GROUND WATER AND DISTRIBUTION (NWTC)

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TABLE OF CONTENTS

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CHAPTER OVERVIEW

1: Groundwater Sources

1.1: Water Resources and the Origin of Contaminants

Learning Objectives

After reading this section, you should be able to:

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

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

Water Sources

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

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

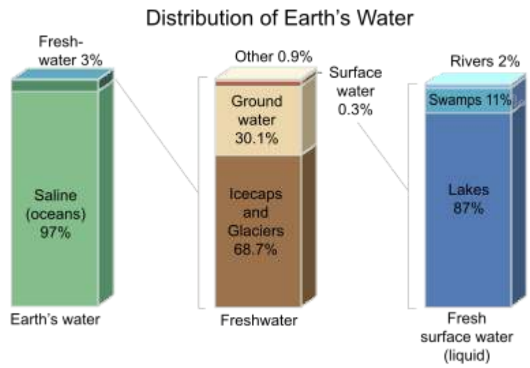


Figure 1.1.1: Distribution of Earth's Water.

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

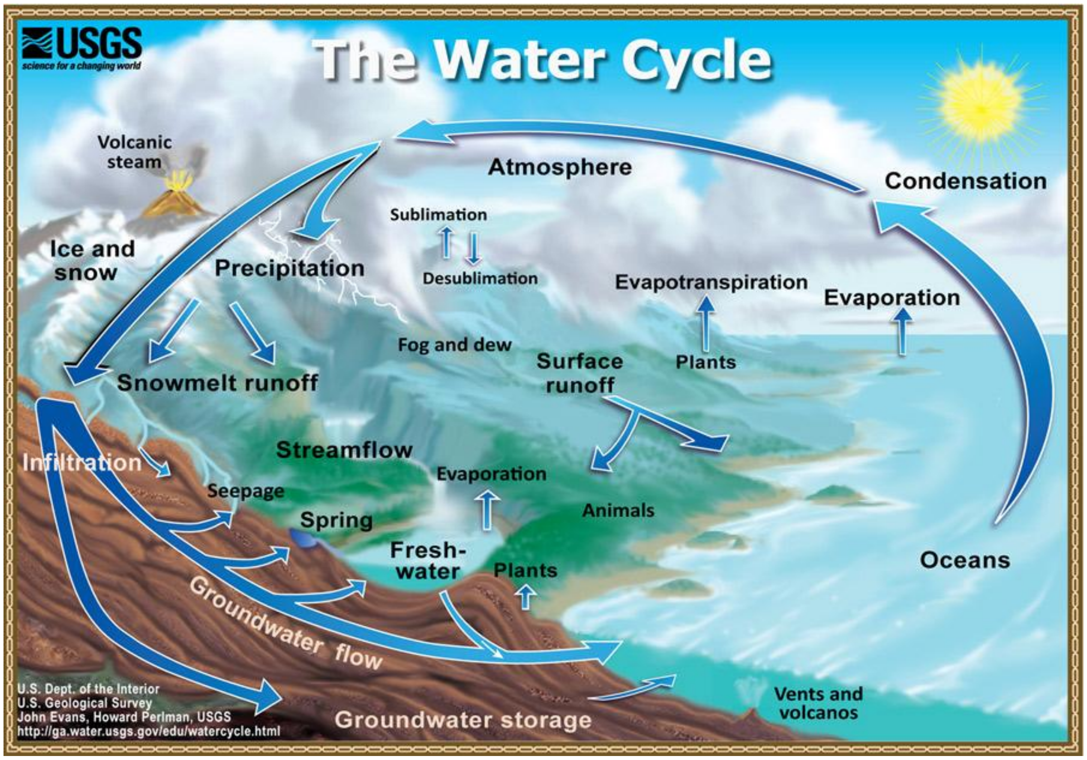


Figure 1.1.2: Water Hydrologic Cycle

Classifications of Contaminants

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

Pin It! Misconception Alert

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

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

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

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

Pin It! Misconception Alert

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

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

Key Terms

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

Review Questions

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

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

Chapter Quiz

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

4. sun

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

1.2: Source Water Quality

Learning Objectives

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

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

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

The Hydrologic Cycle

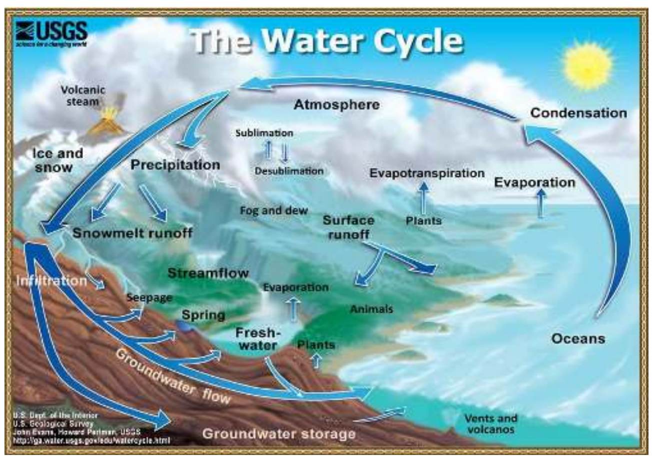


Figure 1.2.1: The Water Cycle by the USGS is in the public domain

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

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

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

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

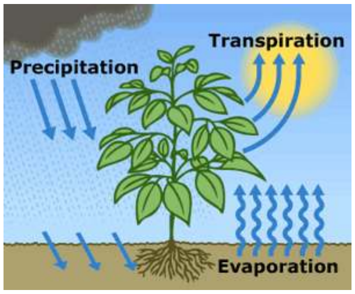


Figure 1.2.2: Water Cycle Image Source by the USGS is in the public domain - Evapotranspiration is the sum of evaporation from the land surface plus transpiration from plants. Precipitation is the source of all water

Groundwater

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

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

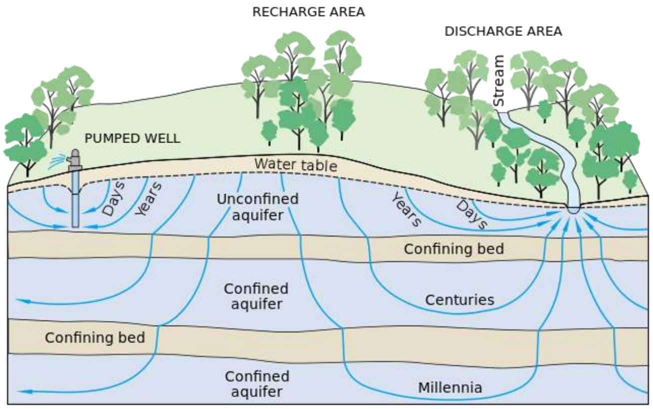


Figure 1.2.3: Groundwater Image Source by the USGS is in the public domain

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

Wells

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

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

Specific Capacity Calculation

$$\text{Specific capacity} = \text{Flow (GPM)} \div \text{Drawdown (ft)} \tag{1.2.1}$$

Example 1.2.1

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

Solution

This is a direct application of Equation 1.2.1

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

Surface Water

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

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

Natural Watercourses

Key Terms

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

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

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

Figure 1.2.4: Image of the Colorado River by Paul Hermans is licensed under CC BY-SA 3.0

Figure 1.2.5: Santa Clara River Map by Shannon1 is in the public domain

Lakes

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

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

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

Figure 1.2.6: Image of Castaic Lake by Rehman is in the public domain

Introduction to Water Math

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

Table 1.1: Units and Conversion Factors

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

Working with Fractions

NumeratorDenominator

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

Rounding

Rounding the number 324.179

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

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

Unit Dimensional Analysis

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

Example 1

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

48 inches11 foot12 inches=4 ft1

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

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

Example 2

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

22.44 gallons11 ft^{3}7.48 gallons=3 ft^{3}1

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

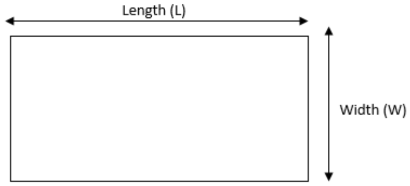
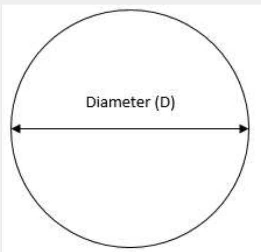
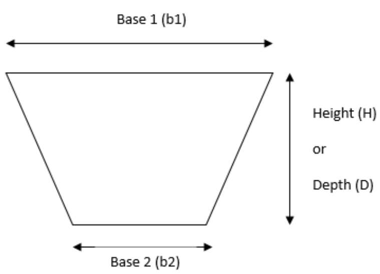
Example 3

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

300ft317.48 gal1ft3=2,244 gallons

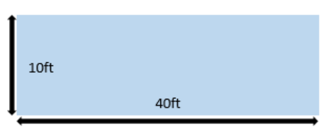
Area

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

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

Example 1

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

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

Example 2

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

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

Area = 3.14 x 50 x 50

Area = 7,850 ft^2

Equation #2 Area= .785 x d^2

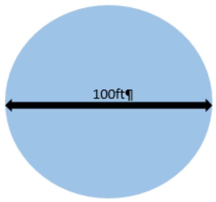
Area = .785 x 100 x 100

Area = 7,850 ft^2

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

Example 3

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

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

Chapter Review

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

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

Math Questions

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

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

3. 45 Bags
4. 48 Bags

1.3: Sources and Characteristics of Water

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

Student Learning Outcomes

After reading this chapter, you should be able to:

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

Hydrologic Water Cycle

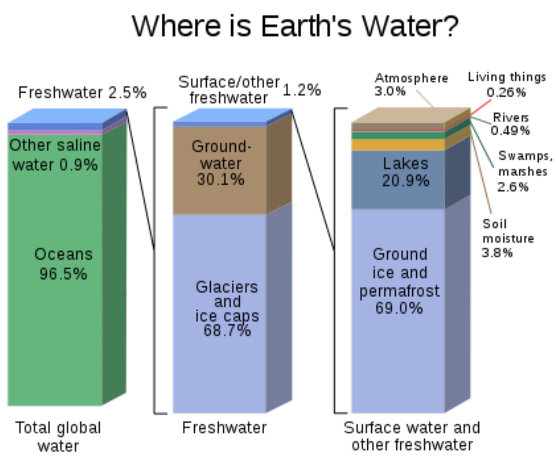


Figure 1.3.1: Water Location Image Source by the USGS is in the public domain

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

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

The image below (courtesy of the United States Geological Survey - USGS) shows a lot of detail regarding the hydrologic cycle. First, try to focus on the three phases we just discussed (liquid, gas, and solid). Precipitation is the liquid state, ice and snow the solid state, and evaporation represents the gas or vapor state. As you can see from this diagram, it is a little more complicated, but water passes through these three phases (states) in a continuous movement on, above, and below the surface of the earth. There are three (3) other terms you should become familiar with in this process. The terms are evapotranspiration, infiltration, and sublimation.

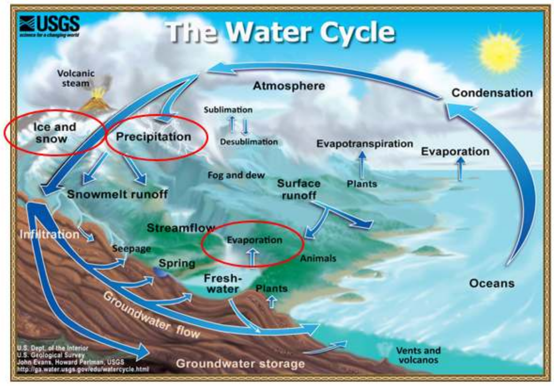


Figure 1.3.2: Water Cycle Image Source by the USGS is in the public domain

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

Water Sources

Surface Water

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

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

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

Groundwater

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

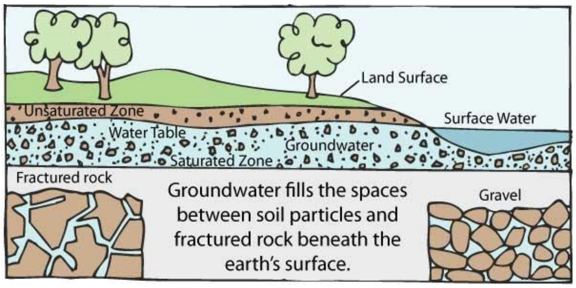


Figure 1.3.3: This material was reproduced from groundwater.org with the permission of The Groundwater Foundation. © The Groundwater Foundation. All Rights Reserved.

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

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

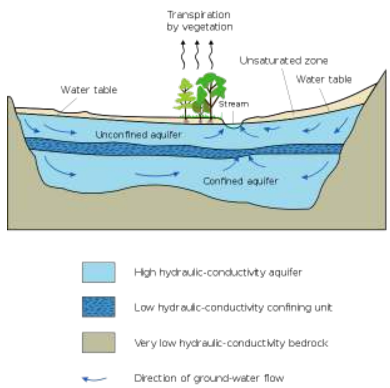


Figure 1.3.4: Groundwater Image Source by Hans Hillewaert is licensed under CC BY-SA 3.0

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

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

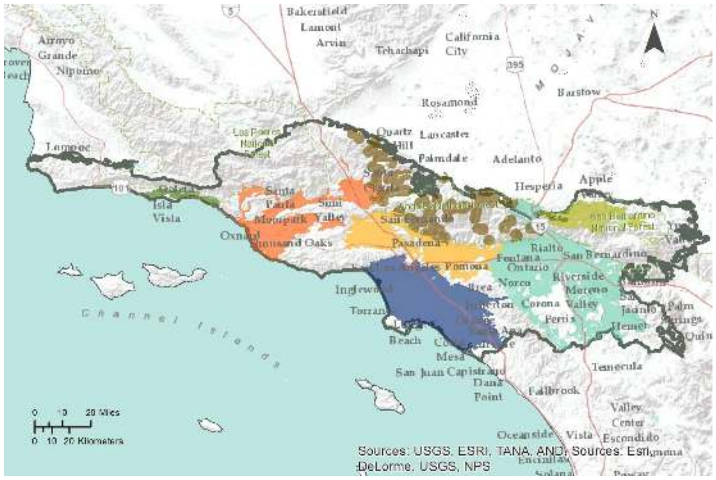


Figure 1.3.5.1: Map by the USGS is in the public domain

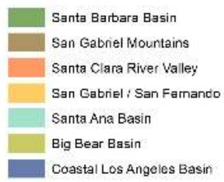


Figure 1.3.5.2: The Transverse Ranges and Selected Peninsular Ranges Province consists of the following Study Units

Recycled Water

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

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

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

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

Water Characteristics

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

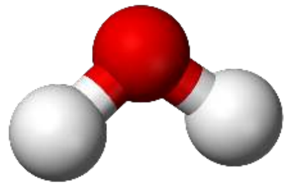


Figure 1.3.6: Water-3D-balls by Benjah-bmm27 is in the public domain

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

Figure 1.3.7: Gerris by webrunner is licensed under CC BY-SA 3.0

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

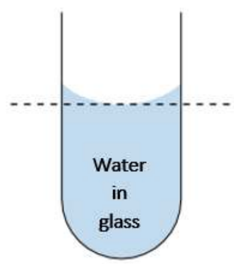


Figure 1.3.8: Water in Glass Image Source by Jleedev is licensed under CC BY-SA 3.0 (image modified by COC OER)

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

Physical Characteristics

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

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

The final physical property of water we will discuss in this text is temperature. As the temperature of water changes, the physical nature of water also changes. For example, as water approaches 0°C it changes form from a liquid to a solid. Conversely, as water approaches 100°C, it starts to boil and transitions from a liquid to a gas.

Sample Questions

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

2: Wells

Student Learning Outcomes

After reading this chapter, you should be able to:

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

Groundwater Sources of Supply

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

Aquifers

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

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

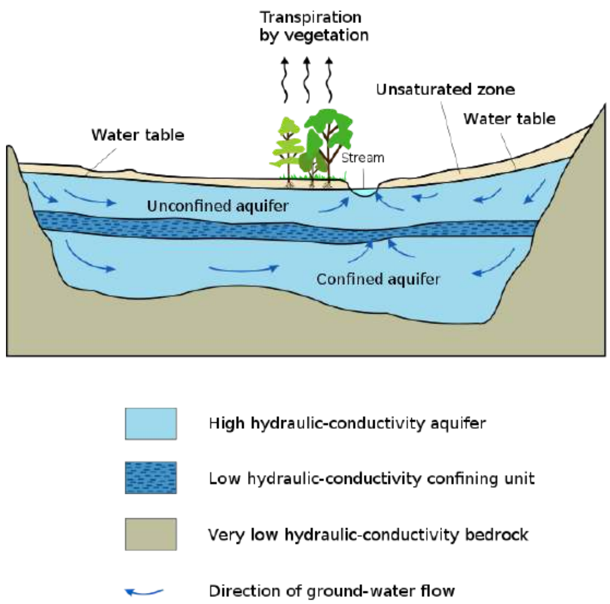


Figure 2.1: Image by the USGS is in the public domain

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

Wells

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

Figure 2.2: Image by Didiervberghe is in the public domain

Figure 2.3: Image Source by SuSanA Secretariat is licensed under CC BY 2.0

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

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

Well Components

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

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

Well Casing Vent

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

Gravel Tube

When a well is drilled, a pipe is lowered into the ground. Water enters into this pipe from the surrounding soil. We want water to enter the well, but we do not want the surrounding soil (sand) to enter the well. Gravel is used as a barrier between the surrounding soil outside of the casing and the water entering the casing. A gravel tube is installed to monitor the level of gravel within the well and to add additional gravel as necessary.

Sounding Tube

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

Pump Pedestal

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

Pump Motor Base

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

Sampling Taps

Drain Line (Discharge to waste)

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

Casing

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

Conductor casing

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

Annular seal

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

Intake section

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

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

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

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

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

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

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

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

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

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

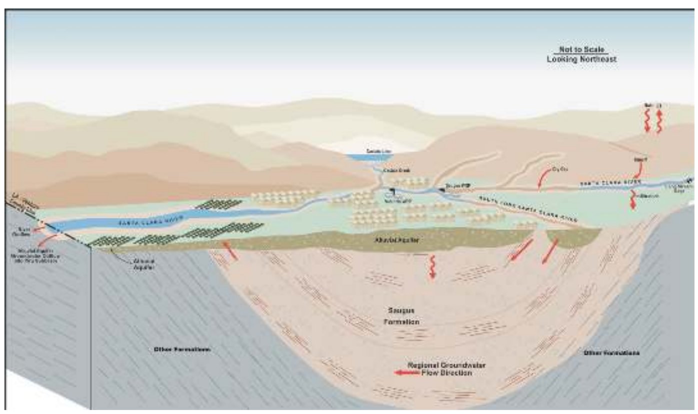


Figure 2.4: Source: Adapted by LACSD from the Task 2A - Conceptual Model Development East and Piru Subbasins Final Report by CH2M HILL 2006

Well Drilling

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

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

Cable Tool Method

The cable tool method of drilling wells is also referred to as the "percussion" method. This method involves the lifting and dropping of a heavy string of drilling tools into the borehole. The cable tools can weigh in excess of one (1) ton and the drill bit breaks or crushes consolidated rock into smaller and smaller fragments. In unconsolidated rock the bit loosens and breaks apart the material. The reciprocating action of the tools mixes the crushed and loosened materials with water to form a slurry at the bottom of the borehole. The slurry needs to be removed and is done so with the use of a sand pump or bailer. The cable tool drilling equipment consists of five (5) components; drill bit, drill stem, drilling jars, swivel socket, and cable.

California Stovepipe

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

Direct Rotary

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

Reverse Circulation Rotary

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

Air Rotary

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

Shallow Wells

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

Here is an animation of a well being constructed.

Well Pumps

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

Suction Head, Suction Lift, and Discharge Head

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

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

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

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

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

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

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

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

- 1 psi = 2.31 feet (head)

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

- 100 psi12.31 feet1 psi=231 feet

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

Measuring Groundwater Levels

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

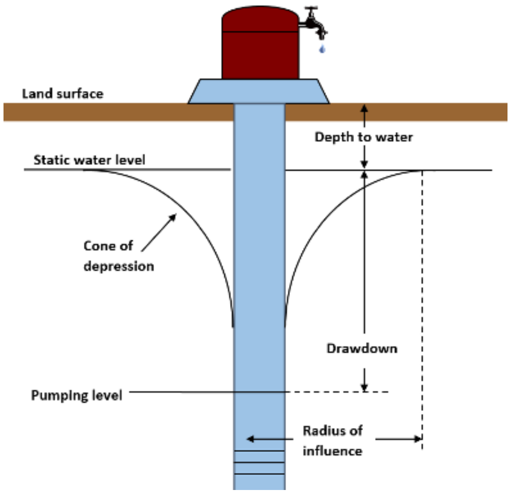


Figure 2.5: Image by COC OER is licensed under CC BY 4.0

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

Sample Questions

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

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

3: Water Treatment Overview

> **Learning Objectives**
>
> After reading this section, you should be able to:
>
> - Describe water quality characteristics
> - Describe disinfection processes
> - Describe the classes of water quality
> - Explain water quality characteristics

Water Quality Characteristics

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

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

Factors Influencing Disinfection

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

pH

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

Temperature

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

Turbidity

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

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

Organic Matter

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

Inorganic Matter

Inorganic compounds found in residual silts or a compound such as ammonia (NH3) in water will reduce the amount of disinfectant.

Reducing Agents

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

Microorganisms

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

Removal Processes

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

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

Disinfection Process

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

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

Ultraviolet Rays

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

Heat

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

Chemical Disinfection

Iodine

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

Bromine

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

Ozone

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

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

Chlorine

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

Disinfection Action

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

Chlorine Reactions in Water

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

These reactions are reversible and pH dependent.

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

Reactions with Substances in Water

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

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

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

Chloramination

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

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

Hypochlorite

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

Chlorine Dioxide

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

UV Disinfection and Treatment of Water

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

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

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

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

The type of unit depends on the situation for use, source of water, and water quality. Transmitted UV light dosage is affected by water clarity. Water treatment devices are dependent on the quality of the raw water. When turbidity is 5 NTU or greater and/or total suspended solids are greater than 10 ppm, pre-filtration of the water is highly recommended. Normally, it is advisable to install a 5 to 20 micron filter prior to a UV disinfection system.

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

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

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

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

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

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

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

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

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

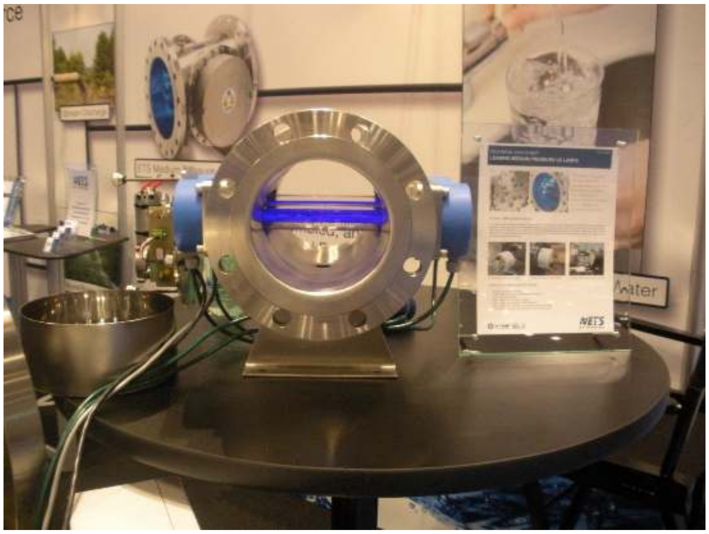


Figure 3.1: UV light used for disinfection in water treatment.

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

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

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

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

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

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

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

Ozone

Ozone is one of the most powerful water treatment compounds available to system managers today. It is a technology that has been in continual commercial use for over 100 years and has distinct properties that allow disinfection of even heavily compromised water streams. With the 1996 reauthorization of the Safe Drinking Water Act, ozone was named as among the best available technologies for water system compliance with National Primary Drinking Water Regulations as overseen by the US Environmental Protection Agency.

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

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

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

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

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

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

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

The five basic components of an ozone system include:

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

Moisture in the feed gas causes two operating problems:

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

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

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

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

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

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

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

Key Terms

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

Review Questions

1. **List the factors that affect chlorination of drinking water?**

2. **Describe disinfection as a process in drinking water treatment.**

3. **What is the purpose of chloramination in drinking water?**

4. **What is ozonation of drinking water?**

5. **How does UV light effect microorganisms?**

6. **Describe the primary reason that chlorine may not be used for drinking water disinfection at a particular drinking water facility.**

Chapter Quiz

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

6. ______ is the strongest oxidant and strongest disinfectant available for potable water treatment. This unique material can be utilized for specific water treatment applications, including disinfection, taste and odor control, color removal, iron and manganese oxidation, hydrogen sulfide removal, nitrite and cyanide destruction, oxidation of organics such as phenols, pesticides, and some detergents, algae destruction and removal, and as a coagulant aid.
   1. Ozone
   2. Chloramination
   3. Ultraviolet light
   4. Chlorine dioxide
7. A major problem with disinfection using _____ is that bacterial regrowth can occur downstream of the application site in the distribution.
   1. Ozone
   2. Chloramination
   3. Ultraviolet light
   4. b and c are correct
8. An alternative used by many water agencies to manage the formation of DBP’s would be ______ disinfection.
   1. Ozone
   2. Chloramination
   3. Ultraviolet light
   4. Chlorine dioxide
9. _______ is a critical process for non-reverse osmosis purification. It is usually coupled with biologic activated carbon filtration. The process reduces TOC and trace chemical pollutants, removes protozoans, kills viruses, and is a flocculation aid. It is an oxidation process used as a disinfection and oxidant prior to biologic activated carbon filtration.
   1. Ozone
   2. Chloramination
   3. Ultraviolet light
   4. Chlorine dioxide
10. Which of the listed factors does not have an influence on the disinfection of water with chlorine?
    1. pH,
    2. Reducing agents
    3. Hardness
    4. Temperature

CHAPTER OVERVIEW

4: Distribution System Design

4.1: System Design

Student Learning Outcomes

After reading this chapter, you should be able to:

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

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

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

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

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

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

Water Availability

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

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

Water Reliability

Accessing water from different sources and locations, such as in the case of Los Angeles, allowed for cities to grow at a rapid rate. In the early 1900s, William Mulholland realized the local groundwater serving the city of Los Angeles would not sustain the growing population and discovered another source of supply to the north. In this case, the Owens Valley not only provided an additional supply (availability) for Los Angeles, it also increased the supply reliability for the region. Multiple supplies of water increase reliability. For example, if an area relies on a surface water supply as their main source and there is not enough precipitation one year to sustain the surface supply, a local groundwater system can supplement the demand.

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

Water Quality

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

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

Location

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

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

Local, State, and Federal Requirements

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

At a minimum, all public water utilities must meet federal drinking water quality regulations. These regulations however, can vary from state to state. State drinking water quality regulations must be at least as strict as the federal standards, but they can be more stringent. An example of this is with the constituent chromium. There are several valance levels of chromium, with chromium VI being the most common. However, the federal **Safe Drinking Water Act (SDWA)** and California (SDWA) have a **maximum contaminant level (MCL)** for "total" chromium. This is the maximum level of all valances of chromium allowed in drinking water. In the federal SDWA, the MCL for total chromium is 100 micrograms per liter (ug/L) and in California, the level is 50 ug/L. This is an example where the state water quality regulation is more stringent than the federal requirement.

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

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

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

Distribution System Layout

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

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

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

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

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

Distribution Design Configurations

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

Arterial Loop System

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

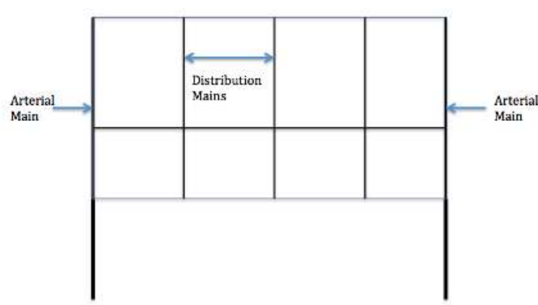


Figure 4.1.1: Arterial Loop Distribution System by Mike Alvord is licensed under CC BY 4.0

Grid System

A grid system is one of the more desirable distribution system layouts. They can provide water to all customers from multiple areas. This configuration allows water to circulate throughout the entire system providing better water quality, pressures, and flow rates. Another positive benefit to a grid system is the ability to limit the number of customers who are out of water during outages from things such as water main breaks. The main difference between an arterial loop and a simple grid system is the grid system shown below is typically fed by a single transmission and/or arterial main.

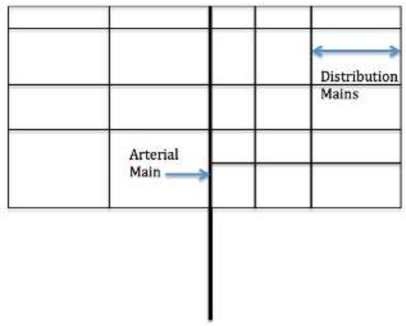


Figure 4.1.2: Grid System by Mike Alvord is licensed under CC BY 4.0

Tree System

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

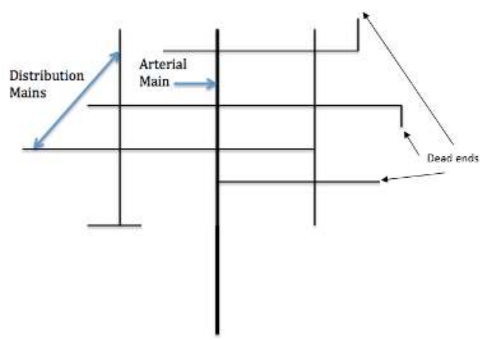


Figure 4.1.3: Tree System by Mike Alvord is licensed under CC BY 4.0

Appurtenances

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

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

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

Figure 4.1.4: Fire Hydrant Image Source by the Anderson Air Force Base is in the public domain

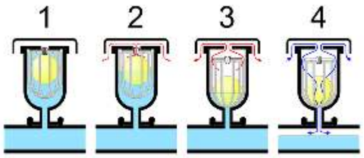


Figure 4.1.5: Air Valve Image Source by Shigeru23 is licensed under CC BY-SA 3.0

Figure 4.1.6: Elbow pipe fitting – Image by Cschirp is licensed under CC BY-SA 3.0

Figure 4.1.7: Downtown Charlottesville Fire Hydrant by Ben Schumin is licensed under CC BY-SA 2.5

Water System Demands

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

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

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

Fire Flow Demands

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

Network Analysis

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

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

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

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

Another tool engineers use to determine the various parameters of a water distribution system is a hydraulic water model. Water models can help determine expected flows and pressures throughout a distribution system network and can sometimes accurately mirror what is occurring in the distribution system. While these models can be accurate in predicting pressures and flows, it is also helpful to calibrate these computer models with actual field data. Pressure recorders can be placed throughout a distribution system on things such as fire hydrants to measure and record the pressure in a distribution system over a period of time. Some pumping equipment can also be equipped with devices to measure the pressure on the suction and discharge side of a pump.

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

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

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

Figure 4.1.8: Pipe Rupture Image Source by Los Angeles Fire Department is licensed under CC BY-ND 2.0

Figure 4.1.9: Image by Mike Alvord is licensed under CC BY 4.0

Mapping (Plans)

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

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

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

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

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

Sample Questions

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

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

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

4.2: Water Storage

Student Learning Outcomes

After reading this chapter, you should be able to:

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

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

Why Water Storage Is Needed

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

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

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

Water Storage and Water Quality

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

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

What Type and Size of Storage Is Needed?

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

Several terms related to water storage should be understood.

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

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

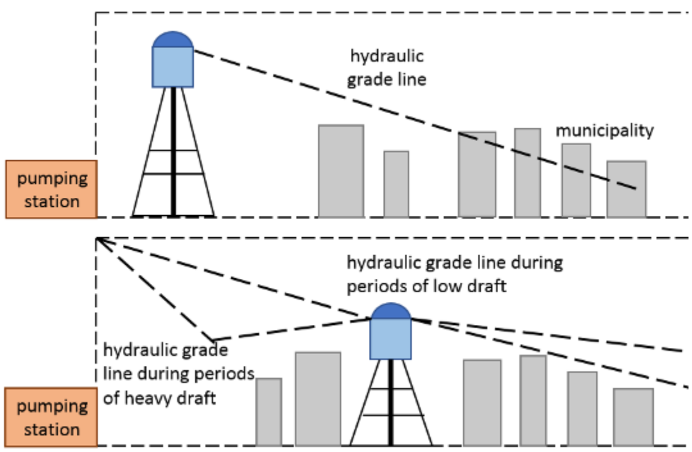


Figure 4.2.1: Images by COC OER is licensed under CC BY

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

Types of Water Storage Structures

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

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

Figure 4.2.2: Image by McGhiever is licensed under CC BY-SA 4.0

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

Figure 4.2.3: Image by Necraig is licensed under CC BY-SA 3.0

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

Figure 4.2.4: Image Source by the U.S. Air Force is in the public domain

Components of Elevated and Above Ground Storage Tanks

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

Inlet and Outlet Pipes

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

Overflow Pipe

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

Drain Connection

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

Monitoring Devices

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

Valves

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

Vents

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

Access Hatches

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

Ladders

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

Cathodic Protection

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

Tank Coatings

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

Operation and Maintenance

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

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

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

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

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

Sample Questions

1. An altitude valve is used to ___________.

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

2. Water storage reservoirs should be completely inspected?

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

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

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

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

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

5. It is recommended that storage tanks have ___________.

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

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 5.1: Pipeline 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.

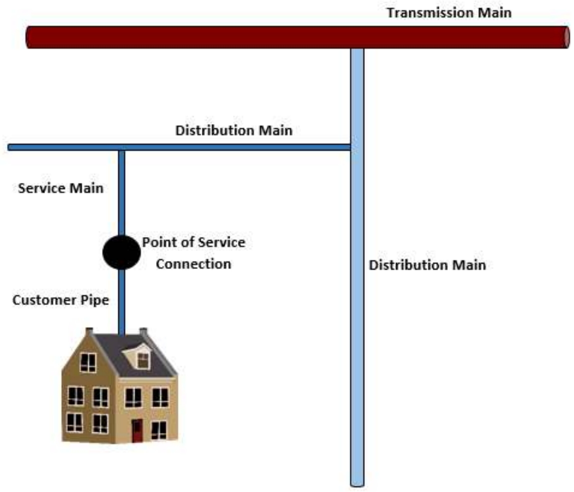


Figure 5.2: Image of house by rdevries is licensed under CC0 1.0 (modified by COC OER)

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 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 5.4: Original mage of pipe 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 5.5: Image by Yeti Hunter is licensed under CC BY-SA 4.0

Figure 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 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 5.8: Image of Pipe 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 5.9: Image of Pipes 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 5.10: Image is in the public domain

Figure 5.11: Image by Dwight Burdette is licensed under CC 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.

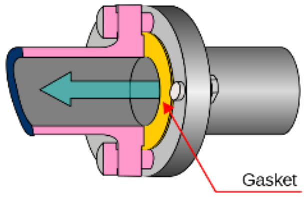


Figure 5.12: Image by Mysid is in the public domain

Figure 5.13: Image by Ian Capper is licensed under this CC BY-SA 2.0

Figure 5.14: Image by Brandonrush is licensed under CC BY-SA 4.0

Figure 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 5.16: Image of Work 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

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

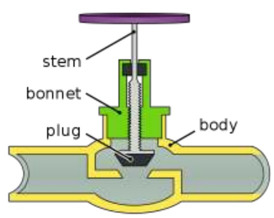


Figure 6.1: Image by Petteri Aimonen is in the public domain

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 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.

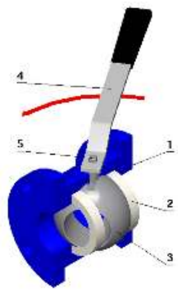


Figure 6.3: 1) Body 2) Head 3) Ball 4) Lever handle 5) Stem - Image by Ruben Castelnuovo licensed under CC BY-SA 3.0

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.

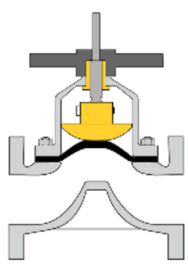


Figure 6.4: Image by Muskid is licensed under CC BY-SA 3.0

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 6.5: Image by COC Water Systems Technology Faculty is licensed under CC BY 4.0

Figure 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 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 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 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 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.

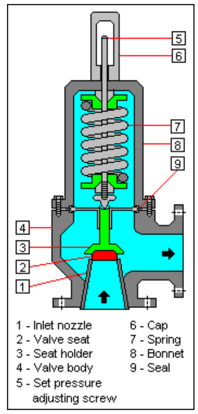


Figure 6.11: Image by Mbeychok is licensed under CC BY-SA 3.0

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 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.

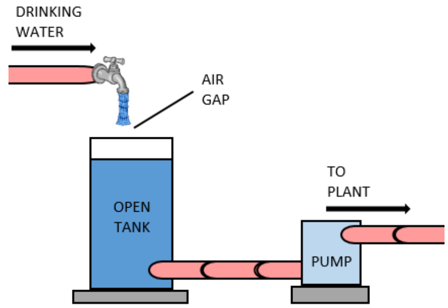


Figure 6.13: Faucet by frankes is licensed under CC0 1.0 (modified by COC OER)

Figure 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.

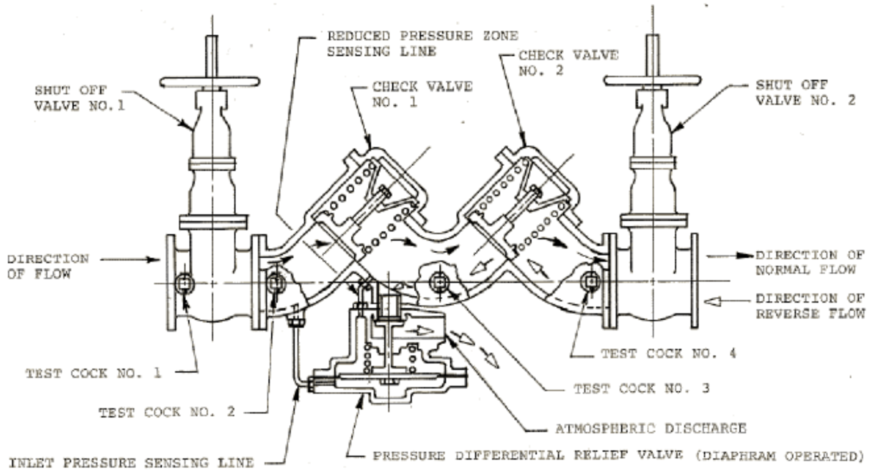


Figure 6.15: Image by the Ohio EPA

Figure 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.

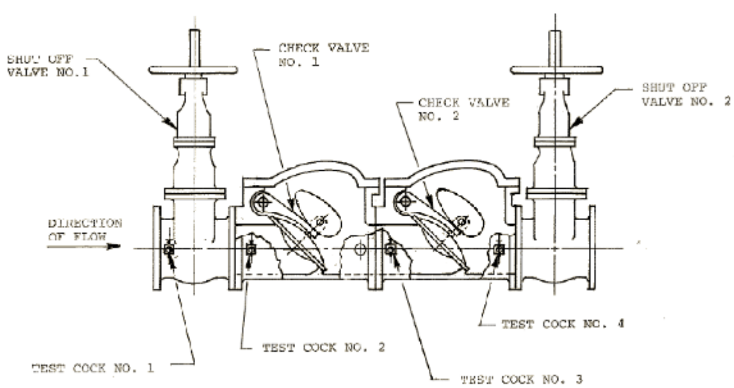


Figure 6.17: Image by the Ohio EPA

Figure 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

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 7.1: Photo by Ashim D'Silva on Unsplash

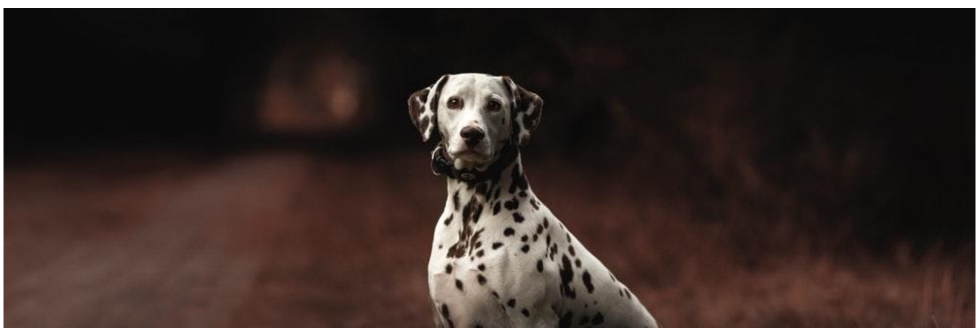


Figure 7.2: Photo by Tim Zänkert on Unsplash

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 add 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 7.3: Hydrant 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 7.4: Image by Ildar Sagdejev is licensed under CC 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 7.5: Hydrant 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 7.6: Image by Ben Schumin is licensed under CC BY-SA 2.5 (modified by COC OER)

Figure 7.7: Firefighter by the US 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 7.8: Image by FEMA is in the public domain

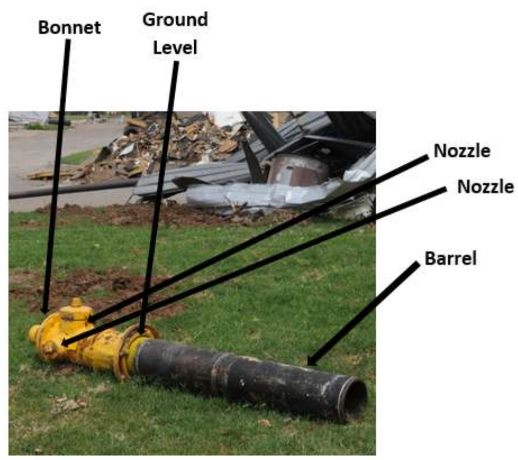


Figure 7.9: Image by FEMA is in the public domain

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.

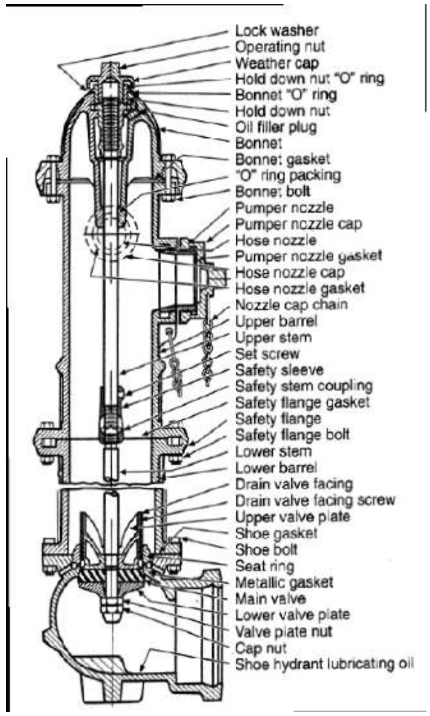


Figure 7.10: Dry Barrel Fire Hydrant by the U.S. Fire Administration is in the public domain

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.

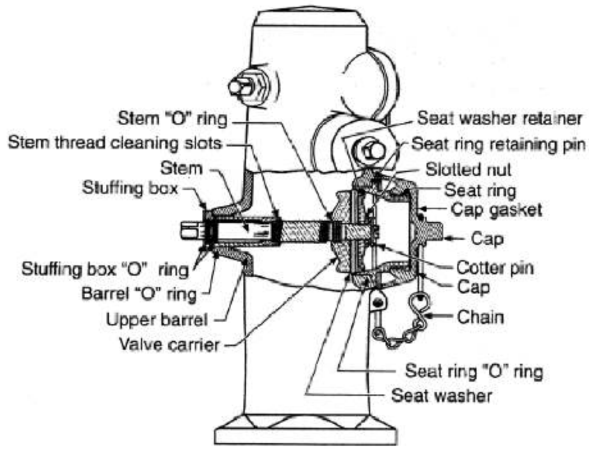


Figure 7.11: Wet Barrel Fire Hydrant by the US Fire Administration is in the public domain

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 are 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

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.

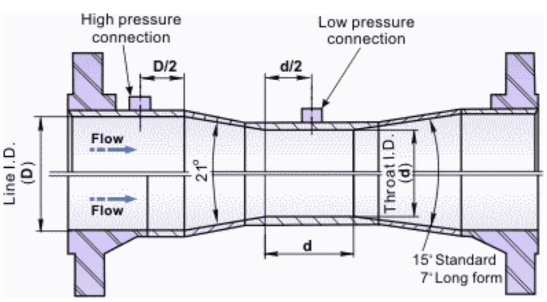


Figure 8.1: Image by Aadilnashit is licensed under CC BY-SA 4.0

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 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.

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Figure 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 recorded installed in a device called a stilling well.

Figure 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 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 8.7: Image by COC Water Systems Technology Faculty is licensed under CC 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 ¾” in size. In a typical residential housing track, it is common to have 1” service laterals and ¾” 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 ¾” 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 5/8” or ¾” 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 ½”, 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 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 8.9: Image by Utilitysupplies is licensed under CC BY-SA 3.0

Figure 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 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) of 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 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

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 – Volutes 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.

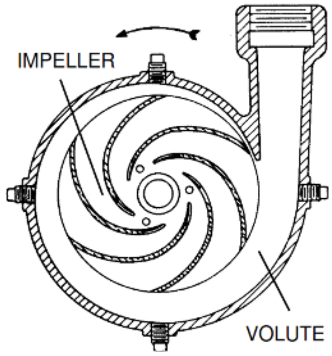

Figure 9.1: Image is in the public domain

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.

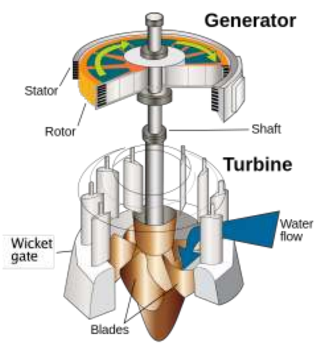

Figure 9.2: Image by the U.S. Army Corps of Engineers is in the public domain

- 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.

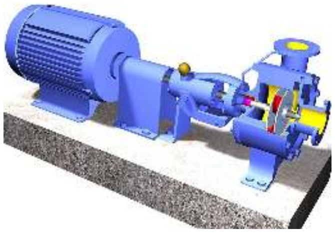

Figure 9.3: Single-Suction Pump - Image by Kaze0010 is licensed under CC BY-SA 3.0

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.

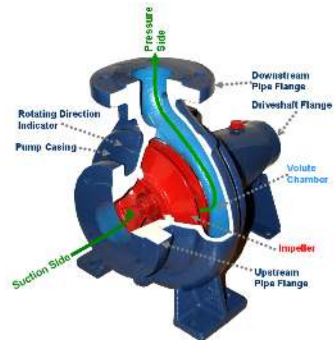

Figure 9.4: Image by Fantagu is in the public domain

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.

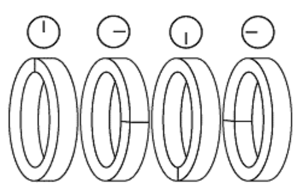

Figure 9.5

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 pumps 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

CHAPTER OVERVIEW

10: Sampling and Regulations

10.1: Microbiology Regulations

Learning Objectives

After reading this section, you should be able to:

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

Total Coliform Rule

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

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

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

Key provisions of the RTCR include:

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

Revised Total Coliform Rule

Overview of the Rule

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

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

General Description

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

The Total Coliform Rule applies to all Public Water Systems.

Implementation of the Total Coliform Rule will result in:

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

Requirements:

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

Routine Sampling Requirements

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

Repeat Sampling Requirements

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

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

If one or more repeat sample is Total Coliform Positive:

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

Routine Sampling Requirements

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

Assessments and Corrective Action

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

Purpose of Level 1 and Level 2 Assessments

To find sanitary defects at the Public Water System including:

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

Deadline for Completing Corrective Actions

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

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

Level 1 Assessments

Conducting Level 1 Assessments

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

Level 1 Assessment Triggers

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

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

Level 2 Assessments

Conducting Level 2 Assessments

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

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

Level 2 Assessment Triggers

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

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

Seasonal System Provisions

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

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

Start-up Procedures for Seasonal Systems

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

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

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

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

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

Routine Monitoring for Seasonal Systems

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

Other Provisions for the State Drinking Water Agency Special Monitoring Evaluation

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

Major Violations

E. coli MCL Violation

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

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

Routine Repeat

EC+ TC+

EC+ Any missing sample

EC+ EC+

TC+ EC+

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

Treatment Technique Violation

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

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

Key Points for Public Water Systems to Remember

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

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

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

Ground Water Treatment Rule

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

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

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

Overview of the Rule

Ground Water Rule (GWR)

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

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

Purpose

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

General Description

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

Utilities Covered

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

Public Health Benefits

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

Requirements for Drinking Water Systems

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

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

Analytical Methods for Source Water Monitoring

Fecal Indicator Methodology Method

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

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

Major Provisions of Rule

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

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

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

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

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

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

Source Water Monitoring

Triggered Source Water Monitoring

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

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

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

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

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

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

Additional Source Water Sampling

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

Assessment Source Water Monitoring

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

Treatment Technique Requirements

Groundwater Systems with Significant Deficiencies or Source Water Fecal Contamination

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

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

New Sources

New Ground Water Sources

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

Sanitary Surveys

All Ground Water Systems

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

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

Existing Regulations for Microbial Pathogens in Drinking Water

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

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

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

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

Introduction to Cryptosporidium

Concern with Cryptosporidium in Drinking Water

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

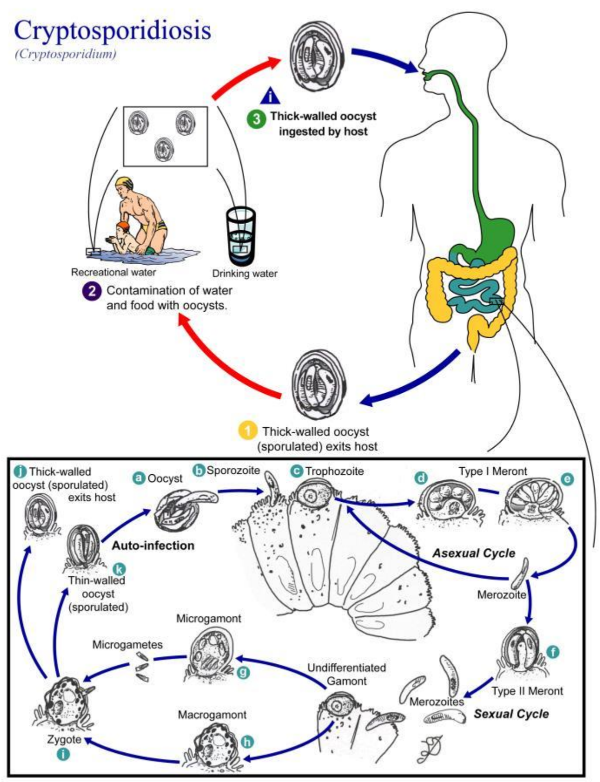

Figure 10.1.1: Cryptosporidiosis.

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

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

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

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

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

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

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

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

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

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

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

Sampling location

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

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

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

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

Sampling Schedule

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

Failing to Monitor

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

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

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

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

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

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

Second Round of Monitoring

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

Process Summary

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

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

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

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

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

1. For PWSs that collect a total of at least 24 but not more than 47 *Cryptosporidium* samples over two or more years, the *Cryptosporidium* bin concentration is equal to the highest arithmetic mean of all sample concentrations in any 12 consecutive months of *Cryptosporidium* monitoring.
2. For PWSs that collect a total of at least 48 samples, the *Cryptosporidium* bin concentration is equal to the arithmetic mean of all sample concentrations.
3. For PWSs that serve fewer than 10,000 people and monitor for *Cryptosporidium* for only one year (collect 24 samples in 12 months), the *Cryptosporidium* bin concentration is equal to the arithmetic mean of all sample concentrations.
4. For PWSs with plants that operate only part-year that monitor for less than 12 months per year, the *Cryptosporidium* bin concentration is equal to the highest arithmetic mean of all sample concentrations during any year of *Cryptosporidium* monitoring.

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

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

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

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

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

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

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

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

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

These findings led EPA to conclude that most filtered PWSs currently provide sufficient treatment for *Cryptosporidium*, but additional treatment is needed in those PWSs with the highest source water Cryptosporidium levels to protect public health.

Further, PWSs can characterize *Cryptosporidium* levels in their source waters with available analytical methods and can provide higher levels of treatment with available technologies. Consequently, risk-targeted treatment requirements for *Cryptosporidium* based on source water contamination levels are appropriate and feasible to implement.

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

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

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

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

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

Key Terms

- ***Cryptosporidium*** - a protozoan parasite that lives and reproduces entirely in one host; ingestion of *Cryptosporidium* can cause cryptosporidiosis, a gastrointestinal (GI) illness; cryptosporidium is excreted in feces.
- **Ground Water Rule (GWR)** – the purpose is to improve drinking water quality and provide protection from disease-causing microorganisms; water systems that have groundwater sources may be susceptible to fecal contamination; applies to public water systems that use ground water as a source of drinking water
- **Surface Water Treatment Rules (SWTRs) –** the purpose is to reduce illnesses caused by pathogens in drinking water, including *Legionella*, *Giardia lamblia*, and *Cryptosporidium*; the SWTRs requires water systems to filter and disinfect surface water sources.
- **Total Coliform Rule** (TCR) - a National Primary Drinking Water Regulation (NPDWR), published in 1989 and became effective in 1990; sets a health goal (Maximum Contaminant Level Goal (MCLG)) and legal limits (Maximum Contaminant Levels, MCLs)) for the presence of total coliforms in drinking water

Review Questions

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

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

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

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

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

Chapter Quiz

1. Total coliforms are used as a(n) _______ of the possible presence of pathogens in drinking water. Total coliforms are used to determine the adequacy of water treatment and the integrity of the distribution system.
    1. indicator
    2. model
    3. log removal
    4. alternative
2. The Revised Total Coliform Rule establishes _________for E. coli and uses E. coli and total coliforms to initiate a find and fix approach to address fecal contamination that could enter into the distribution system.
    1. a log removal
    2. a maximum contaminant level (MCL)
    3. a secondary maximum contaminant level (SMCL)
    4. a model
3. Within 24 hours of learning of a Total Coliform positive routine sample result, at least ____ repeat samples must be collected and analyzed for total coliform.
    1. 1
    2. 2
    3. 3
    4. 4
4. States are required to conduct __________ of all groundwater systems in order to identify significant deficiencies, including deficiencies which may make a system susceptible to microbial contamination.
    1. hydrologic studies
    2. microbial examinations
    3. a sanitary survey
    4. laboratory studies
5. The Surface Water Treatment Rule requires water systems to ________ surface water sources.
    1. filter and disinfect
    2. conserve
    3. aerate
    4. disinfect
6. In order not to be subject to triggered source water monitoring under the Groundwater Rule, a groundwater system can notify the state that it provides at least _______ treatment of viruses using virus inactivation, or removal, before or at the first customer.
    1. 2-log
    2. 3-log
    3. 4-log
    4. 6-log
7. The Long-Term Surface Water Rule establishes risk-targeted treatment technique requirements to control _________ in PWSs using surface water or groundwater under the influence of surface water.
    1. *E.coli*
    2. *Giardiasis lambdia*
    3. *Cryptosporidium*
    4. Coliforms

8. What is the maximum allowable turbidity in the combined filter effluent?
   1. 0.5 NTU
   2. 1.0 NTU
   3. 3.0 NTU
   4. 5.0 NTU
9. EPA promulgated the Long-Term Surface Water Treatment Rule to reduce the public health risk associated with ________ in drinking water.
   1. *Giardiasis lambdia*
   2. *Cryptosporidium*
   3. Coliforms
   4. *E. coli*
10. _________ is a protozoan parasite that lives and reproduces entirely in one host,
    1. *E. coli*
    2. Coliforms
    3. *Cryptosporidium*
    4. Fecal streptococcus

10.2: Regulations

Student Learning Outcomes

After reading this chapter, you should be able to:

- Differentiate between the primary sources of drinking water contamination
- Evaluate the water quality sampling requirements within a distribution system
- Summarize the main federal and state water quality regulatory citations
- Explain the role the American Waterworks association plays in terms of water quality standards

Is My Water Safe to Drink?

One of the biggest questions and concerns people have is whether or not their tap water is safe to drink. However, sometimes there is confusion between the taste, odor, and appearance of the water and the actual "safety" of the water. Many times these two things are not one and the same. Tap water can be discolored, smell strange, and have an odd taste, but from a health and safety standpoint, the water might be perfectly fine. Explaining this to a customer can be a very challenging task. Conversely, a glass of water might be crystal clear and have no apparent taste or odor and could be potentially unsafe (non-potable) for human consumption.

So, how does a water quality professional handle variability in the quality of drinking water? There are several things (tools in a toolbox) water treatment and distribution operators use to make sure the water they are providing to millions of people is safe and to a certain extent "pleasant" to drink. The word pleasant is placed in quotes because things like taste, odor, and color can be very subjective characteristics in terms of drinking water quality.

The tools water utility professionals use can be explained in four main categories; regulations, treatment, testing, and maintenance. Each one of these will be explained throughout this chapter, but below is a concise explanation of each one.

- Regulations – Drinking water quality regulations might be the number one component to ensure a safe drinking water supply is being provided to water utility customers. The United States Environmental Protection Agency (USEPA) is tasked with providing minimum drinking water standards for water utilities throughout the United States to adhere to. These drinking water regulations are found in the Safe Drinking Water Act (SDWA). Among other things, the SDWA sets minimum levels for a variety of contaminants in drinking water.
  - USEPA Safe Drinking Water Act
  - California Safe Drinking Water Act
- Treatment – Within the SDWA, there are rules and regulations regarding the treatment requirements at drinking water treatment plants. Along with the minimum contaminant levels, there are various treatment technologies for drinking water treatment plants.
- Testing – The SDWA also spells out testing requirements for water utilities at treatment plants, at the various sources of supply, and within distribution systems. Additional sampling is also common for a variety of other reasons not spelled out in the regulations. Collecting and analyzing water quality samples is not only a regulatory requirement, it is used by treatment and distribution operators for monitoring and predicting water quality.
- Maintenance – Maintenance (especially within distribution systems) goes a long way with improving and maintaining good water quality. Some of the more common distribution maintenance tasks associated with improving and maintaining good water quality are flushing of water mains and cycling the level of water in storage tanks.

Providing and maintaining a safe supply of drinking water to customers is a primary responsibility of all water utilities. This is achieved through the items discussed above as well as a collaborative and coordinated effort between water utility staff, regulators, and the public receiving this vital resource.

In addition to the regulatory requirements, the American Water Association (AWWA) provides a variety of standards and guidance to water utilities. AWWA is an international, nonprofit, scientific, and educational organization. It was established in 1881 and is the largest Association of water supply professionals in the world. The recent State Water Resources Control Board Division of

Drinking Water's (DDW) waterworks standards were revised in 2008 and most were based on AWWA recommendations and standards.

Sources of Contamination

There are a number of naturally occurring and manmade contaminants, which can be found in water supplies. These contaminants can be broken down into four (4) main categories; physical, biological, chemical, and radiological. Because the sources of drinking water supply vary from region to region, the contaminants present in one part of the world are not necessarily found in other parts of the world. For example, a constituent, such as fluoride, is temperature-dependent and therefore is not typically found in groundwater supplies in cooler regions but may be found in warmer climate regions.

Physical Contamination

Most physical contaminants do not pose a direct health effect. They primarily impact the appearance of drinking water. Physical contamination is more commonly found in surface water supplies and often results from soil erosion. Sediments and organic material can wash off surrounding hillsides along lakes, rivers, and streams. These contaminants mostly affect the aesthetic quality of drinking water, such as taste, odor, and color. However, these types of contaminants can also impede the drinking water treatment process and can act as a barrier, protecting biological contaminants.

Biological Contamination

One of the most common contaminants water utilities collect samples and analyze are part of the biological class of contaminants. While only a few bacteriological organisms are pathogenic, this entire class of organisms can wreak havoc on a water system. From a public health standpoint, we are mainly concerned with the bacteriological and viral disease-causing (pathogenic) organisms. Since it can be difficult and costly to try and analyze all the different strands of viruses and bacterial organisms, which might find their way into a water system, an "indicator" organism is preferred. In drinking water supplies and systems, the indicator of choice is the total coliform group.

Pathogenic organisms include those derived from fecal contamination and viruses, which typically use bacteria as a host for replication. These disease-causing organisms that can be found in drinking water include, but are not limited to *Escherichia coli (E. coli*) and various strains of *Vibrio* and *Enterococcus*, various enteroviruses, and parasites such as *Cryptosporidium* and *Giardia*. Most of these organisms find their way into a drinking water system through some type of contamination with fecal matter. Perhaps an animal feed lot is upstream from a water supply or an underground sewer collection system is leaking next to a drinking water underground well. Therefore, the main source for these contaminants is human or animal feces.

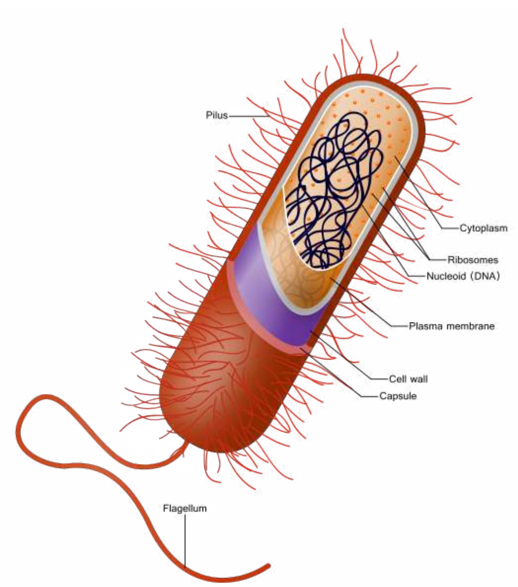

Figure 10.2.1: Contamination Image Source by Ali Zifan is licensed under CC BY-SA 3.0

All of these potential contaminants are routinely monitored through a regulation called the Total Coliform Rule (TCR). In 2013 and 2014, revisions to the 1989 TCR were implemented in order to improve public health. The TCR is now referred to as the Revised Total Coliform Rule (RTCR). Total coliforms are a group of related bacteria, which are (with few exceptions) not harmful to humans. Therefore, the USEPA has identified this group of organisms to represent an indicator for a variety of bacteria, viruses, and parasites which are known pathogens and can cause health problems in humans if they are ingested.

Revised Total Coliform Rule

The USEPA published the Revised Total Coliform Rule (RTCR) in the Federal Register on February 13, 2013 (78 FR 10269) and minor corrections on February 26, 2014 (79 FR 10665). Promulgation of the RTCR began on April 1, 2016.

Most of the major provisions of the TCR stay in place and include:

- Collecting total coliform (TC) samples at representative locations throughout the distribution system.
- Samples must be collected at regular intervals.
- Numbers of samples collected are based on the size of the population the water utility serves.
- Repeat sampling is required for positive results, which include analysis of *E. coli*.

Details of the TCR can be found in the USEPA's Total Coliform Rule: A Quick Reference Guide.

The main changes to the RTCR include the following:

- Setting a maximum contaminant level goal (MCLG) and maximum contaminant level (MCL) for *E. coli*.
- Setting a TC treatment technique (TT).
- Requirements for assessments and corrective actions.
- Specific language in the annual Consumer Confidence Reports (CCR) for violations.

Details of the RTCR can be found in the USEPA's Revised Total Coliform Rule: A Quick Reference Guide.

There are a number of different provisions within each rule and depending on the size of the utility, there are different requirements. In general, every TC positive sample must be followed up with analysis of *E. coli* and repeat samples are also required. At least three (3) repeat samples are required for every TC positive sample. The repeat samples must be collected within 24 hours of learning about the positive TC result. The repeat samples must be collected from the same sample location and within five (5) service connections upstream and downstream of the original sample location. There are additional requirements, but more detail is beyond the scope of this text.

Chemical Contamination

There are many different chemicals used in the world for a variety of different things. For example, arsenic is used to preserve wood and prevent rotting and chromium is used in chrome plating processes. While chemicals are commonly used in various manmade processes, they are also found naturally occurring in the environment. Regardless of the source of contamination (naturally occurring or manmade), if they pose a threat to public health they also need to be regulated if they are found in drinking water supplies. Within this group of contaminants, there are two main categories; inorganic and organic. The main difference between these two categories is the absence of carbon with inorganic chemicals and the presence of carbon with organic chemicals. Below is a short list of common contaminants found in drinking water supplies within both categories.

- Common Inorganic Chemicals – While most of these inorganic chemicals can be found naturally occurring in water supplies, with the exception of arsenic, most are the result of contamination from human activities.
  - Arsenic (As) – As previously mentioned, one of the main uses of arsenic is preserving wood. Arsenic is also commonly found naturally in groundwater supplies, especially in the southwest.
  - Nitrate (NO3) – While nitrate can be found naturally occurring, these levels are relatively harmless. The primary sources of nitrate in drinking water are from fertilizers and contamination from sewage.
  - Chromium (Cr) – Chromium is used in plating processes and can also be found naturally in the environment. One of the unique things about chromium is it is found in two common oxidative states, Cr III and Cr VI.
  - Lead – Lead is most commonly found in plumbing systems, although the allowable levels are being reduced because of the significant health effects. The main reason lead was used in plumbing supplies is because of its malleability.
  - Copper – Copper is also most commonly found in plumbing supplies

- Common Organic Chemicals – The organic chemicals found in drinking water supplies are referred to as volatile organic compounds (VOCs) and synthetic organic compounds (SOCs). While they can be found naturally occurring, the majority of the VOCs and SOCs found in drinking water supplies are from manmade chemicals.
  - Trichloroethylene (TCE) – TCE is a common solvent used as a degreaser
  - Tetrachloroethylene (PCE) – PCE is a common solvent used in dry cleaning
  - Methyl tertiary-butyl ether (MTBE) – A gasoline additive to help improve air quality

Drinking Water Standards

In order to make sure contaminants are limited or kept at levels below those which would pose health effects to consumers, there are a number of regulatory standards in the SDWA. In addition to the federal SDWA, some states have their own set of standards water utilities must adhere to. In California under Title of the California Code of Regulations, there is the California Safe Drinking Water Act (CSDWA). The difference between federal and state drinking water regulations is the ability of state regulations to be more stringent than federal regulations. This means that the CSDWA can have regulatory levels for contaminants set at a lower level than the federal SDWA. They cannot be set higher. Within the SDWA, contaminants are separated into two main categories, primary drinking water standards and secondary drinking water standards. Primary standards are for those chemicals which pose a public health threat. Secondary standards are for contaminants, which have aesthetic effects on the water supply.

The USEPA goes through an extensive process in order to determine if a contaminant needs to be regulated under the SDWA. There are three (3) main criteria the USEPA considers in order to make a regulatory determination. They determine whether or not the contaminant meets the following criteria:

- The contaminant may have an adverse effect on the health of persons
- The contaminant is known to occur or there is a substantial likelihood the contaminant will occur in public water systems with a frequency and at levels of public health concern
- In the sole judgment of the Administrator, regulation of the contaminant presents a meaningful opportunity for health risk reductions for persons served by public water systems

Once the USEPA identifies whether or not a contaminant needs to be regulated, further evaluation is required to determine the technical and economical feasibility of regulating the contaminant. During this process, a non-enforceable level is usually established. This non-enforceable level is referred to as a Maximum Contaminant Level Goal (MCLG). MCLGs are set at levels which no known or anticipated adverse health effect would occur. The next step is to develop an enforceable standard referred to as a Maximum Contaminant Level (MCL). MCLs are set as close to the MCLG as is feasible. The SDWA defines "feasible" as the level that may be achieved with the use of the best available technology or treatment techniques the USEPA finds available (under field conditions and not solely under laboratory conditions), taking cost into consideration. The USEPA can establish a regulatory treatment technique when there is no reliable method that is economically and technically feasible to measure a contaminant.

In addition to MCLs and MCLGs, there are other acronyms related to drinking water quality regulations. These include the following:

- PHG – Public Health Goals are similar to MCLGs. They are California non-enforceable standards where an MCL does not exist.
- AL – Action Levels are set for certain contaminants where an MCL does not exist and some type of response (action) is required by the water utility if an AL is exceeded
- DLR – Laboratories are tasked with analyzing contaminants. As laboratory techniques improve, these levels become smaller (lower) over time. The Detection Limit for Reporting is set at a level laboratories can accurately reproduce with the current method of analysis.

The level of a contaminant is expressed using a ratio of units. The most common units used to express levels of contaminants are the following:

- Milligram per liter (mg/L)
- Microgram per liter (ug/L)
- Nanogram per liter (ng/L)

The above examples express the weight of the contaminant in a liter of water. Therefore, a level of 10 mg/L means that for every liter of water there are 10 mg of a substance. Sometimes, alternative units of measure are used. These alternatives are the following:

- Parts per million (ppm) = mg/L
- Parts per billion (ppb) = ug/L
- Parts per trillion (ppt) = ng/L

These units mean for every part of a contaminant there are a million, billion, or trillion parts of water. For example, a level of 10 ppm (same as 10 mg/L) means that for every million parts of water, there are 10 parts of the substance.

While it is not required for water distribution operators to memorize drinking water quality standards (MCLs), it is important for them and especially the water quality professionals to have a general understanding of the main contaminants within their water supply. In addition, it is important for water quality professionals such as water quality technicians, specialists, supervisors, and managers to understand the health effects associated with common contaminants. Some of the more commonly found primary contaminants in drinking include the following:

Nitrate

Nitrate – MCL = 45 mg/L as NO3 or 10 mg/L as N – The reason there are two MCLs for nitrate is because the value can be expressed as actual amount of nitrate (NO3) or expressed as the total amount of nitrogen (N).

Figure 10.2.2: Nitrogren Image Source by OpenStax is licensed under CC BY 4.0 (image modified by COC OER)

- Source – The primary source of nitrate in drinking water is from fertilizers. This is especially present in areas where there is or was agriculture present. Nitrate can also occur as a result of contamination from animal or human sewage waste.
- Health Effects – The primary health effect associated with elevated levels of nitrate in drinking water is something referred to as “blue baby syndrome”. The medical diagnosis is methemoglobinemia. It is a condition, which effects the body’s ability to release oxygen to tissues. Infants six (6) months old and younger are particularly susceptible.

Arsenic

Arsenic – MCL = 10 ug/L

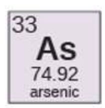

Figure 10.2.3: Arsenic Image Source by OpenStax is licensed under CC BY 4.0 (image modified by COC OER)

- Source – Arsenic is found naturally in certain geologic formations and is also used in some industries. One common use is a preservative for wood products.
- Health Effects – Studies have linked long-term exposure to arsenic in drinking water to cancer of the bladder, lungs, skin, kidney, nasal passages, liver, and prostate. Non-cancer effects of ingesting arsenic include cardiovascular, pulmonary, immunological, neurological, and endocrine effects.

Radiological Compounds

There are several types of radiological compounds found in drinking water supplies and include; uranium, strontium, total alpha, and total beta.

- Source – The primary source of radiological compounds in drinking water is naturally occurring geologic formations. Accidental or intentional releases from human activities is a rare occurrence.
- Health Effects – Elevated levels of radiological compounds in drinking water can increase the risk of kidney damage.

Lead and Copper

Lead and Copper – AL = 15 ug/L for Lead (Pb) and 1,300 ug/L for Copper (Cu) – Lead and copper contamination does not typically occur in the source water or even in the distribution system of drinking water systems. The primary source of lead and copper contamination occurs in internal plumbing systems. Lead and copper are commonly used in the manufacturing of plumbing supplies and can leach out into drinking water. Therefore in 1991, the Lead and Copper Rule (LCR) was passed. The LCR requires water utilities to collect samples for lead and copper within customer homes. While lead and copper is not as common within distribution systems, it is an issue in older communities where lead service laterals and other materials were commonly used. The most recent discovery of lead contamination within a distribution system was in 2014 in Flint, Michigan. As a result, the LCR is going through a number of different revisions.

- Health Effects – The primary effects of copper in drinking water are related to gastrointestinal issues. However, the effects of lead in drinking water are far worse and include damage to the brain, red blood cells, and kidney.

As previously mentioned, secondary drinking water contaminants are not health related. The problems associated with secondary contaminants can be grouped into three categories:

- Aesthetic effects – undesirable tastes or odors
- Cosmetics effects – effects which do not damage the body but are still undesirable
- Technical effects – damage to water equipment or reduced effectiveness of treatment for other contaminants

The periodic table lists the various chemical substances that can be found in water supplies. Below is an image of the periodic table with many of the ions mentioned below circled for reference.

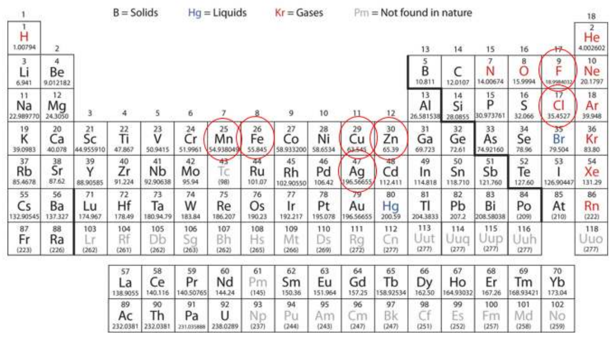

Figure 10.2.4: Periodic Table Image Source by Saylor Academy is licensed under CC BY-NC-SA 3.0 (image modified by COC OER)

Contaminants related to color, odor and taste (aesthetic) include, Chloride (Cl), Copper (Cu), Foaming Agents, Iron (Fe), pH, Sulfate (SO4), Manganese (Mn), Total Dissolved Solids (TDS), and Zinc (Zn).

Contaminants related to cosmetic effects include, Silver (Ag) and Fluoride (F).

Contaminants related to technical effects include, Chloride, Copper, Corrosivity, Iron, Manganese, pH, and Total Dissolved Solids.

Some of the chemical contaminants listed above are compounds or in the case of TDS, are a combination of ions. Sulfate for example is a sulfur ion combined with four (4) oxygen atoms. TDS represents a number of different constituents which include but are not limited to calcium, magnesium, sulfate, chloride, as well as others.

Disinfection

One of the most critical processes in the area of water quality is the ability to control the growth and regrowth of pathogenic organisms throughout the distribution system. This process is commonly handled through disinfection. By definition, disinfection is the process of cleaning something, especially with a chemical, in order to destroy bacteria. Disinfection should not be confused with other processes such as sanitation or sterilization. Sanitation is the process to make something clean, but it doesn't necessarily target disease causing organisms and sterilization is the process of ridding something of all bacteria. The goal of drinking water disinfection is to destroy pathogenic organisms in order to make it safe for human consumption. This process is commonly achieved through the use of chlorine and chlorine related compounds or other oxidants.

Physical Disinfectants

While not common, microorganisms can be inactivated in water supplies through physical means. These include, but are not limited to ultraviolent rays, heat, and ultra-sonic waves. While all of these are physical means of inactivating harmful organisms, they lack something chlorine and chlorine related compounds provide. These processes are good at the time of use but provide no long term protection from regrowth.

Non-chlorine Disinfectants

Chemicals such as iodine, bromine, various bases (alkaline chemicals), and ozone are good oxidizing agents, but each one has limitations when it comes to drinking water disinfection. Iodine has been used for years to disinfect cuts and skin abrasions and in low doses it can be used to disinfect drinking water. However, because of the high costs and potential physiological effects on pregnant women, it is not used in drinking water. Bromine is commonly used in swimming pools and spas, but because of safety related issues with handling the chemical it is not used in drinking water. An example of a base that can be used as a disinfectant is sodium hydroxide. It is also commonly used to disinfect cuts and skin abrasions, but it leaves a bitter taste if it is ingested and is not suitable for drinking water disinfection. Ozone is a great disinfectant for drinking water under certain instances. It is primarily used in the drinking water treatment process to control taste and odor and to reduce the amount of total organic carbon prior to treatment. The main problem with ozone is it does not leave a residual, is difficult to store, and is expensive.

Chlorine and Chlorine Related Compounds

Chlorine has been used in the United States to disinfect drinking water for over 100 years. It does a great job at inactivating pathogenic organisms and leaves a residual preventing regrowth throughout the distribution system. In its natural state, chlorine is a gas with a greenish-yellow color. There are other chlorine related compounds such as calcium hypochlorite (solid) and sodium hypochlorite (liquid) commonly used to disinfect drinking water. In addition to chlorine and these related compounds, chlorine is often combined with ammonia to create chloramine. Chloramine is also an efficient disinfectant. One of the major drawbacks to using chlorine as a disinfectant is the potential creation of disinfection by-products such as total tri-halomethanes and halo-acetic acids

Distribution System Water Quality

As water makes its way through the distribution system, distribution operators need to be able to maintain the quality of the water. Water quality can degrade within a distribution system for a number of reasons, including but not limited to age of water, temperature of water, lack of a disinfectant residual, pH, various reducing agents, and microorganisms. Maintaining a disinfectant residual within distribution systems is an important responsibility for distribution operators. Sampling, monitoring, and various maintenance activities can help with maintaining a disinfectant residual.

Distribution Sampling

The SDWA states how many and where water quality samples need to be collected. In addition, state regulators such as DDW may also require additional sampling based on vulnerabilities and other water quality related issues.

All sources of supply must be sampled routinely for bacteriological, inorganic chemicals, organic chemicals, and radiological contaminants. Each group of contaminants and some individual contaminants have different sampling intervals and procedures. For example, VOCs are required to be sampled at each source annually unless there is a positive detection, in which case they need to be sampled quarterly.

Sampling within the distribution system is also required. However, there are far fewer constituents, which need to be sampled in distributions systems. The main contaminants which are required to be sampled for in distribution systems are bacteriological as part of the TCR and disinfection by-products. If you think about this, it makes sense. If you sample source water for VOCs for example, you would not need to sample for VOCs again in the distribution system. The reason for this is because VOCs do not develop in the distribution system. In contrast, in the absence of a disinfectant residual, bacteria can regrow in a distribution system and disinfection by-products may form in a distribution system under certain conditions.

As part of the TCR, water utilities prepare sample siting plans. These plans identify the number of customers the utility serves, which in turn determines how many samples must be collected for total coliform bacteria. The sample locations and sampling frequency are also identified in these plans. Larger utilities can be required to sample dozens of locations on a weekly basis for total coliform bacteria as part of the TCR, while smaller utilities may just have to sample a few locations a month. At each location the disinfectant residual is also analyzed. This data can help determine if there is the potential for a problem within the distribution system. Let’s take a look at a hypothetical example. Suppose ten (10) locations per week are being sampled for total coliform bacteria and a chlorine disinfectant residual. Over three weeks, all the total coliform results come back negative (absent of total coliform bacteria), but the sampler has noticed a downward trend in the chlorine residual level at one of the sample locations. This sort of information can indicate a potential problem and maybe the next total coliform sample at this site will come back positive. This scenario doesn’t necessarily mean something is wrong, but the sampler at least has data, which can be presented to other operators and may trigger some type of maintenance.

Distribution System Maintenance

Maintaining an efficient distribution system can help maintain good water quality. Water entering a distribution system from a source is routinely disinfected with a chemical such as chlorine. While the water travels through the distribution system the disinfectant will do its job by inactivating pathogenic organisms. As this occurs, the amount of chlorine in the system (residual) will reduce. The further the water travels, the lower the residual level. The water also becomes older as it travels through the distribution system and the water can become stagnant, resulting in discoloration, odors, and low chlorine residuals. One way to help keep a disinfectant level at acceptable levels is to help move the water through the system by flushing dead ends and areas furthest away from sources. By flushing and helping to move water through the distribution system, the water and with it the disinfectant residual travels faster through the distribution system and the water does not become stagnant

Figure 10.2.5: Image by Daniel Case is licensed under CC BY-SA 3.0

Sometimes, residuals drop very rapidly or cannot be maintained within a distribution system. This typically occurs when the initial dose of the disinfectant is not high enough at the source water, the water stays in the distribution system too long because of low use, or there is some other problem within the distribution system. When this occurs, distribution operators may choose to add a disinfectant in water storage tanks. Since disinfectants are added at the sources of supply they are typically found at higher levels in the distribution system around these sources. Storage tanks are commonly placed on the outer edges of distribution systems and if water demands (usage) are low, disinfectant residuals can drop below acceptable levels. This is when distribution operators can add disinfectants, such as calcium hypochlorite granules or liquid sodium hypochlorite to storage tanks. This will help improve disinfectant residuals within the tank and then in the distribution system as water is taken out of the tanks during times of usage.

Figure 10.2.6: Image by Barksdale Air Force Base is in the public domain

Water Quality Violations

When a water utility does not comply with drinking water quality regulations a violation occurs. Since many states (including California) have their own set of regulations, the states are the primacy agency for enforcing drinking water quality regulations. This means the enforcement comes from the state instead of the USEPA. However, since some regulations are specifically promulgated by the USEPA, they would be the primacy agency for those regulations.

Included in the SDWA is something referred to as the Public Notification Rule (PN). This rule ensures consumers will know if there is a problem with their drinking water. These notices are intended to alert customers if there is a risk to public health. Customers are notified when:

- The water does not meet drinking water standards;
- If the system fails to test its water;
- If the system has been granted a variance (use of less costly technology); or
- If the system has been granted an exemption (more time to comply with a new regulation).

If a water utility cannot meet a drinking water standard, that is they exceed an MCL for a contaminant, in addition to notifying their customers, several things are commonly triggered:

- Resampling the water must occur. Depending on the contaminant, several resamples may be required.
- If these results confirm an MCL has been exceeded, then the source is usually taken out of service. There are some exceptions. Depending on the health effect, the primacy agency may allow the source to be blended in order to bring the level of the contaminant below the MCL.
- Depending on the health effect of the contaminant, the utility may be required to notify the public immediately. Other times if the health risk is minimal, the utility would be required to notify their customers in an annual consumer confidence report.
- Depending on the level and the health effect of the contaminant, the utility may be required to install some form of treatment in order to remove or lower the level of the contaminant

With some contaminants where a positive result occurs, but the level is below an MCL, additional monitoring is sometimes required. For example, nitrate has one of the more complex additional sampling requirements.

Figure 10.2.7: Sampling Image Source by Shaw Air Force Base is in the public domain

Nitrate Sampling Requirements

The SDWA states that nitrate must be sampled annually at each source entering the distribution system. If the result is more than half the MCL (>22.5 mg/L as 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 10.2.8: Sample CCR – Photo by Tim Marshall on Unsplash (modified by COC OER)

Figure 10.2.9: Sample CCR – Photo by rawpixel on Unsplash (modified by COC OER)

Sample Questions

1. CCR stands for ___________ and is provided to ___________.
    1. Consumer Confidence Regulations/all water utilities
    2. Customer Certification Requirements/all customers
    3. Consumer Confidence Report/only select customers
    4. Consumer Confidence Report/all customers
2. Stagnant water in a distribution system can have the following qualities ___________.
    1. Discoloration
    2. Odor
    3. Low chlorine residual
    4. All of the above
3. Tri-halomethane are considered ___________.
    1. Surface water contaminants
    2. By-products of the disinfection process
    3. Groundwater contaminants
    4. All of the above
4. AWWA stands for ___________.
    1. American Water Workers Agency
    2. American Water Wage Association
    3. American Water Works Association
    4. None of the above
5. Primary drinking water standards are considered ___________.
    1. Health-related
    2. Aesthetic-related
    3. Not enforceable
    4. Less important than secondary standards

11: Safety

Student Learning Outcomes

After reading this chapter, you should be able to:

- Describe the difference between acute and chronic health effects as they relate to safety
- List the various types of safety practices of a water utility
- Explain the importance of proper record keeping related to safety

Safety in the workplace is something that transcends all industries. Each profession has their own set of safe work practices as it pertains to their specific job functions. For example, construction workers might be exposed to excessive heat. Therefore, these employees should be given the proper training and equipment to help prevent things like heat stroke. People working on an assembly line might be exposed to repetitive motions, which can lead to things like carpal tunnel syndrome. Their employer must provide the right work conditions in order to protect against strains and conditions associated with this type of activity. Another example might be someone working on a loading dock and is required to lift heavy objects. In this case, they must receive the proper instructions on how to lift properly and provided about what to do in the case where something is too heavy to lift.

These are just a few examples of safety-related items workers encounter in various industries. The water utility industry is no different. In fact, a professional water worker might be exposed to many different safety-related issues compared to employees in other industries. In addition, since many water utility operators are required to work around the public, there is an aspect of protecting the public from injuries related to the work they do. This text will attempt to analyze and address many of the safety items water workers might encounter.

Various Types of Safety

We will break the different types of safety into three (3) main categories. These are organizational safety, fleet safety, and public safety. Each of these categories is defined below:

- Organizational Safety—This is the most universal type of safety businesses (organizations) are faced with. It is the overall prevention of injury to employees. This prevention of injury is for employees both on and off the job. You might ask why an employer should be concerned with an employee’s personal safety when they are not working. The main reason organizations should instill the value of safety for employees both on and off the job is two-fold. First, any injury can result in lost time. This means if an employee gets injured at home, they may not be able to report to work. This results in inefficiency in the workplace and sometimes results in a loss of revenue for the employer. The second reason and maybe more importantly is creating a culture where safety is a value within the organization. Valuing safe work practices both on and off the job will result in a safer work environment and less loss time and money for organizations.
- Fleet Safety—Water utility workers work within a community. They are required to operate equipment and drive vehicles. This can result in traffic accidents and equipment-related accidents. Fleet safety is designed to help prevent these types of accidents.
- Public Safety—Put simply, public safety is the prevention of injury to the general public. Water utilities have facilities throughout a community and it is important these facilities do not pose a safety hazard to the general public. An example of this might be something simple like a meter box lid. If the lid is missing or broken, it could present a tripping hazard to someone walking along a sidewalk. Water utility workers also work in public streets. This not only presents a safety hazard to the employee but blocking off portions of a street can lead to traffic accidents and exposes the public to potential safety hazards.

Organizing a Safety Program

Each utility should designate an individual responsible for safety. Unfortunately in smaller agencies this is usually someone in middle management. A full-time safety officer is important in order to have one single person looking after health and safety for the entire organization. When safety is assigned to someone with other responsibilities, safety sometimes gets overlooked. Regardless who is tasked with overseeing the program, it is important that staff, management, and the entire organization look at safety as a core value. Each individual is ultimately responsible for their own safety, but they also need the correct tools and equipment to do their job safely.

A designated safety's main responsibility is to help staff and primarily supervisors. They are not tasked with providing all the training and equipment. They are to assess safety work practices and help implement safety programs. They determine the safety needs of an organization. They plan, develop, and recommend safety plans and programs. A safety officer should evaluate the effectiveness of safety plans and programs and make adjustments and corrections as necessary. Generating safety information and conducting meetings with employees and supervisors is also a function of a safety officer. Investigating accidents and injuries is also part of the responsibility of a safety officer as well as maintain records and reports covering all aspects of the safety program. These are some of the more critical responsibilities and additional tasks may be required as necessary.

Management also plays a large role in regards to safety. Without management's "buy-in", staff sometimes feels disenfranchised. Management needs to establish an overall safety policy for the organization. They appoint the safety officer (or coordinator) and assign responsibility for accident prevention. Management establishes goals, revises as needed, and evaluates results of the overall program.

Supervisors set the patterns for safety and should lead by example. No employee likes the "do as I say, not as I do" attitude. Since supervisors have direct control over employees, they should instill safety as a core value and provide the proper tools, equipment, and safety items needed to do tasks in a safe manner. They should instruct and council staff on safe work habits and review work for compliance with the safety program and regulations.

Employees are the front line workers of an organization. Therefore they are typically exposed to the majority of safety hazards. They must perform their work in accordance with the appropriate safety procedures and actively participate in the safety program. All injuries and hazards should be reported. At no time should an employee work in an unsafe manner or condition. If an employee feels a job is unsafe they are to report these findings to a supervisor.

The following is an example policy safety statement:

- The organization's recognition of the need for safety in order to stimulate efficiency, improve service, build employee morale, and promote better public relations
- The organization's interest in the employee - to provide proper equipment and working conditions, and to promote safety and the expectation that the individual employee will maintain safe work practices
- The fact that the human factor rather than the mechanical is most significant cause of accidents, thus emphasizing the employee's responsibility to perform the job safely
- That an essential part of the supervisor's job is responsibility for development of safe work practices and their environment

Safety Regulatory Requirements

The federal Occupational Safety and Health Administration (OSHA) is responsible for assuring safe and healthful working conditions by setting and enforcing standards and by providing training, outreach, education, and assistance. OSHA is part of the United States Department of Labor. Safe work practices can eliminate and reduce suffering, injury, and death. Safe work practices also reduce lost time, medical costs, and legal judgments. Proper safe work practices save time and money for companies too.

OSHA has established minimum health and safety standards that are applicable to every industry. The mandate that every employer furnish employees with a workplace that is free from recognized hazards that are likely to cause death or serious physical harm.

Causes of Accidents

Unsafe acts and unsafe conditions are two of the most common results in accidents and injuries. Lack of experience or improper training commonly results in unsafe acts. Some employees have an indifference to safety and can result in excess accidents and injuries. Poor work habits or cutting corners, working too fast and impatience results in unnecessary accidents and injuries. It is also important for employees to be well-rested and in good physical condition. There are usually specific condition requirements for some jobs. For example, a job requiring the operation of heavy equipment or strenuous labor may require certain licenses and regular physical fitness testing. Drug and alcohol testing may also be required for certain jobs. Impaired employees pose a danger to themselves and to other co-workers. Below are examples of unsafe acts:

- Ignorance—It is not that employees are ignorant. It is when they lack the experience or training to do their job safely
- Indifference—Some employees and in some instances employers are "indifferent" or do not care about safe work practices

- Poor work habits—Many times employees develop bad habits if they don’t understand how to perform task correctly in the first place
- Laziness—Sometimes employees do not want to or are unable to provide the required effort
- Haste—Working too fast can contribute to unsafe work conditions
- Poor physical condition—Employees need to have proper rest and for some tasks must be physically fit
- Temper—Impatience and anger can cloud judgment and result in accidents

Reading through the list above you might have thought that most if not all of these are preventable. If so, you would be right. Most unsafe acts and conditions are preventable. That is not to say all accidents can be avoided, but many can by simply avoiding the list above.

Safety Training Topics

One of the most important aspects of a safety program is training the workforce. Some training topics are required to be completed by employees on a routine basis. Standard training requirements are found in Occupational Safety and Health Administration (OSHA) regulations. Some safety requirements are under General Industry standards while others are specific based on the type of industry. The following safety training topics are general in nature, required throughout the water industry, and provide a high level of understanding.

Hazard Communication

Any industry where chemicals are used, annual training explaining the hazards associated with exposure to these chemicals in the workplace must be conducted. Employers should provide employees with training prior to initial assignment to their work area. Hazard communication (HazComm) training should identify the activities and locations of the chemicals in the workplace and the health hazards associated with exposure to the chemicals. Additional topics covered in the training include but are not limited to steps employees can take to protect themselves, labeling criteria of the chemicals. And clean up procedures.

As part of hazard communication training, an inventory list of chemicals needs to be provided and available to all employees. The details of which chemicals are required to be covered in training are beyond the details provided in this text. The example we will use is one of the more common chemicals used in the water industry. Chlorine is one of the most widespread chemicals used in drinking water distribution and treatment. In addition, chlorine is hazardous to health.

Several different types of chlorine related compounds are used in the disinfection of drinking water. Calcium hypochlorite is corrosive in water and can support combustion. Sodium hypochlorite is a very strong base on its own and becomes an acid in water. Operators should wear goggles and gloves when working with hypochlorites.

The most common disinfectant in drinking water is chlorine, which is a greenish/yellow gas. Since chlorine gas is two and half times heavier than air, ventilation is required in chlorine rooms. The ventilation vents should be twelve (12) inches above the floor. Since chlorine is a compressed gas and stored in cylinders, it should not be filled more than eighty-five (85) percent to allow for expansion. Another safety feature of chlorine gas cylinders is a fusible plug. One (1) ton cylinders have two (2) valves for removing either gas or liquid and six (6) fusible plugs. A one hundred fifty (150) pound cylinder has one of each. Fusible plugs are designed to melt between the temperatures of one hundred fifty-eight (158) and one hundred sixty-five (165) degrees Fahrenheit. If there are chlorine leaks in a cylinder, an ammonia-soaked rag can be used to help detect the leak. By waving an ammonia-soaked rag a white cloud would appear. High levels of chlorine in the air affect respiration and the immediately dangerous to life and health (IDLH) level is 10 parts per million (ppm).

This example is just one of many where chemicals are used in the workplace and employees need to be properly trained on the hazards associated with working with and around these chemicals. In 2003, the United Nations adopted the Globally Harmonized System of Classification and Labeling of Chemicals (GHS). In 2009, OSHA published regulations to align their Hazard Communication standard (HCS) with the GHS. There are five (5) mandatory components of OSHA’s HCS, one of which includes an update to what was previously known as Material Safety Data S, which sheets. The revised standard refers to Safety Data Sheets (STS) and sixteen (16) required sections with information about each chemical. If there is no relevant information under one of the subject headings, then the SDS must clearly indicate that no applicable information is available.

Personal Protective Equipment

One of the sections on an SDS must reference personal protection from exposure to chemicals. In addition, personal protective equipment (PPE) has its own regulatory standards regarding training, what types of working conditions might require PPE, and how to Don, Doff, and care for PPE.

Each employee is responsible to maintain their own PPE and notify their supervisor whenever it needs replacing. It is the management's responsibility to provide the training and required PPE needed by the employees. The following PPE examples are just some common types of personal protective equipment.

- Hard hats—Any time there is a potential for head injuries including low headroom working conditions or overhead items, which can fall on an employee, hard hats are required. Metal or plastic hard hats can be used, but metal hard hats should not be used where there are electrical hazards.
- Gloves—If there are pinching, cutting, crushing, or other hand-related injuries, then gloves should be worn. In addition, gloves may also be required when working with or around chemicals.
- Respiratory—When surrounding air contains dust, fumes, mists, or any other particulates, which can be inhaled, then respiratory protection is required. Respiratory protection can be as simple as a dust mask or as complex as a self-contained breathing apparatus.
- Eye Protection—Goggles, face shields, safety glasses are all forms of eye protection. Dust and debris can cause irritation is they get into someone's eyes. Any kind of object, including chemicals, can all cause damage to the eye.
- Steel-toed boats—It is prudent to wear foot protection in any construction-related industry. Therefore, steel-toed boats are often required.
- Hearing Protection—Earplugs provide ear protection from loud noises and sounds. Earmuffs can also be used to protect ears.

Understanding how to don and doff PPE is an important aspect of PPE training and all employees should understand the proper way to wear the appropriate equipment.

Slips Trips and Falls

Sometimes, the simplest and most common hazards can result in personal injury. Slips, trips, and falls should always be avoidable. Often times, it is a matter of good housekeeping. Making sure floors and walking surfaces are clear of debris and any kind of slipping or tripping hazards. Walking areas should have slip-resistant surfaces and proper handrails should be provided on stairways, catwalks, and areas where walking can be difficult. Fall protection also needs to be provided on elevated surfaces.

Back Safety

Back injuries are one of the most common injuries in the workplace. Improper lifting, twisting, pulling, and pushing are all aspects of back safety. Whenever lifting something heavy, workers should always bend at the knees and keep their back straight. One person should never lift large and heavy loads. When carrying something heavy, you should always turn with your legs and not at your waist. Equipment should also be used when appropriate to help lift and/or move heavy objects.

Trench Safety

Trenching is a method of digging into the ground to install things such as pipes. Whenever work is done inside a trench, special precautions need to be made in order to protect workers from the possibility of a cave-in. There are specific requirements based on the depth of the trench. If trenches are shallow (less than five (5) feet) then the danger is not as great as it is with deeper trenches. However, workers can still get trapped in shallow trenches. When trenches are five (5) feet or deeper, special protection is required. This protection is referred to as shoring, shielding, or sloping. If there is enough room, then sloping is allowed. Sloping is the process of reducing the depth of a trench by removing soil and opening the width of a trench to prevent the trench walls from collapsing. Shoring and shielding is the process of using equipment placed up against trench walls. The dirt being excavated (referred to as spoils) should be placed at least two (2) feet away from the trench edge and on the side opposite of the pipe being installed. If trenches are long, then ladders should be placed within twenty-five (25) feet of workers. Another important aspect of trench safety is proper supervision. Special training must be provided to individuals overseeing trenching activities. These individuals providing supervision are referred to as a "Competent Person".

Confined Spaces

A confined space is defined, as a workspace, which has limited or restricted means of entry or exit, is large enough for an employee to enter and perform work, and is not designed for continuous work or occupancy. Confined spaces are defined as "permit-required" and "non-permit required" confined spaces. In order for a confined space to be classified as a permit-required confined space, it must meet the following conditions:

- Contains or has the potential to contain a hazardous atmosphere
- Contains a material that has the potential for engulfing an entrant
- Has an internal configuration such that an entrant could be trapped or asphyxiated by inwardly converging walls or by a floor that slopes downward and tapers to a smaller cross-section
- Contains any other recognized serious safety or health hazard

The internal atmosphere of a confined space must be tested for oxygen content, flammable gases, and vapors, potentially toxic air contaminants, hydrogen sulfide, and methane. Ventilation equipment should be used to provide acceptable air conditions. Three (3) or more workers should be involved with permit-required confined spaces. One (1) or more workers inside the confined space, one (1) worker in communication with the worker(s), and one (1) worker to respond and retrieve emergency personnel if needed.

Respiratory Safety

As previously mentioned, it is important to provide workers with respiratory protection if the surrounding atmosphere is not adequate for a working environment. Respiratory hazards include, but are not limited:

- Dust from rock, cement, coal, and wood
- Dust from toxic materials such as lead, arsenic, and asbestos
- Mists and fumes from chemicals and heated materials
- Vapors and gases from chemicals such as chlorine, ammonia, and carbon monoxide
- Oxygen deficient environments

Respiratory problems can range from very mild irritation causing coughing and wheezing, to death. Respirators can be broken down into two main types, air purifying and atmosphere supplying.

Air-purifying—These types of respirators use cartridges, filters, or canisters to remove contaminants from the air. In order to remove vapors and gases, a granular porous material referred to as an absorbent needs to be used. The type of filter, cartridge, or canister is dependent on the type and amount of the airborne contaminate. For example, a particulate filter would not necessarily remove vapors or gases. Therefore the employer must identify the contaminant(s) and provide employees the proper protection against dust, fumes, mists, and solid particulate matter.

Atmosphere-supplying—In certain circumstances, the surrounding atmosphere is not suitable for breathing and purifying the air may not be sufficient. Therefore, a respirator where clean air is provided should be used. A common situation where this might occur is when the surrounding atmosphere lacks adequate oxygen levels or is considered oxygen deficient. At this point, atmosphere-supplying respirators are required.

There are a number of various other safety topics, which should be considered if potential hazards exist. Some of these topics include, but are not limited to hand and power tool safety, electrical, head, body, and extremity protection.

Traffic Control

Utility workers often work in roadways. Whenever work is performed in traffic areas, the Manual on Uniform Traffic Control Devices for Streets and Highways should be used. This manual is published by the US Department of Transportation (USDOT) and specifies approved traffic control devices and procedures. Some states have their own traffic control reference manuals and those should also be reviewed before working in the street. If improper traffic control is set up, the utility can be held liable for damage from accidents. Often times special permits, such as encroachment permits are required as well as special traffic control plans need to be submitted to the governing agency. Traffic control devices such as cones, pylons, and other systems are used to channel the flow of traffic to designated areas. There are five (5) zones within a construction worksite in roadways:

- Advanced Warning Zone—This area is a warning to drivers letting them know what to expect. This advanced warning can be as simple as a single flashing light to a series of signs and notifications prior to the temporary construction work and change in the flow of traffic.
- Transition Zone—Whenever the redirection of the normal flow of traffic is required, a transition area is needed. Traffic must be channelized from the normal flow to the new path in order to avoid the construction area.
- Buffer Zone—While not required, it is an important area for the protection of workers. It is an area between the flow of oncoming traffic and the area where employees are working.
- Work Zone—This is the area where the work is being performed. Workers and equipment are within this area. By the time traffic reaches this area, it should be completely redirected out of this zone.
- Termination Zone—As with the transition zone, the termination zone is redirecting traffic. Except in this zone, traffic is being returned to its normal flow path.

The taper lengths and buffer zones have specific distances in relation to traffic speed. More traffic control devices, longer taper lengths, and larger buffer zones are needed as the speed of traffic increases.

Occupational Injuries

All injuries in the workplace should be reported immediately. This early reporting not only helps the utility determine if the injury occurred at work and it also speeds up the process for the employee to start any type of worker's compensation. An occupation injury is defined as any personal injury sustained by an employee during the course of work. Employees should report their injury to their supervisor or to the organization's safety representative. Utilities typically have injury report forms. These forms should be simple but informative. They should contain information from both the employee and supervisor. The employee is responsible for reporting the injury and the supervisor and safety representative are responsible for making sure the report form is completed correctly.

All injuries should be investigated. Accident and injury investigations provide an opportunity for the safety professional to speak with the employee and any witnesses. It allows for feedback on the cause of the incident and give the safety professional the opportunity to provide feedback on the necessity of exercising care and caution. It also presents the opportunity to identify any unsafe work practices or conditions and allows for recommendations on workplace improvements.

Safety professionals should prepare and review a variety of reports associated with workplace accidents and injuries. These include, but are not limited:

- Number of lost-time injuries—any injuries resulting employees missing time from work
- Number of injuries requiring first aid—first aid kits should be provided at each workplace and with workers who work in remote locations
- Number of injuries requiring medical attention—any injury where an employee receives assistance from a medical professional
- Number of lost time days—when employees miss work due to an injury, this is referred to as lost time

There are also OSHA related performance measures safety professionals use to track and interpret the prevalence of workplace-related injuries. These include:

- Incidence Rate—This is based on the number of injuries requiring more than first aid per 200,000 hours worked
- Frequency Rate—This is the number of lost time accidents per million employee hours worked
- Severity Rate—This is the number of days lost or charged per million employee hours worked

OSHA has specific reporting requirements related to workplace injuries. Most organizations are required to maintain an OSHA Form 300 Log. This log lists all recordable workplace injury and illness. OSHA defines a recordable injury or illness as:

- Any work-related fatality
- Any work-related injury or illness that results in loss of consciousness, days away from work, restricted work, or transfer to another job
- Any work-related injury or illness requiring medical treatment beyond first aid
- Any work-related diagnosed case of cancer, chronic irreversible diseases, fractured or cracked bones or teeth, and punctured eardrums

In addition to these definitions, there are also special recording criteria for work-related cases involving: needle sticks and sharps injuries; medical removal; hearing loss; and tuberculosis. In general, minor injuries and injuries requiring first aid treatment do not need to be recorded. All employers are also required to notify OSHA directly when an employee is killed on the job or suffers a work-related hospitalization, amputation, or loss of an eye. Fatalities must be reported within eight (8) hours and in-patient hospitalization, amputation, or eye loss must be reported within twenty-four (24) hours.

Safety is a very important aspect for all occupations. Water utility operations are no exception. It is important for safety to be supported from the top executives all the way down throughout the organization. Ultimately, the primary person responsible for safety is…YOU!

Sample Questions

1. When symptoms develop rapidly within a person it is considered ___________.
    1. A chronic health effect
    2. An acute health effect
    3. A disease
    4. Both 1 and 3
2. What is the primary responsibility of the safety officer?
    1. Should be a line function
    2. Should be a staff function
    3. Should provide all the training
    4. All of the above
3. Traffic control should be set up in the following order:
    1. Buffer Zone, Transition Zone, Work Zone, Termination Zone, Advanced Warning
    2. Advanced Warning, Buffer Zone, Work Zone, Transition Zone, Termination Zone
    3. Advanced Warning, Transition Zone, Buffer Zone, Termination Zone, Work Zone
    4. Advanced Warning, Transition Zone, Buffer Zone, Work Zone, Termination Zone
4. Fusible plugs are designed to ___________.
    1. Melt, preventing combustion
    2. Melt between 158°F - 165°F
    3. Fuse the valve connection to the hose
    4. Only 1 and 2
5. A 1-ton chlorine cylinder has ___________.
    1. 2 fusible plugs and 6 valves
    2. 2 valves and 6 fusible plugs
    3. 1 valve and 5 fusible plugs
    4. 5 valves and 1 fusible plug
6. The IDLH for chlorine gas is ___________.
    1. 5 ppm
    2. 10 ppm
    3. 20 ppm
    4. 100 ppm
7. All fatalities, serious injuries and illnesses must be reported to Cal/OSHA within ___________.
    1. 8 hours
    2. 16 hours
    3. 24 hours
    4. 48 hours
8. A chronic health effect is ___________.
    1. An adverse effect developing rapidly

2. An adverse effect resulting in cancer
3. An adverse effect developing over a long period of time
4. A disease with little or no symptoms

CHAPTER OVERVIEW

12: Water Customers

12.1: Water Rates

Student Learning Outcomes

After reading this chapter, you should be able to:

- Evaluate different rate structures
- Understand why water rates are needed
- Analyze water rights and utility ownership

Why Are There Water Rates?

Water must be sold in order for a utility to be able to treat, distribute, and deliver water. There are chemical, electrical, infrastructure, labor, and a variety of expenses a water utility must cover. In order to pay for all these expenses, they must receive revenue to cover all the costs associated with operating and maintaining a water utility. This required revenue is referred to as revenue requirements.

Revenue requirements can be explained, as the total revenue required to ensure proper operations and maintenance, development, and perpetuation of a distribution system, and preservation of the utilities' financial integrity. Most of the revenue received by a water utility comes from the sale of water. However, some utilities receive supplemental revenue from renting property, merchandising, services related to other utilities, taxes, capacity, and impact fees.

Utilities must properly budget based on projections of water sales and all associated expenses for proper water rates are assigned in order to generate enough revenue. Sometimes budgets and associated projections extend out multiple years. Regardless of budgetary projections, they should be reviewed annually and adjusted accordingly.

Water rates studies and analysis usually accompanying any rate changes. Budget projections aid this process of rate-making. Additional studies can also include financial and budgetary planning, support for issuance of debt, and evaluation of past and future adequacy of contractual, litigation, rate proceeding or other requirements.

When a utility is calculating the adequacy of revenue in order to recover costs. Budgeting may require projections into the future. Projections beyond ten (10) years tend to be quite speculative, while five (5) projections are usually considered adequate. Historical water usage and other data is used to help determine appropriate water rates. However, the data must be normalized or adjusted to reflect conditions that may not continue in the future. For example, if there will be no future growth of additional customers, the need for additional sources of supply and storage may not be needed.

Below is a list of some factors affecting revenues:

- Number of customers served
- Customer water use
- Rate changes
- Non-recurring sales
- Weather
- Conservation
- Use restrictions
- Price elasticity

Below is a list of factors affecting revenue requirements:

- Number of customers served
- Customer water use
- Non-recurring sales
- Weather
- Conservation
- Use restrictions
- Inflation

- Interest rates on debt
- Capital financing needs
- Changes to tax laws
- Other changes in operating
- Economic conditions

There are two general approaches for projecting revenue requirements. They are cash-needs approach and utility approach.

Cash-Needs Approach

The cash-needs approach ensures revenues are sufficient to recover all the utility cash needs for a given projected time period. This approach simply means the total amount of revenue needed to meet cash expenditures. The cash-needs approach usually relies on debt financing. Debt indentures usually specify sufficient cash to meet cash expenditures, deposits are made to reserve account(s), and debt-service coverage requirements are met.

The accounting term "cash" refers to revenues being recognized as earned when cash is received and expenses charge when cash is disbursed. The term "accrual" refers to revenues being recorded when earned and expenditures are recorded when the become liabilities for benefits received and are not dependent on what period of time they are received.

The cash-needs approach is usually followed by public (government-owned) water utilities. Elected officials of public water utilities are tasked with approving water rates.

Utility Approach

The utility approach of projecting revenue requirements is mandated for all investor-owned (private) water utilities. This approach is also referred to as "utility basis" approach. This approach is similar to the cash-needs approach. However, the governing regulatory body assigns a "rate payer advocate". In California, this rate payer advocate group is referred to as the Division of Rate Payer Advocate (DRA) and the governing body is the California Public Utility Commission (PUC).

This approach involves measuring revenue requirements with or without concern for allocating revenue requirements among classes of customers served. This means assigning or not assigning specific revenue requirements to specific classes of customers.

Revenue Requirement Components

In order to determine the revenue requirements, a utility must determine all the operating expenses. In other words, what does it cost the utility to provide service. On the surface, this might seem like an easy and straightforward task. However, there are a lot of aspects to operating a water utility and it is important to capture all these expenses. The following list is not exhaustive, but it is fairly comprehensive.

- Administrative costs
- Salaries
- Benefits
- Energy costs
- Chemicals
- Supplies
- Fuel
- Equipment costs
- Equipment replacements
- Principal and interest payments on debt
- Miscellaneous

The paragraphs below will provide additional detail for some of these operating costs.

Operations and Maintenance

These expenses are usually based on actual expenditures and adjusted to reflect anticipated changes. Operations and maintenance (O & M) costs include employee salaries, wage, benefits, purchased power to operate pumps and equipment, purchased water from other utilities, chemicals for treatment, supplies, tools, equipment, vehicles, fuel, outside services, and general overhead. Some outside services can include, billing services, construction contractors, engineering and other consultants, other utility services. This list is not exhaustive but should provide a good general understanding of the various O & M expenses.

Some utility expenses are considered fixed costs while others are referred to as variable costs. Fixed costs are the costs the utility most cover to keep the utility in operation and are independent on the amount of water the utility sells. For example, if the water utility does not experience the anticipated water demand (this could be due to water use restrictions during a drought) the amount of revenue recovered would be lower than expected. However, the utility would still need to out salaries, benefits, and administrative costs. The staffing requirements are not directly proportional to the amount of water sold. Water meters would still need to be read, infrastructure, equipment, and vehicles would also need to be maintained. These costs would be considered fixed costs. Whereas, the amount of chemicals needed to treat the water might be less if the utility is producing less water. Therefore, the cost for chemicals would be less and this would be considered a variable cost. Regardless of the type of cost, the utility would still need to recover these revenue requirements.

Debt Service

Sometimes utilities require large amounts of funds in order to pay for large capital improvement projects. Some of these projects consist of new sources of supply such as groundwater wells, large storage facilities, and other major infrastructure improvements. If a utility had to spend several millions of dollars in a given year and tried to collect these expenditures in the same year, water rates would be unusually high. Therefore, a utility acquires debt in order to spread out these costs over multiple years. Debt service is the annual cost to pay the debt back. It includes both principal and interest.

Reserves

Water utilities commonly maintain reserve accounts. Reserve accounts are savings accounts. They are usually set aside for emergencies or unexpected needs. For example, if a utility has earthquake insurance, a specific reserve account can be set aside to cover the deductible costs and start making payments to begin the immediate process for repairs to the system. Another example might be a reserve account to replace a large expensive facility if there is an unexpected failure.

Capital Expenditures

Water utilities will typically have normal routine replacement of existing facilities. All equipment and infrastructure have reasonably expected operating lives. For example, groundwater might last fifty (50) years. The utility would have to plan for the replacement of these facilities. Another example is the piping infrastructure. A utility might have two hundred (200) miles of underground pipelines. Let’s assume the average lifespan of this pipe is seventy-five (75) years. This would mean the utility would need to replace on average 2.7 miles or 14,256 feet a pipe per year to keep up on the replacement schedule. Capital improvement projects (CIP) would also include annual extensions and other improvements. Often times, large CIP is financed through debt, reserves, or some combination. Very rarely are large projects paid for with cash. Issuing debt or using reserve funds prevents the customers from paying 100% of the initial cost of facilities.

Coverage Ratio

A common measurement to help determine the financial health of a utility is the coverage ratio. This is the measure of the ability of the utility to pay the principal and interest on all loans and bonds. It is calculated by subtracting the non-debt expenses from the total revenue divided by debt service expenses. A good financial coverage ration would be above 1.0.

Revenue

Where does a water utility get the money to fulfill revenue requirements? There are typically three (3) classes of revenue; Operating revenues, non-operating revenues, and contributions to capital.

Operating revenues include both metered and unmetered water sales. Most of the time, the sale of water is metered. This means a customer pays for the water, which flows through their meter. Sometimes, utilities sell water at a flat rate or unmetered. If a water utility sells water to another water utility they would be considered a wholesale water provider. The revenue earned from these sales are also considered operating revenue. Any fee for or charge for water service is also considered operating revenue. For example, some utilities have a monthly fee for something referred to as a “readiness to serve” charge. This means if a customer has a meter service, but does not use any water for a period of time (i.e., month) the utility would still bill the customer for the ability or readiness to serve the customer. Often times this monthly service charge is based on the size of the meter. The larger the meter the higher the monthly charge. If a water utility rents property (i.e., cellular leases) or charges for the use of the utilities operating property, these would also be considered operating revenues.

Non-operating revenues is a smaller amount of revenue most utilities earn, but they still need to be taken into account. Examples of non-operating revenues include merchandising interest, dividends, sale of property, tax revenues, and various other revenues not associated with operating the utility. The last classes of revenue include funds contributed by developers and grant funds. These are considered contributions to capital.

Customer Classes

There are generally four (4) main classes of customers. These are identified as residential, commercial, industrial, public authority, and dedicated landscape. Residential customers consist of single and multi-family dwellings. This would include attached and detached homes, apartment buildings, condominiums, and townhomes. Commercial customers would include businesses such as restaurants, small and large businesses. Industrial customers would include manufacturing and processing establishments. Public authority would be public establishments such as schools, city, and county buildings. Dedicated landscape service connections are commonly separated from other service classes.

There are also some special classes of customers. These would include wholesale service, fire-protection, and service for air conditioning and refrigeration.

Wholesale service is usually defined as a situation in which water is sold to a customer at one or more major points or delivery for resale to individual retail customers within the wholesale customer's service area. This water is typically treated before being sold and is sold to a separate municipality or water district.

Fire protection service is primarily a standby service. There is a readiness to deliver relatively large quantities of water for short periods of time at any of a large number of points within a distribution system. The total quantity of water used is typically small and service costs are based on one of the following two criteria:

1. Cost of service is determined on the basis of the potential demand for water for fire fighting purposes in relationship to the total of all potential demands for water.
2. Cost of service is allocated as an incremental cost to the costs of general water service. It is based on the premise that the prime function of a water utility is to supply general water service.

Air conditioning and refrigeration is water sold for use in water-cooled air conditioning and refrigeration systems. Most units now use water referred to as "make-up" water. This is water recycled within the business.

Water Rates

It is common practice for a water utility to provide water service to all general service customers within a given jurisdiction through a single rate schedule, comprised of a two-part rate. There are three (3) common general classes of customers and these are:

- Residential—This customer class generally comprises of one and two family dwellings, usually physically separate.
- Commercial—This customer class is commonly comprised of multifamily apartment buildings and nonresidential, nonindustrial business enterprises.
- Industrial—This customer class represents manufacturing and processing establishments

Sometimes a utility will subdivide the general classes of customers into more specific groups. Water use characteristics, service requirements, and other various reasons may set certain customer classes apart from one another. Sometimes utilities will create special classes of customers, which can include wholesale, fire-protection, irrigation, and air conditioning/refrigeration services.

The jurisdictional area referred to above is the service area boundary. A governing body of each water utility determines service area boundaries. In the case of investor-owned private utilities in California, the governing body is the California Public Utilities Commission (CPUC). Within the County of Los Angeles, the governing body is the Local Agency Formation Commission (LAFCO). Commonly, a two-part water rate includes an initial charge, which generally recovers customer related and possibly some volume related costs of the utility, together with a volumetric charge to recover the remaining costs. Some utilities recover their fixed costs with a monthly charge not associated with the amount of water sold. The variable revenue requirements would then be covered by the volumetric charge for water. The volumetric charge is based on the amount (or volume) of water sold.

Why would a utility have a two-part rate versus just charging water based on the actual usage of each customer? This is a common question people sometimes ask. The simple answer is because of the variability in how much water people use. What would happen if every customer only used a small quantity of water? Earlier in this text, we discussed revenue requirements. A utility must sell enough water or more importantly collect enough revenue from the sale of water, to cover all their related "requirements" to operate. If customers use too little water, then the utility would not be able to collect enough revenue, unless they charged an exorbitant amount for each unit of water. An example of this will be presented in the last chapter of this text (Waterworks Mathematics). Therefore, oftentimes, a utility will have a "fixed" charge. This fixed charge is sometimes referred to as a readiness to serve charge. This allows the utility to collect sufficient revenue to keep the utility running regardless of the amount of water sold. It commonly covers meter reading, billing, and day-to-day operational costs. Therefore, a two-part rate, one part fixed and the other part variable is commonly used.

Flat Rates

A fixed charge is different than a flat rate. A flat rate is something utilities sometimes use when the water supply is plentiful. It is the same charge across all customer classes and users. It is an amount, which must cover the revenue requirements of the utility, but is blind to the amount of water each customer uses. This type of rate is becoming less common, especially in California where drought often affects certain parts of the state. It is also not an even or equitable means of charging for water service. It also does not encourage water savings or conservation.

Variable Rates

As previously mentioned, a variable rate is based on the amount of water customers use. Therefore, the more water a customer uses the more revenue the utility collects. Conversely, if a customer uses zero units of water over the billing cycle, then the utility would collect no revenue from this particular customer. Also, as previously mentioned, fixed charges can and are oftentimes included with a variable water rate.

Tiered Rates

Much like variable rates, a fixed charge is usually included with tiered rates. Tiered rates are another type of variable rate structure. However, in a tiered rate the variable price increases with usage. For example, each unit of water would be sold at a specific amount up to a certain unit usage set point. Then after the designated amount, the charged amount is increased until another specific usage amount, and so on. See a simple example below.

- 0 – 9 Units of Water Used = $1.00
- 10 – 19 Units of Water Used = $2.00
- 20 – 29 Units of Water Used = $3.00
- 30 or More Units of Water Used = $4.00

Tiered rates are designed to encourage water conservation. The belief is as water becomes more expensive as usage goes up, usage would be curbed. While tiered rates have been shown to contribute to conservation efforts. However, there are other issues associated with charging more for water based on customer usage. The utility must explain the reason they are charging more for quantities above specific usage amounts. There have been several lawsuits associated with the legality of tiered water rates. One such lawsuit was in 2015 between a group of San Juan Capistrano taxpayers and their local water utility. It is extremely important a utility properly explains and notifies their customers before implanting water rates, especially tiered water rates.

Budget Based Rates

A budget based rate structure is similar to a tiered rate structure. The difference between the two is instead of charging water purely based on the quality of water used. In a water budget based rate structure, water charges are assigned based on customer usage both indoors and outdoors. While most utilities do not measure these (indoor/outdoor) uses separately, under a budget based water rate, a certain volume is often assigned for indoor water use. In addition, a specific amount is assigned for outdoor water use (irrigation).

These assigned amounts are considered a customer's budget. The rate assigned to the budget is a standard volumetric water rate. If customer's stay within their budget, do not use more than the allocated amount, then the rate does not change. However, if a customer uses more water than their allocation, the cost of water increases similar to a tiered structure.

Another difference to a water budget rate structure compared to a standard tiered rate structure is budgets are commonly personalized for each customer. In a tiered system, all customers follow the same tiered rate, whereas budgets can be based on the specific water needs of each customer.

Regardless of the rate structure, the utility must be able to adequately recover its revenue requirements with the chosen rate structure. Rates are designed for specific periods of time known as the rate schedules. Projections of expenses are compared against projections of water use and then a rate can be calculated. During a water rate study, utilities will commonly use something referred to as a test year. A test year is an annualized period for which costs are analyzed and rates are established.

Utility costs for ongoing operations and maintenance of the system as well as past large capital improvements must be incorporated into the water rate. In addition, utilities need to properly account for future replacements and growth of the utility. While existing customers typically cover a large portion of these costs, some of the future expansion of a system should be and often times is paid for through fees to construction developers. These fees are referred to as facility capacity and connection fees. These fees are associated with expanding a system in order to supply water to additional customers.

The concept of recovering costs and expenditures through the sale of water is a fairly simplistic concept. However, determining necessary costs and expenditures and calculating the water rate associated with recovering this money is a difficult and complex process in order to keep the customer of water reasonable to the customer, but also ensuring the utility has enough cash flow to keep operations flowing.

Sample Questions

1. Budget projections beyond 10 years tend to be ___________.
    1. Accurate
    2. Speculative
    3. Adequate
    4. Both 1 and 3
2. The "Cash-Needs" approach is typically used by ___________.
    1. Private utilities
    2. Public utilities
    3. Agencies with multiple commodities
    4. All of the above
3. Which of the following is not included in O&M expenses?
    1. Salaries
    2. Purchased water
    3. Chemicals
    4. None of the above
4. Investor-owned utilities are governed by ___________.
    1. An elected board of directors
    2. A City Council
    3. The California Public Utilities Commission
    4. A Mayor
5. A periodic stated charge for utility service not based on the metered quantity of service defines ___________.
    1. Firm service
    2. Flat rate
    3. Rate blocks
    4. Standard rates
6. The annualized period for which costs are to be analyzed and rates established defines ___________.

1. Test year
2. Yearly projections
3. Annual analysis
4. None of the above

7. Connection fees are charged to ____________.

1. Create revenue for O&M expenses
2. New customers for the costs of new facilities needed to apply water
3. Help establish service area boundaries
4. All of the above

12.2: Public Relations

Student Learning Outcomes

After reading this chapter, you should be able to:

- Explain the importance of public relations as it pertains to public perception
- Identify the key areas where communicating to the public is important
- List four (4) main areas the public experiences a water utility and their workers

Many times, public relations are looked at as a marketing strategy for businesses selling a product, or, perhaps a government agency disseminating information to a certain constituency or group of voters. Public relations (PR) is nothing more than the spread of information between an individual or an organization to the public. Therefore, PR is just as important for a water utility.

Even though customers do not have a choice who they receive their drinking water from, it is important for a water utility to be open, transparent, and helpful to their customers. Therefore, providing good public relations is important.

A water utility is in the public eye in a variety of ways. Utility vehicles are driving throughout a town performing work. Meter readers often visit customer homes to read a water meter. Every time someone turns on their faucet and the water coming out is unacceptable or when someone receives a high water bill, the water utility is often the one a customer will blame.

Some areas water utility workers are exposed to the general public include, but are not limited to meter reading, operations and maintenance workers, vehicle operation, public meetings, and customer calls and complaints. These are not the only instances where customers can and interact with water utility workers.

Meter Readers

Meter readers have the potential of interacting with customers on a routine basis. Meters are generally located near the property boundary of customers and in some parts of the United States; they can be installed inside customer buildings. Therefore, a customer might approach an employee reading meters. Customers can be in search of specific information about the service they are receiving or perhaps they might have questions about something they heard about in the news. Regardless of what a customer might be asking, it is important for meter readers to be respectful and polite.

Meter readers should maintain a neat appearance. Many utilities provide their employees with uniforms, which clearly display the utility's name. If a meter reader is speaking with a customer they should provide some form of identification letting the customer know who they are and whom they work for. If a customer's meter is inside a customer's residence, a customer may be reluctant to allow them into their home without proper identification or someone who is wearing worn-out clothes, dirty, or unshaven. Meter readers should be properly trained and have a good general understanding of utility operations. However, at no time should any employee, including meters, feel responsible to answer any questions they are unfamiliar with. Sometimes meter readers will carry around brochures with frequently asked questions and they should always provide the customer with a phone number to call, in order to receive additional information. While reading meters, a meter reader should also be aware of any abnormalities with the customer's service. If a leak is detected on the customer's side of the service, they should attempt to contact the customer. If a customer is not home, often times a water service notice tag is left on the customer's door. Whenever dealing with the public a meter reader should stay pleasant and polite.

Operations and Maintenance Workers

This group of workers does not typically have direct contact with customers. Therefore, while they should maintain a neat appearance, it is not as important as with meter readers. Sometimes when workers are working in the public right of way (i.e., streets, sidewalks, etc) a local resident may inquire about the work they are doing. While it may seem obvious to the worker, they need to remember most of the time the public is just curious. Therefore, it is important for the worker to be polite and to refrain from "smart aleck" responses. It is oftentimes best for a worker to refer the inquisitive public to the supervisor in charge of the work instead of trying to answer all the questions they might be asked. It is important for the utility to give the public proper notice whenever service is planned to be disrupted or when streets might be closed. This can be accomplished through mailers, calls, or signs placed in the work area. During planned shutdowns for repairs or new installs, door hangers are commonly used to provide the local residents notice.

All work zones should be properly marked and kept safe. Safety cones, tape, and other means can be used to block public access in order to protect public safety. Work zones should also be kept as clean as possible and workers should avoid sitting or walking on private property. Customers generally do not like workers taking their breaks on their lawns. Equipment and vehicles should look clean and professional and tools should not be scattered around the worksite. After the work is complete, the workers need to leave the area in the condition (or better) as they found it.

Vehicle Operation

Water utility workers generally drive a significant amount throughout their day. This increases the potential for accidents and citations. Therefore, it is critical that all utility drivers need to be careful, follow all driving rules, and be extremely cautious of their surroundings. Careless driving also makes people angry. If a utility worker is driving too fast or appears to be driving carelessly, residents often take note and many times will call the utility to complain. This generally leads to a situation where it is the worker's word versus the resident's word. Courteous driving leaves a better impression on the public and leads to less potential issues. Utility workers should also use good judgment on where they park their vehicles. It might make a bad impression if someone sees a utility truck parked in front of the local tavern, even if the worker is actually working around the corner.

Water Quality

Water quality throughout the United States is highly regulated and safe to drink. However, that doesn't mean customers like the taste, smell, and look of their water. Even if the water is considered safe to drink, if it is discolored, has an odor, and tastes odd, customers will complain. A good PR strategy for handling water quality complaints is very important in order for customers to be confident in the water they are being served. Typically, there are water quality professionals employed by a water utility to answer questions related to water quality complaints. They are trained to explain the potential causes of these unpleasant aesthetic qualities, offer suggestions to improve the quality, and offer to sample the water if necessary.

Many times, the aesthetic quality of the water is a result of internal home plumbing problems, such as old galvanized plumbing. However, sometimes water can be discolored in the distribution system from flushing or other flow changes in pipes. Other times a utility might change the disinfection practices for various reasons. This can result in taste and odor issues. If the utility is aware of potential changes in water quality from distribution activities, it is advised the utility notify customers ahead of time in order to prevent a large number of complaints.

In accordance with federal and state drinking water quality regulations, annual reports must be provided to customers stating the quality of water they are being served. These reports are referred to as annual water quality reports or consumer confidence reports. These reports typically list the sources of supply, results from water quality samples collected, and health effects data related to constituents found in the water supply. These reports while regulatory requirements are also public relations materials and it provides utilities another avenue for communicating with their customers.

Customer Service

The staff in customer service departments is the first exposure a customer has with a utility. Customers often call with questions or complaints about their service. Some customers pay their water bills in person. Customer service representatives can experience angry and hostile customers who are unhappy with the service provided by the utility. They may receive calls and complaints about high water bills, poor water quality, low or high water pressure, leaks, and a host of other issues customers might experience. These customer service representatives should be trained to be able to appropriately handle customer complaints and when to escalate complaints to their supervisors.

Customer service representatives should remain calm and polite, even if a customer raises their voice and/or gets angry. This is easier said than done. However, it is important to try and diffuse conflict with customers. If a customer is aggressive with an employee of a utility getting angry will only escalate the problem. Instead, it is recommended to listen, listen, and listen. People taking the time to call a utility and complain, want to be heard. Once you have listened to the customer's issue, offer to help. Even if there is not much you can do, the simple offer of wanting to help will go a long way.

Customer service representatives need to be provided with the proper tools to be able to adequately address customer concerns. Access to customer account information is important as well as a list of staff that the representative can refer or transfer customers to. For example, if a customer is complaining or has questions about the quality of their water, there should be staff within the organization that are able to answer questions and provide answers to customers. Therefore, properly trained staff is an important aspect of public relations and good customer service.

Media

The general rule most water utility workers should follow when it comes to talking with anyone from the media is, *don't do it*. There are too many opportunities for being misquoted and it can be embarrassing to see incorrect information in print, on the radio or television. Water utilities should have a designated media spokesperson to handle all questions and interviews from reporters. However, oftentimes, the front line workers are the first people on the scene and might be approached by reporters. If this happens, workers should give very brief and factual information about what they are doing and that is all. For example, if crews are responding to a water main break that is all the information the workers should offer. They can explain what they are doing and why they are at the location. However, they should avoid speculating as to the cause of the problem or how long they will be at the work location. They should let reporters know they are not qualified to go into more detail and that a supervisor or media representative will arrive on site soon.

Larger organizations can have designated public relations departments and spokespeople, commonly public information officers. In smaller utilities, middle or upper management staff is typically the designated spokesperson. Regardless of the spokesperson they should speak in facts only and never speculate.

Communication

It is important for a utility to properly communicate with its customers and the community as a whole. General communication about the service provided by the utility is important to convey to customers. Informing customers about changes in their water rates, conservation information, how to pay or where to pay water bills, or things such as business hours are all important items to communicate. In addition, it is important to properly notify customers and the general public whenever there's going to be work performed or water outages.

Strategic communication planning is also important. It is important to properly plan and relay information about changes in regulations, which can affect customers, changes in water quality or service reliability, and meet the public's expectations. There are four steps to successful communication planning. These include understanding the message, identifying the audience who will receive the communication, deciding on the type of communication, and the strategic planning of the dissemination of the communication.

It is important to establish a good working relationship with the local media. Working directly with reporters and writers for local newspapers and news media who typically write and report on environmental and utility-related issues is suggested. Working with the local media provides a means to open and honest dialog and the ability to help frame the stories they cover.

Public relations representatives should be accessible for comments regardless if the story is positive or negative. Access to subject matter experts should also be provided. Many times a story is about a topic involving issues of a complex nature. The subject matter experts should be available for interviews. However, they should also be able to explain complex subject matter in non-technical and understandable terms.

Public Media Events

Often times a utility will host a variety of public events. These events should be designed to provide valuable information and educate the participants about the event. These events can be joint events with other local agencies and organizations. They are typically intended to create public involvement and participation.

It is important to properly advertise the events and host in a location with ample space. All public events should be held in locations convenient to the public, have plenty of parking, and access to restrooms. A public event is designed to create a positive and informative perception of the local community.

While it is not necessary, utilities often have free items to hand out to the visiting public. If the event is a water conservation event, the utility may offer free low flow showerheads or other water-saving devices. If the event is about drinking water quality, free sample water testing kits are sometimes offered. Regardless of the event, free “trinkets” with the utilities logo or name are good ways to publicize the agency.

Emergency Information

No one looks forward to a crisis or emergency. However, all water utilities should be prepared to properly respond to and notify their customers in the case of one of these events. An emergency can be associated with a large water main break where traffic is disrupted and water service is lost to several customers to a major catastrophe where water service is lost to thousands of customers. Regardless of the extent of the emergency, the utility needs to be properly prepared.

In addition to operational planning of how a utility will respond to water quality and operational issues, a utility needs to have proper public relations planning and preparation. Some media notifications are required by regulations. For example, if a utility has a Tier 1 water quality violation, they must notify all of their customer within twenty-four (24) hours. In these situations, it is important not to waste any time. Therefore, it is important for the public relations team to prepare ahead of time. In these situations, if the utility has developed a good working relationship with the media, disseminating information is easier. It is important to know all the media outlets in the utilities service area, including but not limited to newspapers, radio stations, and television stations.

Interviews

When possible, interviews should be conducted with public relations personnel or by knowledgeable staff. There are things you definitely don’t want to say during an interview and there are strategies for giving a successful interview.

One common mistake by interviewees is not listening to the interviewer’s question. You should always take your time before answering a question and listen carefully to what is being asked. If the interview is live radio or television, be sure to speak clearly and try to avoid using acronyms and too technical details. An interviewee should always assume they are providing information to an uninformed audience. Keeping things to basic grade level responses can be effective. Always look at the person (reporter) interviewing you and try and not look at the camera.

Whether in print, audio, or visual media, the interviewee should try and disseminate information that is factual and stands on its own merit. Sometimes interviewers paraphrase information and you want to avoid any misinterpretation. In any print media, in-depth detailed information is generally acceptable. The reader has the opportunity to reread statements if they do not understand something. However, it is still important to provide facts and not opinions.

Sample Questions

1. Which one of the following is not an example where utility workers are exposed to the public?
   1. Meter reading
   2. Public Meetings
   3. Accounting
   4. Vehicle Operation
2. What would be a common mistake in a public relations interview?
   1. Not listening to the interviewer's question
   2. Answering a question specifically
   3. Looking at the person conducting the interview
   4. Disseminate factual information
3. In larger organizations, it is common to have ____________ act as the organization's public spokesperson.
   1. Middle Manager
   2. Public Information Officer
   3. Customer Service Representative
   4. Consultants
4. Operations and Maintenance workers typically have frequent contact with the public.

1. True
2. False

Index

Glossary

Sample Word 1 | Sample Definition 1

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