly outdoors.

The goals (or targets) were widely criticized for not being fair. This is usually referred to as having "equity issues." While the SWRCB separated out commercial, industrial and institutional water use and concentrated strictly on a residential water reduction, it tended to penalize the water suppliers with higher per capita consumption with larger goals. Water suppliers with higher per capita consumption tended to be inland areas with higher water demand—meaning it was simply hotter inland and the plant water needs were much greater.

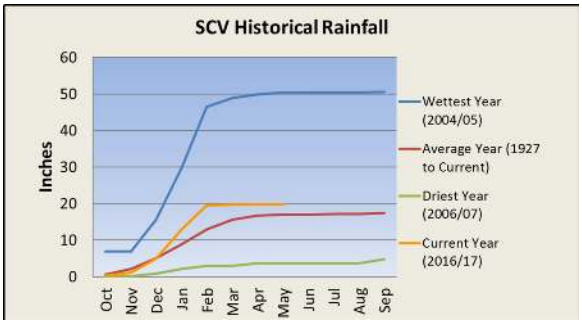


Figure 4.3.1.1

And then the winter of 2017 was wet. In Northern California, it was unbelievably wet breaking records. In Southern California, it was slightly wetter than average. In the Santa Clarita Valley, while it "felt" like a break from the drought, you can see that Water Year 16/17 (October 2016 – September 2017) was only slightly wetter than average with around 20 inches of rain for the entire year.

Is the drought over? Certainly, if you rely on imported water from the State Water Project, there was plenty of water in 2017. But most Southern California communities that used groundwater still found their groundwater supplies below average. For some parts of Southern California, including Ventura and Santa Barbara Counties, the drought was definitely not over. Looking at the graph above, would you say the drought was over in the Santa Clarita Valley?

As of this writing, the State Water Resources Control Board is implementing targets by service area to include an indoor component, a landscape component, a water loss requirement, and separate measures for commercial, industrial, and institutional users.

Building Codes

What type of regulations govern the building of a home? In terms of water use, how does a developer decide what type of toilet to use? Or aerators to install? Or landscaping to put in? These sorts of choices are governed by layers of codes, including city, county, state, and federal. In most instances, when there are overlapping standards, the most stringent apply.

Cal Green Building Code (2014 update)

Indoors	Water Use
Toilets	1.28 gallons per flush
Showerheads	2.0 gallons per minute at 80 psi
Bathroom faucets	1.2 gallons at 60 psi
Kitchen faucets	1.8 gallons at 60 psi
Outdoor	
Controllers	All controllers shall be weather-based or soil-moisture-based and shall have a rain shut off

All of the indoor devices listed above have a specific flow or flush rate. This is the rate from the manufacturer and may not be the rate in real life. Toilets, for example, leak over time and may use more than 1.28 gallons per flush. Similarly, faucets have a rating at 60 pounds per square inch, but it is entirely possible to have more pressure inside a house and use more water because of it.

Building codes are very useful in driving long-term demand downwards, primarily inside the home. In California; if there was a change to the code that forbid turf grass from being installed in new homes, demand could be driven down further outside rather than simply relying on controllers.

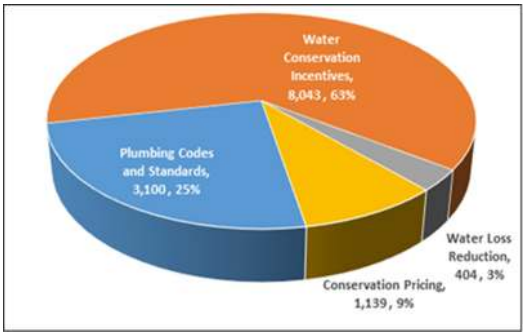


Figure **4.3.1.2**: of Castaic Lake Water Agency

The graph above shows the savings in 2020 in the Santa Clarita Valley as a result of various measures, including incentives (rebates), plumbing code and standards, pricing and water loss reduction. Note that 9% of the savings are from conservation pricing

and 25% of the savings are from plumbing codes and standards. These are powerful ways to drive demand down.

Try It!

Conduct a quick inventory of a bathroom at home. What can you tell about the flow rate of these devices?

Toilets	_____ gallons per flush
Showerheads	_____ gallons per minute at 80 psi
Bathroom faucets	_____ gallons at 60 psi

1. Which type of regulation (SBX7-7, SWRCB restrictions, or Building Code) do you think will result in the most savings over time?
2. Which measure prohibited by the SWRCB would be the most difficult for customers to prevent?

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4.3.2: Water Loss

Learning Objectives

After reading this section, you will

- Differentiate among real losses
- Differentiate among apparent losses
- Prioritize leak fixing

If you were asked to picture water loss, you would probably think of a leak. Water is definitely lost through leaks. In this section, you will learn about types of leaks, but there are other ways systems lose water as well. As a general rule, you can estimate the amount of loss in a system by subtracting total consumption from total production.

Real losses include leaking pipes, joints, fittings; leaks from reservoirs and tanks; reservoir overflows, and improperly open drains and system blow-offs. Real losses are typically used (in terms of a percent of total production) to show how efficient a water retailer is in managing its assets. You can think of real losses as three primary types:

Reported leaks - These are the most dramatic leaks that end up in the local newspaper. These have high flow rates, but a relatively short run time because they are reported. They can be disruptive to staff (Stop everything and fix this!) as well as the customer (Why don't I have any water?)



Figure **4.3.2.1**: Photo used with permission of Laura Miller Ginsberg (taken April 4, 2016)

Unreported leaks—These are hidden underground. They may have low to moderate flow rates, and often very long run times. How would a utility find these leaks? They would need an active leak detection program of some sort or the leak would need to increase in flow to become noticed on the surface.

Background leakage—All systems have weeps and seeps. The flow rates are generally too small to be detected and not cost-effective to be fixed (until the leak escalates).

Keep in mind that as much as customers like to have water under relatively high pressure delivered to their homes, and high pressure is necessary to make it up to the top of hills in your service area, high-pressure systems are much more likely to leak than lower pressure systems.

Leaks are wasted water and money, but there are other consequences too. Wet areas may be liabilities for a water supplier and create a slippery surface or even a sink hole where people may get hurt.

> *Misconception Alert!*
>
> *Many people think of real losses as the only type of loss. But there are losses that occur in all sorts of ways, which you'll learn about below. Imagine what has to happen from the meter read to the actual delivery of the bill. Inaccuracies can be introduced in any number of ways.*

Real losses are not the only source of leaks; they are just the most obvious ones. Water can be lost because of under-recording customer meters or theft. These are considered apparent losses. With an apparent loss, water may not be actually lost from the system. You can think of apparent losses as stemming from these sources:

- Customer metering inaccuracies—It is considered a best practice for all connections to be metered (though in some communities this is certainly not the case). Metering allows customers to make a connection between the volume of water used and the cost of water. It also provides information for water resource planners in terms of consumption trends. As meters age, they slow down. Without a meter replacement program, a water utility could easily be under billing based on customer metering inaccuracies.
- Customer billing system errors and data handling errors—Think of the process to get information from the customer meter to the customer water bill—there are a number of steps, including the actual read of the meter and transfer of information into the customer information system to billing. At any point in data transfer, an error can occur, but data errors can also be introduced in the analysis if estimates are used or accounts are closed or not transferred between customers.
- Unauthorized consumption—You would be surprised how much water is stolen! Yes, intentionally stolen! This could be an illegal opening of a fire hydrant, illegal connection, or tampering with a meter. Some customers will reactivate their own service connection after the service connection has been terminated for non-payment.

As you can see, there are a half dozen ways a water utility can lose water. The biggest reason for recovering water that was lost through real and apparent losses is revenue. This is literally money that is lost, whether it is by a medium-sized leak underground, a broken main above ground, theft, or meter reading errors. Other than weeps and seeps, all of these losses can be fixed, and usually cost-effectively.

Try It!

1. If a water agency tracks the difference between consumption (the sum of all meter reads) and production (the sum of all water pumped from the ground or imported), would the difference between consumption and production be real or apparent losses?
2. What is the relationship between pressure and leaks?
3. What might be an argument to implement a leak detection program?

Glossary

- Apparent losses—Losses from customer metering inaccuracies, customer billing system errors and inaccuracies, and unauthorized consumption (theft)
- Background leakage—Weeps and seeps that have small flow rates and are not cost-effective to fix
- Real losses—Leaking pipes, joints, fittings; leaks from reservoirs and tanks; reservoir overflows and improperly open drains and system blow offs
- Reported leaks—Leaks that are reported with high flow rates, but short run times
- Unreported leaks—Leaks that are most likely hidden underground with moderate flow rates and long run times

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4.3.3: Water Rates

Learning Objectives

- In this section, you will:
- Differentiate among types of water rates
- Classify rates according to whether they encourage conservation

You can look at the ways that water suppliers can organize a volumetric rate structure:

Type of Rate	Description	Benefits	Drawbacks
Uniform Rate	a constant unit price for all volumetric water sales	Simple and perceived as equitable; easy to implement (not a lot of math!); some revenue stability	Not much of a conservation signal
Declining Block Rates	the unit price for each block of water use is charged at a lower unit rate than the previous block	High-water users benefit from lower rates than in other structures	Perceptions of inequity, does not encourage conservation; complicated to design
Increasing Block Rates	the unit price for each block of water use is charged at a higher unit rate than the previous block	Encourages conservation	Perceptions of inequity; complicated to design
Seasonal Rates	the unit price varies by time period (generally a higher price during peak demand months)	Encourages conservation	Complicated to design and administer

The common wisdom is to encourage conservation, you need to make people aware of how much water they use, and increase the price as they use more. In this way, customers get a price signal to be conscious of their water use and are intentional about their water use and conserving.

You can see in the chart above, two rate types (uniform and declining block rates) do not encourage conservation. They actually could encourage an increase in demand. Why do these rate types exist? A uniform rate exists for one reason: equity (or perceptions of equity). A uniform rate treats the smallest customer and the largest customer exactly the same with the same volumetric rate. A declining block rate exists when the agency wants to increase water use, presumably by commercial and industrial users who would benefit.

Why not increase rates across the board to increase conservation? Rates are considered governed by Proposition 218 and have to go through a public process that ties the rates to actual costs from the water retailer. In general, Proposition 218 is intended to make sure that additional taxes are brought to the public for a vote. In short, a water retailer cannot charge more than proportional costs of the water per parcel served. This means that the water retailer can't charge high fees just because it wants to decrease consumption overall.

In the case of Capistrano Taxpayers Association v. City of San Juan Capistrano, the trial court decided that the City of San Juan Capistrano had not provided enough justification for their costs for the higher tiers. This has been interpreted by some as making tiered rates illegal, but this isn't really the case. Rate calculations need to be able to be justified by the cost of service. If it is costing a significant amount more to purchase an additional source of expensive supply because of high water users, these costs can be passed on to the high water users. But you can't simply charge high water users more because you want to decrease their consumption.

> *Misconception Alert!*

> *Many people disregard the fixed charge on their bills and focus on the volumetric charges. While the volumetric charges are a measure of how much water is used, they may not actually be the bulk of the cost. Much of the cost may be in the fixed charge. There is just very little you can do about the fixed charge.*

Try It!

1. Check out your water bill. How are you billed? Is there a fixed and volumetric rate? What type of rate is the volumetric rate?
2. What types of rates will encourage conservation? Why?

Glossary

- Declining block rates—The unit price for each block of water is charged at a lower unit rate than the previous block
- Increasing block rates—The unit price for each block for water use is charged at a higher unit rate than the previous block
- Proposition 218—The legislation that governs the public process for rate setting. In general, Proposition 218 is intended to make sure that additional taxes are brought to the public for a vote.
- Seasonal rates—The unit price varies by time period, generally with a higher price during peak demand months
- Uniform rates—A constant unit price for all volumetric water sales

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4.3.4: Indoor Water Use

Learning Objectives

In this section, you will:

- Analyze indoor water consumption
- Audit and track your own indoor water use

When you start to talk to people about conservation, they generally want to discuss ways of reducing their indoor water consumption, particularly bathing less. This is a problem - most of the water in the residential sector in California is used outside! And, frankly, no one in conservation wants to decrease basic hygiene of the general public. Still, indoor water use and conservation is not a bad place to start because it is a place people are very familiar with.

In the graph below, based on real data from residential homes, you can see that toilets are the biggest users of water in the home, followed by showers and faucets, and then clothes washers. Surprisingly, 14% of all water metered to the home is also lost to leaks. That puts an interesting spin letting a leaky faucet drip. It's using only a little less water than your faucets!

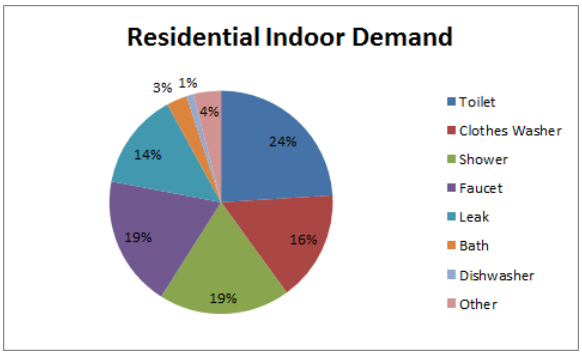


Figure **4.3.4.1**: Residential Indoor Demand by the EPA is in the public domain

Let's return to our inventory of your bathroom fixtures. What did you discover when you inventoried your bathroom?

Toilets	_____ gallons per flush
Showerheads	_____ gallons per minute at 80 psi
Bathroom faucets	_____ gallons at 60 psi

Toilets

How many gallons does your toilet use?

Sometimes it is difficult to tell how many gallons per flush a toilet has by observation. But if you remove the tank lid, often the number of gallons per flush is stamped somewhere on the inside of the tank at the top. In some toilets, you can also find the gallons per flush on the flat surface behind the seat lid. And, of course, in a store, the gallons per flush is written on the box. If you are browsing in a store, a toilet with the WaterSense label guarantees that the product is 1.28 gallons per flush.



Figure **4.3.4.2**

In the United States (as of 2017), you can purchase 1.6 gallon per flush toilets in most states, which is the federal standard, but in California, you can only purchase 1.28 gallon per flush toilets. This is 20% less water used per flush. (1.28 compared to 1.6). Yuck!

you may say. That's not enough water. Actually, it's plenty. Some of us remember the early 1990s, which was the time "low-flush" (a.k.a. low-flow) toilets came on the market in California. These were the first toilets that used 1.6 gallons per flush. Unfortunately, most of them were not re-engineered from the 3.5 gallon per flush toilets of the previous generation. A 1.6 gallon per flush toilet was pretty much a 3.5 gallon per flush toilet with less water. And these did not work well. Water agencies up and down the state of California had to deal with angry customers who felt that the water agency rebate had "recommended" a toilet with poor performance. No one wants a repeat of this. The current 1.28 gallon and 1.6 gallon per flush toilets work well. To check the performance rating of your toilet, see map-testing.com for an entire database of toilet rankings.

Toilet-Related Conservation

Toilet rebates are a "classic" conservation program and a favorite of many in conservation. Why? The toilet stays in place for a long time. The savings are essentially "hard-wired" into the home. In this type of rebate program, a customer buys an approved product from a list, and the water agency gives a check or a credit on the bill after the purchase of the toilet. In order to receive the credit or check, the customer must present the receipt and purchase from the list. The approved list is important. It is a best practice to only rebate fixtures that are more efficient than what is standard in the market. Otherwise, you are essentially rebating for people to replace something with a fixture they would have purchased anyway. So if a high-efficiency toilet (1.28 gallons per flush) is on the market, customers shouldn't be rebated for purchasing it because you are not incentivizing an increase in efficiency. They should be rebated for purchasing an ultra-high-efficiency toilet (1.0 gallon per flush or less).

Sometimes retail water suppliers will run a one-day toilet giveaway program. In this conservation program, people come to a central location, such as a big park, and pick up a new toilet after providing a driver's license for identification purposes and a water bill (with a matching name). They are allowed to take the toilet home, but they must return two weeks later to drop off the old toilet to the park (in a giant dumpster) or they will be charged for the new toilet on their bill. This guarantees (almost!) that the new toilet is installed at the home in the service area. This is one model for success but involves a lot of coordination and disposal of old toilets.

> *Misconception Alert!*
>
> *You have probably heard, "If it's yellow, let it mellow. If it's brown, flush it down." Do not do this. Please keep flushing your toilets. This is advice from the 1980s when toilets used 3.5 gallons per flush or more. It wasn't bad advice then (though still sort of gross), but it's terrible advice now. Upgrade your old toilet with a 1.28 gallon per flush toilet and keep flushing. We don't want to keep waste in our homes, and if you have kids, it's a hard-to-break habit if they learn not to flush. Keep flushing!*

Showerheads

It may be hard to tell how many gallons per minute a showerhead uses just by looking at it. Many showerheads are labeled with this information, but calcium and magnesium in hard water build up to obscure the numbers. In the United States, you can buy showerheads with up to a 2.5 gallons per minute rating, but in California, the only showerhead you can buy is 2.0 gallons per minute or less. To earn a WaterSense label, a showerhead would also need to use 2.0 gallons per minute or less.

Shower-Related Conservation

Many water agencies have giveaway programs with showerheads. One of the challenges with a giveaway program is that the water agency typically does not know that the product is installed properly (or installed at all). So the water agency may "count" on the savings from purchasing and distributing showerheads, but not necessarily receive the savings as a decrease in overall consumption.



Figure 4.3.4.3: Shower Better image by the EPA is in the public domain

Additionally, and equally problematic to conservation program design, showers are seen as “sacred” by many people. It’s their “me” time and they do not want you to mess with their shower, including affecting the quality with a sub-par showerhead and length of shower.

Washing Machines

A traditional style washing machine uses 40-50 gallons per load of laundry. That’s a lot! A high-efficiency washing machine uses about half of that (20-25 gallons). That’s a significant savings. But, of course, high-efficiency washing machines cost more - typically $200 more than a traditional machine (as of 2016). A high-efficiency machine typically soaks the clothes longer to remove stains and dirt rather than using a central agitator. The loads of wash may take longer in a high-efficiency machine.

Washing-Machine-related Conservation

Many water agencies operate washing machine rebates, which offer a rebate of $100-300 to make the purchase more cost-effective for consumers. Washing machines rebates have mostly replaced toilet rebates in popularity in California. While it’s possible that a customer may receive the rebate and move out of the water agency’s service area, it’s also equally possible that a customer may move in with a high-efficiency machine already.

Faucets



Figure 4.3.4.4

A standard faucet purchased in the United States uses 2.2 gallons per minute. A WaterSense approved faucet will use 1.5 gallons per minute. Aerators can be added to standard faucets to inject air into the water flow and make the flow seem fuller with less water.

Faucet-related Conservation

Aerators are typically available at water agencies for free and are given away at events. As with showerheads, aerators are difficult to track and impossible to make sure they are installed properly. They can also present problems in giveaway programs in that customers may need a male or female threaded aerator, but take one of each to hedge their bets.

Audits

Do you remember the table where you quantified your measurements of indoor fixtures? An “audit” is really an extension of that exercise. You make a list of all the water-using fixtures in the house, quantify their use, decide on a number of times per day, and come up with a total. Completing the table below will help you audit your own home.

Try It!

Complete the table below to audit your own home (indoor water use).

Bathrooms	Amount of Water Used per Use	Times Used per Day	Total Water Used per Day by Device
Toilet #1	_____ gallons per flush		
Toilet #2	_____ gallons per flush		
Toilet #3	_____ gallons per flush		
Showerhead #1	_____ gallons per minute		
Showerhead #2	_____ gallons per minute		
Showerhead #3	_____ gallons per minute		
Bathroom faucet #1	_____ gallons per minute		
Bathroom faucet #2	_____ gallons per minute		
Bathroom faucet #3	_____ gallons per minute		
Kitchen			
Kitchen faucet	_____ gallons per minute		
Dishwasher	_____ gallons per use		
Other Water Using Devices			
Total Water Used Per Day			_____

In what category is the most water used per day?

What could you do to save the most water in your home?

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4.3.5: Outdoor Water Use

How much water is used outdoors? Most estimates for outdoor water use in the United States suggest that it is more than 50% of all water used for residential use. In general, the hotter the locale, the more water is used for landscaping.

Learning Objectives

In this section, you will:

- Identify the benefits and needs of landscape
- Differentiate among types of irrigation
- Classify plants according to their watering needs
- Design a landscape with best practices in mind

Why don’t we get rid of all the landscape, cover the ground with cement, and save all that water? Landscape serves a variety of purposes, and is considered a beneficial use of water. After all, plants make oxygen, and we humans love oxygen. Plants also lower the air temperature. An entirely paved landscape would be a hot one - check out the center of a parking lot in the summer. And soil acts as a giant sponge, absorbing and filtering water, which eventually allows for aquifers to replenish. So, keeping landscape is a given, and acknowledging that live plants in the landscapes need water is important. However, choosing a waterwise landscape and giving it just the water it needs is essential.

Couldn’t all of our irrigation problems be solved if we saved the rainwater that falls from the sky? Doesn't that just go to waste if it runs into the ocean? We do save it in both surface reservoirs and in groundwater aquifers. Water isn’t wasted if it infiltrates. And even when it runs into the ocean, it is still part of the water cycle.

Sometimes, rain barrels are presented as the perfect solution to irrigating landscape. However, rain barrels bring with them a host (no pun intended) of other problems, including providing the perfect breeding ground for mosquitoes. We are poised on having a worldwide explosion of babies with microcephaly, caused by the Zika virus, which is spread by mosquitoes.

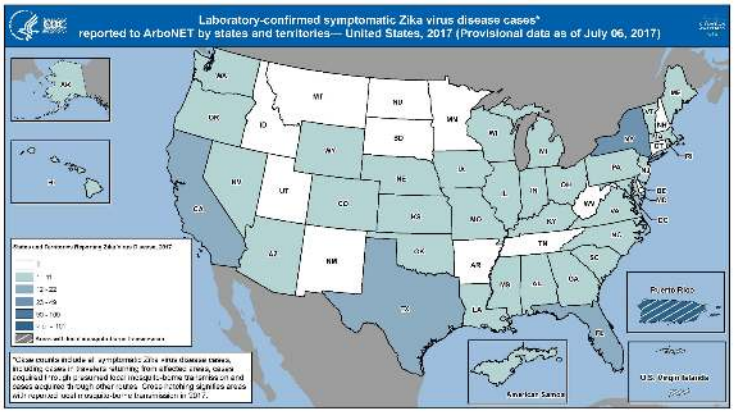


Figure **4.3.5.1**

Additionally, mosquitoes spread the West Nile Virus, and a number of locations in Southern California, including Santa Clarita, are “hot spots” for the disease. It is almost impossible to mosquito-proof a rain barrel—mosquitoes will enter that smallest opening to lay eggs in water. This makes rain barrels perfect for breeding mosquitoes, and not for saving water.

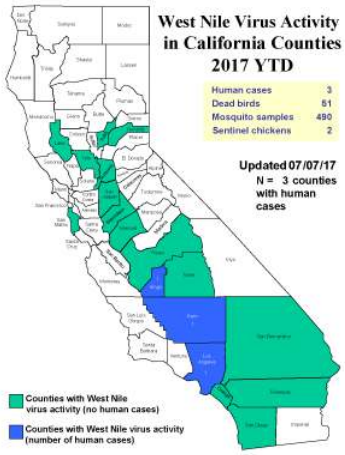


Figure **4.3.5.2**: West Nile Virus Activity map by the California Department of Public Health is in the public domain

Setting mosquitoes aside, why wouldn't rain barrels help save water? In Southern California, most of the rainfall occurs when the plant water needs are the least. Rain barrels may be a good solution in places like Arizona and New Mexico, which get summer monsoonal storms when the water needs for plants are the greatest. In California, our storm season generally lasts from November through February when the plant water needs are the least.

Best Practices in Landscapes

It is a much better idea to look beyond rain barrels and beyond eliminating landscape entirely to principles that would help landscape use water more efficiently. These are practices that are a compromise between what is called "all or nothing" thinking. You will hear a lot of this sort of thinking as you hear people talk about their landscape. This is the sort of thinking that says, "If I can't have my grass in the front and backyard, then I'm going to pave over everything" or "If I can only water twice a week, I'm just going to give up and let everything die." In the next part, you will learn a few of the principles that landscape professionals use to create and maintain drought-tolerant landscapes. There is a middle ground between paving everything and having no landscape and having turf grass everywhere.

Maintain the irrigation system—This means conducting a regular review of the system while it is running to look for common problems (overspray, clogged nozzles, blocked heads). Much like we learned in the section on alternative water supplies, including gray water, frequently maintenance is a hurdle that homeowners do not want to overcome. If something needs maintenance, such as a gray water system or an irrigation system, it may simply be avoided and neglected. There is water-saving potential in conducting maintenance.

Mulch the exposed soil—Any surface that is not covered by a plant (or a six inch space around a plant) should be covered with three to five inches of mulch. Mulch has a ton of benefits including keeping the soil temperature more moderate (warmer in the winter and cooler in the summer), preventing weeds from sprouting in soil and decreasing the evaporation. Mulch does need to be raked periodically and re-applied year to year, but it makes a great improvement in the aesthetics and health of a planted surface.

Hydrozone—The highest water use plants used in California landscapes are types of turf, including cool season turf, which has slender blades of darker green color, and warm season turf, which has wider blades of medium-green color. You can see in the table below how the water needs, measured in evapotranspiration in inches per day, vary tremendously among types of turf grasses. Typically, when someone admires a lawn, the lawn is Kentucky blue grass or another cool season turf grass. There are low water using options, such as Buffalo grass, which can easily use half as much water. But grass overall is still a very water thirsty plant.

Relative Ranking	ET in inches/day	Cool Season	Warm Season
Very low	< 0.24		Buffalo grass
Low	0.24-0.28		Bermuda grass Zoysia grass
Medium	0.28-0.33	Red fescue St. Augustine	
High	0.33-0.39	Perrential Rye grass Kikuyu grass	
Very high	> 0.39	Annual bluegrass Kentucky blue grass Annual rye grass	

Hydrozoning, or separating your plants by their water needs, helps you water the right amount in each zone. In the table below, you can see how you might group plants according to their high, moderate, low and very low water needs. Each plant is compared to a cool season turf grass of 4-7 inches tall that is not stressed. This is the plant with the highest water need. Trees and shrubs should be in their own zone. Anything drought-tolerant typically has a low water need and should be in a separate zone. And anything with a very low water need typically does not need irrigation. Note that a plant with moderate water needs only needs 40-60% of the water of a cool season turf grass. That means that typically anything other than turf grass will need half as much water - this is truly astounding.

Water Needs	Percent of Reference ET	Types of Plants
High	70-90% ET	Most turf grasses
Moderate	40-60% ET	Most trees and shrubs
Low	10-30% ET	Drought-tolerant plants, like salvia (sages)
Very Low	<10% ET	Cacti

Irrigate deeply and water infrequently—Daily watering isn't necessary for most plants, including turf grass, even during the summer. Irrigation depends on a number of factors, including:

Soil type—Both clay and sandy soil in your yard mean you must irrigate in short bursts and allow water to sink in in between bursts. This is typically called cycle and soak because you allow the controller to cycle on once and then let the water soak in before cycling on again.

Depth of roots—If you water grass multiple times a day, you train the grass to have short roots, which mean the roots cannot reach other available water deeper in the soil. Try to water less frequently to encourage deeper roots to grow.

Seasonal variation—Plants have greater water needs in the summer than the spring, fall or winter. This is intuitive, but many people water the same amount of time all year round.

Types of plant material—Would you water your lawn and a cactus the same amount? Of course not. But many people water everything in their yard the same amount, which usually results in over-irrigation of most non-grass plants. This is why separating your yard into hydrozones is so important.

Irrigation system type—Spray heads put out water much faster than rotating heads or than drip irrigation - you need to understand this when you program your system. Spray heads and rotating heads can be high-efficiency, meaning they apply water at a slower rate. Spray and rotating nozzles are appropriate for grass, but drip irrigation is a more appropriate choice for shrubs and trees. The table below summarizes the four major types of irrigation, including their water pattern, ideal use, and precipitation (precip) rate, which is the amount of water that the irrigation type puts out.

Irrigation Type	Water Pattern	Ideal for...	Precipitation Rate	How to irrigate well with it?
Spray	fan	turf grass	Faster than soil can absorb	Cycle and soak
Rotating	stream	turf grass	Faster than soil can absorb	Cycle and soak
Bubbler	gush	trees with wells	Faster than soil can absorb	One run time to fill the wells
Drip	drip	shrubs and trees	Same rate soil can absorb	One long run time (45 minutes +)

Irrigation Controllers

In California, any new homes will come with a weather-based or soil-moisture-based irrigation controller. This means that some of the guess work will be taken out of irrigation decisions. Typically people have no idea how much to water and end up over-irrigating everything. Irrigation controllers can be programmed by the days to water, the time of days to water (called the start time), the length of time to water (called the run time). A weather-based irrigation controller or a soil-moisture based irrigation controller needs to be guided on what days to water and what times to start, but can determine how long to water based on weather or on soil moisture.

When do you think you might see savings from using a weather-based irrigation controller? Typically, people set their controller at the summer levels for irrigation and keep the controller at that level all year. This means they are watering both more frequently than needed and longer than needed for most of the year. The savings when upgrading to a weather-based irrigation controller come in the spring, fall and winter, when the person was over-irrigating.

Grass and Artificial Turf

When is grass appropriate? Are people playing on the surface? If so, grass is the perfect plant - no other plant will take being trampled and literally bounce back. If kids or adults are using the grass to play on, keep it. It's the right plant in the right place at the right time. But the way grass is used in many communities is as a default plant. Grass is easy and inexpensive to install and has been installed in all sorts of places that are hard to irrigate without run-off, like parkways, hills and slopes or medians.

What about **artificial turf**? While artificial turf does not change the landscape aesthetic in a community, it has both benefits and drawbacks, which are detailed in the table below.

Benefits of Artificial Turf	Drawbacks of Artificial Turf
It's green	It can become hot in the sun (and contribute to a heat island effect on your property)
It saves water	Many installers recommend hosing down artificial turf for dust control and to clean pet waste
No mowing is necessary	It can photodegrade in the sun (10-year lifespan)
No fertilizers are necessary	It will smell of pet waste if not cleaned effectively
Costs incurred are most likely one time charges (until time for replacement in around 10 years)	Typically, artificial turf is $10-15 a square foot

There are other types of outdoor water use, but they are negligible in the greater scheme of things when compared to landscaping. For example, leaks may occur outdoors in the irrigation system. Water can also be used for cleaning hardscape (pavement, sidewalks, driveways), washing vehicles, filling fountains and swimming pools.

Try It!

1. Propose a strategy for landscaping an area that you see frequently, such as your home, a local park, or your school. This could be your front or backyard, a common area, or an area at work. Consider the types of plants that you might install, an arrangement for them, the irrigation system you should use, and what obstacles you might encounter along the way. Identify the best practices you have used.
2. A friend wants to install artificial turf in his front and backyard. Give an overview of the benefits and drawbacks of artificial turf.

Key Terms

Cycle and soak—Irrigating in short bursts and allow water to sink in between bursts

Hydrozoning—Separating your plants by their water needs, which helps you water the right amount in each zone

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4.3.6: CII Water Use

What do a car mechanic and an aerospace engineer have in common? They both work in the Commercial, Industrial, and Institutional (CII) section, which is very diverse in terms of water use. Using water for cleaning as a car mechanic or water for manufacture of aerospace parts are very different uses. As we study CII customers, you'll be able to bring together what you've learned about indoor and outdoor conservation and apply it to the workplace.

Learning Objectives

In this section, you will:

- Classify customers according to type
- Identify challenges in the CII sector
- Analyze the consumption history of CII customers

For CII customers considering conservation, financial incentives are typically a useful conservation tool as well as providing information on the return on investment (ROI). One particular challenge in the CII sector is that a master meter typically provides water for both indoor and outdoor use. Sometimes an entire strip mall of diverse businesses (e.g., nail salon, microlender, lawn mower repair) will be behind the same meter. This makes it very difficult to account for individual commercial water use and to offer appropriate rebates and incentives. With the challenges in the CII sector understood, we will spend some time looking at each type of business within the CII sector.

Commercial, Industrial and Institutional Customers

Within the commercial, industrial and institutional (CII) sector, water use varies by type of customer. The EPA provides this bar graph of typical water use within different types of commercial and institutional organizations:

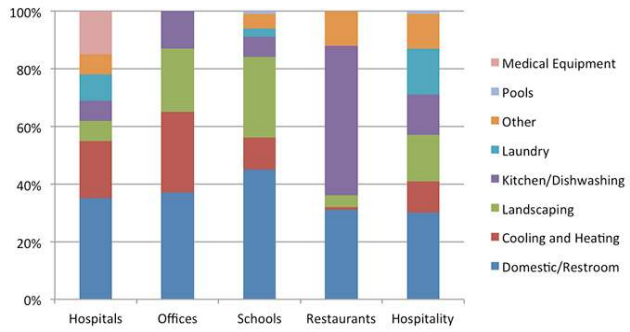


Figure **4.3.6.1**

There are a few key observations you can make, most of which are intuitive:

Most customers have a sizable proportion of domestic or restroom water use. This suggests that a program that rebates toilets, urinals, and aerators might be useful to many types of customers.

- Schools, offices and hospitality (hotels) use a significant amount of water for landscaping. This suggests that a rebate program for smart irrigation controllers, sprinkler nozzles, landscape audits or checkups or for turf grass removal might be useful.
- Some types of customers, such as hospitals or offices, have sizable amounts of water used for heating and cooling (including cooling towers, which can recirculate water).
- Kitchens and hotels (hospitality) use a significant amount of water in the kitchen.

Commercial Customers

Restaurant water use is typically about 50% used in the kitchen, primarily for dishwashing. This suggests that a dishwasher rebate for a water-efficient dishwasher might be in order. And, of course, there is typically a third of total water used for restrooms, which suggests a toilet and urinal rebate program might be well received and needed.

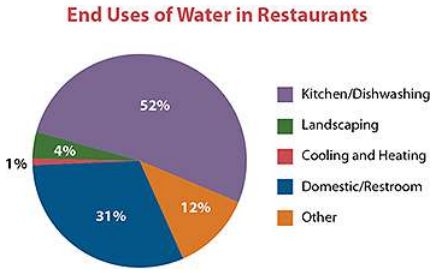


Figure **4.3.6.2**

Restaurants have other uses of water in the kitchen, including woks and dipper wells, both of which may have continuous flows of water. The next time you are in an Asian restaurant, if the restaurant has an open kitchen, check out the wok. Many restaurants have a continuous flow of water in a faucet behind the wok to use while cooking and to cool the wok. Similarly, dipper wells in ice cream parlors may also have a continuous flow of water to keep the ice cream scoop clean. For kitchen clean-up, pre-rinse spray valves, which are used to pre-clean dishes before going in the dishwasher, can also be upgraded to less gallons per minute, and are a common rebate program.

The EPA features a case study in conservation in a restaurant in Chicago, Illinois. The restaurant is called Uncommon Grounds and it conducted three stages of upgrades:

1. Aerators on prep sinks, more efficient pre-rinse spray valves and water only served on request
2. Dishwasher and ice machine upgrades to ENERGY STAR qualified models
3. Rooftop garden with a drip irrigation system that uses a rainwater collection system

This case study illustrates that there are a wealth of possibilities for upgrades, but that for restaurants focusing on the kitchen first often makes the most sense.

Hotels are another common customer type in the commercial sector. Their water use often encompasses a restaurant, but also restrooms, landscape, and laundry uses.

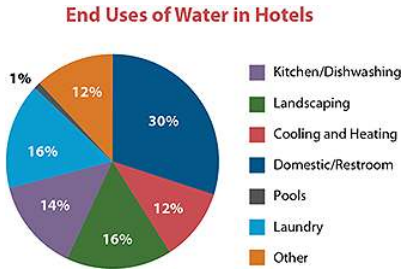


Figure **4.3.6.3**

Hotels may have more flexibility for implementing changes for water conservation if they are small and privately-owned or if they have sustainability as part of their mission, such as Kimpton Hotels. Small behavioral changes may be successful for hotels, such as instituting linens/towels re-use options for customers, particularly if customers have to “opt-in” for fresh daily towels or linens.

The EPA has a case study in water conservation in a hotel in a Holiday Inn in San Antonio Texas. The water utility spent $100,000 in a retrofit of guest bathrooms upgrading as shown below:

Fixture	Original Efficiency	Retrofit Efficient	Number of Units
Toilets	3.5 gpf	1.1 gpf	297
Toilets	5.0 gpf	1.1 gpf	100
Aerators	2.2 gpf	1.5 gpm	397
Showerheads	2.5 gpm	1.75 gpm	397

The hotel achieved an average of 35% savings per upgraded room and $68,000 in water and sewer costs per year.

Industrial Customers

The Mid-Continent Ecology Division Laboratory (MED) of the Environmental Protection Agency (EPA) can also be studied as a case study for water conservation. Located in Duluth, Minnesota, the MED is 50 labs, administrative offices, a library, and 7 constant temperature rooms. As with many scientific laboratories, there was a good deal of water used for cooling of scientific instruments. In particular, single-pass cooling occurred not only in the cooling system for the building but for many elements of the research equipment. Because the facility is adjacent to Lake Superior, the facility was able to use waters from the lake for cooling rather than potable water, which reduced its total potable use by 90 percent. Additionally, the water can be returned to Lake Superior after it is used to cool the building or equipment.

This use of lake water for cooling is innovative. In California, lakes are much more sporadically occurring than in Minnesota and this would be more of a challenge both in finding a lake to use and in not having detrimental environmental effects. Also, aquatic species tend to like water within a temperature range so any water that is returned to the lake would need to be similar in temperature to the lake water.

Institutional Customers

Although decreasing water use by 90% in the case of the MED or 35% for the Holiday Inn seems extreme, the types of processes and analyses that occurred at the MED are the sorts of processes that would need to occur are typical of ways to save with other industrial customers as well as institutional customers. Institutional customers are typically schools and universities, hospitals, houses of worship, and city and county agencies. These are typically the sorts of customers who may have many people visiting their facilities for a short period of time. They may also have a variety of different types of use in one building, such as a church that also has a school during the weekdays and group counseling or AA meetings in the weekday evenings.

Stanford University is useful as a case study because of the wide-ranging uses of the facility ranging from scientific research to residential housing. At Stanford University, conservation staff met with each department to attempt to quantify water use and potential reductions. Important to this effort was the involvement of stakeholders in the process, which include professors and research staff, but also building and grounds staff who understand how the buildings function, particularly the cooling systems.

In the end, a variety of conservation measures were chosen from removal of unnecessary turf grass and installation of weather-based irrigation controllers as outdoor measures to upgrading most bathrooms on campus and replacing one-pass sterilizing equipment, to real-time metering to provide feedback on water use, and especially on leaks.

In the same vein as Stanford University, a case study from the EPA found a wide range of possible upgrades for a hospital in Olympia, Washington, to decrease water use. These water conservation measures concentrated on:

- Upgrading sterilizer equipment
- Recovering condensate from the sterilizer for re-use (non-potable use)
- Upgrading water-using equipment with non-water using equipment

This process resulted in a savings of 5.9 million gallons once the retrofits were completed and a cost savings of $140,000 per year. So while it may seem like the CII sector is technical, case studies such as this one illustrate that by identifying the high-water using appliances and equipment and researching upgrades, there is a significant potential for water savings.

Try It!

1. Where is most water used in a restaurant? Where is most water used in a school?
2. College of the Canyons is considered an “institutional customer.” Where might the greatest water savings lie?

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4.3.7: Social Marketing Campaigns

How do you get people to change? It’s a good question and one with which numerous governmental agencies struggle, particularly those in the health and healthcare fields, where there are the most social marketing campaigns of any field.

As you have seen, there are major water infrastructure projects that can be relied on to a certain extent to bring water to the thirsty parts of California. But how can you decrease the amount of water that is needed in the first place? This is called managing demand. You’ve learned a variety of tools from regulation to restrict water use or limit waste, to building codes that require more efficient devices to water loss detection to conservation programs. Decreasing demand is both an art and a science. One additional way to reduce demand is to engage in a social marketing campaign with residents.

Learning Objectives

In this section, you will:

- Differentiate between awareness campaigns and social marketing campaigns
- Identify behaviors that most water utilities target
- Design a social marketing campaign

Typically, public outreach campaigns in the water industry have focused on awareness. That is to say, the campaign wants you to be aware of the importance of water or the amount of water that you use. In the Santa Clarita Valley, a campaign in 2010 focused on residents knowing their "water number," the amount of water that they used in one day. This campaign relied on the jarring realization that the amount of water that people used was much more than they expected.

An awareness campaign might also focus on a rebate program by promoting toilet or washing machine rebates. The goal of an awareness campaign is to make more people aware of something, but it isn’t necessarily to make people change their behavior. There isn’t a clear call to action.



Figure **4.3.7.1**: of Castaic Lake Water Agency

In the image above, the viewer is made aware that funds are still available for a Cash for Grass Program (called Lawn Replacement). This ad assumes that most people do not know that there is still money available, and is attempting to raise awareness of this. In Southern California, water agencies, such as Castaic Lake Water Agency, frequently have challenges with messaging that contradicts the messaging from Metropolitan Water District of Southern California, which is a much larger wholesale agency. In this case, Castaic Lake Water Agency has funds available for a cash for grass program, while Metropolitan Water District has run out of funds. Customers who do not know who their water wholesaler was were confused about the availability of funds.

Success or failure of the campaign could be measured in a change of awareness in rebates with a phone or email survey of a representative sample of residents. Awareness of the rebate could be measured before the campaign launches to establish a baseline (e.g., 20% of residents surveyed in the Santa Clarita Valley are aware there are funds available for the Lawn Replacement Program) and then a follow-up phone survey after the campaign runs for 3-12 months to see if there is any increase in awareness (e.g., 3 months later, 30% of residents surveyed in the Santa Clarita Valley are aware there are funds available for the Lawn Replacement Program).

Another awareness campaign that you may have seen is a drought awareness campaign. Most water agencies had to launch some sort of drought awareness campaign that combined with efforts from the State of California to make people aware of the severity of the drought. San Diego County Water Authority has an effective ad to make people aware of state-mandated conservation. Using a modified image from the Drought Monitor of the state of California, the campaign make some suggestions for conservation, but is mostly focused on awareness of the drought and restrictions in place.



Figure **4.3.7.2**: of San Diego County Water Authority

A similar awareness campaign from the Family of Water Suppliers in Santa Clarita, including Castaic Lake Water Agency, focuses slightly differently on a common misconception: when it rains, the drought is over. This awareness campaign reminds people that just because it rains, the drought is not over.



Figure **4.3.7.3**: of Castaic Lake Water Agency

A social marketing campaign differs from an awareness campaign significantly. A social marketing campaign is a campaign that tries to change behavior. By presenting images that motivate people to do the "right" thing (or that poke fun of people doing the "wrong" thing), public agencies can gently move people to better practices that are good for the residents and good for the public agency. However, most of the time, you can't just tell people to do the right thing. It generally doesn't work. People have too much going on in their lives to listen, unless you make it extremely relevant. You need to have a campaign that refines your message.

These are the sorts of questions that are used in campaign planning:

- Who are we targeting?
- What is our message?
- What partnerships will help with our message?
- What are the barriers to being understood (or listened to)?

During the last drought, many water agencies in California had to tackle how to let people know it was okay to let their lawn get less water and go dormant (yellow). Because green lawns are one way that people tend to rate their status (i.e., I have a green lawn, so I must be financially secure), this is a particularly challenging task. San Diego County Water Authority has a social marketing campaign that tackles this in a unique way.



Figure **4.3.7.4**: of San Diego County Water Authority

In the image from San Diego County Water Authority, the Authority has chosen to reframe brown grass as "tan" grass, most likely hoping that this will make it seem more appealing. This is a variation of "Brown is the new green," a phrase made popular by Governor Brown in the same drought, but working with language that may be more appealing (i.e., tan rather than brown).

Castaic Lake Water Agency has a similar goal of reducing water use for turf grass, but has taken a different tactic by focusing on the appealing aspects of replacing a lawn (more color, more fun, more time):



Figure **4.3.7.5**: Images used with permission of Castaic Lake Water Agency

Many social marketing campaigns have concentrated on the behavior that was prohibited initially during the drought in California, including stopping irrigation run-off, but also refraining from watering sidewalks or washing cars without shut-off nozzles, or using even non-recirculating fountains. While raising awareness of the drought is important, these were all behaviors that were targeted by many water companies in social marketing efforts to behavior change.

Try It!

1. Do a quick scan through a newspaper or click through a few websites starting with an online newspaper. Give an example of an awareness campaign and an example of a social marketing campaign. Examples do not need to be from the water industry.
2. Design a social marketing campaign and present your results. Answer these questions:
    1. Who are you trying to target?
    2. What is the message?
    3. What are the hurdles?

Key Terms

Awareness campaign—A campaign to make more people aware of something, but it isn't necessarily to make people change their behavior

Social marketing campaign—A campaign that tries to change behavior

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5.1: Water Resources and The Origin of Contaminants

Learning Objectives

After reading this section, you should be able to:

- Understand and describe water sources
- Describe the water cycle
- Compare the term water contaminants with water pollutants

This chapter presents a brief introduction to the water sources that are available for potable supply; detailed information is presented in Water 132 (Water Supply). Understanding drinking water sources is important to assess the variety of contaminants that can be present in water.

Water Sources

According to the United States Geological Survey (USGS), 71% of the Earth's surface is covered in water, and of that 97% are the oceans. The Earth's water can be broken into two different categories: freshwater and salt water. Fresh water is simply water that is not salty and can be found in the planet's surface water such as streams, lakes, and frozen as ice, but also underground in aquifers. Fresh water is stored on the surface as **surface water** or stored underground in aquifers as **groundwater**. Salt water can be found in the world's oceans.

Figure 1.1 shows that our planet's water sources are limited. Freshwater is much easier to use for potable (drinkable) applications because it requires simpler treatment. However, it represents only a small fraction of the Earth's water portfolio. A large proportion of the freshwater is locked in glaciers and is not accessible. As a result, less than 1% of the water present on the planet is groundwater and surface water that can be more easily used as potable water source. Although desalination plants have become more prevalent, they are very costly, and their overall environmental impacts are unknown.

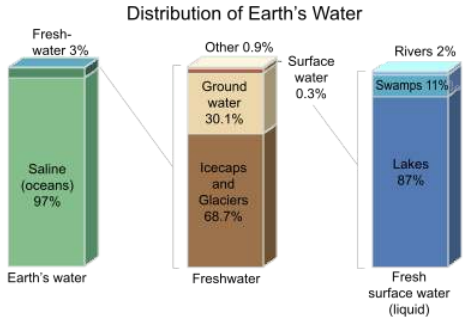


Figure **5.1.1**: Distribution of Earth's Water. (Timothy Bralower is licensed under CC BY-NC-SA 3.0)

The origin of a water source determines its characteristics and the presence of specific contaminants. The concentration and composition of contaminants in water is also influenced by the movements of water, which is illustrated by the water hydrologic cycle (Figure 1.2). The Water Cycle is both driven by gravity (i.e., water flows downhill) and sunlight (i.e., water evaporates and condenses).

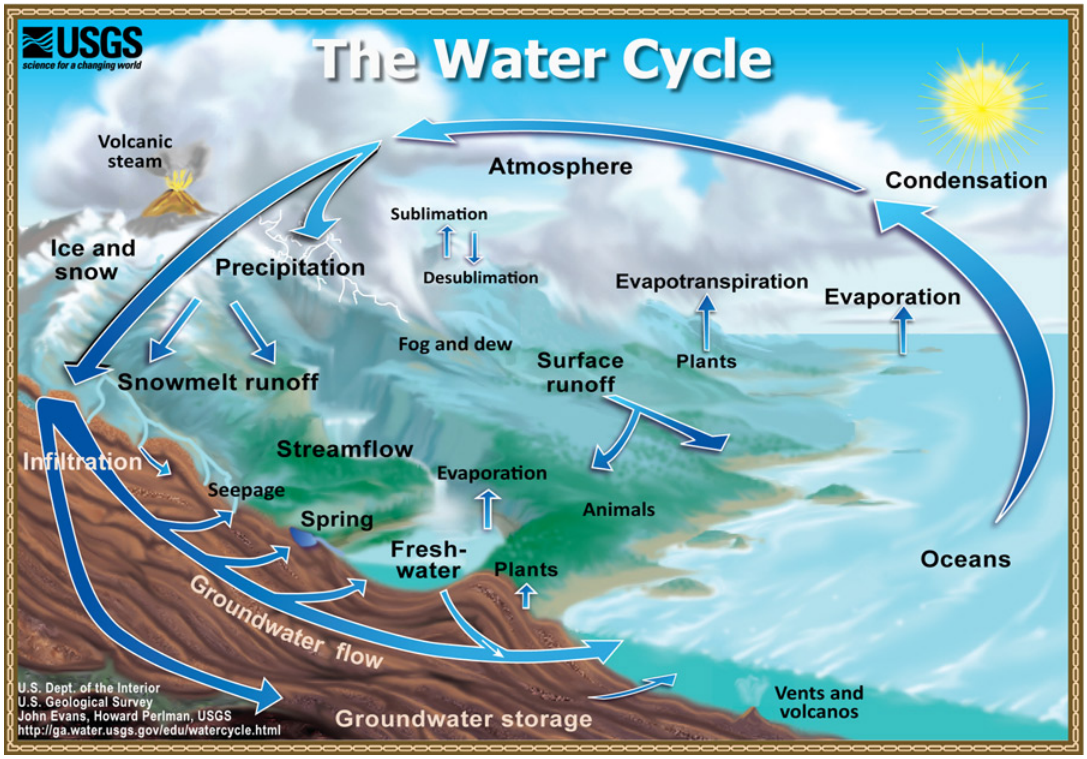


Figure **5.1.2**: Water Hydrologic Cycle. (USGS is in the public domain)

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5.1.1: Classifications of Contaminants

According to the Safe Drinking Water Act, a contaminant is any physical, chemical, biological, or radiological substance in water. While some contaminants are harmless, others are deadly. Contaminants can even mix with water molecules in the atmosphere. Technically, any compound that is not a water molecule is a contaminant when it comes to water.



Pin It! Misconception Alert
Many people think that all contaminants are manmade. They are not! Some have natural sources in the soil, such as arsenic and uranium. These can be expensive to rer rocks around the water source.

Water can be contaminated by various human-caused (anthropogenic) activities or by existing natural features (natural contaminants) like mineral-rich geologic formations. It is not uncommon to find naturally occurring fluoride or arsenic in water.

Agricultural activities, industrial operations, landfills, animal operations, and small and large scale sewage treatment processes, among many other things, all can potentially contribute to contamination. As water runs over the land or infiltrates into the soil and groundwater, it dissolves material left behind by these potential contaminant sources.

There are three major groups of contamination: inorganic chemicals, organic chemicals, and biological agents. The risks and type of remediation for a contaminant depend on the type of chemicals present.



Pin It! Misconception Alert
People use the words contaminants and pollutants interchangeably. What is the difference between a contaminant and a pollutant?

- A contaminant is a substance that is not normally expected.
- A pollutant is a substance found at a concentration that has reached a level that adversely affects the suitability of the water for its intended purpose.

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5.1.2: Key Terms

Key Terms

- **anthropogenic contaminants** – human-caused (manmade) contaminants
- **contaminant** – a substance that is not normally expected
- **groundwater** – water stored in the ground
- **natural contaminants –** contaminants in soil geology, erosion of soils, etc. Examples of contaminants include fluoride and arsenic
- **pollutant** – a substance found at a concentration that has reached a level that adversely affects the suitability of the water for its intended purpose
- **surface water** – water on the surface of the earth

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5.1.3: Review Questions

Review Questions

1. **Outline the water cycle highlighting water sources.**
2. **List the major contaminants of water in the environment.**

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5.1.4: Chapter Quiz

Chapter Quiz

1. How much water on planet earth is easily treated for drinking water?

1. 96%
2. 20.9%
3. 32%
4. < 1.0%

2. Most of the water on earth is found in the _____.

1. atmosphere
2. ocean
3. ground
4. rivers

3. Which of the following is a natural contaminant?

1. Pesticides
2. Nitrates
3. Phosphates
4. Fluoride

4. Anthropogenic contaminants refers to _____.

1. turbidity
2. geological contaminants
3. inorganic contaminants
4. manmade contamination

5. The _____ is(are) essential for the maintenance of most life and ecosystems on the planet.

1. climate
2. water cycle
3. aesthetic characteristic of water
4. atmospheric circulation

6. The _____ drive(s) the water cycle.

1. types of precipitation
2. oxygen concentration
3. nutrient levels
4. sun

7. What portion of surface water is found in the permafrost and ice?

1. 69%
2. 68.7%
3. 96.5%
4. 30.1%

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5.2: Introduction to Chemistry and Matter

Learning Objectives

After reading this section, you should be able to:

- Discuss matter, elements, molecules, and atoms
- Explain electronegativity
- Explain chemical bonding and compounds
- Explain chemical equations and reactions
- Discuss physical states of matter

This chapter presents the fundamentals of chemistry, starting with an introduction on matter and its elemental constituents. Molecular arrangements and chemical bonding are then introduced, followed by examples of chemical nomenclature.

Composition of Matter

Matter can be viewed as anything that has a mass and occupies a space, i.e., that has a specific volume. **Mass** is defined as a measurement of the quantity of matter present.



Pin It! Misconception Alert
Mass is different than weight though people commonly use them interchangeably. Mass is how much matter is present. Weight is a measure of the gravitational pull on the object. So, your weight will change if you travel to the moon, but your mass will not!

Elements and Atoms

At the center of all matter are elements. **Elements** are basic substances that cannot be broken down without altering their basic identities; they cannot be further simplified (e.g., hydrogen, H; oxygen, O). An **atom** is the smallest amount of an element. The center of each atom contains a nucleus made of **protons** (very small particles with a positive electric charge) and **neutrons** (very small particles, without electrical charge), with **electrons** (very small, negatively charged particles) that gravitate around the nucleus. Electrons have an insignificant mass compared to protons and neutrons.

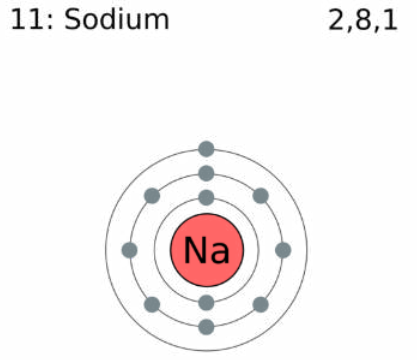


Figure 5.2.1: Electron Shells Gravitating Around Sodium Atom. (Image by Greg Robson is licensed under CC BY-SA 2.0)

Electrons gravitate around the nucleus of protons and neutrons in layers or shells (Figure **5.2.1**. There is only a limited number of electrons per shell, as shown in Figure \(\PageIndex{2}\.

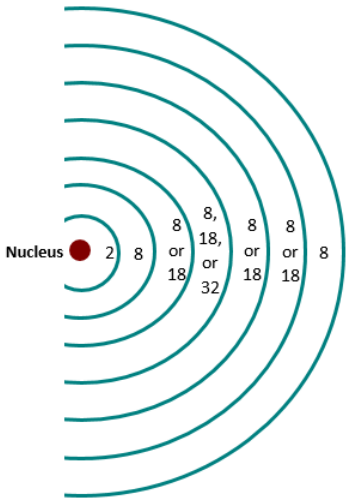


Figure **5.2.2**: Maximum Number of Electrons per Shell. (Image by COC OER is licensed under CC BY 4.0)

Atoms have the same number of protons and electrons; thus, atoms have a neutral electrical charge. However, most atoms tend to gain or lose electrons to complete their last electron shell and obtain a stable electron configuration. Only the Noble Gasses (such as helium, neon, and argon) do not tend to gain or lose electrons because their electron configuration is naturally stable. An atom with an unequal number of protons and electrons is called an **ion**. Atoms that lose electron(s) become positively charged and are called **cation** (e.g., sodium, Na^+). Atoms that gain electron(s) become negatively charged and are called **anion** (e.g., chloride, Cl^-). Note that only electrons are gained, lost, or shared because they are readily available; only radioactive compounds can release protons and neutrons.



Pin It! Misconception Alert
Be careful distinguishing between cations and anions. An atom with an unequal number of protons and electrons is an ion. Cations are positively charged ions and anions are negatively charged ions.

The **Periodic Table** illustrates all elements that have been found or were synthesized to date (Figure **5.2.3**. In this table, elements are ordered in increasing number of protons (from left to right in each row; rows are called periods) and are grouped in columns (called groups) by electron configuration. For example, chlorine appears as number 17 in the Periodic Table (i.e., its atomic number is 17), which means that it has 17 protons. Chlorine is part of the Halogen Family, which all tend to gain an electron to stabilize their last electron shell. While gaining this electron, they become negative charged (e.g., chlorine becomes chloride, Cl^-). Each column represents a family, e.g., Alkali Metals (Column 1), Alkali Earth Metals (Column 2), Halogens (Column 17), and Noble Gases (Column 18). Some families are named after their first element, e.g., Boron Family (Column 13), Nitrogen Family (Column 15), and Oxygen Family (Column 16). Additional characteristics are presented later.

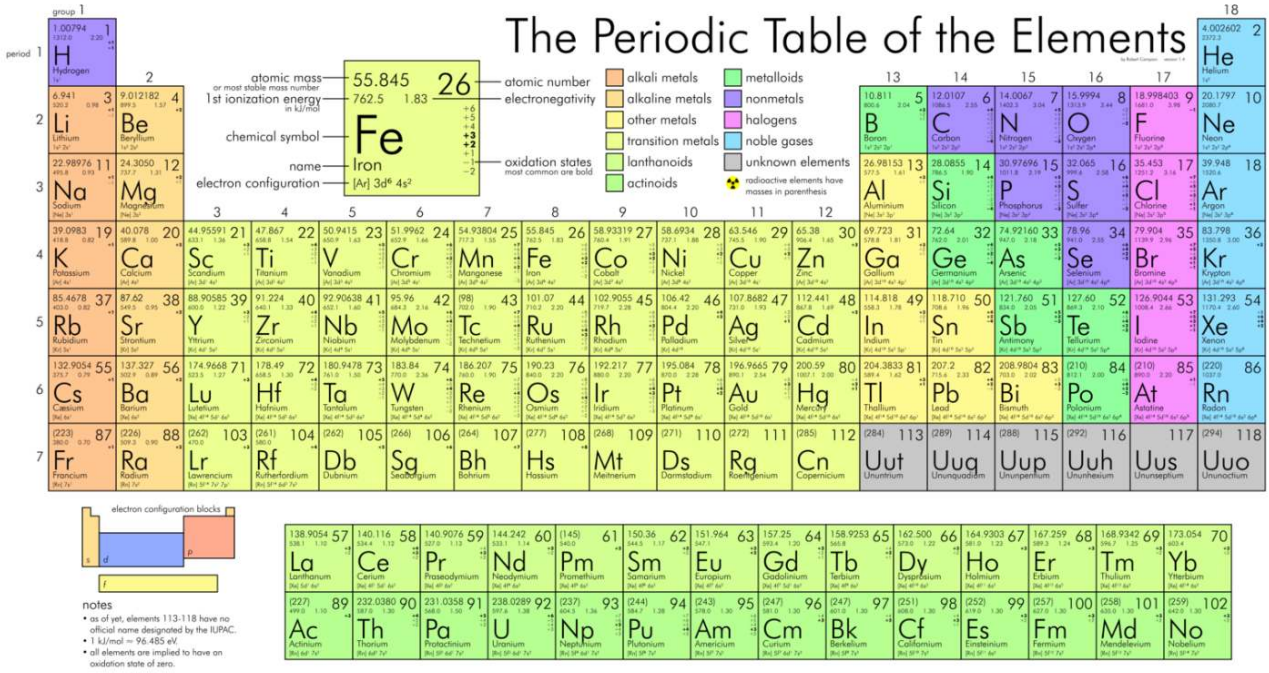


Figure **5.2.3**: Period Table of the Elements. (Image is in the public domain)

The **valence** (also called the ionic state or oxidation state) is the number of electrons gained, lost, or shared between atoms. Because all elements of a family share similar electron configuration, they all tend to have the same valence, as follows:

- Noble Gases are stable, thus their valence is 0.
- Alkali Metals tend to lose one electron, thus their valence is +1.
- Alkali Earth Metals tend to lose two electrons, thus their valence is +2.
- Elements of the Boron Family tend to lose three electrons, thus their valence is +3.
- Halogens tend to gain one electron, thus their valence is -1.
- Elements of the Oxygen Family tend to gain two electrons, thus their valence is -2.
- Elements of the Nitrogen Family tend to gain three electrons, thus their valence is -3.

Certain elements have multiple valences with different characteristics based on their valence. For example, ferrous iron, Fe^{2+}, has lost two electrons (it has a valence of +2) and is highly soluble in water. On the other hand, ferric iron, Fe^{3+} (valence of +3), has lost three electrons and is insoluble in water, i.e., it forms a solid and precipitates. Trivalent chromium (i.e., chromite, also called chromium 3, Cr (III), or Cr^{3+}) has lost three electrons and has a valence of +3. It is an essential element that helps regulate the body's use of sugar, proteins, and fats. However hexavalent chromium (i.e., chromate, also called chromium 6, Cr (VI), or Cr^{6+}) has lost six electrons (valence of +6) and is toxic to humans.

Electronegativity is the degree of attraction of an element for electrons; it defines an element's affinity for electrons. Electronegativity determines whether an atom will gain, lose, or share electrons.

Molecules and Compounds

Molecules or compounds result from the combination of two or more atoms that are chemically joined (or bonded); e.g., oxygen in the air, O_2; water, H_2O. Atoms will tend to combine in such ways to increase their stability and complete their electron configuration. For some molecules, this means that they will obtain a zero net electrical charge.

Chemical bonds can be grouped in two broad categories, as illustrated in Figures \(\PageIndex{4}\ and \(\PageIndex{5}\.

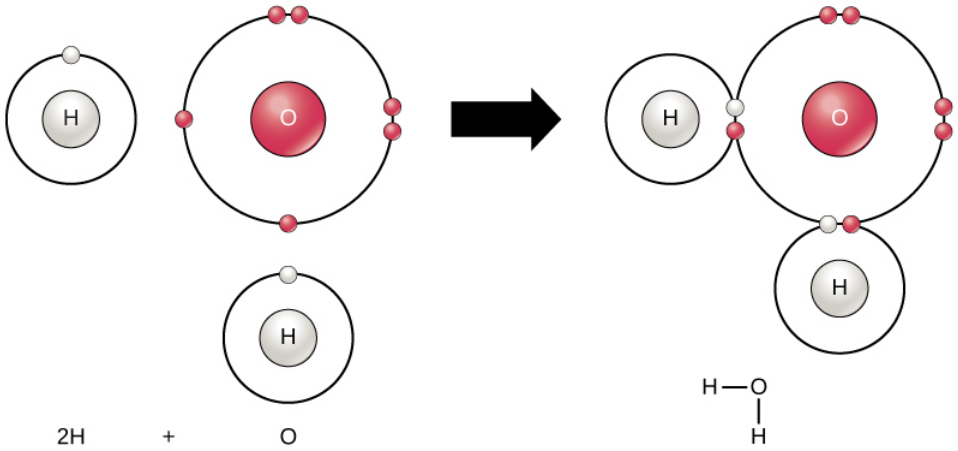


Figure 5.2.4: Example of a covalent bond. (Image by OpenStax is licensed under CC BY4.0)

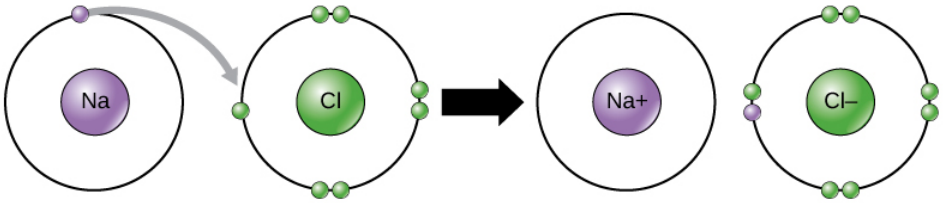


Figure 5.2.5: Example of an ionic bond. (Image by OpenStax is licensed under CC BY 4.0)

1. In an **ionic bond**, electrons are transferred from one atom to another. The atom that loses electron(s) becomes positively charged and is called a cation. Conversely, the atom that gains electron(s) becomes negatively charged and is called an anion. Examples of ionic bonds are shown in Table \(\PageIndex{1}\.
2. In a **covalent bond**, electrons are shared between atoms. The electronegativity of each atom will determine the polarity of the resulting molecule.

Table \(\PageIndex{1}\: Examples of Ionic Bonds

Example	Explanation
Sodium chloride, NaCl	1. Sodium tends to lose 1 electron to become Na^{+} 2. Chloride tends to gain 1 electron to become Cl^{-} 3. Net zero charge: $Na^{+1} + Cl^{-1} = NaCl^{0}$
Sodium oxide, Na_2O	1. Sodium tends to lose 1 electron to become Na^{+} 2. Oxygen tends to gain 2 electrons to become O^{2-} 3. Net zero charge: $(2 \times Na^{+1}) + (1 \times O^{2-}) = Na_2O$

Table \(\PageIndex{2}\: Examples of Covalent Bonds

Example	Explanation
Homonuclear molecules: Equal attraction for the shared electron(s)	Hydrogen, H_2: Single covalent bond: H– H Chlorine, Cl2: Single covalent bond: Cl– Cl Oxygen, O_2: Double covalent bond: O = O Nitrogen, N_2: Triple covalent bond: N ≡ N
Heteronuclear molecule: Unequal attraction for the shared electron(s) Example: Water, H2O	1. Hydrogen, H^+ Valence of +1: Need 1 bond 2. Oxygen, O^{2-} Valence of -2: Need 2 bonds 3. Net zero charge: $(2 \times H^{+1}) + (1 \times O^{2-}) = H_2O$

The key differences between ionic and covalent bonds are summarized in Table \(\PageIndex{3}\) on the following page.

Table \(\PageIndex{3}\): Comparison of Ionic Bonds and Covalent Bonds

Ionic Bonds	Covalent Bonds
• Transfer of electron(s) from one atom to another • Tend to be inorganic • High melting point • Often solid at room temperature • Good conductor • Resulting substance is called a compound	• Electrons are shared between atoms Organic compounds • Low melting point • Solid, liquid or gas at room temperature • Poor conductor • Resulting substance is called a molecule or molecular compound

Dissociation

Molecules that result from polar covalent bond (i.e., atoms of different types that share electrons) may breakdown or dissociate. This is the case for water, H_2O, which dissociates into hydrogen ion, H^+, and hydroxide, OH^-. The dissociation of water is measured as pH.

Chemical Names[1]

The Period Table (Figure **5.2.3** presents all the elements that are known to mankind to this day.

Cations keep is the same name as the element name listed in the Periodic Table. For example, the sodium ion Na^+. Anions have "-ide" at the end when they are formed from elements. For example, chloride, Cl^- is the anion of the element chlorine.

Binary compounds (contain only two elements) are a little more complicated to name based on whether they have ionic or covalent bonds. If they are composed of a metal and a polyatomic ion (non-metal), then you use the name of the metal in the periodic table and then the name of the polyatomic ion. If the polyatomic ion is a single element, then change the ending to “ide”, even if one element has multiple atoms: for example, magnesium chloride, $MgCl_2$.

Metals with variable valences, such as the Transition Metals (Columns 3 through 12 of the Periodic Table, Figure **5.2.3**, are more complex because they are followed by a symbol that reflects the valence. This was introduced earlier in Section 2.1.1. For example, trivalent chromium (i.e., chromite) has a valence of +3, and is referred to as Cr(III), or Cr^{3+}; hexavalent chromium (i.e., chromate) has a valence of +6 and is referred to as Cr(VI), or Cr^{6+}.

Naming acids and their derivatives is more complex and may depend on the acid’s oxidation state. Generally, the acids with the highest oxidation state end in –ic; e.g., sulfuric acid (H_2SO_4), nitric acid (HNO_3), or phosphoric acid (H_3PO_4). Their salts end in –

ate; e.g., sulfate (SO_4^{2-}), nitrate (NO_3^-), or phosphate (PO_4^{2-}). Acids with the next lowest oxidation state end in –ous; e.g., sulfurous acid, H_2SO_3. Their salts end in –ite; e.g., sulfite, SO_3^{2-}. Acids with the lowest oxidation state begin in hypo– and end in –ous; e.g., hypochlorous acid, HOCl. Their salts begin in hypo– and end in –ite; e.g., hypochlorite ion, OCl^-.

Physical States of Matter

States of matter are distinct forms that matter can take. They are based on how elements are arranged in matter. Matter can take four different states (Figure **5.2.6**:

1. Solid: Volume and shape are fixed;
2. Liquid: Fixed volume, but variable shape that adapts to its container;
3. Gas: Volume and shape are variable;
4. Plasma: Variable volume and shape, with electrical charges.

The physical states of matter reflect different energy levels: solids have the lowest energy level, followed by liquids. Gases have higher energy levels, and plasma have the highest energy level. In water, the first three states (i.e., solid, liquid and gas) are important.

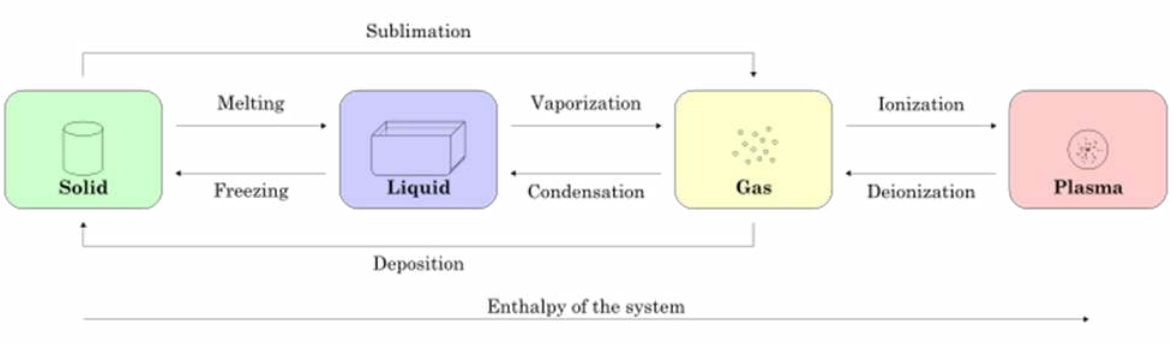


Figure **5.2.4**: Physical States of Matter. (Image by ElfQrin is licensed under CC BY-SA 4.0)

Key Terms

- **anion** – an atom that gains electrons and becomes negatively charged
- **cation** – an atom that loses one or more electrons and becomes positively charged
- **covalent bond** – A type of bond in which electrons are shared between atoms; organic compounds; low melting point; solid, liquid or gas at room temperature; poor conductor; resulting substance is called a molecule or molecular compound
- **electronegativity** – the degree of attraction of an element for electrons; it defines an element's affinity for electrons. Electronegativity determines whether an atom will gain, lose, or share electrons.
- **ionic bond** – Transfer of electron(s) from one atom to another; tend to be inorganic; High melting point; often solid at room temperature; good conductor; resulting substance is called a compound
- **mass –** a measurement of the quantity of matter present
- **matter –** anything that has a mass and occupies a space; can take on four states (solid, liquid, gas, and plasma)
- **periodic table** – an organization of all elements that have been found or synthesized in order from increasing number of protons (from left to right in each row); rows are called periods and columns are called groups
- **valence** - also called the ionic state or oxidation state; the number of electrons gained, lost, or shared between atoms. Because all elements of a family share similar electron configuration, they all tend to have the same valence

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5.2.1: Review Questions

Review Questions

1. **Define matter.**
2. **Define element.**
3. **Define atom.**
4. **Define electronegativity.**
5. **List the types of chemical bonding and define each one.**
6. **What is a chemical reaction?**
7. **List the physical states of matter and describe each one.**

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5.2.2: Chapter Quiz

Chapter Quiz

1. _____ determines whether an atom will gain, lose, or share electrons.

1. Covalent bonding
2. Ionic bonding
3. Physical states of matter
4. Electronegativity

2. The physical states of matter reflect different energy levels; _____ have the lowest energy level.

1. solids
2. liquids
3. gas
4. plasma

3. _____ are basic substances that cannot be broken down without altering their basic identities; they cannot be further simplified.

1. Atoms
2. Molecules
3. Electrons
4. Protons

4. The center of each atom contains a nucleus made of protons (very small particles with a positive electric charge) and neutrons (very small particles, without electrical charge), with electrons (very small, negatively charged particles) that gravitate around the nucleus.

1. protons and neutrons
2. electrons
3. neutrons
4. protons

5. _____ are very small particles with a positive electric charge.

1. protons and neutrons
2. electrons
3. neutrons
4. protons

6. _____ are very small, negatively charged particles.

1. protons and neutrons
2. electrons
3. neutrons
4. protons

7. _____ cannot be created or destroyed over the course of chemical reactions. Thus, the number of _____ must be the same for each element and on each side of the equation.

1. Molecules, molecules
2. Reactants, products
3. Atoms, atoms
4. Products, reactants

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5.3: Chemical Equations

Learning Objectives

After reading this section, you should be able to:

- Describe ionic, covalent, and hydrogen bonding
- Explain synthesis, decomposition, exchange, and combustion reactions
- Describe the energy flow through chemical reactions

Bonding[1]

The model of the atom presented in Chapter 2 is known as the “Bohr” model, and was developed in 1913, by Danish scientist Niels Bohr (1885–1962). His model shows the atom as a central nucleus containing protons and neutrons, with the electrons in circular **orbitals** at specific distances from the nucleus, as Figure 3.1 illustrates. These orbits form electron shells or energy levels, which are a way of visualizing the number of electrons in the outermost shells. These energy levels are designated by a number and the symbol “n.” For example, 1n represents the first energy level located closest to the nucleus.

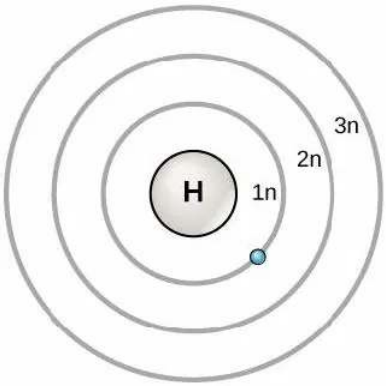


Figure 5.3.1: In 1913, Niels Bohrs developed the Bohr model in which electrons exist within principal shells. An electron normally exists in the lowest energy shell available, which is the one closest to the nucleus. Energy from a photon of light can bump it up to a higher energy shell, but this situation is unstable, and the electron quickly decays back to the ground state. In the process, it releases a photon of light. (Copyright; by OpenStax is licensed under CC BY 4.0)

Electrons fill orbitals in a consistent order: they first fill the orbitals closest to the nucleus, then they continue to fill orbitals of increasing energy further from the nucleus. If there are multiple orbitals of equal energy, they fill with one electron in each energy level before adding a second electron. The electrons of the outermost energy level determine the atom's energetic stability and its tendency to form chemical bonds with other atoms to form molecules. We refer to the outermost energy level as the **valence shell**.

Under standard conditions, atoms fill the inner shells first, often resulting in a variable number of electrons in the outermost shell. The innermost shell has a maximum of two electrons, but the next two electron shells can each have a maximum of eight electrons. With the exception of the innermost shell, atoms are more stable energetically when they have eight electrons in their valence shell. This is an atom’s natural preferred configuration. As such, an atom may give, take, or share electrons with another atom to achieve a full valence shell, and is how covalent and ionic bonds are formed. Refer back to Tables 2.1 and 2.2 in Chapter 2, for examples of these types of bonds.

Remember,

1. In an **ionic bond**, electrons are transferred from one atom to another. The atom that loses electron(s) becomes positively charged and is called a cation. Conversely, the atom that gains electron(s) becomes negatively charged and is called an anion. Examples of ionic bonds are shown in Table 2.5.
2. In a **covalent bond**, electrons are shared between atoms. The electronegativity of each atom will determine the polarity of the resulting molecule.

There is one more bond to talk about, the hydrogen bond.

Hydrogen Bonds[2]

A hydrogen bond is a special type of bond which occurs when a hydrogen atom bonded to a strongly electronegative atom (like oxygen) in the vicinity of another electronegative atom with a lone pair of electrons. These bonds are much weaker than covalent and ionic bonds.

For a hydrogen bond to occur there must be both a hydrogen donor and an acceptor present. The donor in a hydrogen bond is the atom to which the hydrogen atom participating in the hydrogen bond is covalently bonded, and is usually a strongly electronegative atom such as N, O, or F. The hydrogen acceptor is the neighboring electronegative ion or molecule and must possess a lone electron pair in order to form a hydrogen bond.

The most common example of hydrogen bonding in the natural world occurs between molecules of water. It happens before your eyes whenever two raindrops merge into a larger bead, or a creek spills into a river. Hydrogen bonding occurs because the weakly negative oxygen atom in one water molecule is attracted to the weakly positive hydrogen atoms of two other water molecules (Figure **5.3.2**).

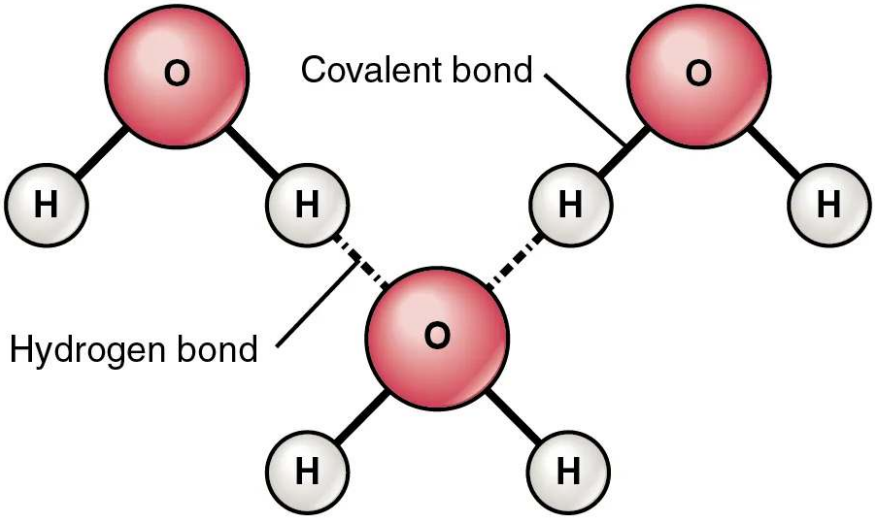


Figure **5.3.2**: Hydrogen Bonds between Water Molecules. Notice that the bonds occur between the weakly positive charge on the hydrogen atoms and the weakly negative charge on the oxygen atoms. Hydrogen bonds are relatively weak, and therefore are indicated with a dotted (rather than a solid) line. (Image by OpenStax is licensed under CC BY 4.0.)

Water molecules also strongly attract other types of charged molecules as well as ions. This explains why "table salt," for example, actually is a molecule called a "salt" in chemistry, which consists of equal numbers of positively-charged sodium (Na^+) and negatively-charged chloride (Cl^-), dissolves so readily in water, in this case forming dipole-ion bonds between the water and the electrically-charged ions (electrolytes). Water molecules also repel molecules with nonpolar covalent bonds, like fats, lipids, and oils. You can demonstrate this with a simple kitchen experiment: pour a teaspoon of vegetable oil, a compound formed by nonpolar covalent bonds, into a glass of water. Instead of instantly dissolving in the water, the oil forms a distinct bead because the polar water molecules repel the nonpolar oil.

Types of Hydrogen Bonds

Hydrogen bonds can occur within one single molecule, between two like molecules, or between two unlike molecules.

- **Intramolecular hydrogen bonds**: Intramolecular hydrogen bonds are those which occur within one single molecule. This occurs when two functional groups of a molecule can form hydrogen bonds with each other. In order for this to happen, both a hydrogen donor an acceptor must be present within one molecule, and they must be within close proximity of each other in the molecule. For example, intramolecular hydrogen bonding occurs in ethylene glycol ($C_2H_4(OH)_2$) between its two hydroxyl groups due to the molecular geometry.
- **Intermolecular hydrogen bonds**: Intermolecular hydrogen bonds occur between separate molecules in a substance. They can occur between any number of like or unlike molecules as long as hydrogen donors and acceptors are present in positions in which they can interact. For example, intermolecular hydrogen bonds can occur between NH_3 molecules alone, between H_2O molecules alone, or between NH_3 and H_2O molecules.

Hydrogen bonding plays a crucial role in many biological processes and can account for many natural phenomena such as the unusual characteristics of water. In addition to being present in water, hydrogen bonding is also important in the water transport system of plants, protein structure, and nucleic acids.

Molecular Mass and Moles[3]

The molecular mass of a substance is the sum of the average masses of the atoms in one molecule of a substance. It is calculated by adding together the atomic masses of the elements in the substance, each multiplied by its subscript (written or implied) in the molecular formula. Because the units of atomic mass are atomic mass units, the units of molecular mass are also atomic mass units.

A mole is defined as the amount of a substance that contains the number of carbon atoms in exactly 12 g of isotopically pure carbon-12. According to the most recent experimental measurements, this mass of carbon-12 contains 6.022142×10^{23} atoms, but for most purposes 6.022×10^{23} provides an adequate number of significant figures. Just as 1 mole of atoms contains 6.022×10^{23} atoms, 1 mole of eggs contains 6.022×10^{23} eggs. The number in a mole is called Avogadro's number, after the 19th-century Italian scientist who first proposed how to measure the number of molecules in a gas.

The mole provides a bridge between the atomic world (amu) and the laboratory (grams). It allows determination of the number of molecules or atoms by weighing them. The numerical value of Avogadro's number, usually written as No, is a consequence of the arbitrary value of one kilogram, called the International Prototype Kilogram, and the choice of reference for the atomic mass unit scale, one atom of carbon-12. Why? Because the number of carbon atoms in exactly 12 g of isotopically pure carbon-12 contains almost exactly 6.022×10^{23} atoms.

So how much does 1 mole of H_2O weigh? The atomic mass of hydrogen is 1. We have two of them in water. The atomic mass of oxygen is 16. So (2 x 1)H + (16)O = 18 g

Chemical Reactions[4]

Chemical energy is the form of potential energy in which energy is stored in chemical bonds. When those bonds are formed, chemical energy is invested, and when they break, chemical energy is released. Notice that chemical energy, like all energy, is neither created nor destroyed; rather, it is converted from one form to another.

All chemical reactions begin with a **reactant**, the general term for the one or more substances that enter into the reaction. Sodium and chloride ions, for example, are the reactants in the production of table salt. The one or more substances produced by a chemical reaction are called the **product**.

In chemical reactions, the components of the reactants—the elements involved and the number of atoms of each—are all present in the product(s). Similarly, there is nothing present in the products that are not present in the reactants. This is because chemical reactions are governed by the law of conservation of mass, which states that matter cannot be created or destroyed in a chemical reaction.

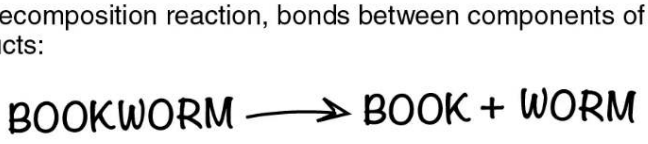
Just as you can express mathematical calculations in equations such as 2 + 7 = 9, you can use chemical equations to show how reactants become products. As in math, chemical equations proceed from left to right, but instead of an equal sign, they employ an arrow or arrows indicating the direction in which the chemical reaction proceeds. For example, the chemical reaction in which one atom of nitrogen and three atoms of hydrogen produce ammonia would be written as $N+3H \rightarrow NH_3$. Correspondingly, the breakdown of ammonia into its components would be written as $NH_3 \rightarrow N + 3H$.

Notice that, in the first example, a nitrogen (N) atom and three hydrogen (H) atoms bond to form a compound. This anabolic reaction requires energy, which is then stored within the compound's bonds. Such reactions are referred to as synthesis reactions. A **synthesis reaction** is a chemical reaction that results in the synthesis (joining) of components that were formerly separate (Figure **5.3.3**. Again, nitrogen and hydrogen are reactants in a synthesis reaction that yields ammonia as the product. The general equation for a synthesis reaction is $A + B \rightarrow AB$.

a) In a synthesis reaction, two components bond to make a larger molecule. Energy is required and is stored in the bond:



b) In a decomposition reaction, bonds between components of a larger molecule are broken, resulting in smaller products:



c) In an exchange reaction, bonds are both formed and broken such that the components of the reactants are rearranged:



Figure **5.3.3**: The Three Fundamental Chemical Reactions. The atoms and molecules involved in the three fundamental chemical reactions can be imagined as words. (Copyright; by OpenStax is licensed and modified under CC BY 4.0.)

In the second example, ammonia is catabolized into its smaller components, and the potential energy that had been stored in its bonds is released. Such reactions are referred to as decomposition reactions. A **decomposition reaction** is a chemical reaction that breaks down or "de-composes" something larger into its constituent parts (see Figure 3.3). The general equation for a decomposition reaction is: AB→A+BAB→A+B.

An **exchange reaction** is a chemical reaction in which both synthesis and decomposition occur, chemical bonds are both formed and broken, and chemical energy is absorbed, stored, and released (see Figure **5.3.3**). The simplest form of an exchange reaction might be: A+BC→AB+C. Notice that, to produce these products, B and C had to break apart in a decomposition reaction, whereas A and B had to bond in a synthesis reaction. A more complex exchange reaction might be: AB+CD→AC+BD. Another example might be: AB+CD→AD+BC.

In theory, any chemical reaction can proceed in either direction under the right conditions. Reactants may synthesize into a product that is later decomposed. Reversibility is also a quality of exchange reactions. For instance, A+BC→AB+C could then reverse to AB+C→A+BC. This reversibility of a chemical reaction is indicated with a double arrow: A+BC⇄AB+C. Many chemical reactions do proceed in a predictable direction, either one way or the other. You can think of this more predictable path as the path of least resistance because, typically, the alternate direction requires more energy.

Combustion Reactions

Combustion reactions are types of chemical reactions where compounds and oxidants react to produce heat and new products. A common combustion reaction is the reaction between oxygen and hydrocarbons to yield water and carbon dioxide:

(Oxygen) + (Hydrocarbon) (Carbon Dioxide) + (Water) + heat

For example:

- $2H_2 + O_2 \rightarrow 2H_2O$ + heat
- $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ + heat

It is also common for a combustion reaction to release light and produce a flame. However, it is not necessary. For a combustion reaction to be initiated, the activation energy for the reaction must be overcome. Often combustion reactions are started with a flame, which provides the heat to initiate the reaction. Once combustion begins, the heat that is produced sustains the reaction until the reactants are used.

In order to recognize combustion reactions, oxygen will be on the reactant side of the equation and the release of heat will be on the product side of the equation. Sometimes the fuel molecule contains oxygen. For example, the combustion of ethanol:

$C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$

Combustion is an exothermic reaction so that it releases heat. However, sometimes the reaction proceeds so slowly that a temperature change is not noticeable. The signs that a combustion reaction occurs is the presence of oxygen as a reactant and carbon dioxide, water, and heat as products. Inorganic combustion reaction may not form the same types of products; however, they are recognizable by the reaction of oxygen. The surest method of recognizing a combustion reaction is that the products contain carbon dioxide and water.

Combustion does not always proceed to completion or 100-percent efficiency. The reactions are prone to limiting reactants. Two types of combustion reactions exist:

1. **Complete Combustion**: known as clean combustion where oxidation of the reactants (hydrocarbons) produces only carbon dioxide and water. The burning of candle wax, where the heat from the wick vaporizes the wax (hydrocarbon), is an example. The reaction results from the oxygen in the air so that carbon dioxide and water are the products. All of the wax burns so that nothing remains once the candle is consumed. The water vapor and carbon dioxide dissipate into the atmosphere.
2. **Incomplete Combustion**: incomplete combustion is the oxidation of a hydrocarbon that is incomplete or dirty. The products are carbon monoxide and carbon (soot) in addition to carbon dioxide. An example would be the combustion of coal, where soot and carbon monoxide are the products. Fossil fuels oxidize incompletely, and they release waste products.

Energy Flow in Chemical Reactions

Chemical bonds represent stored chemical energy, and chemical reactions ultimately result in net absorption or release of energy. Reactions that release energy are called exergonic reactions. These reactions yield products with less energy than the initial reactants, along with energy that can be harvested for use. Catabolic and oxidative reactions are exergonic for the most part.

The products of energy absorbing, endergonic, reactions contain potential energy in their chemical bonds which is more than the energy that the reactants contained. Anabolic reactions are energy absorbing reactions. For example, the energy released when fuel molecules are broken down (oxidized) is captured in ATP molecules and used to synthesize complex biological molecules the body needs to sustain life.

Factors that Influence the Rate of Chemical Reactions[6]

If chemical reactions are to occur quickly, the atoms in the reactants have to have easy access to one another. Thus, the greater the surface area of the reactants, the more readily they will interact. As a general rule, gases tend to react faster than liquids or solids, again because it takes energy to separate particles of a substance, and gases by definition already have space between their particles. Similarly, the larger the molecule, the greater the number of total bonds, so reactions involving smaller molecules, with fewer total bonds, would be expected to proceed faster.

Reactions that involve highly reactive elements like hydrogen proceed more quickly than reactions that involve less reactive elements. Reactions involving stable elements like helium are not likely to happen at all.

Increasing the temperature of a substance increases the kinetic energy of its particles and the force of their collisions. Chemical reactions proceed more quickly at higher temperatures.

Chemical reactions progress more rapidly when the reacting particles are present in high numbers, concentrations, because the chance of collisions are greater. As the concentrations of the reactants declines, the reaction slows. Chemical equilibrium eventually occurs unless additional reactants are added or products are removed from the reaction site.

Smaller particles move faster than large particles and tend to collide more frequently and more forcefully. The smaller the reacting particles, the faster a chemical reaction proceeds at a given temperature and concentration.

Chemical reactions in nonliving systems can be speeded up by heating. However drastic increases in body temperature are life threatening because important biological molecules are destroyed. At normal body temperature, most chemical reactions would proceed at too slow of a pace to maintain life, if catalysts were not present. **Catalysts** are substances that increase the rate of chemical reactions without becoming chemically changed or part of the product. Biological catalysts are called enzymes.

Key Terms

catalysts – substances that increase the rate of chemical reactions without becoming chemically charged or part of the product; biological catalysts are called enzymes

combustion reactions – types of chemical reactions where compounds and oxidants react to produce heat and new products

decomposition reactions – a reaction in which larger molecules are split into smaller molecules, ions, or atoms

mole – one mole of a substance is its molecular weight expressed in grams

synthesis reactions – a reaction in which two or more atoms, ions, or molecules combine to form new and larger molecules

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5.3.1: Review Questions

Review Questions

1. **Describe hydrogen bonding.**
2. **Describe synthesis reactions.**
3. **Describe decomposition reactions.**
4. **Describe exchange reactions.**
5. **Describe combustion reactions**

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5.3.2: Chapter Quiz

Chapter Quiz

1. The _____ or combining capacity of an atom is the number of extra or missing electrons in its outermost electron shell.

1. valence
2. atomic number
3. exchange rate
4. nucleus

2. _____ is the oxidation of a hydrocarbon that is incomplete or dirty. The products are carbon monoxide and carbon (soot) in addition to carbon dioxide.

1. Complete combustion
2. Incomplete combustion
3. Reduction
4. Decomposition

3. _____ is where a hydrogen atom that is covalently bonded to one oxygen or nitrogen atom is attracted to another oxygen or nitrogen atom. These bonds are weak and do not bind atoms into molecules.

1. Ionic bonding
2. Covalent bonding
3. Hydrogen bonding
4. Temporary bonding

4. _____ is an attraction between ions of opposite charge that holds them together to form a stable molecule.

1. Ionic bonding
2. Covalent bonding
3. Hydrogen bonding
4. Temporary bonding

5. _____ are stronger and more common in living organisms than are true ionic bonds. In the hydrogen molecules, H_2, two hydrogen atoms share a pair of electrons.

1. Ionic bonds
2. Covalent bonds
3. Hydrogen bonds
4. Temporary bonds

6. _____ represent stored energy.

1. Chemical bonds
2. Hydrogen bonds
3. Covalent bonds
4. Ionic bonds

7. When two or more atoms, ions, or molecules combine to form new and larger molecules, the reaction is called a _____.

1. decomposition reaction
2. exchange reaction
3. combustion reaction
4. synthesis reaction

8. _____ are substances that increase the rate of chemical reactions without becoming chemically changed or part of the product.

1. Products

2. Reactants
3. Catalysts
4. Chemical bonds

9. For a combustion reaction to be initiated, the _____ energy for the reaction must be overcome.

1. kinetic
2. potential
3. activation
4. decomposition

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5.4: Organic Chemistry

Learning Objectives

After reading this section, you should be able to:

- Explain carbon-based compounds
- Describe molecular structure
- Describe organic matter
- Describe methane, trihalomethanes, acetic acid, haloacetic acid

Organic compounds contain carbon. All organic compounds are covalently bonded molecules, and most organic compounds are large molecules. All other chemicals are considered **inorganic compounds,** which do not contain carbon. Inorganic compounds include water, salts, and many acids and bases. Organic and inorganic compounds are equally essential for life.

Organic materials are derived from plant fibers and animal tissues, which are produced by synthesis reactions that produce materials like rubber, plastics, and other compounds; and fermentation reactions that produce alcohols, acids, antibodies, and other compounds.



Pin It! Misconception Alert
In chemistry, the word “organic” refers to compounds containing carbon. It does not refer to organic food (e.g., grown without chemical fertilizers or pesticides).

Inorganic compounds, in contrast to organic compounds, are combustible, high in molecular weight, and sparingly soluble in water and a source of food for animal consumers and microbial decomposers.

Organic compounds essential life include carbohydrates, lipids, proteins, and nucleotides. Each of these molecules contain carbon and they are referred to as organic compounds. Organic compounds are distinguished by the fact that they contain carbon, and inorganic compounds are defined as compounds that lack carbon. However, carbon dioxide and carbon monoxide are carbon containing compounds but are considered inorganic compounds.

Organic molecules are large molecules. Only small, reactive parts of their structure interact with other compounds. These areas are referred to as active sites and are functional groups, such as acid groups, amines, and others.

Carbon is a special atom. No other small atom is so electroneutral. The consequence of its electroneutrality is that carbon does not lose or gain electrons. It shares them. With four valence shell electrons, carbon forms four covalent bonds with other elements, as well as with other carbon atoms. As a result, carbon helps to form long, chainlike molecules, ring structures, and other structures that are uniquely suited for specific roles in living systems.

Many biologic molecules are polymers like carbohydrates and proteins. Polymers are chainlike molecules made of many similar or repeating units, monomers, which are joined together by dehydration synthesis. During dehydration syntheses, a hydrogen atom is removed from one monomer and a hydroxyl group is removed from another monomer. The resultant products are joined together with a covalent bond, and in the process, a water molecule is released. The removal of a water molecule at the bond site occurs each time a monomer is added to the growing polymer chain.

Hydrocarbons

In organic chemistry, any chemical compound that consists of the elements of carbon and hydrogen is a **hydrocarbon**. Carbon and hydrogen atoms share an electron pair forming covalent bonds in hydrocarbons. One of the special properties of carbon is its ability to form double and triple bonds.

Saturated hydrocarbons contain only the elements of carbon and hydrogen with single bonds between carbon atoms. Methane is the simplest hydrocarbon, and it is a gas produced in the anaerobic decomposition of organic compounds.

When hydrocarbon molecules include one or more double or triple bonds between some of the carbon atoms it is not possible for as many hydrogen atoms to be included in the molecule as when the bonds are single bonds. The term used to describe the presence of one or more double or triple bonds in a molecule of an organic compound is **unsaturated**. If the organic compound contains all single bonds, it is called **saturated**.

Alkanes, Alkenes, and Alkynes

Hydrocarbons are classified as unsaturated or saturated. Alkanes are a group of saturated hydrocarbons meaning that the hydrocarbon contains only single bonded carbon atoms represented as:

C-C-C-C (C_nH_{2n+2})

Alkenes are a group of unsaturated hydrocarbons meaning that the hydrocarbon contains double carbon-carbon bonds represented as:

C=C=C ($C_nH_{2n)}$

Alkynes are hydrocarbons that include triple carbon-carbon bonds (C_nH_{2n-2}).

A bromine solution is used to test for unsaturation of hydrocarbon molecules. Bromine solution is orange in color. When an alkene is added to a bromine solution, the orange color disappears resulting in a colorless solution. Bromine reacts with alkenes forming a new colorless compound. This test is useful in distinguishing alkenes from alkanes because alkanes do not react with bromine solution.

Unsaturated hydrocarbons are distinguished from paraffins by the presence of multiple bonds between some carbon atoms. The multiple bonds between carbon atoms displace hydrogen atoms, creating molecules containing fewer hydrogen atoms.

Vegetable shortenings available as solid fats are produced from oils through the process of hydrogenation which adds hydrogen atoms through the addition of hydrogen gas under controlled conditions. Reducing the number of unsaturated bonds increases the melting point, converting an oil to a solid fat.



Figure **5.4.1**: Vegetable shortening. (Image by doornekamph on Pixabay)

Chemical Structure

The parent compound of aromatic hydrocarbons is benzene. **Benzene** is a 6-carbon ring with double bonds between alternate atoms. Benzene is used in the manufacture of a variety of commercial products including insecticides, plastics, solvents, explosives, and dyes.

Alcohols

Alcohols are formed from hydrocarbons by replacing one or more hydrogen atoms by hydroxyl groups (-OH). **Methanol** is manufactured synthetically by a catalytic process from carbon monoxide and hydrogen. It is used extensively in manufacturing organic compounds, like solvents, fuel additives, and formaldehyde. **Ethyl alcohol** for beverage purposes is produced through the fermentation of a variety of natural organic materials, like corn, wheat, rice, and potatoes. Industrial ethanol is produced from fermentation of waste solutions containing sugars, like blackstrap molasses and residues resulting from the purification of cane sugar.



Figure 5.4.2: Grains of cane sugar. (Image by Fritzs is licensed under CC BY-SA 3.0)

Propanol has two isomers, the more common is **isopropyl alcohol**, which is widely used by industry and sold as a medicinal rubbing alcohol. The three primary alcohols have boiling points less than 100ºC, and they are miscible with water.

- Methanol or methyl alcohol (CH_3OH)
- Ethanol or ethyl alcohol (CH_3CH_2OH)
- Isopropyl alcohol or 2-Propano (CH_3CH_3CHOH)

Miscible liquids are homogenous when mixed together.

The derivative of benzene containing one hydroxyl group, known as phenol, has a molecular formula of C_6H_5OH. The formula and –ol in the name indicate the characteristics of an alcohol; however, phenol, known as carbolic acid, ionizes in water yielding hydrogen ions, and exhibits features of an acid. It occurs as natural component of wastes from coal, gas, petroleum, and a variety of industrial wastes where phenol is used as a raw material. Phenol is a strong toxin that makes the waste materials particularly difficult to treat in biological systems. Phenols impart undesirable tastes to water at low concentrations.

Aldehydes and Ketones

Aldehydes and ketones are compounds containing a carbonyl group. **Formaldehyde** is used to produce plastics and resins. **Acetone** (dimethyl ketone) is a good solvent of fats and is a common cleaning agent for laboratory glassware.

- Formaldehyde (CH_2OH)
- Acetone (CH_3CHCOH)



Figure 5.4.3: Nail polish remover (Image by Chris is licensed under CC BY-NC-SA 2.0)

Carboxylic Acids

Organic acids contain the carboxyl group, -COOH. **Carboxylic acid** is the highest state of oxidation that an organic radical can achieve. Further oxidation results in the formation of carbon dioxide and water. Acids through 9-carbons are liquids, and those acids with more carbons are greasy solids, fatty acids. Organic acids are weak and ionize poorly.

Formic, acetic, and propionic acids have sharp penetrating odors, and butyric and valeric acids have extremely disagreeable odors associated with rancid fats and oils. Anaerobic decomposition of long chain fatty acids result in the production of 2 and 3-carbon acids, which are converted to methane and carbon dioxide gas in decomposition reactions.

- Formic acid (HCOOH)
- Acetic acid (CH_3COOH)
- Propionic acid (CH_3CH_2COOH)
- Butyric acid ($CH_3CH_2CH_2COOH$)
- Valeric acid (C_4H_9COOH)
- Caproic acid ($C_5H_{11}COOH$)

Basic compounds react with acids to produce salts. NaOH, sodium hydroxide, reacts with acetic acid to produce sodium acetate. Soaps are salts of long chain fatty acids. Other derivatives of carboxylic acids include esters, such as ethyl acetate and amides.

- Methylamine ($CH_3NH_{2)}$

Organic Matter

Biodegradable organic matter in water is classified into three categories: fats, carbohydrates, and proteins. **Carbohydrates** consist of sugar units containing the elements of carbon, hydrogen, and oxygen. A single sugar is known as a monosaccharide. Disaccharides are composed of two monosaccharide units. Sucrose, table sugar, is glucose plus fructose. The most prevalent sugar in milk is lactose, consisting of glucose plus galactose. Polysaccharides, long chains of sugar units, are divided into two groups: readily degradable starches, like potatoes, rice, corn, and other edible plants; and cellulose which is found in wood, cotton, paper, and similar plant tissues. Cellulose compounds degrade biologically at a slower rate than starches.

Proteins are long strings of amino acids containing carbon, hydrogen, oxygen, nitrogen, and phosphorus. They form an essential part of living tissue and constitute a diet necessary for higher life forms.

Fats refer to a variety of biochemical substances that have the property of being soluble to varying degrees in organic solvents, like ether, ethanol, acetone, and hexane, while being sparingly soluble in water. Because of their limited solubility, degradation by microorganisms is very slow. A simple fat is a triglyceride composed of a glycerol unit with short or long chain fatty acids attached.

The majority of carbohydrates, fats, and proteins in nature are in the form of large molecules that cannot penetrate the cell membrane of microorganisms. Bacteria, in order to metabolize high-molecular weight substances, must be capable of breaking down the large molecules into diffusible fractions for assimilation into the cell. The first step in bacterial decomposition of organic compounds is hydrolysis of carbohydrates into soluble sugars, proteins into amino acids, and fats into short fatty acids. Aerobic biodegradation results in the formation of carbon dioxide and water. Anaerobic digestion, decomposition in the absence of oxygen, results in the formation of organic acids, alcohols, and other liquid intermediates as well as gaseous entities of carbon dioxide, methane, and hydrogen sulfide.

Several organic compounds, like cellulose, long chain saturated hydrocarbons, and complex compounds, although available as a bacterial substrate, are considered non-biodegradable because of the time and environmental limitations of biological treatment systems. Petroleum derivatives, detergents, pesticides, and synthetic organic compounds are also resistant to biodegradation, and some of these compounds are toxic and inhibit the activity of microorganisms in biological processes.

Some waste odors are inorganic compounds, like hydrogen sulfide gas; however, many odors are caused by volatile organic compounds, such as mercaptans and butyric acid. Industries may produce a variety of medicinal odors in the processing of raw materials. Surface water supplies plagued with blooms of blue green algae have fishy or pigpen odors. The cause of odors can be anaerobic decomposition, industrial chemicals, or growths of obnoxious microorganisms.



Figure 5.4.4: Green ocean water. (Image by Tom Archer is in the public domain.
)

Methane and Trihalomethane

Chlorine is used to inhibit or destroy harmful organisms. This method of disinfection alters cell chemistry causing microorganisms to die. Chlorine is the most widely used disinfectant chemical. Chlorine is relatively inexpensive and leaves a residual chlorine that can be measured. An increased interest in disinfection other than chlorine has developed because of the carcinogenic compounds that chlorine may form, trihalomethanes, THMs.

The exact mechanism of chlorine disinfection action is not fully understood. It is felt that chlorine exerts a direct action against bacterial cell, destroying them. Another theory is that the toxic character of chlorine inactivates the enzymes, which enable living microorganisms to use their food supply. As a result, the organisms die. However, the exact mechanism of chlorine disinfection is less important than its demonstrated effects as a disinfectant.

When chlorine is added to water, several chemical reactions take place. Some of the reactions involve the molecules of the water, and some reactions involve organic and inorganic substances suspended in the water.

Chlorine combines with organic and inorganic materials to form chlorine compounds. If chlorine is added continuously, eventually all of the materials in the water that will react with chlorine are used and the chlorine reactions stop. At this point, the chlorine demand is satisfied.

The chemical reactions between chlorine and organic and inorganic substances produce chlorine compounds. Some chlorine compounds have disinfecting properties, and some compounds do not. Chlorine also reacts with the water and produces substances with disinfecting properties. The total of all of the compounds with disinfection properties plus any remaining free, uncombined, chlorine is known as the chlorine residual. The presence of this measurable chlorine residual indicates that all possible chemical reactions with chlorine have taken place and that a sufficient available residual of chlorine is available to kill microorganisms present in the water.

When organic materials are present in water being disinfected with chlorine, the chemical reactions that take place can produce suspected carcinogenic compounds, THMs. The formation of these compounds can be prevented by limiting the amount of chlorination and by removing the organic materials before chlorination of the water.

Methane

Methane is a colorless, odorless, flammable gas, and it is the primary constituent of marsh gas and the firedamp of coal mines. It is obtained commercially from natural gas, and it is the first member of the alkane series of hydrocarbons. The formation of methane can occur through organic matter decomposition or through organic synthesis which involve microorganisms, methanogenesis. The synthesis involves anaerobic and aerobic processes. Naturally occurring methane is produced by microbial methanogenesis. This multistep process is used by microorganisms as an energy source. The net reaction is:

$$CO_2 + 8H^+ \rightarrow CH_4 + 2\,H_2O$$

The final step in the process is catalyzed by the enzyme coenzyme-B sulfoethylthiotransfersase. Methanogenesis is a form of anaerobic respiration used by organisms that occupy landfills, ruminants, and the guts of termites.

Trihalomethanes

Trihalomethanes are harmful by-products arising from a process of water disinfection with chlorine. Trihalomethanes are formed when organic materials react with chlorine to form chlorinated by-products. Trihalomethanes are chemical compounds where 3 of

the 4-hydrogen atoms of methane are replaced by halogen atoms. Trihalomethanes (THMs) are used in industry as solvents or refrigerants. THMs are environmental pollutants, and many of them are considered carcinogenic. Trihalomethanes with all the same halogen atoms are called haloform, and they are considered to be volatile organics. Some examples of trihalomethanes are:

- Chloroform
- Bromodichloromethane
- Bromoform
- Carbon tetrachloride
- Tetrachloroethlene

Trihalomethanes are formed as a by-product when chlorine is used to disinfect drinking water. They represent a group of chemicals referred to as disinfection by-products. They result from the reaction of chlorine or bromine with organic matter present in the water being treated. THMs have been associated through epidemiological studies with adverse health effects. Governmental agencies have set limits on the amount permissible in drinking water. The EPA limits the total concentration of the four chief constituents, chloroform, bromoform, bromodichloromethane, and dibromochloromethane, referred to as total TTHMs to 80 parts per billion in drinking water.

In drinking water, THM levels tend to increase with pH, temperature, contact time with chlorine, and the level of the organic precursors. The precursors, organic material, reacts with chlorine to form THMs. One method that is used to decrease THMs is to eliminate or reduce chlorination before the filters and to reduce precursors. Since more precursors are present before filtration, the treatment process is directed toward reducing or eliminating the time chlorine is in contact with the water. If some oxidation before filtration is required, an alternative disinfectant like potassium permanganate or peroxide should be considered. This strategy is not an option if pre-chlorination is necessary to achieve the required CT, contact time, values.

The EPA has advocated that the best available technology for THM control at treatment facilities is to remove precursors through enhanced coagulation. Enhanced coagulation refers to a process of optimizing the filtration process to maximize removal of precursors. Removal is improved by decreasing pH levels to 4 or 5, increasing the feed rate of coagulants, and using ferric coagulants in place of alum.

Acetic Acid and Haloacetic Acid

Haloacetic acids (HAA) are carboxylic acids where a halogen atom takes the place of hydrogen atoms in acetic acid. In monohaloacetic acid, a single halogen replaces a hydrogen atom. Chloroacetic acid has the structural formula of CH_2ClCO_2H. In this manner, two chlorine atoms are present in dichloroacaetic acid where two hydrogen atoms are replaced with chlorine atoms. Dichloroacetic acid has a structural formula of $CHCl_2CO_2H$.

Haloacetic acids (HAA) are a common undesirable by-product of drinking water chlorination. Exposure to such disinfection by-products in drinking water, at high levels has been associated with undesirable health outcomes through epidemiological studies. The five most common HAAs in water are:

- Monochloroacetic acid ($CLCH_2COOH$)
- Dichloroacetic acid ($Cl_2CHCOOH$)
- Trichloroacetic acid (Cl_3CCOOH)
- Monobromoacetic acid ($BrCH_2COOH$)
- Dibromoacetic acid ($Br_2CHCOOH$)

Collectively, these chemicals are called HAA_5.

HAAs can be formed by chlorination, ozonation, or chloramination of water with the formation of HAAs promoted by slightly acidic water, high organic matter content, and elevated temperature. Chlorine from the water disinfection process reacts with organic matter and small amounts of bromide present in the water to produce various HAAs.

Key Terms

- **acetone** – a good solvent of fats and is a common cleaning agent for laboratory glassware
- **carbohydrates** – sugar units containing the elements of carbon, hydrogen, and oxygen
- **carboxylic acid** – the highest state of oxidation that an organic radical can achieve

- **ethyl alcohol** – alcohol for beverage purposes that is produced through the fermentation of a variety of natural organic materials, like corn, wheat, rice, and potatoes
- **fats** – a variety of biochemical substances that have the property of being soluble to varying degrees in organic solvents, like ether, ethanol, acetone, and hexane, while being sparingly soluble in water
- **formaldehyde** – used to produce plastics and resins
- **haloacetic acids (HAA)** – carboxylic acids where a halogen atom takes the place of hydrogen atoms in acetic acid, a common undesirable by-product of drinking water chlorination
- **inorganic compounds** – molecules that do not contain carbon
- **isopropyl alcohol** – a type of alcohol, which is widely used by industry and sold as a medicinal rubbing alcohol.
- **methanol** – a type of alcohol manufactured synthetically by a catalytic process form carbon monoxide and hydrogen; used extensively in manufacturing organic compounds, like solvents, fuel additives, and formaldehyde
- **methane** – a colorless, odorless, flammable gas, and it is the primary constituent of marsh gas and the firedamp of coal mines
- **organic compounds** – molecules that contain carbon
- **proteins** – long strings of amino acids containing carbon, hydrogen, oxygen, nitrogen, and phosphorus.
- **trihalomethanes (THMs)** – harmful by-products arising from a process of water disinfection with chlorine; formed when organic materials react with chlorine to form chlorinated by-product

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5.4.1: Review Questions

Review Questions

1. **What is an organic compound?**
2. **List some types of organic compounds.**
3. **Define an inorganic compound.**

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5.4.2: Chapter Quiz

Chapter Quiz

1. _____ are covalently bonded molecules, and most are large molecules.

1. Inorganic compounds
2. Hydrocarbons
3. Aldehydes
4. Organic compounds

2. _____ are harmful by-products arising from a process of water disinfection with chlorine. They are formed when organic materials react with chlorine to form chlorinated by-products.

1. Ketones
2. Trihalomethanes
3. Organic compounds
4. Alkehydes

3. _____ can be formed by chlorination, ozonation, or chloramination of water. They are promoted in slightly acidic water, high organic matter content, and elevated temperature. These compounds are precursors to Trihalomethanes.

1. Haloacetic acids
2. Organic compounds
3. Inorganic compounds
4. Carboxylic acids

4. _____ is(are) a colorless, odorless, flammable gas, and it is the primary constituent of marsh gas and the firedamp of coal mines.

1. Bromides
2. Chlorates
3. Methane
4. Chloroform

5. _____ is the highest state of oxidation that an organic radical can achieve. Further oxidation results in the formation of carbon dioxide and water.

1. Haloacetic acids
2. Organic compounds
3. Inorganic compounds
4. Carboxylic acids

6. Biodegradable organic matter in water is classified into three categories _____.

1. THMs, HAA5s, carboxylic acids
2. fats, carbohydrates, and proteins
3. alkanes, alkenes, alkynes
4. chloroform, bromodichloromethane, bromoform

7. The parent compound of aromatic hydrocarbons is _____.

1. benzene
2. alcohol
3. chloroform
4. acetic acid

8. Hydrocarbons are classified as unsaturated or saturated. _____ are a group of saturated hydrocarbons meaning that the hydrocarbon contains only single bonded carbon atoms.

1. All

1. Alkanes
2. Alkenes
3. Alkynes
4. Acetic acids

9. _____ are derived from plant fibers and animal tissues, which are produce by synthesis reactions that produce materials like rubber, plastics, and other compounds; and fermentation reactions that produce alcohols, acids, antibodies, and other compounds.

1. Inorganic materials
2. Biologic acids
3. Hydrocarbons
4. Organic materials

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5.5: Acids, Bases, and Salts

Learning Objectives

After reading this section[1], you should be able to:

- Explain the properties of water
- Describe inorganic and organic acids
- Describe inorganic bases
- Explain pH, acids, and bases
- Describe buffers

Water is the most abundant and important inorganic compound on earth. It makes up 60 to 89-percent of the volume of most living cells, and it possesses several properties that make it vital to life**.** The capability for a molecule to absorb heat energy is called heat capacity. Water has the highest heat capacity of any liquid. It would require calorie of heat energy to change the temperature of water by 1. As a result, it takes water a long time to heat and a long time to cool. This property prevents sudden changes in temperature caused by external factors, such as sun or wind exposure, or by internal conditions that release heat rapidly, such as vigorous muscle activity. As part of blood system or the environment, water redistributes heat among adjacent structures ensuing the temperature remains homeostatic.[2]

When water evaporates, or vaporizes, water changes from a liquid to a gas, water vapor. The transformation requires that large amounts of heat be absorbed to break hydrogen bonds that hold water molecules together. This property is beneficial because as water evaporates from an object or organism large amounts of heat are removed providing efficient cooling. This property is referred to as high heat of vaporization.

Water is the best solvent in nature. It is called the universal solvent. Biological molecules do not react chemically unless they are in solution, and virtually all chemical reactions that occur in the living cells depend on water's solvent properties. Water molecules are referred to as being polar. They orient with their slightly negative ends toward the positive ends of the solutes. . This characteristic is called polarity, and it explains the reason that ionic compounds and other small reactive molecules, such as acids and bases, dissociate in water, where their ions separating from each other and become evenly scattered in the water forming a true solution.

Water also forms layers of water molecules, called hydration layers, around large, charged molecules such as protein, shielding them from the effects of other charged substances in the areas and preventing them from settling out of solution. Such protein water mixtures are biological colloids. Water is also the major transport medium because it is an excellent polar solvent. Nutrients, gases, and metabolic wastes are carried dissolved in water based fluids. Wastes are excreted form living organisms in watery fluids. Specialized molecules that lubricate organisms also use water as the dissolving medium.

As a reactant, water is involved in many important chemical reactions. Nutrients are decomposed by adding a water molecule to each chemical bond that is broken. Decomposition reactions are more specifically referred to as hydrolysis reactions. When large carbohydrates or protein molecules are synthesized from smaller molecules, a water molecule is removed for every bond formed, a reaction that is called dehydration synthesis.

Water forms resilient cushions, cushioning around certain biological structures providing protection from physical trauma.

Other than binary molecular compounds, most inorganic compounds can be classified as acids, bases, or salts. Acids are characterized by the H^+ion, the presence of which in water, makes the water acidic. An acid either contains this ion or produces it when it dissolves in water. A base either contains hydroxide ion, OH^-, or reacts with water to produce hydroxide. Most bases that contain hydroxide consist of metal cations and hydroxide; examples are sodium hydroxide, NaOH, and calcium hydroxide, $Ca(OH)_2$. Acids and bases react to form a salt, an ionic compound that has a cation other than H+ and an anion other than OH^-. This kind of reaction always produces water.

Acids

Salts, acids, and bases are electrolytes. They ionize and dissociate in water and can conduct an electrical current.

Acids have a sour taste, and they can react with or dissolve metals. The definition of an acid is a substance that releases hydrogen ions (H^+) in measurable amounts. Acids are also characterized as being proton donors because a hydrogen ion is a hydrogen nucleus, or a single proton.

When acids dissolve in water, they release hydrogen ions (protons) and anions, negative charged particles. The concentration of the protons determines the acidity of the solution. The anions have little or no effect on the acidity of the solution. Hydrochloric acid (HCl) dissociates into a proton and a chloride ion:

$$HCl \rightarrow H^+, \text{proton} + Cl^-, \text{anion}$$

Living organisms require a balance of acids and bases to function. We can measure this balance by determining the number by the amount of H^+, and OH^- dissociated in a solution. Simply stated, more H^+ hydrogen ions in a solution means more acidic. More OH^- hydroxide ions means more basic (alkaline).

Biochemical reactions are sensitive to small changes in the acidity or alkalinity of the environment in which they occur. H^+ and OH^- are involved in almost all biochemical processes, and any deviation from a narrow band of the normal H^+ and OH^- concentration dramatically modifies the systems' functioning. Acids and bases that are formed in living systems must be kept in balance.

It is convenient to express the amount of H^+ in a solution by a logarithmic pH scale that ranges from 0 to 14. The term **pH** means potential of hydrogen ion concentration. On a log scale, a change of one whole number has 100 times more hydrogen ions than a solution of pH 2, and a pH of 2 has 100 times more hydrogen ions than a solution of pH 3.

Acidic solutions contain more H^+ than OH^- and have a pH lower than 7. If a solution has more OH^- than H^+, it is a basic or alkaline solution. In pure water, a small percentage of molecules are dissociated into H^+ and OH^- ions so that it has a pH of 7. When the ion concentrations of a solution are equal, the solution has a pH of 7 and is considered to be neutral.

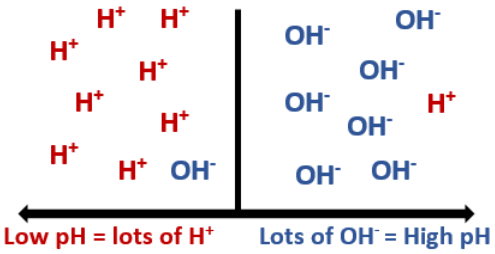


Figure **5.5.1**: Depiction demonstrating the concentrations of H+ and OH- at differing pH levels. (Copyright; [3] Image by COC OER is licensed under CC BY 4.0.)

The pH of a solution can be managed with buffers. Buffers resist a change in pH and will be discussed later in the chapter.

Bases

Bases have a bitter taste, feel slippery, and are proton acceptors. They take up hydrogen ions in measurable amounts. Common inorganic bases include the hydroxides like magnesium hydroxide and sodium hydroxide. Lye acids, hydroxides dissociate when dissolved in water. In this case, hydroxyl ions (OH^-) and cations are released. Ionization of sodium hydroxide produces a hydroxyl ion and a sodium ion. The hydroxyl ion binds to a proton present in the solution. This reaction produces water and simultaneously reduces the acidity of the solution by taking up free H^+ ions:

$$NaOH \rightarrow Na^+ + OH^-$$

$$OH^- + H^+ \rightarrow H_2O$$

The term pH is used to express the intensity of an acid or alkaline solution.

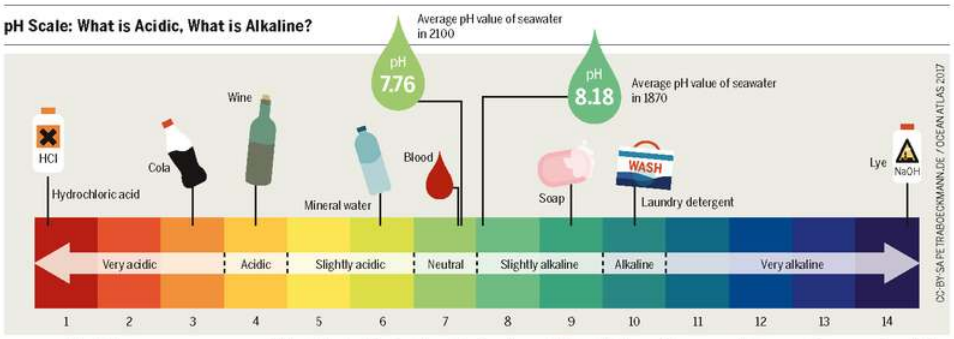


Figure **5.5.2**: pH scale from 0 to 14 demonstrating acid, neutral, and base. (Copyright; Image by Heinrich-Böll-Stiftung is licensed under CC BY-SA 2.0)

Salts and Neutralization

Acids and bases react to form salts, an ionic compound that has a cation other than H+ and an anion other than OH^-. This kind of reaction always produces water and is known as a neutralization reaction. The most well-known salt is sodium chloride, NaCl.

$$HCl + NaOH \rightarrow NaCl + H_2O$$

Acid Base Salt Water

The salt produced is dissolved in the aqueous solution and disassociated into Na^+ and Cl^- ions. Although sodium chloride is commonly what one means in referring to "salt," there are many other salts as well. For example, Sodium sulfate, Na_2SO_4, dissociates into two Na^+ ions and one SO_4^{-2}. The salt dissociates because the ions are formed. The water overcomes the attraction between the oppositely charged ions, and they disassociate.

All ions are electrolytes which are substances that conduct an electrical current in solution. Salts dissociate in aqueous solutions into ions, and the most common salts are sodium salts. In their ionized form, salts play a vital role in nature and aqueous solutions.

Buffers[3]

How can organisms whose bodies require a near-neutral pH ingest acidic and basic substances (a human drinking orange juice, for example) and survive? Buffers are the key. Buffers usually consist of a weak acid and its conjugate base; this enables them to readily absorb excess H^+ or OH^-, keeping the system's pH within a narrow range. Organisms are extremely sensitive to slight changes in the pH of the environment. In high concentrations, acids and bases are damaging to cells. Homeostasis of acid-base balance is regulated by chemical systems called buffers.

Buffers resist abrupt and large changes in the pH of a solution by releasing hydrogen ions when the pH begins to rise and by binding hydrogen ions when the pH drops.

Chemical buffer systems react by binding hydrogen ions or by releasing hydrogen ions. The acidity of a solution reflects the free hydrogen ions and not the hydrogen ions bound to anions. Acids that dissociate completely and irreversibly in water are called strong acids. They can dramatically change the pH of a solution. Acids that do not dissociate completely, like carbonic acid (H_2CO_3) and acetic acid, are weak acids. Undissociated acids do not affect pH, so that acetic acid solutions are much less acidic than hydrochloric acid solution. Weak acids disassociate in predictable ways, and molecules of the intact acid are in dynamic equilibrium with the dissociated ions.

For this reason, when a strong acid is added to a solution of a weak acid the equilibrium will shift to the left and some H^+ will recombine to form acetic acid. On the other hand, if a strong base is added and the pH begins to rise, the equilibrium shifts to the right and more acetic molecules disassociate to release H^+ ions. This characteristic of weak acids allows them to play a role in the chemical buffer systems found in nature.

$$H^+ \text{ acetic acid} \leftrightarrow H^+ + \text{Acetic}^-$$

Bases are proton acceptors. Strong bases are those bases, like hydroxides, which dissociate easily in water and quickly bind H^+ ions. Sodium bicarbonate ionizes incompletely and reversibly. Since it accepts relatively few protons, its released bicarbonate ion is

considered to be a weak base.

One of the buffer system that helps to maintain the pH in aqueous solutions is the carbonic acid-bicarbonate system. Carbonic acid dissociates reversibly in aqueous solutions releasing bicarbonate ions and protons, H^+. The chemical equilibrium between carbonic acid, a weak acid, and bicarbonate ion, a weak base, resists changes in pH by shifting to the right or the left as H^+ ions are added to or removed from the solution:

Rise in pH

$$H_2CO_3 \leftrightarrow H^+ + HCO_3^-$$

Drop in pH

As the pH rises and becomes more alkaline, the equilibrium shifts to the right, forcing more carbonic acid to dissociate. Similarly, as the pH begins to drop, the equilibrium shifts to the left as more bicarbonate ions begin to bind with protons. Strong bases are replaced by a weak base, bicarbonate ion. Protons are released by strong acids and are tied up in weak acids, carbonic acid. As a result, the pH changes are much less than they would be in the absence of the buffering system.

Key Terms

- **acid** – a substance that dissociates into one or more hydrogen ions (H+); proton donors; acids release hydrogen ions in measurable amounts; sour taste
- **base** – a substance that dissociates into one or more positive ions (cations) that can accept or combine with protons; proton acceptors; bases take up hydrogen ions in measurable amounts; bitter taste
- **buffer** – buffers prevent the pH of a solution from changing drastically
- **pH** – the potential of hydrogen ion concentration

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5.5.1: Review Questions

Review Questions

1. **What properties of water make it essential for life?**
2. **What are acids and bases?**
3. **Define a buffer.**

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5.5.2: Chapter Quiz

Chapter Quiz

1. _____ is the most abundant and important inorganic compound on earth.

1. Salt
2. Water
3. Bicarbonate
4. Oxygen

2. A(n) _____ can be defined as a substance that dissociates into one or more hydrogen ions (H+) and one or more negative ions (anions) an acid is also called a proton donor (H+).

1. base
2. buffer
3. acid
4. salt

3. _____ are added to solutions or to the natural environment to prevent changes in pH.

1. Base
2. Buffer
3. Acid
4. Salt

4. _____ have a bitter taste, feel slippery, and are proton acceptors. They take up hydrogen ions in measurable amounts.

1. Bases
2. Buffers
3. Acids
4. Salts

5. When acids and bases are mixed, they react with each other in displacement reactions to form water and a(n) _____.

1. base
2. buffer
3. acid
4. salt

6. Nutrients are decomposed by adding _____ to each chemical bond that is broken.

1. a salt
2. water
3. bicarbonate
4. oxygen

7. _____ system that helps to maintain the pH in aqueous solutions is the carbonic acid-bicarbonate system.

1. A base
2. A buffer
3. An acid
4. A salt

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5.6: Basic Microbiology Principles

Learning Objectives

After reading this section, you should be able to:

- Describe the nomenclature and classification that is used for microorganisms
- Evaluate the factors that affect growth of microorganisms
- Describe the structure of microorganisms

In a simpler time when scientists began to classify all living things visible to the naked eye, there were only two categories or so called “Kingdoms” to consider for living things. You were either a plant or an animal. Botanist and physician Carolus Linnaeus was responsible for initial significant developments in the science of classifying living things with his publication *Systema Naturae*, in 1735. During that era, new discoveries were being made through observations in microscopes and what appeared to be very small living things. These small living things are referred to as **microorganisms**, or microbes for short. You can imagine how complex the classification of life forms was about to become. Of course, today we now know just how ubiquitous microbes are. They are found in all of nature; on land, soil and water including oceans and lakes. They include bacteria, algae, yeasts, molds, mushrooms, and other fungi. The human body alone contains millions of microorganisms.

Currently, almost 2 million organisms have been identified so far, and the estimate is that 10-100 million total organisms occupy the earth. All cellular organisms evolved from a common ancestor.

Naturally occurring microbes play an important role in many processes necessary to sustain life on our planet. Microbes are used in food preparation, pharmaceuticals, food supplements and even to safely reduce pollutants in the environment.



Figure Figure **5.6.1**. Beer (Image by Engin_Akyurt on Pixabay)



Figure Figure **5.6.2** White Vinegar (Image by Willis Lam is licensed under CC BY-SA 2.0)



Figure Figure **5.6.3** Yogurt (Image by Jin Zan is licensed under CC BY-SA)

A minority of microorganisms are **pathogenic** or disease-producing.



Pin It! Misconception Alert
People frequently think all microorganisms are pathogenic. But only a few are actually pathogenic or disease-producing!

Classifying Microbes

The process of classifying all living things is called Taxonomy. The Meriam Webster dictionary defines taxonomy as:

The study of the general principles of orderly scientific classification of plants and animals according to their presumed natural relationships.

Carolus Linnaeus introduced a binomial nomenclature system, where each species is given a unique two-part Latin name; a genus and species. For example, a domestic dog would have the scientific name Canis lupus familiaris. Genus: Canis, Species: lupus. A wolf is also from the Genus: Canis. Linnaeus' work laid the foundation for the modern system of naming and categorizing living organisms. All living things can be identified and classified based on their evolutionary relationships. The hierarchy, from broader to more specific levels, is shown in the figure below.

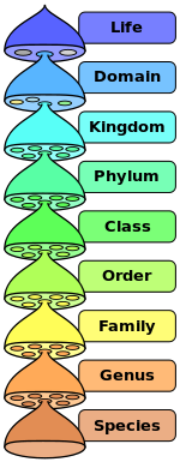


Figure **5.6.4**: Hierarchal system of scientific nomenclature for classification of living organisms. (Copyright; Image by Pengo is in the public domain)

Kingdoms

In 1969, a five-kingdom scheme proposed by biologist Robert Whittaker gained attention and it serves as the basis for current classification systems. Whittaker organized living organisms into five kingdoms based on their cellular organization, nutritional patterns, and other characteristics:

1. Kingdom Prokaryote, which includes all bacteria.
2. Kingdom Protista (unicellular eukaryotes) are algae and protozoa, and they are nutritionally diverse: autotrophs, heterotrophs, and intracellular parasite.
3. Kingdom Fungi are yeasts, molds, and mushrooms that absorb organic material through their plasma membrane.
4. Kingdom Animalia are multicellular animals that ingest organic food through a mouth and have cells organized into tissues.
5. Kingdom Plantae are multicellular plants that undergo photosynthesis to convert carbon dioxide and water into organic molecules. This Kingdom has cells that are organized into tissues.

Domains

The most popular scheme found in textbooks today is one which basically classifies life forms based on whether it is a bacteria or not a bacteria. That's pretty much it. So, what is so special about bacteria? Well, when you study tiny microbes with taxonomy in mind, you are looking at similarities in appearance of cells and how they will react with dyes and stains, and also cell chemistry.

Definition: Term

The Oxford dictionary defines a microscopic cell as:

- The smallest structural and functional unit of a living organism.
- That cell contains all the structure like the cell nucleus and information necessary for energy capture, growth, and reproduction.
- But bacteria do not have a distinct cell nucleus. All other life forms do have a distinct nucleus.

Biologists refer to cells without a distinct nucleus as **prokaryotes** and cells with a distinct nucleus as **eukaryotes**. Another way to classify if a life form is a bacteria or not can be described as either being a prokaryote (bacteria) or eukaryote (everything else). It should be noted that bacteria represent the oldest life forms on our planet. They have a simple cell structure with an average size of 1 to 2 micrometers. Biologists have identified ancient types of bacteria which have some differences from other bacteria. So much so, that the classification system of bacteria or not bacteria is officially comprised of three domains which you will find in most microbiology textbooks. We call this the Three Domain System.

- Domain Eubacteria
- Domain Archaea
- Domain Eukarya.

The Domain, Archaea is where you will find the ancient bacteria. Fungi, Plantae, and Animalia Kingdoms are all included in the Domain Eukarya. Most scientists will refer to Eubacteria and Archaea as bacteria, and not make a distinction. So, think of Eubacteria and Archaea simply as bacteria (prokaryotes).

Eukaryotes have a complex cell structure and are much larger than prokaryotes on average by several thousand in terms of volume.

Bacteria may be further differentiated by their morphology. They are classified into five groups based on their basic cell shapes. These shapes include spherical (cocci), spiral (spirilla), rod (bacilli), comma (vibrios), or corkscrew (spirochaetes). These cells can exist as single cells, in pairs, chains, or in clusters.

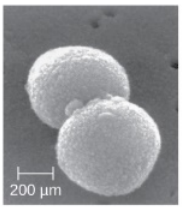
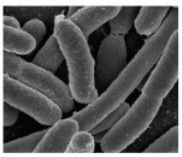
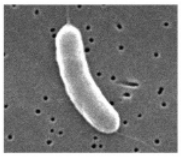
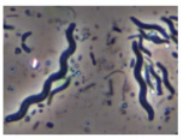
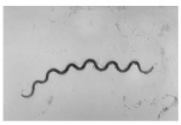
Common Prokaryotic Cell Shapes			
Name	**Description**	**Illustration**	**Image**
Coccus (pl. cocci)	Round		
Bacillus (pl. bacilli)	Rod		
Vibrio (pl. vibrios)	Curved rod		
Coccobacillus (pl. coccobacilli)	Short rod		
Spirillum (pl. spirilla)	Spiral		
Spirochete (pl. spirochetes)	Long, loose, helical spiral		

Figure **5.6.5**: Basic Shapes of Bacteria. (Copyright; Image by OpenStax is licensed under CC BY 4.0.)

Another method used to classify bacteria based on their cell wall structure and composition is the Gram stain method. It was developed in 1884 by Hans Christian Gram and remains a hallmark technique used by microbiologists. Bacteria are classified into two groups, either **Gram positive** (purple) or **Gram negative** (red or pink).

Structure

Prokaryotes–Structure/Function

Prokaryotes are distinguished from eukaryotes by their smaller size (0.2- 10µm), their lack of internal organelles (mitochondria), the presence of a cell wall, and their cell division by binary fission rather than mitosis. They lack introns, are not capable of endo/exocytosis, and have single-stranded circular DNA rather than multiple discrete chromosomes.

Gram positive bacteria have a large peptidoglycan structure. This structure accounts for the differential staining with Gram stain. Some Gram positive bacteria are also capable of forming spores under stressful environmental conditions such as when there is limited availability of carbon and nitrogen. Spores therefore allow bacteria to survive exposure to extreme conditions.

Gram negative bacteria have a small peptidoglycan layer but have an additional membrane, the outer cytoplasmic membrane. This membrane creates an additional permeability barrier and results in the need for transport mechanisms across it. A major component of the cytoplasmic membrane that is unique to Gram negatives is endotoxin.

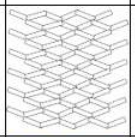
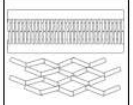
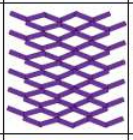
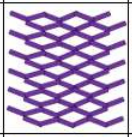
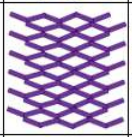
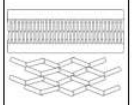
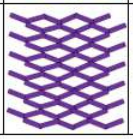
Gram Staining Procedure		Gram Positive Cell Wall		Gram Negative Cell Wall	
Process of test	Appearance of Cells	Effect of Step	Effect on Cell Wall	Effect of Step	Effect on Cell Wall
Step 1: Begin with heat fixed cells		**Step 1:** Cell wall remains clear.		**Step 1:** Cell wall remains clear.	
Step 2: Flood slide with crystal violet dye for 1 min.		**Step 2:** Peptidoglycan cell wall is flooded with crystal violet and appears purple.		**Step 2:** Cell wall is stained purple from the crystal violet dye.	
Step 3: Add iodine solution for 1 min.		**Step 3:** A crystal violet – iodine complex is formed within the peptidoglycan cell wall trapping the purple stain.		**Step 3:** A crystal violet-iodine complex is formed but does not adhere to the cell wall due to the thin layer of peptidoglycan.	
Step 4: Wash slide with alcohol for 20sec.		**Step 4:** The crystal violet – iodine complex is trapped with the peptidoglycan cell wall and doesn't wash out.		**Step 4:** The crystal violet – iodine structure is washed out of the thin peptidoglycan layer.	
Step 5: Counter stain with safranin.		**Step 5:** As the peptidoglycan cell wall remains stained purple the red safranin has no effect.		**Step 5:** The red safranin stains the washed gram negative cells.	

Figure **5.6.6**: Gram staining of bacterial cell for identification. (Image by Michigan State University. Microbiology 301-702 Summer 2016 is licensed under CC BY-SA 4.0)

Microorganism Identification

The classification is based on morphological characteristics that refer to size, shape, cellular characteristics (capsule, flagella, endospores), differential staining (Gram stain, Acid fast stain), and biochemical tests that probe for specific enzyme activities that lead to carbohydrate fermentation, nitrogen fixation, sulfur oxidation, gas production, acid production, and nitrate reduction.

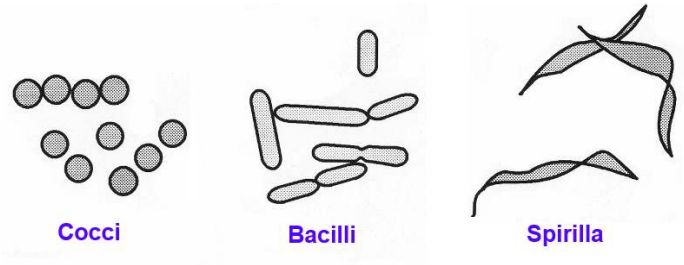


Figure **5.6.7**: lassification of bacteria by shape and environmental appearance. (Image by CKRobinson is licensed under CC BY-SA 4.0)

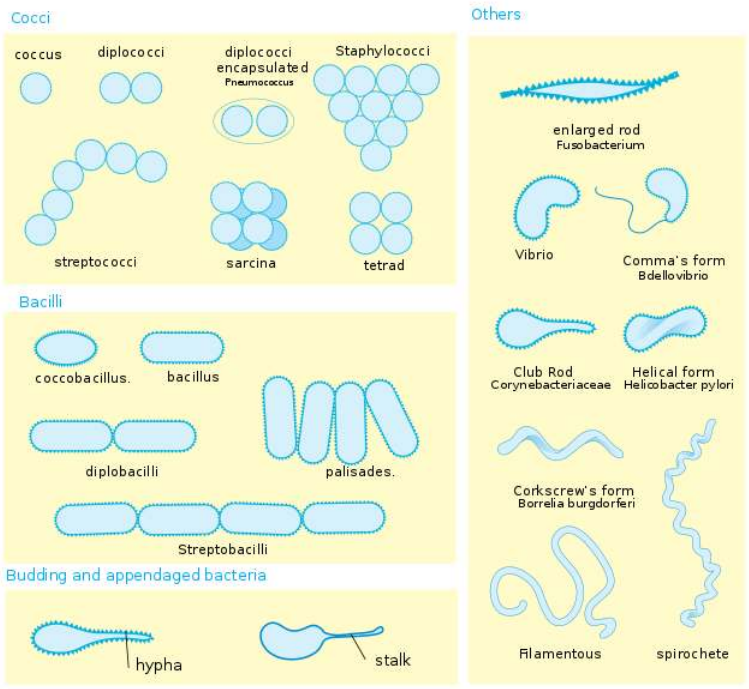


Figure 5.6.8: Morphology of bacterial cells (Image by LadyofHats is in the public domain)

Growth of Microorganisms

All microorganisms require energy to grow. They obtain their energy primarily from chemical reactions or the sun utilizing photosynthesis. They use the energy to help produce nutrients to help them grow. Almost half of a bacteria's dry weight is carbon. They need it to grow and can access it from the environment, or from carbon dioxide.

Microbe requirements can include nitrogen, phosphorous and sulfur. Water is a requirement for almost all microbes. Most microorganisms require oxygen, but there are some which thrive in a zero oxygen environment. Other microbes also utilize the so-called trace elements of zinc, copper, and iron to grow. Iron bacteria, which is a common nuisance in groundwater wells, is a good example.

Microorganisms can grow in cold temperatures as low as 0 , or at temperatures higher than 40 ,. But most prefer temperatures between 20 , to 40 ,. Different species have typically their own optimal temperature that will produce a maximum growth rate.

The pH is also very important. For bacteria, the range is between 6.5 to 7.5. Some bacteria used in food processing prefer a pH less than 6 (an acidic environment).

Another growth factor involves the osmotic pressure in a microorganism and is largely influenced by the salt concentration in its surroundings. If the salt concentration is less than 1%, microbes will grow well. If the salt concentration rises, the microbe is likely to die as water will flow out of the cell. As you can probably surmise, one way to control the growth of microorganisms is to create an environment which keeps them out of their optimal chemical and physical ranges to grow and thrive.

Phylogenetic Tree of Life for Microbes

A universal Phylogenetic Tree has been developed for living organisms that establishes a tripartite division of all living organisms– bacteria, archaea, and eukarya. The classification is based on a comparison of 16s ribosomal RNA sequences. These sequences are highly conserved and undergo change at a slow, gradual, and consistent rate. They are therefore useful for making comparisons among different living organisms.

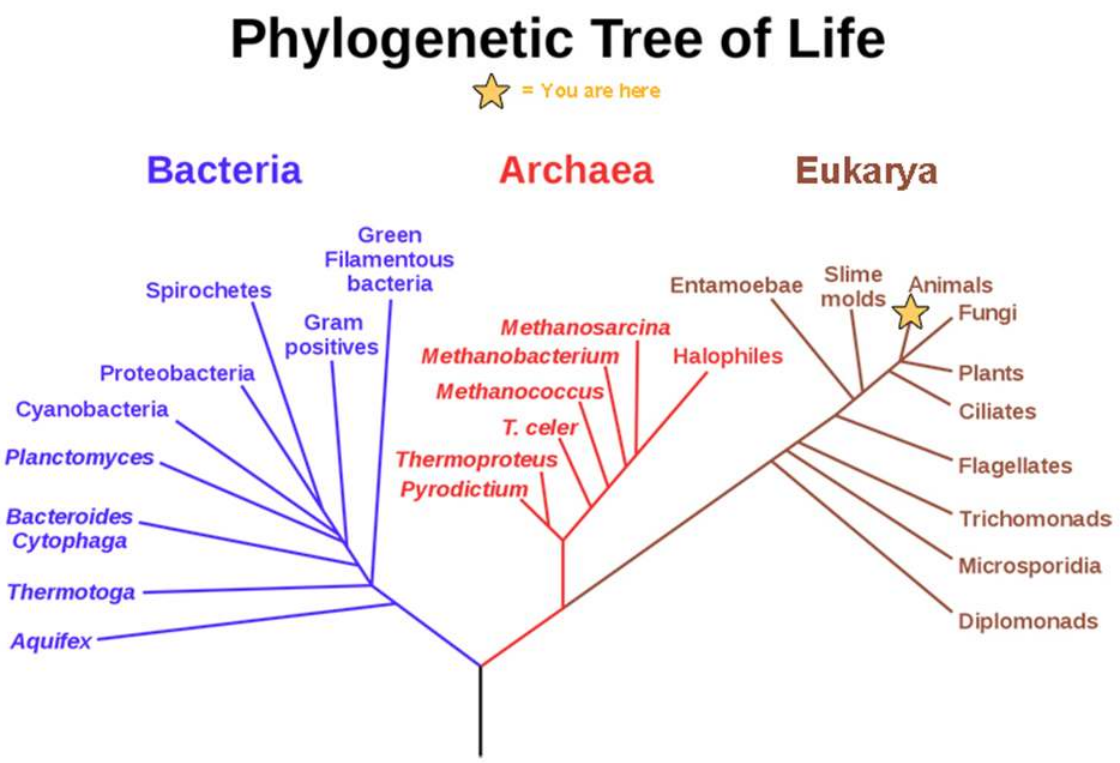


Figure **5.6.1**: Phylogenetic Tree for microorganisms (Copyright; Image by OpenStax is licensed under CC BY 4.0)

Taxonomic/Phylogenetic Hierarchy groups are based on similarities. The groups begin very general and become more restricted. DNA hybridization and rRNA sequencing are used to determine evolutionary relationships and classification. Organisms that are grouped together are based on relatedness; very general relatedness at the top, followed by more and more specific and restricted subgroups where genus is all related species, and species is a single unique organism group.

Prokaryotic Classification-prokaryotes have two domains:

1. Eubacteria are all pathogenic prokaryotes, many non-pathogenic prokaryotes, and all photoautotrophic prokaryotes. They include the oldest and smallest living organisms ever discovered which date back 3.5 million years.
2. Archaea are all prokaryotes with walls that are not peptidoglycan, that carryout unusual metabolism and live in extreme environments, and are groupings based entirely on gene sequencing since most look similar. Archaea are associated with extreme environments.

Viral Classification

Viruses do not fit into a domain system because they are acellular. They are usually only classified by Family and Genus. Viral species are defined as a population of viruses with similar characteristics (including morphology, genes, and enzymes) that occupy a particular ecological niche.

In early 2020, one virus that became very well-known was coronavirus-19, which swept the world as a pandemic. This virus was a type of coronavirus that was extremely contagious and had a wide range of symptoms. It is currently not well understood

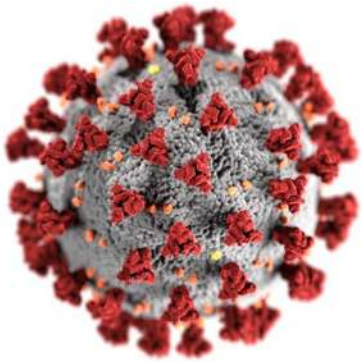


Figure 5.6.1: Corona Virus(Copyright; Image by OpenStax is licensed under CC BY 4.0)

Key Terms

- **algae** – diverse group of photosynthetic eukaryotic protists[1]
- **Archaea** – prokaryotes that are found in extreme environments; non-disease causing
- **Bacteria (prokaryotes)** – the domain that includes the pathogenic prokaryotes as well as many of the nonpathogenic prokaryotes found in soil and water; simple single-celled organisms
- **Eukarya (eukaryotes)** – the domain that includes animals, plants, and fungi
- **fungi** – eukaryotes with cells which contain a distinct membrane bound nucleus, mitochondria, and a complex system of internal membranes[2]
- **gram negative** – bacteria with a small peptidoglycan structure and additional membranes that creates additional permeability barriers and results in the need for transport mechanisms across it
- **gram positive** – bacteria with a large peptidoglycan structure and causes differential staining with Gram staining
- **pathogenic** – disease-causing
- **peptidoglycan** - a building block of cell walls of bacteria
- **Prokarya (prokaryotes)** – distinguished from eukaryotes by their smaller size (0.2- 10µm), their lack of internal organelles (mitochondria), the presence of a cell wall, and their cell division by binary fission rather than mitosis
- **protozoa** – unicellular eukaryotic protists which have the ability to move with some sort of cilia or flagella and must obtain their energy from other sources[3]
- **scientific nomenclature** – a binomial nomenclature so that every organism has a unique binomial identification that indicates the individual and its taxonomic placement among other organisms
- **taxonomy** – the science of classification.
- **viruses** – microorganisms so small that most can be seen only with an electron microscope; acellular; reproduction occurs using cellular machinery of other organisms

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[4]

[5]

[6]

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5.6.1: Review Questions

Review Questions

1. **Name the two major types of cells found in nature.**
2. **List and describe the five types of microorganisms.**
3. **List the classifications in descending order for the hierarchal system of scientific nomenclature for the classification of living organisms.**
4. **Distinguish the features between gram positive and gram negative bacteria.**

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5.6.2: Chapter Quiz

Chapter Quiz

1. Microorganisms that are disease-producing are _____.

1. pathogenic
2. Streptococcus
3. Staphylococcus
4. gram negative

2. Bacteria and archaea are referred to as _____ cells.

1. eukaryotic
2. prokaryotic
3. gram negative
4. gram positive

3. Cells with cell walls that lack peptidoglycan are _____.

1. bacteria
2. algae
3. protozoans
4. archaea

4. _____ are eukaryotes. They are organisms whose cells have a distinct nucleus containing the cell's genetic material, surrounded by a special envelope called a nuclear membrane.

1. Archaea
2. Bacteria
3. Viruses
4. Fungi

5. _____ bacteria have a large peptidoglycan structure.

1. Streptococcus
2. Staphylococcus
3. Gram negative
4. Gram positive

6. Most bacteria grow best in a narrow pH range near neutrality, between _____.

1. 2.0 to 6.5
2. 6.5 to 7.5
3. 8.0 to 10.0
4. 11.0 to 14.0

7. _____ is a binomial nomenclature so that every organism has a unique binomial identification that indicates the individual and its taxonomic placement among other organisms.

1. Taxonomy
2. Scientific nomenclature
3. DNA hybridization
4. Genus species

8. _____ is the science of classification.

1. Taxonomy
2. Scientific nomenclature
3. DNA hybridization

4. Genus species

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5.7: Microbiology Regulations

Learning Objectives

After reading this section, you should be able to:

- Explain the Total Coliform Rule
- Compare the Groundwater Treatment Rule and Surface Water Treatment Rule
- Describe the concern with Cryptosporidium

Total Coliform Rule

The Total Coliform Rule (TCR), a National Primary Drinking Water Regulation (NPDWR), was published in 1989 and became effective in 1990. The rule sets a health goal (Maximum Contaminant Level Goal (MCLG)) and legal limits (Maximum Contaminant Levels, MCLs)) for the presence of total coliforms in drinking water.

The Environmental Protection Agency (EPA) published the Revised Total Coliform Rule (RTCR) in the Federal Register (FR) in February 2013 (78 FR 10269) and minor corrections in February 2014 (79 FR 10665). The RTCR is the revision to the 1989 Total Coliform Rule (TCR) and is intended to improve public health protection. All public water systems (PWSs), except aircraft PWSs subject to the Aircraft Drinking Water Rule (ADWR) (40 CFR 141 Subpart X), must comply with the RTCR starting April 2016, or an earlier state effective date.

Total coliforms are a group of related bacteria that are, with few exceptions, not harmful to humans. This is very important to note. The EPA considers total coliforms a useful indicator of other pathogens for drinking water. Total coliforms are used to determine the adequacy of water treatment and the integrity of the distribution system.

Key provisions of the RTCR include:

1. Setting a maximum contaminant level goal (MCLG) and maximum contaminant level (MCL) for E. coli for protection against potential fecal contamination.
2. Setting a total coliform treatment technique (TT) requirement.
3. Requirements for monitoring total coliforms and E. coli according to a sample siting plan and schedule specific to the PWS.
4. Provisions allowing PWSs to transition to the RTCR using their existing Total Coliform Rule(TCR) monitoring frequency, including PWSs on reduced monitoring under the existing TCR.
5. Requirements for seasonal systems (such as, Non-Community Water Systems not operated on a year-round basis) to monitor and certify the completion of a state-approved start-up procedure.
6. Requirements for assessments and corrective action when monitoring results show that PWSs may be vulnerable to contamination.
7. Public notification (PN) requirements for violations.
8. Specific language for CWSs to include in their Consumer Confidence Reports (CCRs) when they must conduct an assessment or if they incur an E. coli MCL violation.

Revised Total Coliform Rule

Overview of the Rule

Revised Total Coliform Rule (RTCR) 78 FR 10269, February 2013, Vol. 78, No. 30

Purpose: Increase public health protection through the reduction of potential pathways of entry for fecal contamination into distribution systems.

General Description

The rule establishes a maximum contaminant level (MCL) for E. coli and uses E. coli and total coliforms to initiate a find and fix approach to address fecal contamination that could enter into the distribution system. It requires public water systems (PWSs) to perform assessments to identify sanitary defects and subsequently take action to correct them.

The Total Coliform Rule applies to all Public Water Systems.

Implementation of the Total Coliform Rule will result in:

1. A decrease in the pathways by which fecal contamination can enter the drinking water distribution system.
2. Reduction in fecal contamination should reduce the potential risk from all waterborne pathogens including bacteria, viruses, parasitic protozoa, and their associated illnesses.

Requirements:

1. Public Water Systems must develop a written sample siting plan that identifies the system's sample collection schedule and all sample sites, including sites for routine and repeat monitoring.
2. PWSs monitoring quarterly or annually must also identify additional routine monitoring sites in their sample siting plans.
3. Sample siting plans are subject to state review and revision.

Routine Sampling Requirements

1. Total coliform samples must be collected by Public Water Systems at sites which are representative of water quality throughout the distribution system according to a written sample siting plan subject to state review and revision.
2. For Public Water Systems collecting more than one sample per month, collect total coliform samples at regular intervals throughout the month, except that ground water systems serving 4,900 or fewer people may collect all required samples on a single day if the samples are taken from different sites.

Repeat Sampling Requirements

Within 24 hours of learning of a Total Coliform positive routine sample result, at least 3 repeat samples must be collected and analyzed for total coliform:

1. One repeat sample must be collected from the same tap as the original sample.
2. One repeat sample must be collected from within five service connections upstream.
3. One repeat sample must be collected from within five service connections downstream.
4. The PWS may propose alternative repeat monitoring locations that are expected to better represent pathways of contamination into the distribution system.

If one or more repeat sample is Total Coliform Positive:

1. The TC+ sample must be analyzed for the presence of E. coli.
2. If any repeat TC+ sample is also EC+, then the EC+ sample result must be reported to the state by the end of the day that the PWS is notified.
3. The PWS must collect another set of repeat samples, unless an assessment has been triggered and the PWS has notified the state.

Routine Sampling Requirements

1. Each total coliform-positive (TC+) routine sample must be tested for the presence of E. coli.
2. If any coliform-positive (TC+) sample is also E. coli-positive (EC+), then the EC+ sample result must be reported to the state by the end of the day that the PWS is notified.
3. If any routine sample is TC+, repeat samples are required.
4. Public Water Systems on quarterly or annual monitoring must take a minimum of three additional routine samples (known as additional routine monitoring) the month following a TC+ routine or repeat sample.
5. Reduced monitoring may be available for Public Water Systems using only ground water and serving 1,000 or fewer persons that meet certain additional Public Water System criteria.

Assessments and Corrective Action

The RTCR requires PWSs that have an indication of coliform contamination (e.g., as a result of TC+ samples, E. coli MCL violations, performance failure) to assess the problem and take corrective action. Two levels of assessments exist (i.e., Level 1 and Level 2) based on the severity or frequency of the problem.

Purpose of Level 1 and Level 2 Assessments

To find sanitary defects at the Public Water System including:

1. Sanitary defects that could provide a pathway of entry for microbial contamination
2. Sanitary defects that indicate failure (existing or potential) of protective barriers against microbial contamination.

Deadline for Completing Corrective Actions

When sanitary defects are identified during a Level 1 or Level 2 Assessment, they should be corrected as soon as possible to protect public health. The Public Water System must complete corrective actions by one of the following timeframes:

1. No later than the time the assessment form is submitted to the state, which must be within 30 days of triggering the assessment, or
2. Within state-approved timeframe which was proposed in the assessment form.

Level 1 Assessments

Conducting Level 1 Assessments

1. Performed by the PWS owner or operator each time a Level 1 Assessment is triggered.
2. Upon trigger of a Level 1 Assessment, the Level 1 Assessment form must be submitted within 30 days to the state.

Level 1 Assessment Triggers

Level 1 Assessment is triggered if any one of the following occurs:

1. A Public Water System collecting fewer than 40 samples per month has 2 or more TC+ routine/ repeat samples in the same month.
2. A PWS collecting at least 40 samples per month has greater than 5.0 percent of the routine/repeat samples in the same month that are TC+.
3. A PWS fails to take every required repeat sample after any single TC+ sample.

Level 2 Assessments

Conducting Level 2 Assessments

Performed by the state or state-approved entity each time a Level 2 Assessment is triggered.

1. The Public Water System is responsible for ensuring that the Level 2 Assessment is conducted regardless of the entity conducting the Level 2 Assessment.
2. (3)Upon trigger of a Level 2 Assessment, the Level 2 Assessment form must be submitted within 30 days to the state.

Level 2 Assessment Triggers

Level 2 Assessment is triggered if any one of the following occurs:

1. A Public Water System incurs an E. coli MCL violation.
2. A Public Water System has a second Level 1 Assessment within a rolling 12-month period.
3. A Public Water System on state-approved annual monitoring has a Level 1 Assessment trigger in 2 consecutive years.

Seasonal System Provisions

The Total Coliform Rule defines seasonal systems and specifies additional requirements for these types of PWSs:

1. A seasonal system is defined as a non-community water system that is not operated as a PWS on a year round basis and starts up and shuts down at the beginning and end of each operating season.

Start-up Procedures for Seasonal Systems

At the beginning of each operating period, before serving water to the public, seasonal water systems must:

1. Conduct state-approved start-up procedures.
2. Certify completion of state-approved start-up procedures.

3. An exemption from conducting state-approved start-up procedures may be available for seasonal systems that maintain pressure throughout the distribution system during non-operating periods.

Examples of state-approved start-up procedures, which need to be completed prior to serving water to the public, may include one or more of the following:

1. Disinfection.
2. Distribution system flushing.
3. Sampling for total coliform and E. coli.
4. Site visit by state.
5. Verification that any current or historical sanitary defects have been corrected.

Routine Monitoring for Seasonal Systems

1. The baseline monitoring frequency for seasonal systems is monthly.
2. A reduced monitoring frequency may be available for seasonal systems that use ground water only and serve fewer than 1,000 persons.

Other Provisions for the State Drinking Water Agency Special Monitoring Evaluation

The state must perform a special monitoring evaluation at all ground water systems serving 1,000 or fewer persons during each sanitary survey to review the status of the Public Water System and to determine whether the sample sites and monitoring schedule need to be modified.

Major Violations

E. coli MCL Violation

A Public Water System will receive an E. coli MCL violation when there is any combination of an E.coli positive sample result with a routine/repeat Total Coliform positive or E. coli positive sample result:

E. coli MCL Violation Occurs with the Following Sample Result Combination

Routine Repeat

- EC+ TC+
- EC+ Any missing sample
- EC+ EC+
- TC+ EC+
- TC+ TC+ (but no E. coli analysis)

Treatment Technique Violation

A PWS will receive a Treatment Technique violation when any of the following occur:

1. Failure to conduct a Level 1 or Level 2 Assessment within 30 days of a trigger.
2. Failure to correct all sanitary defects from a Level 1 or Level 2 Assessment within 30 days of a trigger or in accordance with the state-approved timeframe.
3. Failure of a seasonal system to complete state-approved start-up procedures prior to serving water to the public.

Key Points for Public Water Systems to Remember

Find and correct sanitary defects as soon as you become aware of them. This can help reduce E. coli MCL violations, which trigger a Level 2 Assessment. This can help reduce TC+ sample results, which may trigger a Level 1 Assessment.

Make sure to collect all routine and repeat samples as required. Timely and correct monitoring can help reduce triggering a Level 1 or Level 2 Assessment because:

1. Failure to conduct repeat monitoring triggers a Level 1 Assessment.
2. A Level 1 Assessment triggered twice within a certain timeframe triggers a Level 2 Assessment.

Ground Water Treatment Rule

EPA issued the **Ground Water Rule (GWR)** to improve drinking water quality and provide protection from disease-causing microorganisms. Water systems that have groundwater sources may be susceptible to fecal contamination. In many cases, fecal contamination can contain disease-causing pathogens.

The purpose of the Ground Water Rule (GWR) is to reduce disease incidence associated with harmful microorganisms in drinking water.

The Ground Water Rule applies to public water systems that use ground water as a source of drinking water. The rule also applies to any system that delivers surface and ground water to consumers where the ground water is added to the distribution system without treatment. The Ground Water Rule was published in the Federal Register in November 2006.

Overview of the Rule

Ground Water Rule (GWR)

71 FR 65574, November 2006, Vol. 71, No. 216

Correction 71 FR 67427, November 2006, Vol. 71, No. 224

Purpose

The rule should reduce the risk of illness caused by microbial contamination in public ground water systems (GWSs).

General Description

The Groundwater Rule establishes a risk-targeted approach to identify groundwater systems susceptible to fecal contamination, and the rule requires corrective action to correct significant deficiencies and source water fecal contamination in all public groundwater systems.

Utilities Covered

The Ground Water Rule applies to all public water systems that use groundwater, including consecutive systems, except that it does not apply to public water systems that combine their groundwater with surface water or with groundwater under the direct influence of surface water prior to treatment.

Public Health Benefits

Targeted protection for over 70 million people served by groundwater sources that are not disinfected or receive less than 4-log treatment or reduction in 99.99% harmful microorganisms. Implementation created an avoidance of 42,000 viral illnesses and 1 related death annually.

Requirements for Drinking Water Systems

New groundwater sources must meet triggered source water monitoring requirements or conduct compliance monitoring. Groundwater systems must conduct triggered source water monitoring if the system does not provide at least 4-log virus inactivation, removal, or a state-approved combination of these technologies before or at the first customer and the system is notified that a sample collected for the Total Coliform Rule (TCR) is total coliform-positive.

Groundwater systems identified as a significant deficiency and systems that have had at least one of the five additional groundwater source samples that has tested positive for fecal contamination must comply with the treatment technique requirements.

Analytical Methods for Source Water Monitoring

Fecal Indicator Methodology Method

EPA Method 1604

1. E. coli Colilert
2. Colisure
3. Membrane Filter Method with MI Agar

4. m-ColiBlue24 Test
5. E*Colite Test
6. EC-MUG
7. NA-MUG
8. 9223 B
9. 9223 B
10. 9221 F
11. 9222 G
12. Enterococci Multiple-Tube Technique
13. Membrane Filter Technique
14. Enterolert
15. 9230 B
16. 9230 C
17. EPA Method 1600.
18. Coliphage Two-Step, Enrichment, Presence-Absence Procedure
19. Single Agar Layer Procedure
20. EPA Method 1601
21. EPA Method 1602

Major Provisions of Rule

1. Compliance Monitoring
2. Treatment
3. Technique
4. Compliance
5. Monitoring

In order not to be subject to triggered source water monitoring, a groundwater system can notify the state that it provides at least 4-log treatment of viruses using virus inactivation, removal, or a state-approved combination of 4-log virus inactivation and removal before or at the first customer. The groundwater system must then begin compliance monitoring designed to show the effectiveness of their treatment processes.

Groundwater systems that use chemical disinfection and serve more than 3,300 people must continuously monitor their disinfectant concentration. These systems must maintain the minimum disinfectant residual concentration determined by the state.

Groundwater systems that use chemical disinfection and serve 3,300 people or fewer must take daily grab samples or meet the continuous monitoring requirements described for public groundwater systems serving more than 3,300 people.

Groundwater systems using membrane filtration for 4-log treatment of viruses must monitor the membrane filtration process according to state-specified monitoring requirements.

Groundwater systems may use alternative treatment technologies (e.g., ultraviolet radiation [UV]) approved by the state. Groundwater systems must monitor the alternative treatment according to state specified monitoring requirements and must operate the alternative treatment according to compliance requirements established by the state.

Source Water Monitoring

Triggered Source Water Monitoring

Groundwater systems that do not conduct compliance monitoring and are notified of a total coliform-positive routine sample collected in compliance with the Total Coliform Rule (40 CFR 141.21) must conduct triggered source water monitoring.

Groundwater systems must collect at least one ground water source sample from each source in use at the time the total coliform-positive sample was collected. The triggered source water sample must be analyzed for the presence of a fecal indicator as specified in the rule.

If the triggered source water sample is fecal indicator-positive, the Groundwater system must either take corrective action, as directed by the state, or if corrective action is not required by the state and the sample is not invalided by the state, the Groundwater system must conduct additional source water sampling.

States may waive the triggered source water monitoring requirement if the state determines and documents, in writing, that the total coliform-positive routine sample is the result of a documented distribution system deficiency.

States may develop criteria for distribution system conditions that cause total coliform positive samples. A Groundwater system can document to the state that it met the state criteria within 30 days of the total coliform-positive sample and be exempt from collecting triggered source water sample(s).

States may invalidate a fecal indicator-positive groundwater source sample under specific conditions. If a fecal indicator-positive source sample is invalidated, the Groundwater system must collect another source water sample within 24 hours of being notified by the state of its invalidation decision.

Additional Source Water Sampling

If the state does not require corrective action in response to a fecal indicator-positive triggered source water sample, the Groundwater system must collect five additional source water samples (from the same source), using the same indicator as used in triggered source water monitoring, within 24 hours of being notified of the fecal indicator-positive sample.

Assessment Source Water Monitoring

States have the opportunity to target higher risk GWSs for additional testing. States independently can determine on a case by case basis whether monitoring is necessary and when corrective action needs to be taken.

Treatment Technique Requirements

Groundwater Systems with Significant Deficiencies or Source Water Fecal Contamination

Groundwater systems must take corrective action if a significant deficiency is identified, or if the initial source samples (if required by the state) or one of the five additional groundwater source samples tests positive for fecal contamination. The Groundwater systems must implement at least one of the following corrective actions:

1. Correct all significant deficiencies
2. Provide an alternate source of water
3. Eliminate the source of contamination
4. Provide treatment that reliably achieves at least 4-log treatment of viruses (using inactivation, removal, or a state-approved combination of 4-log virus inactivation and removal) before or at the first customer for the groundwater source.

New Sources

New Ground Water Sources

New sources which come online after November 2009 are required either to conduct triggered source water monitoring as required by the Groundwater Rule, or provide at least 4-log inactivation, removal, or a state-approved combination of these technologies and conduct compliance monitoring within 30 days of the source being put in service.

Sanitary Surveys

All Ground Water Systems

States are required to conduct sanitary surveys of all Groundwater systems in order to identify significant deficiencies, including deficiencies which may make a system susceptible to microbial contamination.

Following the initial sanitary survey, states must conduct sanitary surveys every 3 years for most Community Water Systems and every 5 years for Non-community Water Systems that provide at least 4-log treatment of viruses or have outstanding performance records, as determined by the state.

Surface Water Treatment Rule

The purpose of the **Surface Water Treatment Rules (SWTRs)** is to reduce illnesses caused by pathogens in drinking water. The disease-causing pathogens include *Legionella*, *Giardia lamblia*, and *Cryptosporidium*.

The SWTRs requires water systems to filter and disinfect surface water sources. Some water systems are allowed to use disinfection only for surface water sources that meet criteria for water quality and watershed protection. This combination of rules is designed to provide protection from microbial pathogens.

Simultaneously, the rules minimize health risks to the population from disinfection byproducts.

For PWSs that use surface water sources and are not required to filter, existing regulations do not require any treatment for Cryptosporidium. New survey data suggest that typical Cryptosporidium levels in the treated water of unfiltered PWSs are higher than in the treated water of filtered PWSs. Thus, Cryptosporidium treatment by unfiltered PWSs is needed to achieve comparable public health protection.

Further, results from recent treatment studies has allowed EPA to develop standards for the inactivation of Cryptosporidium by ozone, ultraviolet (UV) light, and chlorine dioxide. Based on these developments, the EPA has established requirements for all unfiltered PWSs to treat for Cryptosporidium, with the required degree of treatment depending on the source water contamination level. Additionally, the long-term rule addresses risks in uncovered finished water storage facilities, in which treated water can be subject to significant contamination as a result of runoff, bird and animal wastes, human activity, algal growth, insects, fish, and airborne deposition. Existing regulations prohibit the building of new uncovered finished water storage facilities. Under the long-term rule, PWSs must limit potential risks by covering or treating the discharge of such storage facilities. The requirements in the Surface Water Treatment Rule reflect consensus recommendations from the Stage 2 Microbial and Disinfection Byproducts (M–DBP) Federal Advisory Committee. These recommendations are set forth in the Stage 2 M–DBP Agreement in Principle.

Long-Term Surface Water Treatment Rule

Source Water Monitoring. The rule requires PWSs using surface water or groundwater under the direct influence (GWUDI) of surface water to monitor their source water (the influent water entering the treatment plant) to determine an average Cryptosporidium level. Monitoring results determine the extent of Cryptosporidium treatment requirements.

Large PWSs (serving at least 10,000 people) must monitor for Cryptosporidium (plus E. coli and turbidity in filtered PWSs) for a period of two years. To reduce monitoring costs, small filtered PWSs (serving fewer than 10,000 people) initially monitor just for E. coli for one year as a screening analysis and are required to monitor for Cryptosporidium only if their E. coli levels exceed specified trigger values. Small filtered PWSs that exceed the E. coli trigger, as well as all small unfiltered PWSs, must monitor for Cryptosporidium for one or two years, depending on the sampling frequency.

Under the long-term rule, specific criteria are set for sampling frequency and schedule, sampling location, using previously collected data, providing treatment instead of monitoring, sampling by PWSs that use surface water for only part of the year, and monitoring of new plants and sources. The long-term rule also establishes requirements for reporting of monitoring results, using analytical methods, and using approved laboratories. The rule also requires a second round of monitoring to begin approximately 6.5 years after the first round concludes in order to determine if source water quality has changed to a degree that should affect treatment requirements.

The long-term rule establishes risk-targeted treatment technique requirements to control *Cryptosporidium* in PWSs using surface water or GWUDI. These treatment requirements supplement those established by existing regulations. Filtered PWSs are classified in one of four treatment categories (or bins) based on the results of the source water *Cryptosporidium* monitoring. This bin classification determines the degree of additional *Cryptosporidium* treatment, if any, that filtered PWS must provide. PWSs classified in Bins 2, 3, or 4 must achieve 1.0 to 2.5-log of treatment (90 to 99.7 percent reduction) for *Cryptosporidium* over and above that provided with conventional treatment. Different additional treatment requirements may apply to PWSs using other than conventional treatment, such as direct filtration, membranes, or cartridge filters.

Filtered PWSs must meet the additional *Cryptosporidium* treatment required in Bins 2, 3, or 4 by using one or more treatment or control processes from a microbial toolbox of options. The long-term rule requires all unfiltered PWSs to provide at least 2-log (99 percent) inactivation of *Cryptosporidium*. If the average source water *Cryptosporidium* level exceeds 0.01 oocysts/L, the unfiltered PWS must provide at least 3-log (99.9 percent) inactivation of *Cryptosporidium*. Further, under the long-term rule, unfiltered PWSs

must achieve their overall inactivation requirements (including *Giardia lamblia* and virus inactivation) using a minimum of two disinfectants.

PWSs with uncovered finished water storage facilities must take steps to address contamination risks. Existing regulations require PWSs to cover all new storage facilities for finished water but do not address existing uncovered finished water storage facilities. Under the long-term rule, PWSs using uncovered finished water storage facilities must cover the storage facility or treat the storage facility discharge to achieve inactivation and/or removal of 4-log virus, 3-log *Giardia lamblia*, and 2-log *Cryptosporidium* on a state-approved schedule.

The rule applies to all PWSs using surface water or GWUDI, including large and small PWSs, community and non-community PWSs, and non-transient and transient PWSs. Wholesale PWSs must comply with the requirements of the rule based on the population of the largest PWS in the combined distribution system.

Consecutive PWSs that purchase treated water from wholesale PWSs that fully comply with the monitoring and treatment requirements of the rule are not required to take additional steps for that water.

Existing Regulations for Microbial Pathogens in Drinking Water

1. The Surface Water Treatment Rule (SWTR) (54 FR 27486, June 1989) applies to all PWSs using surface water or ground water under the direct influence (GWUDI) of surface water as sources (Subpart H PWSs). It established MCLGs of zero for *Giardia lamblia*, viruses, and *Legionella*, and includes the following treatment technique requirements to reduce exposure to pathogenic microorganisms:
    a. Filtration, unless specific avoidance criteria are met
    b. Maintenance of a disinfectant residual in the distribution system
    c. Removal and/or inactivation of 3-log (99.9%) of *Giardia lamblia* and 4-log (99.99%) of viruses
    d. Maximum allowable turbidity in the combined filter effluent (CFE) of 5 nephelometric turbidity units
    e. (NTU) and 95th percentile CFE turbidity of 0.5 NTU or less for plants using conventional treatment or direct filtration
    f. Watershed protection and source water quality requirements for unfiltered PWSs
2. The Total Coliform Rule (TCR) (54 FR 27544, June 1989) applies to all PWSs. It established an MCLG of zero for total and fecal coliform bacteria and an MCL based on the percentage of positive samples collected. Coliforms are used as an indicator of fecal contamination and to determine the integrity of the water treatment process and distribution system. Under the Total Coliform Rule, no more than 5 percent of distribution system samples collected in any month may contain coliform bacteria (no more than 1 sample per month may be coliform positive in those PWSs that collect fewer than 40 samples per month). The number of samples to be collected in a month is based on the number of people served by the PWS.
3. Interim Enhanced Surface Water Treatment Rule (63 FR 69478, December 16, 1998) (USEPA 1998a) applies to PWSs serving at least 10,000 people and using surface water or GWUDI sources. Key provisions established by the interim rule include the following:
    a. An MCLG of zero for *Cryptosporidium*
    b. *Cryptosporidium* removal requirements of 2-log (99 percent) for PWSs that filter
    c. More stringent turbidity performance standards of 1.0 NTU as a maximum and 0.3 NTU or less at the 95th percentile monthly for treatment plants using conventional treatment or direct filtration
    d. Requirements for individual filter turbidity monitoring
    e. Disinfection benchmark provisions to assess the level of microbial protection that PWSs provide as they take steps to comply with new disinfection by-products standards
    f. Inclusion of Cryptosporidium in the definition of GWUDI and in the watershed control requirements for unfiltered PWSs
    g. Requirements for covers on new finished water storage facilities
    h. Sanitary surveysfor all surface water systems regardless of size

The interim surface water treatment rule was developed in conjunction with the Stage 1 Disinfectants and Disinfection Byproducts Rule (Stage 1 DBPR) (63 FR 69389, December 1998), which reduced allowable levels of certain DBPs, including trihalomethanes, haloacetic acids, chlorite, and bromate.

4. Long Term 1 Enhanced Surface Water Treatment Rule (67 FR 1812, January 2002) builds on the microbial control provisions established by the interim rule for large PWSs through extending similar requirements to small PWSs. The long-term interim rule applies to PWSs that use surface water or GWUDI as sources and that serve fewer than 10,000 people. Like the interim rule, the long-term rule established the following:
    a. 2- log (99 percent) *Cryptosporidium* removal requirements by PWSs that filter
    b. Individual filter turbidity monitoring and more stringent combined filter effluent turbidity standards for conventional and direct filtration plants
    c. Disinfection profiling and benchmarking; inclusion of *Cryptosporidium* in the definition of GWUDI and in the watershed control requirements for unfiltered PWSs
    d. The requirement that new finished water storage facilities be covered.
5. Filter Backwash Recycle Rule (66 FR 31085, June 2001) requires PWSs to consider the potential risks associated with recycling contaminants removed during the filtration process. The provisions of the filter backwash rule apply to all PWSs that recycle, regardless of population served. In general, the provisions include the following:
    a. PWSs must return certain recycle streams to a point in the treatment process that is prior to primary coagulant addition unless the State specifies an alternative location
    b. Direct filtration PWSs recycling to the treatment process must provide detailed recycle treatment information to the State
    c. Certain conventional PWSs that practice direct recycling must perform a one-month, one-time recycling self-assessment

Introduction to Cryptosporidium

Concern with Cryptosporidium in Drinking Water

EPA is promulgating the Long-Term Surface Water Treatment Rule to reduce the public health risk associated with *Cryptosporidium* in drinking water.

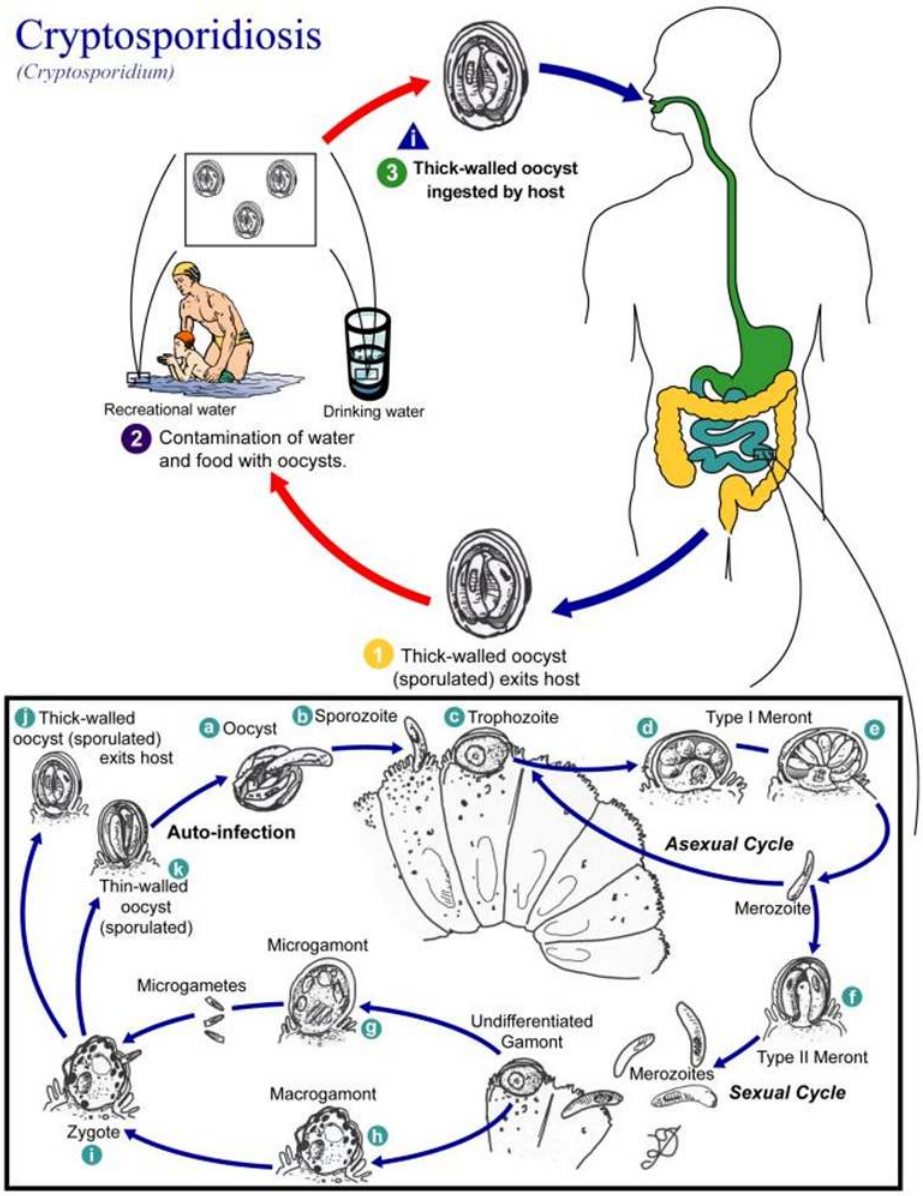


Figure **5.7.1**: Cryptosporidiosis.(Copyright: Image by the CDC is in the public domain)

Cryptosporidium is a protozoan parasite that lives and reproduces entirely in one host. Ingestion of *Cryptosporidium* can cause cryptosporidiosis, a gastrointestinal (GI) illness. Cryptosporidium is excreted in feces. Transmission of cryptosporidiosis occurs through consumption of water or food contaminated with feces or by direct or indirect contact with infected persons or animals. In the environment, Cryptosporidium is present as a thick-walled oocyst containing four organisms (sporozoites).

The oocyst wall insulates the sporozoites from harsh environmental conditions. Oocysts are 4–5 microns in length and width. Upon a host's ingestion of oocysts, enzymes and chemicals produced by the host's digestive system cause the oocyst to excyst, or break open. The excysted sporozoites embed themselves in the surfaces of the epithelial cells of the lower small intestine. The organisms then begin absorbing nutrients from their host cells. When these organisms sexually reproduce, they produce thick and thin-walled oocysts. The host excretes the thick-walled oocysts in its feces. The thin-walled oocysts excyst within the host and contribute to further host infection.

The exact mechanism by which *Cryptosporidium* causes GI illness is not known. Factors may include damage to intestinal structure and cells, changes in the absorption/secretion processes of the intestine, toxins produced by *Cryptosporidium* or the host, and proteins that allow *Cryptosporidium* to adhere to host cell surfaces. Upon excretion, *Cryptosporidium* oocysts may survive for

months in various environmental media, including soil, river water, seawater, and human and cattle feces at ambient temperatures. *Cryptosporidium* can also withstand temperatures as low as 20 °C for periods of a few hours, but they are susceptible to desiccation.

Cryptosporidium is a widespread contaminant in surface water used as drinking water supplies. *Cryptosporidium* contamination can come from animal agriculture, wastewater treatment plant discharges, slaughterhouses, birds, wild animals, and other sources of fecal matter. *Cryptosporidium parvum* (C. *parvum*) has been the primary species of concern to humans.

Cryptosporidium infection is characterized by mild to severe diarrhea, dehydration, stomach cramps, and/or a slight fever. Incubation is thought to range from 2 to 10 days. Symptoms typically last from several days to 2 weeks. In a small percentage of cases, the symptoms may persist for months or longer in healthy individuals. Symptoms may be more severe in immunocompromised persons. Such persons include those with AIDS, cancer patients undergoing chemotherapy, organ transplant recipients treated with drugs that suppress the immune system, and patients with autoimmune disorders.

Cryptosporidium oocysts are highly resistant to standard disinfectants like chlorine and chloramines. Consequently, control of *Cryptosporidium* in most treatment plants is dependent on physical removal processes. However, due to their size (4–5 microns), oocysts can sometimes pass through filters. Monitoring data on finished water show that *Cryptosporidium* is sometimes present in filtered, treated drinking water.

Certain alternative disinfectants can be more effective in treating for *Cryptosporidium*. Ozone and chlorine dioxide have been shown to inactivate *Cryptosporidium* at doses higher than those required to inactivate *Giardia*, which has typically been used to set disinfectant doses. Studies have also demonstrated a synergistic effect of treatment using ozone followed by chlorine or monochloramine. UV light has recently been shown to achieve high levels of *Cryptosporidium* inactivation at feasible doses. Other processes that can help reduce *Cryptosporidium* levels in finished water include watershed management programs, pretreatment processes like bank filtration, and additional clarification and filtration processes during water treatment. Further, optimizing treatment performance and achieving very low levels of turbidity in the finished water has been shown to improve *Cryptosporidium* removal in treatment plants.

Cryptosporidium has caused a number of waterborne disease outbreaks since 1984 when the first was reported in the United States. Data from the Centers for Disease Control and Prevention include ten outbreaks caused by *Cryptosporidium* in drinking water between 1984 and 2000, with approximately 421,000 cases of illness. The most serious outbreak occurred in 1993 in Milwaukee; an estimated 403,000 people became sick, and at least 50 *Cryptosporidium*-associated deaths occurred among the severely immunocompromised.

A PWS that begins using a new surface water source after the date the PWS is required to conduct source water monitoring under the Long-Term 2 Surface Water Treatment Rule must monitor the new source on a schedule approved by the State. This applies to new plants that begin operation and previously operating plants that bring a new source on-line after the required monitoring date for the PWS. The State may determine that monitoring should be conducted before a new plant or source is brought on-line or initiated within some time period afterward.

The new source monitoring must meet all long-term rule requirements. The PWS must also determine its treatment bin classification and comply with any additional *Cryptosporidium* treatment requirements based on the monitoring results on a schedule approved by the State.

Background and Analysis Monitoring requirements in the rule are designed to ascertain *Cryptosporidium* levels with suitable accuracy for making treatment bin classifications and in a time frame that does not delay the installation of *Cryptosporidium* treatment where needed. A mean *Cryptosporidium* concentration of 0.01 oocysts/L determines whether unfiltered PWSs are required to provide 2 or 3-log *Cryptosporidium* inactivation. No *E. coli* concentration was effective in determining whether PWSs were likely to fall above or below this level. Consequently, the rule requires all unfiltered PWSs to monitor for *Cryptosporidium*, unless they choose to provide 3-log *Cryptosporidium* inactivation.

Sampling location

The requirements in the rule for the source water sample collection location are designed to achieve two objectives:

1. Characterize the influent water to the treatment plant at the time each sample is collected.
2. Ensure that samples are not affected by treatment chemicals that could interfere with *Cryptosporidium* analysis.

The first objective is the basis for requiring PWSs that use multiple sources to analyze a blended source sample or calculate a weighted average of sources that reflects the influent at the time of sample collection. It is also the reason that PWSs are required to sample after certain pretreatment processes like bank filtration that do not involve chemical addition.

The second objective is why PWSs are generally required to sample upstream of chemical addition and prior to backwash addition (for PWSs that recycle filter backwash). However, EPA recognizes that in some situations, sampling prior to chemical addition will not be feasible and discontinuing chemical addition for a period of time prior to sampling will not be advisable. This situation could occur when a treatment chemical is added at an intake that is difficult to access. Further, some treatment chemicals may not interfere with *Cryptosporidium* analyses when present at very low levels. Consequently, the rule allows States to approve PWSs sampling after chemical addition when the State determines that collection prior to chemical treatment is not feasible, and the treatment chemical is not expected to interfere with the analysis of the sample. EPA believes that States should review source water monitoring locations for their PWSs.

Sampling Schedule

The requirement will help to ensure that monitoring determines the mean concentration of *Cryptosporidium* in the treatment plant influent. To achieve this objective, the timing of sample collection must not be adjusted in response to fluctuations in water quality, such as the avoidance of sampling when the influent water is expected to be of poor quality. EPA believes that the 5-day window for sample collection and associated allowances for sampling outside this window provide sufficient flexibility. If circumstances arise that prevent the PWS from sampling within the scheduled 5-day window, such as a weather event or plant emergency, the PWS must collect a sample as soon as feasible. In this case, feasibility includes the ability of the PWS to safely collect a sample and the availability of an approved laboratory to conduct the analysis within method specifications. In addition, the rule allows States to authorize a different date for collecting the delayed sample.

Failing to Monitor

For most monitoring and testing procedure violations under the Long-Term Rule 2, PWSs must provide a Tier 3 public notification, which is standard for this type of violation under an NPDWR. However, if a PWS fails to collect three or more *Cryptosporidium* samples, the violation is elevated to a Tier 2 special public notice. The reason for elevating the public notice at this point is the persistence of the violation and the difficulty the PWS will have in collecting the required number of samples for bin classification by the compliance date. The rule requires bin classification within six months following the end of the monitoring period specified for the PWS. This six-month period provides some opportunity for collecting and analyzing missed samples. The number of samples that can be made up in this period is limited, though, due to the need for samples to be evenly distributed throughout the year, as well as for PWSs and States to spend time during this period evaluating monitoring results to determine bin classification.

Failure by a PWS to collect the required number of *Cryptosporidium* samples for bin classification by the compliance date is a treatment technique violation with a required Tier 2 public notice. This violation reflects the inability of the PWS to determine and comply with its *Cryptosporidium* treatment requirements under the rule and provide the appropriate level of public health protection. The violation ends when the State determines that the PWS is carrying out a monitoring plan that will lead to bin classification.

A PWS that has already provided a Tier 2 public notice for missing three sampling dates and is successfully meeting a State-approved sampling schedule is not required to issue another public notice for missing the bin classification date. Alternatively, the PWS can choose to provide the highest level of *Cryptosporidium* treatment required under the rule, which is 5.5-log for filtered PWSs and 3-log for unfiltered PWSs.

Requirements for grandfathering previously collected monitoring data in the rule based on the principle that to be eligible for grandfathering, previously collected data must be equivalent in quality to data that will be collected under the rule.

The Stage 2 M–DBP Advisory Committee recommended that EPA accept previously collected *Cryptosporidium* data that are equivalent in sample number, frequency, and data quality (volume analyzed, percent recovery) to data that would be collected under the long-term rule to determine bin classification in lieu of further monitoring.

Ongoing watershed assessment treatment requirements under the rule are based on source water quality. Consequently, the rule requires watershed assessment and, a second round of monitoring following initial bin classification to determine if source water quality has changed to the degree that the treatment level should be modified. States are allowed to use programs other than the

sanitary survey to assess changes in the watershed. The rule leverages the existing requirement for States to perform sanitary surveys on surface water PWSs. During the source water review in the sanitary survey, the rule requires States to determine if significant changes have occurred in the watershed that could lead to increased contamination by *Cryptosporidium*. The State can also choose to make this determination through an equivalent review of the source water under a program other than the sanitary survey, such as a Source Water Protection Assessment. If the State determines that significant changes have occurred, the State may specify that the PWS conduct additional source water monitoring or treat the potential contamination. This approach allows the PWS and State to respond to a significant change in source water quality prior to initiating a second round of monitoring or any time thereafter.

Second Round of Monitoring

A more rigorous reassessment of the source water occurs through a second round of monitoring that begins six years after initial bin classification. If EPA does not develop and finalize modifications to the rule prior to the date when PWSs must begin the second round of monitoring, then this second round must conform to the same requirements that applied to the initial round of monitoring. PWSs may be classified in a different treatment bin, depending on the results of the second round of monitoring.

Process Summary

Source water monitoring to determine additional treatment requirements for Cryptosporidium.

1. Sampling parameters and frequency, sampling location, sampling schedule, monitoring plants that operate only part-year, failing to monitor, providing treatment instead of monitoring, grandfathering previously collected data, ongoing source water assessment, second round of monitoring, and new source monitoring.

The Rule requires filtered PWSs using surface water or GWUDI sources to provide greater levels of treatment if their source waters have higher concentrations of *Cryptosporidium*. Filtered PWSs are classified in one of four treatment bins based on results from the source water monitoring. PWSs classified in the lowest concentration bin are subject to no additional treatment requirements, while PWSs assigned to higher concentration bins must reduce *Cryptosporidium* levels. All PWSs must continue to comply with the requirements of the SWTR, IESWTR, and LT1ESWTR, as applicable. This section addresses procedures for classifying filtered PWSs in *Cryptosporidium* treatment bins and the treatment requirements associated with each bin. Microbial toolbox that PWSs must use to meet additional Cryptosporidium treatment requirements.

- Bin classification-after completing initial source water monitoring, filtered PWSs must calculate a *Cryptosporidium* bin concentration for each treatment plant where *Cryptosporidium* monitoring is required. This *Cryptosporidium* bin concentration is used to classify filtration plants in one of the four treatment bins.

In general, the *Cryptosporidium* bin concentration is calculated by averaging individual sample results from one or more years of monitoring. Specific procedures vary, however, depending on the frequency and duration of monitoring. These procedures are as follows:

1. For PWSs that collect a total of at least 24 but not more than 47 *Cryptosporidium* samples over two or more years, the *Cryptosporidium* bin concentration is equal to the highest arithmetic mean of all sample concentrations in any 12 consecutive months of *Cryptosporidium* monitoring.
2. For PWSs that collect a total of at least 48 samples, the *Cryptosporidium* bin concentration is equal to the arithmetic mean of all sample concentrations.
3. For PWSs that serve fewer than 10,000 people and monitor for *Cryptosporidium* for only one year (collect 24 samples in 12 months), the *Cryptosporidium* bin concentration is equal to the arithmetic mean of all sample concentrations.
4. For PWSs with plants that operate only part-year that monitor for less than 12 months per year, the *Cryptosporidium* bin concentration is equal to the highest arithmetic mean of all sample concentrations during any year of *Cryptosporidium* monitoring.

In data sets with variable sampling frequency, PWSs must first calculate an arithmetic mean for each month of sampling and then apply one of these four procedures using the monthly mean concentrations. PWSs may grandfather previously collected *Cryptosporidium* data where the sampling frequency varies (one year of monthly sampling and one year of twice-per- month sampling). Filtered PWSs serving fewer than 10,000 people are not required to monitor for *Cryptosporidium* if they demonstrate a

mean E. *coli* concentration less than or equal to 10/ 100 mL for lake/reservoir sources or 50/ 100 mL for flowing stream sources or do not exceed an alternative State-approved indicator trigger. PWSs that meet this criterion are classified in Bin 1.

When determining the *Cryptosporidium* bin concentration, PWSs must calculate individual sample concentrations as the total number of oocysts counted, divided by the volume as saved. In samples where no oocysts are detected, the result is assigned a value of zero for the purpose of calculating the bin concentration. Sample analysis results are not adjusted for analytical method recovery or the percent of *Cryptosporidium* oocysts that are infectious. PWSs must report their treatment bin classification to the State for approval following initial source water monitoring. The report must include a summary of the data and calculation procedure used to determine the bin concentration. PWSs must recalculate their bin classification after completing the second round of monitoring and report the results to the State for approval. If the State does not respond to a PWS regarding its bin classification after either report, the PWS must comply with the *Cryptosporidium* treatment requirements of the rule based on the reported bin classification.

- Bin treatment requirements. All filtered PWSs must comply with the treatment requirements based on their bin classification.

The total *Cryptosporidium* treatment required for plants in Bins 2, 3, and 4 is 4.0-log, 5.0-log, and 5.5-log, respectively. Conventional treatment (including softening), slow sand, and diatomaceous earth filtration plants in compliance with the IESWTR or LT1ESWTR, as applicable, receive a prescribed 3.0-log *Cryptosporidium* treatment credit toward these total bin treatment requirements. Accordingly, these plant types must provide 1.0 to 2.5-log of additional treatment when classified in Bins 2–4, respectively. Direct filtration plants in compliance with existing regulations receive a prescribed 2.5-log treatment credit and, consequently, must achieve 0.5-log greater treatment to comply with Bins 2–4.

For PWSs using alternative filtration technologies, such as membranes, bag filters, or cartridge filters, no prescribed treatment credit is available because the performance of these processes is specific to individual products. Consequently, when PWSs using these processes are classified in Bins 2–4, the State must determine additional treatment requirements based on the credit the State awards to a particular technology. The additional treatment requirements must ensure that plants classified in Bins 2–4 achieve total *Cryptosporidium* reductions of 4.0- to 5.5-log, respectively. PWSs can achieve additional *Cryptosporidium* treatment credit through implementing pretreatment processes like pre-sedimentation or bank filtration, by developing a watershed control program, and by applying additional treatment steps like ozone, chlorine dioxide, UV, and membranes. In addition, PWSs can receive a higher level of credit for existing treatment processes through achieving very low filter effluent turbidity or through a demonstration of performance.

A combination of options from the microbial toolbox can be used to gather additional credit. PWSs in Bin 2 can meet additional *Cryptosporidium* treatment requirements by using any option or combination of options from the microbial toolbox. For Bins 3 and 4, PWSs must achieve at least 1-log of the additional treatment requirement by using ozone, chlorine dioxide, UV, membranes, bag filtration, cartridge filtration, or bank filtration.

- The rule increases protection against *Cryptosporidium* and other pathogens in PWSs with the highest source water contamination levels. This targeted approach builds upon existing regulations under which all filtered PWSs must provide the same level of treatment regardless of source water quality. The rule is to ensure that PWSs with higher risk source waters achieve public health protection commensurate with PWSs with less contaminated sources.

The rule establishes risk-targeted *Cryptosporidium* treatment requirements and sets specific bin concentration ranges and treatment requirements that apply to filtered PWSs. The IESWTR established a *Cryptosporidium* MCLG of zero and requires large filtered PWSs to achieve 2-log *Cryptosporidium* removal. The LT1ESWTR extended this requirement to small PWSs. After these rules were promulgated, advances were made in analytical methods and treatment for Cryptosporidium, and EPA collected new information on *Cryptosporidium* occurrence and infectivity. Consequently, EPA assessed the implications of these developments for further controlling Cryptosporidium to approach the zero MCLG. The risk-targeted approach for filtered PWSs in the rule stems from four general findings based on new information on *Cryptosporidium*:

1. New data on *Cryptosporidium* infectivity suggest that the risk associated with a particular level of *Cryptosporidium* is most likely higher than EPA estimated at the time of earlier rules.
2. New data on *Cryptosporidium* occurrence indicate that levels are relatively low in most water sources, but a subset of sources has substantially higher concentrations.

3. The finding that UV light can readily inactivate *Cryptosporidium*, as well as other technology developments, makes achieving high levels of treatment for *Cryptosporidium* feasible for PWSs of all sizes.
4. EPA Methods 1622 and 1623 are capable of assessing annual mean levels of *Cryptosporidium* in drinking water sources.

These findings led EPA to conclude that most filtered PWSs currently provide sufficient treatment for *Cryptosporidium*, but additional treatment is needed in those PWSs with the highest source water Cryptosporidium levels to protect public health. Further, PWSs can characterize *Cryptosporidium* levels in their source waters with available analytical methods and can provide higher levels of treatment with available technologies. Consequently, risk-targeted treatment requirements for *Cryptosporidium* based on source water contamination levels are appropriate and feasible to implement.

Basis for bin concentration ranges and treatment requirements. To establish the risk-targeted treatment requirements in today's rule, EPA had to determine the degree of treatment that should be required for different source water *Cryptosporidium* levels to protect public health. This determination involved addressing several questions:

1. What is the risk associated with *Cryptosporidium* in a drinking water source?
2. How much *Cryptosporidium* removal do filtration plants achieve?
3. What is the appropriate statistical measure for classifying PWSs into treatment bins?
4. What degree of additional treatment is needed for higher source water *Cryptosporidium* levels?
5. How should PWSs calculate their treatment bin classification?

The risk of infection from *Cryptosporidium* in drinking water is a function of exposure (the dose of oocysts ingested) and infectivity (likelihood of infection as a function of ingested dose). Primary (direct) exposure to *Cryptosporidium* depends on the concentration of oocysts in the source water, the fraction removed by the treatment plant, and the volume of water consumed (secondary exposure occurs through interactions with infected individuals). Thus, the daily risk of infection (DR) is as follows:

DR = (oocysts/L in source water) × (fraction remaining after treatment) × (liters consumed per day) × (likelihood of infection per oocyst dose). Assuming 350 days of consumption per year for people served by community water systems (CWSs), the annual risk (AR) of infection is as follows: AR = 1 ¥ (1 ¥ DR)350.

EPA has estimated the mean likelihood of infection from ingesting one *Cryptosporidium* oocyst to range from 4 to 16 percent. Median individual daily water consumption is estimated as 1.07 L/day.

Key Terms

- Cryptosporidium - a protozoan parasite that lives and reproduces entirely in one host; ingestion of *Cryptosporidium* can cause cryptosporidiosis, a gastrointestinal (GI) illness; cryptosporidium is excreted in feces.
- **Ground Water Rule (GWR)** – the purpose is to improve drinking water quality and provide protection from disease-causing microorganisms; water systems that have groundwater sources may be susceptible to fecal contamination; applies to public water systems that use ground water as a source of drinking water
- **Surface Water Treatment Rules (SWTRs)** – the purpose is to reduce illnesses caused by pathogens in drinking water, including *Legionella*, *Giardia lamblia*, and *Cryptosporidium*; the SWTRs requires water systems to filter and disinfect surface water sources.
- Total Coliform Rule (TCR) - a National Primary Drinking Water Regulation (NPDWR), published in 1989 and became effective in 1990; sets a health goal (Maximum Contaminant Level Goal (MCLG)) and legal limits (Maximum Contaminant Levels, MCLs)) for the presence of total coliforms in drinking water

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5.7.1: Review Questions

Review Questions

1. **What are the primary components of the Total Coliform Rule?**
2. **What is the basis of the Total Coliform Rule?**
3. **What is the primary requirement in the Groundwater Rule?**
4. **List four EAP approved laboratory methods for testing for coliforms.**

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5.7.2: Chapter Quiz

Chapter Quiz

1. Total coliforms are used as a(n) _____ of the possible presence of pathogens in drinking water. Total coliforms are used to determine the adequacy of water treatment and the integrity of the distribution system.

1. indicator
2. model
3. log removal
4. alternative

2. The Revised Total Coliform Rule establishes _____for E. coli and uses E. coli and total coliforms to initiate a find and fix approach to address fecal contamination that could enter into the distribution system.

1. a log removal
2. a maximum contaminant level (MCL)
3. a secondary maximum contaminant level (SMCL)
4. a model

3. Within 24 hours of learning of a Total Coliform positive routine sample result, at least ____ repeat samples must be collected and analyzed for total coliform.

1. 1
2. 2
3. 3
4. 4

4. States are required to conduct _____ of all groundwater systems in order to identify significant deficiencies, including deficiencies which may make a system susceptible to microbial contamination.

1. hydrologic studies
2. microbial examinations
3. a sanitary survey
4. laboratory studies

5. The Surface Water Treatment Rule requires water systems to _____ surface water sources.

1. filter and disinfect
2. conserve
3. aerate
4. disinfect

6. In order not to be subject to triggered source water monitoring under the Groundwater Rule, a groundwater system can notify the state that it provides at least _____ treatment of viruses using virus inactivation, or removal, before or at the first customer.

1. 2-log
2. 3-log
3. 4-log
4. 6-log

7. The Long-Term Surface Water Rule establishes risk-targeted treatment technique requirements to control _____ in PWSs using surface water or groundwater under the influence of surface water.

1. *E.coli*
2. *Giardiasis lambdia*
3. *Cryptosporidium*
4. Coliforms

8. What is the maximum allowable turbidity in the combined filter effluent?

1. 0.5 NTU
2. 1.0 NTU
3. 3.0 NTU
4. 5.0 NTU

9. EPA promulgated the Long-Term Surface Water Treatment Rule to reduce the public health risk associated with _____ in drinking water.

1. *Giardiasis lambdia*
2. *Cryptosporidium*
3. Coliforms
4. *E. coli*

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5.8: Total Coliform Rule

Learning Objectives

After reading this section, you should be able to:

- Describe biofilms
- Explain common microbiological techniques
- Outline and describe coliform bacterial analysis

Biofilms

Bacteria may grow and persist in the environment as free floating (planktonic) cells in liquids or attached to surfaces as biofilm. In 1683, Antoni van Leeuwenhoek observed and described biofilms by using his primitive microscope on matter from his own teeth. Biofilm form when bacteria adhere to environmental surfaces, especially those located in the presence of high moisture. Biofilm typically persist in a matrix containing slimy, glue-like substances (extracellular polymeric substances) which facilitate their attachment to many hard surfaces. The biofilm matrix provides embedded bacteria with protection from dehydration and other environmental stresses and may interfere with the action of chemical disinfectants.[1]

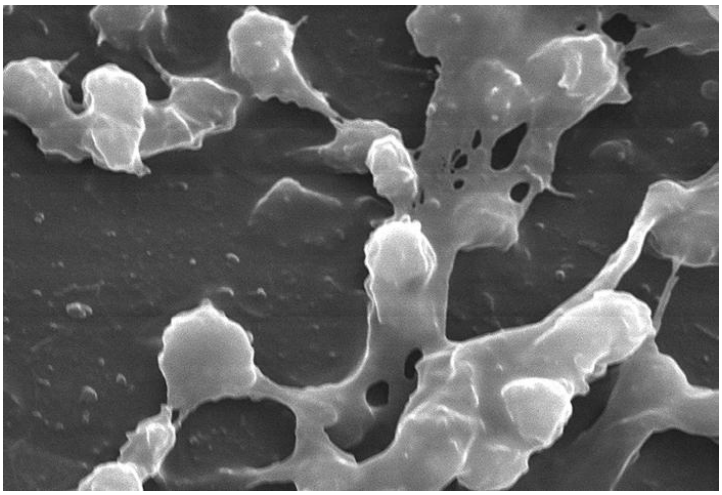


Figure **5.8.1**: Copy and Paste Caption here. (Copyright; Image by CDC is in the public domain)

A biofilm is considered to a hydrogel. According to Wang et. al (2020), hydrogels are "three-dimensional (3D) cross-linked polymer networks that can absorb and retain large amount of water. Because of their tunable properties as well as their versatile fabrication methods, hydrogel materials have been applied in a wide range of biomedical and engineering applications, ranging from tissue engineering and regenerative medicine to wastewater treatment…"[2]

Culture Media

Culture medium or growth medium is a liquid or gel designed to support the growth of microorganisms. There are different types of media suitable for growing different types of cells. Nutrient broths and agar plates are the most common growth media, although specialized media are sometimes required for microorganism and cell culture growth. Some organisms, termed fastidious organisms, need specialized environments due to complex nutritional requirements. Viruses, for example, are obligate intracellular parasites and require a growth medium containing living cells. Many human microbial pathogens also require the use of human cells or cell lysates to grow on a media. The most common growth media nutrient broths (liquid nutrient medium) or LB medium (Lysogeny Broth) are liquid. These are often mixed with agar and poured into Petri dishes to solidify. These agar plates provide a

solid medium on which microbes may be cultured. They remain solid, as very few bacteria are able to decompose agar. Many microbes can also be grown in liquid cultures comprised of liquid nutrient media without agar.

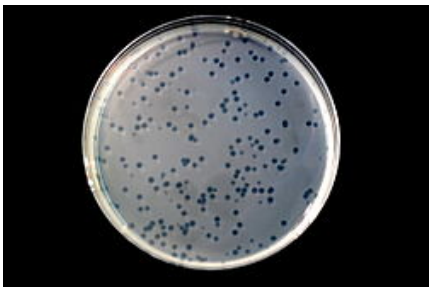


Figure 5.8.2: Petri Dish #1. (Copyright; Image by Ninjatacoshell is licensed under CC BY-SA 3.0)



Figure 5.8.3: Petri Dish #2. (Copyright; Image by NASA is in the public domain)

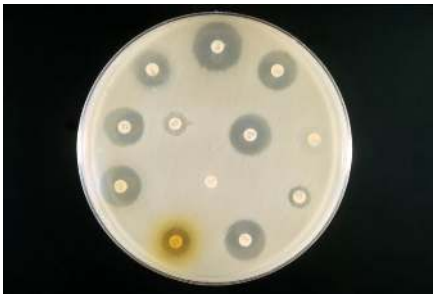


Figure 5.8.4: Petri Dish #3. (Copyright; Image by the CDC is in the public domain)

Chemically Defined Medium

A *defined culture* medium will have known quantities of all ingredients. For microorganisms, it provides trace elements and vitamins required by the microbe and especially a defined carbon and nitrogen source. Glucose or glycerol are often used as carbon sources, and ammonium salts or nitrates as inorganic nitrogen sources. A chemically defined medium is entirely free of animal-derived components (including microbial derived components such as yeast extract) and represents the purest and most consistent cell culture environment.

Complex Undefined Media

An undefined medium has some complex ingredients, such as yeast extract or casein hydrolysate, which consist of a mixture of many, many chemical species in unknown proportions. Undefined media are sometimes chosen based on price and sometimes by necessity – some microorganisms have never been cultured on defined media. A defined medium (also known as chemically defined medium or synthetic medium) is a medium in which all the chemicals used are known, no yeast, animal, or plant tissue is present.

Anaerobic Growth Media and Methods

Quite a few human pathogens are strict **anaerobes**. One way to culture and grow anaerobes is the use of reduced media--media without oxygen. Thioglycollate broth has a reducing agent in it---the chemical thioglycollate---which binds any free oxygen within the medium. These tubes have screw caps, allowing a tight closure, to reduce oxygen entry. However, some oxygen will be in the tube between the cap and the broth and there is no way to get rid of it. So, there will be some diffusion of oxygen into the top portion of the broth, and that is where any aerobic bacteria may grow.

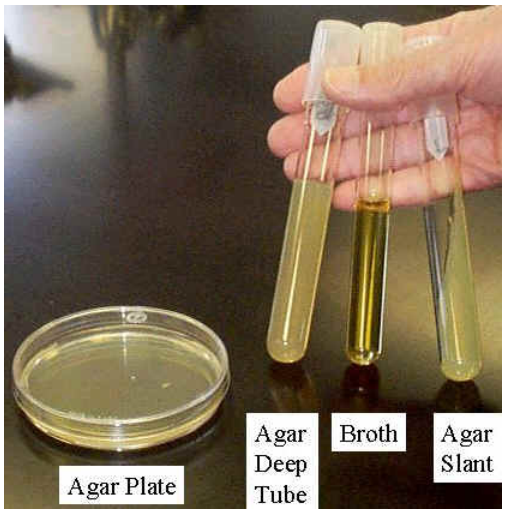


Figure 5.8.5: Nutrient Broth. (Image by LibreTexts is licensed under CC BY-SA 3.0.[8])

Special Culture Techniques

Microbes are incredibly varied in what they use as a food source, the environments they live in, and the danger levels they may have for humans and other organisms they may compete with. Therefore, they need special nutrient and growth environments that are not easily accommodated. For example, a microaerophile is a microorganism that requires oxygen to survive but requires environments containing lower levels of oxygen than are present in the atmosphere (~20% concentration). Many microphiles also require an elevated concentration of carbon dioxide. In the laboratory they can be easily cultivated in a candle jar. A candle jar is a container into which a lit candle is introduced before sealing the container's airtight lid. The candle's flame burns until extinguished by oxygen deprivation, which creates a carbon dioxide-rich, oxygen-poor atmosphere in the jar.

Pure Cultures

It is often essential to isolate a pure culture of microorganisms. A pure (or axenic) culture is a population of cells or multicellular organisms growing in the absence of other species or types. A pure culture may originate from a single cell or single organism, in which case the cells are genetic clones of one another. Microbiological cultures can be grown in petri dishes of differing sizes that have a thin layer of agar-based growth medium. Once the growth medium in the petri dish is inoculated with the desired bacteria, the plates are incubated at the best temperature for the growing of the selected bacteria.

But most bacteria samples contain a variety of different kinds and would be termed a mixed culture. However, it is possible to isolate specific bacteria by depositing the sample into a petri dish with agar with an inoculating loop or sterile cotton swab. using the streak plate method. If you swab a door handle, where bacteria are likely to be present, and then pass the swab across the surface of a petri plate, cells would be deposited onto the surface from the swab. Initially, the swab may have a fairly high concentration of cells and the area touched by it will have lots of different cell types placed close together. After these grow up, the cells' progeny will crowd together and overlap with other cells' progeny forming areas called confluent growth. As the swab moves across the agar leaving cells on the agar in a zig zag pattern as shown in Figure 8.6, regions touched later in the process will have fewer and fewer cells. Individual cells are far enough apart that each one would grow into a discrete isolated colony.



Figure 5.8.6: Streak plate pure cultures. (Copyright;Image by Bill Branson is in the public domain.
)

Coliform Bacterial Analysis

Municipal sewage contains human feces and water contaminated with these effluents may contain pathogenic (disease-causing) organisms and, consequently, may be hazardous to human health if used as drinking-water or in food preparation. Fecal contamination of water is routinely detected by microbiological analysis.

It is impractical to attempt the routine isolation of pathogens because they are present in relatively small numbers compared with other types of microorganism. Moreover, many types of pathogens exist, and each organism requires a unique microbiological isolation technique. The approach that has been adopted is to analyze samples for indicator organisms that inhabit the gut and are excreted in human feces. The presence of these indicator organisms in water is evidence that fecal contamination is present, and a risk exists that pathogens are present.

If indicator organisms are present in large numbers, the contamination is considered to be recent and/or severe. Bacteria in water are, in general, not present individually, but as clumps or in association with particulate matter. When enumerating bacteria in water it is not the number of individual bacteria present which are counted, but the number of clumps of bacteria or the particles and their associated bacteria. Each clump or particle may have many bacteria associated with it.

Total Coliforms

The term **total coliforms** refer to a large group of Gram-negative, rod-shaped bacteria that share several characteristics. The group includes heat-tolerant coliforms and bacteria of fecal origin, as well as some bacteria that may be isolated from environmental sources. The presence of total coliforms may or may not indicate fecal contamination. In extreme cases, a high count for the total coliform group may be associated with a low, or zero, count for thermos-tolerant coliforms. A result of this nature would not necessarily indicate the presence of fecal contamination. It might be caused by entry of soil or organic matter into the water or by conditions suitable for the growth of other types of coliform. In the laboratory total coliforms are grown in or on a medium containing lactose, at a temperature of 35 or 37 °C. They are provisionally identified by the production of acid and gas from the fermentation of lactose.

The term fecal coliform has been used in water microbiology to denote coliform organisms which grow at 44 or 44.5 C and ferment lactose to produce acid and gas. In practice, some organisms with these characteristics may not be of fecal origin and the term thermos-tolerant coliform is, therefore, more correct and is becoming more commonly used. Nevertheless, the presence of thermos-tolerant coliforms nearly always indicates fecal contamination.

Usually, more than 95 percent of thermos-tolerant coliforms isolated from water are the gut organism *Escherichia coli*, the presence of which is definitive proof of fecal contamination. As a result, it is often unnecessary to undertake further testing to confirm the

specific presence of *E. coli*.

The presence of fecal streptococci is evidence of fecal contamination. Fecal streptococci tend to persist longer in the environment than thermos-tolerant or total coliforms and are highly resistant to drying. It is, therefore, possible to isolate fecal streptococci from water that contains few or no thermos-tolerant coliforms as, for example, when the source of contamination is distant in time or space from the sampling point. Fecal streptococci grow in or on a medium containing sodium azide, at a temperature of 37-44°C. They are usually detected by the reduction of a dye (a tetrazolium-containing compound) or the hydrolysis of aesculin. Routine methods may give false positives and additional confirmatory tests may be required.

Key Terms

- **biofilm** – three-dimensional structures that create a matrix referred to commonly as a slime
- culture – the microbes that grow or multiply in or on a culture medium
- culture medium – a nutrient material prepared for the growth of microorganisms in a laboratory
- inoculum – microbes introduced into a culture medium to initiate growth
- streak plate method – an isolation method to achieve pure cultures by streaking a pattern over a surface of nutrient medium
- total coliform – a large group of Gram-negative, rod-shaped bacteria that share several characteristic and include heat-tolerant coliforms and bacteria of fecal origin, as well as some bacteria that may be isolated from environmental sources

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[1] (Efficacy Test Methods, Test Criteria, and Labeling Guidance for Antimicrobial Products with Claims Against Biofilm on Hard, Non-Porous Surfaces https://www.epa.gov/pesticide-analyt...eling-guidance)

[2] Wang, W., Narain, R., & Zeng, H. (2020). Hydrogels. Polymer Science and Nanotechnology, 203–244. https://doi.org/10.1016/b978-0-12-816806-6.00010-8

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5.8.1: Review Questions

Review Questions

1. **Describe a biofilm. Give two examples.**
2. **What does the term “coliforms” refer to? How are “coliforms” different than “fecal coliform”?**
3. **What is a culture medium?**

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5.8.2: Chapter Quiz

Chapter Quiz

1. A nutrient material prepared for the growth of microorganisms in a laboratory is called a _____.

1. enrichment medium
2. culture medium
3. selective media
4. complex media

2. Most investigations of microbes require a pure culture, or clones of bacteria. The isolation method used to achieve pure cultures is the _____.

1. selective selection
2. streak plate method
3. inoculation method
4. defined medium method

3. The term _____ refer(s) to a large group of Gram-negative, rod-shaped bacteria that share several characteristics. The group includes heat-tolerant bacteria of fecal origin.

1. virus
2. protozoan
3. parasite
4. total coliforms

4. _____ assume that each bacterium, clump of bacteria, or particle with bacteria attached, will give rise to a single visible colony. Each clump or particle is, therefore, a colony forming unit (cfu) and the results are expressed as colony forming units per unit volume.

1. Multiple Fermentation Tube Technique
2. Membrane Filter Technique
3. Heterotrophic Plate Count
4. Sabouraud

5. _____ count includes microorganisms that are capable of growing in or on a nutrient-rich solid agar medium.

1. Multiple Fermentation Tube Technique
2. Membrane Filter Technique
3. Heterotrophic Plate Count
4. Sabouraud

6. More than 95-percent of thermos-tolerant coliforms isolated from water are the gut organism, _____, the presence of which is definitive proof of fecal contamination.

1. Streptococcus
2. *E. coli*
3. Staphylococcus
4. Bacteroides

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5.9: Water Treatment for Contaminant Removal

Learning Objectives

After reading this section, you should be able to:

- Describe water quality characteristics
- Describe disinfection processes
- Describe the classes of water quality
- Explain water quality characteristics

Water Quality Characteristics

Water functions as a solvent due to its polarity and small molecular size. It has the ability to form hydrogen bonds which allows it to dissolve many types of molecules. It is often referred to as a "universal solvent". Microorganisms rely on water in order to grow. As such, pathogens which cause human illness are found in untreated surface water and groundwater. Waterborne diseases include typhoid fever, cholera, giardia, dysentery, E coli., hepatitis A, cryptosporidium, and Salmonella.

Public water system treatment plants use a combination of different treatment methods to remove or inactivate all disease-causing organisms and viruses. The process is referred to as a **multi-barrier treatment** approach. The final step in this approach involves chemical disinfection using chlorine or chloramines. Complete sterilization like the process used in hospitals is not necessary in water treatment.

Factors Influencing Disinfection

Several physical characteristics of a microorganism and chemical factors can influence the disinfection of water and include:

pH

Worldwide, many agencies have historically limited the range of pH values of distributed water between 6.5 and 8.5.[1] Although this range is not a regulatory limit, many jurisdictions have used it as one. The antimicrobial activity of chlorine is optimal at a neutral pH of 7.0. But an increase in pH will reduce its efficacy (pH over 8.0).

Temperature

The activity of most disinfectants will increase as the temperature increases. Chlorine is very effective at temperatures above 65 . Temperature measurements for calculating treatment contact times is important.

Turbidity

Turbidity is the measure of the relative clarity of a liquid. Cloudy (turbid) water would be due

To the presence of clay, silt, tiny inorganic and organic matter and other microorganisms.[2] This would definitely interfere with the disinfection process and is why a multi-barrier treatment approach with filtration precedes disinfection.

Organic Matter

A disinfectant like chlorine or bromine will react with natural organic residue found in water. This reduces the amount of disinfectant available. But more importantly the formation of chemical disinfection by-products called trihalomethanes (THMs) also occurs.[3] These compounds are regulated by the EPA. Consequently, most water agencies in California now use chloramines instead of chlorine as a primary disinfectant.

Inorganic Matter

Inorganic compounds found in residual silts or a compound such as ammonia (NH_3) in water will reduce the amount of disinfectant.

Reducing Agents

A reducing agent loses electrons and is oxidized in a chemical reaction. Examples of reducing agents include earth metals, formic acid, and sulfite compounds.[4] Chlorine combines with reducing agents, thereby affecting the amount of chlorine available to disinfect. Examples of reducing agents in water include hydrogen sulfide (H_2S), ferrous ion (Fe^{+2}), manganous ion (Mn^{+2}), ammonia (NH_3), and nitrite (NO_2^-).

Microorganisms

The physical characteristics of a microorganism can influence the disinfection process for example, spores are resistant to disinfectants because the spore coat and cortex act as a barrier. But most microorganisms can be filtered or settled out prior to disinfection.

Removal Processes[5]

A multi-barrier approach is used to remove pathogens before they are killed or inactivated (if a virus) by chemical disinfection.

1. **Coagulation.** Coagulation is often the first step in water treatment. During coagulation, chemicals with a positive charge are added to the water (floc). The positive charge neutralizes the negative charge of dirt and other dissolved particles in the water. When this occurs, the particles bind with the chemicals to form slightly larger particles. Common chemicals used in this step include specific types of salts, aluminum, or iron. In an international report published in 1998, it was found that coagulation and sedimentation alone can remove between 27 and 84 percent of viruses and between 32 and 87 percent of bacteria. Usually, the pathogens that are removed from the water are removed because they are attached to the dissolved substances that are removed by coagulation.[6]
2. **Sedimentation.** This refers to one of the steps water treatment plants use to separate out solids from the water. During sedimentation, flocs settle to the bottom because they are heavier than water.
3. **Filtration.** Once the flocs have settled to the bottom of the water, the clear water on top is filtered to separate additional solids from the water. During filtration, the clear water passes through filters that have different pore sizes and are made of different materials (such as sand, gravel, and charcoal). These filters remove dissolved particles and germs, such as dust, chemicals, parasites, bacteria, and viruses. Activated carbon filters also remove any bad odors.

Disinfection Process

After the water has been filtered, water treatment plants may add one or more chemical disinfectants (such as chlorine, chloramine, or chlorine dioxide) to kill any remaining parasites, bacteria, or viruses. To help keep water safe as it travels to homes and businesses, water treatment plants will make sure the water has low levels of the chemical disinfectant when it leaves the treatment plant. This remaining disinfectant kills pathogens living in the pipes between the water treatment plant and your tap.

In addition to or instead of adding chlorine, chloramine, or chlorine dioxide, water treatment plants can also disinfect water using UV light and ozone. They work well to disinfect water in the treatment plant, but these disinfection methods do not continue killing germs as water travels through the pipes between the treatment plant and your tap (no disinfection residual).

Ultraviolet Rays

Advances in UV disinfection have been made in recent years. An Ultraviolet (UV) disinfection system transfers electromagnetic energy from a mercury arc lamp to an organism's genetic material (DNA and RNA). When UV radiation penetrates the cell wall of an organism, it destroys the cell's ability to reproduce. UV radiation, generated by an electrical discharge through mercury vapor, penetrates the genetic material of microorganisms and retards their ability to reproduce. Unfortunately, this method leaves no disinfectant residual and is expensive.[7]

Heat

Primarily used in emergencies, heating water to a boil for 5 minutes will kill all microorganisms which may have breached the distribution system. From a practical perspective, it is an expensive and inefficient way to disinfect water for a public water system.

Chemical Disinfection

Iodine

Iodine is a good disinfectant and has been utilized for potable water treatment since the early 1900's in concentrations between 2.5 – 7 ppm. The US Army continues to issue iodine-based tablets to field soldiers and other personnel to disinfect water in emergencies. It is expensive and is also not recommended for use as a primary disinfectant due to lack of knowledge on long-term toxic effects.[8]

Bromine

Bromine is primarily used as an alternative disinfectant for swimming pools, spas and cooling tower water, but not for municipal drinking-water, partly due to cost and partly to concerns about the formation of brominated DBPs.[9]

Ozone

Ozone is used to disinfect water along with reducing taste and odors. Drawbacks of ozone for disinfection include a high cost, big physical footprint, lack of residual, difficulty in storing, and maintenance requirements.

Ozone has its advantages and disadvantages. Ozone treatment has the ability to achieve higher levels of disinfection than chlorine or UV, however, the capital costs as well as maintenance expenditures are not competitive with available alternatives.[10]

Chlorine

At room temperature, chlorine is a yellow-green gas that is heavier than air and has a strong irritating odor. It can be converted to a liquid under pressure or cold temperatures. Chlorine is mainly used as bleach in the manufacture of paper and cloth and to make a wide variety of products. Chlorine appears as a greenish yellow gas with a pungent suffocating odor. Chlorine does not burn but, like oxygen, supports combustion. Long-term inhalation of low concentrations or short-term inhalation of high concentrations has ill effects. Vapors are much heavier than air and tend to settle in low areas.[11]

Disinfection Action

Chlorine destroys organisms by oxidizing their cellular material. It is extremely effective for inactivating pathogens with one exception, Cryptosporidium. Leaving chemistry out of this discussion, let's consider what happens if 1 mg of chlorine gas is added to 1 liter of pure distilled water. Chemical reactions will occur to form two chlorine species which are referred to as free chlorine. That free chlorine "residual" is 1 mg/liter and has the ability to disinfect. Now consider 1 liter of water as it exists in nature. Let's also say there are no pathogens in the water. It will still contain natural organic compounds, non-organic elements like iron and manganese, and other compounds found in nature like nitrites, ammonia, and hydrogen sulfide. Chlorine will also react with them to form other compounds but won't have the ability to disinfect. Consequently, you won't have 1mg/liter of free chlorine residual. It will be less. You would need to add more chlorine gas to get back to 1mg/liter.

Chlorine Reactions in Water

Chlorine and water will react to form hypochlorous acid HOCL and hydrochloric acid HCl. These are weak compounds and HOCL will dissociate further into the hypochlorite ion OCL^-. Hypochlorous acid and the hypochlorite ion are what make up the free chlorine residual. As a disinfectant, the hypochlorite ion is only 1% as effective as hypochlorous acid.

These reactions are reversible and pH dependent.

- between pH 3.5 and 5.5, HOCl is the predominant species.
- between about pH 5.5 and 9.5, both HOCl and OCl^- species exist in various proportions.
- above pH 8, OCl^- predominates.

Reactions with Substances in Water

Chlorine will react with natural organic and inorganic compounds. This will reduce the free chlorine residual for disinfection purposes and necessitate the addition of additional chlorine gas. Hydrogen sulfide is a common compound found in groundwater. It has an unpleasant smell and is responsible for many taste and odor complaints from retail customers who may be served with groundwater sources of supply. Chlorine is very effective at removing it.

When chlorine reacts with natural organic matter, a group of disinfection byproducts, known as THM's or trihalomethanes may form. They may be harmful to certain segments of the population and are listed as a contaminant and regulated by the EPA.

Consequently, many water agencies have switched from using the direct use of chlorine gas as a primary disinfectant.

Chloramination

Chloramines have been used as a disinfectant in water systems for many years, primarily to control taste and odor. They can maintain a detectable disinfectant residual in a distribution system. But chloramine is a weaker disinfectant than chlorine. Consequently, higher chloramine doses and longer contact times are required to achieve the same level of disinfectant effectiveness as chlorine. A big advantage of using chloramines is to significantly reduce trihalomethane (THM) levels in order to meet the regulatory requirements of the Surface Water Treatment Rule.

Chloramines are formed when chlorine reacts with ammonia. They will form when natural untreated water contains ammonia. To maintain very low THM levels but maintain effective disinfection residuals, treatment plant operators will apply chlorine gas with ammonia concurrently in the treatment plant influent, or sequentially at a different downstream location in order to create a high chorine residual in part of the treatment process.

Hypochlorite

Rather than use chlorine gas, hypochlorite is available as calcium hypochlorite or sodium hypochlorite. They are a good alternative to supplying chlorine. Calcium hypochlorite is available as a solid. Sodium hypochlorite is available in solution.

Chlorine Dioxide

Chlorine dioxide (ClO_2) is an effective disinfectant. Chlorine dioxide does not form THM's like chlorine gas. It is more costly, and more hazardous to use. Chlorine dioxide is highly reactive and flammable.

UV Disinfection and Treatment of Water

Ultraviolet (UV) rays are part of the light that comes from the sun. The UV spectrum is higher in frequency than visible light and lower in frequency compared to x-rays. The UV spectrum has a larger wavelength than x-rays and a smaller wavelength than visible light and the order of energy, from low to high, is visible light, UV, and x-rays.

UV is known to be an effective disinfectant due to its strong germicidal (inactivating) ability. UV disinfects water containing bacteria and viruses and can be effective against protozoans, such as *Giardia lamblia* cysts or *Cryptosporidium* oocysts. UV is used in the pharmaceutical, cosmetic, beverage, and electronics industries. In the United States, it is used for drinking water disinfection; however, high operating costs compared to disinfection by chlorination has limited its usage.

Because of safety issues associated with the reliance of chlorination and improvements in UV technology, UV has experienced increased acceptance in municipal water systems. Two classes of disinfection systems are certified and classified by the NSF under Standard 55, Class A and Class B Units.

1. Class A These ultraviolet water treatment systems must have an intensity and saturation rating of at least 40,000 uw-sec/cm^2 and possess designs that will allow them to disinfect and/or remove microorganisms from contaminated water. Affected contaminants should include bacteria and viruses. Class A point-of-entry and point-of-use systems covered by this standard are designed to inactivate and/or remove microorganisms, including bacteria, viruses, and *Cryptosporidium* oocyst and *Giardia* cysts from contaminated water. Systems covered by this standard are not intended for the treatment of water that has obvious contamination or intentional source contamination, such as raw sewage, nor are these systems intended to convert wastewater to drinking water. These systems are intended to be installed on visually clear water.
2. Class B These ultraviolet water treatment systems must have an intensity and saturation rating of at least 16,000 uw-sec/cm^2 and possess designs that will allow them to provide supplemental bactericidal treatment of water already deemed safe, such that no elevated levels of *E. coli* or a standard plate count of less than 500 colonies per 1 ml exists. NSF Standard 55 suggests Class B UV systems are designed to operate at a minimum dosage and are intended to reduce normally occurring non-pathogenic or nuisance microorganisms only. The Class B or similar non-rated UV systems are not intended for the disinfection of microbiologically unsafe water.

The type of unit depends on the situation for use, source of water, and water quality. Transmitted UV light dosage is affected by water clarity. Water treatment devices are dependent on the quality of the raw water. When turbidity is 5 NTU or greater and/or

total suspended solids are greater than 10 ppm, pre-filtration of the water is highly recommended. Normally, it is advisable to install a 5 to 20 micron filter prior to a UV disinfection system.

UV disinfection is based on the principles associated with wave lengths of light that damage the nucleic acids of water borne pathogens. UV radiation has three wavelength zones, UV-A, UV-B, and UV-C, and it is the last region, the shortwave UV-C, that has germicidal properties for disinfection. A low-pressure mercury arc lamp resembling a fluorescent lamp produces the UV light in the range of 254 manometers (nm). These lamps contain elemental mercury and an inert gas, such as argon, in a UV-transmitting tube, usually quartz. Traditionally, most mercury arc UV lamps have been the low-pressure type because they operate at a relatively low partial pressure of mercury, low overall vapor pressure (about 2 mbar), low external temperature (50-100° C), and low power. These lamps emit nearly monochromatic UV radiation at a wavelength of 254 nm, which is in the optimum range for UV energy absorption by nucleic acids (about 240-280 nm).

In recent years, medium pressure UV lamps that operate at much higher pressures, temperatures, and power levels have been installed. They emit a broad spectrum of higher UV energy between 200 and 320 nm.

An essential requirement for UV disinfection with lamp systems is an available and reliable source of electricity. While the power requirements of low-pressure mercury UV lamp disinfection systems are modest, they are essential for lamp operation to disinfect water. Since most microorganisms are affected by radiation around 260 nm, UV radiation is in the appropriate range for germicidal activity. UV lamps are available that produce radiation in the range of 185 nm, and they are effective in reducing microorganisms as well. They will also reduce the total organic carbon (TOC) content of the water.

For typical UV systems, approximately 95-percent of the radiation passes through a quartz glass sleeve and into the untreated water. The water is flowing as a thin film over the lamp. The glass sleeve is designed to keep the lamp at an ideal temperature of approximately 104° F.

UV radiation affects microorganisms by altering the DNA in the cells and impeding reproduction. UV treatment does not remove organisms from the water. It inactivates them. The effectiveness of this process is related to exposure time and lamp intensity, as well as general water quality parameters.

The exposure time is reported as microwatt-seconds per square centimeter (uwatt-sec/cm^2), and the U.S. Department of Health and Human Services has established a minimum exposure of 16,000 µwatt-sec/cm^2 for UV disinfection systems. Most manufacturers provide a lamp intensity of 30,000-50,000µwatt-sec/cm^2. In general, coliform bacteria are destroyed at 7,000 µwatt-sec/cm^2.

Since lamp intensity decreases over time with use, lamp replacement and proper pretreatment are key to the success of UV disinfection. In addition, UV systems should be equipped with a warning device to alert operators when lamp intensity falls below the germicidal range.

Used alone, UV radiation does not improve the taste, odor, or clarity of water. UV light is a very effective disinfectant, although the disinfection can only occur inside the unit. No residual disinfection in the water exists to inactivate bacteria that may survive or may be introduced after the water passes by the light source. The percentage of microorganisms destroyed depends on the intensity of the UV light, the contact time, raw water quality, and proper maintenance of the equipment.

If material builds up on the glass sleeve or the particle load is high, the light intensity and the effectiveness of treatment are reduced. At sufficiently high doses, all waterborne enteric pathogens are inactivated by UV radiation. The general order of microbial resistance (from least to most) and corresponding UV doses for extensive (>99.9%) inactivation are vegetative bacteria and the protozoan parasites *Cryptosporidium parvum* and *Giardia lamblia* at low doses (1-10 mJ/cm^2) and enteric viruses and bacterial spores at high doses (30-150 mJ/cm^2).

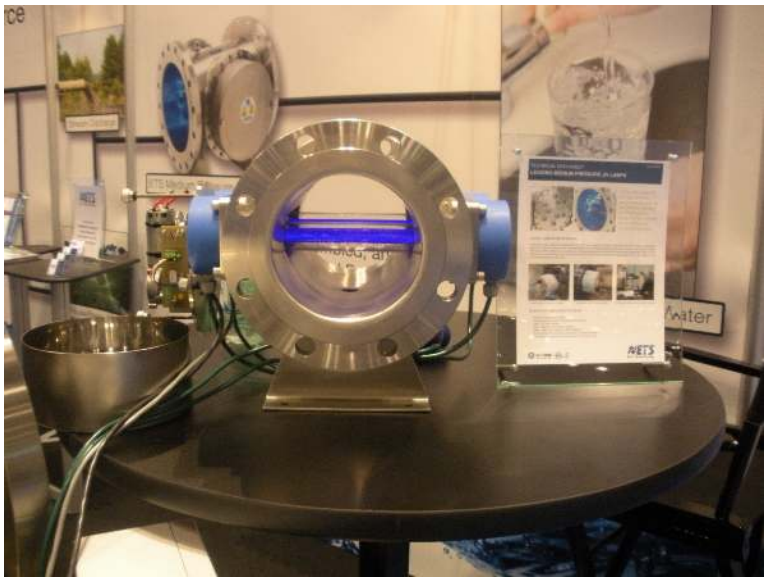


Figure 5.9.1: UV light used for disinfection in water treatment. (Copyright; mage by Pam Broviak is licensed under CC BY-SA 2.0)

Most low-pressure mercury lamp UV disinfection systems can readily achieve UV radiation doses of 50-150 mJ/cm^2 in high quality water; and therefore, efficiently disinfect waterborne pathogens. However, dissolved organic matter, such as natural organic matter, certain inorganic solutes such as iron, sulfites and nitrites, and suspended matter (particulates or turbidity) will absorb UV radiation or shield microbes from UV radiation, resulting in lower delivered UV doses and reduced microbial disinfection. Another concern surrounding disinfecting microbes with lower doses of UV radiation is the ability of bacteria and other cellular microbes to repair UV-induced damage and restore pathogenicity, which is a phenomenon known as reactivation.

UV inactivates microbes primarily by chemically altering nucleic acids. However, the UV-induced chemical lesions can be repaired by cellular enzymatic mechanisms, some enzymes act independent of light (dark repair) and other enzymes require visible light (photo-repair or photo-reactivation). Therefore, achieving optimum UV disinfection of water requires delivering a sufficient UV dose to induce greater levels of nucleic acid damage; and thereby, overcome DNA repair mechanisms.

UV units have a maximum flowrate capacity and some equipment have minimum flowrates. If the flow is too high, water will pass through without enough UV exposure. If the flow is too low, heat may build up which can damage the UV lamp. A UV unit with minimum flow requirements should not be placed on the water line supplying pressure stations in a non-recirculating system. UV units are most often used in constant flow systems.

UV lamps do not burn out as normal florescent lamps do. Instead, the UV lamps will solarize, which reduce their intensity to about 60% of a new lamp after about one year of continuous use. When lamps are new, they will generate a dosage level near 60,000 µW-s/cm^2. When the dosage drops to 30,000 µW-s/cm^2, the minimum dosage needed to effectively kill bacteria, lamps should be replaced. Lamp life will be shortened significantly if the lamp is turned on and off more frequently than once every eight hours.

Water should be sampled and tested for bacteria counts regularly. Sample before and after the UV unit to test its performance. Water should also be sampled in the distribution since bacterial regrowth can occur downstream of the UV unit.

As water passes through the UV unit, minerals, debris, and other material in the water will deposit onto the quartz or Teflon sleeve. This activity will limit the penetration of UV rays through the sleeve and into the water. To maintain high clarity, the glass around the lamp must be cleaned regularly. Cleaning frequency depends on the water quality and will be minimal with RO treatment upstream.

UV light intensity meters are available which indicate the penetration of UV light through the glass sleeve and the water. Low intensity means the UV dose is too low to provide adequate disinfection. This meter will indicate when cleaning or lamp replacement is needed.

Ozone

Ozone is one of the most powerful water treatment compounds available to system managers today. It is a technology that has been in continual commercial use for over 100 years and has distinct properties that allow disinfection of even heavily compromised water streams. With the 1996 reauthorization of the Safe Drinking Water Act, ozone was named as among the best available technologies for water system compliance with National Primary Drinking Water Regulations as overseen by the US Environmental Protection Agency.

Ozone (O_3) is formed when oxygen molecules are exposed to electron flow. Ozone molecules are unstable and will lose the third oxygen atom over time. Ozone is formation characterization:

1. Ozone generators provide an electron flow between dielectric and SS tubes.
2. Oxygen is passed through the gap between dielectrics resulting in ozone generation.
3. Oxygen feed gas must be dry and free of particles.
4. Ozone generators must be cooled, and cooling water removes .90 percent of the heat that is generated.

Ozone is a powerful oxidant with high disinfectant capacity. Ozone residuals between 0.3 to 2.0 mg/L inactivate viruses. Inactivation rates range from >3.9-log to >6-log, and occur within very short contact periods, 5 seconds. Microorganisms in natural waters are very sensitive to ozone. *Giardia* and enteric viruses are inactivated by ozone, as a primary disinfectant, with 5 minutes of contact time. Ozone residuals of 0.5 to 0.6 mg/L result in 3-log and 4-log removals, respectively. When ozone is used as a primary treatment, the criterion for its use is based on ozone residuals, competing ozone demands, and a minimum contact time to meet the required cyst and viral inactivation requirements.

Ozone is the strongest oxidant and strongest disinfectant available for potable water treatment. This unique material can be utilized for a number of specific water treatment applications, including disinfection, taste and odor control, color removal, iron and manganese oxidation, hydrogen sulfide removal, nitrite and cyanide destruction, oxidation of organics such as phenols, pesticides, and some detergents, algae destruction and removal, and as a coagulant aid. Even though ozone is the strongest chemical disinfectant available for water treatment, some refractory organics are not oxidized, or oxidize too slowly. In such cases, ozone can be combined with UV radiation and/or hydrogen peroxide to produce hydroxyl free radicals, HO^-, which is a stronger oxidant than molecular ozone, O_3. Deliberate production of hydroxyl free radicals starting with ozone has been termed ozone advanced oxidation. Groundwater that is contaminated with chlorinated organic solvents and some refractory hydrocarbons are being treated successfully with ozone advanced oxidation techniques.

At ambient temperatures, ozone is an unstable gas, partially soluble in water; generally, more soluble than oxygen. Due to its instability, ozone quickly reverts to oxygen. Ozone cannot be produced at a central manufacturing site, bottled, shipped, and stored prior to use. It must be generated and applied on-site. The installation of an ozone production plant requires storage of pure oxygen on-site as the feed gas. Ozone is generated for commercial uses using corona discharge or ultraviolet radiation. The UV technique produces low concentrations of ozone, whereas corona discharge produces ozone concentrations in the range of 1 – 4.5 % when dry air is fed to the ozone generator. When concentrated oxygen is used as the feed gas, gas phase ozone concentrations of up to 14 to 18% can be produced. Since ozone is only partially soluble in water, once it has been generated it must be contacted with the water to be treated in such a manner as to maximize the transfer of ozone from the gas phase into water. For this purpose, many types of ozone contactors have been developed. However, as higher concentrations of ozone gas are employed, contacting system designs become more critical because of the lower gas to liquid ratios.

The use of oxygen as the feed gas can result in oxygen super saturation of the treated water causing operational problems and corrosion in the distribution system. Ozone contacting system options include atmospheric tall towers or pressurized gas to liquid mass transfer processes. Fine bubble diffusers, static mixers, or venturi injectors can be used to mix the gas with the water to be treated in full flow or side stream configurations. Once dissolved in water, ozone is available to act on water contaminants to accomplish its intended purposes of disinfection and/or oxidation. At pH levels of 3-6, ozone is present primarily in its molecular form (O_3). However, as the pH rises, the decomposition of ozone to produce the hydroxyl free radical (HO^-) becomes increasingly rapid. At pH 7 about 50% of the ozone transferred into water produces HO^-. At pH >10, the conversion of molecular O_3 to HO^- is virtually instantaneous.

Because ozone is such a powerful oxidant/disinfectant, the trick to applying it to solve water treatment problems is to do so in a manner that is effective for water treatment, yet at the same safe for the people in the vicinity. Ozone safety issues are handled

easily by using proper ambient ozone monitoring, tank venting, and ozone destruction. In the case of systems driven solely by a pumping/injector system, ozone may be produced under vacuum, which ensures no leakage of ozone into the operating environment.

The five basic components of an ozone system include:

1. Gas preparation–either drying gas to a suitable dew point or using oxygen concentrators
2. A suitable electrical power supply
3. A properly sized ozone generator(s)
4. An ozone contacting system
5. Ozone off-gas destruction or suitable venting system

Moisture in the feed gas causes two operating problems:

1. The amount of ozone produced by application of a given electrical energy level is lowered as relative humidity rises. Consequently, it is usually cost-effective to dry the air to a recommended dew point of minus 65’C (-65’C or -76’F) or lower.
2. Ozone generated using air in the presence of moisture allows small amounts of nitrogen oxides to react with the moisture to produce nitric acid. In this instance, gas condensation at the cooling/heat transfer surfaces produces a corrosive compound which can cause corrosion problems in the ozone generation equipment with concomitant increases in equipment maintenance requirements.

Because of the high oxidative qualities of gas-phase ozone and the chance of moisture from a failing feed gas unit, system managers must take extra care to make certain that all components in the ozone generator, ozone supply line, ozone gas to liquid mass transfer equipment and the contact vessel are ozone-compatible.

For large scale ozone systems, the equipment for cleaning and drying feed gases can become quite complex. For example, effective air drying can involve multiple treatment steps including air filtration, compression, cooling, desiccation, and final filtration prior to passage into an operating corona discharge ozone generator.

A need exists for efficient ozone contacting and destruction of excess ozone in contactor off-gases. Absent an effective ozone off-gas destruct unit, excess ozone would be present for people in the vicinity to breathe, which is not recommended because of its strong oxidizing nature. Additionally, ozone is heavier than ambient air, and can settle in the vicinity, and attack oxidizable materials. Destruction of contactor off-gas ozone is readily accomplished thermally (370’C), catalytically, thermal-catalytically, and by passing the off-gas through granular activated carbon. Care should be exercised in selecting an ozone destruct method whenever very high concentrations of ozone are encountered.

Ozone is a critical process for non-reverse osmosis purification. It is usually coupled with biologic activated carbon filtration. The process reduces TOC and trace chemical pollutants, removes protozoans, kills viruses, and is a flocculation aid. Ozone treatment is an oxidation process used as a disinfection and oxidant prior to biologic activated carbon filtration.

Instrumentation and controls for ensuring effective and safe operation of ozone systems are concerned with applying ozone effectively and affordably. System processes control ozone generation, oxygen usage, drying, ozone injection and diffusing, and ozone destruction.

The instrumentation monitors each step, and each step has an alarm associated with the process.

Key Terms

- **Coagulation –** a process that is followed by sedimentation and filtration will remove 90 to 95-percent of the pathogenic organisms depending on which chemicals are used; alum usage in coagulation can increase virus removals up to 99-percent.
- **Disinfection –** a process that destroys harmful organisms physically or chemically
- **Filtration** – a process through granular filters is an effective means of removing pathogenic and other organisms form water; removal rates vary from 20 to 99-percent, depending on the coarseness of the filter media and the type of effectiveness of pretreatment.
- **Sedimentation** – a process through which pathogenic organisms settle out by gravity, assisted by chemical floc; proper design of sedimentation processes can effectively remove 20 to 70-percent of the pathogenic microorganisms

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5.9.1: Review Questions

Review Questions

1. **List the factors that affect chlorination of drinking water?**
2. **Describe disinfection as a process in drinking water treatment.**
3. **What is the purpose of chloramination in drinking water?**
4. **What is ozonation of drinking water?**
5. **How does UV light effect microorganisms?**
6. **Describe the primary reason that chlorine may not be used for drinking water disinfection at a particular drinking water facility.**

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5.9.2: Chapter Quiz

Chapter Quiz

1. _____ is the process designed to kill or inactivate most microorganisms in water, including essentially all pathogenic (disease-causing) bacteria.

1. Sterilization
2. UV treatment
3. Application of chlorine
4. Disinfection

2. Which of the diseases listed is not caused by a waterborne pathogenic organism?

1. Gastrointestinal anthrax
2. Shigellosis
3. Polio
4. All of these are water borne diseases

3. Hypochlorous Acid and hypochlorite when considered together are also known as the _____.

1. chlorine dose
2. chlorine demand
3. free chlorine
4. chlorine residual

4. _____ is a gas that does not form carcinogenic compounds like those compounds formed by chlorine disinfection. It also is not affected by ammonia, and it is a very effective disinfectant at higher pH levels. It is also used to diminish taste and odor problems in the distribution system. It is especially useful in inhibiting *Legionella*.

1. Chloramination
2. Chlorine dioxide
3.
4.

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5.10: Customer Questions, Complaints, and Investigation

Learning Objectives

After reading this section, you should be able to:

- Outline common customer questions and complaints
- Explain recording keeping
- Explain response process to customer inquiries and complaints

Questions and Issues

Water agencies rely on customer inquiries or complaints for effective monitoring water quality in a distribution system. Most customer questions are regarding secondary or aesthetic concerns:

- Why does my water look this way?
- Why does it taste this way?
- Why does it have this smell?

Many of these questions can be answered without launching a full investigation. But water quality complaints at times may provide an early warning of a more serious water quality incident. As such, well run agencies have established effective customer complaint monitoring and communication programs.

EPA designed a Water Quality Surveillance and Response System, in 2017, which includes a customer complaint component. It was designed for the water resource professional and is flexible and adaptable based on a water utility's goals.[1] It is based on a "Funnel, Filter and Focus" approach whereby utilities can quickly identify which complaints may identify an actual water quality incident.

Water utility customer service departments typically follow this approach:

1. **Collect Data.** (Funnel and Filter) Customer contact is directed to a central location to representatives who are trained to collect and filter information based on the type of complaint, including the customer's contact information, description of the problem, and dates that it started (and ended, if it did).
2. **Investigate.** (Focus) Forward the complaint to the proper department or person for evaluation, if necessary. Then the relevant department should initiate an investigation, consider potential causes, gather additional data from the customer and other sources such as operations records of the plant or distributions system, laboratory, or field testing results on water samples, and distribution system inspection results, such as cross connections and proper valve operation. Water quality staff will determine if the complaint could indicate contamination and take corrective action if necessary.
3. **Communicate.** Keep the customer informed of the results of the complaint investigation. If it is an actual water quality incident, notification rules to the public and other agencies may be required.

Open, positive, and transparent communication with the public cannot be overstated. All utility employees should be provided with training by the water utility they represent. Customer service representatives should be able to respond to billing or meter reading concerns and general water quality complaints related to minor issues such as taste and odor changes when switching from chloramine to free chlorine. All water operators should have the knowledge and basic understanding of all aspects of their source water, distribution system, and treatment plant. They will likely encounter regulators from other agencies in the course of their career.

Social media is a major resource employed by well-run agencies to reach customers, address complaints and manage water quality issues. Social media platforms like "Facebook" and community based "Nextdoor" are presently used by many agencies. The irony is that the public will judge its water supply on secondary standards (cloudy, rust colored, musty smell) and not primary standards. Social media can go a long way towards explaining what is taking place when these nuisance water quality issues arise.



Figure 5.10.1: A water utility customer service department. (Copyright; [1] of SCV Water)

Pin It! Misconception Alert
It's easy to dismiss customer concerns, particularly if they are vocalized loudly or rudely. All complaints should be treated as legitimate.

It is important for customers to know how to communicate complaints to their utility and that all complaints are captured and funneled into one location regardless of how they are received. The near real-time acquisition of this information is invaluable in the event of a real emergency.

Agencies have used their Consumer Confidence Reports to clearly explain how to report water quality issues. They include examples of the type of information the customer should provide (taste, odor, appearance of the water).

Records

Written records should be kept on all facilities in the distribution system. These records should describe the facility, its construction, date installed, repairs and maintenance work completed, manufacture, and condition during the latest inspection.

As new facilities are installed, they should be included in the existing record system. Records should also note those facilities retired from service. Other types of records that should be kept are:

1. Results of water quality monitoring
2. Cross-connection control
3. Main flushing
4. Main cleaning
5. Consumer questions, complaints and conservation programs participated in
6. Disinfection
7. Pressure surveys
8. Leaks
9. Engineering reports
10. Any operations done in compliance with the request of the health department
11. A daily log kept on any and all unusual events occurring, such as equipment malfunction, unusual weather conditions, and natural or manmade disasters.

Each public water system is required by the primary Drinking Water Regulations to maintain records of water quality analyses, written reports, variances or exemptions, and actions taken to correct violations of the regulations.

Complaints

Customer complaints may vary based on geographic region. Within the southwestern United States, complaints about hard water are very common. Customers may complain about the water containing “floating objects,” which are often calcium or magnesium. These are minerals that are naturally occurring in groundwater, but may cause customers to think the water is not safe to drink. It is not common for many customers to utilize water softener services and under sink filtration and reverse osmosis treatment systems.

Many water quality complaints originate within the customers own plumbing system downstream from their retail service connection. There may be low pressure problems or rusty colored water incidents due to the customer’s valves or water lines. It is not uncommon for a utility to dispatch an employee to take a water quality sample at the customer’s residence and report back with the results.

Water utilities will also receive complaints about illnesses in a home due to the drinking water. The customer should also be referred to city or county public health agencies while the utility is performing its own investigation.

Surveys

Most utilities go directly to their customers to find out how the customers feel about the system and its operations. The process is part of an overall plan by utility to self-evaluate and collect customer opinions. Follow-up after a survey with consumers, and develop an improvement program to address the issues that were uncovered in the questionnaire. The questionnaires should be designed to ask questions that a layperson could understand, and it may be advantageous to field test the survey before wide distribution. Problems can be identified, and priorities can be designated as to which problems can be solved soon and which must wait for solutions at some later date. Again, social media can be a valuable platform for this.

When customers or stakeholders complain about an aspect of the drinking water or service, document the complaints. Maintain a data file of all complaints that are received and use it to monitor underlying symptoms of problems that are larger than the immediate issue raised. The data file should be such that it can be searched for any patterns that could surface from the complaints. Importantly, the utility should use the complaints as a tool for early detection of potential problems.

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[1] USEPA, Designing Customer Complaint Surveillance For Water Quality Surveillance and Response Systems https://www.epa.gov/sites/default/files/2018-02/documents/customer_complaint_surveillance_design_guidance.pdf)

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5.10.1: Review Questions

Review Questions

1. **Outline the steps that should be implemented when responding to customer complaints concerning drinking water quality.**
2. **What is a common consumer complaint that is received by the drinking water treatment plant?**
3. **Why should complaint logs and responses to customer complaints be reviewed periodically?**

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5.10.2: Chapter Quiz

Chapter Quiz

1. The _____ of a utility are responsible for customer relations and for positive customer communication.

1. customer service personnel
2. employees (all)
3. public relations officer
4. operators

2. Which of the following is not included in the process of dealing with a consumer complaint?

1. Collect as much information from the consumer as possible
2. Direct the complaint to the proper department or person for evaluation, if necessary
3. Consider different potential causes of the problem and methods of testing
4. Correcting the complaint and having as little public contact as possible is the goal

3. When presented with a complaint, _____ should show concern, listen carefully, and calmly offer to look into the complaint. Help correct any problems that are found within the system and answer questions or obtain answers to questions.

1. customer service personnel
2. employees (all)
3. public relations officer
4. operators

4. Sometimes, it is through _____ that a water utility learns the service being provided is not satisfactory.

1. complaints
2. award applications
3. records
4. surveys

5. A customer may complain about a lack of _____in the home which is typically due to valving problems in the home's plumbing.

1. pressure
2. red water or dirty water
3. illness resulting from drinking water
4. too much chlorine

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6.1: Source Water Quality

Learning Objectives

After reading this chapter you should be able to identify and explain the following:

- The Earth's Hydrologic Cycle
- Sources of groundwater
- Sources of Surface Water
- Water math: Area and Unit Conversions

A very finite amount of water on our planet (0.34%) is available to treat for human consumption. Knowing where the water comes from assists certified operators in treating raw source water to make it potable. Newer technology has been developed to treat salinized or salty water found in the ocean. These treatment methods are still extremely expensive and not widely accessible. Supplying water to the public is an extremely important function in society as water is the basic building block of life. Because water quality is of the utmost importance new regulations and water quality standards are continually changing and evolving to make sure the public has safe sources of drinking water. The first drinking water standards were written in the Safe Drinking Water Act (SDWA), which was signed into law by President Ford in 1974. Throughout the text, new concepts will be introduced and an acronym will be given and used subsequently. You are going to learn to love acronyms if you become a certified operator. We use them quite frequently!

The Hydrologic Cycle

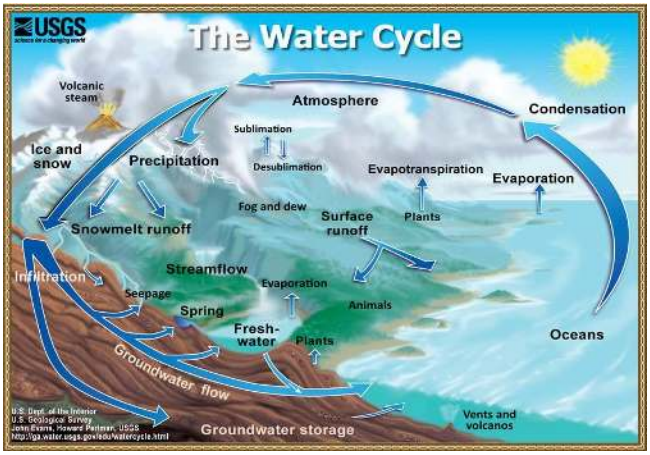


Figure **6.1.1**: The Water Cycle by the USGS is in the public domain

The Hydrologic cycle is the continual movement of water on the surface of the planet. The water moves above, below, and across the Earth's surface as a liquid, gas, or solid. The 12 elements of the hydrologic cycle are defined as follows:

- Evaporation—Water moves in the gas state from the Earth's surface to the atmosphere
- Transpiration—Water moves in the gas state from plants to the atmosphere.
- Advection—Water in the gas state moves through air currents in the atmosphere
- Condensation—Water vapor converts from gas to liquid state in the form of water droplets.
- Precipitation—Water as a liquid and/or solid falls from the atmosphere. We commonly refer to this as rain, snow, sleet, and hail.
- Interception—Water in the liquid state that is captured by plants
- Infiltration—Water in the liquid state that soaks into the surface of the ground. This will be what is known as groundwater which will be detailed later in this chapter.
- Subsurface Flow—Water in the liquid state flows below the Earth's surface. The movement is generated by gravity and obstructions below the surface of the Earth.
- Runoff—Water in the liquid form travels to bodies of water. This would include the ocean, lakes, rivers, and streams. This is also known as surface water which will be detailed more later in this chapter.
- Channel flow—Water in the liquid form that flows from small channels into rivers and streams

- Storage—Water is naturally stored in liquid form in lakes, ponds, wetlands, and groundwater aquifers. In solid form, water is naturally stored in ice, snow, and glaciers. This natural storage provides much of the water treated for human consumption.
- Snowmelt—Water in the solid form converts to water in the liquid form and is returned to the hydrologic cycle. Note: In California, snowpack is a critical water supply indicator as it is the melting snowpack that recharges rivers and the general supply of water

There are other important terms to note in regard to the hydrologic cycle. The surface to atmosphere movement of water is known as evapotranspiration. This is the combination of evaporation and transpiration from plant life to the atmosphere. The most widely known movement of water is precipitation which is when water in various physical states falls from the atmosphere to the surface of the Earth. The movement of water from the surface to subsurface is known as percolation. Percolation might also be referred to as infiltration or recharge. These terms are commonly associated with underground aquifers. Finally, surface to surface flow is called runoff.

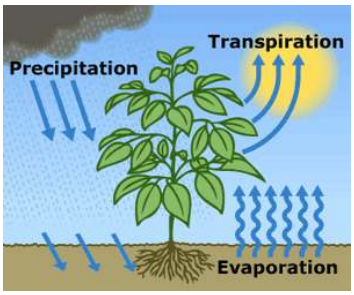


Figure **6.1.2**: Image by the USGS is in the public domain - Evapotranspiration is the sum of evaporation from the land surface plus transpiration from plants. Precipitation is the source of all water

Groundwater

Groundwater is one of the two main sources of storage used by municipalities to produce potable water. It is formed by the **percolation** (infiltration and/or recharge) of water from the surface of the earth to the subsurface. Water moves through holes and cracks in the subsurface and collects in an underground aquifer. An aquifer is a geologic formation that accumulates water due to its porousness. Important characteristics of groundwater include consistent water quality and the ability to remain safe from surface contamination. With greater technology and testing methods chemicals and constituents known to be harmful to humans have been found in numerous well sites throughout the United States. Wells close to industrial areas have been contaminated with harmful chemicals and substances. New regulations are continually being updated to ensure source groundwater is safe to drink. In normal circumstances, very little treatment is required to yield groundwater.

The **Groundwater Treatment Rule** (GWTR) was enacted in 2006 to prevent microbial contamination from underground water supplies. The purpose of the new rule was to classify water systems that were at a greater risk for fecal contamination. These systems must employ a multiple-barrier protection similar to the surface water treatment rule which will be covered in more detail in the next section.

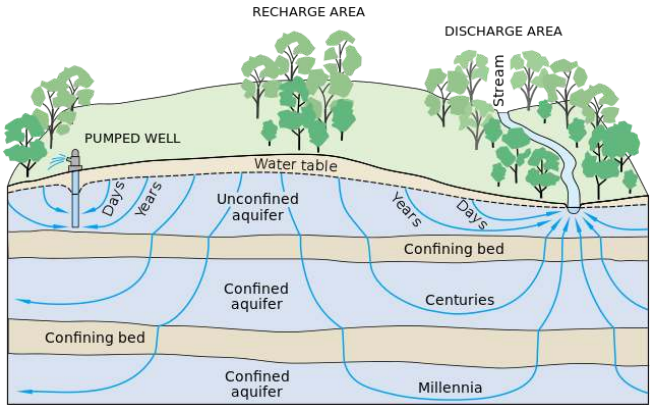


Figure **6.1.3**: Image by the USGS is in the public domain

There are two kinds of aquifers, confined and unconfined. In an unconfined or water table aquifer the water table is free to rise and fall. The water table in unconfined aquifers rise and fall depending on the amount of precipitation that recharges the aquifer. Confined aquifers, also known as artesian wells, contain water that is confined due to layers of low permeability. These layers, which restrict movement, are comprised of rock or hard clay and are referred to as confining beds, aquitards, or aquicludes. Artesian wells are generally under pressure when drilled. Once drilled the water level at which the column of water will rise is known as the piezometric surface. Sometimes, the water will rise to the surface or past the surface but in the instance, the water remains below it is known as a non-flowing artesian well.

Wells

The construction of wells is critical in the extraction of water from underground water supplies. The placement of wells is very important because proper location will produce the greatest yield. Important terms related to underground wells:

- Static Water Level—The level in the well when no water is being removed from the aquifer. This level can be measured in feet or elevation.
- Pumping water level—The level when water is being removed from the aquifer. This level can vary depending on the rate of flow from the well.
- Drawdown—The difference between the pumping water level and the static water level
- Cone of depression—The shape or “cone” created by the movement of water in all directions during pumping.
- Zone of influence—The area of water affected by the drawdown of water during pumping. It is important to note that wells cannot be placed too closely together because their zones of influence may affect each other.
- Well yield—The amount of water drawn from an aquifer over a specific period of time
- Specific capacity—The amount of water produced per drawdown expressed in gpm/ft
- Safe Yield/Perennial yield—The amount of water that can be pulled from an aquifer per year without a drop in the water table
- Overdraft—Too much water removed. Greater than the safe yield of a well
- Subsidence—The permanent drop in the water table due to overdraft

Specific Capacity Calculation

$$\textbf{Specific capacity} = \textbf{Flow (GPM)} \div \textbf{Drawdown (ft)} \tag{6.1.1}$$

Example 6.1.1

A well has a yield of 600gpm and the drawdown is 50 ft. What is the specific capacity of the well?

Solution

This is a direct application of Equation 6.1.1

\[\text{Specific Capacity = 600\, \text{GPM} ÷ 50\, \text{ft} = 12\]

Surface Water

Throughout the United States, surface water is the most widely used source of water for large cities and other municipalities. Groundwater is not as widely available so is not a sufficient water supply for major cities. Surface water includes lakes, ponds, rivers, and streams. California is unique as the southern half of the state has 2/3 of the population but only 1/3 of the available water and the northern half of the state has 1/3 of the population but 2/3 of the water. Snowpack in northern California is critical to the state’s water supply. Most of Southern California is very arid and densely populated so water travels from Northern California through the State Water Project to Southern California.

Surface runoff supplies water for all surface water sources. Influences of surface runoff include intensity of rainfall, duration of rainfall, composition of soil, amount of moisture in soil, slope of the ground, vegetation coverage, and human influences. One would think that a lot of rain would be ideal. However, if the rainfall density is too great, more water can be lost because the ground will no longer absorb the water. The same applies to the duration of rainfall. A prolonged rain even makes the soil too moist and unable to capture water. Vegetation coverage and the slope of the ground are very important to stopping runoff. If the slope of the ground is steep, the speed of runoff is increased. Vegetation slows the speed of runoff and allows more water to absorb or

infiltrate into the ground. Human influences have a great impact on water runoff. Impervious surfaces like concrete entirely prevent infiltration.

Natural Watercourses

Key Terms

Natural water courses include rivers, creeks, streams, washes, and arroyos. They flow in one of three ways:

- Perennial streams—Watercourses which flow continuously throughout the year
  - EX: Colorado River
- Ephemeral streams—Watercourses that flow sporadically, generally after rainfall
  - EX: Santa Clara River which runs through Santa Clarita and Ventura County
- Intermittent—Watercourses which flow somewhere between ephemeral and perennial streams. Rainfall and high groundwater levels will affect how often these streams flow.

Rivers and Streams are a good water supply source but are not necessarily the best source for public water supplies.



Figure **6.1.4**: Image of the Colorado River by Paul Hermans is licensed under CC BY-SA 3.0



Figure **6.1.5**: Santa Clara River Map by Shannon1 is in the public domain

Lakes

Lakes are the most widely used public water supply source. However, very few “natural” lakes exist. Most lakes used for public water supply are man-made and use a dam to create the lake and contain the water. This is known as an impoundment. Water from these lakes is piped to treatment facilities. Due to variances in temperature lakes develop “layers” also known as stratification. Denser, colder water will drop to the bottom (Benthic zone) of a lake during the summer. There are three layers:

- Epilimnion—The strata closest to the surface
- Hypolimnion—The strata near the bottom
- Thermocline—Middle strata with the greatest variance in temperature

Lake turnover will occur during seasonal temperature changes. When the temperature of a lake is uniform it is known as isothermal. Algae growth is a serious problem that causes taste and odor issues in treated water. Copper sulfate can be added to a lake to help remedy algae blooms. In severe cases, the water undergoes eutrophication which is the loss of oxygen. Complete or extreme oxygen depletion can kill all living creatures in the water including animals and fish.



Figure **6.1.6**: Image of Castaic Lake by Rehman is in the public domain

Introduction to Water Math

Mathematics is a key component of water treatment. Operators use conversion tables and basic algebra to complete many daily tasks. Charts are available on the State Water Resources Control Board website that assist operators with most calculations you would find on the state exams or while on the job. Below is a list of basic units and their respective conversion factors:

Table 1.1: Units and Conversion Factors

Measurement	Equivalent
1 cubic foot of water	62.3832lbs
1 gallon of water	8.34lbs
1 liter of water	1,000 grams
1 mg/L	1 part per million (ppm)
1 ug/L	1 part per billion (ppb)
1 mile	5,280 feet
1 yard	3 feet
1 yard3	27ft3
1 acre	43,560 square feet or ft2
1 cubic foot or ft3	7.48 gallons
1 gallon	3.785 Liters or L
1 L	1,000 milliliters (ml)
1 pound	454 grams

Working with Fractions

NumeratorDenominator

44=11 or =1 42=21 or =1

Rounding

Rounding the number 324.179	
3 = Hundreds	The above number (324.179) rounded to the nearest tenth would be 324.2. Since the number in the hundredth place is at or above 5, the number in the tenth place is rounded up. If you were rounding this number to the nearest whole number it would be 323 since the number in the tenth place is below 5.
4 = Tens	
9 = Units	
1 = Tenth	
7 = Hundredth	
9 = Thousandth	

Unit Dimensional Analysis

This is the most important function in most water math problems. Make sure to always place your factors in the proper place or the equation will be impossible to solve correctly. The example below will use unit measurements. Water operators will commonly convert between different units of measurement.

Example 1

Convert 48 inches into feet. (There are 12 inches in a foot.)

48 inches11 foot12 inches=4 ft1

Drop the one from the denominator and the answer is 4 ft.

The same process will be to convert between gallons and cubic feet.

Example 2

Convert 22.44 gallons into cubic ft. or ft3 (There are 7.48 gallons in one cubic foot.)

22.44 gallons11 $ft^3$7.48 gallons=3 $ft^3$1

Drop the 1 from the denominator and your answer is 3 ft^3

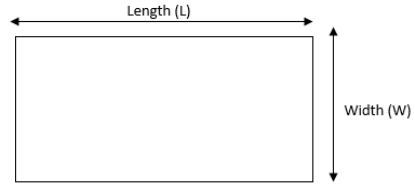
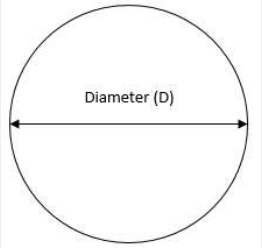
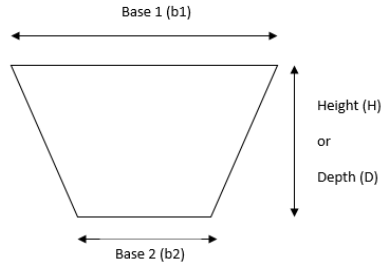
Example 3

How many gallons are there in a tank which holds 300ft^3 of water?

300ft317.48 gal1ft3=2,244 gallons

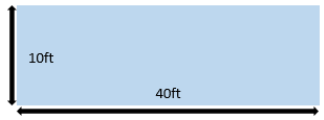
Area

Area will be important for many applications in water math. It may be necessary to calculate the area of a tank that requires painting or an area of ground cover near equipment.

Rectangles  	Area = L × W
Circle  	Area = $0.785 \times D^2$
Trapezoid  	Area = $\frac{b1 + b2}{2} \times H$

Example 1

A wall that is 10ft wide and 40ft in length needs to be painted. What is the total square feet of the wall?

 	Area = Length x Width Area = 10ft x 40ft Area = $400ft^2$

Example 2

What is the area of the top of a circular storage tank that is 100 feet in diameter? (Note: Use the formula .785 x d2. In most cases in water math, we will always be dealing with the diameter and not the radius. These short cuts will help as the problems become more difficult. In this problem I will demonstrate why we will use this formula and not the standard mathematical equation for solving area problems.)

Equation #1 Area= π (3.14) x r^2 (100ft ÷ 2 = 50 to find radius)

Area = 3.14 x 50 x 50

Area = 7,850 ft^2

Equation #2 Area= .785 x d^2

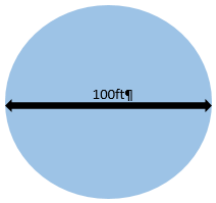
Area = .785 x 100 x 100

Area = 7,850 ft^2

In this example, the first equation was easy to solve because we were working with a pretty friendly number. As the equations become more difficult we do not want to take the extra step to divide the diameter by two to solve for the radius. If the diameter of the tank was 357ft, this problem would have been slightly more difficult using the first equation.

Example 3

The top of a circular storage tank needs to be painted. It is 100 ft. in diameter. Each gallon of paint covers approximately 200 square feet. How many gallons of paint will you need to buy?



Area= .785 x d^2
Area= .785 x 100ft x 100ft
Area= 7,850 ft^2
7850 $ft^2$1x1 gal200 ft^2=39.25 gal

Chapter Review

1. What is the middle layer of a stratified lake called?
    1. Thermocline
    2. Benthic Zone
    3. Epilimnion
    4. Hypolimnion
2. What is the conversion of liquid water to gaseous water known as?
    1. Advection
    2. Condensation
    3. Precipitation
    4. Evaporation
3. Water weighs _____.
    1. 7.48 lbs/gal
    2. 8.34 lbs/gal
    3. 62.4 lbs/ft^3
    4. Both 2 and 3
4. What is the static level of an unconfined aquifer also known as?
    1. Drawdown
    2. Water Table
    3. Pumping Water Level
    4. Aquitard
5. What is the cause of taste and odor problems in raw surface water?
    1. Copper sulfate
    2. Blue-green algae
    3. Oxygen
    4. Lake turnover
6. What chemical reduces blue-green algae growth?
    1. Chlorine
    2. Caustic Soda
    3. Copper Sulfate
    4. Alum

7. A water-bearing geologic formation that accumulates water due to its porousness.
    1. Aquifer
    2. Lake
    3. Aquiclude
    4. Well
8. What kind of stream flows continuously throughout the year?
    1. Ephemeral
    2. Perennial
    3. Intermittent
    4. Stratified
9. The surface to atmosphere movement of water is known as _____.
    1. Precipitation
    2. Percolation
    3. Stratification
    4. Evapotranspiration
10. An aquifer that is underneath a layer of low permeability is known as _____.
    1. Confined aquifer
    2. Water Table aquifer
    3. Unconfined aquifer
    4. Unreachable groundwater
11. What is the middle layer of a stratified lake known as?
    1. Hypolimnion
    2. Benthic Zone
    3. Thermocline
    4. Epilimnion
12. The amount of water that can be pulled from an aquifer without depleting.
    1. Drawdown
    2. Safe yield
    3. Overdraft
    4. Subsidence

Math Questions

Please show all work. On the State exams, you will not get credit if work is not shown.

1. What is the area of the top of a storage tank that is 75 feet in diameter?
    1. 4,000 ft^2
    2. 4416 ft^2
    3. 1104 ft^2
    4. 17,663 ft^2
2. What is the area of a wall 175 ft. in length and 20 ft. wide?
    1. 3,000 ft^2
    2. 2,500 ft^2
    3. 3,500 ft^2
    4. 4,000 ft^2
3. You are tasked with filling an area with rock near some of your equipment. One (1) bag of rock covers 250 square feet. The area that needs rock cover is 400 feet in length and 30 feet wide. How many bags do you need to purchase?
    1. 40 Bags
    2. 42 Bags

3. 45 Bags
4. 48 Bags

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6.2: Water Chemistry and Standards

Learning Objectives

After reading the chapter the student should be able to identify:

- Matter, elements, and compounds
- Public water systems: community and non-community
- Primary and secondary standards
- Water treatment violations
- Volume math problems

Water treatment is a complex process that involves parts that the human eye cannot see. In this chapter, you will learn about the basic scientific principals related to the water treatment. We will also discuss drinking water standards in the United States and different community standards.

Matter, Elements, and Compounds

Matter

The smallest parts of an element are comprised of particles known as atoms. Even though they are so small, atoms still retain the characteristics of the element. Even with technological advancements, microscopes are still unable to capture atoms. The multiple arrangements of atoms make each element unique. The atom ever so small, is comprised of three particles known as the proton, neutron, and electron. Each particle is associated by different charges.

- Proton-positive
- Neutron-no charge
- Electron- Negative charge

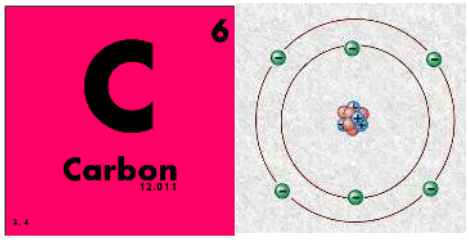


Figure **6.2.1**: (left) Carbon by Science Activism is licensed under CC BY 2.0. Figure **6.2.2**: (right) Carbon atom by Alejandro Porto is licensed under CC BY-SA 3.0

The defining characteristic of an atom is identified by the proton. The proton, located in the nucleus, has a distinctive number. For example, carbon has six protons located in the nucleus. No other element has six protons in the nucleus. The number of protons is represented as the atomic number. The atomic weight is the number of protons and neutrons. The number of protons that exist for a given element is always the same, but the number of neutrons can vary. When there is a varying number of neutrons of a given element, it is known as an isotope. When an atom has a difference in electrons, it is called an ion. When the charges of the atom are not balanced, they become unstable. An atom that has more protons than neutrons is called a cation. An atom that has more electrons than protons is called an anion.

Most common elements in the water treatment profession:

- Aluminum (Al)
- Antimony (Sb)
- Arsenic (As)
- Barium (Ba)
- Beryllium (Be)
- Boron (B)
- Bromine (Br)

- Cadmium (Cd)
- Calcium (Ca)
- Carbon (C)
- Chlorine (Cl)
- Chromium (Cr)
- Copper (Cu)
- Fluorine (F)
- Hydrogen (H)
- Iodine (I)
- Iron (I)
- Lead (Pb)
- Magnesium (Mg)
- Manganese (Mn)
- Mercury (Mn)
- Nickel (Ni)
- Nitrogen (N)
- Oxygen (O)
- Phosphorus (P)
- Potassium (K)
- Radium (Ra)
- Selenium (Se)
- Silicon (Si)
- Silver (Ag)
- Sodium (Na)
- Strontium (Sr)
- Sulfur (S)
- Thallium (Tl)

There are elements that are pure in form, such as oxygen. Since elements are unstable, they often combine with other elements to form compounds. Water (H_2O), for example, is a compound. It is a combination of two hydrogen atoms and one oxygen atom. A compound is two or more elements that are bonded together due to their attraction by reverse charges. The combining elements form a molecule. When two chemicals are mixed together without a chemical reaction it is called a mixture. The difference between a mixture and a compound is bonded together by a chemical reaction. A good example of a mixture is saltwater. The salt can be removed from the water through distillation. Water chemistry will be covered in greater detail in the Water Quality text and course.

Drinking Water Standards

The first drinking water standards created in the United States occurred in 1974 and were called the Safe Drinking Water Act (SDWA). The US EPA sets drinking Water Standards that all Water Municipalities must adhere to. Although States are able to come up with their own Standards, they must meet the minimum requirements set forth by the federal EPA. In California, drinking water standards are much more stringent than the federal requirements and therefore have primacy. As of 2014, the State regulatory group responsible for drinking water is the State Water Resources Control Board. Revisions to the safe drinking water act include approval techniques for treatment plants, specifying criteria for filtration of public water supplies, distinguishing different treatment techniques for surface and groundwater, and prohibiting lead products in drinking water systems. There are two sets of drinking water Standards identified as primary standards and secondary standards. Primary Standards affect human health and are mandated with **Maximum Contaminant Levels** (MCL). The MCL is the official safe level at which a human can consume the given contaminant without adverse health effects. Secondary Standards do not affect human health and are controlled with **Maximum Contaminant Level Goals** (MCLG). When a contaminant is reported, there is no such thing as zero. Levels are set to protect human health but are also set based on the best available technology. As technology improves MCL's may be reexamined.

Instrumentation to measure contaminant levels are not always capable of reading to absolute zero. Because of this, a Detection level for reporting is required.

Public Water Systems

There are three different categories of public water systems:

- Community Public Water System: A community public water system has 15 or more service connections and serves at least 25 or more people year-round. These would include municipalities, mobile home parks, condos, and apartment buildings.
- Nontransient, NonCommunity System: A nontransient, NonCommunity public water system owns its own system and serves an average of 25 people for at least six months. Schools, hospitals, and office buildings are included in this category.
- Transient, NonCommunity System: A transient, NonCommunity public water system owns their own water system and serves an average of 25 people per day. In this category people consume the water for a short period of time. This category includes churches, parks, restaurants, and motels.

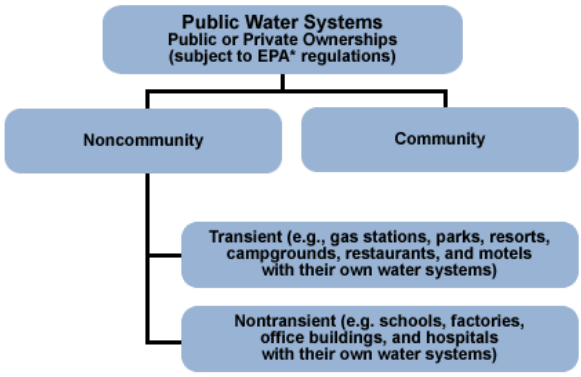


Figure **6.2.2**: Image by the CDC is in the public domain

Primary Drinking Water Standards are split into five categories. The categories include Inorganics, Organics, Turbidity, Microbiological, and Radiological.

- Inorganics: Metals, Nitrate, and Fluoride
- Organics: Pesticides, solvents, and Disinfectant byproducts (DBP's)—The combination of Chlorine and natural organic material. This topic will be discussed in greater detail later in the text.
- Turbidity: The cloudiness of the water. Turbidity has the ability to shield microbiological material.
- Microbiological: Coliform testing (This will be covered in greater detail later in the text. Water operators do not test for specific microbiological agents. We test for the indicator organism coliform. They colonize in greater numbers so if a sample comes back positive there is a greater likelihood of fecal contamination.)
- Radiological: Gross alpha, beta, and radon

Secondary drinking water standards are solely based on the aesthetic quality of drinking water. The main focus of secondary standards is taste, odor, and color. A glass of water that smells like fish and is orange in color may be "safe" to drink but wouldn't be well received or readily consumed. California, as well as some other states, has endorsable secondary standards.

Table 2.1: Recommended Levels for Contaminants and Characteristics

Contaminant/characteristic	Recommended level
Aluminum	0.05 to 0.2 mg/L
Chloride	250 mg/L
Color	15 color units
Copper	1 mg/L
Corrosivity	Non-corrosive
Fluoride	2 mg/L
Foaming agents	0.5 mg/L
Iron	0.3 mg/L
Manganese	0.05 mg/L
Odor	3 threshold odor number
pH	6.5 to 8.5
Silver	0.10 mg/L
Sulfate	250 mg/L
Total dissolved solids	500 mg/L
Zinc	5 mg/L

Source: Graph by the EPA is in the public domain

Public Notification

In the event that a treatment plant does not meet requirements of the SDWA, the public must be notified. There are three different tiers of notification with tier I being the worst of violations and tier III being the least. The EPA provides very specific language for public notifications in the event of a violation. Violating a SDWA compliance is bad enough, but failing to report violations brings even stiffer penalties and fines. In 2014 in Flint Michigan 15 people were criminally charged due to their negligence in the water treatment profession. It all started when the city of Flint changed their source water without properly testing. Officials knew the water was not safe to drink and numerous violations had been made. The public was not properly informed of these violations which resulted in 10 deaths and 77 others becoming severely ill. It is something that is rarely discussed because people in industrialized countries never really worry about the quality of their drinking water. The most important thing you can do as an operator is say something if there appears to be a problem with the quality of the drinking water. Otherwise, you may end up in jail. Notification options include radio or television announcements, newspapers, hand delivery, posting in public places, loudspeakers, texting, and reverse 911. The notification will vary based on the severity of the violation.

Violations

Tier I

- Any positive fecal coliform positive test and failure to sample after an initial positive test
- Nitrate or Nitrite violation
- Chlorine Dioxide Maximum residual disinfection limit
- Exceed treatment plants allowable turbidity level. Can be a tier II if the primacy agency does not elevate violation.
- Waterborne emergency or outbreak of waterborne illness

Tier II

- MCL, MRDL and, Treatment Technique (TT) violations if treatment plant does not perform corrective actions to fix issues in treatment plant or fails to inform public.
- Water quality monitoring violation—not taking required water quality samples. Can also be a tier III violation but can be elevated for gross negligence
- Noncompliance of a variance or an exemption

Tier III

- Water testing and monitoring violation
- Any time the treatment system is running under a variance or exception. Primacy agency may give a treatment plant a variance or exemption for a short period of time. The public notification is to inform the public that a water agency is not running in accordance with an approved treatment technique. It doesn't mean the water is unsafe to drink, but the operating manuals are very specific.

Water Quality monitoring

Continuous monitoring of drinking water ensures quality; reliable drinking water is being delivered to the public. The number of samples taken, frequency of sampling, sampling location, testing procedures, and requirements for record-keeping are all specified by state and federal requirements. If sampling requirements are not met, it can lead to public notification. The tier violation is based on the contaminant and whether or not the contaminant causes acute health effects.

The type of monitoring is based on the source of the water, the treatment technique, and the size of the system. Reporting and record keeping is based on the primacy agency's regulations. The state regulations must meet federal requirements at a minimum but may be more stringent as is the case in California.

Record Keeping

Below is a list of records that must be kept and the amount of time the records must be retained on file.

- Bacteriological and Turbidity—5 years
- Chemical analysis—10 years
- Corrective actions from violations—3 years
- Sanitary surveys—10 years
- Exemptions—5 years after expiration

Variances and Exemptions

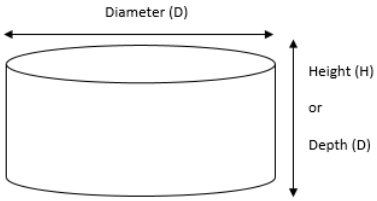
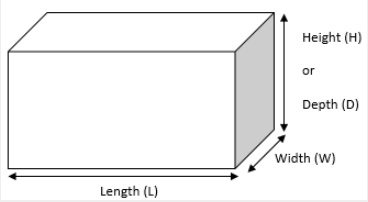
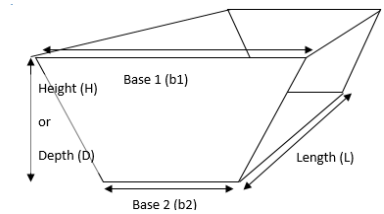
In the event a water system is unable to meet a MCL because of the source water, a primacy agency can grant a variance or exemption. The variance is only given when the agency has incorporated the best available technology and there is zero risk to public health. In the case of Flint Michigan, the new source water was not properly tested before it was used in the system. Flint Water plant was unable to properly treat the source water which had elevated levels of lead and the City was not using the best available technology. Even if the City of Flint would have applied for a variance or exemption, it would not have been granted because the lead levels in the water create a significant risk to public health.

In future chapters of the text, we will examine regulations added to the SDWA. Several changes and enhancements have been made since the exception of the original legislation. We will discuss in greater detail the Total Coliform Rule, Surface Treatment Water Rule, Long Term 2 Enhanced Surface Water Treatment Rule, Lead and Copper Rule, Ground Water Rule, and Stage 1 &2 Disinfectant Bi-Product Rule.

Volume

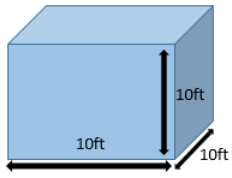
Volume calculations will become very common for water treatment operators. Operators use volume calculations to solve math questions with circles, triangles, and rectangles. If you look around a water treatment facility, it is full of geometric shapes. Tanks

can be cylindrical or rectangular in nature. Settling ponds may have a triangular nature to them. The basic volume questions will become more involved later on in the text as you may have to solve a volume question first, and then solve a flow-related question.

Cylinder  	Volume = 0.785 × D2 × H
Rectangle  	Volume = L × W × H
Trapezoid  	Volume = $\frac{b1 + b2}{2}$ × H × L

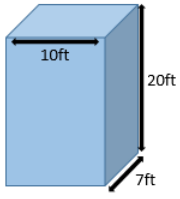
Example 6.2.1

What is the volume of a cubed tank that is 10 feet high? (Remember cubes have the same unit of length on all three sides. This is the easiest problem to solve.)

 	Volume = Length × Width × Height Volume (ft^3) = 10ft × 10ft × 10ft Answer is 1,000 ft^3

Example 6.2.1

What is the volume of a rectangular tank that is 20 ft. high, 10 ft wide, and 7ft in length?

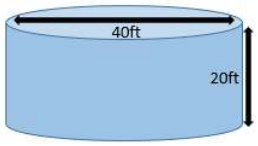
 	Volume= Length × Width × Height Volume= 7ft × 10ft × 20ft Answer is 1,400ft^3

There are two different ways to solve cylindrical math problems. The easiest formula to use is volume= .785 d^2 H. This formula is easiest because in water math we are generally looking at the diameter of a cylindrical shape and not the radius. The

radius of a circle is half the diameter. It is a straight line measured from the center of the circle to the edge of the circle. The diameter is a straight line that passes through the center of the circle with endpoints on the circle.

Example 6.2.2

What is the volume of a storage tank that measures 40 ft. in diameter and is 20 ft. deep?



Volume= .785 × d^2 × H
Volume= .785× 40ft × 40ft × 20ft
Answer is 25,120ft^3

Often the water math word problems will require multiple steps to solve. Typically, we want to know how many gallons a given tank will hold. Once we find the volume of the tank in cubic feet, we will then convert the cubic feet into gallons.

Example 6.2.3

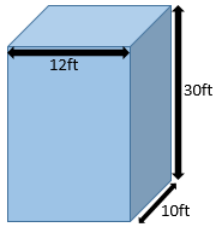
Convert the answer from Example **6.2.3** into gallons.

25,120 ft^3 x 17.48 gal x 1 ft^3 = 187,898 gal x 1

Answer: 187,898 gallons

Example 6.2.4

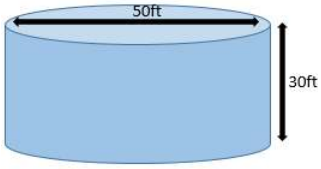
A rectangular water tank is full. The dimensions are 30ft high 12ft wide and a length of 10 ft. Convert to gallons.



Volume= 10ft x 12ft x 30 ft
Volume= 3,600ft^3
3,600 ft^3 x 17.48 gal x 1 ft^3 = 26,928 gal x 1
Answer: 26,928 gallons

Example 6.2.5

A cylindrical storage tank has a diameter of 50ft and a height of 30ft. The tank is half full. How many gallons are in the tank?



Volume= .785 x 50ft x 50ft x 15ft
Volume= 29,437.5 rounded to 29,438ft^3
29,438 ft^3 x 17.48 gal x 1 ft^3 = 220,196 gal x 1
Answer: 220,196 gallons

Chapter Review

1. The smallest part of an element is known as _____.
    1. Proton
    2. Neutron
    3. Atom
    4. Nucleus

2. The atomic weight is comprised of _____.
    1. Neutrons and electrons
    2. Protons and neutrons
    3. Nucleus and neutrons
    4. Atom and nucleus
3. An atom with a negative charge is known as _____.
    1. Proton
    2. Neutron
    3. Nucleus
    4. Electron
4. What does the symbol mg/L stand for?
    1. Micrograms per liter
    2. Milligrams per/L
    3. parts per million
    4. Both 2 and 3
5. What does the acronym MCL stand for?
    1. Minimum contaminant level
    2. Micron contaminant level
    3. Maximum contaminant Level
    4. Milligrams counted last
6. How long do sanitary surveys have to be retained for records?
    1. 3 years
    2. 5 years
    3. 7 years
    4. 10 years
7. The most severe water system violation that requires the fastest public notification is _____.
    1. Tier I
    2. Tier II
    3. Tier III
    4. Tier IV
8. The primacy agency may grant a variance or exemption as long as _____.
    1. The agency is using the Best Available Technology
    2. There is no threat to public health
    3. There is never a scenario for a variance or exemption
    4. Both 1 and 2
9. A public water system that serves at least 25 people six months out of the year is known as _____.
    1. Nontransient noncommunity
    2. Transient noncommunity
    3. Community public water system
    4. None of the above
10. Regulations based on the aesthetic quality of drinking water are known as _____.
    1. Primary Standards
    2. Secondary Standards
    3. Microbiological Standards
    4. Radiological Standards
11. The lowest reportable limit for a water sample is _____.

1. 0.5 mg/L
2. Zero
3. Public health goal
4. Detection Level for reporting

12. Primary Standards are based on _____

    1. Color and Taste
    2. Aesthetic quality
    3. Public Health
    4. Odor

13. A circular clearwell is 150 feet in diameter and 40 feet tall. The Clearwell has an overflow at 35 feet. What is the maximum amount of water the clearwell can hold in Million gallons rounded to the nearest hundredth?

    1. MG
    2. 4.62 MG
    3. 18.50 MG
    4. 7.50 MG

14. A sedimentation basin is 400 feet length, 50 feet in width, and 15 feet deep. What is the volume expressed in cubic feet?

    1. 100,000 ft^3
    2. 200,000 ft^3
    3. 300,000 ft^3
    4. 400,000 ft^3

15. A clearwell holds 314,000 ft^3 of water. It is 100 ft in diameter. What is the height of the clearwell?

    1. 25 ft
    2. 30 ft
    3. 35 ft
    4. 40 ft

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6.3: Microorganisms

The most important job of a Water Treatment Operator is providing reliable and quality water to the public. This is accomplished through chemical deactivation or physical removal of disease-causing microorganisms in the water. Microorganisms are deactivated by the addition of a chemical such as Chlorine or Ozone while physical removal is accomplished with the use of a filtration system.

Surface Water Treatment Rule

The **Surface Water Treatment Rule** (SWTR) was created in 1990 to further protect the public from waterborne illness. The specific diseases the SWTR seeks to prevent are those caused by viruses, legionella, and *Giardia* lamblia. Disease-causing microorganisms are also known as pathogens. The microbes that cause most waterborne illnesses are found in most surface water in the United States. Every public agency that uses surface water as source water must adhere to the SWTR. Surface Water is defined as any open body of water that is susceptible to surface runoff. Rainfall and snowmelt that enter open bodies of water such as lakes, rivers, and man-made reservoirs are susceptible to contamination from sewage treatment plants and animal feces.

At this time there are no simple inexpensive tests for viruses, legionella, and *Giardia* lamblia; therefore, other protective measures are used to test the source water and treated water. Water regulations provide detailed inactivation and removal regulations for Protozoa, also known as *Giardia*, and viruses. Bacteria fall somewhere in the middle of both microorganisms so there is no need to "regulate" them. Bacteria will be removed and/or deactivated within the parameters or regulations that are in place. *Giardia* and *Cryptosporidium* form hard cysts that are very difficult to deactivate chemically with Chlorine. They are larger than viruses so they or more easily removed through filtration. Newer technological advances such as ozone addition are excellent ways to deactivate *Giardia*.

Treatment plants must use a combination of disinfectant (chemical deactivation) and filtration and must achieve 99.9% removal or inactivation of *Giardia* cysts and 99.99% of viruses. You might also see the percentages expressed as 3 Log and 4 Log. 99.9% will be expressed as 3 Log and 99.99% will be expressed as 4 Log. Treatment plants, which use filtration, achieve their removal factor by monitoring the combined filter effluent turbidity. Turbidity is the measurement of the cloudiness in water. The reason it is important to measure turbidity is because microorganisms can hide behind the very small particles and render treatment techniques ineffective. Turbidity readings are expressed as nephelometric turbidity units (NTU). Most surface source water will not meet standards that would enable a treatment plant to refrain from using approved filtration techniques. The approved treatment techniques currently used by water operators are conventional treatment, direct filtration, slow sand, diatomaceous earth, reverse osmosis, and alternate treatment technologies approved on a case by case basis by the primacy regulating board. Newer technologies such as membrane filtration and UV treatment are being employed by some water agencies.

Table 3.1: Waterborne Pathogens

Bacteria	Viruses	Protozoa
• Campylobacter • Escherichia coli (E-coli) • Salmonella • Yersinia • Vibrio • Legionella • Aermmonas • Mycobacterium • Shigella • Pseudomonas	• Hepatitis A • Reovirus • Calicivirus • Enterovirus • Coxsackievirus • Adenovirus • Echovirus • Poliovirus	• *Giardia Lamblia* • *Cryptosporidium* • Entameoba • *Microsporidium*

A continuous disinfectant residual must always be in the distribution system to prevent waterborne illness. A disinfectant residual of .2 mg/L must be present at all times in the distribution system, however, most water operators will maintain somewhere between 2.5 mg/L-3.0 mg/L. The CT calculation is used to make sure proper disinfectant levels are being used during the treatment and distribution process. The effectiveness of the treatment process is calculated with the CT formula and uses data such as disinfectant

used, residual of disinfectant, length of time disinfectant is in contact with water, water temperature, and pH of the water. It is important to note that during the treatment process the goal is to disinfect the water (kill all pathogens) and not to sterilize (kill all organisms).

The “C” is the concentration of disinfectant while the “T” is the amount of time the disinfectant is in contact with water. On days with higher effluent plant rates, an operator may need to raise chlorine doses as the disinfectant will be in contact with the water for less time. Conversely, if plant flow rates are lower, a lower chlorine dose can be used because the disinfectant is in contact with the water for a greater time.

Case Study: Milwaukee April 1993

In April of 1993, the largest outbreak of *Cryptosporidium* on record occurred in Milwaukee, Wisconsin. Over 400,000 people reported illness and 100 people died. All of the people who died after drinking the tainted water had the AIDS virus. It can’t be for certain that the *Cryptosporidium* was the cause of each of their deaths, but as will be discussed later in this chapter, people with weakened immune systems are much more susceptible to death if they drink tainted water.

The Milwaukee incident was the catalyst for enhancements to the SWTR. Since *Cryptosporidium* creates cysts and is not killed by chlorine, the “double barrier” treatment approach was created. Treatment plants were then required to monitor turbidity effluent levels and use alternative treatment techniques, such as ozone or ultraviolet light, that would deactivate the *Cryptosporidium*. An effective filtration plant using coagulation, flocculation, sedimentation, and filtration, should have been able to handle the outbreak, thus turbidity levels were not within standards.

The source of the *Cryptosporidium* was believed to be a sewage spill that was very close to the intake of the Southern Milwaukee treatment plant where the outbreak occurred. Others believe that the operators of the treatment plant were using higher quantities of waste stream water in the treatment process. Recycling washed filter water is a common practice, but after this event, it was established that only 10% of the sourced raw water can come from the wastewater.

The lesson everybody learned here is water quality is ever-changing and evolving. Mother Nature throws curveballs at us that change the quality of the source water. If something is wrong, it is your duty as an operator to say something. Regulations are all well and good but if they are not being followed, people can become very ill or possibly even die.

Total Coliform Rule

The **total coliform rule** was published in 1989 and was revised in 2014. It set up minimum requirements for the frequency and amount of coliform tests that would be taken by water agencies. As discussed earlier, the coliform bacteria exist in larger quantities than other bacteria. If there is a positive coliform test, there is a greater chance the treatment process is not functioning properly and there is an increased chance of pathogens in the water. Bacterial outbreaks in water cause gastroenteritis with the associated symptoms of nausea, diarrhea, vomiting, and cramps. Very young people, elderly, and people with weakened immune systems are at an even greater danger should there be waterborne illnesses in water. Each water agency is required to have an approved sampling site map approved by the primacy agency.

The Total Coliform Rule goal is zero positive coliform samples. Water systems that take less than 40 samples per month are only allowed one positive sample while systems that take greater than 40 samples must not find positive results in more than 5% of the coliform samples taken. If a positive coliform sample is found, it is not necessarily an indicator of a problem. Human sampling error could be the culprit. Once a positive is found the coliform sample is retaken within 24 hours at the positive sampling site and two additional samples are taken, one upstream and one downstream of the initial positive site. If there is a second positive coliform result, the water is then tested for E-Coli. If E-Coli is present in the sample, it is an immediate public health risk and is deemed an acute MCL violation. This would be considered a Tier I violation and public notification would have to occur within 24 hours.

Long-Term 1 Enhanced Surface Water Treatment Rule

The Long-Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR) applies to water systems that serve less than 10,000 people. Below is a list of requirements for water agencies that fall under this category:

- Must achieve 99% or 2 log removal of *Cryptosporidium*

- Most systems are required to meet turbidity standards of 0.5 NTU from 95% of combined filter effluent turbidity readings. Smaller systems will get 2 log removal credit of *Giardia* with a stricter .03 NTU combined filter effluent.
- Monitoring of individual filter is required. Higher turbidity reading from individual filters will require corrective action.
- Some states might require a disinfectant byproduct profile
- Any change in primary disinfectant must be profiled and approved
- All treated water clearwells must be covered and not open to atmosphere

Long-Term 2 Enhanced Surface Water Treatment Rule

The Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) covers all water systems which serve more than 10,000 customers.

- This rule added enhancements to the SWTR. Water providers are required to test the source raw water for *Cryptosporidium* and E-coli for a 2 year period. This step was put in to ensure all treatment plant equipment was capable of properly deactivating and removing pathogens from water.
- After testing, systems were given a bin number which determined how susceptible the system was to contamination.
- If systems were susceptible, a time frame was given to correct deficiencies
- Continuous monitoring of the distribution system influent and maintaining at least .02 mg/L chlorine residual is required

Filter Back Wash Recycling Rule

As noted in the Milwaukee case study, water systems are able to use recycled wastewater as a raw water source. Many treatment plants utilize waste ponds, waste lagoons, and waste basins to capture recycled wash water and water from drains throughout treatment plant. In order for plants to use the recycled water, plants must put the wastewater through the same treatment process as raw untreated water. The amount of water that can be returned is based on the plants size and maximum plant flows.

Lead and Copper Rule

The lead and copper rule differs from most other water guidelines because these two constituents are usually found in water after it has gone through the treatment cycle. Most raw water has very low levels of lead and copper. Lead and copper are found in drinking water after a chemical reaction takes place in distribution pipes. Water that is more acidic can erode lead and copper pipes causing them to leach into water. The use of lead pipes in drinking water systems was banned in 1986 and they can no longer be used. Lead is known to cause several health problems in fetuses and young children. It can cause developmental problems. Lead can also have effects on the kidney, brain, red blood cells, and is known to cause anemia.

With optimal corrosion control, the ability of water to chemically react with lead and copper pipes is lowered. Many treatment plants add chemicals such as caustic soda to raise the pH of the water. Treated water with a pH around 8 will keep a thin layer of calcium on the inside of a distribution pipe which protects the pipe from corrosion. Corrosion control is tested by monitoring the conductivity, testing pH of water, water temperature, testing for calcium, testing for alkalinity, and testing for phosphate or silica corrosion inhibiter if used to control corrosion.

The Lead and Copper rule also differs from other rules because it bases its parameters on action levels. If 10 percent of the customers' water tests in the 90th percentile of the action level for lead and copper, then further preventative actions must be met. Most customers do not have to worry about this due to advances in corrosion control in the past few decades.



Figure **6.3.1**: Image of lead pipes by Borsi112 is licensed under CC BY-SA 3.0

Stage 1 and 2 Disinfectant Bi-Product Rule

When natural organic matter mixes with chemical disinfectants, it is possible for disinfectant byproduct formation (DBP). Chemical disinfectants used in water treatment that form DBP's are chlorine, chlorine dioxide, chloramines, and ozone. The Stage 1 disinfectant byproduct rule established MCL's for trihalomethane (TTHM), haloacitic acid (HAA5), chlorite, and bromate. Compliance is set up on a running annual average for TTHM, HAA5, and Bromate and on a monthly average for chlorite. The rule also set up maximum disinfection levels for chlorine, chloramines, and chlorine dioxide.

The Stage 2 disinfectant byproduct rule applies to all community and nontransient noncommunity water systems that add a chemical disinfectant or purchase treated water that has a chemical disinfectant. The purpose of the Stage 2 rule is to monitor local sampling of individual connections. Some parts of the water system have less movement, therefore they are more susceptible to DBP formation. The Stage 2 rule covers TTHM and HAA5 and has the same MCL as the Stage 1 rule. See the chart below:

Disinfectant Residual	MRDL* as mg/L	Compliance Based On
Chlorine	4.0 mg/L	Running annual average RAA
Chloramines	4.0 mg/L	Running annual average RAA
Chlorine Dioxide	0.8 mg/L	Daily samples

*Maximum residual disinfectant level

Disinfection Byproduct	Maximum Contaminant Level	Compliance Based On
Trihalomethane	.080 mg/L (80 ppb)	Running annual average
Haloacetic acid	.060 mg/L (60 ppb)	Running annual average
bromate	.010 mg/L (10 ppb)	Running annual average
chlorite	1.0 mg/L (1 ppm)	Monthly average

*ppb- parts per billion ppm- parts per million

Consumer Confidence Reports

The public has a right to know what is in their drinking water. As you continue to read through the text you will notice that a lot of the terminology is quite a mouthful. In 1998 consumer confidence reports were made available to the public for transparency. Eight groups of information were added to the report:

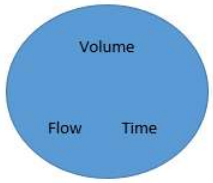
- System information including contact info
- Different sources of water (i.e. lakes, wells, rivers)
- Definitions non-water personnel can understand including MCL's, MCLG's and treatment techniques
- Any detected contaminants in the system along with a listing of the possible health effects if limits and goals are not met

- Non-regulated contaminants found
- List of violations if they occurred
- Variances and exemptions
- Educational tools for contaminants and affected populations

The internet has made it possible for water treatment facilities to post information monthly on company websites; however, a consumer confidence report will be mailed/electronically delivered to its customers on a yearly basis.

Flow Rate Calculation

The flow rate calculation will be one of the most frequently used in water math. This calculation tells us a lot about what is going on in our water system. Common flow rates you will see are Gallons per Minute (GPM), Cubic Feet Per Second (CFS), Million Gallons a Day (MGD), and Acre Feet per Year (AFY). Water operators use flow rates for different purposes. If you were running a small treatment plant, you might use GPM or CFS in your day to day operations but when looking at water produced throughout the entire month or year, calculating in Acre Feet may be more appropriate. Like any algebraic formula, there will be an unknown factor you are solving for. In the case of a flow question, there will be 3 values, two known and one unknown.

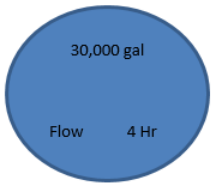


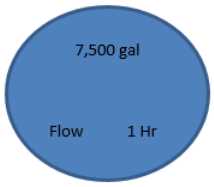
Flow Rate Equation
Flow Rate = Volume ÷ Time
The algebraic "Wheel" is a very effective way to solve many water math problems. Those students with more "mechanical" minds may find this way of solving math problems easier. Below is an example of how to solve a flow rate equation with both methods.

Example 1

In 4 hours, a water tank's volume increases by 30,000 gallons. What was the flow rate of the water entering the tank? Express in gallons per minute.

Flow Rate = Volume/Time
Flow Rate = 30,000 gallons/4 hours
7,500 gallons/1 hour
7,500 gallons/1 hour = 1 hour/60 min
= 125 gallons/minute





We can also use the Flow Rate calculation to solve for volume or time.

Example 2 - Solve for Time

How long will it take to drain a 100,000-gallon storage tank where the water is exiting at 2,500 Gallons per minute?

Time = 100,000 gal/2,500 GPM = 40 minutes

Always put the unknown in the left part of the formula so your factors cancel out properly.

Example 3 - Solve for Volume

Your water tank pump is set to run for 90 minutes. Your pump output is 3,000 GPM. How many gallons of water will enter the tank?

Volume = 3,000 GPM x 90 min

Volume = 270,000 gallons

Example 4

A water tank's full capacity is 500,000 gallons. The operator will bring the tank down to half full in an 8-hour period. What is the flow rate of the water exiting the tank?

(Note: The state gets very creative with their test questions. Remember to read the question multiple times before solving it. Don't be the test taker that uses 500,000 gallons in the equation instead of 250,000 gallons!)

Flow Rate = 250,000 gallons/8 hours

Flow Rate = 31,250 gallons/1 hour

31,250 gal/1 hour = 1 hour/60 min = 520.83 GPM

Chapter Review

1. A disease-causing microorganism:
    1. Pathogen
    2. Colilert
    3. Pathological
    4. Turbidity
2. According to the Surface Water Treatment Rule, what is the combined inactivation and removal for *Giardia*?
    1. 1.0 Logs
    2. 2.0 Logs
    3. 3.0 Logs
    4. 4.0 Logs
3. What is the equivalency expressed as a percentage for the SWTR inactivation and removal of viruses?
    1. 99.9%
    2. 99.99%
    3. 99.0%
    4. 99.999%
4. A water agency that takes more than 40 coliform samples must fall under what percentile?
    1. 10%
    2. 7%
    3. 5%
    4. No positive samples allowable
5. The multiple barrier treatment approach includes _____.
    1. Sterilization and filtration
    2. Disinfection and filtration
    3. Disinfection and sterilization
    4. Infection and filtration
6. The maximum disinfectant residual allowed for chlorine in a water system is _____.
    1. .02 mg/L
    2. 2.0 mg/L
    3. 3.0 mg/L
    4. 4.0 mg/L
7. How do water agencies monitor the effectiveness of their filtration process?
    1. Alkalinity
    2. Conductivity
    3. Turbidity
    4. pH
8. What is the disinfectant byproduct caused by ozonation?
    1. Trihalomethanes
    2. Bromate
    3. Chlorite

4. No DBP formation

9. Haloacitic Acids are also known as _____.
    1. TTHM
    2. HOCL
    3. Chlorite
    4. HAA5
10. What is the MCL for trihalomethanes?
    1. .10 mg/L
    2. .06 mg/L
    3. .08 mg/L
    4. .12 mg/L
11. What is the MCL for Haloacitic Acids?
    1. 100 ppb
    2. 60 ppb
    3. 80 ppb
    4. 120 ppb
12. What is the MCL for bromate?
    1. .010 mg/L
    2. .020 mg/L
    3. .030 mg/L
    4. .040 mg/L
13. A treatment plant operator must fill a clearwell with 10,000 ft3 of water in 90 minutes. What is the rate of flow expressed in GPM?
    1. 111 GPM
    2. 831 GPM
    3. 181 GPM
    4. 900 GPM
14. A water tank has a capacity of 6MG. It is currently half full. It will take 6 hours to fill. What is the flow rate of the pump?
    1. 3,333 GPM
    2. 6,333 GPM
    3. 8,333 GPM
    4. 16,666 GPM
15. A clearwell with a capacity of 2.5 MG is being filled after a maintenance period. The flow rate is 2,500 GPM. The operator begins filling at 7 AM. At what time will the clearwell be full?
    1. 10:00 PM
    2. 10:40 PM
    3. 11:00 PM
    4. 11:40 PM

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6.4: Coagulation and Flocculation

Learning Objectives

After reading this chapter you should be able to identify and explain the following:

- Coagulant types
- Coagulation chemistry
- Mixing systems for both coagulation and flocculation
- Flocculation process theory
- Pounds formula

One of the most important steps in the water treatment process is the removal of suspended solids. The two-part process in water treatment involves chemical deactivation and physical removal of pathogenic organisms. The physical removal of pathogens is accomplished in several steps. The first two steps include the processes of **coagulation** and **flocculation**. In this process, colloidal particles are destabilized to gather all the suspended material together. They can also be referred to as **nonstable solids**. This process increases particle sizes which assists in removal during the filter process. The larger floc particles will be removed during the sedimentation and filtration process. Coagulation occurs very quickly in the rapid mix or flash mix process. The flash mix process only lasts several seconds as the coagulant rapidly mixes and reacts with the raw untreated water. The floc will gain in size during the second step of flocculation. Filtration cannot occur without proper coagulation and flocculation.

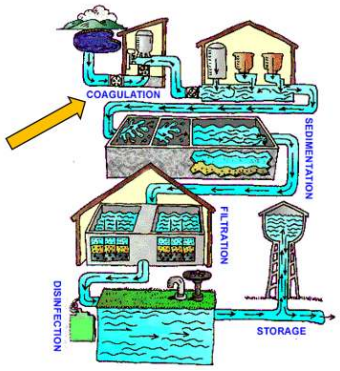


Figure **6.4.1**: Image of water treatment by the EPA is in the public domain

Coagulant Types

In general, two types of coagulants are used during coagulation. A **primary coagulant** and a **coagulant aid** will be used during the rapid mix process. The colloidal surfaces are negative thus positively charged metal salts are used as primary coagulants. The coagulant dissolves in water and ionizes. To ionize is when a molecule loses or gains an electron to form an ion. The three most common coagulants used in water treatment are Aluminum Sulfate (Alum), Ferric Sulfate, and Ferric Chloride. The most commonly used primary coagulant in water treatment is Alum because of its wide availability and affordability.

Synthetic polymers are often used as a coagulant and filter aid but have also been used as a primary coagulant. Operators use different charged groups of polymers known as cationic (positive), anionic (negative), and nonionic (without ionizable groups). Coagulation aids assist in the building of settable floc.

Important things to consider when choosing a polymer:

- Overdosing a polymer can decrease the efficiency of the coagulation process and cause filter binding and increased headloss in filters
- Not all supply water is created equal. Every single water source has a different chemistry and jar tests must be performed to see what polymer works best with the specific source water.
- There is no widespread standard for choosing a polymer. Different states have chemical approval standards that must be met.
- The addition of chlorine can effect polymer effectiveness
- As with any chemical, there is a dosage limit

Chemistry

Like many processes in water treatment, the theory of coagulation is very complex. As an operator, you should have a basic understanding of the chemistry involved in each process. The coagulant added to the water will react with the alkalinity in the water to form insoluble floc. Insoluble is something that will not dissolve. If the floc is not formed properly, then operators cannot effectively remove pathogens from the treated water. Alkalinity is not the same as pH. This gets very confusing as “alkaline water” has become a more widely popularized marketing term. Alkalinity is the water’s ability to neutralize an acid based on its makeup of carbonate, bicarbonate, or hydroxide. The measure of alkalinity is the amount of acid that would have to be added to water to lower the pH to 4.5 and there is where the confusion arises.

Coagulation is most effective in the pH range of 5-7 because of the waters ability to react with alkalinity. In this range, the water tends to buffer or stay in the same pH range and will allow the complete mixing of coagulant chemicals. If the raw water has a low pH, agents such as soda ash can be added to increase the pH.

Proper water quality tests must be performed by operators to promote the proper addition of coagulant chemicals. Underdosing coagulants will cause problems with floc formation while overdosing coagulants can cause clogging during the filter process. Clogged filters lead to head loss problems in the filters and increased filter washing.

Mixing

As noted earlier the coagulation process is completed within a matter of seconds. Mixing can be achieved by utilizing hydraulic mixers, mechanical mixing, diffusers, or pumped blenders. Hydraulic mixers use flow to achieve mixing. This kind of mixing requires enough flow to create a disturbance in the water to achieve proper mixing. Mechanical mixers require the greatest amount of energy because they require an electrical source to achieve mixing. Diffusers apply uniform flow during the coagulation process but may require many adjustments after flow changes. Finally, pumps can be used to push coagulant into water flow. Mixing can occur in a basin, channel, or pipeline.

Flocculation

Flocculation is the slow mixing process that causes smaller particles to merge into larger particles that settle more easily. The particles are then more easily removed in the sedimentation and filtration process. The process of flocculation is achieved by controlling the rate of impacts between particles as they gain size. Floc size can range between 0.1 mm-3 mm. The size of the floc produced depends on which type of treatment process is utilized at a specific plant. It is important that floc has good size but also density so the floc will not shear during the sedimentation and filtration process. This process is much longer than coagulation lasting roughly 15-45 minutes.

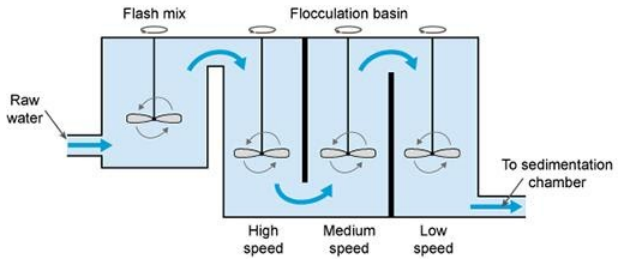


Figure **6.4.2**: The coagulation–flocculation process by The Open University and partners is licensed under CC BY-NC-SA 4.0

Shown Above: The flash mix portion is also known as coagulation. The chemicals are added together and the process occurs within seconds. After flash mix, the water heads to the flocculation basins to allow floc particles to gather in size.

Mechanical flocculators can be installed both horizontally and vertically. The horizontal type utilizes paddle-style mixers while the vertical style mixers can include paddle, turbine, and propeller style mixers. The shape and size of a flocculation basin is determined by the type of mixing used and the adjacent structures such as the sedimentation basins. Flocculation basins are usually split into 3 compartments. The speed of the mixing is decreased in each compartment to prevent the particles from breaking apart as they become larger. If the particles break apart during flocculation, the particles will place a heavier burden on the filters during the filtration process causing lower filter run times. This phenomenon will be discussed in further detail in Chapter 6.

Monitoring and Process Control

The coagulation and flocculation process requires a great amount of attention to detail along the way. An operator cannot just set a dose and "hope" everything works out. Water quality can change frequently and operators must ensure they are on top of changing conditions. One way an operator can achieve this is through jar testing. This is a laboratory procedure that finds the best coagulant dose based on water quality conditions.



Figure **6.4.3**: Image of a jar test by Jigchen L. Norbu is licensed under CC BY-SA 4.0

The efficiency of water treatment plants is determined by the combined effluent turbidity reading. Individual filter efficiency is also closely monitored. This will be discussed at length in the filtration chapter of the text, but it's important to have a basic grasp of that concept at this point in the treatment process. Water treatment is a lengthy process. What's occurring right now can have grave impacts down the line in the treatment process. Because of this consideration, jar testing and plant monitoring is all the more critical. Jar testing and laboratory grab sampling ensure the water which is theoretically being treated now, will be safe when entering the distribution system hours from now.

During abnormal conditions, it is important for operators to take notes and inform senior operators and/or a supervisor. Record keeping is important because operators can go back to notes used from previous experiences. For example, a large rain event has changed the influent turbidity entering the treatment plant. A similar event happened three years prior and the influent turbidity is very similar to the ones operators are seeing currently. Wouldn't it be nice to have a record of what the operators did three years ago? Hopefully, the operations staff from three years ago noted changes in coagulant dose, mixing speeds, chlorine demand, and other significant plant changes.

Enhanced Coagulation

The **enhanced coagulation** process is used to remove natural organic matter by adjusting the pH and coagulant dose to remove the greatest amount of suspended matter during the treatment process. The addition of acid is used to achieve the proper pH unlike sweep treatment were the operator overdoses the coagulant to achieve the correct pH range. Enhanced coagulation occurs at a lower pH. and accordingly will see improvements in treatment such as:

- Humic and fulvic molecules separate better with lower pH. Humic and fulvic acids are organic acids commonly found in raw water sources
- Less coagulant is required for treatment
- Flocculation improves at a lower pH
- Sulfuric Acid addition before coagulant is added preconditions organic matter

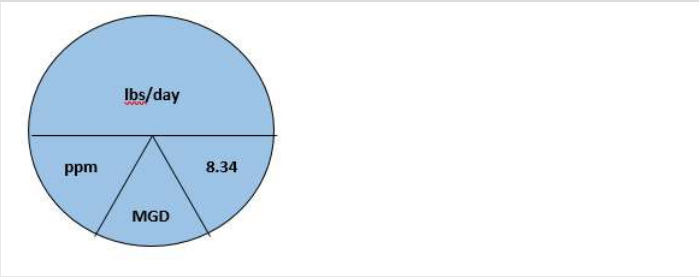
The Pounds Formula (Chemical Dosage Problems)

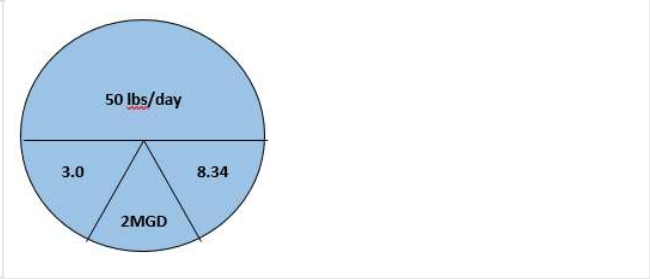
One of the most important calculations an operator will use is the "Pounds Formula." The pounds formula can be used to solve water math problems including milligrams per liter to pounds per day, feed rate, chlorine dosage, percent strength, and dilution calculations. The formula for the pounds calculations is:

$$\text{Feed Rate (lbs/day)} = \text{dosage (parts per million)} \times \text{Flow Rate (million gallons per day)} \times 8.34 \text{ lbs/gal}$$

Below is the pounds formula expressed in a mechanical wheel. The mechanical wheel can be used to solve a chemical dosage problem by plugging in the given information and then multiplying or dividing as indicated to determine the solution. For example,

a treatment plant will produce 2 MG a day. The chlorine dose is 3.0 mg/L. How many pounds of chlorine will the operator use?





$$\text{Feed Rate} = 3.0 \times 2 \times 8.34$$

$$\text{Feed Rate} = 50 \text{ lbs/day}$$

It is important to note that when using the pounds formula, the water production is always expressed in MGD. For example, a problem may ask what the chlorine production is for a water treatment plant that produces 1,000,000 gallons a day. This is the easiest expression because 1,000,000 ÷ 1,000,000 = 1.

EX: A water treatment operator must super chlorinate a 650,000-gallon tank at 50 ppm. How much chlorine must the operator add?

$$50 \times .65 \times 8.34 = 271 \text{ pounds}$$

* You must divide 650,000 by one million to get .65 to solve the equation. Round to the nearest tenth or hundredth place to get the most accurate answer. Remember you must show all work during exams to get credit but the format is still multiple choice so be careful when rounding.

Practice Pounds Formula Problems

Example 6.4.1

The dry alum dosage rate is 15 mg/L. The daily flow rate of a treatment plant is 5 MG. How many pounds of dry alum per day is required?

Solution

$$\text{Feed Rate} = 15 \text{ mg/L} \times 5 \text{ MGD} \times 8.34 \text{ lbs/gal}$$

Feed Rate = 625.5 lbs/Day

* This sample problem is pretty simple. Plug the numbers into the equation and multiply to get your answer.

Example 6.4.2

A treatment plant uses 300 lbs of alum a day. The plant output is 2,500,000 gallons a day. What is the dose?

Solution

Step 1: 2,500,000 ÷ 1,000,000 = 2.5 MGD

Dose = 300 lbs/day/(2.5 × 8.34)

Dose = 250/20.85

Dose = 12 mg/L

Example 6.4.3

How many pounds of 65% available chlorine must an operator add to a treatment plant with a dose of 3.0 mg/L and a plant output of 5 MGD?

Solution

* Start the equation as you normally would. Since you are adding a solution of chlorine that is not 100 percent an extra step is needed to solve the problem. Remember, if the chlorine solution is not 100 percent available chlorine you are going to need more to dose properly!

Feed Rate = 3.0 × 5 × 8.34 = 125 lbs/day

Next, you will need to make an adjustment based on chlorine strength.

(.65)(x lbs/day) = 125 lbs/day

x = 125.65

x = 192 lbs/Day

Note: If the number is smaller than the original number, you multiplied instead of dividing. You will always need more chemical if it's not 100% strength.

Example 6.4.4

A water tank that is 30 ft high and 100 f in diameter must be dosed at 50 ppm for disinfection. How many pounds of 65% calcium hypochlorite must be added to dose the tank?

Solution

$$0.785 \times 100ft \times 100ft \times 30ft \times 7.48\ Gal/ft^3 = 1{,}761{,}540\ gallons$$

1,761,540 gallons/1,000,000 = 1.76MGD

Feed Rate = 50 × 1.76 × 8.34 = 733.92 pounds/day

(.65)(x) = 734

x = 734/.65

x = 1129 lbs

Chapter Review

1. The optimal coagulant dose is determined by a _____.
    1. Chlorine test
    2. Flocculation test
    3. Jar test
    4. Coagulation test
2. The most common primary coagulant is _____.
    1. Alum
    2. Cationic polymer
    3. Fluoride
    4. Anionic polymer
3. Bacteria and viruses belong to a particle size known as _____.
    1. Suspended
    2. Dissolved
    3. Strained
    4. Colloidal
4. The purpose of coagulation is to _____.
    1. Increase filter run times
    2. Increase sludge
    3. Increase particle size
    4. Destabilize colloidal particles

5. The purpose of flocculation is to _____.
    1. Destabilize colloidal particles
    2. Increase particle size
    3. Decrease sludge
    4. Decrease filter run times
6. Primary coagulant aids used in the treatment process are _____.
    1. Poly-aluminum chloride
    2. Aluminum sulfate
    3. Ferric chloride
    4. All of the above
7. Flocculation is used to enhance _____.
    1. Number of particle collisions to increase floc
    2. Charge neutralization
    3. Dispersion of chemicals in water
    4. Settling speed of floc
8. If there is a problem with floc formation, what would you consider changing?
    1. Adjust coagulant dose
    2. Stay the course
    3. Adjust mixing intensity
    4. Both 1 and 3
9. Which step in the treatment process is the shortest?
    1. Filtration
    2. Sedimentation
    3. Flocculation
    4. Coagulation
10. To lower the pH for enhanced coagulation the operator will add _____.
    1. Chlorine
    2. Sulfuric acid
    3. Lime
    4. Caustic soda
11. The flocculation process lasts how long?
    1. Seconds
    2. 5-10 minutes
    3. 15-45 minutes
    4. Over an hour
12. The function of a flocculation basin is to _____.
    1. Settle colloidal particles
    2. Destabilize colloidal particles
    3. Mix chemicals
    4. Allow suspended particles to grow
13. A treatment plant has a maximum output of 30 MGD and doses ferric chloride at 75 mg/L. How many pounds of Ferric Chloride does the plant use in a day?
    1. 18,765
    2. 17,765
    3. 19,765
    4. 16,765

14. A treatment plant uses 750 pounds of alum a day as it treats 15 MGD. What was the dose rate?
    1. 4 mg/L
    2. 5 mg/L
    3. 6 mg/L
    4. 7 mg/L
15. A treatment plant operates at 1,500 gallons a minute and uses 500 pounds of alum a day. What is the alum dose?
    1. 18 mg/L
    2. 28 mg/L
    3. 8 mg/L
    4. 38 mg/L

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6.5: Sedimentation

Learning Objectives

After this chapter you should be able to identify and explain:

- Sedimentation process
- Zones of sedimentation basin
- Types of sedimentation basins
- Velocity math problems
- Detention time

Sedimentation is the 3rd step in a conventional treatment process. It occurs after coagulation and flocculation and before filtration. Sedimentation removes suspended solids with the use of gravity by slowing the flow of water down to allow material to settle. The settleable solids fall to the bottom of the sedimentation basin reducing the load on the filtration process. A sedimentation basin acts like a lake in the sense that it allows particles to settle naturally. Deeper lakes have much higher quality water entering the treatment plant because the water is able to "settle" for a longer period of time. Treatment plants that use imported water from higher turbidity water sources may be required to use conventional treatment with sedimentation for efficient treatment.

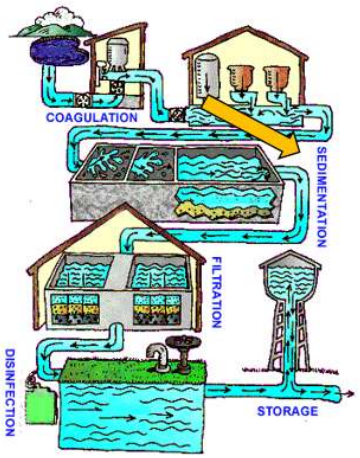


Figure **6.5.1**: Image of water treatment by the EPA is in the public domain

Factors affecting Sedimentation

Several factors can affect the sedimentation process including physical and environmental conditions. Increased pretreatment may be necessary when adverse conditions are present. Factors that affect the sedimentation process include the shape and size of particles, the density of particles, water temperature, particle charge, dissolved substances in the water, environmental effects, and characteristics of the basin.

As discussed in the previous chapter, smaller particles do not settle out easily and their size must be increased with coagulation and flocculation. The larger, denser particles created are called floc. Particles greater than .01 millimeters will settle in the sedimentation process. The shape of particles is also a consideration. Smoother particles with less jagged edges settle out quicker and easier.

Temperature decreases will cause the settling rate to decrease. The settling rate or velocity decreases when the water temperature is colder. Chemical dosage rates need to be adjusted during colder periods of the year or lower flows are necessary in the flocculation basins.

There are three types of currents, surface, density, and eddy, found in a sedimentation basin. Surface currents are caused by wind while density currents are caused by temperature differences and the concentration of solids. Eddy currents are caused by the influent and effluent flow of water in the sedimentation basin. Currents can be beneficial as they can help to promote the building of floc, but they can also cause uneven disbursements of solids throughout a sedimentation basin reducing the efficiency.

Sedimentation Zones

The four zones of a Sedimentation basin include:

- Inlet Zone: Where the water enters seamlessly from the flocculation basin. Water is distributed evenly throughout the sedimentation basin to prevent short-circuiting. Short-circuiting occurs when water entering a treatment process tank or basin quickly moves from influent to effluent reducing the waters detention time in a given process.
- Settling Zone: Is the largest part of a sedimentation basin. The water will stay here undisturbed for three or more hours while particles settle to the bottom.
- Sludge Zone: Located at the bottom of the settling zone. It is where settled particles collect in the form of sludge. Velocities at the bottom of the sludge zone should be minimized to prevent solids from re-suspending.
- Outlet Zone: The location where water seamlessly enters a channel or conduit. Launders also known as effluent troughs are used to collect the clarified or settled water.

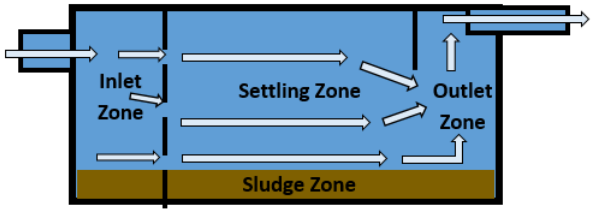


Figure 6.5.2: Image by COC OER is licensed under CC BY

Types of Sedimentation Basins

There are several different types of basin designs available for engineers and planners when building a water treatment facility. Rectangular basins are typically found at large scale water facilities because of their predictable treatment and high tolerance to turbidity, color, and algae. They are cost-efficient, require lower maintenance, and have less short-circuiting issues. The figure above representing the different zones of a sedimentation basin is an example of a rectangular sedimentation basin.

Circular and square basins are used in areas where space is limited. They are sometimes called clarifiers and are subject to short-circuiting in the corners. The circular variety can also include up-flow clarifiers or solids contact clarifiers. In these types of clarifiers, the coagulation, flocculation, and sedimentation process all occur in the same basin or clarifier.

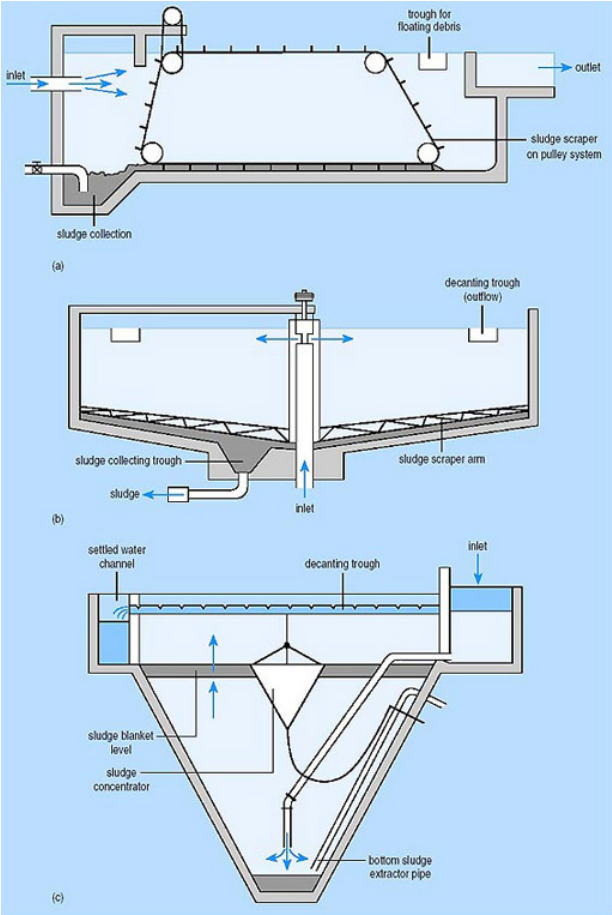


Figure **6.5.3**: Typical sedimentation tanks: (a) rectangular horizontal flow tank; (b) circular, radial-flow tank; (c) hopper-bottomed, upward flow tank – Image by The Open University is licensed under CC BY-NC-SA

Detention Time

Detention time is the amount of time it takes water to travel through a tank or sedimentation basin. It is also referred to as retention time. You will hear some operators use the terms CT and contact time interchangeably but it is incorrect. The term CT will be discussed in greater detail in Chapter 7. Detention time can be used to solve equations for time and flow. Formulas for both types of equations are listed below:

Detention Time (Hours) = Volume gal((24Hours/day))/Flow gal/day

Flow, gal/day = Volume((24Hours/day))/Detention Time, Hours

Reminder: Circular volume calculation (.785)(D ft)^2(Depth ft)

Rectangular Volume calculation: (L ft)(W ft)(D ft)

Answers will be in cubic feet so it will be multiplied by 7.48 gal/ft^3 to convert to gallons.

Example 6.5.1

A rectangular sedimentation basin is 80 ft long by 25 ft wide and is 25 ft deep. The flow per day is 2.0 MGD. What is the detention time in hours?

Solution

Step One: calculate the volume of the basin (80 ft)(25 ft)(25 ft)(7.48 gal/cubic ft.) = 374,000 gallons

Step two: DT = (374,000 gal x 24 Hours)/2,000,000 gal day

Step Three: Detention Time = 4.5 hours

*Note: more complicated problems will have you solve for hours and minutes. Keep this in mind for future math equations that ask for more information.

.5 hours/1 x 60 min/1 Hour = 30 min

Example 6.5.2

A circular basin is 100 ft in diameter. The basin is 25 ft deep and has a detention time of 4 hours. What is the flow per day?

Solution

Step one: Calculate volume .785(100 ft)^2(25 ft)(7.48 gal/cubic ft.) = 1,467,950 gal

Step Two: Flow = (1,467,950 gal x 24 Hours)/4 hours

Step three: Answer is 8,807,700 divide by 1,000,000 to get 8.807 or 8.8 MGD

Sludge Handling and Removal

Sludge that collects at the bottom of a sedimentation basin must be removed from time to time for several reasons. As discussed earlier in the chapter, sludge can become re-suspended after settling creating greater load on the downstream filter. Next, sludge buildup can cause the water source to become septic. In this scenario, microbiological growth occurs when oxygen supplies are depleted. Septic conditions can cause taste and odor problems in treated water and also require more chlorine during the disinfection process. Finally, the more sludge that builds up leads to decreased detention time because there is less area for the water to travel and for solids to settle out.

Larger plants will have to remove sludge at a greater rate and with the assistance of sludge removal equipment. Smaller plants may be able to remove sludge manually with portable sanitary pumps and squeegees and hoses to complete cleanup. The amount of time between cleanups can vary with the quality of the water source and the amount of water being treated. Consequently, shutdowns for sludge clean-up will vary dramatically from treatment plant to treatment plant.

Sludge removal equipment includes mechanical rakes, drag-chain and flights, and traveling bridges. The chain and flight system is used in rectangular basins. A chain with scrappers attached moves across the bottom of the basin collecting sludge and moving it to a sump. This system works well but has several moving parts. Additionally, the basin must be dewatered to perform maintenance. The traveling bridge system is also used in a rectangular basin. It travels the entire length of the basin. A pump is attached to the bottom of the system and sludge is pumped to a trough just below the top of the sedimentation basin. The bridge system is easier to perform maintenance on because the parts can be removed from the basin; therefore, dewatering the entire basin isn't required. Finally, mechanical rakes are used in rectangular or circular basins. A rake spans the entire length of the basin while spinning around the basin. Sludge is moved into a trough that can be pumped out or moved by gravity to a sludge collection tank.

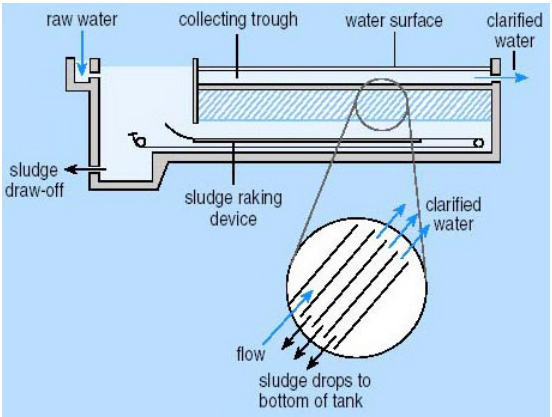


Figure **6.5.4**: Image by The Open University is licensed under CC BY-NC-SA

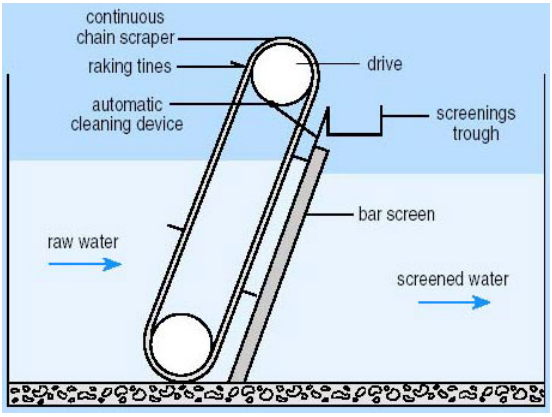


Figure **6.5.5**: Image by The Open University is licensed under CC BY-NC-SA

Review and Daily Operations of Sedimentation Basins

In review, the purpose of sedimentation is to allow suspended solids to settle through the physical process of gravity. The flow of water is slowed down to allow settling to occur. During the process, sedimentation can remove 95% or more of the total solid material operators remove during the entire water treatment process.

Water treatment plants with low turbidity or fewer than 10 turbidity units may find direct filtration or clarification to be a more cost-effective process. A reoccurring theme that should be noted throughout the text is the fact that all treatment facilities are different and the factor that dictates plant processes including facility building and day to day operation is the source water.

The settling characteristics of suspended material dictates how well sedimentation performs. Flow rate through the sedimentation basin drives performance as well as the control of sludge. High flow rates cause solids to carry over, and could also impact the sludge at the bottom of the sedimentation basin. Operators must perform regular jar testing and laboratory testing as well as operate sedimentation basins based on the designed capacity of the basin to ensure optimal performance. Improper operation of sedimentation basins will lead to increased load on downstream filters resulting in early filter washes, increased disinfectant use, and possibly tier violations.

Velocity Math

The movement of water is obviously an important thing to know if you are a water treatment operator. You will need Algebra to solve the next set of water math problems which will have two known values and one unknown value. Flow rates can be used to determine dosage rates, to identify daily averages, to dewater pipelines, to fill pipelines, and for future planning of distribution and treatment equipment.

To solve a flow problem, you need the diameter of the pipe and the velocity of the water (or liquid) in the pipe. Flow rate is expressed as Volume over Time. The equation will be:

$$Q(Flow) = A(area) \times V(velocity). \tag{6.5.1}$$

A velocity problem occurs when the known value is the pipe diameter and flow rate of pipe.

$$V(Velocity) = Q(Flow) \div A(Area). \tag{6.5.2}$$

Finally, pipe size is used when known value is pipe flow rate and velocity.

$$A(Area) = Q(Flow) \div V(Velocity). \tag{6.5.3}$$

Proper use of dimensional analysis is critical when attempting to solve velocity equations. These types of problems often take multiple steps because answers need to be converted to the appropriate units based on the situation.

Example 6.5.3

A pipeline is 18” in diameter and flowing at a velocity of 125 ft per minute. What is the flow in gallons per minute?

Solution

Step one: Convert pipeline diameter to feet: 18 inches/(12 inches/foot) = 1.5 ft

Step Two: Q(Flow) = (.785)(1.5ft.)2(125 ft./min)

Step Three: 221 ft^3 per minute × 7.48 gal/ft^3 = 1651 gpm

Example 6.5.4

The flow of a pipe is 2,000 gallons per minute. The diameter of pipe is 24". What is the velocity of the pipe in ft. per minute?

Solution

Step one: Convert units 2,000 gpm ÷ 7.48 gal./ft^3 = 267 ft^3/min. 24 inches ÷ 12 inches/ft = 2 feet

Step two: V(velocity) = 267 ft^3/min ÷ .785(2 ft.)^2

Step three: V = 85 feet per minute

Example 6.5.5

The velocity in a pipeline is 2 ft./sec. and the flow is 3,000 gpm. What is the diameter of the pipe in inches?

Solution

Step One: Convert flow to match units of measurement of velocity: 3,000 gal/min x 1 min/60 sec x 1 ft^3/7.48 gal = 6.68 ft^3/sec

Step two: Area= 6.68 ft^3/sec ÷ 2 ft/sec= 3.3 feet

Step three: Convert feet to inches: 3.3 ft/1 × 12 inches/1 ft = 40 inches

Chapter Review

1. The treatment process that involves coagulation, flocculation, sedimentation, and filtration is known as _____.
    1. Direct filtration
    2. Slow sand filtration
    3. Conventional treatment
    4. Pressure filtration
2. Sedimentation produces waste known as _____.
    1. Backwash water
    2. Sludge
    3. Wastewater
    4. Mud
3. What kind of process is the sedimentation step?
    1. Physical
    2. Chemical
    3. Biological
    4. Direct
4. The weirs at the effluent of a sedimentation basin are also called _____.
    1. Effluent weirs
    2. Baffling
    3. Launders
    4. Spokes
5. Sedimentation is used in water treatment plants to _____.
    1. Settle pathogenic material
    2. Destabilize particles
    3. Disinfect water

4. Reduce loading on filters

6. Scouring is a term that describes conditions in a sedimentation tank which _____.
    1. Could impact the rest of the treatment process
    2. Higher flow rates in the sludge zone
    3. Re-suspends settle sludge
    4. All of the above
7. The four zones in a Sedimentation basin include _____.
    1. Inlet, sedimentation, sludge, outlet
    2. Inlet, filter, waste, outlet
    3. Inlet, top, bottom, outlet
    4. Surface, sedimentation, sludge, outlet
8. Short-circuiting in a sedimentation basin could be caused by _____.
    1. Surface wind
    2. Ineffective weir placement, or weirs covered in algae
    3. Poor baffling in sedimentation inlet zone
    4. All of the above
9. How much solids should be removed during sedimentation?
    1. 95% or more
    2. 80-95%
    3. 70-80%
    4. 60-70%
10. The type of basin that includes coagulation and flocculation is _____.
    1. Rectangular
    2. Triangular
    3. Up-flow
    4. None of the above

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6.6: Filtration

Learning Objectives

After reading this chapter you should be able to identify and explain the following:

- Treatment technologies
- Filter media configurations and types
- Filter operation and backwashing
- Filtration math

Filtration is the final and most important removal requirement required by the Surface Water Treatment Rule (SWTR). Water passes through material such as sand, gravel, and anthracite coal to remove floc and disease-causing microorganisms from the finished water. Physical removal of colloids is also achieved during sedimentation but this filtration is the final step. This is the process where suspended colloidal particles are removed from the water. Along with removing possible pathogenic material in the water, removal of turbidity is also achieved which could hide pathogenic organisms and add color to the finished water.

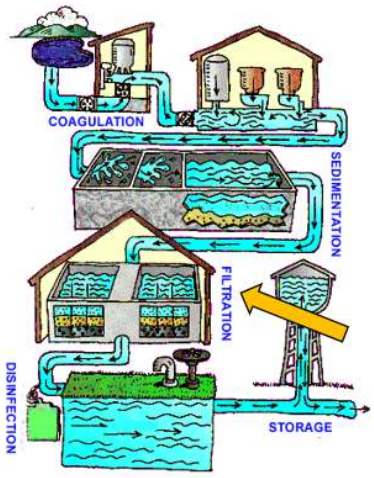


Figure **6.6.1**: Image of water treatment by the EPA is in the public domain

The SWTR sets forth guidelines for all public water agencies that use surface water as a source. Surface water was covered in chapter #1 and is any water open to atmosphere that is susceptible to runoff. The minimum requirements for treatment is disinfection, but most water sources do not meet these very stringent guidelines.

The effectiveness of filtration is based on several important factors. Proper filtration occurs based on incoming source water quality. For example a storm event near the source water could case higher incoming turbidity than the treatment plant is used to handling. Operational changes such as washing filters may be required. The physical and chemical characteristics of suspended material also come into play during treatment. Too much or too little chemical can lead to ineffective filtration. To follow the storm event example an operator may need to make changes to coagulant and polymer doses to account for increased turbidity and particulate entering the treatment plant. Finally the type of filtration used by a treatment facility is also very important. This decision is mostly out of operators hands as engineers and water quality experts will decide what the most effective treatment process is for the source water before building a treatment facility.

Pictured below is a filter in normal operation.



Figure **6.6.2**

Treatment Technologies

There are four approved treatment technologies in the United States. The most widely used treatment technologies include conventional treatment, direct filtration, diatomaceous earth treatment, and slow sand filtration. Below are the descriptions:

Slow sand filtration facilities are becoming less common because of the large amount of time it takes to treat water and the large amount of space the facilities require. The filtration rates for slow sand filtration are .05 to .10 GPM/sq ft. Particles are adsorbed in a chemical layer known as a schmutzdeke. After an amount of time the biological layer must be manually removed by an operator or maintenance staff. The slow time and intensive labor make this treatment method the least ideal especially in areas with larger populations.

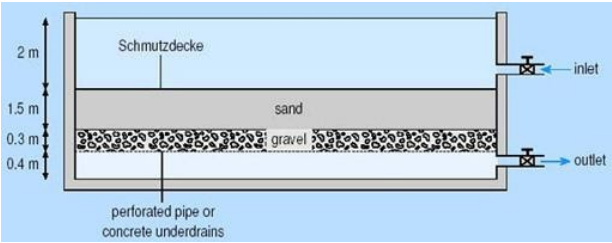


Figure **6.6.3**: Image by The Open University is licensed under CC BY-NC-SA

Diatomaceous Earth filtration is accomplished through pressure filtration. It can also be referred to as precoat filtration. The filter media in this case is added as slurry to the treatment vessel. Within the vessel lays a pipe known as a septum. The slurry attaches itself to the septum and water is run through the vessel where pathogenic and suspended material is captured and strained out of the finished water. This kind of treatment process is very common for swimming pool treatment and beverage companies. This type of treatment method is generally not used by larger municipalities because of the large amount of disposal of sludge and the continuous purchasing of filter media.

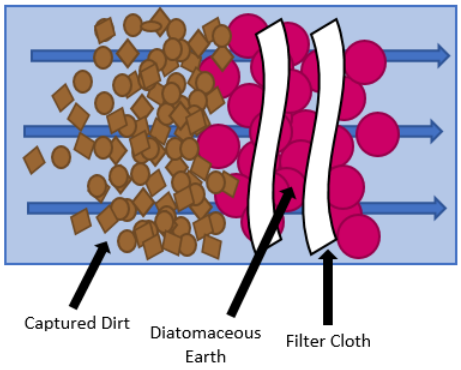


Figure **6.6.4**: Image by COC OER is licensed under CC BY

Gravity filtration is comprised of the final two approved Water Treatment technologies. Direct Filtration and conventional treatment are the most widely used treatment technologies in the United States. It is described as gravity filtration because the head pressure of the water forces the water to travel through filtered media in order to remove impurities from the drinking water. Direct Filtration differs from conventional treatment because the sedimentation process is skipped. Areas with source water higher in quality may opt for direct filtration to reduce costs and the amount of land space for sedimentation basins can be substantial. The average filtration rate for gravity filtration beds is 3.0 GPM/Sq. ft.- 6.0 GPM/ sq. ft.

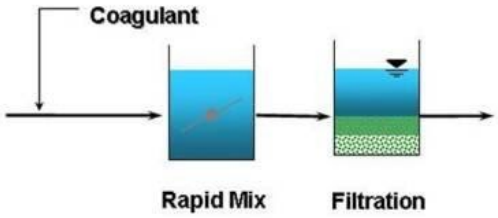


Figure **6.6.5**: Direct Filtration - Image by the EPA is in the public domain

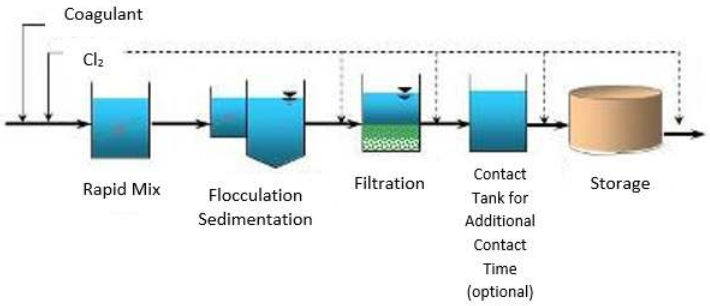


Figure **6.6.6**: Conventional Treatment - Image by the EPA is in the public domain

Alternative treatment plant methods can be approved on a case by case basis. Newer technologies such as membrane filtration and reverse osmosis have been utilized as the technology has improved and the costs associated with running these particular operations have decreased. Santa Clarita Valley (SCV) Water utilizes an alternative technology known as Upflow Clarification. SCV Water is able to use this technology because of the very low turbidity levels in the water provided by Castaic Lake. It is a more condensed version of conventional treatment and requires much less space due to the lack of sedimentation basins.

Filter Media

The type of media used in gravity filters is sand, anthracite coal and garnet. Garnet is a reddish colored mineral sand comprised of silicates (calcium, iron, manganese, and magnesium) and its density is greater than sand. Gravel is also used as a filter under layer below the filter media being used. It has to be heavier than the filter media so it is able to settle back under media after a completed filter wash cycle.

When choosing filter media it is important to select media that has good hydraulic characteristics, is durable, has no impurities, is insoluble in water, will not dissolve, and does not react with constituents in the water supply. Media is classified by four parameters including its effective size, uniform efficiency, specific gravity, and the hardness of the media. The effective size is the sieve opening in the media that allows water to pass through while collecting the impurities in water. 90 percent of the particles must be bigger than the opening to filter out particles.

When deciding what kind of media to choose for the filer it is important to consider the amount of time it takes for filter turbidity to break through. For example, you operate a treatment plant that requires individual filters say below 0.3 NTU (or Nephelometric Turbidity Units). Once an individual filter goes above this limit it must be washed. Secondly, head loss must be a consideration. Head loss occurs after material builds up over time during the filtration process. The head loss will cause longer filtration times and cause the filter level to rise. Once a filter reaches terminal head loss it must be back washed. The media is not always the cause of head loss and turbidity breakthrough. As discussed earlier, operators must ensure they are dosing chemicals properly as improper dosage can cause the aforementioned head loss and breakthrough.

The uniform coefficient is the ratio between the different sizes of media comprised in the filter bed. The lower the uniform coefficient means the media is closer to the same size than if it were higher. The lower the efficiency number adds to the cost of the media.

Filter production is the amount of water that a given filter can produce in a day. This flow is usually accounted for in Million Gallons per Day (MGD). Individual filtration rates are calculated by dividing the flow rate of the filter in gallons per minute by the surface area of a filter. The filtration rate for gravity filters can be between 2gpm-10gpm/ square foot. This topic will be discussed in more detail during the math portion of this chapter.

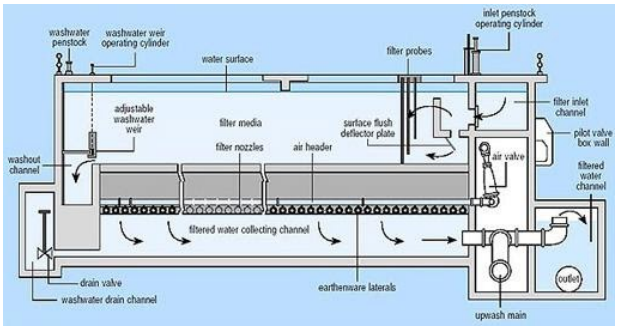


Figure **6.6.7**: Rapid gravity sand filter - Image by The Open University is licensed under CC BY-NC-SA

Filter Media Types			
			
Gravel Image by Martin Olsson is licensed under CC BY-SA 3.0	Sand Image by Yug is in the public domain	Garnet Image by Siim is licensed under CC BY-SA 4.0	Anthracite Image is in the public domain

There are several different types of media configurations. Filtration plants can utilize monomedia, duel media, and multimedia configurations. A monomedia plant has only one type of media which could be coarse sand or anthracite coal. Single media filters may have to be washed more frequently as they tend to be smaller and have more frequent head loss issues. Dual media filters consist of a lower sand level and an upper anthracite layer with larger diameter pores that allow deeper solids penetration. Finally, multimedia filters are used in pressure vessel treatment applications. Multimedia filters have sand, anthracite, and an upper garnet layer. The drawback to pressure vessels is the inability to view filter media within the pressure vessel.

Filter Operation and Backwashing Filters

Throughout the chapter, the subject of “washing” has come up. Filter run times are dependent on three factors but first it is important to know how filter efficiency is measured. The efficiency of a filter is measured by the filter effluent turbidity. And the overall plant efficiency measures the combined effluent turbidity of all the filters. Improper coagulation and filtration could lead to turbidity spikes and in the worst-case scenario could lead to a public health crisis.

Pictured below is a photo of a typical filter deck at a water treatment plant.



Figure **6.6.8**

The first factor that an operator uses to determine whether a filter wash is necessary is the individual filter turbidity. Each treatment plant will have its own operating conditions and permits to follow. If an individual filter fails to meet the turbidity goals or limits, the filter must be put in a backwash cycle. Filters that continue to have decreased run times may need a filter profile ran to figure out why the filters are not meeting standards.

High head loss is the second factor that will lead to a filter wash. After the filter is used for a certain period of time it becomes clogged with the solids the filter is removing. This condition will also lead to increased turbidity as the solids that should be getting captured “breakthrough” the effluent into the treated water supply. Finally, a filter wash will be performed after a certain period of time no matter what the operating conditions are. This is the ideal scenario for washing a filter.

The backwash procedure is the reverse flow of water through the filter. This process removes solids from the filter after breakthrough or the filter run time is hit. Operators must operate the backwash rates at an optimal range because inadequate rates will not properly remove the solids from the filter and excessive rates can cause mud balls and mounds to form within the filter.

Washed water is able to be recycled by sending the waste stream to collection basins. The water can then be returned to the head works of the plant and be mixed with raw water to be treated again. The filter backwash rule limits the amount of water that can be returned into the head works of the plant at a given time. Returning too much recycled water could increase the chances of allowing microorganisms such as *Cryptosporidium* into the treatment plant.



Figure **6.6.9**

The Filter to the left is in the process of a filter back wash. The water is moving in the opposite direction and overflowing over the weir and heads to the waste basin where it is collected and eventually returned into the head works of the plant to be treated again. Operator Actions

As a Water Treatment operator, you will be expected to have knowledge of how to properly use equipment related to filtration. While running a treatment plant you will routinely:

- Monitor filter performance
- Check turbidity levels with online analyzers and grab samples
- Adjust chemical flow rates
- Backwash filters
- Visually inspect filters

Filters run differently under changing water conditions. The plant will not always run the same as temperature differences and storm events will make operators examine important operational considerations from time to time. It is important to look at the weather and understand how it might affect the treatment plant. A severe rainstorm near your source water could increase turbidity levels coming into the plant. Under these conditions, operators may have to wash filters more frequently and make adjustments to chemical doses.

There are other abnormal conditions to consider when monitoring filter performance. Monitor filter washes to look for mud balls, excessive boiling in certain spots, and media being displaced and sent to waste basins. These conditions would indicate that the backwash flow is too high. Also identify shorter filter run times, filters that may not be coming clean, and algae growth. These factors may be due to improper chemical dosing and a backwash flow that is too low.

Filtration Math

Filtration Rate

Calculating the filtration rate of the filters in your plant is an important function. Operating plans and permits limit the amount of water a filter can produce so it is important to have an understanding of filter rates also known as loading rates. Filtration rates will also give an operator a basic understanding of the treatment plants daily average production.

The filtration rate formula is a velocity equation. These formulas are easily confused with flow problems so make sure you pay attention to the units you add into the formula and pay attention to what the problem is asking. The formula for filtration rate is:

Filtration Rate = Flow Rate ÷ Area

Filtration rate equations will use GPM and the area of a given filter. The area of the filter is length x width. A problem may give you the depth of a filter to confuse you. Pay very close attention to the wording in the problem.

Example 1

What is the filtration rate of a treatment plant that has 3 filters that are 20 ft. wide and 20 ft. in length in a plant that produces 1 MGD?

Filtration Rate = (20 ft x 20 ft x 3) ÷ 1 MGD

1,000,000 gal/1 Day x 1 Day/24 hours x 24 hours/60 min = 694 GPM1

**Note: Quick shortcut for future equations, there are 1,440 minutes in a day.*

Filtration Rate = 1,200 ft^2 ÷ 694 GPM

Filtration Rate = 1.73 gpm/ft^2

Backwash Rate

As discussed in the chapter, after a filter reaches its capacity due to head loss, turbidity break through, or maximum amount of hours run, the filter must be washed. The filter wash cycle water velocity will be much greater than the amount of water that flows through the filter during normal operation. Many math equations will have the operator solve for rate of rise which is expressed as in/min. The backwash is the flow of water in the opposite direction where water is moving up instead of down.

Example 2

The maximum backwash rate for a filter is 5,000 GPM. The filter is 20 ft. wide and 20 ft in length. What is the rate of rise in the filter?

Rise Rate = Flow Rate ÷ Area

Rise Rate = 5,000 GPM ÷ 400 ft^2

Rise Rate = 12.5 GPM/ sq./ft

12.5 gal/min(ft)/1 x 12 inches/1 ft x 1 ft^3/7.48 gal = 20 inches rise/min

Percent Back Wash

Water treatment plants are very efficient at recycling waste stream water. The water sent to waste basins and lagoons is able to be recycled but only a certain amount at a time. The percent backwash math problems compare the total plant production with the amount of finished water used to backwash a filter.

Example 3

A treatment plant treats 2 MGD. It has 2 filters that are washed each day and each uses 10,000 gallons during the wash. What is the percent backwash water?

2 filters x 10,000 gallons = 20,000 gallons

20,000 gal/2,000,000 gal = 0.01

100 × 0.01 = 1%

1% of the water the plant uses is for backwash water.

Chapter Review

1. Solids removed from a filter are most commonly removed by what method?
    1. Adsorption
    2. Straining
    3. Deactivation
    4. Flocculation
2. What is a typical filtration rate for slow sand filters?
    1. 2.0-6.0 GPM/sq. ft
    2. 6.0-10.0 GPM/sq. ft

3. 1.0-2.0 GPM/sq. ft
4. 0.5-0.10 GPM/sq. ft

3. In a typical conventional treatment plant, the finished water turbidity for an individual filter should be less than _____.
    1. 1.0 NTUs
    2. 0.3 NTUs
    3. 5.0 NTUs
    4. 3.0 NTUs
4. A filter running under normal conditions will see head loss in a filter _____.
    1. Remain constant
    2. Increase slowly
    3. Rapidly increase
    4. Decrease slowly
5. A filter must be washed if this condition is met:
    1. Head loss
    2. Turbidity breakthrough
    3. Maximum filter run time
    4. All of the above
6. Filter performance is measured by the removal of _____.
    1. Oxygen
    2. Head loss
    3. Turbidity
    4. Chlorine
7. What is the biologically active layer of a slow sand filter called?
    1. Mixed media
    2. Duel media
    3. Sludge layer
    4. Schmutzdecke
8. The pressure drop in a filter is called _____.
    1. Turbidity breakthrough
    2. Head Loss
    3. Filtration
    4. Backwash
9. What is the most common reason for putting a filter into the wash cycle?
    1. Head loss
    2. Filter run time
    3. Turbidity breakthrough
    4. Water level decrease
10. Formation of mud balls and excessive boiling during a wash is an indicator of _____.
    1. Proper backwash rate
    2. Too low backwash rate
    3. Excessive backwash rate
    4. Improper chemical dose
11. Important processes which occur during filtration are _____.
    1. Sedimentation
    2. Adsorption
    3. Straining
    4. All of the above

12. Typical filtration rates for a conventional treatment plant are _____.
    1. 0.2-0.6 GPM/sq.ft
    2. 2.0-10.0 GPM/sq.ft
    3. 10.0-20.0 GPM/sq.ft
    4. 200-400 GPM/sq.ft
13. There are four filters at a water treatment plant. The filters measure 20 feet wide by 30 feet in length. What is the filtration rate if the plant processes 8.0 MGD?
    1. 1.51 GPM/sq.ft
    2. 2.31 GPM/sq.ft
    3. 2.61 GPM/sq.ft
    4. 2.91 GPM/sq.ft
14. A water treatment plant treats 6.0 MGD with four filters. The filters use 60,000 gallons per wash. What is the percent backwash at the plant?
    1. 10%
    2. 8%
    3. 6%
    4. 4%
15. A treatment plant filter washes at a rate of 10,000 GPM. The filter measures 18ft. wide by 24ft. long. What is the rate of rise expressed in inches per minute?
    1. 17 inch/min
    2. 27 inch/min
    3. 37 inch/min
    4. 47 inch/min

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6.7: Disinfection

Learning Objectives

After reading this chapter you should be able to identify and explain the following:

- Disinfection terminology
- Regulations
- Types of disinfectants used during water treatment

The final step in the water treatment process before finished or treated water enters a clearwell for storage is the disinfection process. Disinfection is the process where chemical agents are added to a water source to kill or inactivate pathogenic microorganisms. Pathogenic microorganisms are disease-causing and must be eliminated from treated water. As population sizes increase and freshwater sources become scarcer, the ability to remove and deactivate microorganisms becomes increasingly important. Another factor to consider, especially in California, is stricter regulations due to advancements in technology and water quality testing.

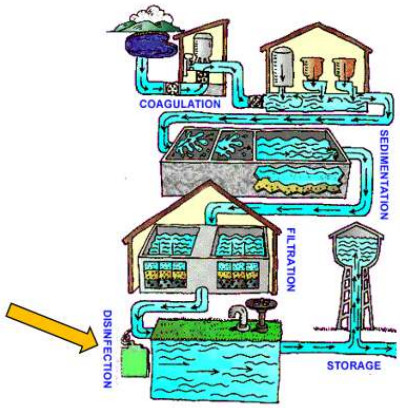


Figure **6.7.1**: Image of water treatment by the EPA is in the public domain

Disinfection Basics

Treatment plant operators use the two-part process of removal and deactivation of microbiological constituents in water. Most of the pathogens water treatment professionals remove and deactivate from drinking water have adapted to living in the bodies of warm-blooded animals. Pathogens thrive and survive in those environments. Outside those environments, these pathogens can stay dormant until they are consumed. Even more frightening, some of the illnesses can cause death. In the United States, our water is generally safe to drink and we often take for granted that turning on a tap will produce a flow of potable water.

Because of limitations in testing, it is difficult to indicate the presence of specific waterborne illnesses caused by virus, bacteria, and *Giardia*. Water professionals use tests such as the total coliform test to look for the likely presence of waterborne disease. The Surface Water Treatment Rule sets specific guidelines for removal and treatment to ensure the removal and inactivation of pathogenic organisms.

Strict regulations set forth by the Safe Drinking Water Act were created to ensure the public's drinking water was safe to consume. To ensure drinking water is safe for human consumption, 3 log removal and deactivation or 99.9% of *Giardia* lamblia is required. For viruses, 4 log or 99.99% removal and deactivation is required. Bacteria fall in the middle of viruses and *Giardia* so the government determined it was not necessary to have regulations specifically regulating their inactivation and removal.

Below is a list of waterborne diseases and illnesses.

Table 7.1: Waterborne Diseases and Illnesses

Bacteria	Internal Parasite from Protozoa	Virus caused
• Anthrax • Dysentery • Cholera • Gastroenteritis (Stomach Flu) • Leptospirosis • Paratyphoid • Salmonella • Shigellosis (Shigella) • Typhoid fever	• Dysentery • Ascariasis (round worm) • Cryptosporidiosis from *Cryptosporidium* • Giardiasis from *Giardia*	• Gastroenteritis • Heart anomalies • Hepatitis A • Meningitis • Poliomyelitis

Purpose of Disinfection

Operators disinfect water to destroy the harmful organisms listed in the above chart. Filtration is used to remove the organisms while disinfection kills them or deactivates them. Operators do not sterilize water because sterilization would kill everything in the water. The process of disinfection relies heavily on everything that occurs downstream in the treatment process. As water enters the treatment plant in the form of raw water, the chemistry of that water affects how well the specific disinfectant will work at each stage of the treatment process.

What Affects Disinfection?

There are several characteristics of water that can affect treatment. Water is more easily disinfected with higher temperatures. In lower temperatures, longer contact times may be required and larger amounts of chemical must be used. Higher turbidity rates will decrease disinfection as well. The chapters before have covered how critical it is to remove suspended material early and efficiently. Excess turbidity will require greater amounts of chemical to properly disinfect the water supply. Chemicals such as chlorine can interact with organic and inorganic matter. Chlorine's ability to interact with these constituents may reduce or eliminate the effectiveness of the disinfectants.

Types of Disinfectants Physical

Physical disinfection is not widely used to treat potable water at this time. Ultraviolet rays are starting to be used more consistently but chemical means of disinfection must still be used as ultraviolet disinfection does not carry a disinfectant residual. The process is very expensive and thus is not used by large scale treatment operations in the United States. Other means of physical disinfection include boiling and ultrasonic wave production. Agencies will call for boil water notifications during emergencies and when there is a waterborne illness outbreak but it is not used as a primary means to disinfect drinking water.

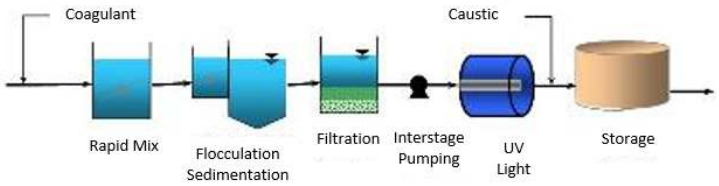


Figure **6.7.2**: Image by the EPA is in the public domain

Types of Disinfectants Chemical

There are several chemical disinfectants available in drinking water applications. The most commonly used in the United States is Chlorine. The topic of Chlorine will be discussed in greater detail in the following chapter. The basics will be covered below as well as a background on the other chemicals available. The chemicals will be broken down into subcategories based on their practical usage in the United States.

Rare

- Iodine—It is commonly used for emergency treatment in the form of droplets or tablets. It is not used by the water treatment industry because of its cost and the potential health hazards to pregnant women and possible thyroid issues, which can develop

with frequent use.

- Bromine—It is not used by water treatment facilities as it is very corrosive and can cause severe skin burns. It is used more commonly as a disinfectant in swimming pools. When it reacts with choline (a common nutrient from plants and animals) in water, it can create disinfectant byproducts. It was used by the United States Navy for a time, but most systems have been removed because of bromine's corrosiveness.
- Sodium Hydroxide and Lime—More frequently used to sterilize pipes. They are not used as an everyday disinfectant because of the bitter taste that is left behind after application. Sodium hydroxide and lime are more often used to increase the ph of the water in the distribution system after treatment with gas chlorine.

More Common

- Chlorine Dioxide—Used as a water treatment disinfectant and oxidizer. It does not react with ammonia which is an issue with chlorine. Chlorine dioxide is used as a disinfectant but is also very effective at removing iron, manganese, taste, odor, and color from treated water. *Cryptosporidium* is resistant to chlorine but is not resistant to chlorine dioxide. Up to 70 percent of chlorine dioxide is converted to chlorite, which is a regulated disinfectant by-product so the dosage rates when using it as a disinfectant must be lower than 1.4 mg/L. Chlorine dioxide must also be made on site which necessitates higher operational and maintenance costs.
- Ozone—Ozone was first used in Europe in the early 1900's. It is a strong disinfectant that also reduces taste and odor issues. The drawback of ozone is that it is very expensive to produce, has high electrical costs, has limited solubility, and does not leave a residual in the treated water because it is so reactive. If bromide is present in the water, ozone can react with it to form bromate, an undesirable DBP (this is an issue for SCV Water). Ozone is very efficient at disinfecting *Cryptosporidium* so it is generally used as a secondary disinfectant along with chlorine or chloramines.

Most Common

- Chlorine—The most widely used disinfectant in the United States is free chlorine. Chlorine can be added as a gas in the form of chlorine gas, as a solid in the form of calcium hypochlorite, or as a liquid in the form of sodium hypochlorite. Most likely, you have a bottle of sodium hypochlorite in your house. We call it bleach. The use of free available chlorine has declined over the years because of the discovery of disinfectant by-products (DBPs). This topic will be discussed in further detail in the next chapter.
- Chloramines—The use of chloramines has become more common in recent years in order to reduce DBPs mainly trihalomethane (THM). Chloramines are also referred to as combined chlorine as it is the combination of chlorine and ammonia. Chloramines are also effective at eliminating taste and odor problems and the residual lasts longer in the distribution system. However, chloramine disinfection is not as strong as chlorine and the improper addition of ammonia can lead to excessive amounts of ammonia in the treated water which results in nitrification.



Figure **6.7.3**: Image by olegschedrin0 is licensed under CC0

Regulations

The Safe Drinking Water Act (SDWA) is the basis of all drinking water regulations in the United States. It is the umbrella in which all new regulations and rules have subsequently been created and enacted. The SDWA regulates drinking water standards in the United States along with its territories. We take for granted all of the research and technology we have available that allows us to

never really be concerned about the quality of our drinking water. The SDWA was passed in 1974 and set fourth standards to regulate public water sources. It was amended in 1986 to include some basic principle definitions:

- Defined regulated contaminants and approved treatment techniques
- Defined criteria for filtration of drinking water
- Defined criteria for disinfecting surface and groundwater
- Outlawed the use of lead material in drinking water facilities

After a large public health crisis in Milwaukee, Wisconsin, provisions were made to support drinking water programs through operator training and certification programs. All entities serving water to the public were required to meet program standards with regards to training and certification. In 1999, the government allowed states to hold primacy over drinking water certification programs as long as federal minimums were met. States such as California often have stricter standards than the federal standards.

Surface Water Treatment Rule

The Surface Water Treatment Rule (SWTR) was enacted in 1990 and sought to prevent waterborne illness from surface water sources. Water systems with supplies from surface sources which are susceptible to carrying viruses, legionella, and *Giardia lamblia*, have to follow new requirements with regards to filtration and disinfection known as the multiple barrier approach. The rule also required that systems that used groundwater as a source for drinking water had to adhere to SWTR standards if their water source could come into contact with surface water sources.

Water treatment plants would have to achieve removal and deactivation requirements through the combined efforts of filtration and disinfection. The removal and deactivation of 99.9% of *Giardia* or 3 Logs and the removal and deactivation of 99.99% of viruses or 4 Logs was the new standard set forth. This requirement is measured by monitoring combined effluent turbidities in the combined filters and meeting disinfection requirements through the CT calculation. The CT calculation will be covered in greater detail in the following chapter.

Groundwater Rule

The Groundwater Rule (GWR) was established in 2009 in response to the frequency of groundwater contamination from surface water runoff sources. The rule requires monitoring for systems that do not disinfect to make sure microbiological contamination is not occurring. If a groundwater supplier did use disinfection, they are to meet 99.99% virus inactivation much like groundwater sources.

Total Coliform Rule

The final rule which indirectly relates to water disinfection is the **Total Coliform Rule** (TCR) which was established in 1990. As stated several times within the text, it is nearly impossible and certainly too costly to test for every type of microbiological contaminant that could lead to a public health risk. Instead, the TCR uses a risk based process which tests for the “worst case scenario”. Coliforms grow in warm blooded animals just like viruses, bacteria, and *Cryptosporidium*. They pose no health risk to humans and they grow more abundantly than forms of microbiological agents that will do us harm. If coliforms are present in the water supply, there is a chance for a public health concern.

In the event of a positive coliform test, the downstream and upstream sampling sites as well as the site where the positive sampling occurred will be retested. System maps and sampling plans are a requirement of the TCR. The amount of samples the water supplier takes is based on the population served. Systems which collect less than 40 samples a month can only have one positive sample before notifying the public of a Maximum Contaminant Level (MCL) violation. Systems that collect more than 40 samples a month must not have positives in more than 5% of their coliform samples. If you work at a water supplier that takes 50 samples a month and had 3 positive samples are you in compliance with the TCR?

$$47 \div 50 = 0.94 \times 100$$
$$= 94\%$$

So 6% of the samples were positive so you would not be in compliance) or...

$$\frac{3}{50} = 0.06 \times 100$$
$$= 6\%$$

Therefore, 3 positives are 6% of the total samples.

Disinfectant By-Product Rule

The disinfectant by-product rule (DBPR) was put in place to protect the public from cancer causing risks associated with disinfectants reacting with organic and inorganic matter in treated drinking water. Disinfectant by-products such as trihalomethanes are classified as volatile organic compounds. The Stage 1 DBPR established maximum contaminant levels for several DBPs including:

- Trihalomethane (TTHMs) - 80 ug/L or 80 ppb
- Haloacitic Acid (HAA5) - 60 ug/L or 60 ppb
- Bromate - 10 ug/L or 10 ppb
- Chlorite - 1.0 ppm

While it is all together possible to remove DBPs from treated water with activated carbon, it is a very expensive treatment process and not cost effective for large treatment operations. Other forms of disinfection are possible but will also cause DBP formation. Chlorite formation is associated with chlorine dioxide treatment, while bromate is associated with ozone treatment. The issue of DBP formation becomes even more problematic as chlorite and bromate are often found naturally in source water.

The stage II DBP Rule enhanced regulations on DBP formation by targeting water sources that are more vulnerable to DBP formation and the rule also requires monitoring for HAA5s and THMs. The number of samples taken and the number of sampling sites is based on the size of the population served by the water agency. The use of chloraminated water is being used more commonly to combat DBP formation but using chloramines instead of other disinfectants has other risks associated with its use which will be covered in greater detail in the next chapter.

This is the link to the quick reference guide from the EPA with information on the Stage I and Stage II DBP rule.

Chapter Review

1. What is residual chlorine?
    1. Chlorine used to disinfect
    2. The amount of chlorine after the demand has been satisfied
    3. The amount of chlorine added before disinfection
    4. Film left on DPD kit to measure residual
2. When Chlorine reacts with natural organic matter in water it can create _____.
    1. Disinfectant by-products
    2. Coliform bacteria
    3. Chloroform
    4. Calcium
3. What are trihalomenthanes classified as?
    1. Salts
    2. Inorganic compounds
    3. Volatile organic compounds
    4. Radio
4. What disinfectant is used for emergency purposes and not utilized in the water treatment industry?
    1. Chlorine
    2. Iodine
    3. Ozone
    4. Chlorine dioxide
5. What is the disinfectant with the least killing power but that has the longest lasting residual?
    1. Chlorine
    2. Ozone
    3. Chlorine dioxide

4. Chloramines

6. The active ingredient in household bleach is _____.
    1. Calcium hypochlorite
    2. Calcium hydroxide
    3. Sodium hypochlorite
    4. Sodium hydroxide
7. *Cryptosporidium* is not resistant to this chemical:
    1. Ozone
    2. Chlorine dioxide
    3. Chlorine
    4. Both 1 and 2
8. The Removal and inactivation requirement for *Giardia* is?
    1. 99.9%
    2. 99.99%
    3. 99.00%
    4. 90%
9. If a coliform test is positive, how many repeat samples are required at a minimum?
    1. None
    2. 1
    3. 3
    4. Depends on the severity of the positive sample
10. Your water system takes 75 coliform tests per month. This month there were 6 positive samples. What is the percentage of samples which tested positive? Did your system violate regulations?
    1. 3% Yes
    2. 5 % No
    3. 8 % Yes
    4. 10 % No

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6.8: Chlorine

Learning Objectives

After reading this chapter you should be able to identify and explain the following concepts related to chlorine:

- Chlorine terminology
- Chlorine chemistry
- Chlorine safety
- Advanced chlorine calculations

As discussed in previous chapters, chlorine is the chemical most frequently used in the water treatment industry for disinfection purposes to meet the standards of the surface water treatment rule. Chlorine is used in several different forms and can be fed into the system in a variety of different methods. It is a very dangerous chemical, so proper safety and handling procedures must always be followed. In addition to being used as a disinfectant, Chlorine may also be used as a controlling agent for the removal of algae, for taste, and for odor. Other beneficial applications of Chlorine include disinfecting new water facility infrastructure such as pipes and tanks and the oxidation of iron, manganese, and hydrogen sulfide.

Chlorine Terminology

Chlorine is available in three forms: gaseous, solid, and liquid.

- Gaseous(chlorine)—Cl_2
- Solid (Calcium hypochlorite)—$Ca(OCl)_2$
- Liquid (Sodium Hypochlorite)—$NaOCl$

It is not explicitly known how chlorine disinfection works. One explanation is that chlorine attacks a bacterial cell and destroys it. The other theory suggests that chlorine deactivates enzymes within the cell enabling the microorganisms to use their food supply. Adding chlorine to a water supply causes chemical reactions to take place between the water and the organic and inorganic molecules within the water. After chlorine is done combing with organic and inorganic material in the water, the demand has been satisfied.

The dose of chlorine minus the demand is the residual. The reason chlorine is used in the United States over other disinfecting chemicals is Chlorine's ability to leave a lasting residual within the framework of the water distribution system. This residual continues to fight potential disease-causing microorganisms after treatment has concluded.

Assume that you are working as an operator at a water treatment plant. Your chief operator would like to maintain a residual of 2.0 mg/L of chlorine residual in the distribution system. The demand is 1.5 mg/L. What is the dose you must add to achieve a residual of 2.0 mg/L?

$$\begin{aligned} \text{Dose} &= \text{Demand} + \text{Residual} \\ &= 2.0\,\text{mg/L} + 1.5\,\text{mg/L} \\ &= 3.5\,\text{mg/L} \end{aligned}$$

Therefore, you would need to maintain an average of a 3.5 mg/L dose of Chlorine to achieve the residual requested by your chief operator.

Other Chlorine terminology includes Free Chlorine, Combined Chlorine, and Total Chlorine. It is important to understand these terms before taking a deeper dive into the chemistry of chloramination. The term Free or Available Chlorine refers to the amount of Chlorine that is "free" or "available" in the system to kill or deactivate pathogenic organisms. Combined Chlorine is chlorine that has combined with other molecules and Total Chlorine is the combination of Free or Available Chlorine and Combined Chlorine. Although Combined Chlorine lasts longer in the distribution system, it is a far less effective disinfectant. It is also important to note, not all Chlorine has the same strength. This will be covered more thoroughly later in the chemistry and math portion of the chapter.

Chlorine Content

As mentioned earlier in the chapter, Chlorine is available in different states of matter. The amount of chlorine used to dose water in a treatment plant is determined by the compound used. Below is a chart illustrating the different compounds of chlorine. The percent column indicates the percentage of Chlorine in the compound. For example, Chlorine Gas is pure Chlorine and yields the highest available percentage at 100%.

Table 8.1: Chlorine Content in Different Chlorine Compounds

Chlorine Compound	Percent	Amount needed to attain 1lb
Chlorine Gas	100	1 lb
Calcium Hypochlorite	65	1.54 lbs
Sodium Hypochlorite	15	.8 gallons
Sodium Hypochlorite	12.5 (most common)	1.0 gallons
Sodium Hypochlorite	5 (household bleach)	2.4 gallons

In the math section of this chapter, the impact of the Chlorine percentage will become evident. It is important to read the question and understand what concentration of chlorine is being added to the treatment plant. The third column in the table provides the lb or gallon needed of the specific compound to provide 1 lb of chlorine. For example, if your plant requires a weight or quantity of 100 lbs of chlorine and you use gas chlorine, then you will be adding 100 lbs. of Chlorine Gas. If you are using calcium hypochlorite, you will need to calculate the number of pounds required. From the table, Calcium Hypochlorite is 65% Chlorine. To determine the total number of pounds of Calcium Hypochlorite needed to provide 1 lb of Chlorine, divide the dose required by the percent chlorine.

$$100 \div 0.65 = 153.8\,lbs \tag{6.8.1}$$

Therefore, you will need to use 153.8 lbs of Calcium Hypochlorite to obtain a 100 lbs dose of chlorine.

Factors of Chlorine Success

Several factors during the water treatment process will impact the effectiveness of the Chlorine. The five factors that affect chlorine treatment are:

- The concentration of chlorine, more specifically the dose
- The amount of time chlorine is in contact with the water
- The temperature of the source water
- The pH of the source water
- The constituents in the source water

The amount of time the chlorine is in contact with the water determines the effectiveness of the chlorine disinfection. The CT (Concentration multiplied by Contact Time) formula is used to calculate the time chlorine is in contact with the water. C is the concentration of chlorine residual, therefore CT is expressed as (mg/L-min). If water is leaving a drinking water storage tank, also referred to as a clearwell, at a rapid rate, then the chlorine concentration will have to be increased. If the concentration of chlorine is decreased, then the water will have to stay in contact with the disinfectant for a longer period of time. Combined Chlorine treatment associated with monochloramine disinfection will require longer holding periods due to its decreased effectiveness.

Temperature affects chlorine treatment in a variety of ways. Chlorine is more effective at killing pathogens at higher temperatures but at lower temperatures, the chlorine residual will last longer. Practically speaking, chlorine disinfection works better in warmer temperatures as more credit is given with the CT calculation. The pH level of the water is also a significant factor when treating with chlorine. The ratio of HOCl to OCl- is affected based on the pH. HOCl will remain the dominant disinfectant in water with a lower pH while OCl- will remain in higher quantities in water with a higher pH.

In the disinfection process, chlorine not only reacts with organisms that are to be killed, but it also reacts with the turbidity in the water and other substances such as ammonia. Reducing turbidity in treated water through coagulation, sedimentation, and filtration

ensures disinfection will be more effective. The maximum and minimum chlorine residual in the distribution system is 4.0 mg/L and 0.2 mg/L respectively. However, corrective measures must be taken when you see the residual in the distribution system dramatically decreasing. You would never want to see the minimum chlorine residual of 0.2 in the distribution system.

Chlorine Chemistry

Below is the reaction that occurs between water and free available chlorine:

$$\underset{\text{(hypochlorous acid)}}{HOCl} + \underset{\text{(hydrochloric acid)}}{HCl} \quad \underset{\text{(Chlorine)}}{Cl_2} + \underset{\text{(Water)}}{H_2O} \longrightarrow \quad (6.8.2)$$

Hypochlorous acid is more effective of the two forms of available chlorine. First, it is important to understand how chlorine demand works. We can do this by examining the effects of adding free available chlorine to distilled water. If we were to dose distilled water with 1.0 mg/L of free available chlorine, the residual would be 1.0 mg/L chlorine because there is nothing in distilled water that will react with the chlorine other than the water itself. Distilled water lacks impurities.

It is clear that the raw source water is filled with impurities. Chlorine will have many constituents to react with during the treatment process. When the Chlorine reacts with the water and the impurities, five different types of chlorine residuals result. The following chart illustrates the effectiveness of each type of residual. The most effective is hypochlorous acid (HOCl) so the effectiveness of the remaining four types of residuals are in comparison to HOCl.

Table 8.2: Effectiveness of Different Residuals

Residual	Abbreviation	Effectiveness
Hypochlorous Acid	HOCl	1
Hypochlorite Ion	OCl-	1%
Trichloramine	NCl_3	More info later in the chapter
Dichloramine	$NHCl_2$	1.25 %
Monochloramine	NH_2Cl	.667%

As the chart shows, dichloramines are a “more effective” disinfectant than monochloramines but their use may cause taste and odor problems. The effectiveness of trichloramines has not been extensively researched and as with dichloramines, a pungent taste and odor problem occurs with its use. Thus the water industry only uses monochloramines as a disinfectant. Below are the chemical formulas which illustrate when hypochlorous acid disassociates and becomes a weaker disinfectant.

$$\underset{\text{(Hypochlorous acid)}}{HOCl} \longrightarrow \underset{\text{(Hydrogen ion)}}{H^+} + \underset{\text{(Hypochlorite ion)}}{OCl^-} \quad (6.8.3)$$

$$\underset{\text{(Hypochloric acid)}}{HCl} \longrightarrow \underset{\text{(Hydrogen ion)}}{H^+} + \underset{\text{(Chlorine ion)}}{Cl^-} \quad (6.8.4)$$

Chlorine Handling and Safety

As a Treatment operator, you will come in contact with many dangerous chemicals used to treat water. One chemical that is widely used in the water treatment industry is chlorine. As discussed earlier in the chapter chlorine comes in three different states: gas, powder, and liquid. All three types of chlorine have risks associated with the handling and storage of the chemical. It is important that proper safety procedures are followed at all times.

Chlorine Gas

Chlorine gas is 2.5 times heavier than air. The odor is pungent and the color is greenish-yellow. Gas chlorine is only visible in very high concentrations and you don’t ever want to see it. Chlorine gas is irritating to eyes, nasal passages, and the respiratory system. It is a very dangerous substance and concentrations as low as 100 parts per million can kill a person.

Chlorine gas is available in three different types of containers: 150-pound containers, 1-ton containers, and, for very large plant operations, in railroad containers. A majority of treatment operations will use chlorine tanks. The amount of chlorine used in a given day will determine which type of chlorine container your plant will use.

When delivered to a treatment plant, the “150-pound” chlorine gas cylinder container weighs roughly 250-280 pounds. A chlorine cylinder consists of the cylinder body, neck ring, valve, and protective hood.

Cylinders are transported around the facility with the use of a dolly or hand truck. The use of a safety chain or strap is mandatory at all times. Cylinders should never be rolled because it could lead to employee injury or the shearing off of the valve. The maximum daily withdrawal rate for a chlorine cylinder is 40 pounds.

Chlorine “ton” containers hold 2000 pounds of chlorine and usually weigh around 3700 pounds when filled with chlorine. The Containers are shipped and stored horizontally. The edge of the chlorine container has a ring, which enables cranes and hoists to move them from the truck to the storage or withdrawal area. Containers are stored on trunnions that allow operators to rotate containers with the use of a special tool. Each container has two valves, one at the top and one at the bottom. The top valve allows the chlorine to be withdrawn as a gas while the bottom valve allows chlorine to be withdrawn as a liquid. When putting containers in storage, they should placed such that the liquid chlorine is allowed to settle in the bottom of the container. The maximum daily withdrawal rate for a 1-ton tank is 400 pounds.

Gas chlorine cylinders and 1-ton containers use similar methods to feed chlorine into the water. Feeding systems include a scale, valves and piping, a chlorinator, and an injector or diffuser. The weighing scales are used to keep track of how much chlorine has been used or is left in the cylinder or tank. Record keeping is critical for all chemical use. Monitoring and reviewing the recorded data can help identify problems with the chlorine system and manage costs by reducing chemical waste.



Figure **6.8.1**

Pictured above is a standard chlorine scale and trunnion system. The trunnion acts as a form of storage while also keeping an accurate measure of the amount of chemical left in the tanks. In California, the tanks must also be secured with straps due to earthquakes.

Valves and piping are just as important in the chlorine system as they are in the water system. Each chlorine tank or cylinder is equipped with valves which allow or prohibit the flow of the chlorine during the transfer and storage of the product. In an emergency, the valves can also be used to quickly shutoff the flow of chlorine. Large scale systems will include piping manifolds that allow for the transfer of chlorine from multiple tanks. The associated feed system will include valves and piping to provide chlorine to different feed points in the system.

The chlorinator is the piece of equipment that feeds the chlorine directly into the system. Chlorine is dispersed evenly into the system based on a dosage set point using vacuum and pressure regulators. For safety, a vacuum must be maintained in the line. The vacuum ensures that the chlorine is always being pulled into the chlorine feed system. Most modern systems have emergency shutoff valves which prevent the flow of chlorine if a leak is detected. Chlorine systems will also include alarms, leak detectors, and repair kits.

Other safety measures are also required when working around chlorine gas. For example, when switching tanks, the operator should be wearing a self-contained breathing apparatus (SCBA). As noted earlier, a 0.1 part per million dose of chlorine gas can be immediately fatal.

Hypochlorination

Gaseous chlorine is the strongest and least expensive form of chlorine even with the required use of bases such as caustic soda to increase the pH of the finished water. However, due to safety concerns associated with the use and transportation of gaseous chlorine, Hypochlorination is becoming more common in water treatment. When building or redesigning a treatment plant, an analysis of the costs and benefits of each type of chlorine will determine which type the facility will use.

The two types of hypochlorite used are calcium and sodium. Calcium hypochlorite is a whiteish-yellow dry chemical. It contains 65% available chlorine. Since it is highly reactive with organic compounds, special requirements must be used when storing it. Additionally, it is flammable if enough heat and oxygen are added. Calcium hypochlorite should always be added to water and not the opposite. Generally, Calcium hypochlorite is primarily used for disinfecting new and repaired water mains and storage tanks. It is not used for the day-to-day treatment of finished water.

Sodium hypochlorite is a clear to yellowish liquid available in a variety of different concentrations. Household sodium hypochlorite, known as bleach, is available in a 5% solution. Treatment plant operations will use an industrial-strength concentration of 12.5% available chlorine. Sodium hypochlorite does not have special storage requirements, but it is a strong base at 9-11 on the pH scale so it is highly corrosive. Additionally, the chemical loses its effectiveness over time in storage. Stored for a month, the chemical can lose 2% to 4% of its chlorine content. Direct exposure to sun and/or heat will further the loss of available chlorine. Therefore, it is recommended that sodium hypochlorite be stored no more than two weeks (in the event the treatment plant is offline) in a temperature-controlled room to prevent excessive strength loss.

Cylinder Tank Safety and Connecting

When attaching a chlorine regulator to a tank to go into service, safety precautions must be used. Any time you are dealing with gas chlorine the operator must wear a respirator, but a SCBA is recommended. The SCBA has a 30-60 minute supply of oxygen. SCBA's operate under positive pressure, so in the event of a leak, no chlorine gas will be able to enter your mask, assuming a proper seal of the mask has been established. Along with a respirator or SCBA the operator should wear gloves and a long sleeve shirt when changing cylinders or tanks.

A new lead washer should be used every time a new tank is put into service. Inspect the lead washer for any deformities, cracks, or bends. Washers must be thrown out after one use. When the chlorine tank valve is first opened, rapidly open and close the valve. Use an ammonia solution near the valve and tubing to check for leaks. The ammonia solution used is commercial Be ammonia. If chlorine is present, you will see a white cloud. In the event of a white cloud, a leak is present. The operator will have to remove the regulator from the valve and use a new lead washer.

Lastly, be vigilant. Changing chlorine cylinders will become routine as it is something you will have to do often if your facility uses chlorine gas. Chlorine gas is a highly dangerous chemical that must be respected. Forgetting how dangerous it is, could lead to serious harm or death for you or your co-workers.

Chapter Review

1. The form of Chlorine which is 100% available chlorine is?
    1. Sodium hypochlorite
    2. Calcium hypochlorite
    3. Calcium hydroxide
    4. Gaseous chlorine
2. What is the minimum amount of chlorine residual required in the distribution system?
    1. There is no minimum
    2. mg/L
    3. 0.2 mg/L
    4. mg/L
3. What is the approximate pH range of sodium hypochlorite?
    1. 4-5
    2. 6-7
    3. 9-11
    4. 12-14
4. What is the typical concentration of sodium hypochlorite utilized by water treatment professionals?
    1. 5%
    2. 65%

3. 100%
4. 12.5%

5. Chlorine demand refers to _____.
    1. Chlorine in the system for a given time
    2. The difference between chlorine applied and chlorine residual—usually caused by inorganics, organics, bacteria, algae, ammonia, etc.
    3. Chlorine needed to produce a higher pH
    4. None of the above
6. What is the most effective chlorine disinfectant?
    1. Dichloramine
    2. Trichloramine
    3. Hypochlorite ion
    4. Hypochlorous acid
7. What can form when chlorine reacts with natural organic matter in source water?
    1. Disinfectant by-products
    2. Sulfur
    3. Algae
    4. Coliform bacteria
8. What is the maximum withdrawal rate per day for a 150-pound chlorine cylinder?
    1. There is no maximum
    2. 20 pounds
    3. 40 pounds
    4. 50 pounds
9. What kind of solution is used to check for a gas chlorine leak?
    1. Sodium hydroxide
    2. Ozone
    3. Ammonia
    4. Calcium hypochlorite
10. Chlorine is _____.
    1. Heavier than air
    2. Lighter than air
    3. Brown in color
    4. Not harmful to your health
11. Chlorine demand may vary due to _____.
    1. Chlorine demand always stays the same
    2. Temperature
    3. pH
    4. Both 2 and 3
12. What effect does high turbidity have on disinfection?
    1. It can increase chlorine demand
    2. It has no effect
    3. It gives the water a milky appearance that will clear out after some time
    4. You must increase the temperature of the water

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6.9: Chloramination and Nitrification

Learning Objectives

After reading this chapter you should be able to explain and identify the following topics:

- Why chloramine treatment has been employed, (hint) DBP formation
- The use of ammonia in water treatment
- Breakpoint chlorination
- Nitrification

The water treatment profession is constantly evolving and continuously in motion. Advancements in science and lab procedures help water professionals find constituents in drinking water that can be harmful to human beings. We take for granted the fact that clean drinking water will flow when we turn on the tap.

Currently, chlorine is the best disinfectant available. However, the use of chlorine causes any number of disinfectant by-products (DBPs). Many of the DBPs have not been researched and are not regularly monitored. As screening methods improve, it is likely that more of the possible DBPs will be regulated in the future. Trihalomethanes (THMs) are a DBP of chlorine disinfection and are classified as volatile organic chemicals. Rising THM levels in raw water are increasing the use of chloramine as the preferred disinfectant. In this chapter, we will discuss chloramine disinfection and the associated challenges that come with its implementation. Nothing is easy in water treatment.

Why Use Chloramines?

As discussed, chlorine has been used with great effectiveness in water treatment for many years in the United States. However recently, many water agencies have been switching to Chloramine treatment. Now here is the twist; they have done it because they must, not because they necessarily want to. When natural organic matter reacts with chlorine, it can result in the formation of DBPs, specifically trihalomethanes (THM) and haloacetic acids (HAA5). It is believed that long term exposure to these DBPs should be avoided as it may lead to cancer.

Because of the implementation of the Stage 2 DBP Rule in 2012, many water agencies could no longer meet the regulatory limits established, if they continued using chlorine as a primary disinfectant. To continue using chlorine alone, enhanced coagulation would have to be used but its effectiveness is limited. Carbon or GAC absorption is also a solution but it is very expensive, and thus not employed by larger water treatment facilities. The other option is to limit contact with the water and chlorine, but this is limited by the chlorine demand. The last and most effective option is to use chloramines.

Chloramine treatment is also effective in limiting taste and odor problems in finished water. When free chlorine reacts with phenol it can cause taste and odor issues. Chloramine disinfection is not as strong a disinfectant as free chlorine, chlorine dioxide, or ozone, but it does leave the longest-lasting residual in finished water. Because of chloramines weaker disinfecting power, it is often added just before the treated water enters the clearwell for storage. If implementing this method, the operator must ensure the THM levels are low enough as not to violate any regulations. Determining the most effective way to treat drinking water while remaining in compliance is a complex and difficult task.

Chloramine Chemistry

Chlorine reacts with a number of substances in water including dissolved organic matter, particulate organic matter, iron, nitrite, sulfide, and ammonia. It reacts by taking away an electron from them. Ammonia in the water supply is undesirable as it strips away the Chlorine residual which then requires the need to use more Chlorine. What makes chloramine treatment so effective is chlorine's quick formation with ammonia (NH_3). (Ammonia is a compound of Nitrogen and Hydrogen.)

$$Cl_2 + NH_3 \longrightarrow NH_2Cl + HCl \tag{6.9.1}$$

Note that monochloramine is expressed as NH_2Cl.

The unit weight of Chlorine is 70 and the unit weight of Nitrogen is 14. When chloramine treatment is employed, the ratio of chlorine to ammonia will always be 5:1 because 5 mg/L of chlorine will always combine with 1.0 mg/L of ammonia. (70 ÷ 14 = 5)

You will often hear monochloramines referred to as combined chlorine due to this reaction.

Below is a list of terms dealing with Chloramine disinfection:

- Free Chlorine: Cl_2 (Free chlorine can refer to gaseous, sodium hypochlorite, or calcium hypochlorite.) If using hypochlorite, remember you must dose the water to achieve 100 percent free chlorine.
- Monochloramine: NH_2Cl or combined chlorine. Chloramine with the least taste and odor problems.
- Free Ammonia: NH_3 Ammonia is measured as nitrogen
- Chlorine: Ammonia ratio: Total chlorine to total ammonia nitrogen. You will always target a 5:1 ratio to avoid excess free chlorine or free nitrogen in the water supply.

Breakpoint Chlorination

The breakpoint chlorination curve is the visual representation of chlorine's ability to react with a variety of compounds to form a combined chlorine residual or to completely react with compounds to form a free chlorine residual. When using free available chlorine as a disinfectant we want to stay out of the combined curve. Some water agencies buy imported water that has a combined residual. To treat the water more effectively or eliminate the possibility of nitrification, some of these agencies add chlorine to "break" over to a free chlorine residual. We will discuss Nitrification in greater detail later in this chapter.

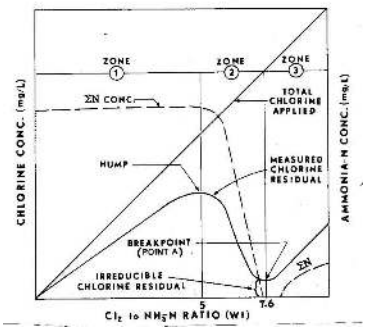


Figure **6.9.1**: The breakpoint chlorination curve. This curve represents chlorine's ability to have either a combined residual or a free residual. Image by the NSW Department of Premier and Cabinet is licensed under CC BY 4.0

A common problem that operators run into when using combined chlorine is "breaking over" to free chlorine by misdiagnosing problems on the treatment plant. For example, an operator is looking at a Supervisory Control And Data Acquisition (SCADA) screen. (SCADA is the computer system that monitors and controls the plant.) For the sake of ease, we will call this operator #1. He or she notices the chlorine effluent residual is beginning to drop. Operator #1 was not aware that the previous operator (Operator #2) had raised the chlorine dose a few hours before. With the added chlorine dose, the chlorine residual was "lowering" as it got closer to breaking over. If operator #1 panics and raises the chlorine dose again the combined chlorine residual will lower even further.

The important thing to remember is there are many things to look at if your chlorine dose is lowering. It may very well be an issue with your chlorine feed, but there are many other options to consider. If you check your chlorine feed system and everything is functioning normally, you may have an issue with the ammonia feed system. Many modern water treatment facilities have calculations built into the SCADA system that make chloramine dosing easier. Make sure to go to the screen with the chlorine: ammonia: ratio to make sure that it is set up correctly.

Lastly, free chlorine is always the preferred disinfectant as it is 25 times stronger a disinfectant than chloramines. However, chloramines last much longer in the distribution system. There are several factors that may lead to a lowered chlorine residual. An increase in biological growth is possible, but you should see other signs such as an increase in turbidity. The most common problem in chloramine treatment with a decreasing chlorine residual is operator error or an issue with the water treatment process.

Nitrification

Nitrification is a process in which bacteria reduces ammonia and organic nitrogen in treated water into nitrate and then nitrite. This condition usually occurs during the summer months when water temperatures are higher. It can also occur during the improper

turnover of reservoirs, when there are high levels of ammonia, and in dark environments, a typical condition for most water reservoirs.

This condition is one of the drawbacks of chloramine treatment. Nitrate and Nitrite are inorganic chemicals regulated by primary drinking water standards. The MCL (Maximum Contaminate Level) for Nitrate is 10 ppm and the MCL for Nitrite is 1 ppm. High nitrate and nitrite levels in drinking water can lead to methemoglobinemia also known as “blue baby syndrome.” This condition affects infants under six months old that consume water contaminated with nitrates and nitrites. The infant's blood is not able to carry enough oxygen to blood cells and tissue within their body.

The condition of Nitrification is a reoccurring cycle that can lead to the total loss of chloramine residual in the distribution system and in water storage tanks. If this was to occur, all the water in the system would have to be dumped and it would be a total loss. As an operator, this is something that you never want to happen. Not only would it be a loss of money for your company, but it could lead to an outbreak of methemoglobinemia. The cycle is below:

Chloramine decay → Release of ammonia→ oxidation of ammonia to nitrite from oxidizing bacteria → Biomass increase → (back to chloramine decay until there is a possibility of total loss of residual)

Some early indicators of nitrification:

- Lowering chloramine residual
- Increase in bacterial heterotrophic plate counts
- Excess ammonia in the treated water
- Total coliform positive samples

In summation, nitrification can cause a variety of problems and violations within the water system. What can we as operators do to minimize any chance of nitrification from occurring? There are a few steps every operator can take to avoid nitrification. First, you want to minimize free ammonia in treated water. Sampling and equipment around the treatment plant will help operators determine if there is too much free ammonia in the treated water.

Second, operators should always maintain a good chlorine residual. Isn’t that the name of the game? Sure, but it is easier said than done in some cases. Many water treatment companies will lower their target chlorine residual in the summer to save on costs because the disinfectant works more efficiently during the summer months. It is a good practice in theory, but not necessarily the best practice if you are working with chloramines and trying to combat nitrification.

Reducing water age is the third step operators can use to combat nitrification. This can be done by cycling reservoirs during the summer months and taking reservoirs out of service during the winter when water demands are lower. Distribution operators are continually balancing maintaining a good amount of water for fire flow and demand, but also cycling reservoirs to fight nitrification. A good practice is to take all the reservoirs in the distribution system and divide it into thirds. At any given point during the day 1/3 of the reservoirs are full, 1/3 are in the middle range, and 1/3 are in the lower range. This allows operators to cycle water while also keeping water in the system.

The last step is to keep the water system clean. This can be accomplished by flushing dead ends to prevent lower chlorine residuals at the end of the distribution system. Boosting chlorine by adding it directly to a reservoir is also an option but not always the best practice. The problem with this method is it could lead to short circuiting. Chlorine must mix adequately to be effective. Mixing can be accomplished by adding mechanical mixers in the reservoir to keep water moving and prevent short circuiting. Chlorine can also be added to the inlet of the reservoir so the water pressure acts as a mixer.

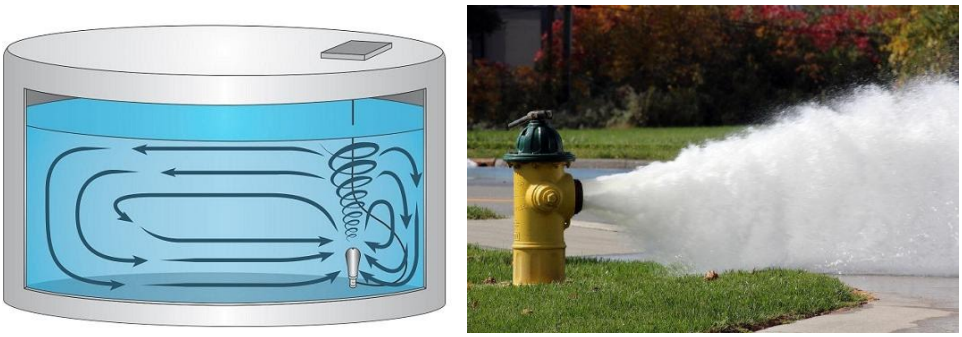


Figure 6.9.2: (left) an example of a water reservoir mixer used to cycle water and prevent short-circuiting. (right) Hydrant flushing (CC0)

Hydrant flushing is a method that can be used to get rid of stagnant water at the ends of a distribution system. Stagnant water can lead to lower chlorine residuals and possible nitrification.

In summary, the use of chloramines as a disinfectant is being employed by many water agencies in the United States to prevent DBP formation. It is not the most ideal disinfectant available, but it does have some advantages. Chloramine disinfection limits DBP formation and has a longer-lasting disinfectant residual. This can be useful for larger systems where water must travel great distances to get to storage.

The drawbacks include the difficulty in effectively managing the breakpoint chlorination curve and managing nitrification. Because of advancements in water quality testing and more stringent regulations with DBPs, chloramine treatment is and will continue to be a more popular option in water treatment.

Chapter Review

1. What is the target chlorine to ammonia ratio?
    1. 2:1
    2. 3:1
    3. 4:1
    4. 5:1
2. What is the MCL for nitrates?
    1. 1 ppm
    2. 10 ppm
    3. 5 ppm
    4. None of the above
3. What is the atomic weight of chlorine?
    1. 70
    2. 14
    3. 65
    4. 20
4. What disinfectant has the longest-lasting residual?
    1. Ozone
    2. Chlorine
    3. Chloramine
    4. Chlorine dioxide
5. What are some of the early indicators of nitrification?
    1. Lowering chlorine residual
    2. Excess ammonia in treated water
    3. Raise in bacterial heterotrophic plate counts
    4. All of the above

6. What are THMs classified as?
    1. Turbidity
    2. Radiological
    3. Volatile organic chemicals
    4. Salts
7. What method can operators employ to combat nitrification?
    1. Lower residual chlorine target
    2. Keep reservoir levels static
    3. Minimize free ammonia in treated water
    4. Increase water age
8. How many times stronger is Chlorine compared to monochloramine?
    1. 25 times
    2. 20 times
    3. 15 times
    4. 5 times

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6.10: Laboratory

Learning Objectives

- After reading this chapter you should be able to identify and explain the following topics related to treatment plant laboratories:
- Equipment in the laboratory
- Laboratory safety
- Water quality testing
- Contaminants tested in the laboratory and throughout the treatment plant

Working in a laboratory is probably something you never thought about when deciding to explore the career of water treatment. However, working in a laboratory is one of the more critical aspects of the profession. Many larger agencies have a dedicated staff of laboratory personnel that handles a lot of the day to day water quality analysis, but operators still play a key role. After all, the operator is the person in charge of running the plant, monitoring chemical feeds, and performing routine plant checks to ensure the system is running smoothly. A laboratory scientist can run all the tests in the world, but since they are not the ones running the plant, a lower chlorine residual may not stand out to them. The responsibility falls squarely on the shoulders of the operator. State regulations require operators to take grab samples throughout the day to ensure monitoring equipment throughout the plant is running correctly.

This topic is discussed at length in the water quality course. This is meant to be a brief overview if you have not taken that course yet.

Laboratory Instruments and Equipment

Throughout the lab, you will find a variety of beakers, flasks, dilution bottles, and graduated cylinders. A lot of these instruments look the same or similar but they all have a unique job and purpose. Beakers range in size from 25 to 4000 mL. They are used to mix samples during chemical analysis. A burette is a long skinny tube-like glass receptacle used to measure and disperse liquid. Flasks have a narrow neck and are round at the bottom. Each kind of flask serves a different purpose, but they all look very similar.

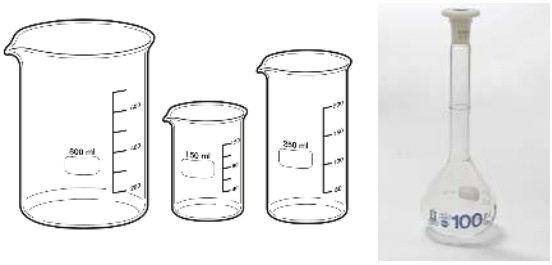


Figure 6.10.1: (left) Beakers – Image by Xavax is in the public domain. (right) Volumetric flask – image by Lucasbosch is licensed under CC BY-SA 3.0

Graduated cylinders are tall and cylindrical and range in size from 10 mL-4000 mL. They are used to measure liquid, but not with accuracy. For example, they can be used during a chlorine test to gather a general volume of water. If you need an exact amount, it should be measured with a pipette or other similar and accurate liquid measuring device. The pipette measures a liquid with 100 percent accuracy.



Figure 6.10.2: Sample Bottle – Image by Σ64 is licensed under CC BY-SA 3.0

You will find sample bottles in any laboratory. The bottles can be made of plastic or glass. They are used to store water for future lab tests and not used for measuring liquid. Sample bottles are used to collect bacteriological samples and for organic chemical analysis. The bacteriological bottle is one of the most important sample bottles you find in a lab. They are made of plastic and are 100 mL. Water treatment operators must take bacteriological samples per the Total Coliform Rule. These tests will be performed daily in the lab and throughout the distribution system based on your coliform sampling plan.

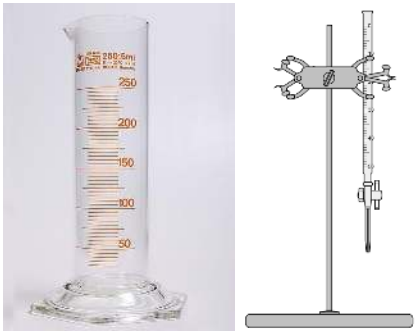


Figure **6.10.3**: (left) Graduated Cylinder – Image by Lilly_M is licensed under CC BY-SA 3.0. (right) Burette – Image by Roland1952 is licensed under CC BY-SA 3.0.

Other Items Found In the Laboratory

Incubators will be found in every lab at a water treatment plant. They are used to hold a temperature for bacteriological cultures. There are two types of incubators used, dry heat and water baths. Common uses for incubators include coliform testing, multiple tube testing, and heterotrophic plate counts. Ovens are other pieces of equipment found in the lab. Autoclaves, for example, are used to sterilize glassware items but can also be used to sterilize material that has been contaminated from perhaps a positive coliform test. Refrigerators are used to store samples for future testing and to store chemicals used for water quality testing. These refrigerators are for work use only and should not be used to store food and beverages.

Laboratory Safety

Operators should always be aware of safety regardless of where they are at the treatment plant. The laboratory should be treated no differently than if an operator was changing chlorine cylinders. There are chemicals that are combustible and others that can cause severe burns if they are exposed to skin. Some common safety equipment found in water treatment plant laboratories:

- Eye protection—Eye protection should include safety goggles, safety glasses, or face shields. It is not recommended to wear contact lenses if working with dangerous chemicals. Prescription safety eyewear is available. You only have one set of eyes, so it is important to protect them. Water laboratories have liquids and solids that can easily penetrate your eyes if you are not wearing the proper PPE (personal protective equipment).
- Safety Showers/Eyewash Bottles—In the event that something gets in your eyes, every lab is equipped with a safety shower. The shower should have a pull lever and an eyewash sink.
- Fire Extinguisher—Fire extinguishers are located throughout any building in the United States. Most water treatment companies will provide formal training on proper use of a fire extinguisher. In the event that you cannot put a lab fire out with the use of an extinguisher, exit the room right away and call the fire department. Fire extinguishers are meant to put out very small fires very quickly.



Figure **6.10.4**: Emergency eyewash and shower – Image by Korn966 is licensed under CC BY-SA 4.0

Meters

Laboratories use a variety of meters for water quality testing. Although meters are located throughout the treatment plant, the meters in the lab are used to verify that equipment throughout the treatment plant is functioning correctly. The most common meters used by water treatment operators are pocket colorimeters for chlorine testing in the field, turbidity meters, and pH meters. Pocket colorimeters are great to be used in the field, but the results are not reportable. For compliance purposes, you must use an electric colorimeter or photometer.

pH meters and turbidimeters are used to verify equipment is working throughout the plant. At a minimum, an operator will run labs on turbidity, chlorine residual, water temperature, and pH. All of these parameters are required for CT compliance and verification. These measurements are important in ensuring the treatment plant is operating in compliance with the surface water treatment rule.

Microbiological Testing

Microbiological testing is probably the most important testing done by water treatment professionals. As discussed at length in this text, treatment water operators aim to remove and deactivate pathogenic organisms from drinking water through filtration and disinfection. Water regulations require 3Log removal and deactivation of *Giardia* and 4 log removal and deactivation of viruses. Bacteria fall in the middle of *Giardia* and viruses. Therefore, it is safely assumed bacteria will be removed and deactivated along the same process.

Water professionals test for microbiological agents by testing for the indicator organism coliform. Coliform bacteria cause no harm to humans but are generally present when pathogens are present in the water. The reason coliforms have been used to identify contaminated water for over 100 years is because they are always present in contaminated water. Even if there is no fecal contamination, they are still present. They survive longer in water than pathogens and they are easy to identify with proper testing. When a positive sample is identified, we assume the water is contaminated until it can be proven otherwise.

Water treatment facilities use four different tests for coliform monitoring. The easiest, least expensive, and the most common method for coliform testing is the presence absence test (P-A). Both the P-A and multiple tube fermentation (MTF) tests work based on the fact that coliform produces gas from the fermentation of lactose within 24-48 hours. The MTF method uses three steps for the test. It includes the presumptive, confirmed, and completed test cycle. The presumptive test is accomplished in 24 hours. Samples are incubated at 35 degrees Celsius for 24 hours and then checked to see if a gas bubble has formed or if the sample is cloudy. You want to see no bubble or gas. The samples are then incubated for another 24 hours. If gas does not form, the test is over and the sample is absent. If there is a gas bubble, you move on to the confirmed test.

The confirmed test verifies the sample is positive from coliform and not another type of bacteria. Brilliant Green Lactose Vile is added to the sample and then incubated for another 48 hours. The same method is used. The lab technician or operator checks to see if gas is produced during the incubation period. The minimum requirement for water treatment operations is the presumptive and confirmed test. The completed tests are rarely used except for quality control by laboratory personnel. In the event of a positive confirmed test, coliform bacteria violation protocol will go into effect.

The P-A method is the most common method for treatment operators and field sampling staff. The bottles are easily transferred in an ice chest and the set-up is very simple. This method is commonly referred to as the Colilert method. The test uses a 100 mL plastic sample bottle. A nutrient is added to the sample, which is then incubated for a period of 24 hours at 35 degrees Celsius. The nutrient will cause the water to turn yellow if coliforms are present. In the event of a positive test, the bottle can be placed behind a fluorescent light that will turn a blue color which indicates fecal E. coli contamination.

The other two bacteriological tests include MMO-MUG and the membrane filter method. The MMO-MUG tests come with the testing agent already in the vials. A 10 mL sample is simply added to the vial. As with the P-A test, samples positive for coliform will turn yellow and for fecal contamination will turn blue. The membrane process begins with filtering 100 mL of water through a membrane filter. Then the sample is added to a petri dish and incubated for a 24-hour period. Coliform positive samples turn a red-pink color. Confirmative tests require incubation of a broth for another 24 hours.

Physical Water Quality

Operators test the water for both physical properties and contaminants that will cause harm to humans. There are secondary standards related to many of the physical tests operators perform. Acidity is the ability to neutralize a base. Alkalinity is the ability of water to neutralize acid. The reason operators are concerned with the acidity and alkalinity of drinking water is different pH scales have different effects on water treatment. When acids are added to water, they lower the pH of the water. A strong base may need to be added to boost the pH. Operators want a small amount of calcium carbonate present in the water to deposit around the pipes of the distribution system. This helps combat corrosion.

When we think of water drinkability, we might think of color, taste, odor, and temperature. The physical aesthetic of the water matters and impacts our desire to drink the water. The color of the drinking water may indicate water with higher levels of organic compounds and water with THMs.

Taste and odor issues in treated drinking water are hard to test. Many customers complain of a strong chlorine smell in their drinking water. Taste and odor problems can come from organic matter, chlorine, dissolved gases, and even industrial wastes. The threshold odor test is measured on the TON scale. (Water sample of 100 mL + dilution divided by 100 = TON.) Water registering as a 3 will most likely draw complaints from customers.

Water temperature plays a key role in water treatment because disinfectants work better at higher temperatures. However, nitrification occurs during the warmer months of the year so the water temperature has to be carefully managed. Water agencies in colder regions of the country must deal with freezing conditions within their treatment and distribution system. During the winter even in warmer regions, lake turnover can cause vast changes in water quality.

Turbidity is the suspension of particles in water. High levels of turbidity can signify major issues within the treatment plant. Therefore, turbidity is used to verify how efficiently the treatment plant is operating. High turbidity values may indicate higher levels of organic and inorganic matter. Pathogenic organisms can hide behind turbidity and render disinfection ineffective. Turbidity is measured in the lab with a nephelometric counter. A light source is added and, in the presence of turbidity, the light scatters, producing higher numbers with greater amounts of turbidity.

The final two water quality testing procedures most commonly performed by water treatment operators are chlorine and pH. The chlorine or chloramine feed system is one of the most critical components of a water treatment plant that operators monitor through online testing and grab samples.

The measurement of the hydrogen ion concentration in water is pH. The pH scale ranges from 1- 14 with 1 being the most acidic and 14 the most basic. The higher ends of both ranges produce the most corrosiveness. 7 is considered neutral. Do not confuse pH with acidity or alkalinity. It is important to monitor pH because the pH is used to control many chemical reactions in the treatment plant including coagulation, disinfection, corrosion control, and the removal of ammonia. pH also plays a key role in the CT calculation.

Chapter Review

1. An organism used to indicate the possible presence of E. coli contamination is _____.
    1. *Cryptosporidium*
    2. *Giardia*

3. Coliform
4. Brilliant green vile

2. The presence-absence (P-A) test used for microbiological testing is also commonly referred to as _____.
    1. Multiple tube fermentation
    2. Membrane filtration
    3. Confirmed test
    4. Colilert
3. When testing for coliform bacteria with the multiple tube fermentation (MFT) method what is the best indicator for a positive test?
    1. Color change
    2. Gas bubble formation
    3. Formation of a cyst
    4. Formation of turbidity
4. Coliform bacteria share many characteristics with pathogenic organisms. Which of the following is not true?
    1. They survive longer in water
    2. They grow in the intestines
    3. There are less coliform than pathogenic organisms
    4. They are still present in water without fecal contamination
5. What is the second step in the multiple tube fermentation test?
    1. Presumptive test
    2. Negative test
    3. Completed
    4. Confirmed
6. What is the removal and deactivation requirement for *Giardia*?
    1. 2 Log
    2. 3 Log
    3. 4 Log
    4. There is no requirement
7. The multiple barrier approach to water treatment includes removal through which method?
    1. Filtration
    2. Coagulation
    3. Disinfection
    4. Both 1 and 3
8. A pH reading of 7 is considered _____.
    1. Slightly acidic
    2. Acidic
    3. Basic
    4. Neutral
9. A higher than normal turbidity reading could signify _____.
    1. A change in water quality
    2. Nothing. Keep operating as normal
    3. Microbiological contamination
    4. Both 1 and 3
10. What is the ingredient used during the second multiple tube fermentation test?
    1. Colilert
    2. MMO/MUG
    3. Brilliant green vile

4. Chlorine

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