

WTRM 202: BEGINNING WATER, WASTEWATER, DISTRIBUTION MATH



Regina Blasberg, Mike Alvord & Kelly Brooks
College of the Canyons & Eastern
Gateway Community College

WTRM 202 Beginning Water, Wastewater, Distribution Math

by

Catherine Ames

Remixed for Gavilan College

ZTC Grant Funding provided by the ASCCC 2025

This text is disseminated via the Open Education Resource (OER) LibreTexts Project (<https://LibreTexts.org>) and like the thousands of other texts available within this powerful platform, it is freely available for reading, printing, and "consuming."

The LibreTexts mission is to bring together students, faculty, and scholars in a collaborative effort to provide an accessible, and comprehensive platform that empowers our community to develop, curate, adapt, and adopt openly licensed resources and technologies; through these efforts we can reduce the financial burden born from traditional educational resource costs, ensuring education is more accessible for students and communities worldwide.

Most, but not all, pages in the library have licenses that may allow individuals to make changes, save, and print this book. Carefully consult the applicable license(s) before pursuing such effects. Instructors can adopt existing LibreTexts texts or Remix them to quickly build course-specific resources to meet the needs of their students. Unlike traditional textbooks, LibreTexts' web based origins allow powerful integration of advanced features and new technologies to support learning.



LibreTexts is the adaptable, user-friendly non-profit open education resource platform that educators trust for creating, customizing, and sharing accessible, interactive textbooks, adaptive homework, and ancillary materials. We collaborate with individuals and organizations to champion open education initiatives, support institutional publishing programs, drive curriculum development projects, and more.

The LibreTexts libraries are Powered by [NICE CXone Expert](#) and was supported by the Department of Education Open Textbook Pilot Project, the California Education Learning Lab, the UC Davis Office of the Provost, the UC Davis Library, the California State University Affordable Learning Solutions Program, and Merlot. This material is based upon work supported by the National Science Foundation under Grant No. 1246120, 1525057, and 1413739.

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation nor the US Department of Education.

Have questions or comments? For information about adoptions or adaptations contact info@LibreTexts.org or visit our main website at <https://LibreTexts.org>.

This text was compiled on 04/23/2026

TABLE OF CONTENTS

Licensing

1: Waterworks Mathematics (Alvord and Blasberg)

- 00: Front Matter
 - Table of Contents
- 1.1: Mathematical Review- Fractions
 - 1.1.1: Understanding Fractions
 - 1.1.2: Reducing Fractions
 - 1.1.3: Why Fractions
 - 1.1.4: Multiplying Fractions
 - 1.1.5: Dividing Fractions
- 1.2: Decimals
 - 1.2.1: Understanding Decimals
 - 1.2.2: Multiplying and Dividing Decimals
 - 1.2.3: Rounding
- 1.3: Percentages
 - 1.3.1: Expressing Numbers as Percentages
 - 1.3.2: Word Problems
- 1.4: Equations and Word Problems
 - 1.4.1: Solving Equations
 - 1.4.2: Ratios and Proportions
- 1.5: Unit Dimensional Analysis
 - 1.5.1: Units
- 1.6: Geometric Shapes
 - 1.6.1: Areas
 - 1.6.2: Volumes
 - 1.6.3: Circumference
- 1.7: Water Hydraulics
 - 1.7.1: Pressure
 - 1.7.2: Force
 - 1.7.3: Flow Rate
- 1.8: Chemical Dosage Analysis and Waste Water Treatment
 - 1.8.1: The "Pound Formula"
 - 1.8.2: Food to Microorganism Ratio
 - 1.8.3: Mean Cell Residence Time (MCRT)
- 1.9: Water Treatment Mathematics
 - 1.9.1: Detention Time
 - 1.9.2: Weir Overflow Rate
 - 1.9.3: Filtration Rate
- 1.10: Engineering and Construction
 - 1.10.1: Planning
- 1.11: Using What You Learned and Preparing for Certification Exams

- [1.11.1: Examples](#)

2: Water Distribution Operator I (Alvord)

- [00: Front Matter](#)
 - [Table of Contents](#)
- [2.1: Introduction To The Operator Certification](#)
- [2.2: Sources and Characteristics of Water](#)
- [2.3: Regulations](#)
- [2.4: System Design](#)
- [2.5: Pipelines](#)
- [2.6: Valves](#)
- [2.7: Hydrants](#)
- [2.8: Meter Services](#)
- [2.9: Pumps](#)
- [2.10: Wells](#)

3: Mathematics for Wastewater Management (Brooks)

- [00: Front Matter](#)
 - [Table of Contents](#)
- [3.1: Numbers, Decimals, and Fractions](#)
 - [3.1.1: The Set of Real Numbers](#)
 - [3.1.2: Mathematical Operations](#)
- [3.2: Powers, Roots, Order of Operations, and Evaluating Expressions](#)
 - [3.2.1: Powers and Roots](#)
 - [3.2.2: Order of Operations](#)
 - [3.2.3: Evaluating Expressions](#)
- [3.3: Solving Equations and Formulas](#)
 - [3.3.1: Addition, Subtraction, Multiplication, and Division Properties of Equality](#)
 - [3.3.2: Solving a Formula for a Variable \(Rewriting a Formula\)](#)
 - [3.3.3: Solving Quadratic Equations of the Form- \$\(x-a\)^2=c\$](#)
- [3.4: Scientific Notation, Rounding, Conversions, and Dimensional Analysis](#)
 - [3.4.1: Scientific Notation](#)
 - [3.4.2: Rounding](#)
 - [3.4.3: Dimensional Analysis](#)
- [3.5: Ratios, Proportions, and Percentages](#)
 - [3.5.1: Ratios](#)
 - [3.5.2: Proportions](#)
 - [3.5.3: Percentages](#)
- [3.6: Geometry](#)
 - [3.6.1: Definitions](#)
 - [3.6.2: Examples](#)
- [3.7: Reading and Interpreting Graphs](#)
 - [3.7.1: Types of Graphs](#)
 - [3.7.2: Examples](#)

4: Advanced Water Mathematics (Alvord)

- 00: Front Matter
 - Table of Contents
- 4.1: Unit Dimensional Analysis (UDA)
 - 4.1.1: Applying the Math of UDA
- 4.2: Geometric Shapes
 - 4.2.1: The Shapes of Things
 - 4.2.2: Applying the Math of Geometric Shapes
- 4.3: Density and Specific Gravity
 - 4.3.1: It's All About the Weight
 - 4.3.2: Parts Per Hundred vs. Parts Per Million
- 4.4: Chemical Dosage Analysis
 - 4.4.1: It's a Pound Formula!
- 4.5: Weir Overflow Rate
 - 4.5.1: What's a Weir?
- 4.6: Water Treatment Math Detention Time
 - 4.6.1: It's a Lag in Time
 - 4.6.2: Filtration Rates
- 4.7: CT Calculations
 - 4.7.1: How Much For How Long?
- 4.8: Pressure, Head Loss, and Flow
 - 4.8.1: Are You At a Loss?
 - 4.8.2: Head Loss
 - 4.8.3: Flow Rate
- 4.9: Well Yield, Specific Capacity, and Drawdown
 - 4.9.1: It's All Underground
- 4.10: Horsepower and Efficiency
 - 4.10.1: The Power of Water
 - 4.10.2: Head Loss and Horsepower
 - 4.10.3: Calculating Power Costs
- 4.11: per Capital water Usage
 - 4.11.1: How Much Water Do We Really Use?
- 4.12: Blending and Diluting
 - 4.12.1: Is Dilution the Solution to Pollution?
 - 4.12.2: Mixing and Diluting Solutions
- 4.13: Supervisory control and data acquisition (SCADA) and the Use of mA
 - 4.13.1: SCADA?
- 4.14: Water Utility Management
 - 4.14.1: Managing With Numbers

[Index](#)

[Glossary](#)

[Detailed Licensing](#)

[Detailed Licensing](#)

Licensing

A detailed breakdown of this resource's licensing can be found in [Back Matter/Detailed Licensing](#).

00: Front Matter

This page was auto-generated because a user created a sub-page to this page.

TABLE OF CONTENTS

00: Front Matter

- Table of Contents

1.1: Mathematical Review- Fractions

- 1.1.1: Understanding Fractions
- 1.1.2: Reducing Fractions
- 1.1.3: Why Fractions
- 1.1.4: Multiplying Fractions
- 1.1.5: Dividing Fractions

1.2: Decimals

- 1.2.1: Understanding Decimals
- 1.2.2: Multiplying and Dividing Decimals
- 1.2.3: Rounding

1.3: Percentages

- 1.3.1: Expressing Numbers as Percentages
- 1.3.2: Word Problems

1.4: Equations and Word Problems

- 1.4.1: Solving Equations
- 1.4.2: Ratios and Proportions

1.5: Unit Dimensional Analysis

- 1.5.1: Units

1.6: Geometric Shapes

- 1.6.1: Areas
- 1.6.2: Volumes
- 1.6.3: Circumference

1.7: Water Hydraulics

- 1.7.1: Pressure
- 1.7.2: Force
- 1.7.3: Flow Rate

1.8: Chemical Dosage Analysis and Waste Water Treatment

- 1.8.1: The "Pound Formula"
- 1.8.2: Food to Microorganism Ratio
- 1.8.3: Mean Cell Residence Time (MCRT)

1.9: Water Treatment Mathematics

- 1.9.1: Detention Time
- 1.9.2: Weir Overflow Rate
- 1.9.3: Filtration Rate

1.10: Engineering and Construction

- 1.10.1: Planning

1.11: Using What You Learned and Preparing for Certification Exams

- 1.11.1: Examples

SECTION OVERVIEW

1.1: Mathematical Review- Fractions

1.1.1: Understanding Fractions

1.1.2: Reducing Fractions

1.1.3: Why Fractions

1.1.4: Multiplying Fractions

1.1.5: Dividing Fractions

1.1: Mathematical Review- Fractions is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

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

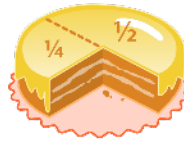


Figure 1.1.1.2: [Cake Fractions](#) by Acidx is in the public domain

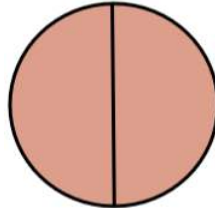


Figure 1.1.1.3: Circle with Proportions by [COC OER](#) is licensed under [CC BY 4.0](#)

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

1.1.1: Understanding Fractions is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- [1.1: Understanding Fractions](#) by Mike Alvord & Regina Blasberg is licensed [CC BY 4.0](#).

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:

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

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

Example:

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

Exercise 1.2

Reduce the following fractions to their lowest terms.

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

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

1.1.2: Reducing Fractions is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- [1.2: Reducing Fractions](#) by Mike Alvord & Regina Blasberg is licensed [CC BY 4.0](#).

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.

1.1.3: Why Fractions is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- 1.3: Why Fractions by Mike Alvord & Regina Blasberg is licensed [CC BY 4.0](#).

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, $2 \times 3 = 6$ and $1 \times 1 = 1$. The resulting answer is 6 over 1 or more simply put 6. However, when “units” are introduced, you can’t just say the answer is “6”. Always remember to reduce as necessary. Look at a couple other examples below:

Example 1.1.4.1

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

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 2×2 . The resulting answer would be 1 over 4 or one fourth. 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

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

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

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

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

Exercise 1.4

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

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

1.1.4: Multiplying Fractions is shared under a [CC BY 1.0](https://creativecommons.org/licenses/by/1.0/) license and was authored, remixed, and/or curated by LibreTexts.

- 1.4: Multiplying Fractions by Mike Alvord & Regina Blasberg is licensed [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/).

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

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

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

13. $5 \div 25$

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

15. $\frac{13}{33} \div \frac{6}{39}$

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

[1.1.5: Dividing Fractions](#) is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- [1.5: Dividing Fractions](#) by Mike Alvord & Regina Blasberg is licensed [CC BY 4.0](#).

SECTION OVERVIEW

1.2: Decimals

1.2.1: Understanding Decimals

1.2.2: Multiplying and Dividing Decimals

1.2.3: Rounding

1.2: Decimals is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

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:

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

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

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

Exercise 2.1.2

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

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

1.2.1: Understanding Decimals is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- **2.1: Understanding Decimals** by Mike Alvord & Regina Blasberg is licensed [CC BY 4.0](#).

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

$$0.255 \times 0.23 = 0.05865$$

$$25 \times 35 = 875$$

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

Exercise 2.2

Multiply the following problems

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

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

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

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

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

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

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

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

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

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

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

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

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

Example 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.

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

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

3. $14 \div 20 =$
4. $0.54 \div 12 =$
5. $75 \div 40 =$
6. $1.44 \div 12 =$
7. $0.48 \div 2.4 =$
8. $156 \div 0.78 =$

1.2.2: [Multiplying and Dividing Decimals](#) is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- [2.2: Multiplying and Dividing Decimals](#) by Mike Alvord & Regina Blasberg is licensed [CC BY 4.0](#).

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

$$2 \times 2 = 4$$

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

$$2.0 \times 2.0 = 4.0$$

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

$$2.0 \times 2 = 4.0$$

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

Why?

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

Example 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.

1.2.3: Rounding is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- [2.3: Rounding](#) by Mike Alvord & Regina Blasberg is licensed [CC BY 4.0](#).

SECTION OVERVIEW

1.3: Percentages

1.3.1: Expressing Numbers as Percentages

1.3.2: Word Problems

1.3: Percentages is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

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.

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

Note that the decimal moves two places to the right.

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

Example 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% =

1.3.1: Expressing Numbers as Percentages is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- **3.1: Expressing Numbers as Percentages** by Mike Alvord & Regina Blasberg is licensed [CC BY 4.0](#).

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 ($\times$) sign. You must also remember to convert the percent to a decimal prior to solving.

1.3.2: Word Problems is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- [3.2: Word Problems](#) by Mike Alvord & Regina Blasberg is licensed [CC BY 4.0](#).

SECTION OVERVIEW

1.4: Equations and Word Problems

1.4.1: Solving Equations

1.4.2: Ratios and Proportions

1.4: Equations and Word Problems is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

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

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

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

Example 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. $15 = 5 + \frac{2}{5}P$

1.4.1: Solving Equations is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- [4.1: Solving Equations](#) by Mike Alvord & Regina Blasberg is licensed [CC BY 4.0](#).

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.

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

Exercise 4.2

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

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

Example 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.

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

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

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

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

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

Exercise 4.2.1

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

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

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

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

Example 1.4.2.3

10% of 100 is

$10\% \times 100 =$

$0.10 \times 100 = 10$

Exercise 4.2.2

Solve the following percent problems.

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

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

Exercise 4.2.3

Solve the following word problems.

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

1.4.2: Ratios and Proportions is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- **4.2: Ratios and Proportions** by Mike Alvord & Regina Blasberg is licensed [CC BY 4.0](#).

SECTION OVERVIEW

1.5: Unit Dimensional Analysis

1.5.1: Units

1.5: Unit Dimensional Analysis is shared under a [CC BY 1.0](https://creativecommons.org/licenses/by/1.0/) license and was authored, remixed, and/or curated by LibreTexts.

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.

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

In the above example, if we just do the first step you can see that canceling seconds will yield minutes as the result. By continuing the same process you can end up with the unit the question is asking.

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

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

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

Example 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.

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

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

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

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

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

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

Exercise 5.1

Solve the following problems using UDA

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

1.5.1: Units is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- 5.1: Units by Mike Alvord & Regina Blasberg has no license indicated.

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

1.6.1: Areas

1.6.2: Volumes

1.6.3: Circumference

1.6: Geometric Shapes is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

1.6.1: Areas

Circle

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

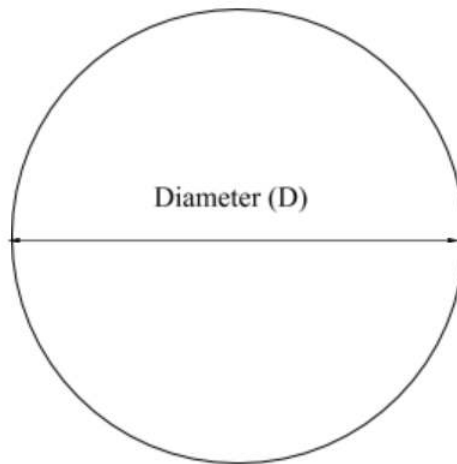


Figure 1.6.1.1: Area of a circle = $0.785 \times D^2$

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

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

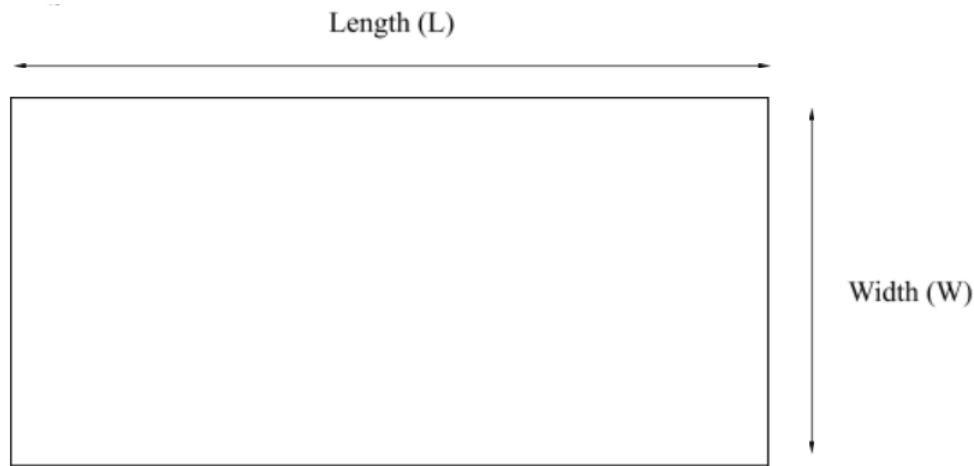


Figure 1.6.1.2: Area of a rectangle = $L \times W$

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

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

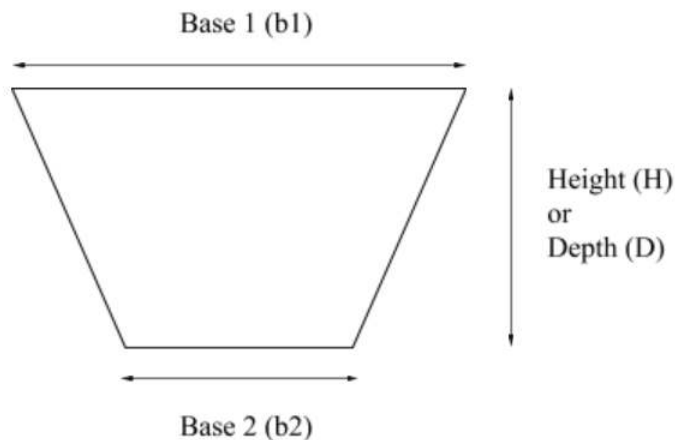


Figure 1.6.1.3: Area of a trapezoid = $\frac{b_1 + b_2}{2} \times H$

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

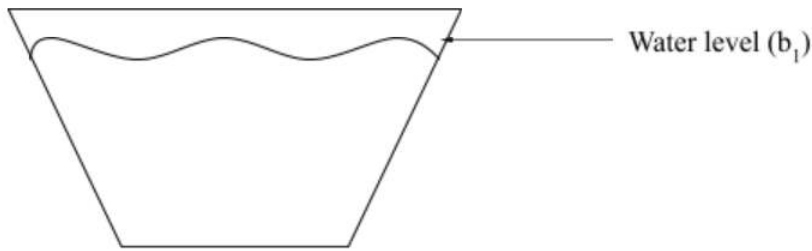


Figure 1.6.1.3: Example of the base 1

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?

1.6.1: Areas is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- **6.1: Areas** by Mike Alvord & Regina Blasberg is licensed [CC BY 4.0](#).

1.6.2: Volumes

Cylinder

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

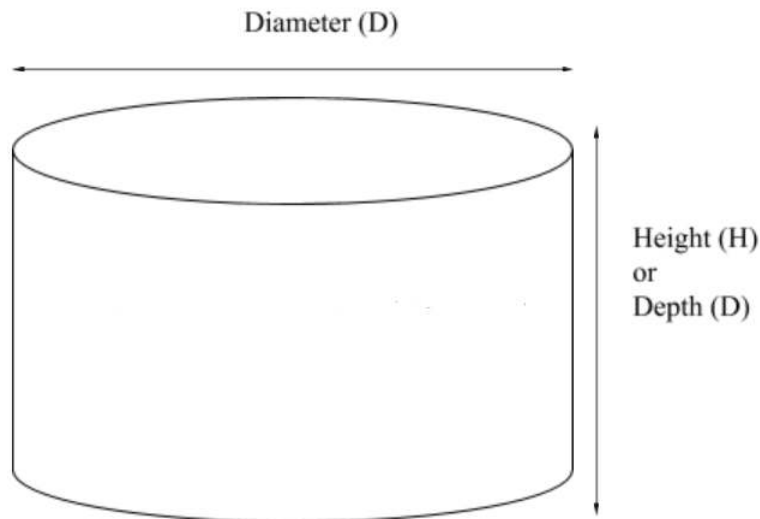


Figure 1.6.2.1: Volume of a cylinder = $0.785 \times D^2 \times H$

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

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

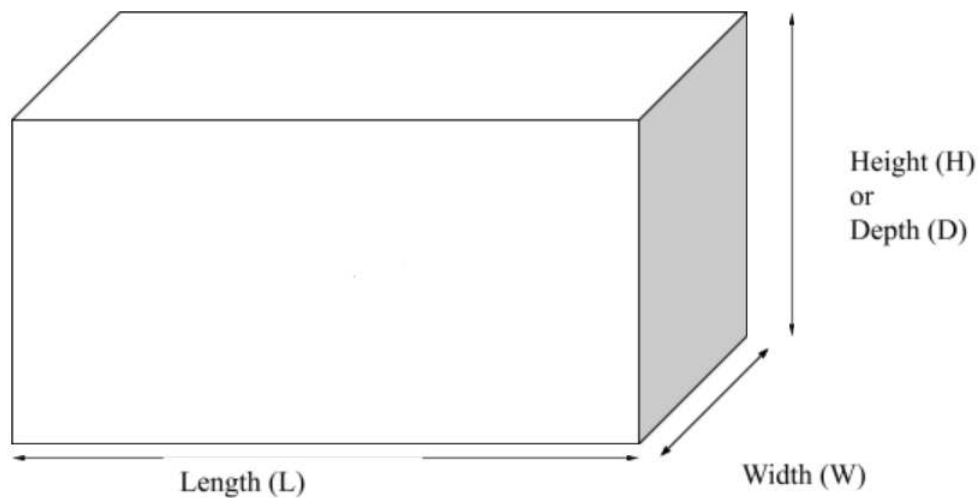


Figure 1.6.2.2: Volume of a rectangle = $L \times W \times H$

Trapezoid

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

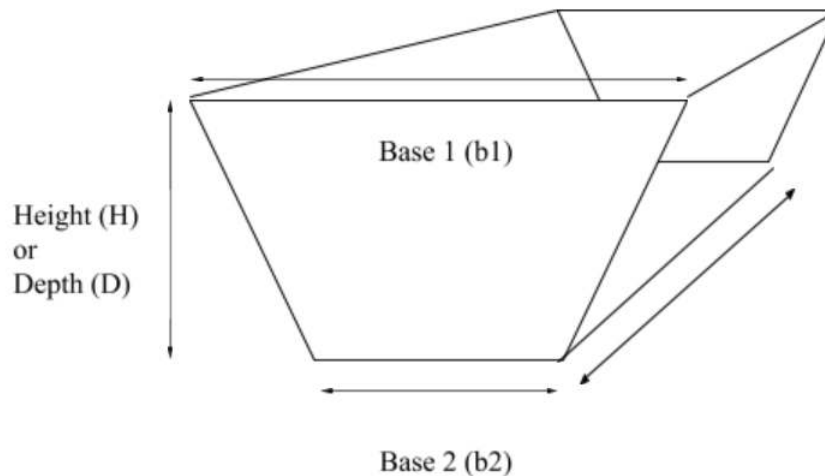


Figure 1.6.2.3: Volume of a trapezoid = $\frac{b1 + b2}{2} \times H \times L$

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 $\frac{3}{4}$ full and has a 30 foot diameter. How many gallons of water are in it?
10. What is the capacity of a water basin that is 200 feet long, 40 feet wide, and 30 feet deep?
11. A water tank is being emptied at a rate of 1 foot per hour. If the tank has a diameter of 100 feet, how many gallons will be emptied in 4 hours?
12. A reservoir with the following dimensions (75 feet long, 20 feet wide, 10 feet deep) is 35% empty. How many gallons of water are in the reservoir?

1.6.2: Volumes is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- 6.2: Volumes by Mike Alvord & Regina Blasberg is licensed [CC BY 4.0](#).

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.

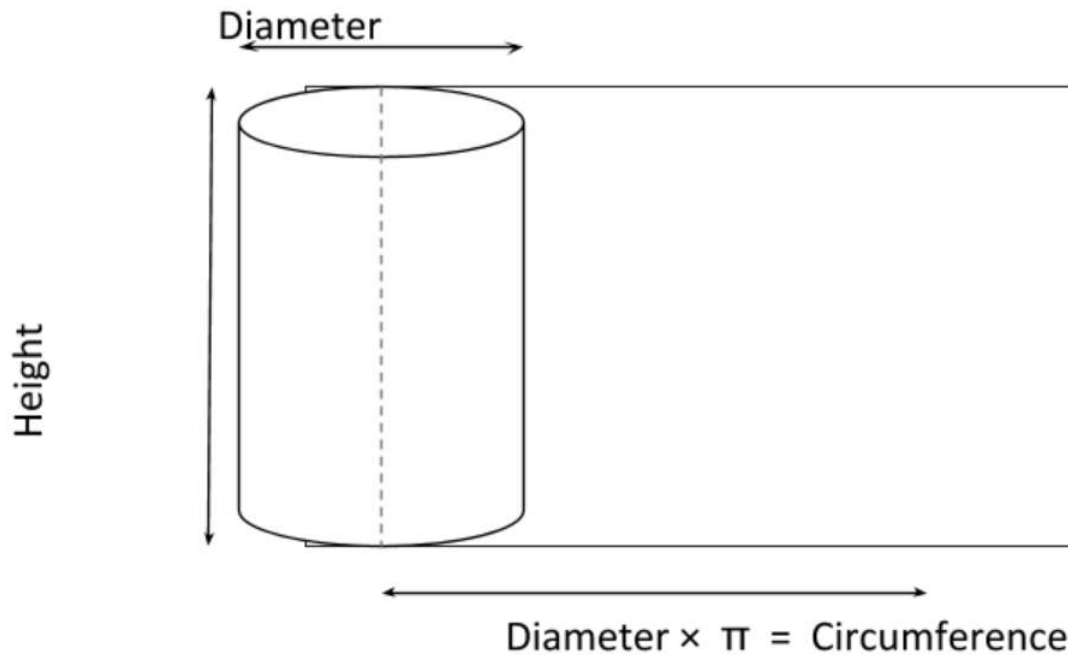


Figure 1.6.3.1: Circumference of a cylinder

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 (**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?

1.6.3: Circumference is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- 6.3: Circumference by Mike Alvord & Regina Blasberg is licensed [CC BY 4.0](#).

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

[1.7: Water Hydraulics](#) is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

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

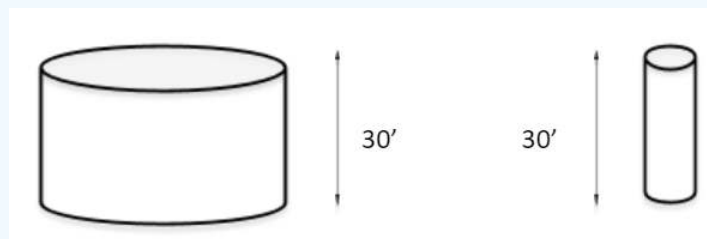


Figure 1.7.1.1

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

Solution

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

Exercise 7.1

Calculate the following pressure problems

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

1.7.1: Pressure is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- 7.1: Pressure by Mike Alvord & Regina Blasberg is licensed [CC BY 4.0](#).

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 (in²). Therefore, the resulting unit is pounds per square inch (psi). However, in the previous section we looked at pressure based on the height or elevation of a column of water and compared it against a conversion factor.

Recall the following conversion factors:

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

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

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

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

In this example, there is

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

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

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

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

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

This volume can now be converted to pounds.

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

This is the force exerted.

Exercise 7.2

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

1.7.2: Force is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- 7.2: Force by Mike Alvord & Regina Blasberg is licensed [CC BY 4.0](#).

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 UNITS – CUBIC FEET PER SECOND, where Q represents Flow Rate.

Expressed as

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

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

$$Q = A \times V$$

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

And

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

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

Therefore, the equation should look like this

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

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

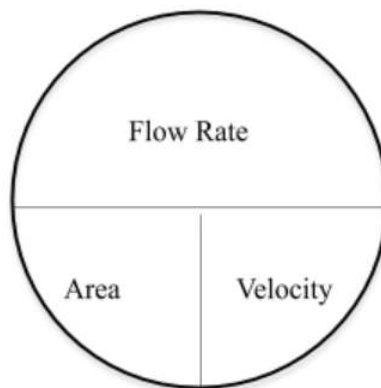


Figure 1.7.3.1: Pie Wheel

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

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

1.7.3: Flow Rate is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- 7.3: Flow Rate by Mike Alvord & Regina Blasberg is licensed [CC BY 4.0](#).

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 chlorine or a chlorine related compound. However, it can be also used to calculate alum, ferric chloride, or any other type of chemical dosage.

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

1.8.1: The “Pound Formula”

1.8.2: Food to Microorganism Ratio

1.8.3: Mean Cell Residence Time (MCRT)

1.8: Chemical Dosage Analysis and Waste Water Treatment is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

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

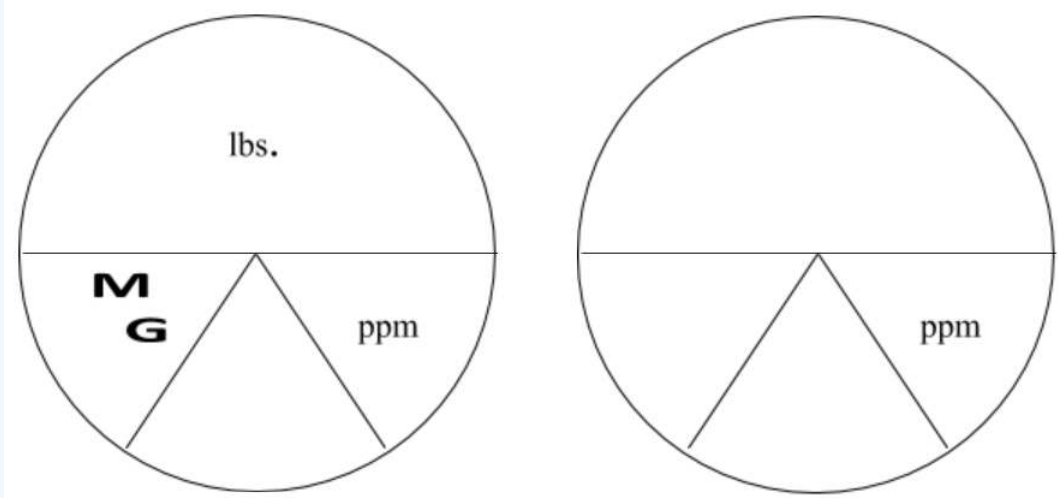


Figure 1.8.1.1

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 Biochemical Oxygen Demand (BOD) test. Wastewater has a large amount of organic material that would put a certain demand on an aquatic system by depleting the available oxygen. The results of

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

Exercises 8.1

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

1.8.1: The “Pound Formula” is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- **8.1: The “Pound Formula”** by Mike Alvord & Regina Blasberg is licensed [CC BY 4.0](#).

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:

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

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

Exercise 8.2

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

Influent Q = 4.8 MGD

Influent BOD = 425 mg/L

Primary Effluent BOD = 272 mg/L

MLSS = 2,100 mg/L

Aeration Volume = 2,890,000 gallons

1.8.2: Food to Microorganism Ratio is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- 8.2: Food to Microorganism Ratio by Mike Alvord & Regina Blasberg is licensed [CC BY 4.0](#).

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 too low then treatment will be insufficient. If the MCRT is too high then there is excess MLSS in the system which adds to the cost of operation.

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

For this introductory class we will use the following equation:

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

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

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

Exercise 8.3

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

Influent flow = 10.5 MGD

Primary Effluent BOD = 285 mg/L

Aeration Volume = 5 MG

MLSS = 2,280 mg/L

WAS Q = 115 gpm

WAS Conc. = 8,110 mg/L

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

1.8.3: Mean Cell Residence Time (MCRT) is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- [8.3: Mean Cell Residence Time \(MCRT\)](#) by Mike Alvord & Regina Blasberg is licensed [CC BY 4.0](#).

SECTION OVERVIEW

1.9: Water Treatment Mathematics

1.9.1: Detention Time

1.9.2: Weir Overflow Rate

1.9.3: Filtration Rate

1.9: Water Treatment Mathematics is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

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.

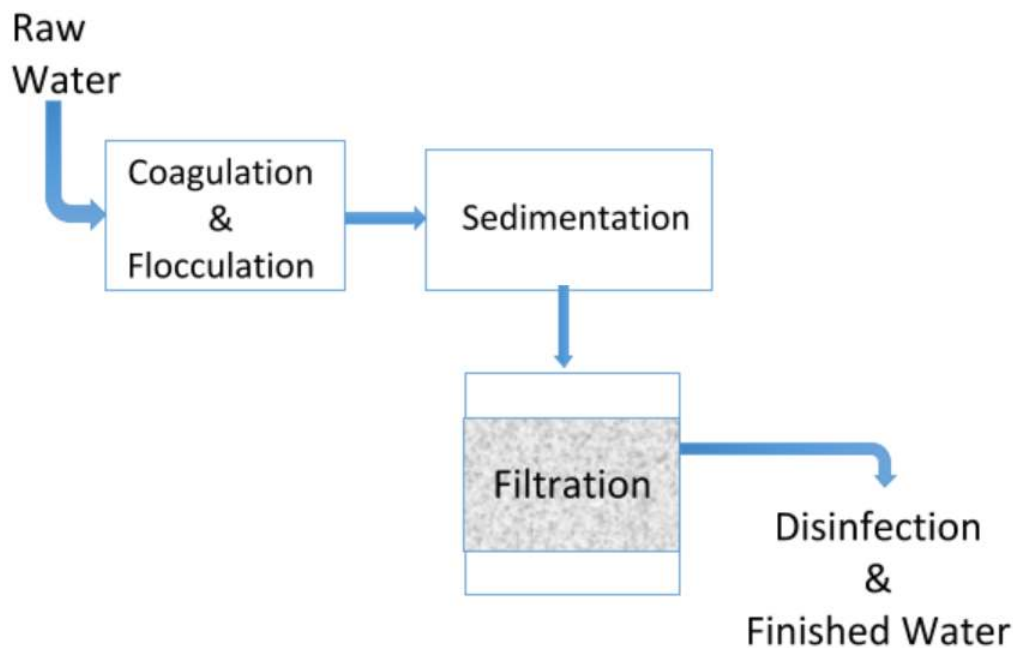


Figure 1.9.1.1: Treatment Process Example

The following formula is used for calculating detention times.

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

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

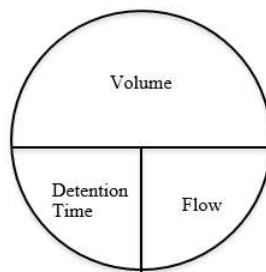


Figure 1.9.1.2: Pie Wheel

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

1.9.1: Detention Time is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- [9.1: Detention Time](#) by Mike Alvord & Regina Blasberg is licensed [CC BY 4.0](#).

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.

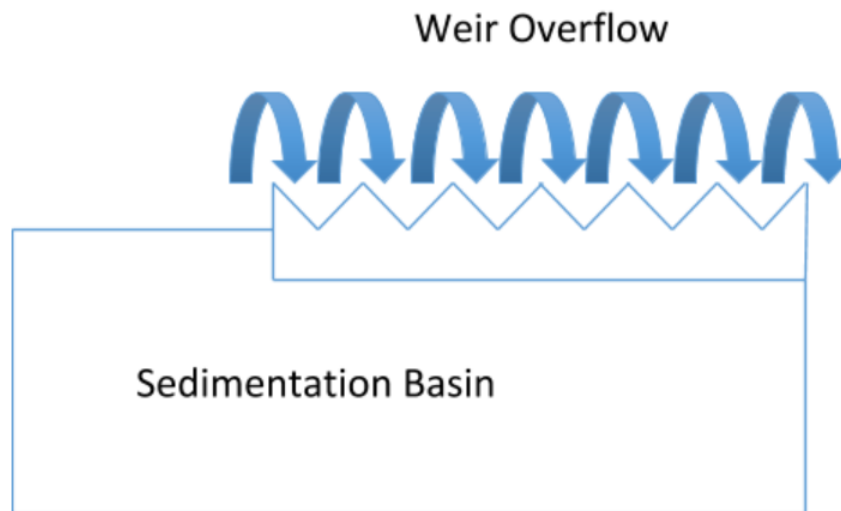


Figure 1.9.2.1: Overflow

This formula is used:

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

Exercise 9.2

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

1.9.2: Weir Overflow Rate is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- [9.2: Weir Overflow Rate](#) by Mike Alvord & Regina Blasberg is licensed [CC BY 4.0](#).

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/ft²). It is the flow of water through the surface area of a filter.

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

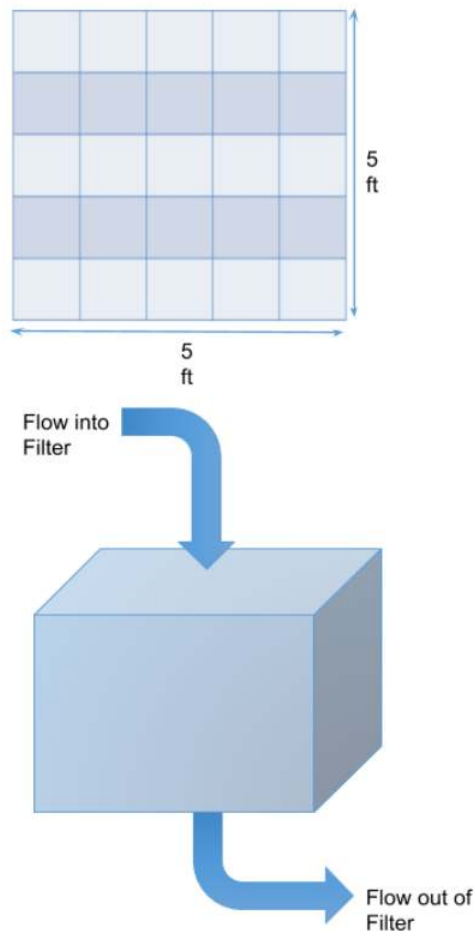


Figure 1.9.3.1: Demonstration of how filtration rates are expressed

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:

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

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

The “Pie-Wheel” for Filtration Rates looks like this:

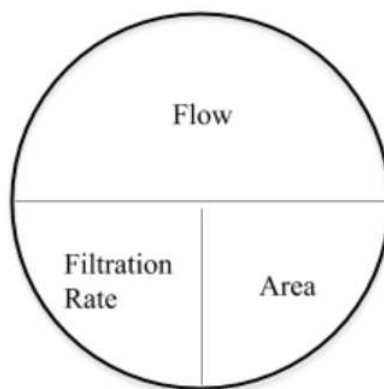


Figure 1.9.3.2: Pie wheel for Filtration Rates

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/ft².

Solution

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

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

Example 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/ft²?

Solution

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

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

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

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

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

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

Then plug this into the filtration rate formula.

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

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

Exercise 9.3

(Express all filtration rates as gpm/ft²)

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

2. A circular filter with a diameter of 74 feet receives a flow of 2,200 gpm. What is the filtration rate?
3. A three-hour test revealed that 75,000 gallons passed through a filter with dimensions of 10 ft by 20 ft. Find the filtration rate.
4. A water treatment plant has a total of 4 filters. The plant is designed to treat a daily flow of 7.25 million gallons. The target filtration rate is 2.25 gpm/ft². 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/ft²?
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/ft². 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/ft², 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/ft² 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 ft² needs to be backwashed for 12 minutes using 94,500 gallons. What would the corresponding backwash rate be in gpm/ft²?

1.9.3: Filtration Rate is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- **9.3: Filtration Rate** by Mike Alvord & Regina Blasberg is licensed [CC BY 4.0](#).

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

1.10: Engineering and Construction is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

1.10.1: Planning

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

Pipeline Installation Project Planning

Budget

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

Environmental

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

Timing

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

Design

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

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

Stationing

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

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

Example 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

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

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

Exercise 10.1

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

1.10.1: Planning is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- **10.1: Planning** by Mike Alvord & Regina Blasberg has no license indicated.

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

[1.11: Using What You Learned and Preparing for Certification Exams](#) is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

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.

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

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

1.11.1: Examples is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- [11.1: Examples](#) by Mike Alvord & Regina Blasberg has no license indicated.

00: Front Matter

This page was auto-generated because a user created a sub-page to this page.

TABLE OF CONTENTS

00: Front Matter

- Table of Contents

2.1: Introduction To The Operator Certification

2.2: Sources and Characteristics of Water

2.3: Regulations

2.4: System Design

2.5: Pipelines

2.6: Valves

2.7: Hydrants

2.8: Meter Services

2.9: Pumps

2.10: Wells

2.1: Introduction To The Operator Certification

This textbook is designed to provide the reader with a general understanding of many of the drinking water distribution systems topics. It will also help prepare you for the California Certification Examinations. This chapter will introduce distribution systems and provide information related to becoming a certified operator and the associated regulations.

Student Learning Outcomes

After reading this chapter, you should be able to:

- Explain the general concept of water distribution
- Identify the topics of the other chapters within this textbook
- State three main goals of a water professional
- List the various certification levels of both distribution and treatment operators
- Discuss the criteria associated with becoming and working as a certified operator
- Explain the content associated with taking a certification examination

Introduction to Water Distribution

A water distribution system is nothing more than a network of components designed to deliver water from a source to a user. It can be thought of as an array of piping networks and various pieces of equipment taking water from one location and delivering it to another.

As a comparison, the human body has a number of different “distribution” systems. The circulatory system, for example, distributes blood throughout the body through a series of organs. You can also look at our roadways as a “distribution system”. You leave your house and follow a path to a destination. In between are turns, signals, signs, etc. Understanding this general description of water distribution systems by no means undermines the complexity of delivering safe and reliable drinking water to consumers. It is merely a broad perspective of the water distribution goal. Take water from one point and deliver it to another.

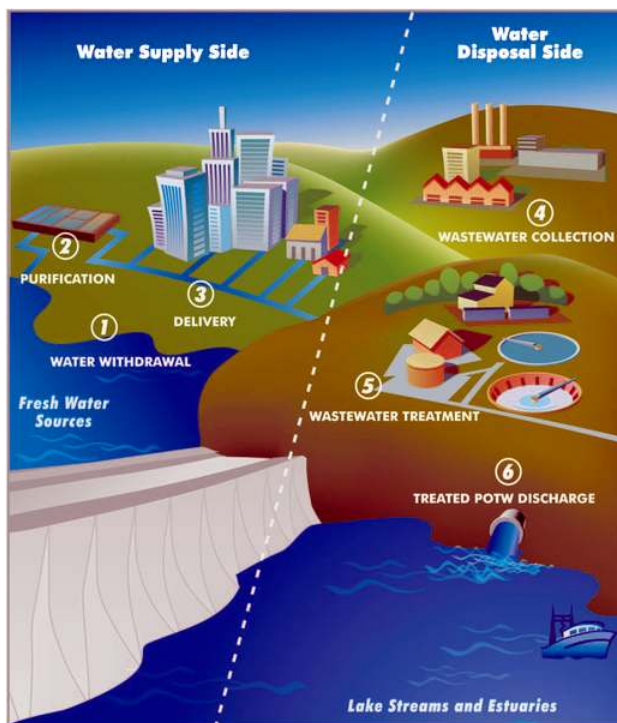


Figure 2.1.1: Image from the *Primer for Municipal Wastewater Treatment Systems* by the EPA is in the public domain

Many people put little thought into the water treatment and distribution processes. The same might be said with electricity. As long as water comes out of the faucet (tap) when you turn it on or lights turn on when you flip a switch, most people seem content and

don't give the delivery process much thought. However, when the water stops flowing, customers take notice of their water service. Even then, the question is "Why is my water off?" and "When will it be back on?" There still isn't much thought put into the why? Or, very rarely are people interested in the process of water distribution when water service is uninterrupted. The complexities of getting water from its source to the "tap" often go unnoticed.

Drinking water originates from various places, but the largest amount of water on the planet can be found in the oceans. Approximately seventy percent (70%) of the surface of the earth is covered by ocean. This corresponds to approximately ninety-six percent (96%) of all the water on earth. There is just one problem.

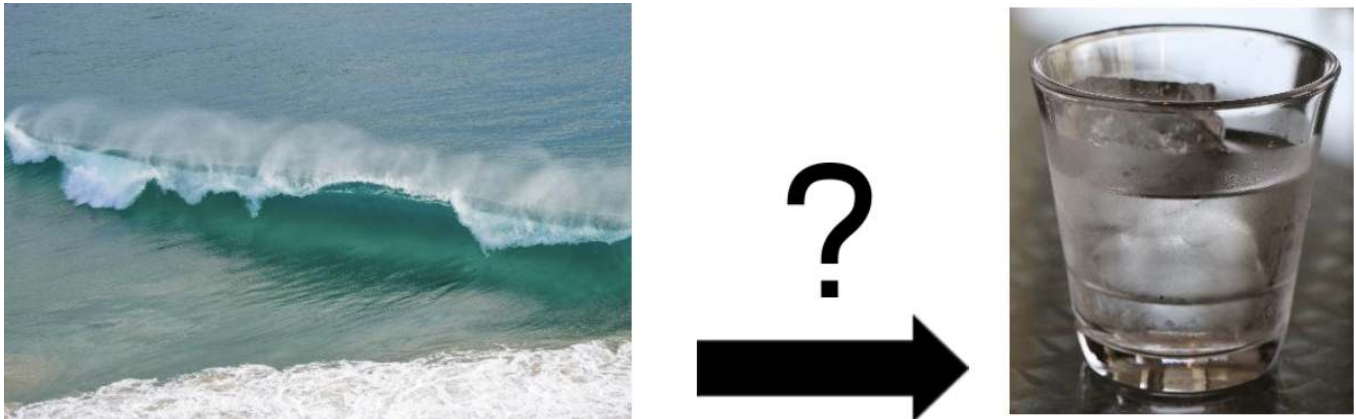


Figure 2.1.2: Photo by [Marianne Heino](#) on [Unsplash](#); Photo by insightzaoya is licensed under [CC0](#)

...this water is salty and not suitable for human consumption. There is only a small portion of freshwater (not having salt) that is accessible for sustaining human life. This topic will be discussed in more detail in Chapter 2.

Once "fresh" water is accessible, for example diverting water from lakes and rivers or pumping groundwater to the surface, it needs to be transported to communities. A simple description of this process can be broken down into four simple terms, conveyance, treatment, distribution, and customer tap. This may seem like a relatively straightforward and easy process, but there are complexities to this system. These processes (except water treatment) will be discussed in detail in this text.

This text is designed to cover these specific aspects of water distribution. They include:

- Operator Certification
- Sources of Supply
- Water Characteristics
- Water Quality and Regulatory Compliance
- Distribution System Design
- Water Main Pipes
- Water Valves
- Fire Hydrants
- Water Meters and Services
- Pumping
- Water Wells
- Water Storage
- Cross Connection Control
- Safety

Water is essential to life. Therefore, water utility employees should always remember the following goals:

1. Provide a safe and potable water supply to the customer
2. Provide a reliable water supply to the customer
3. Provide this water supply at a reasonable cost with excellent service to the customer

If you haven't noticed, the common thread in each of these objectives is the "customer". It is important for water professionals to understand and realize they are providing a critical service to millions of people throughout the world. Having an understanding of

these main objectives helps each employee put into perspective the responsibility associated with being a water utility professional. We are providing a vital service to society.

Each chapter in this text will delve into various topics ranging from where our water originates and how it gets to our taps in a safe, reliable, and cost-effective manner. It will focus on the distribution of potable drinking water and the work required to deliver this vital resource.

This chapter introduces a general background of how water is delivered and the regulatory framework of ensuring the workforce behind the distribution process is properly trained and certified. Chapter 2 focuses on the source of water, where our water comes from, and the physical, chemical, and biological properties of one of our most precious resources. Chapter 3 enters into the regulatory framework of making our water safe to drink. The discussion will involve how and why drinking water regulations are created and the importance of complying with these ever-changing regulations. Chapter 4 begins the concepts of water distribution network systems. Chapters 5 through 11 build on this concept and begin describing the underground and above ground distribution system components. The distribution system is comprised of pipes, pumps, storage facilities, valves, hydrants, meters, and a vast array of appurtenances (general term for other components), which are interconnected to bring water from the source to the tap.

The transportation of water for human consumption has been around for over 3,500 years. The Minoan civilization used tubular conduits to convey water and the Romans used intricate stone aqueduct systems to bring water great distances. In the early 1400s, cast iron pipes were introduced and in the mid-1600s, water flowed through pipes in Boston bringing spring water to what is now known as the Quincy Market area. In the U.S in the 1700s many of the early piping systems were made of bored logs.



Figure 2.1.3: Image by [kim traynor](#) is licensed under [CC BY-SA 2.0](#); Image by [caitriana](#) is licensed under [CC BY-SA 2.0](#)

Advances in technology brought about various advancements in flow technologies and an understanding of how to efficiently and economically treat and distribute drinking water. In 1914, the first drinking water standards were established in the U.S. However, it wasn't until the early 1970s when the United States Environmental Protection Agency was formed that drinking water quality standards really started to take form. Details regarding drinking water quality will be discussed in Chapter 4 of this text.



Figure 2.1.4: EPA Seal is in the public domain

Although modern water distribution systems in the U.S. are relatively young, the components both under and above ground need maintenance and over time, replacement. In 2014, one of the oldest water systems in the U.S. had a major failure. A 100-year-old pipe in Philadelphia burst, releasing millions of gallons of water.



Figure 2.1.5: Photo of Mill Creek Sewer is in the public domain

According to the Los Angeles Times, the Los Angeles Department of Water and Power has over 6,730 miles of water main pipes in their distribution network and it is estimated it will cost \$1.34 billion to replace what are considered “at-risk” mains by 2025.

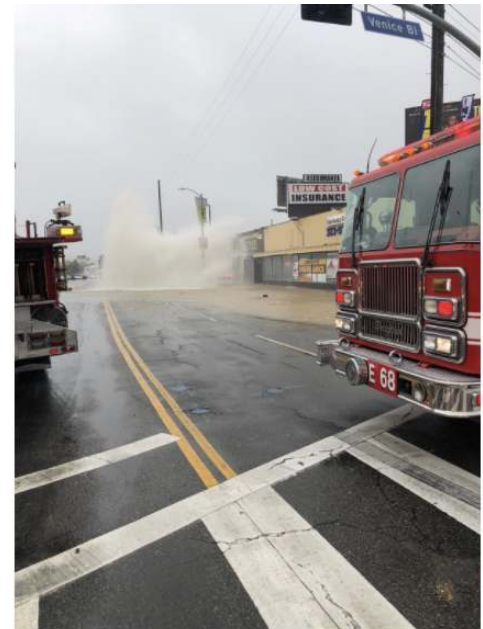


Figure 2.1.6: Image by Los Angeles Fire Department is licensed under CC BY-ND 2.0; Image by Los Angeles Fire Department is licensed under CC BY-ND 2.0

What does this mean? It means a few things. First of all, it means there will be plenty of work (jobs) for the foreseeable future in the water utility industry. Second, it means we can expect more frequent and large water main breaks, causing at times severe damage. Lastly, it means the water utility needs to increase the amount of money spent on large improvement and replacement projects, which directly correlates to higher water rates for the consumer. Water treatment and distribution are critical industries for the sustainability of modern civilization. Drinking water treatment and distribution are not the only areas within the world of water, which needs attention. Water is becoming scarcer; therefore conservation efforts will be a way of life, especially in California. We also need to focus our efforts on the wastewater industry. As you will see in Chapter 2, water follows the hydrologic cycle, which means water passes through a continuous cycle from one phase to another. Wastewater is a process within this cycle. Humans consume and use potable water and some of it becomes wastewater. This wastewater must also go through conveyance systems, treatment, and then is discharged back into the environment. The infrastructure associated with conveying and treating wastewater must also be maintained and replaced from time to time. Throughout this text “water companies” will be referred to in a number of different ways. Here are some of the more common terms used:

- Water Utility
- Water Agency
- Water District
- Water Company
- Public Water Supplier
- Urban Water Supplier
- Water Retailer
- Water Purveyor
- Public Drinking Water System

Do not get confused with all these different terms. In essence, they all mean the same thing. The reason there is a variety of ways to identify a company that delivers water has to do with how they are governed and how they are identified in various regulations. Just understand in this text if you read any of these terms (or possibly others), realize we are discussing the same thing.

State Water Resources Control Board

In California, regulations governing water distribution and treatment fall under the Division of Drinking Water (DDW) within the State Water Resources Control Board (SWRCB). The reason both agencies are identified separately is that the breadth of authority expands beyond drinking water for SWRCB. DDW regulates public water systems and is broken into three branches, the Southern

California Field Operation Branch, the Northern California Field Operation Branch, and the Program Management Branch. Each branch has its own set of responsibilities and authority. In addition to drinking water, the SWRCB is also responsible for the Regional Water Quality Control Boards (RWQCB) and functions as the regulatory authority for surface water quality and surface water rights.

Field Operations Branches

The Southern and Northern Field Operations Branches (FOB) within DDW are responsible for the enforcement of the federal and state Safe Drinking Water Acts (SDWA). They have oversight of approximately 7,500 public water systems. Their primary responsibility is assuring the delivery of safe drinking water to Californians. The following is a list of some of the main functions of FOB staff:

- Issue operating permits
- Review plans and specifications for new facilities
- Review water quality monitoring results
- Issue enforcement actions for non-compliance
- Conduct field inspections
- Promote water system security

FOB staff also work on recycled water projects, conservation efforts, and source water assessments. Although each FOB is empowered with the regulatory and enforcement authority over public water systems they carry the same goal and typically work closely with water industry professionals on providing safe and reliable drinking water. They provide review and oversight of water-related infrastructure plans and they conduct field inspections giving guidance of how a proper distribution system should be operated.

Program Management Branch

The Program Management Branch (PMB) within DDW works separately from the FOBs. Typically PMB staff do not work as routinely with public water system staff as the FOBs. They are charged with collecting, compiling, evaluating, and reporting water quality data from laboratories that monitor drinking water for public water systems. The PMB also coordinates emergency response and associated training and provides advice on technical matters associated with drinking water contaminants. There are two additional sections under the PMB, the Environmental Laboratory Accreditation Program Section (ELAP) and the Technical Operations Section (TO). ELAP is responsible for evaluating and accrediting water quality testing laboratories to ensure the quality of the analytical data used for regulatory purposes to meet the requirements of the State's drinking water. TO prepares the Annual Compliance Report for the United States Environmental Protection Agency (USEPA), analyzes proposed drinking water-related legislation, provides information and reports on fluoridation by public water systems and oversees the Drinking Water Additives Program. The above descriptions and tasks associated with DDW are in no way an exhaustive list. However, it should provide the reader with a basic understanding of the overarching regulatory framework governing public water systems. In addition, to the jurisdictional authority of DDW and SWRCB, other applicable laws and standards within California legislation covering public water systems will not be discussed in this text.

Operator Certification

Another function of DDW is of operator certification. Although the USEPA SDWA was not promulgated until 1974, laws and regulations governing the certification of potable water treatment facility operation were enacted in 1971. These rules established the level the water treatment facilities should be manned, the minimum qualifications for testing at each of the five grade levels, and the criteria for the renewal and revocation of operator certificates. However, it wasn't until 1996, as part of the SDWA Amendments, that regulations pertaining to operator certification were enacted. In 1998, the USEPA used these amendments to establish guidelines for the certification and re-certification of operators of public water systems. These guidelines established five (5) different certification levels for both water distribution and water treatment operators. This section of the text will focus on distribution operator certification. However, the drinking water treatment certification criteria are similar. In addition, there are certifications for wastewater as well. In drinking water, there are five (5) certification levels for both distribution and treatment (1 – 5). A level one (1) certification is the lowest and level five (5) the highest. The distribution certification levels are as follows:

Distribution

D1, D2, D3, D4, D5

The operator certification regulations provide specific requirements that water utilities and their employees must follow. Title 22 regulations state “all suppliers of domestic water to the public are subject to regulations adopted by the USEPA under the SDWA as well as by the SWRCB DDW under the California Safe Drinking Water Act (CSDWA).” Title 22, Division 4, Chapter 13 identifies these requirements. Each water utility is designated a certain distribution and/or treatment classification. This classification is based on a variety of different parameters. For example, a distribution system has a classification based on things such as:

- Number of service connections
- Number of sources and types of supply
- Number of storage facilities
- Type(s) of disinfection processes and chemicals used

There are other criteria, but these are the main benchmarks used to set the classification. Once the system has its classification, it determines the level of certification the operators must obtain. There are two types of operators; Chief and Shift. Article 1, Section 63750.25 of the above-referenced chapter in Title 22, defines a Chief Operator as “the person who has overall responsibility for the day-to-day, hands-on, operation of a water treatment facility or the person who has the overall responsibility for the day-to-day, hands-on, operation of a distribution system.” Section 63750.70 defines a Shift Operator as “a person in direct charge of the operation of a water treatment facility or distribution system for a specified period of the day.” There are specific requirements in order to become certified, which will be discussed later in this Chapter. Below is a table showing the minimum certification requirements for Chief and Shift Operators based on the classification of a distribution system.

Distribution System Classification	Minimum Certification of Chief Operator	Minimum Certification of Shift Operator
D1	D1	D1
D2	D2	D1
D3	D3	D2
D4	D4	D3
D5	D5	D4

In addition to a Chief and Shift Operator, there are day-to-day operators who work for water utilities, but do not have any authority or decision-making responsibilities. These operators are still required to become certified, but they can hold any level based on their agency's requirements. For example, if a water utility is classified as a D5 distribution system, the employees can become D5 Distribution Operators, but may not necessarily be listed by the utility as the Chief Operator. There are specific requirements in the regulations stating what types of activities must be performed by a certified operator. A distribution water system must use only certified operators to make decisions addressing:

- Installing, tapping, re-lining, disinfecting, testing, and connecting water mains and appurtenances
- Shutdowns, repairs, disinfecting, and testing broken water mains
- Flushing, cleaning, and pigging existing water mains
- Stand-by emergency response duties for after-hours distribution system operational emergencies
- Draining, cleaning, disinfecting, and maintaining distribution reservoirs
- Determining and controlling proper chemical dosage rates for wellhead distribution residual maintenance
- Investigating water quality problems in the distribution system

While reading the above activities, some of you may be wondering what some of these terms mean. Don't worry; they will all be addressed later in this text.

Examination Certification Eligibility Criteria

Not just anyone can become a certified operator. There are eligibility criteria for taking operator certification examinations. These criteria include completion of approved courses related to distribution and/or treatment topics, experience working in the industry with a distribution system and/or treatment plant, and holding a high school diploma or GED. A general description of the criteria for each certification level is as follows:

D1 Certification – You must have a high school diploma or GED. Although no experience is required, specific experience can be substituted for a high school diploma or GED. If you do not hold a high school diploma or GED equivalent, you must successfully complete the “Basic Small Water Systems Operations” course provided by DDW, or have one year or more experience as an operator of a facility that required an understanding of chemical feeds, hydraulic systems, and pumps.

D2 Certification – You must meet the requirements of a D1 certification exam plus at least one course of specialized training covering the fundamentals of drinking water distribution or treatment.

D3 Certification – You must meet the requirements of a D1 certification exam plus at least two courses of specialized training. At least one of the courses must cover the fundamentals of drinking water distribution or treatment.

D4 Certification – You must have a valid D3 operator certificate plus at least three courses of specialized training. At least two of the courses must cover the fundamentals of drinking water distribution or treatment.

D5 Certification – You must have a valid D4 operator certificate plus at least four courses of specialized training. At least two of the courses must cover the fundamentals of drinking water distribution or treatment.

In some instances, advanced degrees such as an Associate or Bachelor’s degree can be used to fulfill operator experience. The degrees must be in specific disciplines and they only fulfill a certain amount of operator experience.

Operator Certification Examination Content

Anyone who wishes to take an operator certification examination must meet the criteria explained above and complete the required application. This sounds easy enough. The trick is you must pass an exam in order to become certified. DDW provides the expected range of knowledge for each certification examination level. These include the following and can also be found here:

- Disinfection
- Distribution System Design and Hydraulics
- Equipment Operation, Maintenance, and Inspections
- Drinking Water Regulations, Management, and Safety
- Water Mains and Piping
- Water Quality and Water Sources
- Water Treatment Processes
- Laboratory Procedures
- Regulations and Administration Duties

Each one of these categories includes an array of information and topics. Textbooks like this one and courses offered at colleges, water-related organizations, and private companies provide the information needed to pass certification examinations. The operator certification information provided in this Chapter should provide you a general understanding of the operator certification guidelines and regulations. However, there is much more detail available regarding this topic. The following uniform resource locator (URL) will take you to the SWRCB website regarding Operator Certification. There you will find specific information regarding the regulations, expected range of knowledge, examinations, schedules, applications, fees, renewals, frequently asked questions, and more. While each type of certification exam will focus primarily on the main discipline (distribution or treatment), there are overlapping topics.

Drinking Water Distribution & Treatment System Operators

The following link is a source of guidelines for Drinking Water Treatment & Distribution System Operators.

Sample Questions

1. In order to take the D1 exam, you must _____.
 1. Have successfully completed one 3 unit course
 2. Have a high school diploma or equivalent
 3. Successfully completed two 3 unit courses
 4. Both 1 and 2
 2. SWRCB stands for _____.
 1. Safe Water Regional Control Board
 2. State Water Regional Control Board
 3. State Water Resources Control Board
 4. Safe Water Resources Conservation Bureau
 3. A utility worker who is in direct charge of the operation of a water distribution facility for a specified period of a day is considered a _____.
 1. Chief Operator
 2. Shift Operator
 3. Distribution Operator
 4. All of the above
 4. There are _____ levels in water distribution certification.
 1. 2
 2. 3
 3. 4
 4. 5
 5. The transportation of water for human consumption dates back to _____.
 1. 500 years
 2. 1,500 years
 3. 2,500 years
 4. 3,500 years
 6. A common element in the delivery of water to customers is the distribution framework.
 1. True
 2. False
 7. The Division of Distribution Water is the governing body for water utilities in California.
 1. True
 2. False
 8. Advanced degrees such as Associate and Bachelor's can be sometimes used to fulfill experience requirements.
 1. True
 2. False
 9. Which one of the following regulations encompasses the California State Drinking Water Act?
 1. Title 11
 2. Title 22
 3. Title 33
 4. Title 44
 10. Which one of the following would not be considered a main goal of a water professional?
 1. Provide a safe and potable water supply to the customer
 2. Provide a reliable water supply to the customer
 3. Provide this water supply at a reasonable cost with excellent service to the customer
 4. Ensure your public retirement pension is fully funded
-

This page titled [2.1: Introduction To The Operator Certification](#) is shared under a [CC BY](#) license and was authored, remixed, and/or curated by [Mike Alvord \(ZTC Textbooks\)](#) .

- [1.1: Introduction To The Operator Certification](#) by [Mike Alvord](#) is licensed [CC BY 4.0](#).

2.2: 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

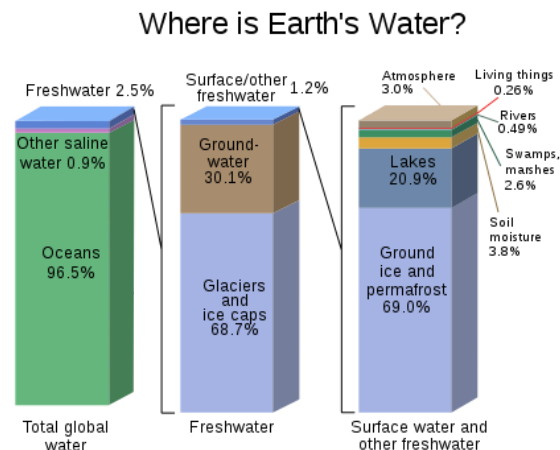


Figure 2.2.1: Image by the USGS is in the public domain

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.

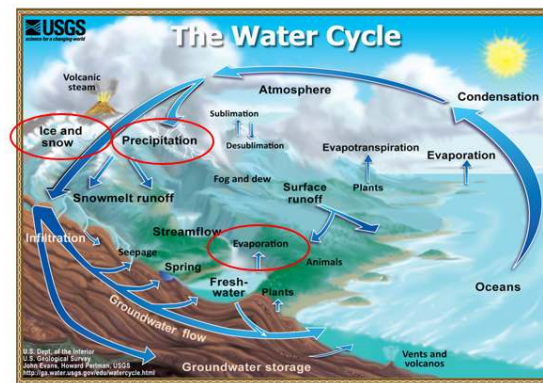


Figure 2.2.2: Image by the USGS is in the public domain

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.

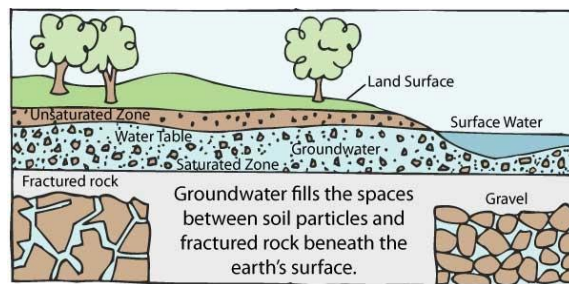


Figure 2.2.3: This material was reproduced from groundwater.org with the permission of The Groundwater Foundation. © The Groundwater Foundation. All Rights Reserved.

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.

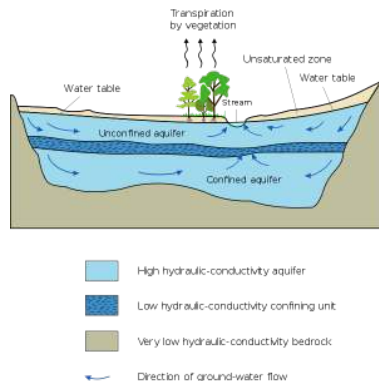


Figure 2.2.4: Image by Hans Hillewaert is licensed under CC BY-SA 3.0

- **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.

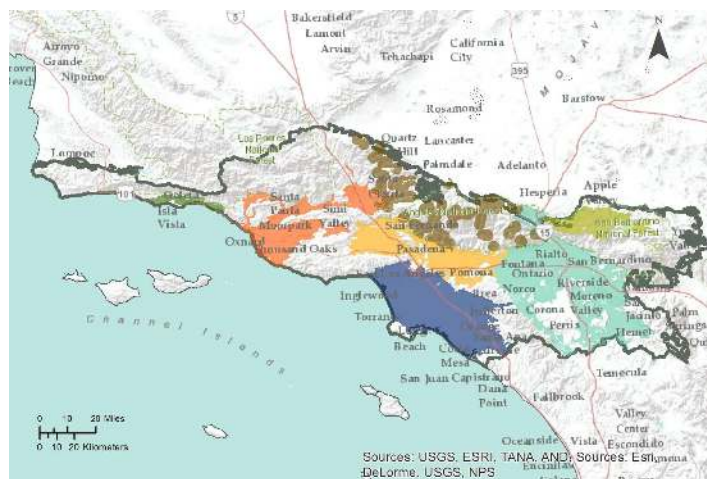


Figure 2.2.5.1: Map by the USGS is in the public domain

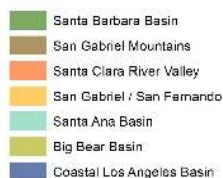


Figure 2.2.5.2: The Transverse Ranges and Selected Peninsular Ranges Province consists of the following Study Units

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).

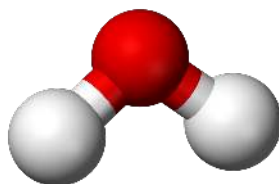


Figure 2.2.6: [Water-3D-balls](#) by [Benjah-bmm27](#) is in the public domain

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 2.2.7: [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.

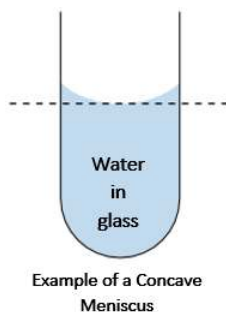


Figure 2.2.8: [Image](#) by Jleedev is licensed under [CC BY-SA 3.0](#) (image modified by COC OER)

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

This page titled [2.2: Sources and Characteristics of Water](#) is shared under a [CC BY](#) license and was authored, remixed, and/or curated by [Mike Alvord \(ZTC Textbooks\)](#).

- [1.2: Sources and Characteristics of Water](#) by [Mike Alvord](#) is licensed [CC BY 4.0](#).

2.3: 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.

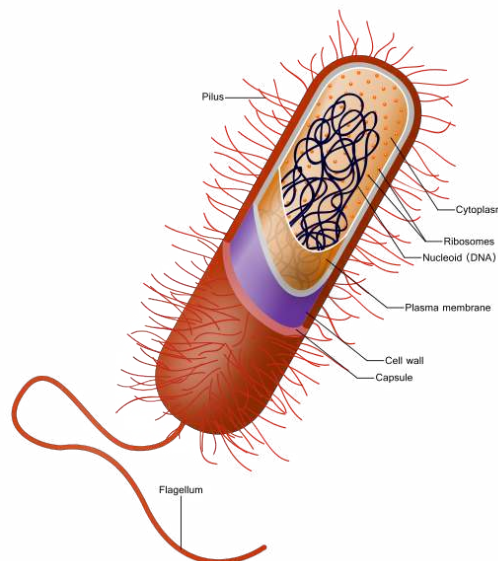


Figure 2.3.1: Image by Ali Zifan is licensed under CC BY-SA 3.0

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).

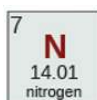


Figure 2.3.2: Image by OpenStax is licensed under CC BY 4.0 (image modified by COC OER)

- 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 2.3.3: Image 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 2.3.4: Image 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 ultraviolet 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 distribution 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 2.3.5: 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 2.3.6: 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 2.3.7: Image 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 NO_3 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 2.3.8: Sample CCR – Photo by [Tim Marshall](#) on [Unsplash](#) (modified by COC OER)



Figure 2.3.9: 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

This page titled [2.3: Regulations](#) is shared under a [CC BY](#) license and was authored, remixed, and/or curated by [Mike Alvord](#) ([ZTC Textbooks](#)) .

- [1.3: Regulations](#) by [Mike Alvord](#) is licensed [CC BY 4.0](#).

2.4: 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, grid, 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.

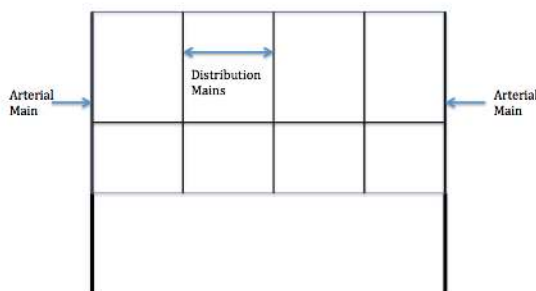


Figure 2.4.1: Arterial Loop Distribution System by Mike Alvord is licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/)

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.

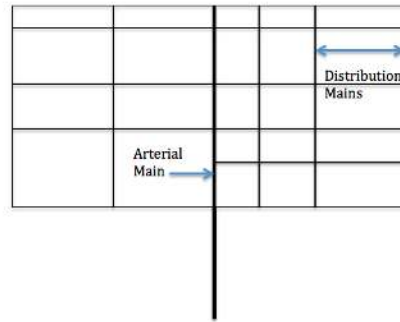


Figure 2.4.2: Grid System by Mike Alvord is licensed under [CC BY 4.0](#)

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.

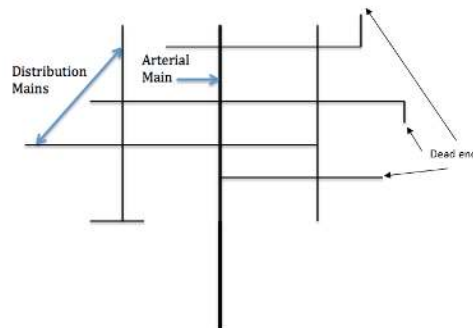


Figure 2.4.3: Tree System by Mike Alvord is licensed under [CC BY 4.0](#)

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 2.4.4: Image by the [Anderson Air Force Base](#) is in the public domain

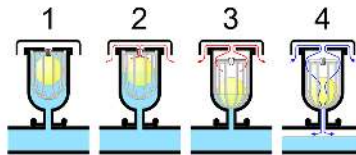


Figure 2.4.5: Image by Shigeru23 is licensed under [CC BY-SA 3.0](#)



Figure 2.4.6: Elbow pipe fitting – Image by Cschirp is licensed under [CC BY-SA 3.0](#)



Figure 2.4.7: 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).

$$100 \text{ feet} \times \frac{1 \text{ psi}}{2.31 \text{ feet}} = 43.3 \text{ psi}$$

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 2.4.8: Image by Los Angeles Fire Department is licensed under CC BY-ND 2.0



Figure 2.4.9: Image by Mike Alvord is licensed under [CC BY 4.0](https://creativecommons.org/licenses/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

This page titled [2.4: System Design](#) is shared under a [CC BY](#) license and was authored, remixed, and/or curated by [Mike Alvord](#) (ZTC Textbooks)

- [1.4: System Design](#) by [Mike Alvord](#) is licensed [CC BY 4.0](#).

2.5: Pipelines

Student Learning Outcomes

After reading this chapter, you should be able to:

- Describe the different pipe materials and sizes
- Explain hydraulics and how water moves through pipes
- Identify the causes and results from water hammer and tuberculation

Throughout the history of water distribution, a critical component of getting water from the source to the customer is pipelines. Pipelines within a distribution system can be separated into three (3) main categories:

- Transmission Piping
- Distribution Piping
- Service Piping

These three (3) categories have very distinct characteristics and uses.

Transmission Piping

Transmission water mains (piping) are the largest in diameter of the three. They can range from as small as 16" in diameter up to more than 120" in diameter depending on the size of the distribution system, the location of the source water, and the number of customers within the distribution system service area. Smaller utilities with the sources of supply relatively close to the distribution system would have the smaller diameter pipes while larger utilities with the source water further from the distribution system would have larger diameter transmission mains. Transmission water mains convey large volumes of water from the source to areas within the main distribution system. They are commonly installed without any other connections to the pipe until it reaches the distribution system. However, in smaller distribution systems there can be additional pipes connected to a transmission main and there may even be service connections. Below is an example of a transmission water main.



Figure 2.5.1: Image by [James T M Towill](#) is licensed under [CC BY-SA 2.0](#)

Distribution Piping

Distribution system piping is simply that, piping that distributes water throughout the distribution system. Diameters of distribution system piping range from as small as 4" up to 24" and sometimes larger. The most common sizes of distribution system water mains are 8" – 12". Distribution mains connect to transmission mains as these pipes enter a distribution system. These water mains branch off into roads within communities to bring water supplies to customers.

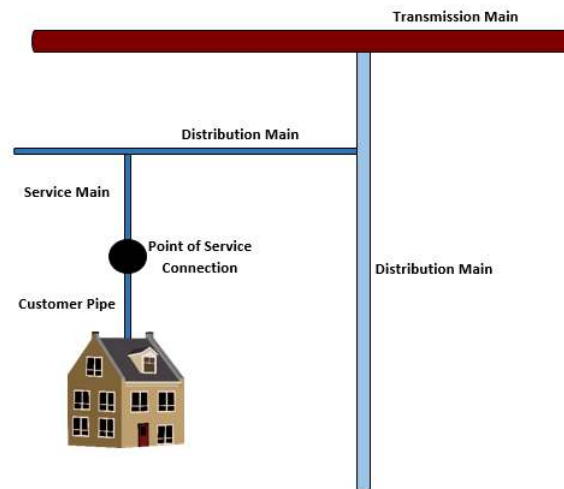


Figure 2.5.2: Image of house by rdevries is licensed under CC0 1.0 (modified by COC OER)

Service Main

In order to get water from the distribution main to a customer, a service main (lateral) is attached to the distribution main. In the diagram above, you can see this pipe between the distribution main and a black dot. The black dot represents the water meter or point of connection between the water utilities infrastructure and the customer's piping. Service laterals typically range in size from 1" to 10" in diameter. Most single-family residential service laterals are 1" to 2" in diameter, while larger commercial services can range in size up to 10" in diameter and sometimes even larger. The size of a service lateral is dependent on the amount of water use from the customer.

Pipe Selection

There are a number of things, which dictate the type of pipe material a utility would select. As discussed above, the use is something utilities look at to determine the material to use. Other things include resistance to corrosion, interior smoothness, cost, ease of use, strength, and local conditions (i.e., soil type).

Pipeline Materials

There are various materials used for water mains. In the 1800s up to the early 1900s, wooden water mains were used. Wood was a usable material because hollowed-out wooden logs did not expand like metal pipes and the thickness provided insulation properties. However, as distribution systems became more sophisticated and pressures increased, wooden pipes were replaced with grey cast-iron pipes.



Figure 2.5.3: Image by John Newcomb is licensed under CC BY 3.0

Grey cast-iron pipe (CIP) was easier to manufacture. They were strong and provided a long service life. One of the main drawbacks of this pipe was its brittleness. If the pipe wasn't handled carefully, it would easily crack. Another major drawback was the lead

poured joints. In order to properly connect sections of the pipe together a molten lead joint was poured around each connection point.



Figure 2.5.4: Image by Andrew Curtis is licensed under CC BY-SA 2.0

Ductile Iron Pipe

In the early 1970s, manufacturing plants moved away from CIP and started manufacturing ductile-iron pipe (DIP). DIP is even stronger than CIP, more versatile, not brittle, and does not use any lead. The only drawback to DIP is the susceptibility to corrosion from aggressive waters and soil. In order to protect the inside of DIP from corroding, they are commonly lined with cement mortar. If soils are corrosive, DIP is usually wrapped in plastic bags. The images below show examples of cement mortar lined (CML) DIP and DIP that has been “bagged” before installation. DIP typically comes in diameters of 4” – 64” and usually in lengths of 18’ – 20’. The pressure range for DIP is 150 psi to 350 psi.



Figure 2.5.5: Image by Yeti Hunter is licensed under CC BY-SA 4.0



Figure 2.5.6: Image by Frankemann is licensed under CC BY-SA 4.0

Steel Pipe

Steel pipe has been used for well over a century. In the mid-1800s when water pressures were high, steel pipe was commonly manufactured for use. While steel pipe can be manufactured to small diameters (4”), the more common use of steel pipe is when large diameters are needed. Diameters of steel pipe ranges up to 120” and even larger if needed. Steel pipe is lighter in weight than CIP and DIP and can be fabricated for special needs. Some of the main disadvantages to steel pipe are both internal and external corrosion and the potential for a partial vacuum to collapse the pipe.



Figure 2.5.7: Image by Mike Alvord is licensed under [CC BY 4.0](#)

Asbestos-Cement Pipe

Asbestos-Cement Pipe (ACP) was first introduced in the US around 1930. It was commonly used in areas where metallic pipe was subject to corrosion. Pressure classes are not typically as high as pipe made from metal, but they come in pressure ranges up to 200 psi. ACP only comes in diameters ranging from 4" to 42" and the lengths (10' – 13') are shorter than their DIP counterpart. ACP is not subjected to aggressive waters as metal pipe, it is fairly lightweight and has a relatively smooth interior surface. It is fairly brittle and can crack if not properly handled. Special safety precautions must be taken in order to prevent employees from being exposed to asbestos fibers.



Figure 2.5.8: Image by [DDanielsson](#) and [Wayne Eddy](#) is licensed under [CC BY-SA 3.0](#)

Polyvinyl Chloride Pipe

Polyvinyl chloride pipe (PVC) were first introduced around 1940. The durability, resistance to corrosion, lightweight, and cost-effectiveness soon became very attractive in the waterworks industry. Because these pipes are made with vinyl chloride, they must be tested and meet certain criteria to ensure no harmful chemicals leach out. In some instances, PVC pipe can also cause taste and odor problems. Another desirable characteristic of PVC piping is flexibility. When using PVC piping, special care must be taken when storing for long periods of time since plastic is susceptible and can become damaged from ultra-violet light.



Figure 2.5.9: Image by [Pam Broviak](#) is licensed under [CC BY-SA 2.0](#)

The above-mentioned pipes are primarily used for transmission and distribution piping. The material used for service laterals are commonly made of either copper or PVC. However, in years past, galvanized pipes were also used. Copper is malleable and resistant to corrosion, which makes it a perfect material for piping between a distribution main and the point of connection to a customer. PVC is also used with the preferred type of PVC being polybutylene since it is not as ridged as schedule 40 or schedule 80.

Pipeline Connections

Water mains are generally connected together with either mechanical or push-on joints and sometimes flanged connections. The type of connection is determined by the installation. For example, above-ground pipeline installations, such as in pump stations, flanged connections are very common. A flanged connection provides a strong and ridged connection and allows for easy disassembly if a section of pipe or other appurtenance needs to be removed. Flanged connections are not as common in underground installations, primarily because of the exposed nuts and bolts of flanged fittings. Pipes connected with push-on joints are manufactured in a “bell” and “spigot” style. The bell end is a wider flared end and the spigot is narrower and tapered. See the example below.



Figure 2.5.10: Image is in the public domain



Figure 2.5.11: Image by Dwight Burdette is licensed under [CC BY 3.0](https://creativecommons.org/licenses/by/3.0/)

The bell end has a gasket inside and the spigot end is “pushed” on to make the connection. Both ends of the pipe must be thoroughly cleaned and lubricated before making the connection. One of the main problems with push-on joints is the possibility of the joints separating under certain conditions. In addition, on slopes, push on joints must be installed with the bell end facing uphill. This will prevent the spigot end from sliding out of the bell. In some instances where additional support is needed, there are certain restraints that can be used. These types of connections are typically less expensive than other connections and are easier to install.

Mechanical joints, restrained joints, and flanged connections are also used to connect pipes and fittings together. Flanged connections are typically limited to above-ground installations because of the potential of corrosion and dirt filling in around the bolts.

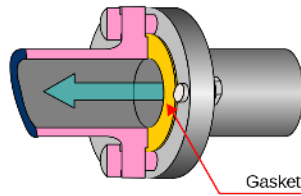


Figure 2.5.12: Image by Mysid is in the public domain



Figure 2.5.13: Image by Ian Capper is licensed under this [CC BY-SA 2.0](#)



Figure 2.5.14: Image by Brandonrush is licensed under [CC BY-SA 4.0](#)



Figure 2.5.15: Image by Markus Schweiss is licensed under [CC BY-SA 3.0](#)

Mechanical joints are similar to push-on joints. However, they have a means to “lock” the pipe and fittings together. Restrained joints are used with push-on fittings and require some type of restraining system. Below is an example of one such restraining system, mega lug rods. Tie rods are another type of restraining system. These help to hold two sticks of pipe together.



Figure 2.5.16: Image by Tech. Sgt. Michael Boquette of the U.S. Air Force is in the public domain

Sample Questions

1. Flanged pipeline connections are very common _____.
 1. In below-ground installations
 2. Only for sewer systems
 3. In above-ground installations
 4. None of the above
2. Asbestos-cement pipe come in lengths _____.
 1. Longer than DIP
 2. Shorter than DIP
 3. The same as DIP
 4. All of the above
3. Transmission water mains deliver _____.
 1. Water directly to customers
 2. Water to treatment plants
 3. Carry large amounts of water
 4. Water directly from service laterals
4. Which of the following would be a correct order for how water gets to a customer?
 1. Source, distribution main, transmission main, service lateral
 2. Service lateral, distribution main, transmission main, source
 3. Source, transmission main, service lateral, distribution main
 4. Source, transmission main, distribution main, service lateral
5. Which of the following pipe material is most susceptible to collapse from partial vacuum?
 1. Steel
 2. DIP
 3. Plastic
 4. Concrete

This page titled 2.5: Pipelines is shared under a CC BY license and was authored, remixed, and/or curated by Mike Alvord (ZTC Textbooks) .

- 1.5: Pipelines by Mike Alvord is licensed CC BY 4.0.

2.6: Valves

In this chapter, we will examine water distribution valves and why they are used.

Student Learning Outcomes

After reading this chapter, you should be able to:

- Describe the different types of valves
- Explain why different valves are used with different applications
- Identify the operational and maintenance criteria for valves

Water valves are an important part to any water system. The main purpose of a valve is to stop and isolate the flow of water. There are many different types of valves and the uses vary, but the primary purpose is to stop the flow of water. However, as you will see in this chapter, valves serve a variety of purposes.

Valves are used to stop and start the flow of water. When a pipe breaks, in order to stop the flow of water a valve is commonly closed. This prevents the water from flowing and allows for utility operators to repair the pipe. Once the repair is finished, the valve is opened and water is allowed to flow once again.

Some valves are used to regulate pressure or throttle flow. Sometimes the water pressure is too great and can pose a problem and damage pipes or other equipment. Residential homes commonly use pressure regulating valves in order to reduce the pressure before the water enters a home. These types of valves can also be used within a utilities distribution system. Throttling flow is sometimes needed in order to reduce the amount of water passing through pipes.

Certain valves are used to allow the flow of water in one direction only. These valves prevent the flow of water in the opposite direction. A common type of valve is a check or backflow preventer. These valves are unidirectional valves and allow the water to flow in one direction only.

Other valves are designed to relieve pressure. When water pressure builds up and gets to a point where the pipes or other appurtenances can get damage, a pressure relief valve can be used to allow the water to flow out of the system and relieve the high pressure.

Types of Valves

There are a number of different types of valves in the water industry for the various uses described above. The following list of valves is not an exhaustive list, but it is a very comprehensive list of valves used in the water industry:

- Gate
- Globe
- Pinch
- Diaphragm
- Needle
- Plug
- Ball
- Butterfly
- Check
- Relief
- Control

Each one of these valves has specific uses and some of these valves are more commonly used than others. Understanding the various uses and types of valves is important for understanding how water distribution systems function. For example, there are several types of valves commonly used in water mains in order to stop the flow of water. However, a certain type (butterfly) is not suitable for a maintenance function referred to as “pigging”.

Pigging is a process to clean the inside of a water main. “Pigs” are made from various materials, but are commonly made of foam of various densities and are pushed through a water main. If a water utility uses butterfly valves then this type of cleaning process is

not possible because the valve would be an obstruction. Other types of valves can be used at pump stations, wells, or other locations within a water distribution system.

Each valve will be discussed in detail throughout this text. However, it is important to understand the four (4) principle uses of valves within a distribution system.

- **Starting and Stopping Flow** – In order to change the direction of the flow of water, stop the flow of water, and then start the flow of water, certain valves are used. When a water pipe breaks, a valve is used in order to stop the flow of water and isolate the leak so it can be repaired. Once the repair is made, the valve will be opened in order to start the flow of water once again. Some examples of these valves in a distribution system are distribution system isolation valves, fire hydrant auxiliary valves, pump control valves, and water service valves.
- **Regulate Pressure and Throttle Flow** – Certain valves are used to lower the pressure if it is too high or to reduce the flow of water by throttling the flow. Only specific valves should be used for these purposes because some valves can get damaged if used for the incorrect purpose. An example of a pressure regulating valves within a distribution system is one installed between two different pressure zones. One zone is higher than the other and these types of valves can be installed to reduce the higher pressure and release water when needed to the lower pressure area.
- **Prevent Backflow** – To prevent water from flowing in the wrong direction certain valves can be used to prevent something referred to as backflow. Backflow prevention is needed when a potable water supply is connected to a non-potable water supply. There are five (5) main methods and devices used for preventing backflow. These will be discussed later in this chapter.
- **Relieve Pressure** – When pressure is too high within a water system, sometimes the pressure needs to be relieved in order to prevent a rupture of the system. Pressure relief valves are common in various installations. Air and vacuum valves are an example of a pressure relief valve within a distribution system. These valves allow air to escape preventing sudden rupture of a pipe.

What Differentiates the Various Types of Valves?

Valves can be classified by how they regulate the flow of water. There are four (4) main types of how a valve operates:

- **Closing Down** – Globe and Piston valves close down in order to stop the flow of water

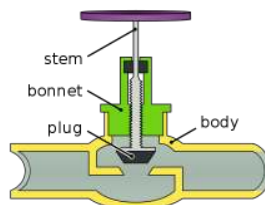


Figure 2.6.1: Image by Petteri Aimonen is in the public domain

A globe valve is commonly found on outside residential faucets, also referred to as a sill cock. The “plug” end of a globe valve closes down into a valve port, which shuts off the flow of water. The distance between fully open and fully closed is relatively short.

A piston valve is similar to a globe valve. It is equipped with a piston shaped closure member, which intrudes into a seat bore to stop the flow of water. Piston valves are commonly used on control valves.

These types of valves are susceptible to sediment being trapped on the seat preventing the valve to close down completely. There is also some amount of flow resistance with these types of valves, especially a piston valve.

- **Sliding** – Gate valves are the most common valve found in distribution systems. They are classified as a sliding down style. A handwheel or a key lowers a “gate” down on a seat. The face of the gate can become worn or objects can get lodged under the gate preventing a tight or complete seal. These types of valves should not be used to throttle flows as the gate can become damaged from the force of the flow of water. There are several different types of gate valves and they will be discussed later in this chapter. The image below is an above-ground type of gate valve with a handwheel attached to the operating nut for opening and closing.



Figure 2.6.2: Image by HerbstrittM is licensed under [CC BY-SA 3.0](#)

- Rotating – The various types of rotating valves include, plug, ball, butterfly, and cone. These types of valves rotate to open and close. Some, for example, plug and ball valves, are rotary style rotating valves. This means they are quarter or half turn rotary valves. While others like butterfly valves rotate on a shaft to open and close.

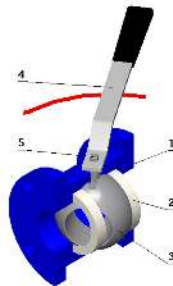


Figure 2.6.3: 1) Body 2) Head 3) Ball 4) Lever handle 5) Stem - Image by Ruben Castelnuevo licensed under [CC BY-SA 3.0](#)

In the diagram above, the lever of a ball valve is turned one-quarter of the way and the ball that is blocking the flow opens to allow water to flow through. The “ball” that is in the line of flow is solid on each side and is open on the other sides. The rotating cylinder on these valves can also be cone-shaped. Smaller plug valves are used on customer service lines. The valve that connects a distribution main to a service lateral is called corporation stops (corp stop) and the valve that connects the service lateral to a meter is a curb stop. These are also referred to as meter and angle stops. They can be used to throttle flow without being damaged.

- Flexing – The last style of valve based on how it operates is a “flexing” valve. These valves are either diaphragm or pinch style valves. The flow is reduced or stopped by a squeezing or pinching effect to obstruct the flow. The material inside of these valves need to be flexible and are commonly resistant to corrosion.

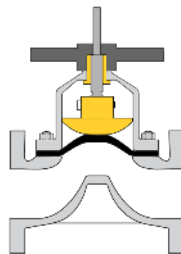


Figure 2.6.4: Image by Muskid is licensed under [CC BY-SA 3.0](#)

Gate Valves

Gate valves are one of the most widely used valves in a water distribution system. As previously mentioned their primary function is to start and stop the flow of water. These types of valves should not be used for throttling the flow of water as they can become damaged. The gate (slide) is lowered and raised by a hand wheel in above-ground installations and a nut with a key on below-ground installations. The face of a gate valve can become worn, especially if they are throttled and objects can become lodged under the gate, which prevents a proper seal.



Figure 2.6.5: Image by COC Water Systems Technology Faculty is licensed under [CC BY 4.0](#)



Figure 2.6.6: Image by Heather Smith is licensed under [CC BY 3.0](#)

The gate picture above is the style used below the ground surface. The nut on top of the valve bonnet is operated with a “T” shaped key with a 2” square case that fits on top of the nut. The other gate valve pictured above is one used in above-ground installations and is operated with a handwheel. There are several different styles of gate valves, and they have various purposes. The list below identifies some of these valves:

- Non-rising stem (NRS) – The below ground gate valves are considered non-rising stem. These valves take up less space and have the screw mechanism protected.
- Rising stem – A rising stem gate valve is commonly used on fire systems. The reason is that it is easily detected if the valve is open or closed by the position of the stem. These types of valves are also called “outside stem and yoke” or OS&Y valves. The picture depicts this type of valve. When the stem is up, the valve is open.



Figure 2.6.7: Image by Mike Alvord is licensed under [CC BY 4.0](#)

- Horizontal – In shallow below ground installations, horizontal gate valves are commonly used. They allow for low clearance and they are also easier to operate. Instead of having to lift the gate up when operating, the gate slides to the side. So, in addition to installations when the ground cover is minimum, large valves can also be horizontal gate valves.



Figure 2.6.8: Image by Mike Alvord is licensed under [CC BY 4.0](#)

- Tapping, Cutting-In, Inserting – Several styles of gate valves are classified based on the use in construction practices. Tapping, cutting-in, and inserting valves are all used based on adding a valve in an existing distribution system. Tapping valves are used exclusively when a connection needs to be made to a water main. Hence, “tapping” into the water main. There are two types of taps, wet or hot tap and dry tap. A hot tap is done while the water main is in use and service cannot be disrupted. A dry tap is when the pipeline is shut down and the water is drained from the pipe.



Figure 2.6.9: Image by Rainier5 is licensed under [CC BY-SA 3.0](#)

The two other methods of adding a valve to an existing water system are cutting-in or inserting. A pipe can be cut and a valve is added or a valve can be inserted into the pipe. The picture below is an example of an insertion gate valve.

A cutting-in valve was one oversized end connection designed to be used with a cutting-in sleeve. The valve and sleeve are used together to facilitate installation of a new valve in an existing main. Pressure must be shut off for a short time. Inserting valves are installed when water cannot be shut off and the main cannot be depressurized.

- Resilient seated – Gate valves are commonly made of various types of metallic materials. However, rubber, urethane rubber, and other synthetic materials are also used to make the closure member. In addition, the seat is made from this same material, providing a tight and complete closing seal.
- Slide – Gate valves are sliding (sluice) valves, but a slide gate is a simple gate style valve. They are designed to release large volumes of water at one time and are often found in large agricultural systems. The gate or blade is relatively thin, they do not provide a completely tight shut off, and can be square, oblong, or round in shape.

One of the main advantages of gate valves is the ability to block or let flow happen in both directions. They also offer little to no resistance when fully open and allow a clear waterway for the flow of water. In addition to the various styles of gate valves, they are classified into three (3) main types: double-disc, solid wedge, and resilient seated (as previously discussed). A double-disc gate valve is made up of two relatively loose-fitting discs that, when closed, are pressed against metal seats by a wedging mechanism. Water pushes past the upstream disc and allows the area between the two discs to become pressurized when the discs are in a closed position. The pressure is then released when the valve is opened. Some of these valves are equipped with a bypass to equalize the pressure on both sides to make it easier to open. The main disadvantage is the large frictional on the downstream disc making it difficult to lift off the seat. A solid wedge gate valve involves a closure member that is a single wedge guided into fitted, tapered seats. Although throttling is not recommended with gate valves, the solid wedge is more desirable because of the close guiding between the wedge and the body. Resilient seated gate valves were previously discussed.

Other Valves

Plug valves are a type of rotary valve and can be used to throttle and control flow. Even when open, they cause some flow resistance. There are three (3) basic types of plug valves, lubricated, non-lubricated, and eccentric. With lubricated plug valves, grease is used to lubricate the plug motion and to seal the gap between the plug and the valve body. On a non-lubricated plug valve,

the valve is mechanically lifted up from or pushed down to the seat. An eccentric plug valve is a non-lubricated valve that rotates the plug and pulls away from the seat. Another type of rotary valve is a cone valve. These are limited in use because of their size and weight, but they are good for controlling flow and provide low flow resistance. Ball valves require a 90-degree rotation between the open and closed position, have low flow resistance, and are also suitable for throttling flow.

Another common valve within the water industry is a **butterfly valve**. A butterfly valve is another valve that rotates. It has a disc similar to a gate valve, but this disc rotates on a shaft to open and close. Butterfly valves are easier to operate than a gate valve because as they open, the force of the water pushes against the opposite side of the disc helping to open the valve. The main disadvantage of a butterfly valve is that they have a high resistance to flow because the valve, even when fully open, is always in the flow path. The disc can also get damaged from the vibration of the flowing water. Since they have a short laying length (distance between each side of the flanges), they are used where space is limited. They are also lighter in weight and less expensive than gate valves.



Figure 2.6.10: Image by Heather Smith is licensed under [CC BY 3.0](#)

A check valve allows flow in only one direction and therefore has very specific applications. There are five (5) main types of check valves.

- Slanting disc – Provide the lowest head loss of any check valve and are commonly used in larger pipelines to save on pumping costs
- Cushioned swing – Results in a soft or cushioned closing of the valve when the flow of water stops
- Rubber swing – Instead of the valve swinging on a hinge pin, like most other check valves, a rubber swing flexes to open
- Double door – While all check valves are designed to allow flow in only one direction, a double door check valve is designed to have a greater seal when closed. These types of valve are more common in industrial operations.
- Foot – These are special types of check valves installed on groundwater wells in order to prevent water from flowing backwards out of a pump and well piping back into the well when the well pump stops operating. They are installed at the bottom of a pump suction line and are used to prime the pump.

Relieving and Controlling Pressure

Pressure relief valves are very common in installations where pressures are high or where pressures can spike. These types of valves are used to control the limiting pressure within a system. The pressure is relieved by allowing the water flow to escape through an auxiliary passage out of the system. Preset pressure limits are designed to prevent damage to specific equipment or plumbing systems. Many residential homes and commercial businesses will have pressure relief valves installed if the incoming water pressure from the distribution system is higher than what is acceptable to the building being served. These valves are designed to open when pressures meet these preset values. A spring-activated disk balances the pressures on both sides of the system and opens when the inlet pressure exceeds the set value.

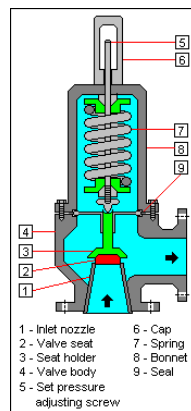


Figure 2.6.11: Image by Mbeychok is licensed under [CC BY-SA 3.0](#)

Controlling pressure is another function of water system valves. If pressures are too low a water system is sometimes incapable of supplying the needs of customers. More importantly, if pressures are very low, the water system might be unable to provide adequate flows for fighting fires. If pressures are too high and relieving the pressure outside of the system is not possible, controlling valves can also be used. In some systems, both relief and controlling valves can be used. For example, the pressures within a system may fluctuate higher and lower beyond what are considered adequate pressures and a control valve would be installed. However, if the chance of extremely high pressures exists, then a relief valve would also be installed. Pressure control valves use hydraulic pilot systems which allow for a high pressure set point for high flow demands and a low pressure set point for low demands.

The valve then automatically adjusts the pressure across the valve to accommodate these pressure ranges. This prevents the system from having too high or too low pressures.



Figure 2.6.12: Image by Markus Schweiss is licensed under [CC BY-SA 3.0](#)

Backflow Prevention

Preventing the contamination of a drinking water is an important aspect of a water distribution system. When a non-potable water supply is connected to a potable water supply the possibility of a cross-connection between these two sources exists. Therefore, every water utility needs to have a cross-connection control program. Cross-connection control and backflow prevention is discussed in another section of this text. In this section, we will look at the actual methods and devices used to prevent the flow of non-potable water back into a potable water supply system.

The safest way to prevent a cross-connection is by not connecting non-potable supplies with potable supplies. When complete isolation of two supplies is not possible, a backflow method can be accomplished with an air gap. A proper air gap has the source supply discharging water into a receiving supply. This air gap distance between the source supply and the receiving supply must be two times the diameter of the supply pipe or one (1) inch, whichever is greater.

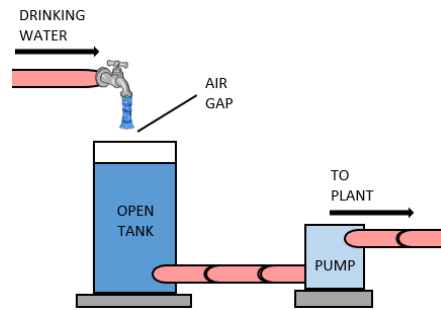


Figure 2.6.13: Faucet image by frankes is licensed under CC0 1.0 (modified by COC OER)



Figure 2.6.14: Images by the Ohio EPA

When complete separation is not possible, a backflow prevention device can be used. These types of valves are reduced pressure principle, double check, or vacuum breakers.

A reduced pressure principle (RP) backflow device consists of two spring-loaded check valves with a pressure-regulated relief valve between the two. Under back-siphonage conditions, both checks will close and the relief valve will open. If there is back-pressure in excess of the water main, both check valves will also close. If leakage occurs in the second valve, it will be allowed to escape through the center relief valve. It is important to install these devices high enough where the relief valve cannot be submerged in water. RP devices are used in commercial, industrial, and irrigation installations.

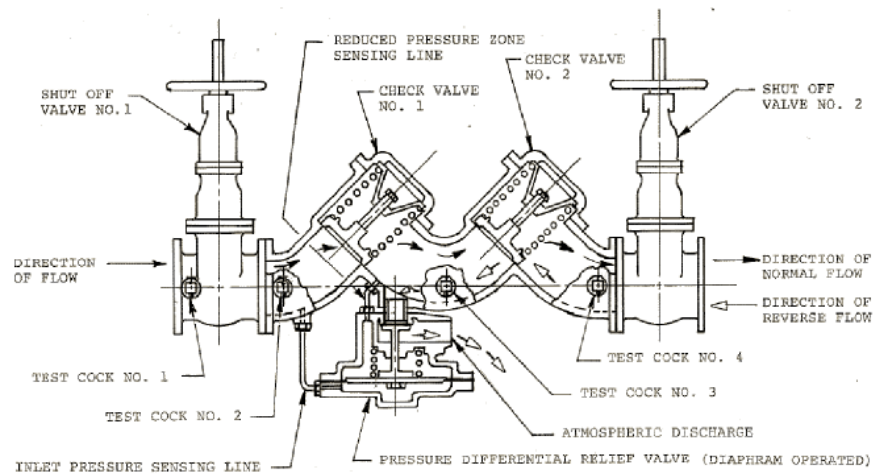


Figure 2.6.15: Image by the Ohio EPA



Figure 2.6.16: Image by the Ohio EPA

Double check (DC) valve devices are similar to RP devices, except they do not have a relief valve in the center. Therefore, the protection is not as positive and should not be used where a health hazard may result. DC valves are commonly used in fire sprinkler installations.

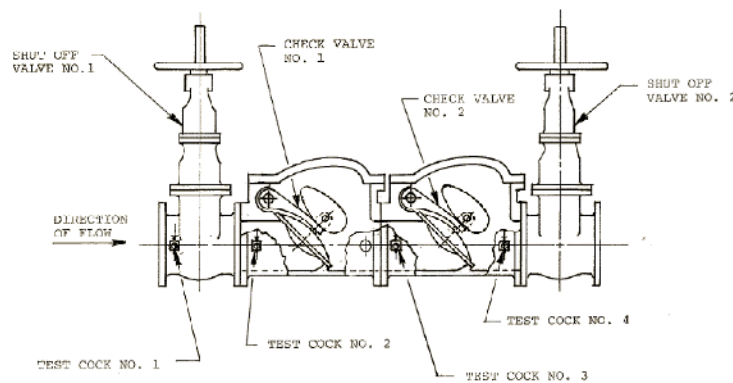


Figure 2.6.17: Image by the Ohio EPA



Figure 2.6.18: Image by the Ohio EPA

Installations where water use is only needed during an emergency, as with a fire sprinkler system, an RP or DC device can be installed with a meter attached. This meter will detect any flow of water through the device and allow the utility to bill the customer for this usage. These meters are referred to as detector assemblies. Therefore, an RPDA would be a reduced pressure principle detector assembly and a DCDA a double check detector assembly. Back-flow prevention devices are required to be monitored and maintained. Most cross-connection control programs require annual testing.

There are other types of devices used where health hazards do not exist and are designed for intermittent use. These devices are called vacuum breakers. There are two main types of vacuum breakers, atmospheric and pressure. Common installations include lawn sprinkler systems, janitor sink faucets, and toilet flush valves. Atmospheric vacuum breakers must be installed beyond the last valve in the piping system. When the supply pipe is under pressure, the check valve closes against an upper seat to prevent leakage. When there is no pressure, the valve drops and allows air to enter the discharge pipe preventing back-siphonage. If there is continuous pressure the valve may malfunction. Pressure vacuum breakers are designed for use under pressure for long periods of time. They should not be used where back-pressure is possible on the discharge side and they must be installed above the highest fixture in the system.

Valve Maintenance

Since valves are mechanical devices, they need to be properly maintained. There is a wide variety of different types and uses of valves throughout the water industry and each type has its own maintenance requirements. As previously mentioned, backflow prevention devices require frequent testing and proper maintenance. The seats of a valve can become worn and damaged and need to be replaced periodically. The springs, which operate the valves and allow them to open and close, need to be replaced from time to time. This sort of maintenance is not only required with backflow devices, all valves need to be monitored and maintained.

Distribution system valves are usually left in the open position to allow water to flow throughout the system. However, in the event of a leak or some other emergency, where the flow of water needs to be stopped, a valve needs to be closed. If a valve is left in the open position for years, closing it may prove to be difficult. Why? Because any mechanical device which has not been operated over a long period of time can become stuck or frozen. Therefore, it is important to operate valves on a routine basis. This routine maintenance operation of distribution system valves is referred to as valve exercising. Exercising a valve is nothing more than operating the valve from its current condition (open or closed) to the other position. Each valve type and valve size has a known amount of turns required to open and close it and the operator should be mindful of the number of turns in order to determine if the valve is in good working condition. If the valve cannot be operated to the required number of turns, it could be damaged or broken and might need to be replaced. A good valve exercise program should include all the information about the valve so the operator can make an assessment as to whether or not the valve is in good working condition. If not, then the valve should be put on a replacement schedule.

Valves are an important part of any water utility system and provide a variety of uses, from stopping and starting flows, allowing flows in only one direction, reducing pressure, relieving pressure, and controlling pressure. These are some of the more critical uses of water system valves.

Sample Questions

1. Which of the following valves is not compatible with a process known as “pigging”?

1. Butterfly
 2. Gate
 3. Ball
 4. All are compatible
2. Which of the following valve should not be used for throttling?
1. Butterfly
 2. Gate
 3. Ball
 4. Plug
3. Which back-flow device provides the most protection?
1. Double check
 2. Reduced pressure
 3. Vacuum breaker
 4. All are equal
4. Which valve is used to prime a groundwater well pump?
1. Butterfly
 2. Gate
 3. Ball
 4. Foot
5. Which of the following valves would be considered a “closing down” type?
1. Gate
 2. Globe
 3. Butterfly
 4. Both 1 and 2

This page titled [2.6: Valves](#) is shared under a [CC BY](#) license and was authored, remixed, and/or curated by [Mike Alvord \(ZTC Textbooks\)](#) .

- [1.6: Valves](#) by [Mike Alvord](#) is licensed [CC BY 4.0](#).

2.7: Hydrants

In this chapter, we will examine water distribution fire hydrants and their uses.

Student Learning Outcomes

After reading this chapter, you should be able to:

- Describe the different types of fire hydrants
- Explain the different uses of fire hydrants
- Identify the operational and maintenance criteria for fire hydrants

From a very early age, we are exposed to fire hydrants. Many kids' storybooks have pictures of red fire hydrants and Dalmatian dogs.



Figure 2.7.1: Photo by [Ashim D'Silva](#) on [Unsplash](#)

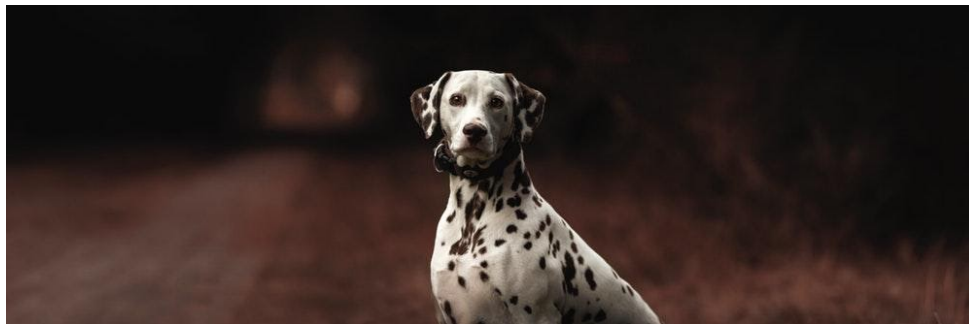


Figure 2.7.2: Photo by [Tim Zänkert](#) on [Unsplash](#)

We start recognizing the red fire plug and associate it with firefighting. However, most fire hydrants we see every day are not red. They are yellow. The use of fire plugs or fire hydrants as we know them today dates back to the 1600s. After a devastating fire destroyed a large portion of London, predrilled holes were added to new water mains and plugs were installed above ground for access. Since early water mains were made out of wood, the early hydrants were holes that had above ground plugs, hence the term “fire plug”. By the 1800s, cast iron hydrants replaced the traditional fire plugs.



Figure 2.7.3: Image by [Matt Gregory](#) is licensed under [CC BY-ND 2.0](#)

Fire Hydrant Uses

The most common and understood use of a fire hydrant is fighting fires. Public fire protection is important for any community and it is the responsibility of water utilities to provide fire hydrants in required locations and the water required for fighting fires. There are other uses of fire hydrants. Some of these uses include flushing water pipelines, storm drains, and sewers, street washing, public landscape watering, and construction. Let's take a look at some of these less obvious uses.

Flushing Water Pipelines, Storm Drains, and Sewers

When a new water pipeline is installed there are various things that need to be done before the pipeline can be connected to the distribution system and used for public water supply. New pipelines need to be disinfected and sampled to make sure the water in the pipe is safe for human consumption. After this disinfection and sampling process, the water needs to be flushed out and replaced with fresh water. This flushing process is commonly performed by the use of fire hydrants. Water in pipelines can also become stagnant if there is little or no use. An example of this would be a cul-de-sac where there is little to no use. Perhaps it is a long cul-de-sac with only one home and the homeowners are out of town for an extended period of time. The water in the pipeline could become stagnant and when the homeowners return may notice some taste and odor problems with the water. If the water utility is notified of these types of issues they would oftentimes flush the water out of the pipeline to replace it with fresh water.

Storm drains and sewers also need to be cleaned from time to time. If debris blocks the flow in these systems, hoses are often connected to fire hydrants in order to push the debris and flush these piping systems. It is important to make sure the potable drinking water distribution does not become contaminated from storm drains and sewers. Often times certain valves known as back-flow devices are used or water trucks are filled through fire hydrants and then these piping systems are flushed.

Street Sweeping and Landscape Watering

In order for city streets to stay clean, vehicles such as street sweepers are commonly used. A street sweeper will connect to a fire hydrant in order to fill up a tank and then the water is discharged to clean the street. A lot of streets have center medians with landscaping which include trees and other plant material. If these medians are not equipped with irrigation systems, water trucks are often used to water these plants. The water to fill these trucks comes from fire hydrants.



Figure 2.7.4: Image by Ildar Sagdejev is licensed under [CC BY-SA 4.0](https://creativecommons.org/licenses/by-sa/4.0/)

Construction

Construction needs water for various purposes. One of the most common uses of water (supplied through fire hydrants) is for dust control. During grading operations, heavy equipment moves and removes dirt, sometimes over large areas. This process of dirt moving creates dust. In order to control the dust, water trucks collect water from fire hydrants and spray it over the entire area to wet the dirt controlling the dust.

Is Water From Fire Hydrants Free?

Unlike water served to customers such as home or business owners, water coming from a fire hydrant is not metered. When a fire truck pulls up to a fire hydrant, connects a hose to the hydrant, and starts to fight a fire, the water used is not metered. In other words, there is nothing to track the amount of water used and there is no one paying for the water being used. Since fighting fires is a public service, it actually makes sense that the water used is not metered. There are some uses from fire hydrants, which should be metered, and the water paid for by the user. Most other uses of water from fire hydrants besides fighting fires is metered for use. Portable hydrant meters are used to keep track of the water used. These meters, often referred to as construction or hydrant meters,

are temporary meters rented to the user. Since these meters are temporary in nature and can be used in multiple locations the user is sometimes asked to provide the meter reads.



Figure 2.7.5: Image by the U.S. Air Force is in the public domain

By charging for water used from fire hydrants there is accountability of the water and it also discourages the wasting of water. It is important for water utilities to account for all the water within a water distribution system. It costs the utility to pump the water throughout the distribution system, so when water leaves the system unaccounted for, there is lost revenue. This lost water is measured by utilities and is referred to as water loss.

There are several ways water utilities monitor and control the use of water from fire hydrants. Specific meters are assigned and used only for connecting to fire hydrants. These meters are commonly referred to as construction or hydrant meters. Often times, deposit fees are charged to “rent” these meters. Deposits are designed to cover cost of the meter in case they are lost or damaged. These fees can also be used to maintain and service these meters to make sure they work and measure flow accurately. Some utilities use a permitting process to issue these meters. This process is designed to help track the meters being issued and often includes a fee, which provides the same coverage for maintenance and replacement costs.

Parts of a Fire Hydrant

There are several parts of a hydrant and can be broken into the upper and lower section. The upper section consists of the nozzle and head. The nozzles are the areas where hoses or meters can be connected and where the water flows from the hydrant. These connections are commonly 2 ½” and 4” in diameter, threaded, and caps are usually provided to cover and protect the threads.



Figure 2.7.6: Image by Ben Schumin is licensed under CC BY-SA 2.5 (modified by COC OER)



Figure 2.7.7: Image by the U.S. Air Force is in the public domain

The top section of a hydrant can also be referred to as the bonnet. The bonnet is the top cover or enclosure. There is an upper barrel portion that sits above the ground and a lower buried portion, oftentimes referred to as the “bury-el”. This buried elbow portion is shown below.



Figure 2.7.8: Image by FEMA is in the public domain

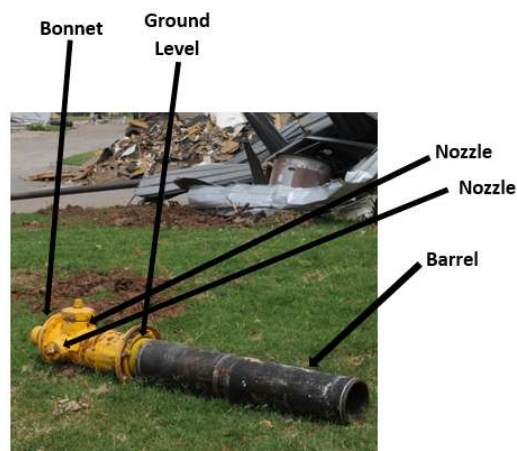


Figure 2.7.9: Image by FEMA is in the public domain

Types of Fire Hydrants

On the surface, most fire hydrants look similar. They are usually molded in cast or ductile iron, bronze, and sometimes steel. They are typically constructed above ground with threaded openings for the attachment of hoses. However, there are a few different types of fire hydrants. The first two we will look at are the dry barrel and wet barrel hydrants.

Dry Barrel Hydrants

A dry barrel hydrant is exactly that...a hydrant with the barrel dry. The barrel of a hydrant is the body above ground and a section below ground. The picture below depicts the barrel. This type of fire hydrant is very common in areas where the weather drops below freezing. In these areas, the barrel of a hydrant needs to be dry in order to prevent the water in the barrel from freezing. If the water in a barrel of a fire hydrant freezes, then the ability of the fire department to access water in order to fight fires is impeded.

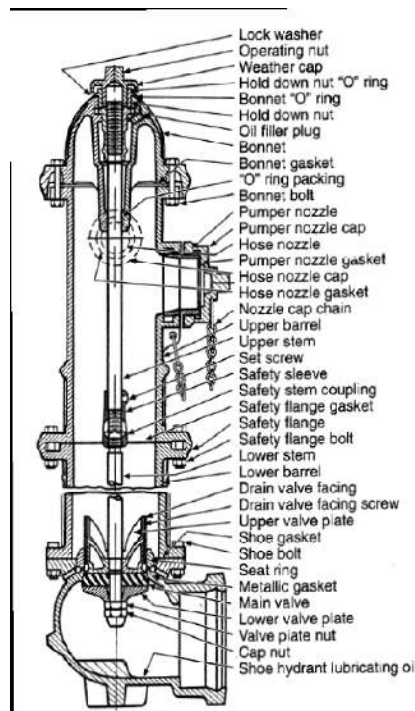


Figure 2.7.10: Dry Barrel Fire Hydrant - Image by the U.S. Fire Administration is in the public domain

There is a nut at the top of a dry barrel fire hydrant, which is connected to a stem. This stem connects to and operates a valve, which allows water to enter the hydrant barrel, and water can flow. There are two types of dry barrel fire hydrants: wet-top and dry-top. A wet-top dry barrel hydrant is constructed such that the threaded end of the stem and the operating nut sealed from water when the valve is open. A dry-top dry barrel hydrant has the threaded end of the stem sealed off from water in the barrel when the hydrant is filled with water and in use. This design reduces the possibility of the threads becoming fouled by sediment or corrosion.

The type of operating valve can further classify a dry barrel hydrant. These types of valves include standard compression, slide gate, and toggle.

- Standard compression – This type of hydrant valve closes the water against the seat of the valve to aid in providing a good seal
- Slide gate – A slide gate is a gate valve similar to a distribution system gate valve
- Toggle – This type of valve closes horizontally and the hydrant barrel extends well below the branch line. This type of valve is also called a “Corey” valve.

Wet Barrel Hydrants

Wet barrel hydrants are used in warm climates where the risk of freezing is minimal. Since most fire hydrants are above ground and exposed to the elements, it is important that the water inside the hydrant doesn’t freeze when the temperatures dip below freezing temperatures. However, it is also important that a fire hydrant flows water when it is opened. This is the design of a wet barrel hydrant. When the valve stem adjacent to a threaded opening is twisted open, water flows directly out of the hydrant.

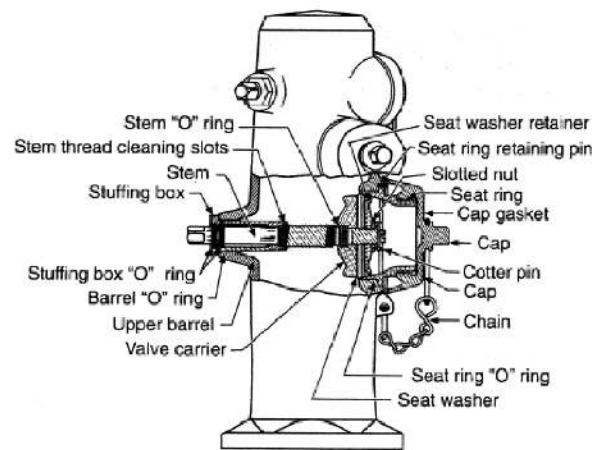


Figure 2.7.11: Wet Barrel Fire Hydrant - Image by the U.S. Fire Administration is in the public domain

Locating Fire Hydrants

Fire hydrants need to be properly located in order for ease of access and properly spaced in order to give proper coverage for firefighters. Hydrants are typically located at street intersections and spaced between 350 and 600 feet apart. The spacing is dependent on the type of structures in the area (residential, commercial, etc) and the density of the buildings. Commonly they are placed about two (2) feet from the back of curb face and located far enough away from buildings to allow the fire department to gain access without being too close to fire. When installed along public roadways on sidewalks, care must also be taken to install them so they do not impede foot traffic or wheelchairs.

Since fire hydrants are commonly installed where there is vehicular traffic, the potential for one to get hit by a vehicle is likely. Therefore, proper installation must be considered in order to provide the least amount of damage. Several methods are commonly used. One method is to use hollow bolts, which connect the flange above ground to the flange below ground. Another method employs the use of a “breakaway” flange. This type of flange is manufactured to split in the center. Both of these methods allow for the hydrant to break away from the below-ground barrel. This prevents the buried components from being damaged and allows for the hydrant to be reinstalled relatively easy without any excavation.

Potential Problems

As discussed above, hydrants are not just operated by water utility operators. Fire departments, City workers, construction workers, and others can and often do operate a fire hydrant for various reasons and uses. This presents a potential problem. Older hydrants may not seat (close) properly and leak after it is closed. Opening a hydrant at the end of a cul-de-sac may stir up sediment in a pipe causing water quality issues and concerns. Proper traffic control must be taken when a hydrant is open on public streets with traffic. When a hydrant is open, it can disrupt the flow of traffic by spraying water across lanes. Whenever a hydrant is open to flow onto the ground, proper drainage needs to be available. If storm drains and gutters are filled with debris, water may not be able to drain properly and some of this debris can be flushed into storm drains ending up in local waterways. Another problem that can occur when a hydrant is improperly opened and closed is something called “water hammer”. Opening or closing a hydrant too fast can cause the flow of water to move or stop too rapidly causing damage to pipes and other appurtenances.

It is important to understand the need and various uses of fire hydrants. They play an important role to the surrounding community, public safety, safety to property, and a variety of other uses.

Sample Questions

1. A fire hydrant referred to as a “Corey” style would be what type?
 1. Flushing
 2. Wet Barrel
 3. Dry Barrel
 4. None of the above
2. The base or buried portion of a hydrant is commonly called the _____.

1. Bonnet
 2. Cap
 3. Nozzle
 4. Bury-El
3. Approved use of a fire hydrant includes all of the following except?
1. Dust control
 2. Fighting fires
 3. Cooling the public during heat waves
 4. Flushing sewers
4. Which of the following is an advantage of a dry-barrel hydrant?
1. Water is easily withdrawn by opening an operating nut
 2. Water will not flow if the hydrant gets hit and knocked off its base
 3. Water will not freeze in the hydrant body
 4. Both 2 and 3
5. A wet-top fire hydrant is a type of _____.
1. Wet barrel hydrant
 2. Flushing hydrant
 3. Dry barrel hydrant
 4. All of the above

This page titled [2.7: Hydrants](#) is shared under a [CC BY](#) license and was authored, remixed, and/or curated by [Mike Alvord \(ZTC Textbooks\)](#) .

- [1.7: Hydrants](#) by [Mike Alvord](#) is licensed [CC BY 4.0](#).

2.8: Meter Services

In this chapter, we will examine water distribution meters and services

Student Learning Outcomes

After reading this chapter, you should be able to:

- Describe the different types of water meters and services
- Explain the different uses of water meters
- Identify the operational and maintenance criteria for water meters

Why Water Meters?

What is the purpose and need for a water meter? Are water meters always used by water utilities? What does a water meter do and where are they used? What is a water meter? These and other questions will be answered in this text.

Purpose of a Water Meter

The primary purpose of a water meter is to monitor and record the amount of water being used by a customer. These customers can be residential homeowners, commercial buildings, industrial customers, other water utilities, and various other customers. The idea of “metering” water usage can be traced back to the early sixteenth century. However, if it rained enough to water crops and landscaping, if water was readily available equally for everyone, there might not be a need for water meters. However, it wasn’t until the early nineteenth century when water meters began to be more widely used. The increase in use coincided with the growth of urbanization and industrialization.

While metering the flow of water is very common among residential and commercial drinking water supply customers throughout much of the world, it is less common with irrigated agriculture customers. Metering is also less common in rural areas and in areas where water is in abundance.

In many parts of the world, water is not always easily accessible and in order for the “people” delivering the water to communities to recover all the costs associated with delivering this coveted resource, meters are used. One of the main uses of a water meter is to measure the amount of water delivered to customers. However, meters are used to measure other volumes of water in addition to what is delivered to a customer.

Types of Water Meters

While there are many different styles of water meters, they are all based on two main methods for measuring flow: displacement and velocity. Displacement meters physically move (or displace) a given amount of water passing through the meter. Velocity meters measure the speed at which the flow of water is passing through the meter. There are a number of different water uses and meters are commonly selected based on size and need. For example, you wouldn’t want to select a small meter if very high volumes and flows are needed. Likewise, you wouldn’t want a large meter for a single-family home. Displacement meters are commonly used in small to medium flow installations and velocity meters in areas where large flows are required.

Positive Displacement Meters

Positive displacement (PD) meters are commonly used for single-family residential water uses. They are very accurate in measuring low intermittent flows. They work by means of a nutating disk or rotating piston, which creates a rotary motion transmitting to gears and then to the register. PD meters are not designed to operate at full flow for extended periods of time. Normal flows for a PD meter should not be more than approximately one half of the maximum capacity in order to extend the life of these types of meters. Common sizes range in diameters from 5/8” to 2”. If PD meters are too large for the required use, lower flows will not be properly registered. For example, if a 2” PD meter is used for a one-bedroom apartment where only indoor water use occurs, lower flows such as when someone is brushing their teeth or filling a glass of water may not be accurately measured. PD meters almost never over register and continuous operation at the maximum flow rates will quickly destroy the meter. They are designed with threaded ends and are not tapered. Therefore, a coupling with a gasket is needed for installations. This type of design allows for quick and easy installation and removal.

Piston PD meters operate by the means of a piston, which moves back and forth as the water flows through. A specific quantified volume is measured for each piston rotation. This rotating motion is transmitted to a register through a magnetic drive connection and series of gears.

Nutating-disk PD meters use a measuring chamber containing a flat disk. As water flows through, the disk wobbles and rotates (nutates) sweeping out a specific volume of water on each cycle. The rotary motion is transmitted to a register.

Velocity Meters

Velocity meters measure the flow through a chamber of specific size and known capacity. The speed of the flow is converted into volumes correlating to water usage. There are several types of velocity meters, which include, single-jet, multi-jet, turbine, and propeller meters. Electromagnetic and ultrasonic meters are also technically velocity type meters, but will be discussed later in a separate section.

Multi-jet meters use a multiblade, multiport rotor mounted on a vertical spindle within a measuring chamber. Water enters this chamber through several tangential orifices around the circumference and leaves through another set of orifices set at a different level. The “jets” of water rotate an impeller where the rotation transmits to a register. Installations requiring low flows, multi-jet meters range in sizes from 5/8” to 2”. Internal strainers are often used in order to protect the jet ports from getting clogged. Unlike PD meters, multi-jet meters can overregister. Multi-jet meters have two basic designs. One design is referred to as a “wet” register design and the other a “dry” register. In a dry register design, the register, which sits at the top of a meter, can be removed without shutting the water supply off. This is a desirable design when a register stops working or becomes damaged and can be replaced easily without disrupting usage.

Turbine and propeller meters measure the flow of water by means of a rotor. Each revolution of the rotor is proportional to the volume of water. The rotor has blades, which are angled to transform energy from the flow stream into rotational energy. The rotor shaft spins on bearings and as the water propels through the meter faster, the rotor spins proportionally faster. The accuracy is not good at low flow rates because there is some drag between the rotor and the bearing, which slows the rotation of the rotor. Propeller meters are similar to turbine meters. The main difference is with the rotating element. A propeller is made of thick molded plastic and faces directly into the flow and is suspended by a single bearing assembly. In contrast, the thinner rotor in a turbine meter is supported on both sides by two lighter weight-bearing assemblies. Common installations of turbine meters are uses where the flow is high and the variance in the flow is minimal. For example, irrigation system flows are commonly measured using a turbine meter (below right). In these installations, the flow is constant and steady. Propeller meters (below left) have similar uses, but are more commonly found on source supply installations, for example on a groundwater well. These installations also have a constant steady stream of high flows.

Venturi and Orifice Meters

A venturi meter consists of an upstream reducer, a short throat piece, and a downstream expansion section. An increase in the flow velocity results in a corresponding pressure drop and the flow rate can be deduced. As the flow of water moves through the contraction in the pipe, it speeds up and so, the pressure drops. By measuring the upstream and downstream pressures, the fluid velocity and flow rate can be calculated.

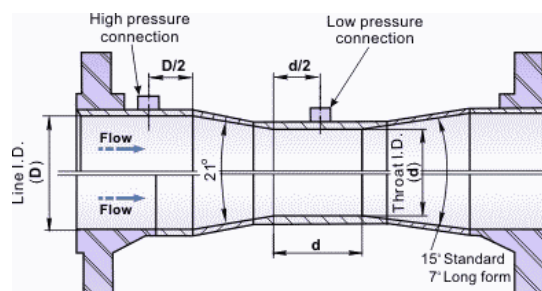


Figure 2.8.1: Image by Aadilnashit is licensed under [CC BY-SA 4.0](https://creativecommons.org/licenses/by-sa/4.0/)

An orifice meters operates in much the same way as a venturi meter. A thin plate with a hole in the center of it is installed between two flanges. The flow rate is then calculated by measuring the pressures on both sides of the plate. These types of meters are considered differential pressure meters.

Magnetic and Ultrasonic Meters

Ultrasonic and magnetic meters operate in a similar fashion. They measure the rate of flow without any moving parts to disrupt the path of the flow. Magnetic (or Mag) meters measure the flow of water using an electromagnetic field resulting in a potential difference proportional to the flow velocity perpendicular to the electrical sensors. The pipe must be properly insulated in order to prevent corrosion from the electrical current. Ultrasonic flow meters use ultrasound frequencies to calculate a volume of flow. Transducers are used to emit a beam of ultrasound against the direction of flow. The pulses are sent in opposite diagonal directions and the sound changes with the velocity of the flow. These types of meters tend to have higher initial costs, but the ongoing maintenance costs are minimal because there are no moving parts to maintain or replace.



Figure 2.8.2: Image by Mike Alvord is licensed under [CC BY 4.0](#)

Weirs and Flumes

Some water systems such as when an open channel is providing a water supply to a community, a different structure is needed to measure the flow. In this particular system, a traditional style meter is not appropriate. An obstruction referred to as a weir is placed across the flow path to measure watersheds, creeks, and stream flows. The depth to which the water rises above the bottom of the weir is directly proportional to the flow. There are two main types of weirs, rectangular and V-notch. Rectangular weirs are constructed in a variety of different configurations including contracted, suppressed, broad crested, and sharp crested.



Figure 2.8.3: Image by Risker is licensed under [CC BY-SA 3.0](#)



Figure 2.8.4: Image by A. Balet is licensed under [CC BY 3.0](#)

- Contracted weirs are constructed where the width of the notch is less than the width of the channel.
- Suppressed weirs have the notch as wide as the width of the channel.
- Broad crested weirs have a flat horizontal surface at the crest ranging from 6" to 15" and are usually made of concrete.
- Sharp crested weirs are made of fiberglass, corrosion-resistant metal, or wood.

V-notch weir angles are commonly 30°, 45°, 60°, and 90°. The larger the angle, the higher volume flows are measured. These types of weirs are always sharp crested design and they measure smaller flows than rectangular weirs. The rate of flow passing over the crest of any type of weir is directly proportional to the depth of water measured from the crest to the water surface. The depth measurement is always made at a distance of at least three times the height upstream of the weir so that the measurement is not affected by the sloping surface of the water approaching the weir. For example, if the weir is 10 feet, then the flow measurement would be collected approximately 30 feet upstream of the weir. The flow depth can be automatically determined and recorded by a float and a recorder installed in a device called a stilling well.



Figure 2.8.5: Image by the FAO is licensed under [CC BY-NC-SA 3.0 IGO](#)

Flumes are similar to weirs and are also designed to measure the flow in an open-channel section. The principal advantage of a flume is that there are no vertical obstructions as there are in weirs. A flume narrows in the center to increase the velocity of the flow. The velocity through a flume must be high, which also helps keep the flume clean. Flumes are generally more expensive than a weir. The most common type of flume is the Parshall flume. The capacity is determined by the width of the throat of the flume. In Parshall flumes, the widths range from 1 inch to 50 feet. The depth of the flow at a particular point in the flume is directly related to the rate of flow. As with weirs, flume depths can be made by a staff gauge or automatically with a transducer.



Figure 2.8.6: Image by the FAO is licensed under [CC BY-NC-SA 3.0 IGO](#)

Compound Meters

At times both low and high flows need to be measured accurately. As previously discussed, most meters are designed to measure either low or high flows. For example, PD style meters are not good for measuring high flows and turbine-style meters are not sufficient at measuring low flows. Installations where both low and high accurate flow measurements are required; a compound meter can be used. Compound meters usually consist of a larger turbine meter, a smaller positive displacement meter, and an automatic valve to switch between the two meters. Water passes through the small meter until a certain velocity is reached and then the valve actuates to divert the flow to the larger turbine meter. Two standard meters can also be connected together to provide the same function.



Figure 2.8.7: Image by COC Water Systems Technology Faculty is licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/)

Meter Selecting and Installation

As previously mentioned, meters are often selected based on the volume of water needing to be measured. Meters are commonly one size smaller than the diameter of size of the service lateral. For example, if the service lateral is 1" in diameter serving a residential home, the meter might be $\frac{3}{4}$ " in size. In a typical residential housing track, it is common to have 1" service laterals and $\frac{3}{4}$ " meters. However, in commercial areas, the service lateral might be sized for greater usage compared to residential units, but still might have smaller meters. For example, a 2" service lateral might be installed for a bookstore where the only usage might be a single restroom and a $\frac{3}{4}$ " meter might be installed. However, if this bookstore changes the use to a restaurant and higher flows are required, the service lateral is already sized appropriately and only the meter would need to be replaced with a larger one. Therefore, it is important to size services for future potential uses.

Residential meters are typically $\frac{5}{8}$ " or $\frac{3}{4}$ " in size depending on water demand. However, in some communities, residential homes might require internal fire sprinkler systems, in which case the meter size might need to be larger. There are various plumbing codes for sizing meter services and can also be dependent on the number of internal plumbing fixtures. Commercial businesses and multi-family residential homes commonly have meter sizes of 1", 1 $\frac{1}{2}$ ", and 2". If accuracy at low rates is not important and if typical flow rates between 5 % and 35% of the maximum rated capacity then a positive displacement style of meter is adequate. If accuracy of low flows is required, as well as being able to accurately measure higher flows then a compound meter should be used. Installations requiring large capacity and low flow accuracy, and flows at 10% to 15% maximum rating then a turbine meter should be selected.



Figure 2.8.8: Image by COC Water Systems Technology Faculty is licensed under [CC BY 4.0](#)

Meters are generally installed in concrete or polymer boxes located in the parkway, between the curb and the sidewalk. In very cold climates, meters are installed in deep meter pits or inside buildings. Larger meters are usually installed in precast concrete vaults. Whenever possible, meters should be installed in areas protected against flooding. They should be installed with an upstream and downstream shutoff valve. A meter, angle, or curb stop is the shutoff valve on the upstream side of the meter and there is usually a small gate, globe, or ball valve on the customer (downstream) side of the meter. Meters need to be accessible for maintenance, inspection, and reading and should be protected from freezing. Whenever a utility operator visits a meter, the condition of the meter box and lid should also be checked to make sure there is not a public hazard and that they are in good condition. Registers should be sealed and should have a means of preventing tampering. Depending on the type of usage, meters can also be installed with a bypass. If it cannot be interrupted, a bypass allows for water service to be maintained while the meter is removed or repaired. Some meter installations can have multiple meters installed in series. This type of setup is a manifold installation. They are used when high flows are required and flow cannot be interrupted. One meter at a time can be removed or repaired without disrupting service.



Figure 2.8.9: Image by Utilitysupplies is licensed under [CC BY-SA 3.0](#)



Figure 2.8.10: Flanged Water Meter - Image by COC Water Systems Technology Faculty is licensed under [CC BY 4.0](#)

Meters up to one (1) inch in size usually have threaded connections each side of the meter. Larger meters tend to have flanged connections. Sometimes a yoke can be used to simplify meter installations in hard to reach areas. Yokes hold the stub ends of the pipe in proper alignment and spacing to support the meter. Yokes also provide a cushion against stress and strain in the pipe. The image below shows a typical yoke.



Figure 2.8.11: Image by COC Water Systems Technology Faculty is licensed under [CC BY 4.0](#)

As previously mentioned, meter boxes are usually installed on public property, but close to the property line. They should be installed in areas to protect against damage from vehicles. If a meter must be installed in a driveway, steel lids are usually sufficient to help protect the meter from vehicles. Meter couplings or flanges should be located where they are accessible and the dimensions of the meter box or vault should be adequate in size and specified prior to installation. If the meter is installed in a building, then a special valve needs to be installed on the upstream side of the service line. A curb box in either an arch-style or Minneapolis style is used in these situations. An arch-style curb box fits loosely over the top of the stop valve. These installations are adequate if the soil is firm enough. If the surrounding soil is loose, it may work its way into the box or the box may shift making access to the stop valve difficult. The Minneapolis style curb box has threads at the bottom and screws onto special threads on the top of the meter. These installations do not have the issue of shifting or dirt entering the box, but if there is damage to the curb box, damage to the meter and service line can occur.

Meter Reading

Meter accuracy is important in order to adequately bill for the amount of water actually used. As flow passes through the body of a meter, the volume is transmitted to a register. Old style meters were equipped with circular or round registers. Some gas meters are still this style. The problem with this type of register is the difficulty to read. It is now common to have a register similar to a car odometer. Some are equipped with one or two fixed zeros. The reason for this is because water usage is commonly billed per hundred cubic feet. Therefore, with two fixed zeros, the first number to register on the meter is a one (1) with two trailing fixed zeros, indicating one hundred (100) cubic feet. Some larger meters might have a multiplier of ten (10) or one hundred (100) times. This is because usage is high and it makes it easier to keep track of this large volume of water.



Figure 2.8.12: Image by Utilitysupplies is licensed under [CC BY-SA 3.0](#)

There are several ways a meter can be read. The simplest and most common of reading meters is to read them directly. This requires a worker to visit each location where the meter is installed and physically read the register. It requires the meter to be accessible and clean so the register can be read. By visiting meters routinely, workers can see if the meter is being tampered with, damaged, or needs to be replaced. However, this type of reading process can be difficult in cold climates and some customers do not like meter readers visiting their homes. There is also the chance for human error. As technology advances, so do the ways meter reads can be collected. Remote meter reading is becoming more and more common. There are several types of remote meter

reading technologies. One remote meter reading technology is referred to as “touch probe” reading. The meter register is connected to touch sensor with a wire. A handheld unit is connected to a probe and is placed on the touch sensor transmitting the meter read. This technology still requires a meter reader to visit each location, but there is less labor involved since the meter box lid does not have to be lifted. Another remote meter reading process is called automatic meter reading (AMR) or “drive-by”. Special electronics are attached to the meter and send out a radio frequency signal. Meter readers’ drive by each location with a computer and a receiving device to pick up the meter reads through the radio frequency signal. The last remote meter reading process is called automatic metering infrastructure (AMI). This type of technology uses radio frequencies with large antennas installed in specific locations or cellular data to transmit meter reads instantly on demand. This type of system requires significant upfront costs, but does not require any labor to read the meters. Some utilities are moving to this type of meter reading technology in order to provide customers real-time data on their water usage. This can assist utilities with their conservation efforts.

All meters are designed to measure flow velocity where the flow is laminar. If the flow has any turbulence, meters can and will often incorrectly register the meter read. Any kind of pipe bend, valve, obstruction, or change in flow direction get cause turbulence. Therefore, meter manufacturers often specify straight pipe lengths before and after the meter. These distances are typically expressed in pipe diameters. As a rule of thumb, five (5) times the pipe diameter before the meter and two (2) times the diameter after the meter. For example, if the pipe is twelve (12) inches in diameter, there should be sixty (60) inches of straight pipe before the meter and twenty-four (24) inches of straight pipe after the meter.

One of the main reasons a worker should visit a meter regularly is because some customers will attempt to steal water. Some common ways customers attempt to steal water are removing the register, turning the meter backward, or removing the meter. In addition to visiting a meter routinely, seals can be placed on the meter. Seals do not necessarily prevent pilferage, but if the seal is broken, a worker can quickly identify if the meter has been tampered.

Meter Testing

Since meter accuracy is important, meters need to be tested to make sure they are operating correctly. Meter manufacturers often include testing results with new meters. In addition, some utilities randomly test new meters to make sure the manufacturer test results are correct. As meters age over time, they can start to under register. Therefore, a routine meter testing program is often recommended. Some utilities randomly remove meters at various ages in order to see if they are still registering properly. Customers can also request for a meter to be tested if they think their meter is not registering correctly. Meters should also be tested after any maintenance.

Some meters (usually larger ones) are testing in place, while smaller meters are typically removed from service and placed on a test bench. Regardless of the location, meters are tested in a similar fashion. A known volume of water is flowed through the meter and the register is compared to this volume. In addition, various flow rates are flowed through the meter, each time comparing the known volume with the volume recorded on the meter register. There are accuracy limits on the different rates of flow that are considered acceptable. Positive displacement meters are tested against a minimum, intermediate, and maximum flow rate, while larger meters might have four (4) or five (5) different flow rates. Below is a set of recommended accuracy limits for different types of meters.

Positive displacement, multi-jet, and turbine meters have an accuracy range of 98.5% to 101.5%. This means if 100 gallons of water are flowed through the meter and the meter registers between 98.5 and 101.5 gallons, then the meter is determined to be accurately measuring flows. The limits for propeller meters are 98% to 102% and compound meters 97% to 103%.

Sample Questions

1. Which of the following meters would be most likely to over-register?

1. Turbine
2. Positive displacement
3. Multi-jet
4. All of the above

2. A compound meter is used when _____.

1. Low flow accuracy is required
2. High flow accuracy is required

3. Constant high velocities at low flows are required
4. Both 1 and 2
3. Positive displacement meters operate by means of a _____.
 1. Rotor
 2. Nutating disc
 3. Propeller
 4. Electromagnetic waves
4. Over time meters tend to _____ and should be _____.
 1. Over register, replaced
 2. Under register, replaced
 3. Over register, tested
 4. Under register, tested
5. Which of the following would not be considered a flow meter?
 1. Weir
 2. Volute
 3. Venturi
 4. Flume

This page titled [2.8: Meter Services](#) is shared under a [CC BY](#) license and was authored, remixed, and/or curated by [Mike Alvord \(ZTC Textbooks\)](#)

- [1.8: Meter Services](#) by [Mike Alvord](#) is licensed [CC BY 4.0](#).

2.9: Pumps

In this chapter, we will examine the pumps that move water throughout a water distribution system.

Learning Outcomes

After reading this chapter, you should be able to:

- List the various types of pumps found in the water industry
- Identify the various components of pumps
- Differentiate the various purposes of pumps in the water industry

Purpose of a Pump

Without a pump, water would only flow through gravitational forces of gravity. This would be fine if the source of water was always higher than the user. However, we know that this is not the case. In addition to pumps being needed to deliver water to customers at varying elevations, pumps are used to “lift” water over mountains to deliver it to treatment plants. Pumps are used to “push” water through treatment systems and to “inject” chemicals into a stream of flowing water for treatment purposes. As you can see, there are a lot of purposes for pumps in the water industry. This chapter will present a variety of examples where pumps are used, the various types of pumps, and how they are used to keep water flowing in a distribution system. There are two main types of pumps, which are primarily used in the water industry; these are positive displacement and variable displacement pumps.

Positive Displacement Pumps

Positive displacement pumps “displace” liquid by mechanical action providing constant flow at a fixed speed, despite changes in pressure. There are two main types of positive displacement pumps: Rotary and Reciprocating. Positive displacement pumps move fluids by trapping a fixed amount and displacing (moving) the trapped volume into a vessel such as a pipe. A good example of a positive displacement pump used in the water industry is for chemical injection such as chlorine disinfection. Below is a picture of a positive displacement pump taking a liquid chemical from a container and pumping it into a pipe.

Positive displacement pumps are commonly used for chemical injection because of their ability to operate against a variety of discharge pressures while maintaining a constant given speed. This enables a consistent chemical dosage. One of the main disadvantages of positive displacement pumps is that they do not have a shutoff head. Therefore, if a positive displacement pump operates against a closed valve it will cause the discharge line to burst and/or cause damage to the pump. Positive displacement pumps include gear, lobe, peristaltic, screw, piston, and rotary.

Variable Displacement Pumps

Variable displacement 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. There are various types of variable displacement pumps and include; jet, turbine, and centrifugal. The most common in the water industry are turbine and centrifugal.

Centrifugal Pumps

Centrifugal pumps are some of the most common types of pumps used in the water industry. They convert rotational kinetic energy to hydrodynamic energy. Electric motors provide this rotational energy. Centrifugal pumps raise the water by a centrifugal force, which is created by a wheel referred to as an impeller. This impeller revolves inside a tight casing. Water enters the pump at the center of the impeller referred to as the eye. The impeller throws the water outward toward the inside wall of the casing by the centrifugal force resulting from the revolution of the impeller. Water then passes through the casing and emerges at the discharge point under pressure. There are two main types of centrifugal pump casings, volute and diffuser.

- Volute casing – Volute are designed to utilize the incoming velocity of the liquid entering the impeller and converting this velocity into pressure. The impeller is housed in a spiral-shaped case and located offset of the center of this casing. This allows pressure to build as the impeller spins counter-clockwise and the distance between the volute and the impeller increases gradually. These are typically single-stage designs and are used for large capacity and low head applications.

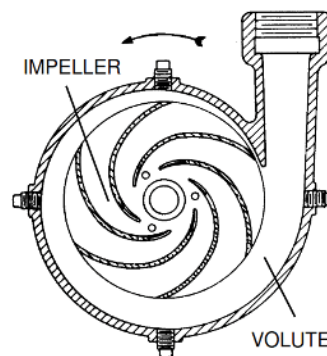


Figure 2.9.1: Image is in the public domain

The impeller of a centrifugal pump is either open, semi-open, or closed design. Open impellers are generally used to pump raw water. This is because raw water may carry with it some solids, which would damage the other impeller designs. Semi-open impellers can pump liquids with some solids, but not as much as the open design. Closed impellers generally pump finished treated waters and provide a controlled area to channel water through the impeller.

- Diffuser casing – A typical diffuser casing has many vanes in order to build pressure at the point where the edge of the casing approaches the edge of the impeller. Diffuser designs are generally more compact compared to volute designs.

There are five (5) distinct types of centrifugal pumps in the water industry: turbine (diffuser), volute, axial flow, radial flow, and mixed flow.

- Turbine – These types of centrifugal pumps are most commonly used in well pump operations. The impeller is surrounded by diffuser vanes, which provide gradually enlarging passages in which the velocity of the water leaving the impeller is gradually reduced, thus transforming velocity head to pressure head. Turbine pumps often come in multiple stages. The stages are bolted together to form a pump bowl assembly. The function of each stage is to add pressure head. The volume lifted and efficiency is almost identical in each stage.

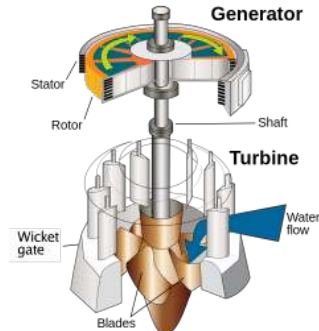


Figure 2.9.2: Image by the [U.S. Army Corps of Engineers](https://www.army.mil/) is in the public domain

- Volute – These types of pumps were discussed earlier and are used in high flow and low-pressure installations and are commonly single-stage pumps. They are either close or long-coupled. Close-coupled pumps have the impeller mounted directly on the motor shaft. A long-coupled (or frame-mounted) has a pump with separate motor bearings and is connected to the motor by a coupling.
- Axial Flow – These types of pumps are in-line and work on a vertical plane in relation to the water. Axial flow pumps offer very high flow rates and very low amounts of pressure head.
- Radial Flow – This type of centrifugal pump discharges the fluid radially (at right angles to the pump shaft). Radial flow means the pump operates on a horizontal plane to the direction of flow.
- Mixed Flow – A mixed flow pump is a cross between an axial flow and radial flow pump. The impeller sits within the pipe and turns, but the turning mechanism is essentially diagonal. The centrifugal force moves the water while accelerating from the axial direction for the impeller.

Pump Components

A pump is made up of a number of different components. The following list composes the main mechanical components of a centrifugal pump. Each item will be discussed.

- Casing
- Single-Suction Pumps
- Double-Suction Pumps
- Impeller
- Wear Rings
- Shaft
- Shaft Sleeves
- Packing Rings
- Lantern Rings
- Mechanical Seals
- Bearings
- Couplings

Some of the components above have been previously discussed, so they will only be mentioned again briefly below.

Casing

Pumps casings are designed to retain pressure and to seal off the inside of a pump to prevent leakage. In centrifugal pumps (as previously explained) the casing surrounds the pump rotor transmitting energy to the fluid by means of an impeller, which is mounted on a rotating shaft. In positive displacement pumps, the casing surrounds the rotary or reciprocating displacement elements.

All casings have inlet and outlet nozzles, which direct the flow into and out of the pump. Inlet nozzles are referred to as suction nozzles and outlets are referred to as discharge nozzles.

Single-Suction and Double Suction Pumps

Many pumps used in the water industry are single-suction pumps. In single-suction pumps, water enters the impeller from one end and discharges across the casing. The fluid moves from the impeller center to the peripheral region of the pump. Another type of pump based on its suction is termed a double- suction pump. In a double-suction pump, the inlet water enters on both sides of the impeller. These are commonly referred to as a horizontal split-case pump. The casing is split into two halves along the centerline of the pump shaft.



Figure 2.9.3: Single-Suction Pump - Image by Kaze0010 is licensed under [CC BY-SA 3.0](https://creativecommons.org/licenses/by-sa/3.0/)

Impeller

Impellers are unique to centrifugal pumps. They rotate inside the pump casing transferring energy from the motor, which drives the pump to the fluid being pumped. The fluid is accelerated outwards from the center of the rotation. The open inlet portion of an impeller is often referred to as the “eye”. According to the Swiss mathematician and physicist Daniel Bernoulli, pump impellers rely on the principle that states an increase in fluid velocity is accompanied by a decrease in pressure or potential energy (and vice versa) in order to operate.

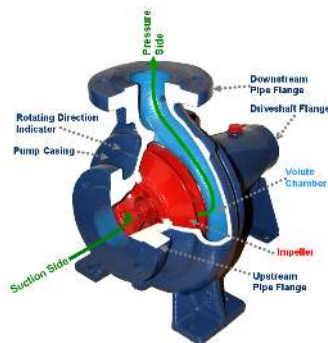


Figure 2.9.4: Image by Fantagu is in the public domain

Wear Rings

In order for impellers to rotate freely within a pump casing, a small clearance needs to be maintained between the casing and the impeller. To minimize damage to the rotating impeller, a set of wear rings are often attached to the impeller and/or the pump casing to allow this small clearance without causing wear to the impeller and casing. These wear rings are designed to wear and be replaced through proper maintenance.

Shaft and Shaft Sleeves

Impellers are mounted on a metal rod commonly made of a nickel alloy or stainless steel referred to as a shaft. Shafts transmit the rotating energy to the impeller. Shafts can be solid or hollow. Solid shafts are connected near the bottom end of a motor, while a hollow shaft extends through the motor shaft and is joined at the motor's crest. Hollow shaft pump motors are most commonly used for deep groundwater wells. A special tool referred to as an arbor press (or gear puller) is required to remove the impeller from the shaft.

A pump shaft sleeve is a hollow tube, typically made of metal and is placed over the shaft in order to protect it as it passes through the packing. These cylinder-shaped metal tubes are protecting the shaft from corrosion and wear and are designed to be replaced as needed.

Packing Rings and Stuffing Box vs Mechanical Seals

At the point where the shaft extends out of the pump casing, leakage can occur. In order to prevent or reduce the amount of leakage, packing rings or mechanical seals are used. Up to six rings can be used and need to be staggered 90 degrees apart beginning at "twelve o'clock". The next ring is installed at "three o'clock" and so on. The packing rings are installed in an assembly called a stuffing box. Mechanical seals can be used instead of packing rings. They are more expensive, but typically last longer, allow minimal to no damage to shaft sleeves, and offer less maintenance. The main downside to mechanical seals is that when they fail, they fail suddenly and they are fairly difficult to replace. In contrast, packing rings require monitoring and adjustment, but are much easier to replace.

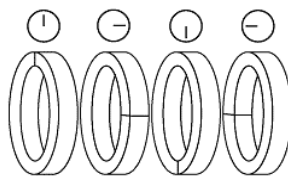


Figure 2.9.5

The picture above is an example of how packing rings are staggered.

Also placed in the stuffing box are lantern rings. They are designed to prevent air from entering the pump casing. Pump discharge water is fed into the ring and flows out of it through a series of holes leading to the shaft side of the packing. Water flows both towards the pump suction and away from the packing gland acting as a seal preventing air from entering the water stream and provides lubrication for the packing.

Bearings

Bearings within a casing (cage) of their own are used to allow the shaft to spin the impeller with minimal friction. The type of bearing used is dependent on the type and size of pump. Most pumps within the water industry have ball-type radial and thrust bearings. These are either grease or oil lubricated. One common feature among bearings is that they usually start to get noisy before they fail.

Couplings

When a pump is mounted on a frame, separate pump shafts are connected together by a coupling. The coupling transmits the rotary motion of the motor to the pump shaft. They are designed and installed to allow slight misalignment between the pump and the motor. This allows the shock from the motor start up to be absorbed. There are two types of couplings: flex and mechanical. The main difference between the two is that flex couplings are installed dry and require no lubrication and mechanical couplings require lubrication.

Pump Operation

Whenever there is machinery with moving parts, friction occurs causing noisy operation and the potential for the development of heat. Therefore, motor and pump temperature, vibration, noise, and other parameters should be monitored. There are various sensors that can be used, but the most efficient way to monitor for these things is direct observation. If the surface of a motor unit is substantially warmer than normal, it should be shut down. Experienced water utility operators commonly get to know the normal sound of pumps and motors as well. However, there are vibration detectors, special thermometers, temperature indicators, and various types of sensors can be installed to monitor these parameters. If the temperature, vibration, or some other factor being measured is out of a specified range, then alarms can sound or signals can be sent. In some instances these sensors can shut down these devices automatically.

Cavitation

Pump speed is also another parameter to monitor. Speed switches or contacts can be provided to monitor and turned off pumps at certain times. Under certain speed conditions, when the pressure acting upon the water falls to or below the vapor pressure of the water, it will begin to vaporize. This will create vapor pockets. At higher pressures, the pockets collapse and a rumbling noise is created. This rumbling, popping, crackling noise is referred to as cavitation. Suction cavitation occurs when the net positive suction head available to the pump is less than what is required. Under these conditions, the pump sounds like it is pumping rocks. There will be high vacuum (suction) pressure readings will occur on the suction line and low discharge pressures with high flows on the discharge side. This can be caused by several things, which include, a clogged suction pipe, a suction pipe which is too long, a suction pipe diameter too small, suction lift too high, and a valve on the suction line only partially open. Discharge cavitation occurs when the pump discharge head is too high where the pump runs at or near shutoff. A similar sound to suction cavitation occurs, resulting in high discharge pressure readings and lower flows. Similar conditions cause discharge cavitation including, a clogged discharge pipe, a discharge pipe that is too long, or a diameter too small, the discharge static head is too high, or the discharge line valve is partially closed. In addition to the noise created by cavitation, pump impellers and bowl surfaces can become pitted. Fluctuations or reductions in yield can occur and erratic power consumption can also be a result of cavitation.

Avoiding Cavitation

In centrifugal and propeller pumps, cavitation can be avoided by preventing the following conditions:

- Avoid heads much lower than the head at peak efficiency of the pump
- Avoid capacity much higher than the capacity at peak efficiency of the pump
- Avoid suction lifts higher or positive heads lower than recommended by the manufacturer
- Avoid speeds higher than the manufacturer's recommendations
- Avoid liquid temperatures higher than that which the system was originally designed

Pump design is an important process when selecting the correct pump for specific operational uses. Using various pump sizes is one way of controlling flow rates and preventing inefficient operations. Variable speed motors or pump drives are other ways to control flow. Discharge valves can also be throttled (partially closed), but this can lead to valve damage or inefficient operations.

However, this process can be utilized in specific circumstances. Starting and stopping pumps too often can cause excessive wear and increases power costs. Variable speed motors are one solution to too many starts and stops of a motor. Daily operations, storage needs, and system pressures should all be evaluated in order to select the correct pump and motor.

Pumps are one of the most important components of any water utility system. They bring water from deep underground to the surface and they distribute water throughout the distribution system. They are used in treatment plants to move water through the treatment process. In areas where the topography varies, pumps are used to lift water to these various elevations. Pumping water requires electricity and this creates a significant cost to water utilities. Water utilities greatest expense is quite often the cost of pumping water.

Sample Questions

1. Which of the following is a pump casing?
 1. Venturi
 2. Weir
 3. Volute
 4. All of the above
2. Which of the following pump is the most common pump in the water industry?
 1. Piston
 2. Turbine
 3. Positive displacement
 4. Centrifugal
3. A negative aspect of mechanical seals is _____.
 1. They fail suddenly
 2. They are difficult to adjust
 3. They don't last long
 4. None of the above
4. Lantern rings are designed to _____.
 1. Provide a small amount of leakage to cool the pump
 2. Fail as the pump wears
 3. Prevent air from entering the pump casing
 4. None of the above
5. Double suction pumps are commonly referred to as _____.
 1. Centrifugal pumps
 2. Turbine pumps
 3. Dual split face
 4. Horizontal split case

This page titled [2.9: Pumps](#) is shared under a [CC BY](#) license and was authored, remixed, and/or curated by [Mike Alvord \(ZTC Textbooks\)](#).

- [1.9: Pumps](#) by [Mike Alvord](#) is licensed [CC BY 4.0](#).

2.10: 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)

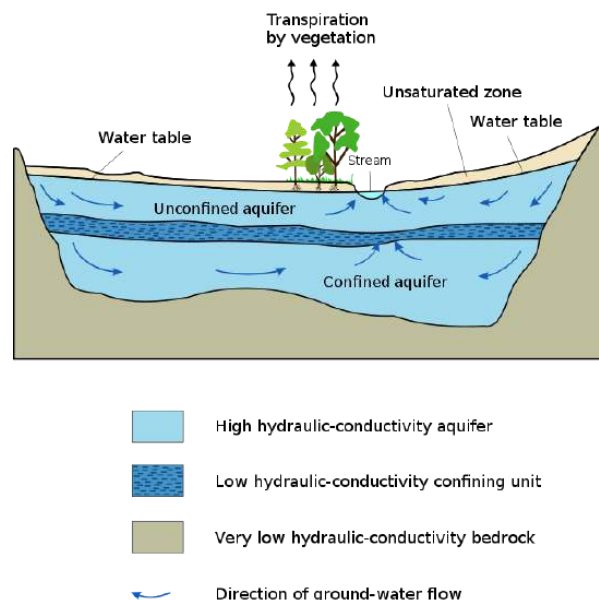


Figure 2.10.1: Image by the [USGS](#) is in the public domain

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 2.10.2: Image by Didiervberghe is in the public domain



Figure 2.10.3: Image 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.

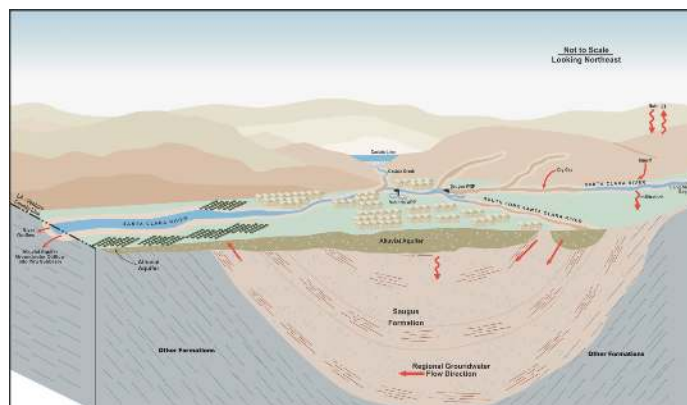


Figure 2.10.4: Source: Adapted by LACSD from the Task 2A - Conceptual Model Development East and Piru Subbasins Final Report by CH2M HILL 2006

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.

- $1 \text{ psi} = 2.31 \text{ feet (head)}$

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

- $100 \text{ psi} \times 2.31 \text{ feet/psi} = 231 \text{ feet}$

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.

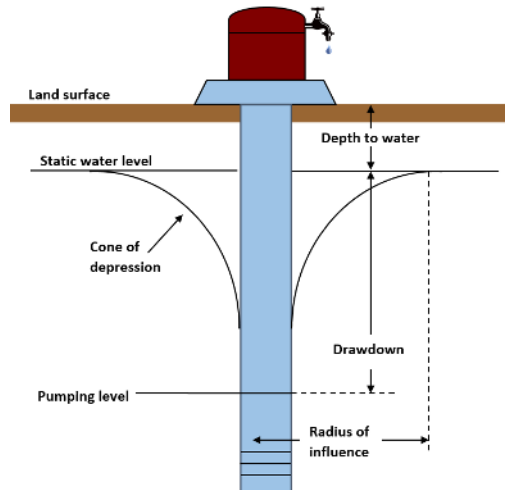


Figure 2.10.5: Image by COC OER is licensed under [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/)

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

This page titled [2.10: Wells](#) is shared under a [CC BY](#) license and was authored, remixed, and/or curated by [Mike Alvord \(ZTC Textbooks\)](#) .

- [1.10: Wells](#) by [Mike Alvord](#) is licensed [CC BY 4.0](#).

00: Front Matter

This page was auto-generated because a user created a sub-page to this page.

TABLE OF CONTENTS

00: Front Matter

- Table of Contents

3.1: Numbers, Decimals, and Fractions

- 3.1.1: The Set of Real Numbers
- 3.1.2: Mathematical Operations

3.2: Powers, Roots, Order of Operations, and Evaluating Expressions

- 3.2.1: Powers and Roots
- 3.2.2: Order of Operations
- 3.2.3: Evaluating Expressions

3.3: Solving Equations and Formulas

- 3.3.1: Addition, Subtraction, Multiplication, and Division Properties of Equality
- 3.3.2: Solving a Formula for a Variable (Rewriting a Formula)
- 3.3.3: Solving Quadratic Equations of the Form- $(x-a)^2=c$

3.4: Scientific Notation, Rounding, Conversions, and Dimensional Analysis

- 3.4.1: Scientific Notation
- 3.4.2: Rounding
- 3.4.3: Dimensional Analysis

3.5: Ratios, Proportions, and Percentages

- 3.5.1: Ratios
- 3.5.2: Proportions
- 3.5.3: Percentages

3.6: Geometry

- 3.6.1: Definitions
- 3.6.2: Examples

3.7: Reading and Interpreting Graphs

- 3.7.1: Types of Graphs
- 3.7.2: Examples

SECTION OVERVIEW

3.1: Numbers, Decimals, and Fractions

3.1.1: The Set of Real Numbers

3.1.2: Mathematical Operations

This page titled [3.1: Numbers, Decimals, and Fractions](#) is shared under a [CC BY 4.0](#) license and was authored, remixed, and/or curated by [Kelly Brooks](#).

3.1.1: The Set of Real Numbers

The set of real numbers consists of the numbers that we use in everyday life. We will define the set of real numbers more precisely, but first, let's define some other sets of numbers.

Natural Numbers: The counting numbers starting with 1: 1, 2, 3, 4, ...

Whole Numbers: 0 and the counting numbers: 0, 1, 2, 3, 4, ...

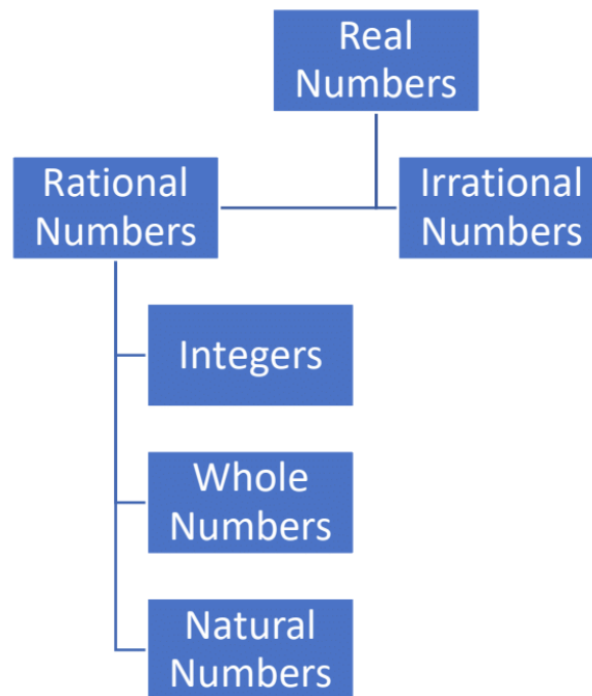
Integers: Positive and Negative Whole Numbers (includes 0); The whole numbers and their opposites: ..., -4, -3, -2, -1, 0, 1, 2, 3, 4, ...

Rational Numbers: A number that can be written as a fraction (integers, terminating decimals and repeating decimals)

Irrational Numbers: Numbers that cannot be written as a fraction (non-terminating decimals and non-repeating decimals)

Real Numbers: All rational and irrational numbers

Some numbers can be classified in many categories. The next diagram displays the relationship between the different sets of numbers.



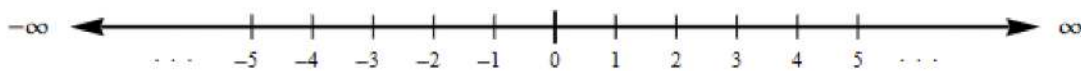
Example: Classify the following numbers

1. 2.718
2. $\sqrt{13}$
3. $\frac{24}{51}$
4. 101
5. $0.\overline{3}$
6. -5

See the video for the solutions.

The Real Number Line

We order real numbers on a number line based on their distance from 0. Positive numbers lie to the right of zero and Negative numbers lie to the left of zero. Each point on the number line corresponds to a real number.



Notice that -2 is represented by a distance of 2 units to the left of zero, the negative determines the side of zero while the 2 represents the distance from zero. Similarly, +2 is represented by a distance of 2 units to the right of zero, the positive indicates we move to the right of zero while the 2 represents the distance from zero. When writing positive numbers, it is customary not to write the “+” sign in the front.

Example: Plot the following numbers on a real number line

1. 2.718
2. $\sqrt{13}$
3. $\frac{24}{51}$
4. 101
5. $0.\overline{3}$
6. -5

See the video for a demonstration.

We determine the size of a number relative to another number using less than ($<$) or greater than ($>$) signs. Whichever number is further to the right, is larger, while a number that is further to the left is smaller.

We say “ a is less than b ” if a lies to the left of b on a real number line and we write this as: $a < b$.

We say “ a is greater than b ” if a lies to the right of b on a real number line and we write this as: $a > b$.

Examples: Use $<$ or $>$ to indicate the relationship between the stated numbers

1. $7 \underline{\hspace{1cm}} -3$
2. $5 \underline{\hspace{1cm}} 12$
3. $5.8 \underline{\hspace{1cm}} 5.7$
4. $-3.2 \underline{\hspace{1cm}} -3.1$
5. $-5 \underline{\hspace{1cm}} -12$

See the video for the solutions.

The Opposite of a Number and Absolute Value

Definition: The opposite of a real number, a , is $-a$.

We can think of the opposite of a real number as changing the sign of the real number.

Examples: The opposite of 5 is -5. The opposite of -7 is $-(-7) = 7$

Hence, $-(-7)$ can be read as “the opposite of -7” or “the opposite of the opposite of 7” or 7.

Definition: The absolute value of a real number is its distance from zero on a real number line. The notation for the absolute value uses two vertical bars on either side of the number, hence “the absolute value of a ” would be denoted as $|a|$. Since the absolute value represents a distance, its value is always positive.

Examples:

$|5| = 5$ since 5 is a distance of 5 from 0

$|-7| = 7$ since -7 is a distance of 7 from 0

This page titled [3.1.1: The Set of Real Numbers](#) is shared under a [CC BY 4.0](#) license and was authored, remixed, and/or curated by [Kelly Brooks](#).

3.1.2: Mathematical Operations

The Addition of Integers and Decimals

Adding Numbers with the same signs

- Add the absolute values of the numbers and assign the common sign to the result
- NOTE: When the signs are both positive, add the values

Example: $23 + 18$

The common sign is +, so the answer will be positive, now we add the numbers to obtain

$$23 + 18 = 41 \quad (3.1.2.1)$$

Example: $-17 + (-31)$

The common sign is -, so the answer will be negative, now we add the absolute values of the numbers to obtain:

$$-17 + (-31) = \quad (3.1.2.2)$$

First, calculate the sum of the absolute values:

$$|-17| + |-31| = 17 + 31 = 48 \quad (3.1.2.3)$$

Next, assign the result the common sign, so the final answer is: -48.

$$-17 + (-31) = -48 \quad (3.1.2.4)$$

Adding Numbers with the Opposite Signs

- Take the absolute value of each number
- Subtract the smaller number from the larger number
- Assign the sign of the result based on the sign of the number with the larger absolute value
- NOTE: The sign of the larger absolute value wins. With practice, these steps will start to feel seamless.

Example: $21 + (-13)$

First, calculate the absolute value of each number:

$$|21| = 21 \text{ and } |-13| = 13 \quad (3.1.2.5)$$

Next, subtract the smaller number from the larger number:

$$21 - 13 = 8 \quad (3.1.2.6)$$

Next, assign the sign of the number whose absolute value was greater, in this case, the sign of 21 is the sign of the final answer (positive), hence

$$21 + (-13) = 8 \quad (3.1.2.7)$$

Scientific calculator keystrokes:

Example: $28 + (-54)$

First, calculate the absolute value of each number:

$$|28| = 28 \text{ and } |-54| = 54$$

Next, subtract the smaller number from the larger number:

$$54 - 28 = 26 \quad (3.1.2.8)$$

Next, assign the sign of the number whose absolute value was greater, in this case, the sign of -54 is the sign of the final answer (negative), hence

$$28 + (-54) = -26 \quad (3.1.2.9)$$

Short-cut: Now that we have gone through the formal process for adding integers, let's get the general idea of the process:

- If the signs are the same, combine the numbers and keep the sign
- If the signs are different, disregarding the signs, subtract the smaller number from the larger number, then keep the sign of the larger number

Example: $13 + (-29)$

Since 29 is larger than 13, we subtract 13 from 29 to get 16, and use the sign of 29 which is negative: -16

Example: $-28 + (-54)$

Since the signs are the same, the answer will have the same sign (negative), now combine the numbers $28 + 54 = 82$, so the final answer is -82

Similarly with decimal numbers:

Example: $-2.34 + (-5.4) =$

Since the signs are the same, we add the numbers: $2.34 + 5.4 = 7.74$ and keep the common sign (negative) to get -7.74

Subtraction of Integers and Decimals

When subtracting an integer or decimal, we add the opposite of the number following the subtraction.

Example: $15 - 7 =$

In this case, we can perform regular subtraction, however, we can also apply the subtraction rule of adding the opposite to obtain:

$$15 + (-7) = 8 \quad (3.1.2.10)$$

since 15 is larger than 7, we subtract and keep the sign of the larger number which is positive

Example: $3 - 12 =$

Remembering to add the opposite of 12, we get

$$3 + (-12) = -9 \quad (3.1.2.11)$$

Since the signs are different and 12 is larger than 3, we subtract $12 - 3$ to get 9, but use the sign of 12 which is negative to obtain -9

Likewise with decimal values:

Example: $8.23 - (-1.2) =$

We first add the opposite of -1.2: $8.23 + 1.2 =$

Next, we combine the numbers since they have same signs to obtain:

$$8.23 - (-1.2) = 8.23 + 1.2 = 9.43 \quad (3.1.2.12)$$

Multiplication and Division of Integers and Decimals

To multiply or divide integers and decimals, we use multiply the numbers and use the following rules for the sign:

- If two numbers have the same signs, the result is positive
- If two numbers have different (opposite) signs, the result is negative

Examples:

1. $(3)(-7) = -21$
2. $(-15)(-10) = 150$
3. $(-5.2)(2) = -10.4$
4. $(2)(7) = 14$
5. $(-25) \div (-5) = 5$
6. $(-12.8) \div (4) = -3.2$
7. $(250) \div (-10) = -25$

8. $(48) \div (6) = 8$

Addition, Subtraction, Multiplication, and Division of Integers and Decimals using a Scientific Calculator

There are many types of scientific calculators available in the retail market, on our personal computers, and even on our personal devices such as cell phones and tablets. As a result, let's first distinguish between two types of scientific calculators: A Display calculator and a non-display calculator. Some examples of display calculators are: TI30XIIS, TI-36X Pro, TI-30XS Multiview, and the Casio fx-350ES PLUS. Some examples of non-display calculators are TI-30Xa, most cell phone calculators, and most calculators on personal computers.

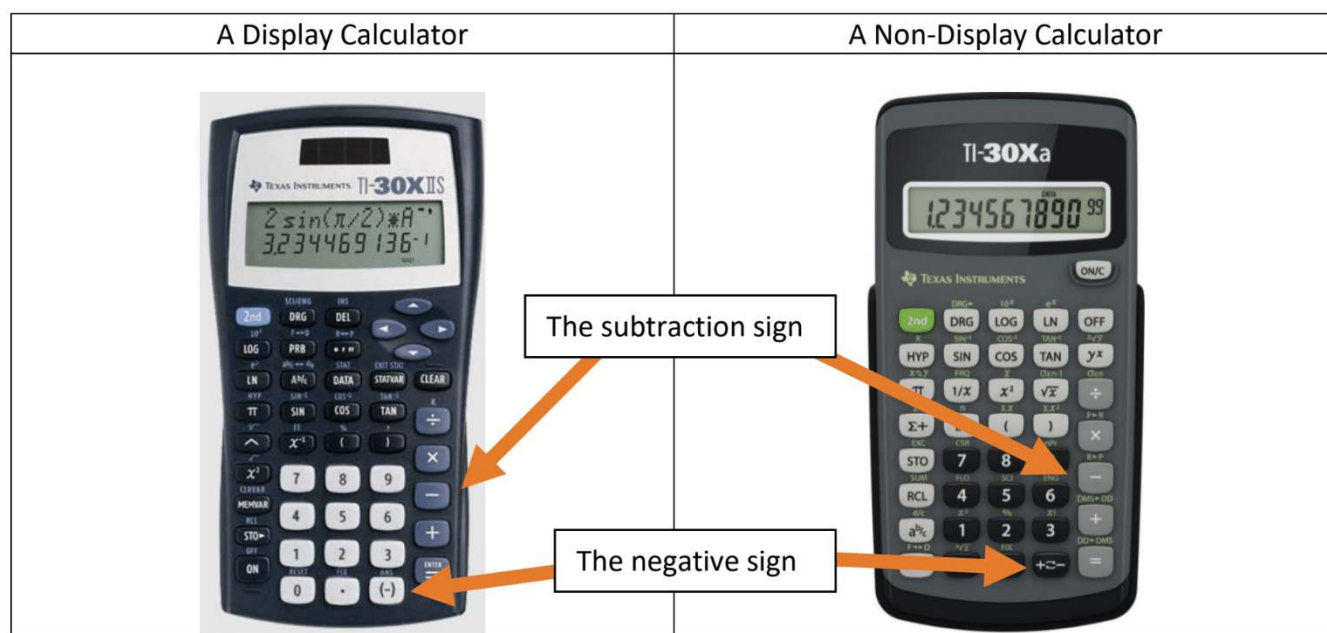
For our purposes, we will determine if a calculator is a "Display" calculator or a "non-display" calculator by doing the following:

Type $2 + 3$ on your calculator.

- If your screen displays the entire expression $2 + 3$, then you have a "Display" calculator.
- If your screen displays only the 3 after typing $2 + 3$, then you have a "non-display" calculator.

On Display calculators, we can usually enter the problem as it is written. On a non-display calculator, we usually must enter the problem in reverse order of operations (see Unit 2 for more information).

Let's revisit some of our earlier examples and calculate them on the scientific calculator. For negative numbers, be sure to use the negative symbol, $(-)$, which is generally at the bottom of the keyboard on a TI calculator and not the subtraction symbol, $-$, which is usually on the right side of the keyboard. Each calculator is different, so you may have to experiment with your calculator to determine the process.



To compute $-17 + (-31)$ use the following sequence of keystrokes to obtain -48 :

Display Calculator:	Non-display Calculator:
$(-) 17 + (-) 31$ ENTER	$17 (-) + 31 (-)=$
Type the negative sign before the number	Type the negative number after the sign

To compute $8.23 - (-1.2) =$ use the following sequence of keystrokes to obtain 9.43:

Display Calculator	Non-display Calculator:
8.23 - (-) 1.2 ENTER	8.23 - 1.2 (-) =
Use the subtraction key, then type the negative sign before the number	Use the subtraction key then type the negative sign after the number

To compute $(-15)(-10) =$ use the following sequence of keystrokes to obtain 150:

Display Calculator	Non-display Calculator:
(-)15 X (-)10 ENTER	15 (-) X 10 (-) =
Type the negative sign before the number	Type the negative sign after the number

To compute $(250) \div (-10) =$ use the following sequence of keystrokes to obtain -25:

Display Calculator	Non-display Calculator:
250 $\div$ (-)10 ENTER	250 $\div$ 10 (-) =
Type the negative sign before the number	Type the negative sign after the number

Fractions

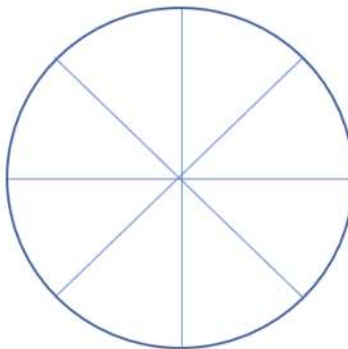
Fractions are real numbers that indicate a portion of a whole. A fraction consists of a numerator and denominator. The denominator represents the number of equal parts of an object and the numerator represents a portion of those equal parts. For example, if pipe is separated into 4 equal parts, $\frac{1}{4}$ would represent 1 out of 4 of the parts, $\frac{2}{4}$ would represent 2 out of the 4 parts, $\frac{3}{4}$ would represent 3 out of the 4 parts, and $\frac{4}{4} = 1$ would represent all 4 parts or the whole pipe. Likewise, $\frac{0}{4}$ would represent 0 of the 4 parts or nothing, hence $\frac{0}{4} = 0$.

The rectangle below is divided into two equal parts. Hence 1 of the pieces out of the 2 pieces would represent $\frac{1}{2}$.



The circle shown below is divided into 8 equal parts. 1 part would represent $\frac{1}{8}$. 2 parts would represent $\frac{2}{8}$ which would reduce to $\frac{1}{4}$ for a couple of reasons:

1. if we were to shade 2 of the 8 pieces, that would also represent 1 of 4 equal pieces and
2. $\frac{2}{8}$ can be reduced by dividing both the numerator (2) and the denominator (8) by the same number, which in this case would be 2, hence: $\frac{2}{8} = \frac{2 \div 2}{8 \div 2} = \frac{1}{4}$



The “bar” in a fraction also represents division, so $\frac{1}{4}$ would also mean $1 \div 4$. This can be interpreted as a whole divided into 4 equal parts or 1 of 4 equal parts.

Fractions have many applications. Fractions can also be used to represent units such as miles per hour or $\frac{\text{miles}}{\text{hour}}$. Fractions can also be used to denote ratios and proportions; we will see the use of fractions in these applications in a later unit.

Multiplying and Dividing Fractions

To multiply fractions:

Multiply the numerators and multiply the denominators.

To simplify, reduce by dividing like factors (numbers that divide into other numbers).

Examples:

1. $\frac{2}{3} \cdot \frac{5}{7}$

a. Multiply the numerators and multiply the denominators.

$$\frac{2}{3} \cdot \frac{5}{7} = \frac{10}{21}$$

Since 10 and 21 do not have any common factors, this is the simplified or reduced answer.

2. $\frac{22}{63} \cdot \frac{9}{24}$

a. Multiply the numerators and multiply the denominators.

$$\frac{22}{63} \cdot \frac{9}{24} = \frac{108}{1512}$$

b. Simplify by reducing the fraction (divide the numerator and denominator by the same number(s))

$$\frac{108}{1512} = \frac{108 \div 12}{1512 \div 12} = \frac{9}{126} = \frac{9 \div 9}{126 \div 9} = \frac{1}{14}$$

Another option for this problem is to reduce before multiplying:

$$\frac{12}{63} \cdot \frac{9}{24}$$

a. Reduce the numerators and denominators by dividing each by the same number

$$\frac{12 \div 12}{63 \div 9} \cdot \frac{9 \div 9}{24 \div 12} = \frac{1}{7} \cdot \frac{1}{2}$$

b. Multiply the numerators and denominators (multiply straight across)

$$\frac{1}{7} \cdot \frac{1}{2} = \frac{1}{14}$$

3. $\frac{24}{72} \cdot \frac{18}{30}$

Since the numbers in the fractions are large, let's reduce first, then multiply.

Determine numbers that divide into both the numerator and denominator:

9 divides into 18 and 72; 6 divides into 24 and 30 OR 6 divides into 18 and 30; 24 divides into 24 and 72

$$\frac{24}{72} \cdot \frac{18}{30} = \frac{24 \div 24}{72 \div 24} \cdot \frac{18 \div 9}{30 \div 9} = \frac{1}{3} \cdot \frac{2}{5} = \frac{4 \div 4}{8 \div 4} \cdot \frac{2}{5} = \frac{1}{2} \cdot \frac{2}{5} = \frac{1}{2 \div 2} \cdot \frac{2 \div 2}{5} = \frac{1}{5}$$

OR

$$\frac{24}{72} \cdot \frac{18}{30} = \frac{24 \div 24}{72 \div 24} \cdot \frac{18 \div 6}{30 \div 6} = \frac{1}{3} \cdot \frac{3}{5} = \frac{1}{3 \div 3} \cdot \frac{3 \div 3}{5} = \frac{1}{5}$$

To divide fractions: Invert the second fraction and change the operation to multiplication and continue as described above.

Example: $\frac{3}{5} \div \frac{9}{10}$

$$\frac{3}{5} \div \frac{9}{10} = \frac{3}{5} \cdot \frac{10}{9} = \frac{30}{45} = \frac{2}{3}$$

Example: $\frac{15}{7} \div \frac{25}{21}$

$$\frac{15}{7} \div \frac{25}{21} = \frac{15}{7} \cdot \frac{21}{25} = \frac{3}{1} \cdot \frac{3}{5} = \frac{9}{5}$$

Adding and Subtracting Fractions

With like denominators

To add or subtract fractions, the fractions must have the same denominator:

Step 1: Verify that the fractions are like fractions (fractions with the same denominator).

Step 2: Add or subtract the numerators and keep the same denominator.

Examples:

1. $\frac{2}{7} + \frac{3}{7} = \frac{2+3}{7} = \frac{5}{7}$
2. $\frac{14}{17} - \frac{5}{17} = \frac{14-5}{17} = \frac{9}{17}$

With unlike Denominators

Step 1: Rewrite the unlike fractions (fractions with different denominators) as like fractions (fractions with the same denominator) with the least common multiple as their new denominator. This new denominator is called the least common denominator (LCD).

To determine the least common denominator (LCD), find the smallest common multiple of the denominators, in other words, find the smallest number that both denominators divide into

Rewrite the unlike fractions as like fractions by multiplying the numerator and denominator of each fraction by the number that makes the denominator of each the least common denominator.

Step 2: Add or subtract the numerators and keep the common denominator.

Examples:

1. $\frac{2}{3} + \frac{1}{9} =$

First find the smallest number that both 3 and 9 will divide into, in this case it will be 9, so 9 is the LCD.

So, we need to multiply the first fraction by $\frac{3}{3}$ to create a 9 in the denominator:

$$\frac{3}{3} \cdot \frac{2}{3} + \frac{1}{9} = \frac{6}{9} + \frac{1}{9} = \frac{7}{9}$$

2. $\frac{3}{7} + \frac{1}{4} =$

The least common denominator = 28 (since 28 is the smallest number that can be divided by both 7 and 4)

Next, multiply the numerator and denominator of $\frac{3}{7}$ by $\frac{4}{4}$ to create a denominator of 28 and multiply the numerator and denominator of $\frac{1}{4}$ by $\frac{7}{7}$ to create a denominator of 28, finally add the numerators and keep the common denominator.

$$\frac{4}{4} \cdot \frac{3}{7} + \frac{1}{4} \cdot \frac{7}{7} = \frac{12}{28} + \frac{7}{28} = \frac{19}{28}$$

NOTE: We add, subtract, multiply, and divide negative fractions similar to how we added, subtracted, multiplied and divided negative numbers in Section ____.

Percents

A percent is defined to be an amount based on 100. If we divide the word into two words, we have “per” and “cent”. Per means divide by and cent means 100, hence divide by 100 or out of 100.

Example: 54% means 54 out of 100

We will use percentages to calculate values in Unit ____.

Converting between different types of numbers (fractions, decimals, and percentages)

To convert from a fraction to a decimal, divide the numerator by the denominator.

To convert from a decimal to a fraction, determine the place of the last digit after the decimal, write the fraction as all the digits after the decimal over the last place of the decimal.

Example: 0.547 represents 547 thousandths since the last digit after the decimal is in the thousandths place, we have 547/1000.

To convert from a fraction to a percent

Option 1: Convert the fraction to a decimal, then convert the decimal to a percent

Option 2: Use a proportion to write the fraction with a denominator of 100, then using the definition of a percent, the percent will be based on the numerator of the fraction with a denominator of 100. We will explore this option more in Unit ____ when we learn about proportions.

To convert from a decimal to a percent, multiply the decimal by 100 or move the decimal place two units to the right.

To convert from a percent to a decimal, divide the percent number by 100 or move the decimal place two units to the left.

This page titled [3.1.2: Mathematical Operations](#) is shared under a [CC BY 4.0](#) license and was authored, remixed, and/or curated by [Kelly Brooks](#).

SECTION OVERVIEW

3.2: Powers, Roots, Order of Operations, and Evaluating Expressions

3.2.1: Powers and Roots

3.2.2: Order of Operations

3.2.3: Evaluating Expressions

This page titled [3.2: Powers, Roots, Order of Operations, and Evaluating Expressions](#) is shared under a [CC BY 4.0](#) license and was authored, remixed, and/or curated by [Kelly Brooks](#).

3.2.1: Powers and Roots

As we learned in Unit 1, we can use the following operations on real numbers: addition, subtraction, multiplication, division, and absolute value. In addition to these operations, we can also apply powers and roots.

Powers

Powers are as the notation for multiplying a number by itself multiple times. Another name for a power is an exponent. The power or exponent is denoted as a superscript.

$$a^n = \underbrace{(a \cdot a \cdot a \cdots a)}_{n \text{ times}} \quad (3.2.1.1)$$

In this notation, the a is called the “**base**” and the n is called the **power** (or **exponent**).

Examples:

1. $5^3 = 5 \cdot 5 \cdot 5 = 125$
2. $(-2)^4 = (-2)(-2)(-2)(-2) = 16$
3. $(2.3)^2 = (2.3)(2.3) = 5.29$
4. $(2/3)^5 = 2/3 \cdot 2/3 \cdot 2/3 \cdot 2/3 \cdot 2/3 = 32/243$

Roots

Roots are obtained by “undoing” a power. There are many types of roots, we will look at square roots, cube roots, and fourth roots.

- The square root of a number, a , is b if $b^2 = a$
- The cube root of a number, a , is b if $b^3 = a$
- The fourth root of a number, a , is b if $b^4 = a$
- We can generalize this to say the n^{th} root of a number, a , is b if $b^n = a$

We use a radical symbol to represent the operation of a root: $\sqrt{\quad}$

- Square root symbol: $\sqrt{\quad}$
- Cube root symbol: $\sqrt[3]{\quad}$
- Fourth root symbol: $\sqrt[4]{\quad}$
- n^{th} root symbol: $\sqrt[n]{\quad}$

The number under a radical symbol is called the **radicand**.

Examples:

1. The square root of 9 is denoted as $\sqrt{9}$, since $3^2 = 9$, then $\sqrt{9} = 3$.
2. $\sqrt{49}$, since $7^2 = 49$, then $\sqrt{49} = 7$.
3. The cube root of 8 is denoted as $\sqrt[3]{8}$, since $2^3 = 8$, then $\sqrt[3]{8} = 2$.
4. $\sqrt{1.44} = 1.2$ since $(1.2)^2 = 1.44$
5. $\sqrt{\frac{36}{121}} = 6/11$ since $(\frac{6}{11})^2 = 36/121$

To compute a root:

- On a scientific display calculator, type the radical symbol first, then the radicand followed by enter.

Example: $\sqrt{1.44}$ the keystrokes would be $\sqrt{\quad} 1.44 \text{ Enter}$

- On a non-display calculator, type the radicand first, then the radical symbol (do not press =)

Example: $\sqrt{1.44}$ the keystrokes would be $1.44 \sqrt{\quad}$

This page titled 3.2.1: Powers and Roots is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Kelly Brooks.

3.2.2: Order of Operations

The order of operations represents a mathematical agreement of the order in which calculations should be performed. The order is Grouping Symbols, Exponents, Multiplication and Division as they appear left to right, and Addition and Subtraction as they appear left to right. Traditionally, we use PEMDAS as the acronym to remember the order of operations using Parentheses, Exponents, Multiplication, Division, Addition, and Subtraction. To allow us to perform operations on more problems, let's consider Grouping Symbols as the first order since it would encompass parentheses, brackets, roots, absolute values, and fraction bars. So, let's learn the acronym GEMDAS, one way to remember the letters is to remember GEMDAS: Greater Education Makes Doctors and Scholars or Good (Environment) Efforts Minimizes Diseased Animals Swimming

Grouping Symbols-Exponents-Multiplication/Division-Addition/Subtraction

GEMDAS

✓ Example 3.2.2.1

Simplify $5 - 3(4 - 6 \div (-2))$.

Solution

In this problem, we start with the inner most grouping symbol which would be the parentheses around the -2, however, there is no operation with this set of parentheses, so we move to the other set of parentheses: $(4 - 6 \div (-2))$. Within this set of parentheses, the division must occur before the subtraction, so we compute $6 \div (-2) = -3$, so the parentheses would be

$$(4 - (-3))$$

Next, we can recall that we subtract integers by adding the opposite, so $(4 - (-3)) = 4 + 3 = 7$ continuing, we now have

$$5 - 3(4 - 6 \div (-2)) = 5 - 3(7)$$

Next, we perform the multiplication before the subtraction to obtain:

$$5 - 21 = -15$$

✓ Example 3.2.2.2

Simplify $2 + 3 \cdot \sqrt{21 - 5} - 8 + 4^2$.

Solution

In this problem, we start with the radical since it is a grouping symbol:

$$\sqrt{21 - 5} = \sqrt{16} = 4$$

So now we have:

$$2 + 3 \cdot 4 - 8 + 4^2$$

Next, we apply the power or exponent:

$$4^2 = 16$$

So, we now have:

$$2 + 3 \cdot 4 - 8 + 16$$

Next, we perform multiplication:

$$3 \cdot 4 = 12$$

So, we now have:

$$2 + 12 - 8 + 16$$

Finally, we perform addition and subtraction as it appears left to right to obtain:

$$2 + 12 - 8 + 16 = 14 - 8 + 16 = 6 + 16 = 22$$

This page titled [3.2.2: Order of Operations](#) is shared under a [CC BY 4.0](#) license and was authored, remixed, and/or curated by [Kelly Brooks](#).

3.2.3: Evaluating Expressions

In the Water Industry, we use many formulas to make calculations. As a result, we need to know how to evaluate expressions, that is, substitute known values for variables, and simplify the expression using the order of operations.

✓ Example 3.2.3.1

If $x = 4$ and $y = 3$ evaluate $3xy^2 + 2\sqrt{x}$.

Solution

First, substitute the given values for x and y :

$$3(4)(3)^2 + 2\sqrt{4}$$

Next, perform order of operations to simplify:

$$3(4)(3)^2 + 2\sqrt{4} = 3(4)(9) + 2(2) = 108 + 4 = 112$$

✓ Example 3.2.3.2

If $a = 9$ and $b = 7$, evaluate $\frac{2\sqrt{a}+3}{b-5}$.

Solution

First, substitute the given values for a and b :

$$\frac{2\sqrt{9}+3}{7-5}$$

Next, simplify using order of operations:

$$\frac{2\cdot 3+3}{7-5} = \frac{6+3}{7-5} = \frac{9}{2}$$

Recall from Unit 1, we could convert this fraction to a decimal to obtain 4.5, however, the general rule of thumb is to use decimals only when you start with decimals, or the directions states to use decimals.

✓ Example 3.2.3.3

A water plant has a rectangular basin with a base that is in the shape of a square with sides of length x and the height of the basin is y . As a result, the volume is calculated using the following expression: x^2y . If the length of the base of the basin is 50 feet and the height of the basin is 20 feet, calculate the volume of the basin.

Solution

First, we substitute the values for x and y : $x^2y = (50 \text{ feet})^2 \cdot (20 \text{ feet})$

Next, we simplify the expression using order of operations to obtain:

$$(2500 \text{ ft}^2)(20 \text{ ft}) = 50,000 \text{ ft}^3 \quad (3.2.3.1)$$

✓ Example 3.2.3.4

To estimate the extra water a town needs to store for emergencies, we must multiply the population by 45 gallons, then add 42,000 gallons to account for what the fire fighters would need in case of a fire, and then multiply the result by a safety factor of 1.8.

- Write an expression for calculating the amount of extra water a town needs to store in case of an emergency.
- Use the expression to calculate the amount of extra water a town needs to store in case of an emergency if the population of the town is 48,000.

Solution

a. We begin by converting the English to math:

Multiply the population, let's call the population P , by 45 gallons: $45P$

Then add 42,000 gallons: $45P + 42,000$

Then multiply by 1.8: $1.8(45P + 42,000)$

Hence, the amount of extra water needed is $1.8(45P + 42,000)$

b. If the population is 48,000, we will replace P in the above expression with 48,000 to obtain: $1.8(45 \cdot 48,000 + 42,000)$
 $= 1.8(2,160,000 + 42,000) = 1.8(2,202,000) = 3,963,600$

Hence, the town needs to reserve 3,963,600 gallons of water in case of an emergency.

This page titled [3.2.3: Evaluating Expressions](#) is shared under a [CC BY 4.0](#) license and was authored, remixed, and/or curated by [Kelly Brooks](#).

SECTION OVERVIEW

3.3: Solving Equations and Formulas

3.3.1: Addition, Subtraction, Multiplication, and Division Properties of Equality

3.3.2: Solving a Formula for a Variable (Rewriting a Formula)

3.3.3: Solving Quadratic Equations of the Form- $(x-a)^2=c$

This page titled [3.3: Solving Equations and Formulas](#) is shared under a [CC BY 4.0](#) license and was authored, remixed, and/or curated by [Kelly Brooks](#).

3.3.1: Addition, Subtraction, Multiplication, and Division Properties of Equality

The addition, subtraction, multiplication, and division properties of equality allow us to add, subtract, multiply, or divide the same value on both sides of an equation, this guarantees the equation remains true (note, we cannot divide by zero).

Concept: We know this to be a true statement: $5 = 5$

The statement will remain true if we perform the same operation on both sides of the equation.

- Add 4 on both sides of the equation to obtain:

$$\begin{aligned}5 + 4 &= 5 + 4 \\9 &= 9\end{aligned}$$

- Subtract 10 on both sides of the original equation to obtain:

$$\begin{aligned}5 - 10 &= 5 - 10 \\-5 &= -5\end{aligned}$$

- Multiply by 2 on both sides of the original equation to obtain:

$$\begin{aligned}5 \cdot 2 &= 5 \cdot 2 \\10 &= 10\end{aligned}$$

- Divide by 5 on both sides of the original equation to obtain:

$$\begin{aligned}\frac{5}{5} &= \frac{5}{5} \\1 &= 1\end{aligned}$$

We use the Addition, Subtraction, Multiplication, and Division Properties of Equality to solve equations for a specified variable or unknown.

Process for Solving a Basic Linear Equation in One-Variable

- Isolate the variable by “undoing” the operation on the variable, that is, applying the opposite operation on both sides of the equation using the Properties of Equality

✓ Example 3.3.1.1

Solve for x : $x + 2 = 9$

Solution

Since 2 is being added to x , to isolate the x , we need to “undo” the addition of 2, the opposite of adding 2 is subtracting 2, so using the Subtraction Property of Equality, let’s subtract 2 on both sides of the equation to obtain:

$$x + 2 - 2 = 9 - 2 \quad (3.3.1.1)$$

$$x = 7 \quad (3.3.1.2)$$

✓ Example 3.3.1.2

Solve for x : $x - 7 = 13$

Solution

Since 7 is being subtracted from x , to isolate the x , we need to “undo” the subtraction of 7, the opposite of subtracting 7 is adding 7, so using the Addition Property of Equality, let’s add 7 on both sides of the equation to obtain:

$$x - 7 + 7 = 13 + 7 \quad (3.3.1.3)$$

$$x = 20 \quad (3.3.1.4)$$

✓ Example 3.3.1.3

Solve for x : $3x = 12$

Solution

Since x is being multiplied by 3, to isolate the x , we need to “undo” the multiplication by 3, the opposite of multiplying by 3 is dividing by 3, so using the Division Property of Equality, let’s divide by 3 on both sides of the equation to obtain:

$$\frac{3x}{3} = \frac{12}{3} \quad (3.3.1.5)$$

$$x = \frac{12}{3} = 4 \quad (3.3.1.6)$$

✓ Example 3.3.1.4

Solve for x : $\frac{x}{8} = 2$

Solution

Since x is being divided by 8, to isolate the x , we need to “undo” the division by 8. The opposite of dividing by 8 is multiplying by 8, so using the Multiplication Property of Equality, let’s multiply by 8 on both sides of the equation to obtain:

$$\frac{x}{8} \cdot 8 = 2 \cdot 8 \quad (3.3.1.7)$$

$$\frac{x}{8} \cdot \frac{8}{1} = 2 \cdot 8 \quad (3.3.1.8)$$

$$x = 16 \quad (3.3.1.9)$$

✓ Example 3.3.1.5

Solve for x : $\frac{1}{2}x = 5$

Solution

We can approach this problem in a couple of different ways,

Option 1: Read the problem as x is being multiplied by $\frac{1}{2}$, hence we can divide both sides by $\frac{1}{2}$ to isolate the variable, x .

$$\frac{\frac{1}{2}x}{(\frac{1}{2})} = \frac{5}{(\frac{1}{2})} \quad (3.3.1.10)$$

$$x = \frac{5}{(\frac{1}{2})} = \frac{5}{1} \cdot \frac{2}{1} = \frac{10}{1} = 10 \quad (3.3.1.11)$$

Option 2: Rewrite the problem or think of the problem as being read as x is being divided by 2 since $\frac{1}{2}x$ is equivalent to $\frac{x}{2}$, so we can multiply both sides of the equation by 2 to isolate x :

$$\frac{1}{2}x = 5 \quad (3.3.1.12)$$

$$\frac{x}{2} = 5 \quad (3.3.1.13)$$

$$\frac{x}{2} \cdot 2 = 5 \cdot 2 \quad (3.3.1.14)$$

$$x = 10 \quad (3.3.1.15)$$

Similarly, if we have a fraction times a variable, let’s say x , then we can multiply both sides of the equation by the reciprocal of the fraction (flip the fraction such that the numerator becomes the denominator, and the denominator becomes the numerator):

✓ Example 3.3.1.6

Solve for x: $\frac{2}{3}x = 7$

Solution

$$\frac{2}{3}x = 7 \quad (3.3.1.16)$$

$$\frac{3}{2} \cdot \frac{2}{3}x = \frac{3}{2} \cdot 7 \quad (3.3.1.17)$$

$$x = \frac{3}{2} \cdot \frac{7}{1} = \frac{21}{2} \quad (3.3.1.18)$$

Process for solving a linear equation in one variable with multiple operations

When solving a linear equation with multiple operations, we reverse the order of operations because we are “undoing” the original operations.

Example:

1. Solve for x: $2x + 5 = 15$

Order of operations state to perform multiplication, then addition, so when solving, we will reverse this order so we will “undo” the addition first, then we will “undo” the multiplication

$$2x + 5 = 15$$

Step 1: “Undo the addition by 5” by subtracting 5 on both sides of the equation

$$2x + 5 - 5 = 15 - 5$$

$$2x = 10$$

Step 2: “Undo the multiplication by 2” by dividing by 2 on both sides of the equation

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

$$x = 5$$

We can check our answer by substituting the value for x into the original equation and verifying that the equation is true: $(2(5) + 5 = 10 + 5 = 15)$, ✓

2. Solve for x: $\frac{2}{3}x + \frac{1}{5} = \frac{2}{7}$

$$\frac{2}{3}x + \frac{1}{5} = \frac{2}{7}$$

Step 1: Subtract $\frac{1}{5}$ on both sides of the equation

$$\frac{2}{3}x + \frac{1}{5} - \frac{1}{5} = \frac{2}{7} - \frac{1}{5}$$

$$\frac{2}{3}x = \frac{2}{7} - \frac{1}{5}$$

Step 2: Find an LCD to subtract the fractions on the right side:

$$\frac{2}{3}x = \frac{2}{7} \cdot \frac{5}{5} - \frac{1}{5} \cdot \frac{7}{7}$$

$$\frac{2}{3}x = \frac{10}{35} - \frac{7}{35}$$

$$\frac{2}{3}x = \frac{3}{35}$$

Step 3: Multiply both sides of the equation by the reciprocal of $\frac{2}{3}$ which would be $\frac{3}{2}$:

$$\frac{3}{2} \cdot \frac{2}{3}x = \frac{3}{2} \cdot \frac{3}{35}$$
$$x = \frac{9}{70}$$

Process for solving linear equations with parenthesis

When an equation contains parentheses, we can clear the parentheses using the distributive property.

Distributive Property: $a(b + c) = ab + ac$

Examples

1. Solve for m: $5(m + 3) - 2(7 - m) = 12$

Step 1: Apply the distributive property to clear the parentheses:

$$5m + 5(3) - 2(7) - 2(-m) = 12$$
$$5m + 15 - 14 + 2m = 12$$

Step 2: Combine like terms

$$5m + 2m + 15 - 14 + 1 = 12$$
$$7m + 1 = 12$$

Step 3: Isolate the variable by subtracting 1 on both sides, then dividing both sides by 7

$$7m + 1 - 1 = 12 - 1$$
$$7m = 11$$
$$\frac{7m}{7} = \frac{11}{7}$$
$$m = \frac{11}{7}$$

2. Solve for x: $-7(3 - x) + 11 = 2(x - 3)$

Step 1: Clear the parentheses by using the distributive property

$$-21 + 7x + 11 = 2x - 6$$

Step 2: Combine like terms

$$-10 + 7x = 2x - 6$$

Step 3: Isolate the variable by subtracting $2x$ on both sides of the equation and adding 10 on both sides of the equation

$$-10 + 10 + 7x - 2x = 2x - 2x - 6 + 10$$
$$5x = 4$$

Now, divide both sides by 5:

$$\frac{5x}{5} = \frac{4}{5}$$
$$x = \frac{4}{5}$$

This page titled [3.3.1: Addition, Subtraction, Multiplication, and Division Properties of Equality](#) is shared under a [CC BY 4.0](#) license and was authored, remixed, and/or curated by [Kelly Brooks](#).

3.3.2: Solving a Formula for a Variable (Rewriting a Formula)

In the Water Industry, we use lots of formulas for computing area, volume, pressure, cost, and so much more. Sometimes, we need to rewrite a formula in terms of a different quantity.

When solving a formula for a particular variable, it is sometimes helpful to place a rectangle or a circle around the variable you are isolating since formulas contain many variables and we may lose our focus as to which variable we are isolating. We will proceed as we did for solving linear equations by “undoing” operations to isolate the variable.

✓ Example 3.3.2.1

The volume of a rectangular tank is given by $V = LWH$, rewrite the formula by solving for H .

Solution

To “undo” the multiplication of H by LW , we divide both sides of the equation by LW to obtain:

$$\frac{V}{LW} = \frac{LWH}{LW} \quad (3.3.2.1)$$

$$\frac{V}{LW} = H \quad (3.3.2.2)$$

✓ Example 3.3.2.2

The filtration rate is defined as $\text{Filtration Rate} = \frac{\text{Flow}}{\text{Surface Area}}$. Solve this equation for the Surface Area.

Solution

Step 1: Multiply both sides of the equation by Surface Area (to remove the Surface Area from the denominator. In other words, we cannot isolate Surface Area until it is no longer in the denominator)

$$(\text{Filtration Rate}) \cdot (\text{Surface Area}) = \frac{\text{Flow}}{\text{Surface Area}} \cdot (\text{Surface Area}) \quad (3.3.2.3)$$

$$(\text{Filtration Rate}) \cdot (\text{Surface Area}) = \text{Flow} \quad (3.3.2.4)$$

Step 2: Isolate the Surface Area by dividing both sides by Filtration Rate

$$\frac{(\text{Filtration Rate}) \cdot (\text{Surface Area})}{(\text{Filtration Rate})} = \frac{\text{Flow}}{(\text{Filtration Rate})} \quad (3.3.2.5)$$

$$\text{Surface Area} = \frac{\text{Flow}}{\text{Filtration Rate}} \quad (3.3.2.6)$$

This is helpful if we need to calculate the Surface Area and we are given the flow and the filtration rate.

This page titled [3.3.2: Solving a Formula for a Variable \(Rewriting a Formula\)](#) is shared under a [CC BY 4.0](#) license and was authored, remixed, and/or curated by [Kelly Brooks](#).

3.3.3: Solving Quadratic Equations of the Form- $(x-a)^2=c$

When solving equations of the form: $(x-a)^2 = c$, we can use the square root property which states to drop the square and take the positive and negative square root of the constant, c. Mathematically, we say the following:

$$\text{If } (x-a)^2 = c,$$

$$\text{then } x-a = \pm\sqrt{c}$$

next, add a on both sides of the equation to obtain

$$x = a \pm \sqrt{c}$$

✓ Example 3.3.3.1

$$\text{Solve } (x-5)^2 = 16$$

Solution

To solve, we first drop the square from the left side and take the positive and negative square root of 16 to obtain

$$x-5 = \pm\sqrt{16} \quad (3.3.3.1)$$

Next, we simplify the square root

$$x-5 = \pm 4 \quad (3.3.3.2)$$

Next, we isolate the variable, x by adding 5 on both sides of the equation:

$$x-5+5 = +5 \pm 4 \quad (3.3.3.3)$$

Such that after simplifying, we obtain two answers

$$x = 5 \pm 4 \quad (3.3.3.4)$$

$$x = 5 + 4 \text{ and } x = 5 - 4 \quad (3.3.3.5)$$

$$x = 9 \text{ and } x = 1 \quad (3.3.3.6)$$

✓ Example 3.3.3.1

$$\text{Solve } 3(x+2)^2 + 5 = 80$$

Solution

To solve, we must first isolate the perfect square to create the form: $(x-a)^2 = c$, so we first subtract 5 on both sides of the equation, then divide both sides by 3

$$3(x+2)^2 + 5 - 5 = 80 - 5 \quad (3.3.3.7)$$

$$3(x+2)^2 = 75 \quad (3.3.3.8)$$

$$\frac{3(x+2)^2}{3} = \frac{75}{3} \quad (3.3.3.9)$$

$$(x+2)^2 = 25 \quad (3.3.3.10)$$

Next, we drop the square and take the positive and negative square root of 25 to obtain

$$x+2 = \pm\sqrt{25} \quad (3.3.3.11)$$

$$x+2 = \pm 5 \quad (3.3.3.12)$$

Next, we isolate the x by subtracting 2 on both sides of the equation

$$x + 2 - 2 = -2 \pm 5 \quad (3.3.3.13)$$

After simplifying, we obtain two answers

$$x = -2 \pm 5 \quad (3.3.3.14)$$

$$x = -2 + 5 \text{ and } x = -2 - 5 \quad (3.3.3.15)$$

$$x = 3 \text{ and } x = -7 \quad (3.3.3.16)$$

This page titled [3.3.3: Solving Quadratic Equations of the Form- \$\(x-a\)^2=c\$](#) is shared under a [CC BY 4.0](#) license and was authored, remixed, and/or curated by [Kelly Brooks](#).

SECTION OVERVIEW

3.4: Scientific Notation, Rounding, Conversions, and Dimensional Analysis

3.4.1: Scientific Notation

3.4.2: Rounding

3.4.3: Dimensional Analysis

This page titled [3.4: Scientific Notation, Rounding, Conversions, and Dimensional Analysis](#) is shared under a [CC BY 4.0](#) license and was authored, remixed, and/or curated by [Kelly Brooks](#).

3.4.1: Scientific Notation

Scientific notation is used to make very large numbers such as 4,895,000,000 or very small numbers such as 0.0000073 easier to use. In the Water industry, we use very large numbers when referring to the volume of water in large tanks or very small numbers when referring to pollutants per gallon of water.

Scientific Notation Form:

$$\underbrace{(a \text{ decimal})}_{\text{between 0 and 10 (not including 10)}} \times 10^{\text{power}} \quad (3.4.1.1)$$

To convert from scientific notation to the actual number

- For a positive exponent on the 10, move the decimal place to the right the equivalent number of spaces as the power
- For a negative exponent on the 10, move the decimal place to the left the equivalent number of spaces as the absolute value of the power

✓ Example 3.4.1.1

Convert the scientific notation to the actual number: 8.735×10^7

Solution

Since the power of 10 is positive 7, we will move the decimal place 7 units to the RIGHT to obtain: 87,350,000

✓ Example 3.4.1.2

Convert the scientific notation to the actual number: 2.356×10^{-4}

Solution

Since the power of 10 is negative 4, we will move the decimal place 4 units to the LEFT to obtain: 0.2356

To convert a positive number to scientific notation

- Move the decimal place to the right of the first non-zero digit. This will be the decimal number portion of the scientific notation.
- If the decimal place was moved to the left, use a positive power of 10 based on the number of places the decimal was moved
- If the decimal place was moved to the right, use a negative power of 10 based on the number of places the decimal was moved

✓ Example 3.4.1.3

Convert 567,900,000 to scientific notation.

Solution

Currently, the decimal is understood to be after the last digit since this is a whole number, so move the decimal to the left 8 places so the decimal is between 5 and 6, hence the scientific notation is 5.679×10^8

✓ Example 3.4.1.4

Convert 0.00032 to scientific notation.

Solution

Move the decimal to the right 4 places so the decimal is between 3 and 2 to create a decimal number of 3.2 and the power of 10 would then be negative 4 since we moved the decimal to the right 4 places. The scientific notation would be 3.2×10^{-4}

Note

Numbers that are larger than 1 will have a positive power of 10 in scientific notation and numbers that are less than 1 (but still positive) will have a negative power of 10 in scientific notation.

Display of scientific notation on scientific calculators

To multiply and divide numbers in scientific notation, we can multiply (or divide) the decimals and multiply (or divide) the powers of 10, then simplify by rewriting into the proper scientific notation form. To do this, we will need to understand some rules of exponents.

Rule of Exponents

1. When multiplying expressions with the same base, we keep the base and add the exponents:

$$a^x \cdot a^y = a^{x+y} \quad (3.4.1.2)$$

2. When dividing expressions with the same base, we keep the base and subtract the exponents:

$$\frac{a^x}{a^y} = a^{x-y} \quad (3.4.1.3)$$

3. Negative exponents become positive exponents if we move the expression to the opposite side of a fraction:

$$a^{-x} = \frac{1}{a^x} \text{ and } \frac{1}{a^{-x}} = a^x \quad (3.4.1.4)$$

4. A non-zero expression raised to an exponent of zero is equivalent to 1:

$$a^0 = 1 \quad (3.4.1.5)$$

✓ Example 3.4.1.5

Multiply and simplify using scientific notation: $(2.45 \times 10^6)(3.23 \times 10^{-15})$

Solution

First, we can rearrange the multiplication to obtain:

$$(2.45 \times 10^6) (3.23 \times 10^{-15}) \quad (3.4.1.6)$$

$$= (2.45) (3.23) \times (10^6)(10^{-15}) \quad (3.4.1.7)$$

Next, we can multiply the decimals, then multiply the powers of 10 using an exponent rule:

$$= 7.9135 \times 10^{6+(-15)} \quad (3.4.1.8)$$

$$= 7.9135 \times 10^{-9} \quad (3.4.1.9)$$

Since the decimal value of 7.9135 is between 0 and 10 (not including 10), then this is the proper scientific notation form.

✓ Example 3.4.1.2

Multiply and simplify using scientific notation: $(8.7 \times 10^{-6})(2.5 \times 10^{12})$

Solution

First, we can rearrange the multiplication to obtain:

$$(8.7 \times 10^{-6})(2.5 \times 10^{12}) = (8.7) (2.5) \times (10^{-6})(10^{12}) \quad (3.4.1.10)$$

Next, we can multiply the decimals, then multiply the powers of 10 using an exponent rule:

$$= 21.75 \times 10^{-6+12} \quad (3.4.1.11)$$

$$= 21.75 \times 10^6 \quad (3.4.1.12)$$

Since the decimal value of 21.75 is not between 0 and 10 (not including 10), we need to convert it to proper scientific notation form and simplify further

$$21.75 \times 10^6 = (2.175 \times 10^1) \times 10^6 \quad (3.4.1.13)$$

$$= 2.175 \times 10^{1+6} \quad (3.4.1.14)$$

$$= 2.175 \times 10^7 \quad (3.4.1.15)$$

✓ Example 3.4.1.3

Divide and simplify using scientific notation: $\frac{4.125 \times 10^{13}}{7.5 \times 10^{-2}}$

Solution

First, we divide the decimals, then divide the powers of 10 using an exponent rule:

$$\frac{4.125 \times 10^{13}}{7.5 \times 10^{-2}} = \frac{4.125}{7.5} \times \frac{10^{13}}{10^{-2}} \quad (3.4.1.16)$$

$$= 0.55 \times 10^{13-(-2)} \quad (3.4.1.17)$$

$$= 0.55 \times 10^{15} \quad (3.4.1.18)$$

Since the decimal value of 0.55 is not between 0 and 10 (not including 10), we need to convert it to proper scientific notation form and simplify further

$$0.55 \times 10^{15} = (5.5 \times 10^{-1}) \times 10^{15} \quad (3.4.1.19)$$

$$= 5.5 \times 10^{-1+15} \quad (3.4.1.20)$$

$$= 5.5 \times 10^{14} \quad (3.4.1.21)$$

This page titled [3.4.1: Scientific Notation](#) is shared under a [CC BY 4.0](#) license and was authored, remixed, and/or curated by [Kelly Brooks](#).

3.4.2: Rounding

We have been using decimal numbers throughout our lives, but let's take some time to formalize the language so we can learn how to round decimals appropriately.

Reading decimal numbers:

Fraction	Decimal	Name
$\frac{1}{10}$	0.1	One-tenth
$\frac{1}{100}$	0.01	One-hundredth
$\frac{1}{1000}$	0.001	One-thousandth
$\frac{1}{10000}$	0.0001	One-ten-thousandth
$\frac{1}{100000}$	0.00001	One-hundred-thousandth

The place values to the right of the decimal are given the following names:

Tenths, hundredths, thousandths, ten-thousandths, hundred-thousandths, millionths, etc.

As a result, we read 5.643 as “five and six-hundredth-forty-three- thousandths since the last digit after the decimal ends in the thousandths place.

Examples:

1. 45.6 is read as “forty-five and six tenths”
2. In the number 543.7892, the 8 is in which place value? Since the 8 is two digits after the decimal point, the place value is hundredths.
3. 0.0143 is read as “one-hundred-forty-three ten-thousandths

For rounding decimals, to round to the nearest decimal place,

1. Consider the number to the right of the desired rounding place value
 1. If the digit is less than 5 (4 or less), we truncate at the desired rounding place value, that is, we drop all the digits after the desired rounding place value
 2. If the digit is 5 or more, we round up by adding 1 to the desired rounding place value before dropping all the remaining digits to the right

Examples:

1. Round 32.784 to the nearest hundredth. Since 8 is in the hundredths place, we consider the number immediately to the right (in the thousandths place), since 4 is less than 5, we drop all the digits after the hundredths place to obtain 32.78.
2. Round 32.786 to the nearest hundredth. Since 8 is in the hundredths place, we consider the number immediately to the right (in the thousandths place), since 6 is more than 5, we add 1 to 8 (in the hundredths place, this is called rounding up) and we drop all the digits after the hundredths place to obtain 32.79.
3. Round 6.48327 to the nearest thousandth. We start by consider the value of the digit immediately after the thousandths place, which is 2, since 2 is less than 5, we drop all the digits after the thousandths place to obtain 6.483 as the rounded number to the nearest thousandth.
4. Round 6.4592 to the nearest
 1. Tenth $\Rightarrow$ Since 5 immediately follows the tenths place, we round the 4 in the tenths place up one number to 5 (by adding 1 to 4) to obtain 6.5 as the rounded number to the tenths place.
 2. Hundredth $\Rightarrow$ Since 9 immediately follows the hundredths place, we round the 5 in the hundredths place up to 6 to obtain 6.46 as the rounded number to the hundredths place.

3. Thousandth $\Rightarrow$ Since 2 immediately follows the thousandths place, we round the 5 in the hundredths place up to 6 to obtain 6.46 as the rounded number to the hundredths place.
5. Round 6.4597 to the nearest thousandth (to three decimal places). Since the fourth digit is 5 or higher, we must round the third digit after the decimal up by adding 1, but if we add 1 to 9, we would get 10, so we think of 59 (the second and third places after the decimal and round it up by 1 to obtain 60, hence 6.4597 rounded to three decimal places or the nearest thousandth becomes 6.460. We must write the zero in the thousandth place in this case to show the rounding to three decimal places, without the zero on the end, the rounding would be incorrect.

Significant Figures

Significant figures are used to assure the accuracy of a calculation based on the numbers used within the calculation. When a problem doesn't specify how to round an answer or it is not implied in its context (such as money), we use significant figures.

The following digits are considered significant:

- Digits between 1-9. Example: 875 would consist of three significant figures.
- Any zeros between non-zero digits. Example: 20.07 and 5608 would both consist of four significant figures.
- The trailing zeros in a decimal number are significant

The following digits represent ambiguous cases, so the best method to determine the significant figures is to convert the number to scientific notation:

- Any zeros in numbers that do not contain a decimal point. Example: 530,000 depending on the situation, this could represent two significant figures or six significant figures, so let's convert it to scientific notation to obtain: 5.3×10^4 which would now represent two significant figures. In general, if the zeros are used to locate the decimal point, they are not significant figures, whereas if the zeros are being used for accuracy, they are included as significant figures.

The following digits are not significant:

- If a number is less than 1, the zeros that occur after the decimal point but before a non-zero digit. Example: 0.0075 would consist of two significant figures

When performing calculations, the number of significant figures of the final answer is equivalent to the fewest number of significant figures provided in the calculation.

Examples:

1. State the number of significant figures in each of the following numbers
 1. 3.402 $\Rightarrow$ 4 significant figures, the non-zero digits are counted since they are between 1-9 and the zero is counted since it is between two non-zero digits
 2. 0.000472 $\Rightarrow$ 3 significant figures; this number is less than 1, so the zeros after the decimal point but before the non-zero digits do not count, so we only count the digits between 1-9
 3. 8.0×10^4 $\Rightarrow$ 2 significant figures; we consider the decimal value (not the power of 10), the trailing zero counts since it is used to show accuracy of the number
 4. 452,000 $\Rightarrow$ ambiguous case, 3 to 6 significant figures depending on the context of the number
2. Round the following numbers to three significant figures
 1. 89.0146 $\Rightarrow$ Since the zero after the decimal point is significant since it is between two non-zero digits, we round to the nearest tenth in this case to obtain 89.0
 2. 0.005324 $\Rightarrow$ Since this number is less than 1, the zeros immediately to the right of the decimal point are not significant, so to round to three significant figures, we round to the nearest hundred-thousandth to obtain 0.00532
 3. 872.58 $\Rightarrow$ Since all the digits are significant, to round to three significant figures, we round to the nearest whole number (three digits from the left) to obtain 873.
 4. 8723.158 $\Rightarrow$ Since all the digits are significant, to round to three significant figures, we round to the nearest ten (three digits from the left) to obtain 8720.
 5. 65,207 $\Rightarrow$ Since all the digits are significant, to round to three significant figures, we round to the nearest hundred (three digits from the left) or 65,200.

3. Based on the given calculations, state the number of significant figures of the answer, then perform the calculation and round it based on the significant figures

1. $(4.5)(2.33)(6.232) \Rightarrow$ Two significant figures since 4.5 has the least number of significant figures.

$$(4.5)(2.33)(6.232) = 65.34252 \text{ which rounds to } 65$$

2. $\frac{(2.543)(3.516)}{0.01} \Rightarrow$ One significant figure since 0.01 has the least number of significant figures.

$$\frac{(2.543)(3.516)}{0.01} = \frac{8.941188}{0.01} = 894.1188 \text{ which rounds to } 900$$

This page titled [3.4.2: Rounding](#) is shared under a [CC BY 4.0](#) license and was authored, remixed, and/or curated by [Kelly Brooks](#).

3.4.3: Dimensional Analysis

Often in the Water and Wastewater Operations, we must use the relationship between different quantities to determine the results of various calculations. In other words, we will need to perform calculations while also recognizing the changes in the measurements and dimensions to assure the measurement of the result is reasonable.

Conversions

In the Water Industry, we often convert between units of measurement such as gallons to liters or days to hours. To convert between units of measurement, we first need to know the conversion factors or equivalencies. These equivalencies are usually provided in a chart and over time, you will most likely start to learn the ones that are used often, much like we know there are 24 hours in a day or 7 days in a week or 12 feet in a yard.

When converting between units, the idea is to multiply by a form of 1. We will create a fraction that is equivalent to 1 by doing the following:

1. Set up the starting measurement as a fraction.
2. The unit we are removing is placed opposite the position of where it is currently
3. The “new” unit will be placed in the other position
4. Insert the equivalencies

Examples:

1. Convert 153 miles per hour to feet per hour. We start by writing the words into a fraction, namely, $\frac{153 \text{ miles}}{1 \text{ hour}}$. Next, since we want to convert miles to feet, we need to eliminate the miles, so we will multiply by a fraction with miles in the denominator (opposite of where the miles are currently) and since we need to replace the miles with feet, we will place the feet in the numerator (to replace the current miles), then insert the equivalencies, 5280 feet = 1 mile, hence we multiply the original measurement by $\frac{5280 \text{ feet}}{1 \text{ mile}}$

$$\frac{153 \text{ miles}}{1 \text{ hour}} \cdot \frac{5280 \text{ feet}}{1 \text{ mile}}$$

Next, we simplify by reducing or canceling the mile unit of measurement and multiply straight across to obtain:

$$\frac{153 \text{ miles}}{1 \text{ hour}} \cdot \frac{5280 \text{ feet}}{1 \text{ mile}} = \frac{153}{1 \text{ hour}} \cdot \frac{5280 \text{ feet}}{1} = \frac{807,840 \text{ feet}}{1 \text{ hour}} \text{ or } 807,840 \text{ feet per hour}$$

2. The Plant needs to treat every 60 gallons of water with 7 grams of chlorine. However, the chlorine is packaged in ounces. Convert the required amount from gallons/gram to gallons/ounce. We start by writing the given information as a fraction, namely, $\frac{60 \text{ gallons}}{7 \text{ grams}}$. Next, since we want to convert the grams to ounces and the grams are currently in the denominator, we create a fraction with the grams in the numerator and the ounces in the denominator (so that the grams are opposite each other) and then insert the equivalencies to obtain:

$$\begin{aligned} \frac{60 \text{ gallons}}{7 \text{ grams}} \cdot \frac{1 \text{ gram}}{0.03527396195 \text{ ounces}} &= \frac{60 \text{ gallons}}{0.246917734 \text{ ounces}} \\ \frac{60 \text{ gallons}}{7 \text{ grams}} \cdot \frac{1 \text{ gram}}{0.03527396195 \text{ ounces}} &= \frac{60 \text{ gallons}}{0.246917734 \text{ oz}} = 242.9959125 \text{ gal/oz} \end{aligned} \quad (3.4.3.1)$$

To convert between metric units, we can use the same process described above or we can use a prefix table and move the decimal point based on the direction and the number of places it takes to move from one metric unit of measure to the others based on the order of the sizes of the prefixes.

Let's begin by using a mnemonic to learn the basic six prefixes along with the base unit measurement and their order on the ladder.

“King Henry Died By Drinking Chocolate Milk”

This statement can help with remembering the order of six prefixes and the base unit.

KILO	HECTO	DEKA	BASE	DECI	CENTI	MILLI
------	-------	------	------	------	-------	-------

For the base, you can have any of the following units of measurement:

- Meters (length)
- Grams (weight)
- Liters (volume)
- Meters² (area)

To convert from one prefix to another,

1. Determine if we must move left or right
2. Determine the number of places to move on the ladder
3. Move the decimal place in the number the same number of places in the same direction as we moved on the prefix ladder.

NOTE: Mega is three units to the left of Kilo and Micro is three units to the right of Milli

Examples:

1. Convert 674.325 centimeters to dekameters

Using the ladder, to move from centi to deka, we must move LEFT 3 places, hence, we must move the decimal place 3 places to the left to obtain 0.674325 dekameters.

2. Convert 67 hectoliters to milliliters.

Using the ladder, to move from hector to milli, we must move RIGHT 5 places, hence, we must move the decimal place 5 places to the right, keeping in mind that for a whole number, the decimal is understood to be after the last digit, 67 hectoliters convert to 6,700,000 milliliters.

3. Convert 6.5 kilograms to megagrams.

Since mega is 3 places to the left of kilo, we must move the decimal place 3 places to the left so 6.5 kilograms becomes 0.0065 megagrams.

4. Convert 8765 centimeters to meters.

Remembering that the base represents meters, we need to move from centi to the base (meters) which would be LEFT by 2 places, so move the decimal two places to the left to convert 8765 centimeters to 87.65 meters.

This page titled [3.4.3: Dimensional Analysis](#) is shared under a [CC BY 4.0](#) license and was authored, remixed, and/or curated by [Kelly Brooks](#).

SECTION OVERVIEW

3.5: Ratios, Proportions, and Percentages

3.5.1: Ratios

3.5.2: Proportions

3.5.3: Percentages

This page titled [3.5: Ratios, Proportions, and Percentages](#) is shared under a [CC BY 4.0](#) license and was authored, remixed, and/or curated by [Kelly Brooks](#).

3.5.1: Ratios

A ratio is a comparison of two numerical quantities in the same units that is usually expressed as a fraction.

Examples:

1. The ratio of 2 meters to 7 meters is $\frac{2m}{7m} = \frac{2}{7}$.
2. There are 200,000 gallons of water in a rectangular basin and 400,000 gallons of water in a cylindrical basin.
 1. What is the ratio of the number of gallons of water in the rectangular basin to the cylindrical basin?

$$\frac{200,000 \text{ gallons}}{400,000 \text{ gallons}} = \frac{2}{4} = \frac{1}{2}$$

2. What is the ratio of the number of gallons of water in the cylindrical basin to the rectangular basin?

$$\frac{400,000 \text{ gallons}}{200,000 \text{ gallons}} = \frac{4}{2} = \frac{2}{1} = 2$$

3. The price of (some chemical) recently increased from \$10.80/case to \$13.50/case. Find the ratio of the increase in price to the original price.

The increase in price is determined by subtracting the original price from the ending price: increase in price = \$13.50 - \$10.80 = \$2.70.

The ratio of the increase in price to the original price = $\frac{\$2.70}{\$10.80} = 0.25$ or $\frac{1}{4}$

This page titled [3.5.1: Ratios](#) is shared under a [CC BY 4.0](#) license and was authored, remixed, and/or curated by [Kelly Brooks](#).

3.5.2: Proportions

A proportion determines the relationship between two variables as it relates to the magnitude or size of the variables. A proportional relationship shows that two ratios are equivalent such that as one amount changes, another amount changes by a relative amount.

To solve proportion problems, we set up an equation such that two ratios are equivalent:

$$\frac{\text{One characteristic from one item}}{\text{A second characteristic from the same item}} = \frac{\text{the same first characteristic from a second item}}{\text{the same second characteristic from the second item}} \quad (3.5.2.1)$$

✓ Example 3.5.2.1

Seven containers of a chemical costs \$125. If the cost of the containers is proportional, meaning the unit price does not change, determine the cost of 12 containers of the same chemical.

Solution

Let's begin by setting up the fractions like in Equation 3.5.2.1:

$$\frac{\text{Number of containers}}{\text{Cost of those containers}} = \frac{\text{Number of another set of containers}}{\text{Cost of those containers}}$$

$$\frac{7 \text{ containers}}{\$125} = \frac{12 \text{ containers}}{x}$$

To solve for x we can use one of two methods:

Method 1: Solve for x by isolating the x (using information learned in Unit 3)

Multiply both sides of the equation by x :

$$\frac{7}{125}x = 12$$

Multiply both sides of the equation by \$125:

$$7x = 12 \cdot 125$$

$$7x = 1500$$

Divide both sides of the equation by 7 containers:

$$x = \frac{1500}{7} = \$214.29$$

Method 2: Use cross multiplication: Multiply the numerator of the first fraction by the denominator of the second fraction and set it equal to the multiplication of the numerator of the second fraction by the denominator of the first fraction.

$$(7 \text{ containers}) \cdot (\$x) = (12 \text{ containers}) \cdot (\$125)$$

$$7x = 1500$$

$$x = \frac{1500}{7}$$

$$= \$214.29$$

Hence, the cost of the 12 containers is \$214.29.

✓ Example 3.5.2.2

We want to estimate the number of fish in a pond. Suppose we capture 280 fish, tag them, and throw them back into the pond. After a couple of days, we go back to the pond and capture 420 fish, of which 28 are tagged. Estimate the number of fish in the pond.

✓ Example 3.5.2.3

We wish to mix a solution of hypochlorite and water by dissolving 4.8 pounds of hypochlorite in 70 gallons of water. For the same concentration, how many pounds of hypochlorite should we dissolve in 20 gallons of water?

Solution

Let's begin by setting up the fractions like in Equation 3.5.2.1:

$$\begin{aligned}\frac{\text{Number of pounds of hypochlorite}}{\text{Number of gallons of water}} &= \frac{\text{Number of pounds of hypochlorite}}{\text{Number of gallons of water}} \\ \frac{4.8 \text{ lbs}}{70 \text{ gal}} &= \frac{x \text{ lbs}}{20 \text{ gal}} \\ (4.8 \text{ lbs})(20 \text{ gal}) &= (70 \text{ gal})(x \text{ lbs}) \\ 96 &= 70x \\ \frac{96}{70} &= x \\ x &= 1.4 \text{ lbs}\end{aligned}$$

Hence, we need 1.4 pounds of hypochlorite to dissolve in 20 gallons of water to create the same concentration.

This page titled 3.5.2: Proportions is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Kelly Brooks.

3.5.3: Percentages

In Unit 1, we learned how to convert between fractions, decimals, and percentages. We also learned that a percent calculated

$$\text{Percent} = \frac{\text{Part}}{\text{Whole}} \cdot 100\% \quad (3.5.3.1)$$

In this unit, we will use percentages in applications. We will concentrate on the following types of calculations which can be derived by rewriting the formula above (as learned in Unit 3):

- Calculating a percent of an amount: $(\text{percentage})(\text{whole}) = \text{part}$
- Determine the percent based on the part and the whole: $\frac{\text{Part}}{\text{Whole}} \cdot 100\% = \text{Percent}$
- A value is a certain percent of a number: $\text{whole} = \frac{\text{part}}{\text{percent}}$

Examples:

1. 52% of 560 is what number?

Since “of” means multiplication, we have $(52\%)(560) = \text{a number}$, so let’s convert 52% to a decimal by dividing 52 by 100 or by moving the decimal place two units to the left to obtain 0.52, hence $(52\%)(560) = (0.52)(560) = 291.2$. As a result, 52% of 560 is 291.2.

2. 32 is what percent of 420?

In this problem, we need to calculate the percent and we have the part, which is 32, and the whole, which is 420. Hence $\text{Percent} = \frac{32}{420} \cdot 100\% = 0.076 \cdot 100\% = 7.6\%$ (using two significant figures; see Unit 5).

3. 23 is 12% of what number? Round the final answer to the nearest hundredth. (Unit 5)

In this problem, we are given the part and the percent and need to determine the whole, so we use: $\text{whole} = \frac{\text{part}}{\text{percent}} = \frac{23}{12\%} = \frac{23}{0.12} = 191.67$

Percentages can be used in the Water Industry in many ways. Below are a few applications of percentages and ratios.

- The volatile content of raw sludge can be calculated as a rate, proportion, or a percent. Generally, we will use a percent to represent the volatile content of raw sludge by calculating the reduction of volatile matter using the following formula:

$$\begin{aligned} & \text{Volatile Solids Reduction (} \\ & \quad \frac{(\text{Value IN}) - (\text{Value OUT})}{(\text{Value IN}) - [(\text{Value IN})(\text{Value OUT})]} \cdot 100\% \end{aligned} \quad (3.5.3.2)$$

When the volatile solids reduction is between 50%-60%, it is a good or healthy anaerobic digester. Any amount less than 50% is not reducing the volatile solids enough. NOTE: The fraction portion of this formula represents the rate or proportion. By multiplying by 100% we obtain the percentage. Also, note that the Value IN and Value OUT are decimal values between 0 and 1.

Example: The volatile content of raw sludge is 68.2% while the digester sludge is 55.6%. Calculate the volatile solids reduction and determine if the reduction is a healthy amount.

$$\text{Volatile Solids Reduction (} = \frac{(\text{Value IN}) - (\text{Value OUT})}{(\text{Value IN}) - [(\text{Value IN})(\text{Value OUT})]} \cdot 100\% \quad (3.5.3.3)$$

$$= \frac{0.682 - 0.556}{0.682 - (0.682)(0.556)} \cdot 100\% \quad (3.5.3.4)$$

$$= \frac{0.126}{0.682 - 0.379} \cdot 100\% \quad (3.5.3.5)$$

$$= \frac{0.126}{0.303} \cdot 100\% \quad (3.5.3.6)$$

$$= 0.4158 \cdot 100\% = 41.6\% \quad (3.5.3.7)$$

Since 41.6% is not between 50% and 60%, this is considered to not be a good reduction of waste solids.

- The efficiency of water can be calculated using the following formula:

$$\text{Efficiency} = \frac{(\text{Value IN} - \text{Value OUT})}{\text{Value IN}} \cdot 100\% \quad (3.5.3.8)$$

where the Value IN corresponds to the water received from another water system through intertie and Value OUT corresponds to water supplied to another water system through an intertie. [Intertie as defined by Merriam- Webster Dictionary, “an interconnection permitting passage of current between two or more electric utility systems” such as in a share federal-state water system.

NOTE: The fraction portion of this formula represents the rate or proportion. By multiplying by 100% we obtain the percentage.

Example: Calculate the efficiency (as a percent) of removing BOD (Biological Oxygen Demand) at a wastewater treatment plant if the influx of BOD is 215 mg per liter and the outflow is 18 mg per liter.

$$\text{Efficiency} = \frac{(\text{Value IN} - \text{Value OUT})}{\text{Value IN}} \cdot 100\% \quad (3.5.3.9)$$

$$= \frac{(215 \frac{\text{mg}}{\text{L}} - 18 \frac{\text{mg}}{\text{L}})}{215 \frac{\text{mg}}{\text{L}}} \cdot 100\% \quad (3.5.3.10)$$

$$= \frac{197 \frac{\text{mg}}{\text{L}}}{215 \frac{\text{mg}}{\text{L}}} \cdot 100\% \quad (3.5.3.11)$$

$$= 0.916 \cdot 100\% \quad (3.5.3.12)$$

$$= 91.6\% \quad (3.5.3.13)$$

Hence, the efficiency of removing BOD at the wastewater treatment plant is 91.6%.

This page titled [3.5.3: Percentages](#) is shared under a [CC BY 4.0](#) license and was authored, remixed, and/or curated by [Kelly Brooks](#).

SECTION OVERVIEW

3.6: Geometry

3.6.1: Definitions

3.6.2: Examples

This page titled [3.6: Geometry](#) is shared under a [CC BY 4.0](#) license and was authored, remixed, and/or curated by [Kelly Brooks](#).

3.6.1: Definitions

In the Water Industry, often it will be important to calculate perimeter, circumference, area, volume, or surface area (lateral area) of various objects. Let's start by defining each geometric calculation.

Definitions

Perimeter: The linear measurement or distance around the outside of a two-dimensional object such as a square, rectangle, triangle, etc. The units are expressed as a linear measurement such as inches, feet, yards, miles, millimeters, centimeters, meters, kilometers, etc.

$$P = \text{length of side 1} + \text{length of side 2} + \text{length of side 3} + \text{length of side 4} + \dots \quad (3.6.1.1)$$

Circumference: The linear measurement around the outside of a circle. The units are expressed as a linear measurement such as inches, feet, yards, miles, millimeters, centimeters, meters, kilometers, etc. NOTE: Circumference is the name we use to represent the perimeter of a circle.

$$C = \pi(\text{diameter}) \text{ or } C = 2\pi(\text{radius}) \quad (3.6.1.2)$$

Area (or Surface Area or Lateral Area): The measurement of the amount of space inside a 2-dimensional object or on the surface of a 3-dimensional object. The units are expressed as square linear units such as square inches (in²), square meters (m²), square feet (ft²), etc.

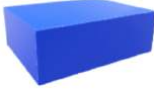
The formula for area depends on the object, so let's start with the area of some common objects:

Geometric Measurement	Formula	Shape
Area of a rectangle	$A = (\text{length})(\text{width})$	
Area of a triangle	$A = \frac{1}{2}(\text{base})(\text{height})$	
Area of a circle	$A = \pi(\text{radius})^2$ or $A = (0.785)(\text{diameter})^2$	
Area of a trapezoid	$A = \frac{1}{2}(\text{base 1} + \text{base 2})(\text{height})$	

Volume: The measurement of the amount of space inside a 3-dimensional object. The units are expressed as cubic linear units such as cubic inches (in³), cubic meters (m³), cubic feet (ft³), etc.

The general formula for volume is: $\text{Volume} = (\text{Area of a surface})(\text{height or length})$

The formula for volume depends on the object, so let's start with the volume of some common objects:

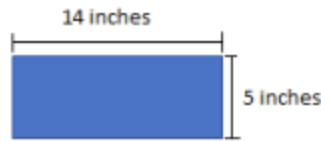
Geometric Measurement	Formula	Shape
Volume of a Rectangular Box or Prism	$V = (length)(width)(height)$	
Volume of a Cylinder	$V = \pi(radius)^2(height)$ or $V = (0.785)(diameter)^2(height)$	
Volume of a Cone	$V = \frac{1}{3}\pi(radius)^2(height)$ or $V = \frac{1}{3}(0.785)(diameter)^2(height)$	
Volume of a Sphere	$V = \frac{4}{3}\pi(radius)^3$ or $V = \frac{2}{3}(0.785)(diameter)^3$	
Volume of a Triangular Prism	$V = (Area \text{ of the triangular surface})(depth)$ or $V = \frac{1}{2}(base)(height)(depth \text{ or width})$	
Volume of a Trapezoidal Prism	$V = (Area \text{ of the trapezoidal surface})(depth)$ or $V = \frac{1}{2}(base \ 1 + base \ 2)(height)(depth \text{ or width})$	

This page titled [3.6.1: Definitions](#) is shared under a [CC BY 4.0](#) license and was authored, remixed, and/or curated by [Kelly Brooks](#).

3.6.2: Examples

1. Calculate the perimeter (or circumference if appropriate) and area of the following shapes:

a. Calculate the perimeter and area of the rectangle using the figure below.



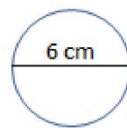
Perimeter = sum of the lengths of the sides

$$= 14 \text{ in} + 5 \text{ in} + 14 \text{ in} + 5 \text{ in} = 2(14 \text{ in}) + 2(5 \text{ in})$$

$$= 28 \text{ in} + 10 \text{ in} = 38 \text{ in}$$

$$\text{Area} = (\text{length}) \times (\text{width}) = (14 \text{ in})(5 \text{ in}) = 70 \text{ in}^2$$

b. Calculate the circumference and area of the circle using the figure below.

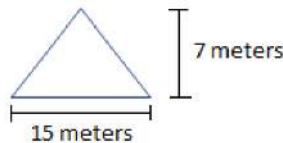


$$\text{Circumference} = \pi (\text{diameter}) = \pi (6 \text{ cm}) = (3.14)(6 \text{ cm}) = 18.84 \text{ cm}$$

$$\text{Area} = (0.785)(\text{diameter})^2 = (0.785)(6 \text{ cm})^2 = (0.785)(36 \text{ cm}^2) = 28.26 \text{ cm}^2$$

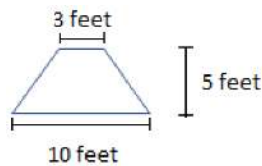
c. Calculate the area of the figures below.

i. A triangle with height of 7 meters and a base of 15 meters.



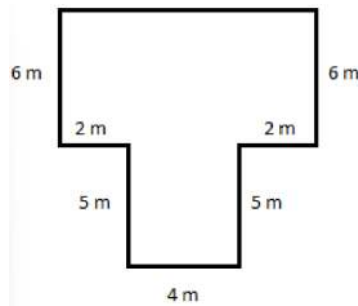
$$\text{Area} = \frac{1}{2}(\text{base})(\text{height}) = \frac{1}{2}(15 \text{ m})(7 \text{ m}) = \frac{1}{2}(105 \text{ m}^2) = 52.5 \text{ m}^2$$

ii. A trapezoid with a height of 5 feet and bases of 3 feet and 10 feet.



$$\begin{aligned} \text{Area} &= \frac{1}{2}(\text{base 1} + \text{base 2})(\text{height}) \\ &= \frac{1}{2}(3 \text{ ft} + 10 \text{ ft})(5 \text{ ft}) \\ &= \frac{1}{2}(13 \text{ ft})(5 \text{ ft}) \\ &= \frac{1}{2}(65 \text{ ft}^2) = 32.5 \text{ ft}^2 \end{aligned}$$

2. Calculate the perimeter and area of the following figure



a. Calculate the perimeter.

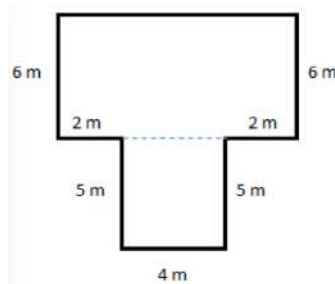
Since the perimeter is the distance around the outer edges, we can calculate the distance across the top edge to be the sum of the lower horizontal edges, namely $2\text{ m} + 4\text{ m} + 2\text{ m} = 8\text{ m}$

Next, add the lengths of the outer edges to obtain

$$\begin{aligned}\text{Perimeter} &= 8\text{ m} + 6\text{ m} + 2\text{ m} + 5\text{ m} + 4\text{ m} + 5\text{ m} + 2\text{ m} + 6\text{ m} \\ &= 8\text{ m} + 2(6\text{ m}) + 2(2\text{ m}) + 2(5\text{ m}) + 4\text{ m} \\ &= 8\text{ m} + 12\text{ m} + 4\text{ m} + 10\text{ m} + 4\text{ m} \\ &= 38\text{ m}\end{aligned}$$

b. Calculate the area.

Using a dashed line, divide the figure into two rectangles by drawing a horizontal line through the figure at the 2 m markings



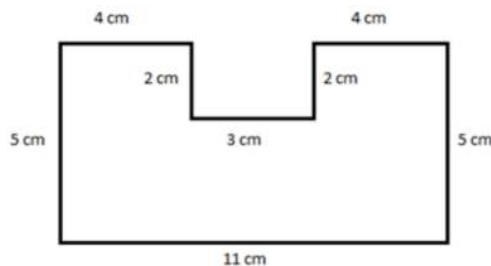
Next, find the area of each figure and add the results to obtain the area of the original figure.

$$\text{The area of the upper rectangle} = A_1 = (6\text{ m})(8\text{ m}) = 48\text{ m}^2$$

$$\text{The area of the lower rectangle} = A_2 = (5\text{ m})(4\text{ m}) = 20\text{ m}^2$$

$$\text{Total Area} = A_1 + A_2 = 48\text{ m}^2 + 20\text{ m}^2 = 68\text{ m}^2$$

3. Calculate the perimeter and area of the figure below.



a. Calculate the perimeter.

Since the perimeter is the distance around the outer edges, we add the lengths of the edges to obtain

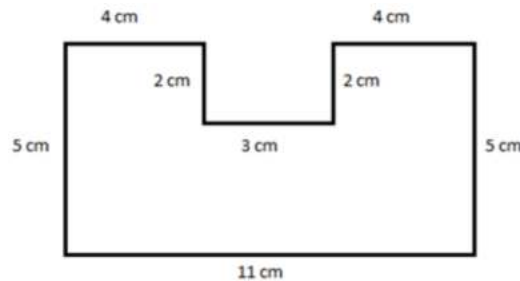
$$\begin{aligned}\text{Perimeter} &= 4\text{ cm} + 2\text{ cm} + 3\text{ cm} + 2\text{ cm} + 4\text{ cm} + 5\text{ cm} + 11\text{ cm} + 5\text{ cm} \\ &= 2(4\text{ cm}) + 2(2\text{ cm}) + 3\text{ cm} + 2(5\text{ cm}) + 11\text{ cm} \\ &= 8\text{ cm} + 4\text{ cm} + 3\text{ cm} + 10\text{ cm} + 11\text{ cm} \\ &= 36\text{ cm}\end{aligned}$$

b. Calculate the area.

We can compute the area of this figure in one of two ways, either using addition or by using subtraction. Let's investigate both methods.

i. Using Addition

Divide the figure into three rectangles by drawing a dashed line from the left side of the figure through to the right side of the figure, connecting at the 3 cm line.



Calculate the area of each rectangle and add the results; let's notice that the two upper rectangles are the same size

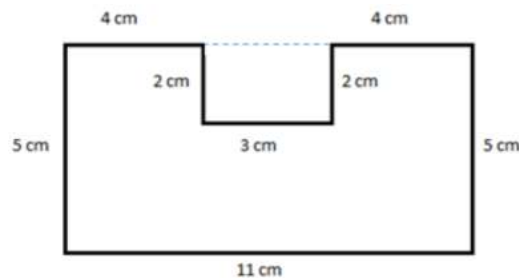
$$\text{Area of small rectangle} = (4 \text{ cm})(2 \text{ cm}) = 8 \text{ cm}^2$$

$$\text{Area of large rectangle} = (3 \text{ cm})(11 \text{ cm}) = 33 \text{ cm}^2$$

$$\text{Total area} = 8 \text{ cm}^2 + 8 \text{ cm}^2 + 33 \text{ cm}^2 = 49 \text{ cm}^2$$

ii. Using Subtraction

Find the area of the outer rectangle and subtract the area of the rectangular hole, so now let's draw a horizontal dashed line across the top opening of the figure



Next, let's find the area of the larger outer edge rectangle

$$\text{Area of large rectangle} = (5 \text{ cm})(11 \text{ cm}) = 55 \text{ cm}^2$$

$$\text{Area of the rectangular hole} = (2 \text{ cm})(3 \text{ cm}) = 6 \text{ cm}^2$$

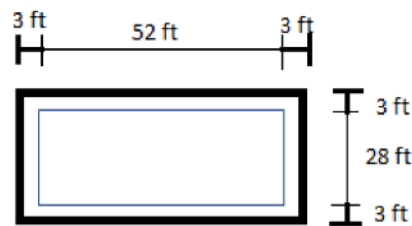
$$\begin{aligned} \text{Total Area} &= \text{Area of large outer rectangle} - \text{Area of the rectangular hole} \\ &= 55 \text{ cm}^2 - 6 \text{ cm}^2 = 49 \text{ cm}^2 \end{aligned}$$

c. A rectangular pool measures 28 feet by 52 feet. Surrounding (and bordering) the basin is a path 3 feet wide. Find the area of the path.

First, let's draw a figure to depict the scenario. Let's start by drawing a rectangle to represent the pool.



Next, let's draw the 3 ft wide border around the pool to represent the path. The path is represented by the shaded region.



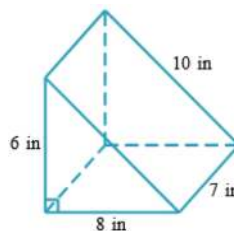
The outer edge of the path creates a larger rectangle whose length is the length of the pool plus twice the width of the path or $52 \text{ ft} + 2(3 \text{ ft}) = 58 \text{ ft}$. The width of the outer edge of the path is the width of the pool plus twice the width of the path or $28 \text{ ft} + 2(3 \text{ ft}) = 34 \text{ ft}$.

To obtain the area of the path, find

the area of the outer edge - the area enclosed by the pool = area of the path

$$\begin{aligned}\text{Area of the path} &= (58 \text{ ft})(34 \text{ ft}) - (28 \text{ ft})(52 \text{ ft}) \\ &= 1972 \text{ ft}^2 - 1456 \text{ ft}^2 \\ &= 516 \text{ ft}^2\end{aligned}$$

d. Calculate the lateral area (surface area) of a triangular prism as shown below



There are five sides or surfaces to this triangular prism. Two of the sides are triangles of the same size, namely with a height of 6 inches and a base of 8 inches and the other three sides are rectangles, the left face is 6 inches by 7 inches rectangle, the bottom face is 8 inches by 7 inches rectangle, and the right-side face is 10 inches by 7 inches rectangle.

To calculate the lateral area or surface area, we find the area of all the surfaces and add the results

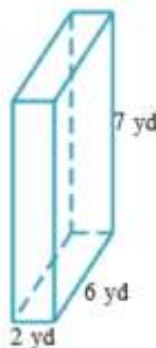
$$\text{Area of the two triangles} = 2 \left[\frac{1}{2} (8 \text{ in})(6 \text{ in}) \right] = 48 \text{ in}^2$$

$$\begin{aligned}\text{Area of the three rectangles} &= (6 \text{ in})(7 \text{ in}) + (8 \text{ in})(7 \text{ in}) + (10 \text{ in})(7 \text{ in}) \\ &= 42 \text{ in}^2 + 56 \text{ in}^2 + 70 \text{ in}^2 \\ &= 168 \text{ in}^2\end{aligned}$$

$$\text{Lateral area} = 48 \text{ in}^2 + 168 \text{ in}^2 = 216 \text{ in}^2$$

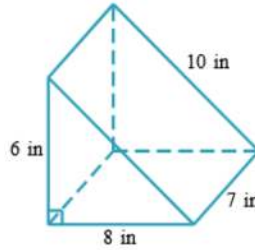
More examples using volume of three-dimensional objects

1. Calculate the volume of the rectangular prism with dimensions 2 yds X 6 yds X 7 yds.



$$\text{Volume} = (\text{length})(\text{width})(\text{height}) = (2 \text{ yds})(6 \text{ yds})(7 \text{ yds}) = 84 \text{ yds}^3$$

2. Calculate the volume of a triangular prism as shown below.



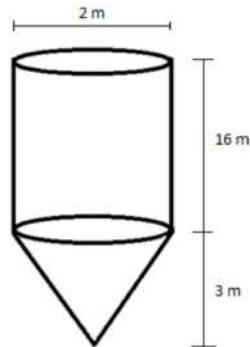
$$V = \frac{1}{2} (\text{base}) (\text{height}) (\text{depth or width})$$

$$V = \frac{1}{2} (8 \text{ in}) (6 \text{ in}) (7 \text{ in}) = 168 \text{ in}^3$$

3. Calculate the volume of a sphere with a diameter of 15.6 mm.

$$V = \frac{2}{3} (0.785) (\text{diameter})^3 = \frac{2}{3} (0.785) (15.6 \text{ mm})^3 = \frac{2}{3} (0.785) (3796.416 \text{ mm}^3) = 1986.8 \text{ mm}^3$$

4. Calculate the volume of the object below (not drawn to scale)



Total Volume = Volume of the cylinder + Volume of the cone

$$\begin{aligned} \text{Volume of cylinder} &= (0.785) (\text{diameter})^2 (\text{height}) \\ &= (0.785) (2 \text{ m})^2 (16 \text{ m}) \\ &= (0.785) (4 \text{ m}^2) (16 \text{ m}) \\ &= (0.785) (64 \text{ m}^3) \\ &= 50.24 \text{ m}^3 \end{aligned} \tag{3.6.2.1}$$

$$\begin{aligned} \text{Volume of cone} &= \frac{1}{3} (0.785) (\text{diameter})^2 (\text{height}) \\ &= \frac{1}{3} (0.785) (2 \text{ m})^2 (3 \text{ m}) \\ &= \frac{1}{3} (0.785) (4 \text{ m}^2) (3 \text{ m}) \\ &= \frac{1}{3} (0.785) (12 \text{ m}^3) \\ &= 3.14 \text{ m}^3 \end{aligned} \tag{3.6.2.2}$$

$$\begin{aligned} \text{Total Volume} &= \text{Volume of the cylinder} + \text{Volume of the cone} \\ &= 50.24 \text{ m}^3 + 3.14 \text{ m}^3 \\ &= 53.38 \text{ m}^3 \end{aligned} \tag{3.6.2.3}$$

This page titled 3.6.2: Examples is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Kelly Brooks.

SECTION OVERVIEW

3.7: Reading and Interpreting Graphs

In the Water Industry, an important skill is reading and interpreting graphs and charts. There are many types of graphs and charts such as pie charts, bar graphs, histograms, line graphs, dials, gauges, etc. When reading and interpreting graphs, it is very important to read the labels on the graph or chart and to consider the units (if any).

3.7.1: Types of Graphs

3.7.2: Examples

This page titled [3.7: Reading and Interpreting Graphs](#) is shared under a [CC BY 4.0](#) license and was authored, remixed, and/or curated by [Kelly Brooks](#).

3.7.1: Types of Graphs

Line graphs: Line graphs are commonly used in the water and wastewater industry. They are quick and easy to create and read. It is important to read the labels on the horizontal and vertical axes and to read the graph from left to right. To read information on a line graph, locate a point on the line graph, find the corresponding value on the horizontal and vertical axes.

Bar graphs: A bar graph can consist of vertical or horizontal bars that can display numerical or categorical data. To read a bar graph, for each category, locate the height (or length) of the bar and read the scale or value. Some bar graphs will consist of double bars or multiple bars for each category. This allows information to be compared at a quick glance.

Pie charts: A pie chart is generally used to show percentages or proportions of categories as they relate to each other. Each wedge in a pie chart represents a category and the size of the wedge represents the percentage or proportion of that category.

Semi-log or log-log graphs: A semi-log graph has logarithmic scales on one axis and a numeric scale on the other axis. A log-log graph has logarithmic scales on both the horizontal and vertical axes. They can be used for showing the flow rate.

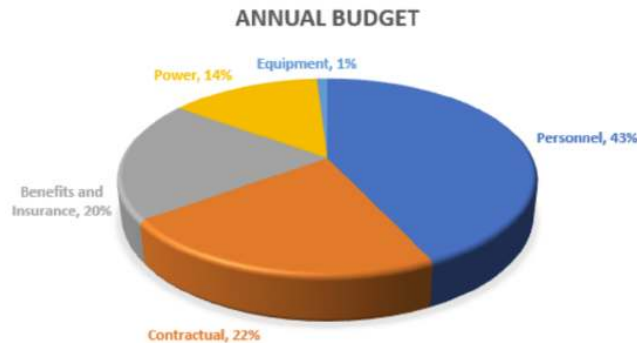
When reading a graph, be sure to pay close attention to the scale of the axes and/or picture. The markings on the axes or picture indicate the size of the numerical values depicted on the graph.

This page titled [3.7.1: Types of Graphs](#) is shared under a [CC BY 4.0](#) license and was authored, remixed, and/or curated by [Kelly Brooks](#).

3.7.2: Examples

Examples:

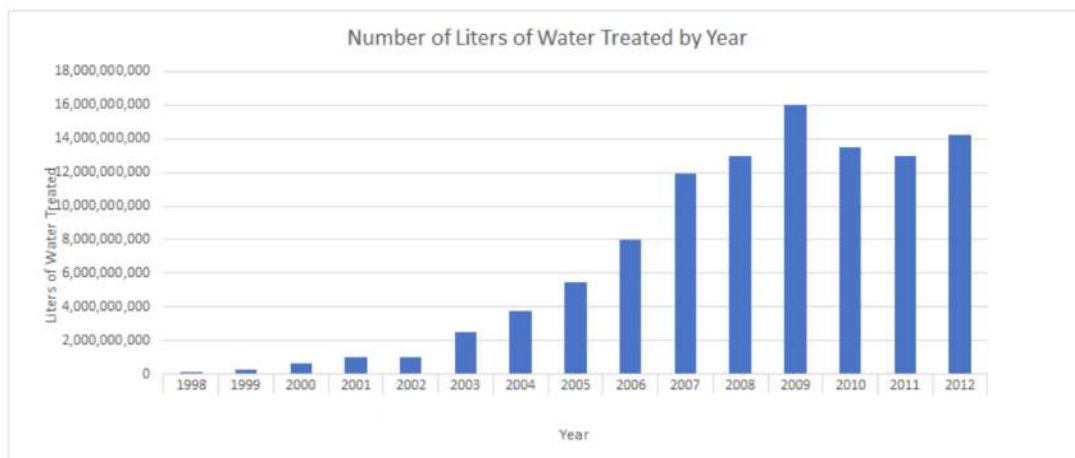
1. A city's sanitary sewer budget for the year is \$350,000. The budget has been divided into five categories: Personnel, contractual, power, benefits and insurance, and equipment. Based on the pie chart, which category has the larger proportion of the budget been allocated to? Which category has the least allocation? Which two categories have similar allocations? What dollar amount has been allocated for power?



Solution

We can visually see that the largest part of the pie is allocated to personnel at 43% and the smallest part of the pie is allocated to equipment at 1%. The two pieces of the pie that are similar in size are for contractual and benefits and insurance which represent 22% and 20% respectively. It is also important to note that these percentages are based on the \$350,000 budget. Hence the amount of money allocated for power is 14% of \$350,000 or $.14(\$35,000) = \$4900$.

2. Using the bar graph below, answer the following questions:
 - a. What general information is provided in the bar graph?
 - b. Which year had the most liters of treated water?
 - c. Which year had the least liters of treated water?
 - d. In which year was 8,000,000,000 liters of water treated?
 - e. The amount of treated water increased between which years?
 - f. The amount of treated water decreased between which years?
 - g. Which years had approximately the same number of treated liters of water?



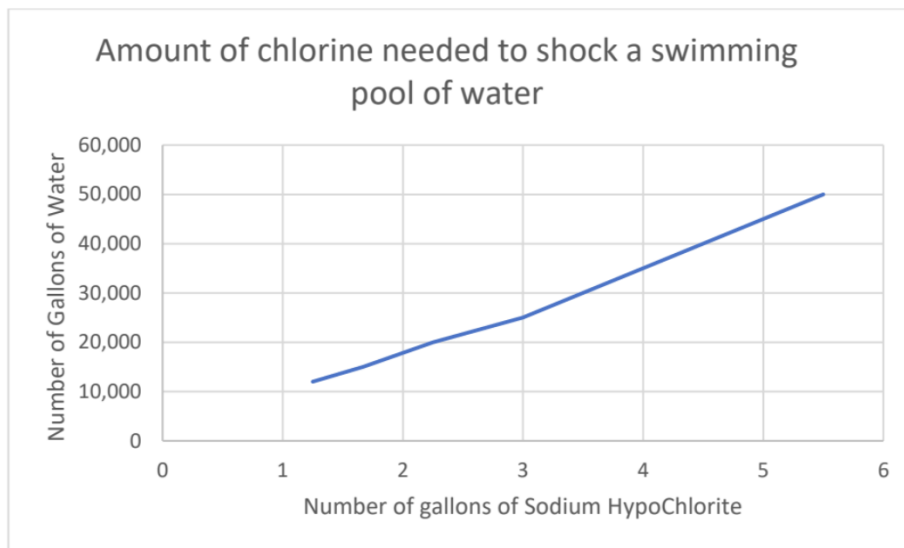
Solution

- a. What general information is provided in the bar graph? The number of liters of water treated each year between 1998 and 2012

- b. Which year had the most liters of treated water? 2009
- c. Which year had the least liters of treated water? 1998
- d. In which year was 8,000,000,000 liters of water treated? 2006
- e. The amount of treated water increased between which years? 1998-2009
- f. The amount of treated water decreased between which years? 2009-2011
- g. Which years had approximately the same number of treated liters of water? 2008 and 2011

3. Using the line graph below, answer the following questions:

- a. What general information is provided in the line graph?
- b. The number of gallons of water in the pool appear to increase, decrease, or remain the same as the number of gallons of Sodium HypoChlorite increases?
- c. How many gallons of Sodium HypoChlorite are needed to shock 25,000 gallons of water?
- d. How many gallons of water can 4 gallons of Sodium HypoChlorite shock?
- e. What is the maximum point on the graph and what does it represent?



Solution

- a. What general information is provided in the line graph? The number of gallons of Sodium HypoChlorite (a type of chlorine) that are needed to shock a certain number of gallons of water in a swimming pool.
- b. The number of gallons of water in the pool appear to increase, decrease, or remain the same as the number of gallons of Sodium HypoChlorite increases? Since the line graph is going up from left to right, the number of gallons of water in the pool is increasing as the number of gallons of Sodium HypoChlorite used increases.
- c. How many gallons of Sodium HypoChlorite are needed to shock 25,000 gallons of water? Reading the vertical axis, we can find 25,000 gallons of water, move to the right to find the point on the graph and read the corresponding number on the horizontal axis, which is 3 gallons of Sodium HypoChlorite.
- d. How many gallons of water can 4 gallons of Sodium HypoChlorite shock? Reading the horizontal axis, we can find 4 gallons of Sodium HypoChlorite, go up the graph to find the point on the graph and read the corresponding number on the vertical axis, which is 35,000 gallons of water.
- e. What is the maximum point on the graph and what does it represent? The highest point on the graph is at (5, 50000). Note: the horizontal number is written first in a point and the vertical axis number is written second. This point means we need 5 gallons of Sodium HypoChlorite to shock 50,000 gallons of swimming pool water.

This page titled [3.7.2: Examples](#) is shared under a [CC BY 4.0](#) license and was authored, remixed, and/or curated by [Kelly Brooks](#).

00: Front Matter

This page was auto-generated because a user created a sub-page to this page.

TABLE OF CONTENTS

00: Front Matter

- Table of Contents

4.1: Unit Dimensional Analysis (UDA)

- 4.1.1: Applying the Math of UDA

4.2: Geometric Shapes

- 4.2.1: The Shapes of Things
- 4.2.2: Applying the Math of Geometric Shapes

4.3: Density and Specific Gravity

- 4.3.1: It's All About the Weight
- 4.3.2: Parts Per Hundred vs. Parts Per Million

4.4: Chemical Dosage Analysis

- 4.4.1: It's a Pound Formula!

4.5: Weir Overflow Rate

- 4.5.1: What's a Weir?

4.6: Water Treatment Math Detention Time

- 4.6.1: It's a Lag in Time
- 4.6.2: Filtration Rates

4.7: CT Calculations

- 4.7.1: How Much For How Long?

4.8: Pressure, Head Loss, and Flow

- 4.8.1: Are You At a Loss?
- 4.8.2: Head Loss
- 4.8.3: Flow Rate

4.9: Well Yield, Specific Capacity, and Drawdown

- 4.9.1: It's All Underground

4.10: Horsepower and Efficiency

- 4.10.1: The Power of Water
- 4.10.2: Head Loss and Horsepower
- 4.10.3: Calculating Power Costs

4.11: per Capital water Usage

- 4.11.1: How Much Water Do We Really Use?

4.12: Blending and Diluting

- 4.12.1: Is Dilution the Solution to Pollution?
- 4.12.2: Mixing and Diluting Solutions

4.13: Supervisory control and data acquisition (SCADA) and the Use of mA

- 4.13.1: SCADA?

4.14: Water Utility Management

- 4.14.1: Managing With Numbers

SECTION OVERVIEW

4.1: Unit Dimensional Analysis (UDA)

4.1.1: Applying the Math of UDA

This page titled [4.1: Unit Dimensional Analysis \(UDA\)](#) is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by [Mike Alvord \(ZTC Textbooks\)](#).

4.1.1: Applying the Math of UDA

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

However, in the “world” of water, converting of units is commonplace. The following few questions are written with the perspective of “real world” scenarios.

Exercises

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

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

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

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

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

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

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

This page titled [4.1.1: Applying the Math of UDA](#) is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by [Mike Alvord \(ZTC Textbooks\)](#) .

- [1.1: Applying the Math of UDA](#) by [Mike Alvord](#) is licensed [CC BY 4.0](#).

SECTION OVERVIEW

4.2: Geometric Shapes

4.2.1: The Shapes of Things

4.2.2: Applying the Math of Geometric Shapes

This page titled [4.2: Geometric Shapes](#) is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by [Mike Alvord \(ZTC Textbooks\)](#).

4.2.1: The Shapes of Things

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

Areas

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

$$0.785D^2 \quad LW \left(\frac{b_1 + b_2}{2} \right) H \quad (4.2.1.1)$$

$$\frac{(0.785D^2)}{2} + LW \quad 4(0.785D^2) \quad \pi DH \quad (4.2.1.2)$$

Circles

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

$$A = 3.14 \times r^2 \quad (4.2.1.3)$$

or

$$A = 0.785 \times d^2 \quad (4.2.1.4)$$

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

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

Examples

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

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

Rectangles

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

Examples

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

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

Trapezoids

Trapezoids are most commonly the shape of an aqueduct. Aqueducts are typically miles and miles of trapezoidal shaped concrete channels. They have flat narrow bottoms that slope up to wider distances at the top. In order to calculate the varying distances across a trapezoid, add the distance (width, b2) across the bottom to the distance (width, b1) across the top and divide by 2. This gives the average width. Then multiply the average width by the height or depth of the trapezoid to calculate the area.

Examples

- Widths = 5 ft and 7 ft, height = 6 ft
 - $(5 \text{ ft} + 7 \text{ ft}) / 2 \times 6 \text{ ft} = 36 \text{ ft}^2$
- Widths = 8 ft and 12 ft, depth = 10 ft
 - $(8 \text{ ft} + 12 \text{ ft}) / 2 \times 10 \text{ ft} = 100 \text{ ft}^2$

Spheres and Other Shapes

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

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

Examples

- D = 100 ft, height = 20 ft
- $3.14 \times 100 \text{ ft} = 314 \text{ ft}$ (which is “L”)
- $314 \text{ ft} \times 20 \text{ ft} = 6,280 \text{ ft}^2$

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

Examples

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

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

Exercises

1. What is the area of the opening of a 10” diameter pipe?
2. A rectangular channel flows millions of gallons of water through it and dumps into a storage reservoir. The channel is 2 miles long 3 feet wide and 2 feet deep. What is the area of the channel opening?
3. A channel is 3 feet wide at the bottom and 5 feet wide at the top and the water is 4 feet deep when the channel is full. What is the area of the channel?
4. An elevated storage tank is shaped like a sphere and needs to be recoated. If the diameter of the tank is 65 feet, what is the surface area?
5. A standpipe needs to be painted. What is the surface area of the entire standpipe? It has a diameter of 30 feet and is 80 feet tall.
6. What is the surface area of a spherical structure that has a 42-foot diameter?

7. A box structure needs to be painted. It is 20 feet wide, 30 feet long and 10 feet tall. What is the total area of all six surfaces (inside only)?
8. What is the inside surface area of a 32" diameter pipe that is 1,000 feet long and is capped with half a sphere at the end? (Assume the sphere diameter is not included in the length)

Volumes

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

Exercises

1. What is the volume of a 30-foot diameter sphere?
2. What is the volume in 2,000 feet of 18-inch diameter pipe?
3. A 5-mile long aqueduct is 5 feet wide at the bottom and 8 feet wide at the water line. If the water depth is $6\frac{1}{2}$ feet, how many acre-feet of water are in the aqueduct?
4. A sedimentation basin is 100 feet long, 30 feet wide, and 20 feet deep. How many gallons can it hold?
5. A standpipe is 80 feet tall and has a 25-foot diameter. Assuming the top of the standpipe is a half-sphere shape, how many gallons will it hold?

This page titled [4.2.1: The Shapes of Things](#) is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by [Mike Alvord \(ZTC Textbooks\)](#).

- [2.1: The Shapes of Things](#) by [Mike Alvord](#) is licensed [CC BY 4.0](#).

4.2.2: Applying the Math of Geometric Shapes

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

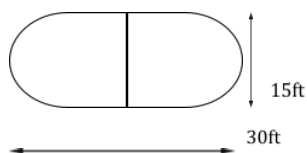
Exercises

1. A water utility operator needs to determine how many gallons of paint are needed to paint the outside of an above-ground storage tank and the cost of the paint. The tank has a 120-foot diameter and is 32 feet tall. (Assume that one gallon of paint can cover 125 ft^2 and costs \$25.75 per gallon)
2. A utility manager needs to find a site for a 3.1 MG storage tank. The tank cannot be taller than 33 feet. What diameter should this tank have?
3. A construction crew will be installing 1,250 feet of 10-inch diameter pipe. The width of the trench will be 30 inches and the depth 36 inches. After the pipe has been installed, how many cubic yards of dirt will be needed to backfill the trench? (Assume the trench will be backfilled up to 6 inches from the ground surface)
4. In the above problem, the construction crew also needs to place 6 inches of aggregate base on top of the fill. How many cubic feet of base are needed?
5. A water quality technician needs to disinfect an elevated storage tank, but first, she needs to calculate the volume of water in the tank. The 20-foot diameter storage tank sits on a 16-foot diameter, 30-foot tall pipe. How many gallons are in the structure?



Figure 4.2.2.1

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



7. A maintenance crew is replacing a 12” meter at a well. The specifications state that there needs to be 3 times the pipe diameter in feet of straight pipe before the meter and 5 times the pipe diameter in feet of straight pipe after the meter. Currently, the well has a 10” diameter pipe. How many feet of 12” pipe are needed?
8. A 1.25-mile section of trapezoidal shaped aqueduct needs to be drained. The aqueduct is 5 feet wide at the base and 10 feet wide at the water line. If there are 9 acre-feet of water in the aqueduct, what is the depth?
9. A contractor just installed 350 feet of 8” diameter pipe, 430 feet of 12” diameter pipe, and 275 feet of 16” diameter pipe. The pipe needs to be filled, but the inflow flow rate is only 10 gpm. How long will it take to fill all this pipe? (Give answer in the best time format)
10. A water utility manager is determining what shaped storage tank should be used to store water for a small mobile home park. The mobile home park needs 110,000 gallons of storage. There is room for a 25-foot diameter and 30-foot tall cylinder-shaped

tank or a 30-foot diameter sphere-shaped tank. Which tank will provide the adequate storage?

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

This page titled [4.2.2: Applying the Math of Geometric Shapes](#) is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by [Mike Alvord](#) (ZTC Textbooks) .

- [2.2: Applying the Math of Geometric Shapes](#) by [Mike Alvord](#) is licensed [CC BY 4.0](#).

SECTION OVERVIEW

4.3: Density and Specific Gravity

4.3.1: It's All About the Weight

4.3.2: Parts Per Hundred vs. Parts Per Million

This page titled [4.3: Density and Specific Gravity](#) is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by [Mike Alvord \(ZTC Textbooks\)](#) .

4.3.1: It's All About the Weight

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

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

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

Examples

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

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

- $8.34 \text{ lbs/gal} \times 1.25 \text{ SG} = 10.43 \text{ lbs/gal}$

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

- $5.75 \text{ lbs/gal} \div 8.34 \text{ lbs/gal} = 0.69 \text{ SG}$

Exercises

Solve the following density related problems.

1. Liquid sodium hypochlorite has a specific gravity of 1.47. What is the corresponding weight in pounds per gallon?
2. Chlorine gas has formed into a liquid state. It weighs 19.75 lbs/gal. What is the specific gravity?
3. What is the weight difference between 75 gallons of water and 42 gallons of sodium hypochlorite with a specific gravity of 1.42?
4. A treatment operator has 50 gallons of 12.5% sodium hypochlorite. How many pounds of the 50 gallons are available chlorine?
5. How much does 45 gallons of 25% Alum weigh if the specific gravity is 1.35?
6. Ferric chloride weighs 14.25 lbs/gal. What is the specific gravity?
7. Chemical A has a specific gravity of 2.31 and chemical B has a specific gravity of 1.95. Chemical A is what percent heavier than chemical B?
8. How many pounds of ferric chloride are in 250 gallons of 22% strength? (Assume the specific gravity is 1.41)
9. What is the weight in lbs/cf of a substance that has a specific gravity of 2.05?

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

This page titled [4.3.1: It's All About the Weight](#) is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by [Mike Alvord \(ZTC Textbooks\)](#) .

- [3.1: It's All About the Weight](#) by [Mike Alvord](#) is licensed [CC BY 4.0](#).

4.3.2: Parts Per Hundred vs. Parts Per Million

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

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

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

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

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

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

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

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

1,000,000 – million

1,000,000,000 – billion

1,000,000,000,000 – trillion

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

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

Exercises

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

1. A 12.5% chlorine solution has a ppm concentration of?
2. What is the percent concentration of a 100 ppm solution?
3. A Water Utility uses a 0.8% sodium hypochlorite solution to disinfect a well. What is the ppm concentration of the solution?
4. A container of liquid chlorine has a concentration of 1,250 ppm. What is the percent concentration of the solution?
5. If a 100-gallon container is $\frac{3}{4}$ full with a 5.25% solution and is then filled with freshwater, what would the resulting ppm of the water be?
6. Complete the following table with the corresponding unit for the various water quality Maximum Contaminant Levels (MCL).

Constituent	ppm	ppb	ppt
Arsenic		10	
Chromium	0.05		
Nitrate (NO ₃)	45		
Perchlorate			6,000
Vinyl chloride		0.5	

This page titled [4.3.2: Parts Per Hundred vs. Parts Per Million](#) is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by [Mike Alvord \(ZTC Textbooks\)](#) .

- [3.2: Parts Per Hundred vs. Parts Per Million](#) by [Mike Alvord](#) is licensed [CC BY 4.0](#).

SECTION OVERVIEW

4.4: Chemical Dosage Analysis

4.4.1: It's a Pound Formula!

This page titled [4.4: Chemical Dosage Analysis](#) is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by [Mike Alvord \(ZTC Textbooks\)](#) .

4.4.1: It's a Pound Formula!

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

$$MG \times 8.34 \text{ lbs/gallon} \times \text{ppm} = \text{lbs} \quad (4.4.1.1)$$

or

$$\frac{MG}{Day} \times 8.34 \text{ lbs/gallon} \times \text{ppm} = \text{lbs/day} \quad (4.4.1.2)$$

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

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

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

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

Therefore, if you are calculating for the amount of pounds needed you divide by the decimal equivalent of the percent concentration. You need more of the chemical since it is not 100% and dividing by a number less than one yields a larger number. If the amount of pounds is known, then by multiplying by the decimal equivalent of the percent concentration you will calculate how much of that chemical is available in the total pounds of the substance. Multiplying by a number less than one yields a smaller number.

Once you understand the concept behind the problem it makes solving them easier. Think of it this way... it takes much more 10% ferric chloride in the coagulation process than let's say ferric chloride at 75% strength. The same is true if you are using calcium hypochlorite as opposed to gas chlorine, because gas is a greater strength than calcium hypochlorite. Similarly, if you have 100 pounds of 65% calcium hypochlorite, you don't have 100 pounds of chlorine. Only 65% or 65 pounds of the substance is actually chlorine. As opposed to 100 pounds of gas chlorine which is 100 pounds of available chlorine. When using chemicals of different strengths, the pound formula can be looked at like this:

$$\% \text{ concentration} \frac{\text{MG}}{\text{Day}} \times 8.34 \text{ lbs/gallon} \times \text{ppm} = \text{lbs}$$

$$\% \text{ concentration} \times \text{MG/Day} \times 8.34 \text{ lbs/gallon} \times \text{ppm} = \text{lbs/day}$$

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

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

Finally, a general understanding of chlorine dosage is needed. The concept is straightforward. The reason drinking water is disinfected is to prevent pathogenic organisms from contaminating the supply causing illness to the population drinking the water. The amount of disinfectant added is not always what is measured later by a water utility operator. Typically the amount of disinfectant measured after the original dosage occurs is lower than the dosage measured which is referred to as the residual. What

happens to the disinfectant? The chlorine that “disappears” is the chlorine demand. It is the amount of chlorine that is inactivating the pathogens. Once the demand is satisfied, the remaining chlorine is termed the residual. This formula is provided below.

$$\text{Dosage} = \text{residual} + \text{demand} \quad (4.4.1.3)$$

Example 4.4.1.1

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

Solution

We use Equation 4.4.1.1 to solve this.

$$\begin{aligned} MG \times 8.34 \text{ lbs/gallon} \times \text{ppm} &= \text{lbs} \\ 2 \text{ MG} \times 8.34 \text{ lbs/gal} \times 3.25 \text{ ppm} &= 54.21 \text{ lbs} \end{aligned}$$

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

Example 4.4.1.2

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

Solution

We use Equation 4.4.1.2 to solve this

$$(5 \text{ MG/Day} \times 8.34 \text{ lbs/gallon} \times 10 \text{ ppm}) / 0.1 = \text{lbs/day}$$

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

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

Example 4.4.1.3

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

Solution

First, the flow rate needs to be converted to MGD.

$$1,500 \text{ gpm} \times 1440 = 2,160,000 \text{ GPD or } 2.16 \text{ MGD}$$

$$(2.16 \text{ MG/Day} \times 8.34 \text{ lbs/gallon} \times 1.75 \text{ ppm}) / 0.15 = 210 \text{ lbs/day}$$

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

$$210 \text{ lbs/day} \times \text{gallons} / (8.34 \text{ lbs} \times 1.42) = 17.75 \text{ gal/day}$$

Exercises

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

1. How many gallons of water can be treated with 100 pounds of 65% High Test Hypochlorite (HTH) to a dosage of 2.55 mg/L?
2. An operator added 165 pounds of 25% ferric chloride to a treatment flow of 10.5 MGD. What was the corresponding dosage?
3. How many pounds of 12.5% sodium hypochlorite are needed to dose a well with a flow rate of 1,000 gpm to a dosage of 1.75 ppm? (Assume the well runs 17 hours a day)
4. In the above problem, how many gallons of chemical are needed per hour? (Assume the SG is 1.4)

5. A treatment operator has set a chemical pump to dose 75 gallons of NaOH (sodium hydroxide) per day for a flow rate of 2.25 MGD. What is the corresponding dosage? (Assume the SG is 1.65)
6. 11,250 feet of 18" diameter main line needs to be dosed to 50 ppm. Answer the following questions.
 1. How many gallons of 12.5% (SG = 1.44) sodium hypochlorite are needed?
 2. How many pounds of 65% HTH are needed?
 3. Assuming the following costs, which one is least expensive?
 1. Sodium hypochlorite = \$2.45 per gallon
 2. HTH = \$1.65 per pound
7. A water treatment operator adjusted the amount of 20% Alum dosage from 85 mg/L to 70 mg/L. Based on a treatment flow of 10 MGD, what is the cost savings if 100% pure Alum costs \$2.50 per pound?
8. A water utility produced 11,275 AF of water last year. The entire amount was dosed at an average rate of 1.5 ppm. If the chemical of choice was 65% HTH at a per pound cost of \$1.85, what was the annual budget?
9. Ferric chloride is used as the coagulant of choice at a 5.75 MGD rated capacity treatment plant. If the plant operated at the rated capacity for 75% of the year and operated at 60% of rated capacity for 25% of the year, how many pounds of the coagulant was needed to maintain a dosage of 45 mg/L?
10. A water softening treatment process uses 25% NaOH during 20% of the year and 50% NaOH for 80% of the year. Assuming a constant flow rate of 1,100 gpm and a dosage of 70 mg/L, what is the annual budget if the 25% NaOH (SG = 1.18) costs \$0.95 per gallon and the 50% NaOH (SG = 1.53) costs \$1.70 per gallon?
11. An operator added 275 gallons of 12.5% (SG=1.32) into 2,550 ft of 12" diameter pipe. After 24 hours, the residual was measured at 10.25 ppm. What was the demand?

This page titled [4.4.1: It's a Pound Formula!](#) is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by [Mike Alvord](#) ([ZTC Textbooks](#)) .

- [4.1: It's a Pound Formula!](#) by [Mike Alvord](#) is licensed [CC BY 4.0](#).

SECTION OVERVIEW

4.5: Weir Overflow Rate

4.5.1: What's a Weir?

This page titled [4.5: Weir Overflow Rate](#) is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by [Mike Alvord \(ZTC Textbooks\)](#).

4.5.1: What's a Weir?

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

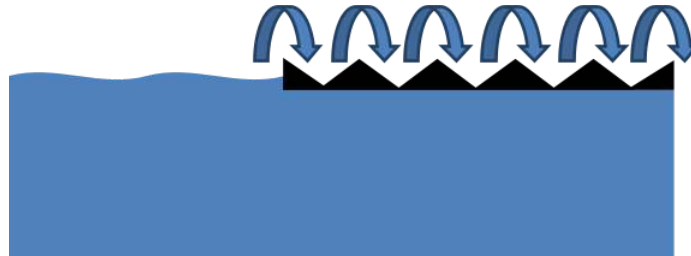


Figure 4.5.1.1

Weir Overflow Rate Formula

Weir Overflow Rate (gpm/ft) = Flow (gpm)/Length of Weir (ft)

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

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

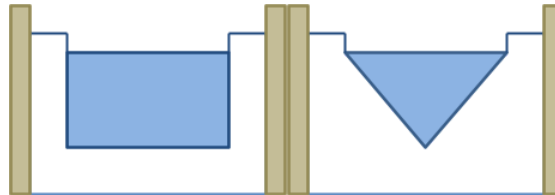


Figure 4.5.1.2: Broad Crested Weir Sharp Crested Weir

Exercises

1. What is the weir overflow rate through a 7 MGD treatment plant if the weir is 30 feet long? (Express your answer in MGD/ft and gpm/ft).
2. A drainage channel has a 10-foot weir and a weir overflow rate of 7 gpm/ft. What is the daily flow expressed in MGD?
3. What is the length of a weir if the daily flow is 8.45 MG and the weir overflow rate is 28 gpm/ft?
4. A 60 ft diameter circular clarifier has a weir overflow rate of 15 gpm/ft. What is the daily flow in MGD?
5. A treatment plant processes 15 MGD. The weir overflow rate through a circular clarifier is 29.5 gpm/ft. What is the diameter of the clarifier?
6. An aqueduct that flowed 36,000 acre-feet of water last year has a weir overflow structure to control the flow. If the weir is 250 feet long, what was the average weir overflow rate in gpm/ft?
7. A 75-mile aqueduct is being reconstructed to widen the width across the top. The width across the bottom is 10 feet and the average water depth is 15 feet. The aqueduct must maintain a constant weir overflow rate of 25 gpm per foot with a daily flow of 0.63 MGD. What is the length of the weir?
8. An engineering report determined that a minimum weir overflow rate of 15 gpm per foot and a maximum weir overflow rate of 20 gpm per foot were needed to meet the water quality objectives of a certain treatment plant. The existing weir is 80 feet long. What is the daily treatment flow range of the plant?

9. A circular clarifier processes 12.5 MGD with a detention time of 2.35 hours. If the clarifier is 50 feet deep, what is the diameter?
10. A water treatment plant is in the process of redesigning its sedimentation basin. The plant treats 4.5 MGD with an average detention time of 1.85 hours. Portable storage tanks will be used when the basin is under construction. The portable storage tanks are 25 ft tall and 20 ft in diameter. How many tanks will be needed?

This page titled [4.5.1: What's a Weir?](#) is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by [Mike Alvord \(ZTC Textbooks\)](#).

- **5.1: What's a Weir?** by [Mike Alvord](#) is licensed [CC BY 4.0](#).

SECTION OVERVIEW

4.6: Water Treatment Math Detention Time

4.6.1: It's a Lag in Time

4.6.2: Filtration Rates

This page titled [4.6: Water Treatment Math Detention Time](#) is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by [Mike Alvord \(ZTC Textbooks\)](#) .

4.6.1: It's a Lag in Time

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

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

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

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

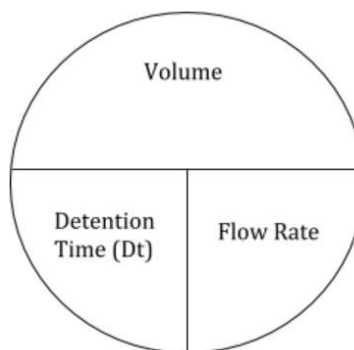


Figure 4.6.1.1

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

The Detention Time formula is:

$$\text{Detention Time (Dt)} = \frac{\text{Volume}}{\text{Flow}} \quad (4.6.1.1)$$

- When solving this equation make sure the units are correct

Take a look at the examples below.

- **Dt** = Volume/Flow
 - gallons/(gallons/minute)
 - cubic feet/(cubic feet/second)
 - gallons/(million gallons/day)

In the first two examples above, the terms can be divided. However, in the third example, they cannot. Dt should be expressed as a unit of time (i.e., sec, min, hours). If you divide the first two examples (gal/gpm and cf/cfs), you will end up with minutes and

seconds, respectively. However, in the third example, gallons and million gallons cannot cancel each other out. Therefore, if you had 100,000 gallons as the volume and 1 MGD as the flow rate:

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

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

$$100,000 \text{ gallons}/(1,000,000 \text{ gallons}/1 \text{ day}) = 0.1 \text{ day}$$

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

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

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

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

Now solve for the Detention Time.

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

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

Exercises

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

1. What is the detention time in hours of a 100 ft by 20 ft by 10 ft sedimentation basin with a flow of 5 MGD?
2. What is the detention time in a circular clarifier with a depth of 30 ft and a 70 ft diameter if the daily flow is 4.5 MG. (Express your answer in hours:minutes)
3. A water utility engineer is designing a sedimentation basin to treat 10 MGD and maintain a minimum detention time of 2 hours 15 minutes. The basin cannot be longer than 80 feet and wider than 40 feet. Under this scenario, how deep must the basin be?
4. Chlorine is injected into an 18” diameter pipe at a well site. The pipeline is 2,000 ft long before it reaches the first customer. Assuming a well flow rate of 1,700 gpm, what is the detention time (contact time) in minutes?
5. A water utility is designing a transmission pipeline collection system in order to achieve a chlorine contact time of 40 minutes once a 2,250 gpm well is chlorinated. How many feet of 24” diameter pipe are needed?
6. A fluoride tracer study is being conducted at a 15.5 MGD capacity water treatment plant. The contact time through the coagulation and flocculation process is 2.45 hours. If the sedimentation basin has a capacity of 500,000 gallons, what is the total detention time through the 3 processes?
7. The chlorine residual decay rate is 0.2 mg/L per ½ hour in a 5 MG water storage tank. If the storage tank needs to maintain a minimum chlorine residual of 10.0 mg/L what is the required dosage if the tank is filling at a rate of 1,500 gpm until the tank is full?
8. A drinking water well serves a community of 2,000 people. The customer closest to the well is 1,250 feet away. The above-ground portion of the well piping is 12” diameter and 25 feet long. The below-ground portion is 750 feet of 10” diameter and 475 feet of 8” diameter piping. What is the chlorine contact time in minutes from the well head to the first customer? Assume a constant flow rate of 3.90 cfs.
9. An aqueduct has a weir that is 5 feet narrower than the distance across the aqueduct. Assuming a constant weir overflow rate of 28.75 gpm/ft, an average depth of 12 feet, a distance across the bottom of 8 feet, a length of 22 miles, and a daily flow of 0.85 MG, what is the capacity of the aqueduct in AF?
10. A 32-foot tall water storage tank is disinfected with chloramines through an onsite disinfection system. The average constant effluent from the tank is 550 gpm through a 16-inch diameter pipe. If the first customer that receives water from the tank is

3,220 feet from the tank, would the required 45 minute contact time be achieved?

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

This page titled [4.6.1: It's a Lag in Time](#) is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by [Mike Alvord \(ZTC Textbooks\)](#).

- [6.1: It's a Lag in Time](#) by [Mike Alvord](#) is licensed [CC BY 4.0](#).

4.6.2: Filtration Rates

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

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

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

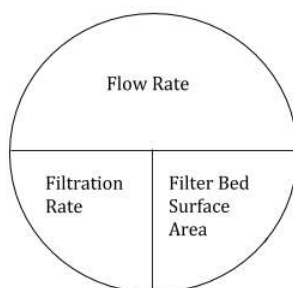


Figure 4.6.2.1

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

- $\text{Flow Rate (gpm)} / \text{Surface Area (sq.ft)} = \text{Filtration Rate}$

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

- $\text{Filtration Rate} = \text{Fall (inches)} / \text{Time (min)}$
- $\text{Backwash Rate} = \text{Rise (inches)} / \text{Time (min)}$

Examples

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

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

- $(2.5 \text{ gal/min}) / \text{sq.ft} \times 1 \text{ cf} / 7.48 \text{ gal} = 0.33 \text{ cfm/sq.ft}$
- $2.5 \text{ gpm/sq.ft} \times 1 \text{ cf} / 7.48 \text{ gal} = 0.33 \text{ cfm/sq.ft}$

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

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

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

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

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

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

Then divide the flow by the area of the filter ($20' \times 20' = 400 \text{ sq.ft}$).

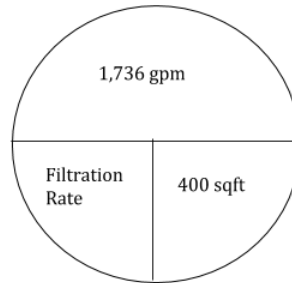


Figure 4.6.2.2

- $1,736 \text{ gpm} / 400 \text{ sq.ft} = 4.34 \text{ gpm/sq.ft}$

Now, calculate the inches per minute.

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

- $1.6 \text{ in/min} = 1 \text{ gpm/sq.ft}$

Exercises

1. A water treatment plant processes 10.5 MGD. What is the required filter bed area needed to maintain a filtration rate of 1.75 gpm/ft²?
2. A 15 ft by 17 ft filter needs to be back washed at a rate of 17 gpm/ft² for a minimum of 20 minutes. How many gallons are used during the backwashing process?
3. In order to properly backwash a certain filter a backwash rate of 20 inches per minute rise is needed. If the filter is 20 ft by 25 ft, what is the backwash flow rate in gpm?
4. A water treatment plant processes a maximum of 18.65 MGD. The plant has 6 filters measuring 20 ft by 22 ft each. Assuming that each filter receives an equal amount of flow what is the filtration rate in gpm/ft²?
5. A water treatment plant processes 4.55 MGD through a 35 ft by 35 ft filter. What is the corresponding inches per minute through the filter?
6. A filter is backwashed at a rate of 15.5 inches per minute for 25 minutes. If the filter is 150 ft², how many gallons were used?
7. An engineer is designing a circular filter to handle 5.75 MGD and maintain a filtration rate of 1.75 inches per minute. What will the diameter be?
8. A filter needs to be backwashed when the fall rate exceeds 3.1 inches per minute. It was determined that this rate is reached after 2.3 MG through a 17 ft by 17 ft filter. How often does the filter need backwashing? Give your answer in the most logical time unit.

This page titled [4.6.2: Filtration Rates](#) is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by [Mike Alvord \(ZTC Textbooks\)](#).

- [6.2: Filtration Rates](#) by [Mike Alvord](#) is licensed [CC BY 4.0](#).

SECTION OVERVIEW

4.7: CT Calculations

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

4.7.1: How Much For How Long?

This page titled [4.7: CT Calculations](#) is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by [Mike Alvord \(ZTC Textbooks\)](#).

4.7.1: How Much For How Long?

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

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

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

The table below compares the Log and Percent Inactivation values.

Table 7.1. Log Percent and Inactivation Values

Log Inactivation	Expressed as Log	Log Value	Percent Inactivation
0.5	100.5	3.162	68.38
1.0	101.0	10	90.00
2.0	102.0	100	99.00
3.0	103.0	1,000	99.90
4.0	104.0	10,000	99.99
5.0	105.0	100,000	99.999
6.0	106.0	1,000,000	99.9999
7.0	107.0	10,000,000	99.99999

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

Converting from Log to Percentage

Example

- 0.5 Log
 - $(1 - (1/10^{\log \text{ inactivation}})) \times 100$
 - $(1 - (1/10^{0.5})) \times 100$
 - $(1 - (1/3.16)) \times 100 = 68\%$
- 3.0 Log
 - $(1 - (1/10^{\log \text{ inactivation}})) \times 100$
 - $(1 - (1/10^3)) \times 100$
 - $(1 - (1/1000)) \times 100 = 99.9\%$

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

Converting from Percentage to Log

Example

- 68.38%
 - $100/(100 - \text{Percent Inactivation}) = \text{Log Inactivation}$
 - $100(100 - 68.38) = 3.162$
 - $3.162 = 10^{0.5} = 0.5 \text{ Log}$

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

- 99.9%
 - $100/(100 - \text{Percent Inactivation}) = \text{Log Inactivation}$
 - $100(100 - 99.9) = 1,000$
 - $1,000 = 10^3 = 3 \text{ Log}$

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

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

Table 7.2. Treatment Credits and Log Inactivation Requirements

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

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

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

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

In the paragraph above, two terms were used; “actual CT” and “required CT.” Actual CT is the actual concentration through the treatment process and the actual time the disinfectant is in contact with the water. For example, if the contact time is 10 minutes and the concentration is 0.2 mg/L then the actual CT is 0.2 mg/L times 10 minutes which equals 2 mg/L · min. The CT Tables give you the required CT, the required concentration time needed to inactivate either *Giardia* or viruses. The ratio of the actual CT and

the required CT is then calculated. If the actual CT is equal to or greater than the required CT then the ratio is equal to or greater than 1.0 and CT is met. If the actual CT is less than the required CT then the ratio would be less than 1.0 and CT would not be met. The following examples show how to calculate CT problems from start to finish.

Example

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

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

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

EPA Guidance Manual

Guidance on Disinfection

C-4

August 1991

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

CHLORINE CONCENTRATION (mg/L)	pH=6.5						pH=7.0						pH=7.5					
	Log Inactivation						Log Inactivation						Log Inactivation					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
<=0.4	12	24	37	49	61	73	15	29	44	59	73	88	17	35	52	69	87	104
0.6	13	25	38	50	63	75	15	30	45	60	75	90	18	36	54	71	89	107
0.8	13	26	39	52	65	78	15	31	46	61	77	92	18	37	55	73	92	110
1	13	26	40	53	66	79	16	31	47	63	78	94	19	37	56	75	93	112
1.2	13	27	40	53	67	80	16	32	48	63	79	95	19	38	57	76	95	114
1.4	14	27	41	55	68	82	16	33	49	65	82	98	19	39	58	77	97	116
1.6	14	28	42	56	69	83	17	33	50	66	83	99	20	40	60	79	99	119
1.8	14	29	43	57	72	86	17	34	51	67	84	101	20	41	61	81	102	122
2	15	29	44	58	73	87	17	35	52	69	87	104	21	41	62	83	103	124
2.2	15	30	45	59	74	89	18	35	53	70	88	105	21	42	64	85	106	127
2.4	15	30	45	60	75	90	18	36	54	71	89	107	22	43	65	86	108	129
2.6	15	31	46	61	77	92	18	37	55	73	92	110	22	44	66	87	109	131
2.8	16	31	47	62	78	93	19	37	56	74	93	111	22	45	67	89	112	134
3	16	32	48	63	79	95	19	38	57	75	94	113	23	46	69	91	114	137
CHLORINE CONCENTRATION (mg/L)	pH=8.0						pH=8.5						pH=9.0					
	Log Inactivation						Log Inactivation						Log Inactivation					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
<=0.4	25	50	75	99	124	149	30	59	89	118	148	177	35	70	105	139	174	209
0.6	26	51	77	102	128	153	31	61	92	122	153	183	36	73	109	145	182	218
0.8	26	53	79	105	132	158	32	63	95	126	158	189	38	75	113	151	188	226
1	27	54	81	108	135	162	33	65	98	130	163	195	39	78	117	156	195	234
1.2	28	55	83	111	138	166	33	67	100	133	167	200	40	80	120	160	200	240
1.4	28	57	85	113	142	170	34	69	103	137	172	206	41	82	124	165	206	247
1.6	29	58	87	116	145	174	35	70	106	141	176	211	42	84	127	169	211	253
1.8	30	60	90	119	149	179	36	72	108	143	179	215	43	86	130	173	216	259
2	30	61	91	121	152	182	37	74	111	147	184	221	44	88	133	177	221	265
2.2	31	62	93	124	155	186	38	75	113	150	188	225	45	90	136	181	226	271
2.4	32	63	95	127	158	190	38	77	115	153	192	230	46	92	138	184	230	276
2.6	32	65	97	129	162	194	39	78	117	156	195	234	47	94	141	187	234	281
2.8	33	66	99	131	164	197	40	80	120	159	199	239	48	96	144	191	239	287
3	34	67	101	134	168	201	41	81	122	162	203	243	49	97	146	195	243	292

Source: AWWA, 1991.

APPENDIX C. CT VALUES FOR INACTIVATIONS ACHIEVED BY VARIOUS DISINFECTANTS

Figure 4.7.1.1

Finding Required CT

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

Calculating Actual CT

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

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

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

- $Dt = \text{Volume}/\text{Flow}$
- $\text{Volume} = 0.785 \times D^2 \times L$
- $\text{Volume} = 0.785 \times 1' \times 1' \times 5,000' \times 7.48 \text{ gal/ft}^3 = 29,359 \text{ gallons}$
- $\text{Flow} = 2 \text{ MGD} = 1,389 \text{ gpm}$
- $Dt = 29,359 \text{ gal}/1,389 \text{ gpm} = 21 \text{ minutes}$

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

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

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

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

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

$$1.2 \text{ mg/L} \times 20 \text{ minutes} = 24 \text{ mg/L} \cdot \text{min} \quad (4.7.1.1)$$

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

$$4.2 \text{ mg/L} \cdot \text{min} + 24 \text{ mg/L} \cdot \text{min} = 28.2 \text{ mg/L} \cdot \text{min} \quad (4.7.1.2)$$

The following table is used to organize the data.

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

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

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

Example

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

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

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

Now, the actual CT needs to be calculated.

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

- Volume = $0.785 \times 3\text{ft} \times 3\text{ft} \times 9,000\text{ft} \times 7.48 \text{ gal/ft}^3 = 475,616$ gallons
- Flow rate = 10 MGD = 6,944 gpm
- Dt = $475,616 \text{ gal} / 6,944 \text{ gpm} = 68.5$ minutes
- $0.4 \text{ mg/L} \times 68.5 \text{ minutes} = 27.4 \text{ mg/L} \cdot \text{min}$ (this is the CT through the pipeline)

CT for the plant is:

- $1.2 \text{ mg/L} \times 30 \text{ minutes} = 36 \text{ mg/L} \cdot \text{min}$ (this is the CT through the plant)

Now finish populating the table:

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

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

Exercises

1. What is the required CT inactivation in a conventional filtration plant for Giardia by free chlorine at 20°C with a pH of 9.0 and a chlorine concentration of 1.0 mg/L?
2. What is the required CT inactivation for viruses with chlorine dioxide, a pH of 8.5, and a temperature of 7°C?
3. What is the required CT inactivation in a direct filtration plant for Giardia by free chlorine at 5°C with a pH of 8.0 and a chlorine concentration of 1.6 mg/L?
4. A conventional water treatment plant is fed from a reservoir 3 miles away through a 5-foot diameter pipe. Disinfection is provided from the supply reservoir to the plant influent at a free chlorine residual of 0.3 mg/L. The daily flow is a constant 50 MGD. And the water is 10°C and has a pH of 8.0. The treatment plant maintains a chloramines residual of 1.0 mg/L. Tracer studies have shown the contact time (T_{10}) for the treatment plant at the rated capacity of 50 MGD to be 30 minutes. Does this plant meet compliance for CT inactivation for *Giardia*?
5. A conventional water treatment plant is fed from a reservoir 2 miles away through a 6-foot diameter pipe. Disinfection is provided from the supply reservoir to the plant influent at a free chlorine residual of 0.2 mg/L. The daily flow is a constant 55 MGD. And the water is 10°C and has a pH of 7.5. The treatment plant maintains a chloramines residual of 1.0 mg/L. Tracer studies have shown the contact time (T_{10}) for the treatment plant at the rated capacity of 55 MGD to be 40 minutes. Does this plant meet compliance for CT inactivation for viruses?
6. A direct filtration water treatment plant is fed from a reservoir 2.5 miles away through a 4-foot diameter pipe. Disinfection is provided from the supply reservoir to the plant influent at a free chlorine residual of 0.4 mg/L. The daily flow is a constant 30 MGD. And the water is 15°C and has a pH of 8.5. The treatment plant maintains a chloramines residual of 0.75 mg/L. Tracer

studies have shown the contact time (T_{10}) for the treatment plant at the rated capacity of 30 MGD to be 20 minutes. Does this plant meet compliance for CT inactivation for *Giardia*?

7. A direct filtration plant is operated at a designed flow of 10 MGD with a contact time of 15 minutes. A free chlorine dose of 0.5 mg/L is maintained through the plant. Upon leaving the plant the effluent is chloraminated (and maintained to the distribution system) to a dose of 1.0 mg/L through a pipeline with a contact time of 10 minutes into a 500,000-gallon reservoir. The pH of the water is 8.0 and has a temperature of 20°C. Does this treatment process meet compliance for CT inactivation for viruses?
8. Does a water utility meet CT for viruses by disinfection if only the free chlorine concentration through 150 ft of 48" diameter pipe at a flow rate of 1,200 gpm is 2.60 ppm? Assume the water is 15°C and has a pH of 7.0.

This page titled [4.7.1: How Much For How Long?](#) is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by [Mike Alvord](#) (ZTC Textbooks) .

- [7.1: How Much For How Long?](#) by [Mike Alvord](#) is licensed [CC BY 4.0](#).

SECTION OVERVIEW

4.8: Pressure, Head Loss, and Flow

4.8.1: Are You At a Loss?

4.8.2: Head Loss

4.8.3: Flow Rate

This page titled [4.8: Pressure, Head Loss, and Flow](#) is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by [Mike Alvord](#) (ZTC Textbooks) .

4.8.1: Are You At a Loss?

Pressure

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

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

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

$$1 \text{ foot} = 0.433 \text{ psi}$$

$$2.31 \text{ feet} = 1 \text{ psi}$$

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

Example

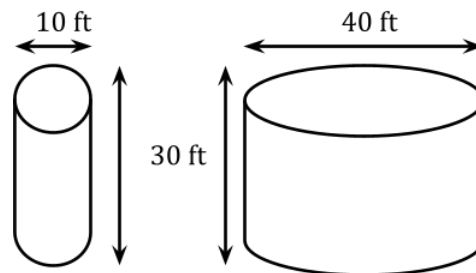


Figure 4.8.1.1

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

- Pressure = $30 \text{ ft} \times 0.433 \text{ psi/ft} = 13 \text{ psi}$ or $30 \text{ ft} \div 2.31 \text{ ft/psi} = 13 \text{ psi}$
- Force = the volume of water (in gallons) in each tank multiplied by 8.34 lb/gal
- Left Tank = $0.785 \times 10 \text{ ft} \times 10 \text{ ft} \times 30 \text{ ft} \times 7.48 = 17,615 \text{ gallons}$
 - $17,615 \text{ gallons} \times 8.34 \text{ lb/gal} = 146,912 \text{ pounds of force}$
- Right Tank = $0.785 \times 40 \text{ ft} \times 40 \text{ ft} \times 30 \text{ ft} \times 7.48 = 281,846 \text{ gallons}$
 - $281,846 \text{ gallons} \times 8.34 \text{ lb/gal} = 2,350,599 \text{ pounds of force}$

Exercises

Solve the following pressure and force related problems.

1. What is the pressure at the bottom of a 30 ft tank if the tank is half full?
2. A 28-foot tall tank sits on a 75-foot tall hill. Assuming the tank is full, what is the pressure at the bottom of the hill?
3. The opening of a 2 1/2” fire hydrant nozzle has a pressure of 135 psi. What is the corresponding force in pounds?

4. A home sits at an elevation of 1,301 ft above sea level. The base of a water tank that serves the home sits at an elevation of 1,475 ft above sea level. The tank is 35 feet tall and $\frac{3}{4}$ full. What is the pressure in psi at the home?
5. Two houses are served by a nearby water storage tank. House A is 55 ft above House B which sits at 725 ft above sea level. The base of the tank sits at 855 ft above sea level. The low water level in the tank is at 7.5 ft. At the low level, will House A meet the minimum pressure requirements of 35 psi?
6. House A sits at an elevation of 975 ft. Another house (B) needs to be built 75 ft below House A. At what elevation should the tank be built in order to give House B the maximum pressure of 130 psi?
7. A flowing pipeline has a pressure of 98 psi and a corresponding force of 4,924 pounds. What is the diameter of the pipe?

This page titled [4.8.1: Are You At a Loss?](#) is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by [Mike Alvord \(ZTC Textbooks\)](#).

- [8.1: Are You At a Loss?](#) by [Mike Alvord](#) is licensed [CC BY 4.0](#).

4.8.2: Head Loss

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

Example

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

- Answer: 3 feet + 1 foot + 1 foot + 1 foot + 1 foot + 0.5 feet + 0.5 feet = 8 feet

Summing all of the head loss values yields the answer.

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

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

Suction Lift and Suction Head

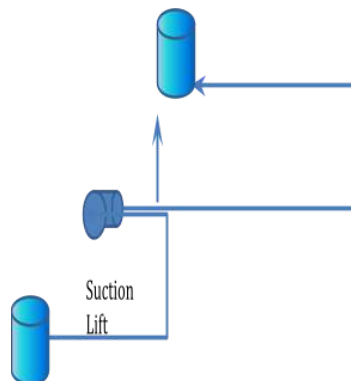


Figure 4.8.2.1

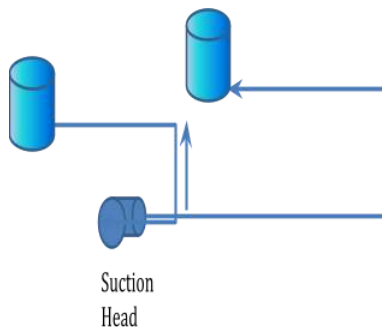


Figure 4.8.2.2

Exercises

Solve the following problems.

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

2. A booster pump receives water from a tank that is 40 feet above the pump and discharges to a tank that is 275 feet above the pump. What is the total head (TH)?
3. A well located at 750 feet above sea level has a below ground surface water depth of 38 ft and pumps to a water tank at an elevation of 1,030 ft above sea level. The water main from the well to the tank has a total head loss of 11 psi. What is the TH in feet?
4. A housing tract is located at an approximate average elevation of 2,225 ft above sea level and is served from a storage tank that is at 2,330 ft. The average head loss from the tank to the housing tract is 15.5 psi. What is the minimum water level in the tank to maintain a minimum pressure 40 psi?
5. A water utility has two different pressure zones (1 and 2.) The zone 1 Tank is 30 ft tall and sits at an elevation of 850 ft and the zone 2 Tank is 40 feet tall and sits at 1,061 ft. The booster pump from zone 1 to 2 sits at an elevation of 925 ft. The head loss is 19 psi. Tank 1 is half full and Tank 2 needs to be $\frac{3}{4}$ full. What is the TH?

4.8.2: Head Loss is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- **8.2: Head Loss** has no license indicated.

4.8.3: Flow Rate

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

- Flow Rates
 - cfs = cubic feet/second
 - gpm = gallons/minute
 - MGD = million gallons/day



Figure 4.8.3.1

Depending on the application, flow rates are expressed in these or potentially other units. For example, the flow rate from a well or booster pump is commonly expressed as gpm, whereas annual production might be expressed as acre-feet per year (AFY). However, when solving a problem for flow rate the common unit of expression is cfs. The reason for this is in part due to the measurement of unit area of the structure that the water is passing through (i.e., pipe, culvert, aqueduct, etc.) The areas for these structures are typically expressed as square feet (ft²). In addition, the speed (distance over time) at which the water is flowing is commonly expressed as feet per second. The flow rate formula and how the units are expressed are shown in the example below.

- Flow Rate = Area x Velocity
- Flow Rate (Q) = Area (A) x Velocity (V)
- $Q = A \times V$
- $Q \text{ (cubic feet/sec)} = \text{Area (ft}^2\text{)} \times \text{Velocity (feet/sec)}$

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

Example

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

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

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

- $1,500 \text{ gpm} \div 448.8 = 3.34 \text{ cfs}$

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

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

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

- $0.51 \text{ ft}^2 = 0.785 \times D^2$
- $D^2 = 0.51 \text{ ft} / 0.785$
- $D^2 = 0.66 \text{ ft}^2$

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

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

- $D = 0.81 \text{ ft}$

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

- $0.81 \text{ ft} \times 12 \text{ in} = 9.7 \text{ or } 10 \text{ inches}$

Exercises

Solve the following problems.

1. What is the flow rate in MGD of a 24" diameter pipe with a velocity of 3 fps?
2. What is the velocity through a box culvert that is 3 feet wide and 2 feet deep if the daily flow is 27 AF?
3. What is the area of a pipe that flows 1.5 MGD and has a velocity of 5 fps?
4. What is the diameter of a pipe that flows 2,500 gpm with a velocity of approximately 7 fps?
5. A 15-mile aqueduct flows 30,000 AFY at an average velocity of 0.45 fps. If the distance across the top is 13 feet and the depth is 8 feet, what is the distance across the bottom?

4.8.3: Flow Rate is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- **8.3: Flow Rate** has no license indicated.

SECTION OVERVIEW

4.9: Well Yield, Specific Capacity, and Drawdown

4.9.1: It's All Underground

This page titled [4.9: Well Yield, Specific Capacity, and Drawdown](#) is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by [Mike Alvord \(ZTC Textbooks\)](#).

4.9.1: It's All Underground

Well Yield

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

Specific Capacity

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

- Specific Capacity = gpm/ft

Drawdown

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

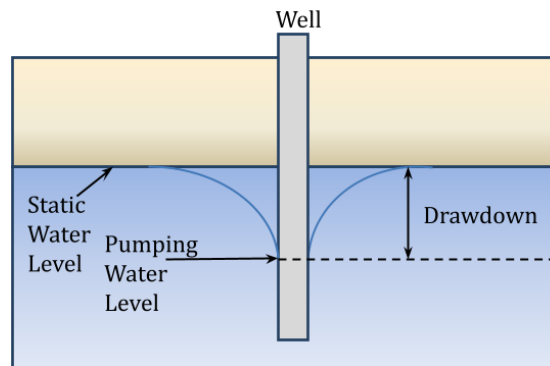


Figure 4.9.1.1

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

Examples

Calculating Drawdown

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

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

Calculating Specific Capacity

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

$$\text{Flow Rate} = 1,000 \text{ gpm}$$

$$\text{Drawdown} = 30 \text{ ft}$$

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

Exercises

Solve the following problems.

1. A well has a static water level of 23 ft bgs and a pumping level of 58 ft bgs. What is the drawdown?
2. A groundwater well has a base elevation of 1,125 ft above sea level. If the drawdown on this well is 44 ft and the pumping level is 80 ft bgs, what is the static water elevation above sea level?
3. A deep well has a static water level of 122 ft bgs. A drawdown has been calculated out to be 65 ft. What is the pumping level of the well?
4. A well has an hour meter attached to a water meter totalizer. After 3 hours of operation, the well produced 279,000 gallons. What is the well yield in gpm?
5. When a well was first constructed it was pumping 1,750 gpm. The efficiency of the well has dropped 35%. In addition, the drawdown has decreased by 15%. If the original drawdown was 42 ft what is the current specific capacity?
6. A well pumped 538 AF over a one year period averaging 10 hours of operation per day. For half the year the static water level was 25 ft bgs and half the year 42 ft bgs. The pumping level averaged 55 ft bgs for half the year and 68 ft bgs the other half. What was the average specific capacity for the year?
7. A well has a specific capacity of 42 gpm per foot. The well operates at a constant 1,500 gpm. What is the drawdown?
8. A well has a calculated specific capacity of 30 gpm per foot and operates at a flow rate of 1.08 MGD. If the static water level is 28 ft bgs, what is the pumping level?

4.9.1: It's All Underground is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- [9.1: It's All Underground](#) has no license indicated.

SECTION OVERVIEW

4.10: Horsepower and Efficiency

4.10.1: The Power of Water

4.10.2: Head Loss and Horsepower

4.10.3: Calculating Power Costs

This page titled [4.10: Horsepower and Efficiency](#) is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by [Mike Alvord \(ZTC Textbooks\)](#) .

4.10.1: The Power of Water

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

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

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

$$\text{Water hp} = \frac{(\text{flow rate in gallons per minute})(\text{total head in feet})}{3,960} \quad (4.10.1.1)$$

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

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

$$\text{Brake hp} = \frac{(\text{flow rate in gallons per minute})(\text{total head in feet})}{3,960} (\text{pump efficiency}) \quad (4.10.1.2)$$

$$\text{Motor hp} = \frac{(\text{flow rate in gallons per minute})(\text{total head in feet})}{3,960 (\text{pump efficiency})(\text{motor efficiency})} \quad (4.10.1.3)$$

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

- Pump Efficiency = 60%
- Motor Efficiency = 80%
- $0.6 \times 0.8 = 0.48$ or 48% efficient

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

Example 4.10.1.1

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

Solution

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

- $2.16 \text{ MGD} \div 1440 \text{ min/day} = 1,500 \text{ gpm}$
- $100 \text{ psi} \times 2.31 \text{ ft/psi} = 231 \text{ ft}$

Now, these numbers can be plugged into the hp formula (Equation 4.10.1.3).

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

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

$$\begin{aligned}\text{hp} &= \frac{(1,500 \text{ gpm})(231 \text{ ft})}{3,960} (0.65)(0.85) \\ &= 158 \text{ hp}\end{aligned}$$

Exercises

Calculate the required horsepower related questions.

1. What is the required water horsepower for 100 gpm and a total head pressure of 50 ft?
2. What is the water horsepower needed for a well that pumps 2,050 gpm against a pressure of 150 psi?
3. It has been determined that the wire-to-water efficiency at a pump station is 58%. If the pump station lifts 650 gpm to a tank 150 feet above, what is the motor horsepower needed?
4. What is the motor horsepower needed to pump 2,420 AF of water over a year with an average daily pumping operation of 12 hours? Assume the pump is pumping against 95 psi and has a pump efficiency of 70% and a motor efficiency of 80%.

4.10.1: The Power of Water is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- [10.1: The Power of Water](#) has no license indicated.

4.10.2: Head Loss and Horsepower

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

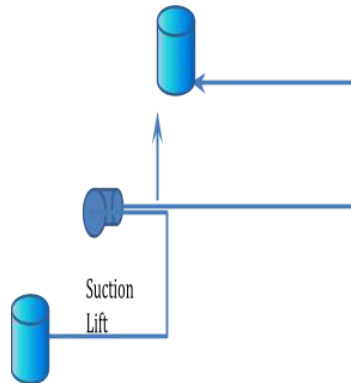


Figure 4.10.2.1

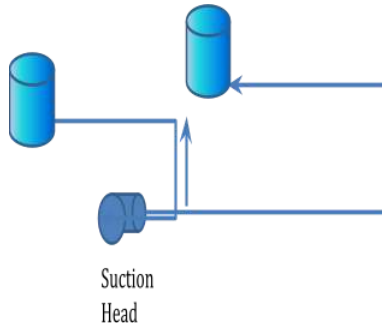


Figure 4.10.2.2

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

Exercises

Calculate the following horsepower related questions.

1. A well is pumping water from an aquifer with a water table 30 feet below ground surface (bgs) to a tank 150 feet above the well. If the well flows 1,000 gpm, what is the required horsepower? (Assume the wire-to-water efficiency is 68%)
2. A booster pump station is pumping water from Zone 1 at an elevation of 1,225 ft above sea level to Zone 2 which is at 1,445 ft above sea level. The pump station is located at an elevation of 1,175 ft above sea level. The pump was recently tested and the efficiencies for the pump and motor were 62% and 78% respectively. The losses through the piping and appurtenances equate to a total of 11 ft. If the pump flows 1,200 gpm, what is the required motor horsepower?
3. A well with pumps located 75 ft bgs pumps against a discharge head pressure of 125 psi to a tank located at an elevation 253 ft above the well. The well pumps at a rate of 1,050 gpm. What is the level of water in the tank and what is the required water horsepower? (Assume the wire-to-water efficiency is 55%)
4. A 200 hp booster pump is pulling water from a 32-foot tall tank that is 50 feet below the pump line. It is then pumping against a discharge head pressure of 112 psi. What is the flow rate in gpm? (Assume the wire-to-water efficiency is 65% and the tank is full)

4.10.2: Head Loss and Horsepower is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- 10.2: Head Loss and Horsepower has no license indicated.

4.10.3: Calculating Power Costs

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

$$1 \text{ horsepower} = 0.746 \text{ kilowatts of power}$$

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

Exercises

Solve the following problems.

1. A well flows an estimated 3,200 gpm against a discharge head pressure of 95 psi. What is the corresponding hp and kW-Hr if the pump has an efficiency of 70% and the motor 88%?
2. Based on the above question, how much would the electrical costs be if the rate is \$0.12 per kW-Hr and the pump runs for 10 hours a day?
3. A utility has 3 pumps that run at different flow rates and supply water to a 500,000-gallon storage tank. The TDH for the pumps is 210 ft. The utility needs to fill the tank daily and power costs are to be calculated at a rate of \$0.135 per kW-Hr. Complete the table below.

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

4. A well draws water from an aquifer that has an average water level of 150 ft bgs and pumps to a tank 225 ft above it. Friction loss to the tank is approximately 22 psi. If the well pumps at a rate of 2,300 gpm and has a wire-to-water efficiency of 62% how much will it cost to run this well 14 hours per day. Assume the electrical rate is \$0.13 per kW-Hr.
5. A utility manager is trying to determine which hp motor to purchase for a pump station. A 400 hp motor with a wire-to-water efficiency of 65% can pump 3,000 gpm. Similarly, a 250 hp motor with a wire-to-water efficiency of 75% can pump 2,050 gpm. With an electrical rate of \$0.155 per kW-Hr, how much would it cost to run each motor to achieve a daily flow of 2 MG? Which one is less expensive to run?
6. Approximately 224 kW of power are needed to run a certain booster pump. If the booster has a wire-to-water efficiency of 67.5% and is pumping against 135 psi of head pressure, what is the corresponding flow in gpm?
7. It costs \$88.77 in electricity to run a well for 7 hours a day. The well has a TDH of 100 psi and an overall efficiency of 58.3%. The cost per kW-Hr is \$0.17. What is the cost of the water per gallon?
8. Complete the table below based on the information provided.

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

4.10.3: Calculating Power Costs is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- [10.3: Calculating Power Costs](#) has no license indicated.

SECTION OVERVIEW

4.11: per Capital water Usage

4.11.1: How Much Water Do We Really Use?

This page titled [4.11: per Capital water Usage](#) is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by [Mike Alvord \(ZTC Textbooks\)](#) .

4.11.1: How Much Water Do We Really Use?

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

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

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

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

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

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

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

Exercises

Solve the following problems.

1. What is the average gpcd of a small community of 3,200 people that use approximately 500,000 gallons per day?
2. A water utility produced 15,000 AF of water last year that supplied a population of 50,000. What was the averaged gpcd for this community?
3. A water utility in northern California has an average gpcd of 155. If the total population of this community is 42,300, how much AF of water must this utility supply in one year?
4. A large water utility has 10 wells that can produce a combined flow of 15,500 gpm. The average gpcd for this community of 175,000 residents is 235. How many AF of water must this utility purchase per year to make up the supply needed for this community?
5. A small water system has one well that pumps 250 gpm. This well serves a population of 1,575 with an average gpcd of 195. How many hours per day must this well run to meet the demand?
6. What is the gpcd of a community with 1,250,000 people if the annual water used is 245,000 AF?
7. A water district has a goal of 145 gpcd and an annual water projection of 21,250 AF. What is the population that can be served?
8. A house of 4 people used 36 CCF of water in 31 days. What is their gpcd?
9. In question 8, what would the gpcd be if you took out 65% of the usage and classified it as outdoor usage?

4.11.1: How Much Water Do We Really Use? is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- 11.1: How Much Water Do We Really Use? has no license indicated.

SECTION OVERVIEW

4.12: Blending and Diluting

4.12.1: Is Dilution the Solution to Pollution?

4.12.2: Mixing and Diluting Solutions

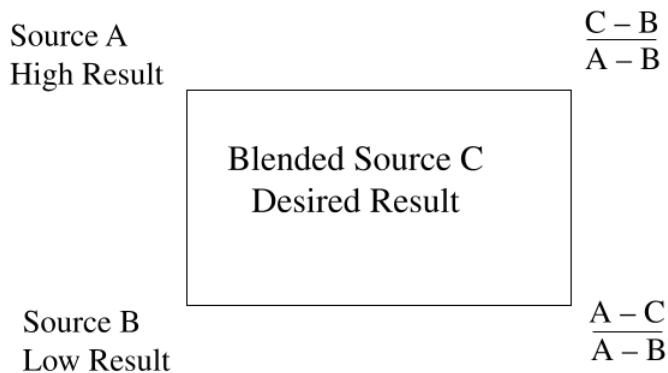
This page titled [4.12: Blending and Diluting](#) is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by [Mike Alvord \(ZTC Textbooks\)](#) .

4.12.1: Is Dilution the Solution to Pollution?

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

An acceptable blending plan may be for reducing manganese in a source that has exceeded the California Secondary Maximum Contaminant Level (MCL) of 0.05 mg/L. Manganese causes black water problems for customers at levels over the secondary MCL. Additionally, an approved blending plan may involve a Primary MCL for nitrate. Nitrates above the MCL of 45 mg/L as NO₃ can cause methemoglobinemia in infants under 6 months old. These are just two examples of blending plans.

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



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

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

Source A 10 ppm	Blended Source C 5 ppm	$\frac{5 - 2}{10 - 2} = 0.375$
Source B 2 ppm		$\frac{10 - 5}{10 - 2} = 0.625$

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

Source A 10 ppm	Blended Source C 5 ppm	$\frac{5 - 2}{10 - 2} = 0.375 \times 5,000 \text{ gpm} = 1,875 \text{ gpm}$
Source B 2 ppm		$\frac{10 - 5}{10 - 2} = 0.625 \times 5,000 \text{ gpm} = 3,125 \text{ gpm}$

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

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

Exercises

Solve the following blending problems.

1. A well has a nitrate level that exceeds the MCL of 45 mg/L. Over the last 3 sample results it has averaged 52 mg/L. A nearby well has a nitrate level of 32 mg/L. If both wells pump up to 2,275 gpm, how much flow is required from each well to achieve a nitrate level of 40 mg/L?
2. A well (A) has shown quarterly arsenic levels above the MCL over the last year, of 14 ug/L, 20 ug/L, 18 ug/L, and 16 ug/L. A utility wants to blend this well to a level of 8.0 ug/L with a well (B) that has a level of 4.5 ug/L. The total production needed from both of these wells is 3,575 gpm. How much can each well produce?
3. A well with a PCE level of 7.5 ug/L is supplying approximately 35% of total water demand. It is being blended with a well that has a PCE level of 3.25 ug/L. Will this blended supply meet the MCL for PCE of 5.0 ug/L?
4. Well A has a total dissolved solids (TDS) level of 850 mg/L. It is pumping 1,500 gpm which is 40% of the total production from two wells. The other well (B) blends with well A to achieve a TDS level of 375 mg/L. What is the TDS level for Well B?

5. Two wells need to achieve a daily flow of 3.24 MG and a total hardness level of 90 mg/L as calcium carbonate (CaCO_3 .) Well #1 has a total hardness level of 315 mg/L as CaCO_3 and Well #2 has a level of 58 mg/L as CaCO_3 . What is the gpm that each well must pump?
6. The State Health Department has requested a blending plan to lower levels of sulfate from a small water utility well. The well has a constant sulfate level of 525 mg/L. The utility needs to purchase the water to blend with the well. The purchased water has a sulfate level of 135 mg/L. They need to bring the sulfate levels down to 265 mg/L and supply a demand of 1.15 MGD. The purchased water costs \$550/AF. How much will the purchased water cost for the entire year?

4.12.1: Is Dilution the Solution to Pollution? is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- [12.1: Is Dilution the Solution to Pollution?](#) has no license indicated.

4.12.2: Mixing and Diluting Solutions

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

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

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

- $C_1V_1 = C_2V_2$
- $0.65 \times 250 \text{ mL} = C_2 \times 950 \text{ mL}$

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

- $162.5 / 950 = 0.17$ or 17%

This says if 250 mL of a 65% solution is diluted with 750 mL of water, the resulting concentration will be 17%.

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

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

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

4.12.2: Mixing and Diluting Solutions is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- [12.2: Mixing and Diluting Solutions](#) has no license indicated.

SECTION OVERVIEW

4.13: Supervisory control and data acquisition (SCADA) and the Use of mA

4.13.1: SCADA?

This page titled [4.13: Supervisory control and data acquisition \(SCADA\) and the Use of mA](#) is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by [Mike Alvord \(ZTC Textbooks\)](#).

4.13.1: SCADA?

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

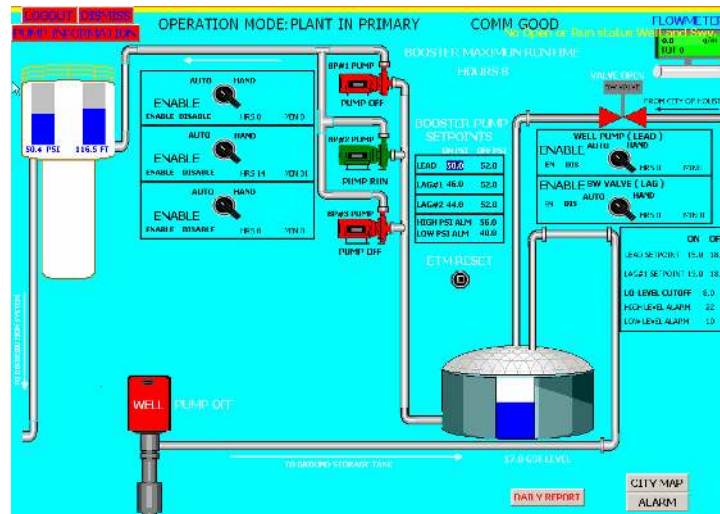


Figure 4.13.1.1

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

This first example is using the 4-20 mA signal to measure the level of water in a storage tank. The tank is 40 ft tall and has a diameter of 30 ft (not to scale).



Figure 4.13.1.2

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

the actual bottom to what is referred to as the “zero” level. In many questions, the “overflow” (actual top-level) and the “bottom” (actual location of the zero level) will be mentioned.

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

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

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

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

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

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

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

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

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

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

- $0.375 \times 40 \text{ ft} = 15 \text{ ft}$

Exercises

1. A 4-20 mA signal is being used to measure the water level in a water storage tank. The tank is 32 feet tall and the low-level signal is set at 0 feet and the high level at 32 feet. What is the level in the tank with a 15 mA reading?
2. A 75 ft tall water tank uses a 4-20 mA signal for calculating the water level. If the 4 mA level is set at 4 feet from the bottom and the 20 mA is set at 4 feet from the top, what is the level in the tank with a 10 mA reading?
3. A chlorine analyzer uses a 4-20 mA signal to monitor the chlorine residual. The 4-20 mA range is 0.5 mg/l – 3.5 mg/L respectively. If the reading is 6 mA, what is the corresponding residual in mg/L?
4. A water tank is 45 ft tall and has 32 ft of water in it. If the 4-20 mA set points are at 2 ft and 42 ft respectively, what is the mA reading?
5. A water tank with a 120 ft diameter is 32 ft tall. The 4-20 mA set points are 3 ft and 29 ft respectively. If the current level reading is 17 mA, how many gallons of water are in the tank?
6. A utility uses a 4-20 mA signal to determine the level in a well based on pressures. The set points are based on pressures in psi below ground surface (bgs). The 20 mA signal is set at 182 psi bgs and the 4 mA signal at 10 psi bgs. If the reading is 9 mA, what is the water level in feet?
7. A water utility uses a 4-20 mA signal to determine groundwater elevations in a well. The set points are based on actually elevations above the mean sea level (MSL). The ground surface elevation at this well is 1,180 ft and this is where the 4 mA signal is set. The 20 mA signal is set at 930 ft. What is the elevation and the feet bgs with a 18 mA reading?
8. A chemical injection system is monitored with a 4-20 mA signal. The reading is 14 mA at 2.45 mg/L and the 4 mA set point is at 0.4 mg/L. What is the 20 mA set point?

4.13.1: SCADA? is shared under a [CC BY 1.0](https://creativecommons.org/licenses/by/1.0/) license and was authored, remixed, and/or curated by LibreTexts.

- [13.1: SCADA?](#) has no license indicated.

SECTION OVERVIEW

4.14: Water Utility Management

4.14.1: Managing With Numbers

This page titled [4.14: Water Utility Management](#) is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by [Mike Alvord \(ZTC Textbooks\)](#) .

4.14.1: Managing With Numbers

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

Budgets

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

Operations and Maintenance (O&M)

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

Capital Improvement Projects (CIP)

In addition to the reoccurring O&M costs, utilities need to plan and budget for future growth and the replacement of old infrastructures, such as pipelines and storage structures. Depending on the age of the utility and the expected future growth, CIP investment can be quite extensive. Typically, utilities can recover the costs of new infrastructure from the developers that are planning to build within the utilities service area. However, as infrastructure ages, it eventually needs to be replaced. The timing and funding of these replacements is an important part of a manager's responsibility.

Debt

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

Revenues and Rates

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

Efficiencies

As part of the budgetary process, managers need to identify if and when certain pieces of equipment will fail. Calculating the return on investment and identifying when the cost of maintenance exceeds the cost to replace the asset is crucial. An example of this is

looking at the efficiencies of pumps and motors. Over time the efficiency decreases and the cost to operate and maintain the pump and motor increases. Another example is with pipelines. As pipes age more and more leaks occur. At some point in time, the cost to repair leaks becomes greater than the cost to replace the pipe.

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

Example Exercise

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

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

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

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

- Fixed Costs Reason:
- Variable Costs Reason:

Discussion

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

It is extremely important that utility managers have a general understanding of the concepts associated with utility management as well as the mathematical computations necessary to support the budgetary decisions being made. The exercises in Chapter 13 provide some basic examples of utility budgeting practices.

Exercises

1. A utility vehicle costs on average \$1,250 per year for maintenance. A replacement vehicle would cost \$35,000. The utility has a vehicle policy that states all vehicles with 150,000 miles or more shall be replaced. The policy also states that once maintenance costs exceed 60% of the cost of a replacement vehicle the vehicle shall be replaced. This particular vehicle averages 18,500 miles per year.
2. Will the vehicle cost more than 60% of a new vehicle cost before reaching 150,000 miles?
3. What is the total maintenance cost if the vehicle reaches 150,000 miles?
4. A pump that has been in operation for 25 years pumps a constant 600 gpm through 47 feet of dynamic head. The pump uses 6,071 kW-Hr of electricity per month at a cost of \$0.085 per kW-Hr. The old pump efficiency has dropped to 63%. Assuming a new pump that operates at 86% efficiency is available for \$9,370, how long would it take to pay for replacing the old pump?
5. A utility has annual operating expenses of \$3.4 million and a need for \$1.2 million in capital improvements. The current water rate is \$1.55 per CCF. Last year the utility sold 6550 AF of water and did not meet their capital budget need. How much does the utility need to raise rates in order to cover both the operational and capital requirements? (Round your answer to the nearest cent)
6. In the question above, how much would the utility need to raise their rates in order to meet their operational and capital requirements and add approximately \$100K to a reserve account?
7. A 250 hp well operates 9 hours a day and flows 2,050 gpm. The electricity cost is \$0.135 per kW-Hr. The well is also dosed with a 65% calcium hypochlorite tablet chlorinator to a dosage of 1.25 ppm. The tablets cost \$1.85 per pound. The labor burden associated with the well maintenance is \$75 per day. What is the total operating expense for this well in one year?
8. In the question above, what is the cost of water per acre-foot?
9. A small water company has a total operating budget of \$400,000. Salaries and benefits account for approximately 68% of this budget. The company has 8 employees. What is the average annual salary?
10. A water treatment manager has been asked to prepare a cost comparison between gas chlorine and a chlorine generation system using salt. Gas chlorine is \$2.35 per pound and salt is \$0.38 per pound. It takes approximately 5 pounds of salt to create 1 gallon of 0.8% chlorine with a specific gravity of 1.15. Assuming that the plant is dosing 15 MGD to a dosage of 2.25, what would be the annual cost of each? Which one is more cost-effective?

4.14.1: Managing With Numbers is shared under a [CC BY 1.0](#) license and was authored, remixed, and/or curated by LibreTexts.

- [14.1: Managing With Numbers](#) has no license indicated.

Index

A

aquifers

[2.10: Wells](#)

B

bored wells

[2.10: Wells](#)

brake horsepower

[4.10.1: The Power of Water](#)

butterfly valve

[2.6: Valves](#)

C

confined aquifer

[2.10: Wells](#)

contact times

[4.6.1: It's a Lag in Time](#)

D

detention time

[4.6.1: It's a Lag in Time](#)

dimensional analysis

[3.4.3: Dimensional Analysis](#)

drawdown

[4.9.1: It's All Underground](#)

E

exponent

[3.2.1: Powers and Roots](#)

G

GEMDAS

[3.2.2: Order of Operations](#)

H

head loss

[4.10.2: Head Loss and Horsepower](#)

head pressure

[4.10.2: Head Loss and Horsepower](#)

horsepower

[4.10.1: The Power of Water](#)

hydrants

[2.7: Hydrants](#)

L

lift pressure

[4.10.2: Head Loss and Horsepower](#)

M

maximum contaminant level (MCL)

[2.4: System Design](#)

motor horsepower

[4.10.1: The Power of Water](#)

O

order of operations

[3.2.2: Order of Operations](#)

P

Parts Per Hundred (percent)

[4.3.2: Parts Per Hundred vs. Parts Per Million](#)

Parts Per Million (ppm)

[4.3.2: Parts Per Hundred vs. Parts Per Million](#)

proportion

[3.5.2: Proportions](#)

Q

quadratic equations

[3.3.3: Solving Quadratic Equations of the Form- \(x-a\)²=c](#)

R

radicand

[3.2.1: Powers and Roots](#)

rounding

[3.4.2: Rounding](#)

S

Safe Drinking Water Act (SDWA)

[2.4: System Design](#)

scientific notation

[3.4.1: Scientific Notation](#)

shallow wells

[2.10: Wells](#)

specific capacity

[4.9.1: It's All Underground](#)

T

total head pressure

[4.10.2: Head Loss and Horsepower](#)

U

unconfined aquifer

[2.10: Wells](#)

V

volume

[4.2.1: The Shapes of Things](#)

W

water horsepower

[4.10.1: The Power of Water](#)

weir

[4.5.1: What's a Weir?](#)

Weir Overflow Rate (WOR)

[4.5.1: What's a Weir?](#)

well yield

[4.9.1: It's All Underground](#)

wet barrel hydrants

[2.7: Hydrants](#)

Glossary

Sample Word 1 | Sample Definition 1

Detailed Licensing

Pages in this book are re-mixes of open content from other books in the LibreTexts Library. Sometimes sections from several sources are used on the same page and there may be no unique open license. Where there is a conflict, the licensing may appear as *undeclared*. On any page, by toggling AutoAttribution on the Tools menu, you can display the detailed attribution on a paragraph level. Material from different books will be color coded and the source displayed by mousing over the paragraph.

Content in the Front and Back Matter, directories and similar can be uncopywriteable, being simple listings and these are also shown as *undeclared*.

Overview

Title: [WTRM 202: Beginning Water, Wastewater, Distribution Math](#)

Webpages: 132

All licenses found:

- [CC BY 1.0](#): 63.6% (84 pages)
- [CC BY 4.0](#): 28% (37 pages)
- [Undeclared](#): 8.3% (11 pages)

By Page

- [WTRM 202: Beginning Water, Wastewater, Distribution Math](#) - *Undeclared*
 - [Front Matter](#) - [CC BY 1.0](#)
 - [TitlePage](#) - [CC BY 1.0](#)
 - [InfoPage](#) - [CC BY 1.0](#)
 - [Table of Contents](#) - *Undeclared*
 - [Licensing](#) - [CC BY 1.0](#)
 - [1: Waterworks Mathematics \(Alvord and Blasberg\)](#) - [CC BY 1.0](#)
 - [00: Front Matter](#) - *Undeclared*
 - [Table of Contents](#) - *Undeclared*
 - [1.1: Mathematical Review- Fractions](#) - [CC BY 1.0](#)
 - [1.1.1: Understanding Fractions](#) - [CC BY 1.0](#)
 - [1.1.2: Reducing Fractions](#) - [CC BY 1.0](#)
 - [1.1.3: Why Fractions](#) - [CC BY 1.0](#)
 - [1.1.4: Multiplying Fractions](#) - [CC BY 1.0](#)
 - [1.1.5: Dividing Fractions](#) - [CC BY 1.0](#)
 - [1.2: Decimals](#) - [CC BY 1.0](#)
 - [1.2.1: Understanding Decimals](#) - [CC BY 1.0](#)
 - [1.2.2: Multiplying and Dividing Decimals](#) - [CC BY 1.0](#)
 - [1.2.3: Rounding](#) - [CC BY 1.0](#)
 - [1.3: Percentages](#) - [CC BY 1.0](#)
 - [1.3.1: Expressing Numbers as Percentages](#) - [CC BY 1.0](#)
 - [1.3.2: Word Problems](#) - [CC BY 1.0](#)
 - [1.4: Equations and Word Problems](#) - [CC BY 1.0](#)
 - [1.4.1: Solving Equations](#) - [CC BY 1.0](#)
 - [1.4.2: Ratios and Proportions](#) - [CC BY 1.0](#)
 - [1.5: Unit Dimensional Analysis](#) - [CC BY 1.0](#)
 - [1.5.1: Units](#) - [CC BY 1.0](#)
 - [1.6: Geometric Shapes](#) - [CC BY 1.0](#)
 - [1.6.1: Areas](#) - [CC BY 1.0](#)
 - [1.6.2: Volumes](#) - [CC BY 1.0](#)
 - [1.6.3: Circumference](#) - [CC BY 1.0](#)
 - [1.7: Water Hydraulics](#) - [CC BY 1.0](#)
 - [1.7.1: Pressure](#) - [CC BY 1.0](#)
 - [1.7.2: Force](#) - [CC BY 1.0](#)
 - [1.7.3: Flow Rate](#) - [CC BY 1.0](#)
 - [1.8: Chemical Dosage Analysis and Waste Water Treatment](#) - [CC BY 1.0](#)
 - [1.8.1: The "Pound Formula"](#) - [CC BY 1.0](#)
 - [1.8.2: Food to Microorganism Ratio](#) - [CC BY 1.0](#)
 - [1.8.3: Mean Cell Residence Time \(MCRT\)](#) - [CC BY 1.0](#)
 - [1.9: Water Treatment Mathematics](#) - [CC BY 1.0](#)
 - [1.9.1: Detention Time](#) - [CC BY 1.0](#)
 - [1.9.2: Weir Overflow Rate](#) - [CC BY 1.0](#)
 - [1.9.3: Filtration Rate](#) - [CC BY 1.0](#)
 - [1.10: Engineering and Construction](#) - [CC BY 1.0](#)
 - [1.10.1: Planning](#) - [CC BY 1.0](#)
 - [1.11: Using What You Learned and Preparing for Certification Exams](#) - [CC BY 1.0](#)
 - [1.11.1: Examples](#) - [CC BY 1.0](#)

- 2: Water Distribution Operator I (Alvord) - CC BY 4.0
 - 00: Front Matter - *Undeclared*
 - Table of Contents - *Undeclared*
 - 2.1: Introduction To The Operator Certification - CC BY 4.0
 - 2.2: Sources and Characteristics of Water - CC BY 4.0
 - 2.3: Regulations - CC BY 4.0
 - 2.4: System Design - CC BY 4.0
 - 2.5: Pipelines - CC BY 4.0
 - 2.6: Valves - CC BY 4.0
 - 2.7: Hydrants - CC BY 4.0
 - 2.8: Meter Services - CC BY 4.0
 - 2.9: Pumps - CC BY 4.0
 - 2.10: Wells - CC BY 4.0
- 3: Mathematics for Wastewater Management (Brooks) - CC BY 4.0
 - 00: Front Matter - *Undeclared*
 - Table of Contents - *Undeclared*
 - 3.1: Numbers, Decimals, and Fractions - CC BY 4.0
 - 3.1.1: The Set of Real Numbers - CC BY 4.0
 - 3.1.2: Mathematical Operations - CC BY 4.0
 - 3.2: Powers, Roots, Order of Operations, and Evaluating Expressions - CC BY 4.0
 - 3.2.1: Powers and Roots - CC BY 4.0
 - 3.2.2: Order of Operations - CC BY 4.0
 - 3.2.3: Evaluating Expressions - CC BY 4.0
 - 3.3: Solving Equations and Formulas - CC BY 4.0
 - 3.3.1: Addition, Subtraction, Multiplication, and Division Properties of Equality - CC BY 4.0
 - 3.3.2: Solving a Formula for a Variable (Rewriting a Formula) - CC BY 4.0
 - 3.3.3: Solving Quadratic Equations of the Form- $(x-a)^2=c$ - CC BY 4.0
 - 3.4: Scientific Notation, Rounding, Conversions, and Dimensional Analysis - CC BY 4.0
 - 3.4.1: Scientific Notation - CC BY 4.0
 - 3.4.2: Rounding - CC BY 4.0
 - 3.4.3: Dimensional Analysis - CC BY 4.0
 - 3.5: Ratios, Proportions, and Percentages - CC BY 4.0
 - 3.5.1: Ratios - CC BY 4.0
 - 3.5.2: Proportions - CC BY 4.0
 - 3.5.3: Percentages - CC BY 4.0
 - 3.6: Geometry - CC BY 4.0
 - 3.6.1: Definitions - CC BY 4.0
 - 3.6.2: Examples - CC BY 4.0
 - 3.7: Reading and Interpreting Graphs - CC BY 4.0
 - 3.7.1: Types of Graphs - CC BY 4.0
 - 3.7.2: Examples - CC BY 4.0
- 4: Advanced Water Mathematics (Alvord) - CC BY 1.0
 - 00: Front Matter - *Undeclared*
 - Table of Contents - *Undeclared*
 - 4.1: Unit Dimensional Analysis (UDA) - CC BY 1.0
 - 4.1.1: Applying the Math of UDA - CC BY 1.0
 - 4.2: Geometric Shapes - CC BY 1.0
 - 4.2.1: The Shapes of Things - CC BY 1.0
 - 4.2.2: Applying the Math of Geometric Shapes - CC BY 1.0
 - 4.3: Density and Specific Gravity - CC BY 1.0
 - 4.3.1: It's All About the Weight - CC BY 1.0
 - 4.3.2: Parts Per Hundred vs. Parts Per Million - CC BY 1.0
 - 4.4: Chemical Dosage Analysis - CC BY 1.0
 - 4.4.1: It's a Pound Formula! - CC BY 1.0
 - 4.5: Weir Overflow Rate - CC BY 1.0
 - 4.5.1: What's a Weir? - CC BY 1.0
 - 4.6: Water Treatment Math Detention Time - CC BY 1.0
 - 4.6.1: It's a Lag in Time - CC BY 1.0
 - 4.6.2: Filtration Rates - CC BY 1.0
 - 4.7: CT Calculations - CC BY 1.0
 - 4.7.1: How Much For How Long? - CC BY 1.0
 - 4.8: Pressure, Head Loss, and Flow - CC BY 1.0
 - 4.8.1: Are You At a Loss? - CC BY 1.0
 - 4.8.2: Head Loss - CC BY 1.0
 - 4.8.3: Flow Rate - CC BY 1.0
 - 4.9: Well Yield, Specific Capacity, and Drawdown - CC BY 1.0
 - 4.9.1: It's All Underground - CC BY 1.0
 - 4.10: Horsepower and Efficiency - CC BY 1.0
 - 4.10.1: The Power of Water - CC BY 1.0
 - 4.10.2: Head Loss and Horsepower - CC BY 1.0
 - 4.10.3: Calculating Power Costs - CC BY 1.0
 - 4.11: per Capital water Usage - CC BY 1.0
 - 4.11.1: How Much Water Do We Really Use? - CC BY 1.0
 - 4.12: Blending and Diluting - CC BY 1.0
 - 4.12.1: Is Dilution the Solution to Pollution? - CC BY 1.0
 - 4.12.2: Mixing and Diluting Solutions - CC BY 1.0

- 4.13: Supervisory control and data acquisition (SCADA) and the Use of mA - *CC BY 1.0*
 - 4.13.1: SCADA? - *CC BY 1.0*
- 4.14: Water Utility Management - *CC BY 1.0*
 - 4.14.1: Managing With Numbers - *CC BY 1.0*
- Back Matter - *CC BY 1.0*
 - Index - *CC BY 1.0*
 - Glossary - *CC BY 1.0*
 - Detailed Licensing - *CC BY 1.0*
 - Detailed Licensing - *Undeclared*

Detailed Licensing

Overview

Title: WTRM 202: Beginning Water, Wastewater, Distribution Math

Webpages: 132

All licenses found:

- [CC BY 1.0](#): 63.6% (84 pages)
- [CC BY 4.0](#): 28% (37 pages)
- [Undeclared](#): 8.3% (11 pages)

By Page

- [WTRM 202: Beginning Water, Wastewater, Distribution Math](#) - *Undeclared*
 - [Front Matter](#) - *CC BY 1.0*
 - [TitlePage](#) - *CC BY 1.0*
 - [InfoPage](#) - *CC BY 1.0*
 - [Table of Contents](#) - *Undeclared*
 - [Licensing](#) - *CC BY 1.0*
 - [1: Waterworks Mathematics \(Alvord and Blasberg\)](#) - *CC BY 1.0*
 - [00: Front Matter](#) - *Undeclared*
 - [Table of Contents](#) - *Undeclared*
 - [1.1: Mathematical Review- Fractions](#) - *CC BY 1.0*
 - [1.1.1: Understanding Fractions](#) - *CC BY 1.0*
 - [1.1.2: Reducing Fractions](#) - *CC BY 1.0*
 - [1.1.3: Why Fractions](#) - *CC BY 1.0*
 - [1.1.4: Multiplying Fractions](#) - *CC BY 1.0*
 - [1.1.5: Dividing Fractions](#) - *CC BY 1.0*
 - [1.2: Decimals](#) - *CC BY 1.0*
 - [1.2.1: Understanding Decimals](#) - *CC BY 1.0*
 - [1.2.2: Multiplying and Dividing Decimals](#) - *CC BY 1.0*
 - [1.2.3: Rounding](#) - *CC BY 1.0*
 - [1.3: Percentages](#) - *CC BY 1.0*
 - [1.3.1: Expressing Numbers as Percentages](#) - *CC BY 1.0*
 - [1.3.2: Word Problems](#) - *CC BY 1.0*
 - [1.4: Equations and Word Problems](#) - *CC BY 1.0*
 - [1.4.1: Solving Equations](#) - *CC BY 1.0*
 - [1.4.2: Ratios and Proportions](#) - *CC BY 1.0*
 - [1.5: Unit Dimensional Analysis](#) - *CC BY 1.0*
 - [1.5.1: Units](#) - *CC BY 1.0*
 - [1.6: Geometric Shapes](#) - *CC BY 1.0*
 - [1.6.1: Areas](#) - *CC BY 1.0*
 - [1.6.2: Volumes](#) - *CC BY 1.0*
 - [1.6.3: Circumference](#) - *CC BY 1.0*
 - [1.7: Water Hydraulics](#) - *CC BY 1.0*
 - [1.7.1: Pressure](#) - *CC BY 1.0*
 - [1.7.2: Force](#) - *CC BY 1.0*
 - [1.7.3: Flow Rate](#) - *CC BY 1.0*
 - [1.8: Chemical Dosage Analysis and Waste Water Treatment](#) - *CC BY 1.0*
 - [1.8.1: The "Pound Formula"](#) - *CC BY 1.0*
 - [1.8.2: Food to Microorganism Ratio](#) - *CC BY 1.0*
 - [1.8.3: Mean Cell Residence Time \(MCRT\)](#) - *CC BY 1.0*
 - [1.9: Water Treatment Mathematics](#) - *CC BY 1.0*
 - [1.9.1: Detention Time](#) - *CC BY 1.0*
 - [1.9.2: Weir Overflow Rate](#) - *CC BY 1.0*
 - [1.9.3: Filtration Rate](#) - *CC BY 1.0*
 - [1.10: Engineering and Construction](#) - *CC BY 1.0*
 - [1.10.1: Planning](#) - *CC BY 1.0*
 - [1.11: Using What You Learned and Preparing for Certification Exams](#) - *CC BY 1.0*
 - [1.11.1: Examples](#) - *CC BY 1.0*
- [2: Water Distribution Operator I \(Alvord\)](#) - *CC BY 4.0*
 - [00: Front Matter](#) - *Undeclared*
 - [Table of Contents](#) - *Undeclared*
 - [2.1: Introduction To The Operator Certification](#) - *CC BY 4.0*
 - [2.2: Sources and Characteristics of Water](#) - *CC BY 4.0*
 - [2.3: Regulations](#) - *CC BY 4.0*
 - [2.4: System Design](#) - *CC BY 4.0*
 - [2.5: Pipelines](#) - *CC BY 4.0*
 - [2.6: Valves](#) - *CC BY 4.0*
 - [2.7: Hydrants](#) - *CC BY 4.0*
 - [2.8: Meter Services](#) - *CC BY 4.0*
 - [2.9: Pumps](#) - *CC BY 4.0*

- 2.10: Wells - CC BY 4.0
- 3: Mathematics for Wastewater Management (Brooks) - CC BY 4.0
 - 00: Front Matter - *Undeclared*
 - Table of Contents - *Undeclared*
 - 3.1: Numbers, Decimals, and Fractions - CC BY 4.0
 - 3.1.1: The Set of Real Numbers - CC BY 4.0
 - 3.1.2: Mathematical Operations - CC BY 4.0
 - 3.2: Powers, Roots, Order of Operations, and Evaluating Expressions - CC BY 4.0
 - 3.2.1: Powers and Roots - CC BY 4.0
 - 3.2.2: Order of Operations - CC BY 4.0
 - 3.2.3: Evaluating Expressions - CC BY 4.0
 - 3.3: Solving Equations and Formulas - CC BY 4.0
 - 3.3.1: Addition, Subtraction, Multiplication, and Division Properties of Equality - CC BY 4.0
 - 3.3.2: Solving a Formula for a Variable (Rewriting a Formula) - CC BY 4.0
 - 3.3.3: Solving Quadratic Equations of the Form- $(x-a)^2=c$ - CC BY 4.0
 - 3.4: Scientific Notation, Rounding, Conversions, and Dimensional Analysis - CC BY 4.0
 - 3.4.1: Scientific Notation - CC BY 4.0
 - 3.4.2: Rounding - CC BY 4.0
 - 3.4.3: Dimensional Analysis - CC BY 4.0
 - 3.5: Ratios, Proportions, and Percentages - CC BY 4.0
 - 3.5.1: Ratios - CC BY 4.0
 - 3.5.2: Proportions - CC BY 4.0
 - 3.5.3: Percentages - CC BY 4.0
 - 3.6: Geometry - CC BY 4.0
 - 3.6.1: Definitions - CC BY 4.0
 - 3.6.2: Examples - CC BY 4.0
 - 3.7: Reading and Interpreting Graphs - CC BY 4.0
 - 3.7.1: Types of Graphs - CC BY 4.0
 - 3.7.2: Examples - CC BY 4.0
- 4: Advanced Water Mathematics (Alvord) - CC BY 1.0
 - 00: Front Matter - *Undeclared*
 - Table of Contents - *Undeclared*
 - 4.1: Unit Dimensional Analysis (UDA) - CC BY 1.0
 - 4.1.1: Applying the Math of UDA - CC BY 1.0
 - 4.2: Geometric Shapes - CC BY 1.0
 - 4.2.1: The Shapes of Things - CC BY 1.0
 - 4.2.2: Applying the Math of Geometric Shapes - CC BY 1.0
 - 4.3: Density and Specific Gravity - CC BY 1.0
 - 4.3.1: It's All About the Weight - CC BY 1.0
 - 4.3.2: Parts Per Hundred vs. Parts Per Million - CC BY 1.0
 - 4.4: Chemical Dosage Analysis - CC BY 1.0
 - 4.4.1: It's a Pound Formula! - CC BY 1.0
 - 4.5: Weir Overflow Rate - CC BY 1.0
 - 4.5.1: What's a Weir? - CC BY 1.0
 - 4.6: Water Treatment Math Detention Time - CC BY 1.0
 - 4.6.1: It's a Lag in Time - CC BY 1.0
 - 4.6.2: Filtration Rates - CC BY 1.0
 - 4.7: CT Calculations - CC BY 1.0
 - 4.7.1: How Much For How Long? - CC BY 1.0
 - 4.8: Pressure, Head Loss, and Flow - CC BY 1.0
 - 4.8.1: Are You At a Loss? - CC BY 1.0
 - 4.8.2: Head Loss - CC BY 1.0
 - 4.8.3: Flow Rate - CC BY 1.0
 - 4.9: Well Yield, Specific Capacity, and Drawdown - CC BY 1.0
 - 4.9.1: It's All Underground - CC BY 1.0
 - 4.10: Horsepower and Efficiency - CC BY 1.0
 - 4.10.1: The Power of Water - CC BY 1.0
 - 4.10.2: Head Loss and Horsepower - CC BY 1.0
 - 4.10.3: Calculating Power Costs - CC BY 1.0
 - 4.11: per Capital water Usage - CC BY 1.0
 - 4.11.1: How Much Water Do We Really Use? - CC BY 1.0
 - 4.12: Blending and Diluting - CC BY 1.0
 - 4.12.1: Is Dilution the Solution to Pollution? - CC BY 1.0
 - 4.12.2: Mixing and Diluting Solutions - CC BY 1.0
 - 4.13: Supervisory control and data acquisition (SCADA) and the Use of mA - CC BY 1.0
 - 4.13.1: SCADA? - CC BY 1.0
 - 4.14: Water Utility Management - CC BY 1.0
 - 4.14.1: Managing With Numbers - CC BY 1.0
- Back Matter - CC BY 1.0
 - Index - CC BY 1.0
 - Glossary - CC BY 1.0
 - Detailed Licensing - CC BY 1.0
 - Detailed Licensing - *Undeclared*