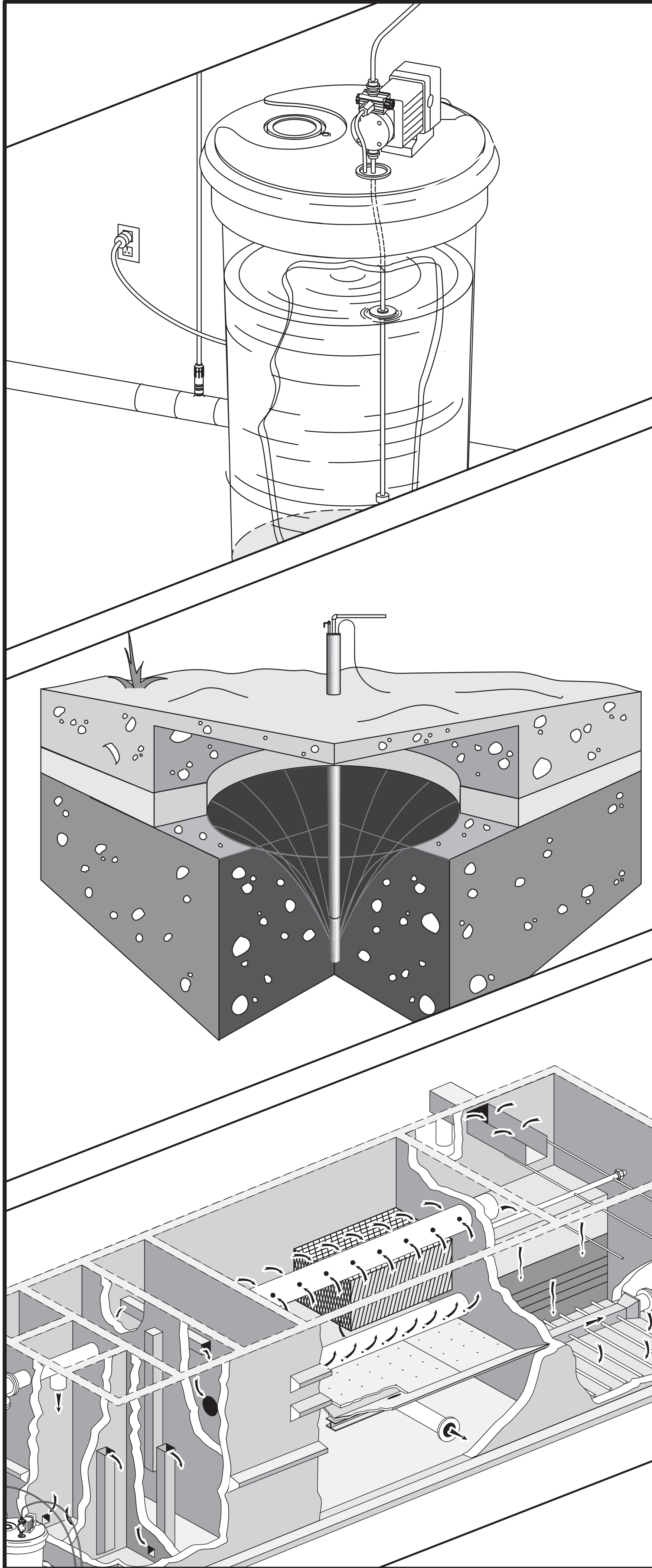

Introduction to Small Water Systems

A Course for Level 1 Operators

Introduction to Small Water Systems: A Course for Level 1 Operators

Original Development

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ATTAC welcomes your comments and suggestions for improvements to this manual in the interest of educating water utility professionals for the benefit of their local community.

Printing This Manual

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Foreword

One of the biggest challenges facing rural Alaskan communities is providing sustainable water services. Having adequately trained and qualified operators is a major part of that challenge. Since 1992 state, federal and private trainers have been delivering entry level water system operator training programs built around this manual. The manual serves as the official text for initial training of water operators, and satisfies the education prerequisite for certification at the Provisional Level. The manual has been critical in the effort to build operational capacity among Alaska's small, rural, public water systems.

This text has been revised to provide owners and operators of small public water systems a basic understanding of the principles and practices involved with collecting, treating, storing and distributing safe drinking water. This course and text material are narrowly focused on communities with a population of less than 3,300. However, we believe that an entry level through Level II operator at any treatment or distribution facility of any size will find the material helpful. Developing an understanding of the concepts discussed in this text should provide the information needed to be successful with the water treatment or the water distribution Provisional Level examination.

The job of water plant operator is an important one and is looked upon by the Alaska Department of Environmental Conservation as a key to the health of the community. Therefore, it is assumed that water plant operators recognize their responsibilities and perform their jobs in a manner that will protect the public health of their community. Failure to perform the responsibilities of the water plant operator can lead to potential health hazards and the loss of the "certified" status.

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Key Words

- Ambient
- Aquatic Life
- Atmosphere
- Celsius
- Community Water System
- Density
- Disinfection
- Evaporation
- Evapotranspiration
- Fahrenheit
- Humidity
- Hydrologic Cycle
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Introduction

Who Is This Manual For?

This training manual and course were developed to provide instruction for water system operators in the State of Alaska. The focus is primarily on small, rural Alaskan **public water systems**[1].

[1] Public Water Systems – Any source of water, intake works, collection system, treatment works, storage facility, or distribution system, including vehicle or vessel used to distribute water, from which water is available for human consumption.

Lesson Content

This manual describes water system components, their functions, and their operation and maintenance techniques and introduces the basic scientific concepts in the field of water system design, operation, monitoring, and management at a level that is addressed on the State of Alaska Provisional Level Water Treatment and Water Distribution System Operator Certification Exams.

The Role of the Water System Operator

Public Health Protection

The water system operator's most important job is that of a guardian of public health. The operator's job performance impacts the health and safety of everyone in the community. The community places its trust in the water system operator to provide a safe, reliable, and aesthetically pleasing source of drinking water. This can be difficult and challenging, but it's an immensely rewarding responsibility.

The Professional Water System Operator

The water system operator assumes a high level of responsibility to maintain the quality, security, and reliability of the community's water supply. The operation, maintenance, and management of public water systems require a working knowledge of water system technology, microbiology, chemistry, hydraulics, electronics, mechanics, and troubleshooting.

The professional water system operator must also understand system regulations and perform necessary monitoring and reporting. The modern professional water system operator is also a public relations specialist, who needs to be able to communicate effectively with the public, the community leaders, and students from schools who may request a tour of water system facilities. The operator should maintain the water system in a clean and orderly condition for reasons of safety, efficiency of operations, and public relations.

To become a water system professional, the operator needs to continually advance in education. The operator needs to develop the skills and knowledge required to pass the certification exams, to invest the time to renew certificates, and be willing to advance in certification levels after acquiring the necessary years of professional experience. This requires a high level of commitment to a career that will involve a lifetime of work, training, and dedication to the protection of public health. It is a profession that can provide excellent employment opportunities and a high level of job satisfaction.

What is Water?

Abundance
Water is one of the most abundant and common materials on earth. It covers 70 percent of the surface of the earth as water and ice.

Lifeblood
Water is the lifeblood of the universe. Without water, there could be no life. Our bodies are 70 percent water. Without drinking water for four to seven days, our blood becomes thick and contains a high concentration of toxic waste materials. We become delirious and unable to function. Death is not far behind.

Other Planets
Even though most other planets have water in some form, the earth is the only planet in the solar system that contains water in all its common forms (gas, liquid, solid). Others have ice, but only the earth has an abundance of this miraculous substance in the proper temperature range to support life.

Universal Solvent
Water is often called the "universal solvent." Given enough time, it will dissolve almost everything that it comes in contact with. Thus, it is effective in carrying food through our bodies to the individual cells and carrying away the cell waste.

Dissolves Minerals
As water flows over and through the ground, it picks up minerals, microorganisms, dirt, and plant material. The water, due to its speed, carries some of these materials along. Others, such as minerals, are dissolved in the water.

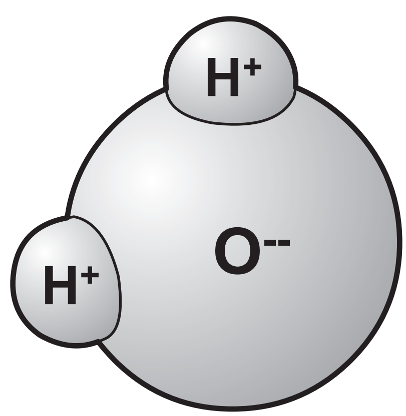
Gases
Water also has the ability to dissolve gases, such as oxygen (O_2) and carbon dioxide (CO_2). Dissolved oxygen in water allows fish and other **aquatic life**[2] to survive. The gills of the fish allow it to filter this dissolved oxygen directly from the water. Without oxygen, fish would die.

[2] Aquatic Life – All forms of plant and animal life that live in water.

The Water Molecule
The water **molecule**[3] has the chemical symbol H_2O (H_2 for two hydrogen atoms and O for one oxygen atom). The chemical symbol is read as "H two O."

[3] Molecule – The smallest division that a substance can be broken down to without separating its individual atoms.

Like a Magnet
The two hydrogen atoms are positioned at one end of the molecule. The hydrogen atoms are positively charged. When they attach themselves to the oxygen atom, the whole molecule becomes polarized with negative and positive poles, like a magnet. Because it has both negative and positive charges, it is much easier for the water molecule to attract other material. This is one of the reasons it is the "universal" solvent.



Water as a Chemical

States of Water

There are three basic states of matter: solid, liquid, and gas. Water is the only material on earth that is found in these basic states at standard temperatures, as ice, liquid water, and water vapor.

Molecules in Motion

The water molecule, like other molecules, is in constant motion. The rate of this motion is directly related to the temperature of the water. It moves slowest when the water is in the form of ice and fastest when it is a vapor.

Density of Water

As the temperature is reduced, the rate of movement slows and the molecules get closer and closer together. At 4°C they are as close together as they are ever going to be. This increases water's **density**[4] to its maximum. The volume that a set amount of water occupies is at a minimum at this point. Below 4°C the molecules are moving so slowly that their electrical charges begin to cause the molecules to line up in a pattern and form crystals.

[4] Density – The weight per unit volume of a substance.

Expands When It Freezes

At 0°C the crystals are fully formed, and the water molecules line up in a way that occupies a greater space than before the temperature reached 0°C. This expansion is what causes water to break a pipe when it is frozen. Water is one of the few compounds that expands when it freezes. This expansion gives ice a lower density than water, which makes it lighter and allows it to float.

Water and Heat

We measure heat by the amount of energy it takes to change the temperature of water. In the English system, the unit of heat measurement is the British Thermal Unit (BTU). One BTU is the amount of heat energy it takes to raise the temperature of one pound of water one degree **Fahrenheit**[5]. In the metric system, heat is measured in calories. One calorie is the amount of heat energy it takes to raise the temperature of one gram of water one degree on the **Celsius**[6] scale.

[5] Fahrenheit – Relating to an English thermometer scale with the boiling point at 212 degrees and the freezing point at 32 degrees.

[6] Celsius – Relating to a metric system thermometer scale with the boiling point at 100 degrees and the freezing point at 0 degrees.

Review

1. The most important job of a water system operator is:

2. List three skills that a professional water system operator should have.

3. Water is called the ____________________ solvent.

4. The three states of water are:

5. Water is at its maximum density at ____ °C.

Distribution of Water on Earth

The Study of Water

The study of water is called **hydrology**[7]. This next section briefly discusses the types of water sources, the distribution of water in those sources, and some of the uses of water.

[7] Hydrology – The applied science pertaining to properties, distribution, and behavior of water.

Definition by Sources

The sources of water on the earth are divided into two categories:

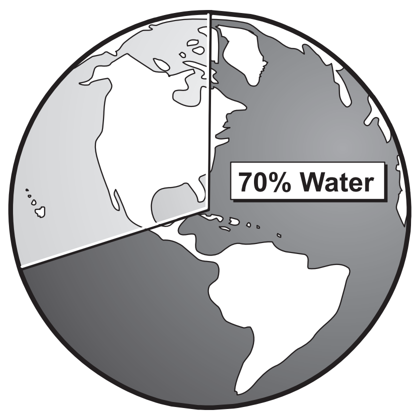
- **Surface Water** – Water that is found in oceans, lakes, streams, springs, and muskeg ponds. Surface water is exposed to the **atmosphere**[8] and is affected by **ambient**[9] conditions. This is the source of drinking water for some of our largest communities.
- **Groundwater** – All the water below the earth's surface. However, we consider only the water down to 2500 feet below the surface to be usable. Water below this depth is too hot and expensive to access. Groundwater may also include springs, which are considered to be either surface water or groundwater.

[8] Atmosphere – The gases that surround the earth.

[9] Ambient – The surrounding atmosphere.

70 Percent of Earth Is Water

Seventy percent of the earth's surface is covered with water. The total volume of water on the earth is approximately 305.79 million cubic miles. Of this total supply, 296 million cubic miles are in the oceans, leaving only 9.79 million cubic miles of fresh water.



Hydrologic Cycle

Introduction

The **hydrologic cycle**[10] is the key to our supply of fresh water. It is made up of four components:

1. The **atmosphere**
2. The **lithosphere**[11] – the crust of the earth
3. The **hydrosphere**[12] – the water on the earth
4. The **sun** – the energy source which drives the hydrologic cycle

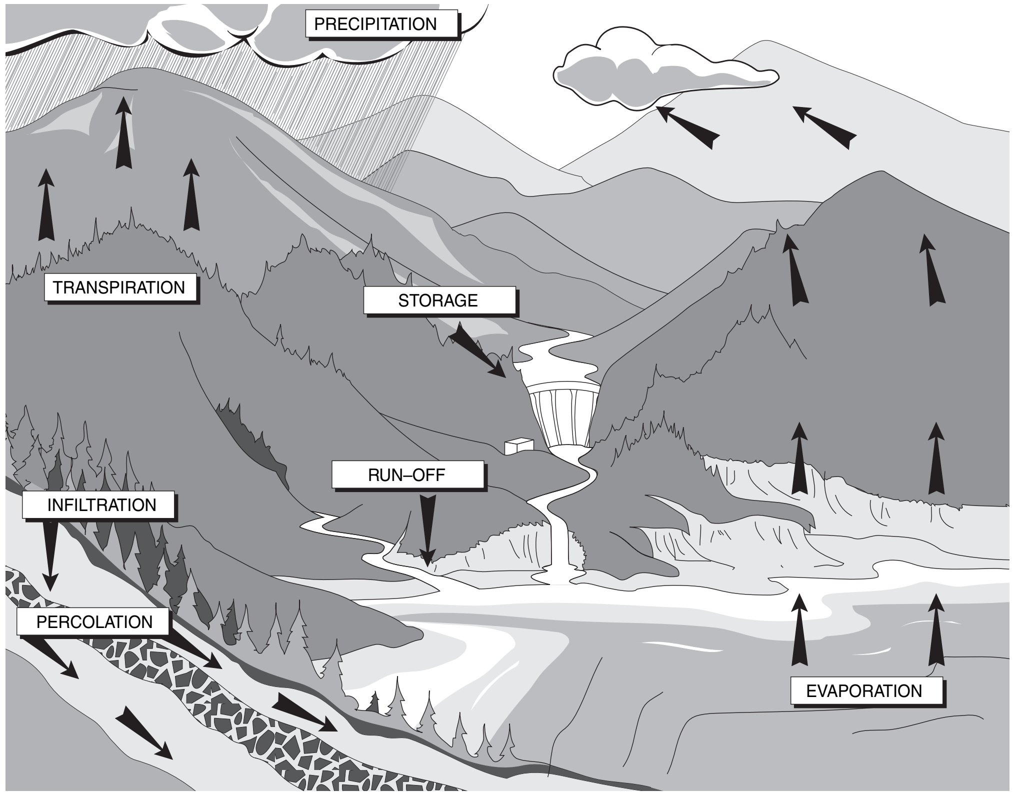
Available Water Supply

The amount of water available in the atmosphere, lithosphere, and hydrosphere remains constant. This water is continually recycled by the action of plants and the sun. To understand this process, let's follow the hydrologic cycle.

[10] Hydrologic Cycle – Nature's method of continuously recycling the earth's renewable water supply, between the earth and atmosphere, makes it possible to use this water over and over again.

[11] Lithosphere – The solid crust of the earth. It consists of the thin, loose layer known as soil and the mass of hard rock, several miles in thickness, upon which soil lies.

[12] Hydrosphere – All of the water on the earth.



Precipitation

You could start the cycle anywhere because it is continuous. So let's pick-up a droplet of precipitation and follow it through the cycle. **Precipitation**[13] in the form of rain, snow, or sleet falls towards the earth.

As the precipitation falls toward the earth, it can pick up contamination from industrial air pollution and natural pollution such as volcanic ash. As it falls toward the earth, some of the precipitation **evaporates**[14].

Evaporation

The amount of evaporation depends on several factors. Among them are the ambient **humidity**[15], air temperature, and the amount of wind. There is a significant amount of precipitation that is recycled back to the atmosphere before ever striking the ground. Some of the precipitation hits the forest canopy, brush, and grass. Some of the precipitation evaporates directly from the leaves of the canopy.

Some water flows down the outside of the trees onto the ground, and some strikes the ground directly. As water accumulates on the ground, it runs downhill. This movement is called **overland flow**[16].

Flows Along the Surface

As the water moves along the surface, it picks up contamination in the form of **organic**[17] material, such as bits of leaves; microorganisms such as bacteria, viruses, and protozoa; and **inorganic**[18] matter such as silt, clay, minerals, and volcanic ash.

[13] Precipitation – The process by which atmospheric moisture is discharged onto the earth's crust. Precipitation takes the form of rain, snow, hail, and sleet.

[14] Evaporate – The process of conversion of liquid water to water vapor.

[15] Humidity – The amount of water vapor in the air.

[16] Overland flow – The movement of water on and just under the earth's surface.

[17] Organic – Chemical substances of animal or vegetable origin, usually containing carbon.

[18] Inorganic – Chemical substances of mineral origin, not usually containing carbon.

Surface Water

The overland flow accumulates in lakes, streams, muskeg ponds, and rivers. These sources are referred to as surface water. A large quantity of surface water evaporates back into the atmosphere. In most of the world, this is the largest single loss of surface water.

Groundwater

Some of the water that runs along the earth's surface seeps into the soil. This process is called **infiltration**[19]. As the water infiltrates the soil and moves downward, some is taken up by the roots of trees and other plants. The water that is taken in by plants moves upward and is given off into the atmosphere through the leaves of the plants in a process called **transpiration**[20].

[19] Infiltration – The initial movement of water from the earth surface into the soil.

[20] Transpiration – The process by which water vapor is lost to the atmosphere from living plants.

Evaporation and Transpiration

This moisture mixes with the moisture that is evaporated from surface waters and from the plants. This combined process is referred to as **evapotranspiration**[21].

[21] Evapotranspiration – The combined vaporization of water from water surfaces and plants.

Groundwater Movement

The water not taken up by plants continues to move downward in a process called **percolation**[22]. This water continues to move downward until it collects in gravels and sands called aquifers. From there the water continues to move slowly towards adjacent lakes, streams, and the ocean, where it collects with the surface water and is evaporated back into the atmosphere.

[22] Percolation – Movement of water into and through the ground.

Springs

Sometime in the past, changes in the earth's crust left the edge of an aquifer exposed to the surface. This allows the groundwater supply to exit the hillside or mountain in what is referred to as a spring. From there it runs along the surface and mixes with surface water.

Back to the Atmosphere

As you can see, both the groundwater and the surface water eventually mix and are evaporated back into the atmosphere and form water vapor. This vapor is condensed by atmospheric conditions and forms precipitation, which falls to the ground and continues the cycle, providing us with clean fresh water for our water systems.

Review

1. The movement of water from the surface of the earth to the atmosphere and back to the surface is called the:

2. The term used to describe the movement of water from the surface of the earth to the atmosphere is called:

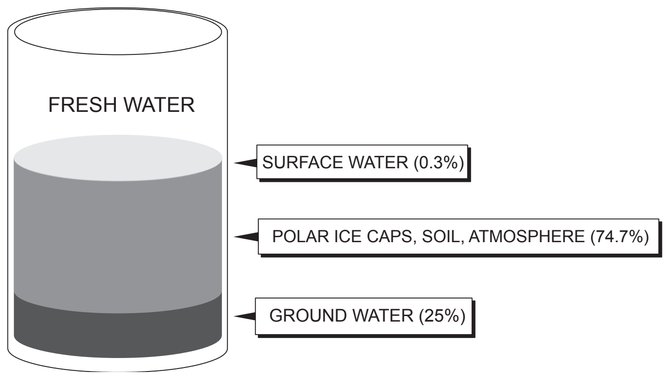
Distribution of Water

Total Supply

The total supply of all water in the world is approximately 305.79 million cubic miles. Of this total supply, 296 million cubic miles are in the world's oceans. This leaves 9.79 million cubic miles or 3.2 percent of all water in the world as fresh water.

Distribution of Fresh Water

Of the 9.79 million cubic miles of fresh water, 74.7 percent is tied up in the polar ice caps, soil moisture, and the atmosphere. Twenty-five percent of this fresh water is in the groundwater supply, leaving 0.3 percent of the fresh water in the lakes and streams.



Fresh water distribution 3.2% of all water

Percent of World's Fresh Water	Location	Million Cubic Miles
68.7	Polar ice caps & Glaciers	5.773
0.05	Soil moisture	0.00396
0.04	Atmosphere	0.003095
30.084	Groundwater between 2500 and 12,500 feet	2.526
0.86	Ground ice and permefrost	.07197
0.26	Lakes	0.0218
0.006	Rivers	0.000509

Source: Igor Shiklomanov's chapter "World fresh water resources" in Peter H. Gleick (editor), 1993, Water in Crisis: A Guide to the World's Fresh Water Resources (Oxford University Press, New York).

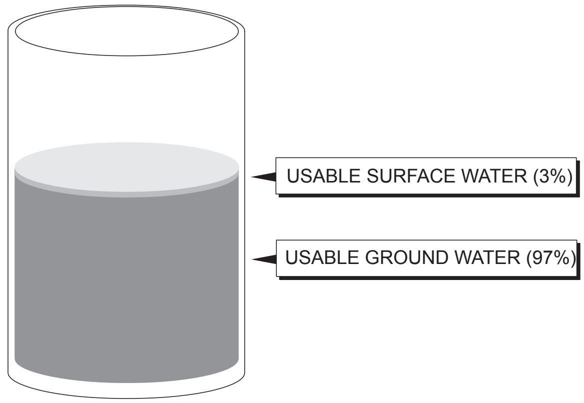
Usable Fresh Water

The total groundwater supply is estimated at 2.52 million cubic miles. Only 44 percent of this, or 1.008 million cubic miles, is usable since it is less than 2500 feet below the surface. Lakes and rivers represent 0.022 million cubic miles of water. This gives a total usable fresh water supply of 1.03 million cubic miles.

Division of Fresh Water

Of the usable fresh water, 99.7 percent is in the groundwater, glaciers and permanent snow cover and 0.3 percent is in the surface water including lake and river storage.

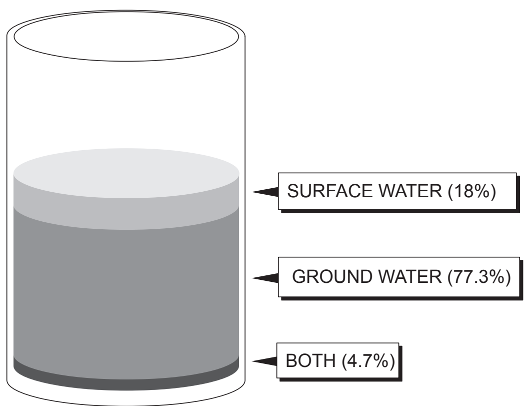
Usable fresh water
1.09 million cubic miles



Distribution by System Type

Within the continental United States, 77.3 percent of all public water systems use groundwater, 18 percent use surface water, and 4.7 percent use a combination of groundwater and surface water.

Water distribution by system type (US)

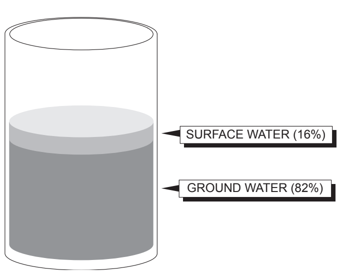


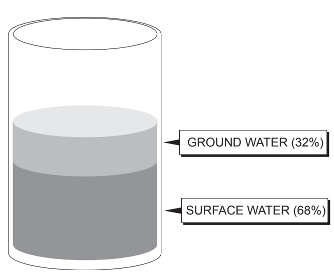
Distribution in Alaska

In the State of Alaska, 82 percent of the community water systems (CWS), non-transient non-community water systems (NTNCWS) and transient non-community water systems (TNCWS) use groundwater; 16 percent use surface water; and two percent use groundwater under the direct influence of surface water. There are approximately 1,600 CWS, NTNCW and TNCWS in Alaska (2008).

Distribution by Population

Within the continental United States, 68 percent of the population is served by surface water suppliers, while only 32 percent of the population relies on groundwater supplies.





Why the Difference?

Water distribution by system type (AK) **Water distribution by population (US)**

In the Continental United States

There are several reasons for the difference between the number of surface water suppliers and the number of people obtaining their drinking water from surface water suppliers. First, in the continental United States, 37 of the 100 largest communities use surface water. This is because the majority of these communities are built next to surface water sources, including 10 that are built next to the Great Lakes. In the West, communities such as Los Angeles, San Francisco, Portland, and Seattle all use surface water.

Water Availability

Although a large portion of this country is without any surface water source, there are few groundwater supplies that can provide sufficient water for a large community.

Alaska Differences

Alaska has distribution conditions similar to the rest of the U.S. First, although there is a significant amount of usable groundwater in the state, most of this water needs some kind of treatment. Second, the North Slope and many Southeast Alaska and Aleutian Island communities primarily use surface water; Fairbanks and many other Interior Alaska and Yukon Kuskokwim Delta communities use groundwater supplies; and Anchorage and Juneau use a combination of groundwater and surface water. This means that except in Southeast Alaska and the North Slope, the majority of smaller Alaskan communities use groundwater supplies.

Review

1. In the United States, water systems serving larger communities usually use ____________________ water as their source.

2. The most common type of water system in Alaska is __________________ water.

Uses of Water

Categories

Water consumption is often categorized based on its intended use:

- Industrial use
- Agricultural use
- Public water supply use
- Domestic use

Industrial Use

Industry in the United States uses an average of 150 billion gallons of water each day to produce the products that Americans use. Typical uses include 270 tons of water to make one ton of steel, 250 tons of water to make one ton of paper, and 10 gallons of water to produce each gallon of gasoline. The processing of seafood requires large volumes of high-quality water, and gold mining in Alaska would have been nearly impossible without the use of water. Water is also used on the North Slope to force oil from the ground. As you can see, water plays an important role in industry.

Agricultural Use

Even the food we eat requires water to grow and process. Each loaf of bread requires 115 gallons of water to produce, and a ton of milk requires 4000 gallons for processing and clean up. These figures do not include the water required to grow the wheat, feed and water the cow, and clean up the dairy. In fact, water for irrigation of farms in the U.S. is one of the largest uses of water, consuming approximately 137 billion gallons per day (gpd).

Public Water Supply Use

Public water systems are designed to deliver **potable water**[23]. Public water systems in the U.S. deliver approximately 39 billion gpd, for a combination of domestic, public and light industrial use. In Alaska, usage varies widely from a few gallons per day for self-haul systems to large volumes where water is allowed to run to prevent freezing. The average domestic consumption in all of the U.S. is 105 gallons per capita (or person) per day (gpcd) and 28 gpcd for commercial (offices, stores, etc.) use.

[23] Potable Water –_Water satisfactorily safe for drinking purposes from the stand of its chemical, physical, and biological characteristics..

Domestic Use

Within the United States, this average of 105 gallons per day per capita (gpdpc) is used for laundry, 20 to 45 gallons per load; showers, 20 to 30 gallons each; baths, 30 to 40 gallon each; flushing toilets, 1.5 to 5 gallons per flush. Most important, each of us drinks one to two quarts of water a day. The amount of water consumed per person per day in the U.S. has declined over the past 20 years with the introduction of more water-conserving fixtures such as reduced-flow shower heads and low-flow toilets.

Demands Are System-Specific

Average Day

The average daily demand for your utility should be determined for each month and recorded as part of the routine records for the water system. Minimizing the average daily demand can reduce the cost of upgrading the system.

Peak Day

Normally a peak day ranges from 1.5 to 3 times the average day. The peak day for each month and the peak day for each year should be identified and recorded as part of normal operating procedure. The average and peak days for each year should be reviewed and changes explained.

Peak Hour

The peak hour of water use is often ten times the average hourly use. This peak hour is important to the operator and design engineer. The water system's pumps, storage, and treatment must be designed so that the system can meet peak hour demands without stressing the system. The peak hourly demand is best determined from a chart recorder. If one is not available, an important piece of data will be missing and could cause difficulties in future design of the facility.

The highest peak hourly flow that water systems will usually encounter is during fire suppression. Fire flow demand thus is the primary design factor for sizing many water systems.

What is a Water System?

Definition

A water system includes all of the means for collecting, treating, storing, distributing, operating, maintaining, and managing the mechanical components in such a way as to provide potable water service to meet the customers' needs.

Adequate and Reliable

Meeting the needs means that the system must be adequate and reliable. The water must be safe to drink at all times and meet the quantity and quality requirements of the customer. This means that not only must the water be potable, but it must also be **palatable**[24] and aesthetically pleasing.

[24] Palatable – In relation to drinking water, it is water that does not give off an unpleasant taste or odor, is cool in temperature, has low color and low turbidity, and is pleasant to drink.

Collection Components

The collection portion of the water system consists of methods of collecting surface water, such as dams, rainwater catchments, intake structures, screens, pumps, and piping. Groundwater is collected using a pump in a well.

Treatment Process

The treatment process varies from community to community. Typical treatment processes include the reduction of color and turbidity as well as the removal of microorganisms and harmful and nuisance chemicals. These treatment processes are accomplished through the addition of chemicals and the use of filtration systems.

Fluoride is added to many water supplies as a means of reducing tooth decay.

In many Alaskan communities, heat is added to the water as a treatment process to keep it from freezing and/or to help in the chemical treatment process.

Disinfection

Nearly all water systems use the process of **disinfection**[25] of their water as a primary means of controlling disease-causing microorganisms. This disinfection process is commonly done with the addition of a small amount of chlorine. Other chemicals and processes, such as the addition of ozone and ultraviolet light, are also used to disinfect drinking water.

[25] Disinfection – The process used to control pathogenic organisms.

Distribution System Types

Like the treatment process, the distribution system varies widely based on community needs and environmental conditions. Typical distribution systems include the following:

- Piped systems
- Circulating loop systems
- Watering points
- Haul systems

Distribution Components

Most distribution systems include pipes, valves, fire hydrants, tanks, pumps, and house service connections.

Review

1. The average water consumption in the U.S. is _________ gpcd.
2. The highest peak hourly flow in most water distribution systems is for what use?
3. Describe four conditions that consumers expect of their water service:

A Brief History of Drinking Water Systems

Ancient History

We have no record of when water systems, as we know them, were first used. However, we know that systems of bamboo pipes and channels were in use as long ago as 3000 BC.

Indus Valley

Somewhere between 1500 and 2000 BC in the Indus Valley of Pakistan, clay pipes were used to form a water distribution system in many of the communities.

Pumps

The screw pump, one of the first pumps ever developed, was designed by Archimedes (287 – 212 BC).

Romans

The Roman Empire existed from 700 BC to 500 AD. During their existence, they built many water-collecting and distribution systems. The most famous of these are the 300 miles of aqueducts that brought water from its sources into the city. The longest of these aqueducts was 20 miles in length. During the height of the empire, these aqueducts moved as much as 84 million gallons a day to the city. The Romans' great concern over the quality of water caused them to enact penalties equivalent to $800 to $1000 of today's money for polluting a water source.

Wells

While there are recordings of hand-dug wells from the beginning of recorded history, it was not until 1126 AD that the first well was drilled in Artois, France.

Public Water System

The first recorded public water system in the United States was established in Boston in 1652. By 1850 there were 83 such systems in the United States. These systems both reduced **waterborne disease**[26] and caused it to spread because once a system was polluted, a large population could be infected.

[26] Waterborne Disease – A disease caused by organisms or toxic substances that are carried by water. The most common waterborne diseases are typhoid fever, cholera, dysentery, giardiasis, and other intestinal disturbances.

Waterborne Disease

In 1880 in the United States, cholera and typhoid fever, both waterborne diseases, killed 75 to 100 people for each 100,000 population. At this time, there were very few systems providing treatment of any type, and there was no disinfection in any system.

Treatment

The first recorded use of a water filtration system was in Europe in the early 1700s. In 1835 the first slow sand filter was installed in the United States in Richmond, Virginia. The first rapid sand filter in the United States was installed in Summerville, New Jersey, in 1885. While it is widely believed that chlorine was used in some systems in the late 1800s, it was not until 1908 in Jersey City, New Jersey, that we have the first recorded use of chlorine for disinfection in a water system in the United States.

Fire Hydrants

Fire hydrants similar to those we use today, called dry barrel hydrants, were first developed in Philadelphia in 1803. This style of fire hydrant allowed access to the water in the system without shutting down the system or losing excessive amounts of water. In addition, the design allowed the hydrant to remain permanently installed with little possibility of freezing.

Piping

Significant strides in piping systems were not developed until the coke-fired furnace was developed in the early 1700s and a method of welding was developed in the early 1800s. The first cast iron pipe was installed in Europe in 1785 and in the United States in 1816. Today there are over 200 utilities in the United States with cast iron pipe over 100 years of age. Ductile cast iron pipe, a material stronger than cast iron, was developed in 1948. Steel pipe was first introduced in 1825. PVC was developed in the 1930s, but not widely used until after the Second World War.

Reasons for Drinking Water Systems

Public Health

The primary reason for having a public water system is to protect public health. The water system serves as a line of defense between disease and the public.

Properly operated systems protect public health by:

- Removing or inactivating **pathogenic microorganisms**[27], including bacteria, viruses and protozoa.
- Reducing and removing chemicals that can be detrimental to health, such as arsenic, nitrates, lead, and copper.
- Providing quality water and discouraging customers from seeking better-tasting or better-looking water (which may be from contaminated sources).

[27] Pathogenic Microorganisms – Bacteria, virus, and protozoa that can cause disease.

Alternative Supplies

When the water produced by a system is objectionable because of odor, taste, or appearance, customers will often seek other sources for their drinking water. These alternative sources, while looking, tasting, and smelling good, could contain harmful microorganisms or chemicals.

Waterborne Diseases

Diseases that are carried by the water are called waterborne diseases. The organisms that cause these diseases do not normally live in the water, but are transported by the water. Examples of typical waterborne diseases include cholera, typhoid, dysentery, polio, hepatitis, and giardiasis. All of these diseases can be prevented from spreading through a water system with proper treatment and disinfection.

Effectiveness of Treatment

At the turn of the century, there were 36 typhoid fever deaths for each 100,000 population. With the installation of water treatment plants and disinfection, this was reduced to 0.1 deaths per 100,000 population. This reduction was enhanced by improvements in personal hygiene.

Worldwide

In the United States, we are fortunate when it comes to waterborne disease. Worldwide, one infant dies every nine minutes from a waterborne disease.

Classification of Systems

Reason for Classification

Water systems are classified by using various methods and criteria:

- Type of source
- Population
- Size and population
- Complexity

The following discussion is a review of each of these systems.

Classification by Source

One of the most common methods of classification is by source. The common classifications are surface water, groundwater and groundwater under the influence of surface water. This last type of system is discussed in detail in the lesson on sources.

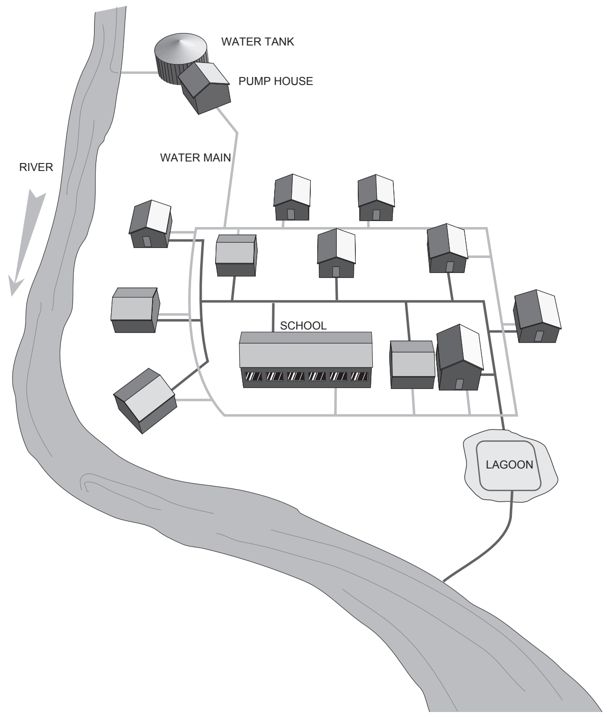
Classification by Population

The U.S. Environmental Protection Agency (EPA) has classified systems according to population. These classifications are used to determine when a specific regulation must be applied. This classification was developed to allow the EPA to phase in regulations so that systems serving the largest segments of the population were addressed first. The typical classifications are populations below 3300, 3300 to 10,000, and above 10,000.

Alaska Classification System

Background

Because of the uniqueness of Alaska, a system that fit the State's needs was developed in 1978. The nomenclature system divided the "public water system" into three categories based on population served (at least 25 residents or individuals per day) and duration (in the normal order of events or at least 60 days per year) for Class A and Class B systems, and for Class C (neither a Class A nor Class B system).



This system, using the state nomenclature for Alaska public water systems rather than using the federal nomenclature, has become too complicated to continue in regards to compliance monitoring requirements. Because the State has adopted federal drinking water rules by reference since 1999, and these rules reference the federal water system nomenclature, the State of Alaska revised the public water system classification nomenclature throughout Title 18, Chapter 80 of the Alaska Administrative Code, dealing with Drinking Water to conform with the nomenclature used in 40 CFR Parts 141, 142, and 143. These changes replace "Class A" with "community" and "non-transient non-community" water systems, and "Class B" with "transient non-community" water systems. The Class C water systems (state regulated systems) will remain in the regulations.

EPA Classification for Regulations

Background

To apply drinking water regulations uniformly across the United States, the EPA classified systems into three categories. All of these systems fall into the general category of a public water system.

Public Water System

For the purposes of the EPA regulations, a public water system is a system that supplies drinking water to the public where there are 15 or more service connections or that regularly serves at least 25 individuals 60 or more days each year.

Community Water System

A community water system is a public water system that has 15 or more service connections and is used by year-round residents or serves 25 or more residents year-round. In Alaska, these were referred to as Class A systems.

Non-Community Water System

Non-community water system means a public water system that is not a community water system. A non-community water system is either a transient non-community water system or a non-transient non-community water system. Generally these are systems with 15 or more connections used by travelers or intermittent users at least 60 days of a year or serves a daily average of at least 25 persons at least 60 days a year. In Alaska, these were referred to as Class B systems.

Non-Transient Non-Community Water System (NTNCWS)

Non-transient non-community water system or NTNCWS means a public water system that is not a community water system and that regularly serves at least 25 of the same persons over six months per year. In Alaska, these were referred to as Class A systems.

Transient Non-Community Water System (TNCWS)
Transient non-community water system means a non-community water system that does not regularly serve at least 25 of the same persons over six months per year. In Alaska, these were referred to as Class B systems.

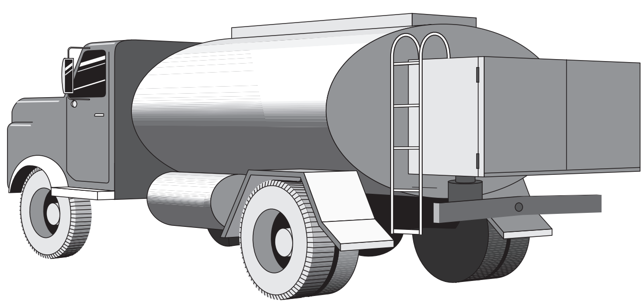
Classification by System Type and Complexity
Background
For the purposes of application of treatment techniques, operator certification and training, and technical assistance and engineering, systems in Alaska are also classified by system type and/or complexity:

- Haul Systems
- Watering Point
- Fill and Draw
- Piped Systems

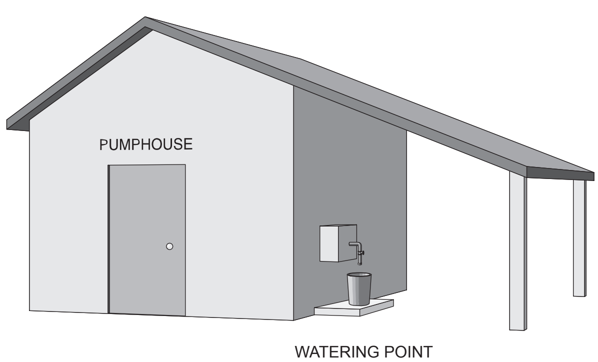
The collection and treatment of water is not directly included in this system.

Haul Systems
In a haul system the **purveyor**[28], transports the water from the treatment plant or storage to the customer, using a truck, trailer, or a track snow machine. Each customer has a storage tank that is filled by the purveyor personnel. Water is delivered on an order-basis in the same way that furnace oil is delivered in much of the country.

[28] Purveyor – An agency or person that supplies potable water.

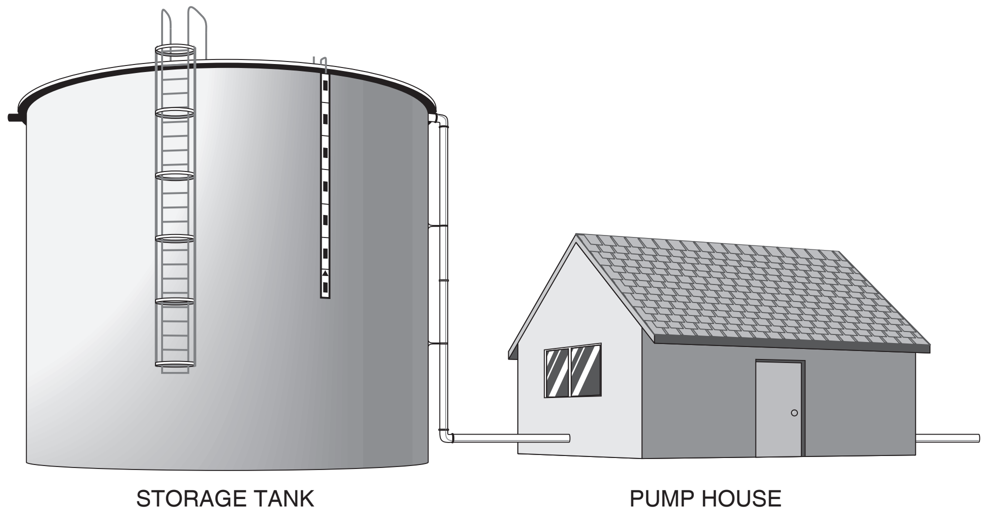


Watering Point
A common village distribution system is the watering point. This is a hosed connection to a storage or treatment facility. This connection may be inside or outside of a building, which is commonly called the pump house or washeteria. Customers bring their container to the watering point, put money in a coin box, and receive a measured amount of water.



Fill and Draw

Another common village system is the fill and draw system. A typical fill and draw system consists of a large tank that is filled with treated water one or more times during the year. The village draws water from the tank during the rest of the year.



Piped Systems

Piped Systems Configurations

A piped system refers to a system where the water is piped directly to the individual houses. There are several variations on this type of system.

Standard System

The simplest variation is the standard system where a large pipeline leads from the storage to the housing area. Individual homes are connected directly to the piped system.

Circulating System

In some locations, it is necessary to heat and circulate the water in the system to prevent it freezing during the winter. These systems require a loop from the treatment facility or storage to the customers and back. The circulating system normally requires a boiler and a circulating pump.

Utilidors

One popular technique to prevent water from freezing in the arctic is to use a utilidor. Utilidors protect and insulate the pipes, so the community can use a traditional piped water system. Utilidors may be above or below ground and are made of insulated wood or insulation covered with a protective material such as corrugated steel or aluminum.

Transient Non-Community Water Systems (TNCWS)

It is common for TNCWSs (lodges, restaurants, etc.) not to have a classic distribution system found in the community water system or non-transient non-community water system.

Introduction to Drinking Water Quiz

1. What is the most important job of the water system operator?
   A. Operate and maintain the water system equipment at the lowest cost.
   B. Keep the water plant clean and orderly.
   C. Protect the public health.
   D. Maintain good public relations with the community.

2. Water is at its maximum density at ___ °C.
   A. 0
   B. 4
   C. 20
   D. 100

3. _______________ is the term used to describe the movement of water from the surface of the earth to the atmosphere.
   A. Hydrologic cycle
   B. Precipitation
   C. Percolation
   D. Evapotranspiration

4. The majority of water systems in Alaska and the rest of the US use surface water supplies.
   A. True
   B. False

5. The average domestic potable water use in the US is approximately_________ gpcd.
   A. 20
   B. 50
   C. 100
   D. 200

6. What causes the highest demand in most US public water systems?
   A. Fire suppression
   B. Half time on Super Bowl Sunday
   C. Morning use by a typical community
   D. Commercial use

7. The term used to describe water that is safe to drink is:
   A. Adequate
   B. Reliable
   C. Potable
   D. Palatable

8. The most common treatment method used to control disease-causing microorganisms is which of the following?
   A. Filtration
   B. Disinfection
   C. Fluoridation
   D. Chemical addition

Basic Science Concepts

Chapter 2

What Is In This Chapter?

1. Chemical characteristics of water
2. Elements
3. Compounds
4. Constituents in water
5. Biological characteristics of water
6. Disease and disease transmission

Key Words

- Aerobic
- Alkalinity
- Anaerobic
- Anion
- Aquatic
- Bacteria
- Cation
- Chemistry
- Colloidal
- Colloidal Solids
- Covalent Bond
- Disinfection
- Dissolved Solids
- Element
- Electromagnetism
- Facultative
- Fungi
- Gases
- Ion
- Ionization
- Liquids
- Matter
- Microorganisms
- Precipitate
- Protozoa
- Saturated Solution
- Solids
- Solute
- Solvent
- Spores
- Sterilization
- Suspended Solids
- Total Solids
- Turbidity
- Viruses
- Waterborne Pathogens

Introduction

The following material is provided as basic background information necessary to understand the components and processes associated with drinking water systems.

Material Depth

Care has been taken to maintain the depth of the material for the Level I operator. As a result, certain complicated concepts have been greatly simplified. One of the problems with simplification of complicated material is the chance that the reader may be misguided. If this should happen, we apologize.

Lesson Content

This lesson is divided into distinct areas:

- Chemical characteristics of water
- Biological characteristics of water

Chemical Characteristics of Water

Introduction

The Operator as Chemist

When you light a match to start a fire, when you take your first breath of fresh morning air, when you put sugar in a steaming cup of coffee, when you digest that delicious donut, when gasoline explodes to power your car, and when you add chlorine to water to make it safe, a chemical reaction takes place. You are dealing with the substances around you and the way those substances react with one another. You are as much a chemist as the person in a laboratory in a white coat with a test tube in hand. When you treat drinking water, you are also a chemist. You are working with substances and controlling the way they react with one another.

What is Chemistry?

[1] Chemistry – The study of substances and the changes they undergo.

Chemistry[1] can be really quite simple and something with which we all are involved. Chemistry is the study of substances and the changes they undergo. Many things in chemistry are familiar to us and have names that we are accustome to. But some things in the study of chemistry are uncommon, and we must use new words to describe these new things. The vocabulary of chemistry describes the structure and activities of the things with which we work. As we discuss the chemistry of water, you will start to learn this new vocabulary and use the new terms to describe and explain the things that you do every day.

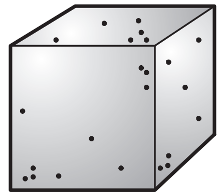
Matter

States of Matter

[2] Matter – Anything that has mass and occupies space.

Every day we come in contact with many kinds of **matter**[2]. Air, coffee, water, gasoline, chlorine, rocks, and paper are all different forms of matter. Matter is anything that has mass and occupies space. And that's just about everything, isn't it? But it's pretty obvious that all matter is not alike. However, we can put all matter into three large groups that are called the physical states of matter:

- **Solids**[3] have a definite shape with their particles closely packed together and sticking firmly to one another. A solid doesn't change its shape to fit a container. If you put a solid on the table, it would keep its shape and volume.

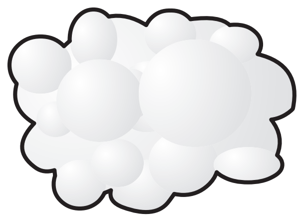


[3] Solids – Substances that maintain definite size and shape.

- **Liquids**[4] maintain a constant volume but will change shape to fit the shape of their container. The particles of the liquid move freely over one another but still stick together enough to maintain a constant volume. Pour water from a glass into a bowl. You have the same volume of water, but a different shape.

[4] Liquids – A definite volume, but not shape, that will fill containers to certain levels and form free-level surfaces.

- **Gases**[5] have no fixed shape and their volume can be expanded or compressed to fill different sizes of containers. The particles of gases do not stick together at all, and they move about freely, filling containers of any shape and size. The air around you and the helium in a balloon are examples of gases.



[5] Gases – Of neither definite volume nor shape, they completely fill any container in which they are placed.

Changing Matter

Matter can change in two different ways:

- **Physical changes** occur when matter changes its physical characteristics, such as its size, shape, density, as well as when it changes its state from a gas, to a liquid, to a solid. When ice melts or when a coffee cup breaks into pieces, a physical change has occurred.
- **Chemical changes** occur when new substances are formed that have entirely different properties and characteristics. When a match burns or iron rusts, a chemical change has occurred.

Review

1. Chemistry is the study of substances and the ______________ they undergo.

2. The three states of matter are:

3. Matter can change in two different ways:

The Elements – The Content of Matter

Basic Building Blocks

All matter on earth is made up of pure basic substances or combinations of these basic substances. The basic substances, which cannot be broken down to simpler substances, are called **elements**[6]. There are 118 known elements, 94 of which occur naturally on earth. They range from simple, lightweight elements to very complex, heavyweight elements. Some of these elements exist in nature in pure form; others are combined. Many of the elements are quite familiar, for example: oxygen, chlorine, gold, carbon, iron, and calcium.

[6] Element – One of 118 fundamental substances that consist of atoms of only one kind and that singly or in combination constitute all matter.

The Atom

If you take a small piece of an element, say aluminum, and subdivide it until you get to a tiny single unit of aluminum that cannot be divided any further and still be aluminum, you have an atom. An atom is the smallest unit of an element.

Element Symbols

For convenience, elements are often identified by one or two letters, called chemical symbols. Most of the time, the symbol is easily recognized as an abbreviation of the element name, such as C for carbon. Some symbols are not as easy to recognize because they refer to the element's Latin name, such as Fe for iron, whose Latin name is ferrum. A properly written element symbol is always capitalized, and if the symbol has two letters (such a Ca), the first letter is upper case and the second is lower case.

Review

1. A(n) _______________ is a basic substance that cannot be broken down any further without changing the nature of the substance.
2. A(n) ______________ is the smallest unit of an element.
3. Abbreviations, called chemical _____________, are used to identify the elements.

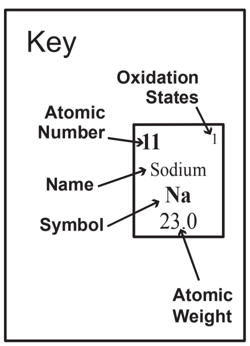
The Periodic Table

The elements are listed together on a chart called the Periodic Table of the Elements. The periodic table shows all the elements arranged in order of increasing atomic number. It also shows the name, symbol, atomic number, and atomic weight of each element and, on some periodic tables, a lot of other information about physical and chemical characteristics. The columns and rows of the periodic table show how the elements are related to one another. Metallic elements are on the left and the nonmetals are on the right. Elements next to each other are about the same size and weight. Elements in the same column have similar chemical reaction characteristics.

Periodic Table of the Elements

Period	Group IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIII	VIII	VIII	IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1	**1** 1 Hydrogen **H** 1.0																	**2** Helium **He** 4.0
2	**3** 1 Lithium **Li** 6.9	**4** 2 Beryllium **Be** 9.0											**5** 3 Boron **B** 10.8	**6** ±4,2 Carbon **C** 12.0	**7** ±3,5,4,2 Nitrogen **N** 14.0	**8** -2 Oxygen **O** 16.0	**9** -1 Fluorine **F** 19.0	**10** Neon **Ne** 20.2
3	**11** 1 Sodium **Na** 23.0	**12** 2 Magnesium **Mg** 24.3											**13** 3 Aluminum **Al** 27.0	**14** 4,2 Silicon **Si** 28.1	**15** ±3,5,4 Phosphorus **P** 31.0	**16** ±2,4,6 Sulfur **S** 32.1	**17** ±1,3,5,7 Chlorine **Cl** 35.5	**18** Argon **Ar** 39.9
4	**19** 1 Potassium **K** 39.1	**20** 2 Calcium **Ca** 40.1	**21** 3 Scandium **Sc** 45.0	**22** 4,3 Titanium **Ti** 47.9	**23** 5,4,3,2 Vanadium **V** 50.9	**24** 6,3,2 Chromium **Cr** 52.0	**25** 7,6,4,2,3 Manganese **Mn** 54.9	**26** 2,3 Iron **Fe** 55.8	**27** 2,3 Cobalt **Co** 58.9	**28** 2,3 Nickel **Ni** 58.7	**29** 2,1 Copper **Cu** 63.5	**30** 2 Zinc **Zn** 65.4	**31** 3 Gallium **Ga** 69.7	**32** 4 Germanium **Ge** 72.6	**33** ±3,5 Arsenic **As** 74.9	**34** -2,4,6 Selenium **Se** 79.0	**35** ±1,5,7 Bromine **Br** 79.9	**36** 0,2 Krypton **Kr** 83.8
5	**37** 1 Rubidium **Rb** 85.5	**38** 2 Strontium **Sr** 87.6	**39** 3 Yttrium **Y** 88.9	**40** 4 Zirconium **Zr** 91.2	**41** 5,3 Niobium **Nb** 92.9	**42** 6,5,4,3,2 Molybdenum **Mo** 95.9	**43** 7 Technitium **Tc** 98.9	**44** 2,3,4,6,8 Ruthenium **Ru** 101.0	**45** 2,3,4 Rhodium **Rh** 102.9	**46** 2,4 Palladium **Pd** 106.4	**47** 1 Silver **Ag** 107.9	**48** 2 Cadmium **Cd** 112.4	**49** 3 Indium **In** 114.8	**50** 4,2 Tin **Sn** 118.7	**51** ±3,5 Antimony **Sb** 121.8	**52** -2,4,6 Tellurium **Te** 127.6	**53** ±1,5,7 Iodine **I** 126.9	**54** 0,2,4,6 Xenon **Xe** 131.3
6	**55** 1 Cesium **Cs** 132.9	**56** 2 Barium **Ba** 137.3	**57** 3 Lanthanum **La** 138.9	**72** 4 Hafnium **Hf** 178.5	**73** 5 Tantalum **Ta** 180.9	**74** 6,5,4,3,2 Tungsten **W** 183.8	**75** 7,6,4,2,-1 Rhenium **Re** 186.2	**76** 2,3,4,6,8 Osmium **Os** 190.2	**77** 2,3,4,6 Iridium **Ir** 192.2	**78** 2,4 Platinum **Pt** 195.1	**79** 3,1 Gold **Au** 197.0	**80** 2,1 Mercury **Hg** 200.6	**81** 3,1 Thallium **Tl** 204.4	**82** 4,2 Lead **Pb** 207.2	**83** 3,5 Bismuth **Bi** 208.9	**84** 4,2,6 Polonium **Po** (210)	**85** ±1,3,5,7 Astatine **At** (210)	**86** 0,2 Radon **Rn** (222)
7	**87** 1 Francium **Fr** (223)	**88** 2 Radium **Ra** (226)	**89** 3 Actinium **Ac** (227)	**104** Rutherfordium **Rf** 1.0	**105** Dubnium **Db** (262)	**106** Seaborgium **Sg** 263	**107** Bohrium **Bh** 262	**108** Hassium **Hs** 265	**109** Meitnerium **Mt** (266)	**110** ---- -- 0	**111** ---- -- 0	**112** ---- -- 0		**114** ---- -- 0		**116** ---- -- 0		**118** ---- -- 0

Series														
Lanthanide Series 6	**58** 3,4 Cerium **Ce** 140.1	**59** 3,4 Praseodymium **Pr** 140.9	**60** 3 Neodymium **Nd** 144.2	**61** 3 Promethium **Pm** (145)	**62** 3,2 Samarium **Sm** 150.4	**63** 3,2 Europium **Eu** 152.0	**64** 3 Gadolinium **Gd** 157.2	**65** 3,4 Terbium **Tb** 158.9	**66** 3 Dysprosium **Dy** 162.5	**67** 3 Holmium **Ho** 164.9	**68** 3 Erbium **Er** 167.3	**69** 3,2 Thulium **Tm** 168.9	**70** 3,2 Ytterbium **Yb** 173.0	**71** 3 Lutetium **Lu** 175.0
Actinide Series 7	**90** 4 Thorium **Th** 232.0	**91** 5,4 Protactinium **Pa** (231)	**92** 6,5,4,3 Uranium **U** 238.0	**93** 6,5,4,3 Neptunium **Np** (237)	**94** 6,5,4,3 Plutonium **Pu** (242)	**95** 6,5,4,3 Americium **Am** (243)	**96** 3 Curium **Cm** (247)	**97** 4,3 Berkelium **Bk** (249)	**98** Californium **Cf** (251)	**99** 3 Einsteinium **Es** (254)	**100** 3 Fermium **Fm** (253)	**101** 3 Mendelevium **Md** (256)	**102** 2,3 Nobelium **No** (254)	**103** 3 Lawrencium **Lr** (257)



The Operator’s Element List

Water operators routinely work with about a third of the elements. A list of these is shown below.

Element	Symbol
Aluminum	Al
Arsenic	As
Barium	Ba
Bromine	Br
Cadmium	Cd
Calcium	Ca
Carbon	C
Chlorine	Cl
Chromium	Cr
Copper	Cu
Fluoride	F
Gold	Au
Helium	He
Hydrogen	H
Iodine	I
Iron	Fe
Lead	Pb
Magnesium	Mg
Manganese	Mn
Mercury	Hg
Nitrogen	N
Nickel	Ni
Oxygen	O
Phosphorus	P
Potassium	K
Radium	Ra
Radon	Rn
Silicon	Si
Sulfur	S
Tin	Sn
Uranium	U
Zinc	Zn

Review

1. A table of the basic elements is called the ____________ table.

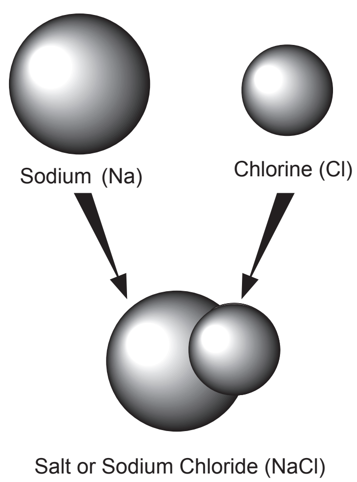
2. Give the symbol for the following elements:

   A. Aluminum ____________
   B. Chlorine ____________
   C. Oxygen ____________
   D. Iron ____________
   E. Lead ____________
   F. Fluoride ____________
   G. Manganese ____________
   H. Magnesium ____________

Compounds

What Are Compounds?

Most forms of matter in nature are composed of combinations of the 94 pure elements. Substances composed of two or more elements are called compounds. Unlike elements, compounds can be broken into simpler substances by chemical changes. A familiar, common compound is table salt, sodium chloride. It is a combination of the two elements sodium and chlorine.



The Molecule

If you have a small piece of a compound, say a crystal of salt or sodium chloride (NaCl), and you subdivide it and continue to subdivide it until you get one tiny unit of sodium chloride that cannot be further subdivided and still be sodium chloride, you have a molecule.

Formulas for Compounds

A shorthand method for writing the names of compounds is a formula showing the kinds and numbers of different elements in the compound by using the symbols of the elements making up that compound. The shorthand representations of chemical compounds are called chemical formulas. The formula for sodium chloride is NaCl. This formula shows that one atom of sodium combines with one atom of chlorine to form one molecule of sodium chloride. An example of a bit more complex compound is sodium carbonate or soda ash: Na_2CO_3. This formula shows that the compound is made up of three elements: sodium, carbon, and oxygen. And there are two atoms of sodium, one atom of carbon, and three atoms of oxygen in each molecule. Here's the formula for sulfuric acid: H_2SO_4 .

Combining Compounds

Chemical equations are shorthand method of expressing chemical reactions. The following equation shows the reaction that occurs when chlorine gas is added to water. It shows the formulas of the molecules that react together and the formulas of the product molecules.

$$Cl_2 + H_2O \longrightarrow HOCl + HCl$$

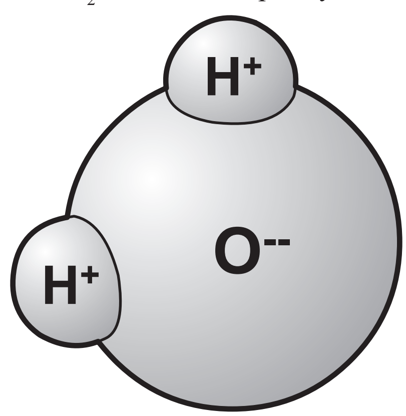
Review

1. A(n) _____________ is the combination of two or more elements.
2. A(n) _____________ is the smallest unit of a compound.
3. A(n) _____________ is the shorthand method of showing the kinds and numbers of elements making up a compound.
4. Chemical _____________ are used to show how chemical react.

Water

Importance of Water

Water, obviously, plays the major role in water chemistry and drinking water treatment. In fact, water is perhaps the most important compound on earth. All life depends on it. Water is really a pretty simple compound: H_2O. But its simplicity is deceiving. It has a number of characteristics that make it unique.



The Water Molecule

Pure water is a colorless, odorless, tasteless liquid. Each molecule of water has two atoms of hydrogen and one atom of oxygen. The two hydrogen atoms are **covalently bonded**[7] to the oxygen atom. The hydrogen atoms tend to be positively charged, and the oxygen atoms tend to be negatively charged. This gives the water molecule an electrical polarity, one end positively charged and one end negatively charged.

[7] Covalent Bond – a form of chemical bonding that is characterized by the sharing of pairs of electrons between atoms.

The Purity of Water

Pure water contains no impurities, but in nature, water contains a number of things besides water. Water is a very good **solvent**[8]. The polarity just described is the main reason water is able to dissolve so many other substances. For those of us interested in making water as pure as possible, this fact makes our job more difficult. It means there are many things dissolved and suspended in the water with which we must deal.

[8] Solvent – The component of a solution that does the dissolving.

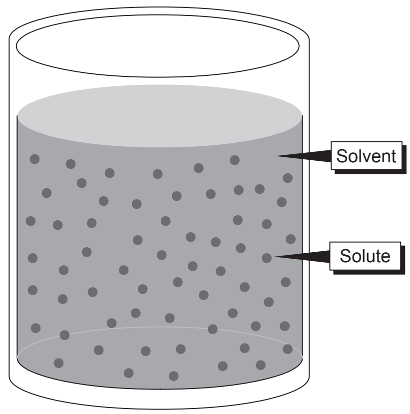
Three States of Water

Water exists in three physical states: ice, liquid, and steam. The temperature at which ice melts is the same as the temperature at which liquid freezes and is called the melting point. The melting point of water is 0°C (32°F). The temperature at which liquid turns to steam or steam condenses into liquid is called the boiling point. The boiling point of water is 100°C (212°F).

Water Solutions

Components of Solutions

A solution is a condition in which substances are uniformly and evenly mixed or dissolved. A solution has two components: a solvent and a **solute**[9]. The solvent is the component that does the dissolving. The solute is the component that is dissolved. In water (**aquatic**[10]) solutions, water is the solvent. Water is an excellent solvent and can dissolve a number of substances (solids, liquids, and gases), many of which must be removed during treatment to make water safe to drink.



[9] Solute – The component of a solution that is dissolved by the solvent.

[10] Aquatic – Pertaining to water.

Solutions and Suspensions

A solution may be colored, but it will be transparent, not cloudy. The solute will remain uniformly distributed throughout the solution and will not settle out with time. If the mixture appears cloudy, the solid particles are not actually dissolved. This situation is referred to as a suspension. The suspended particles will eventually settle out.

How Do We Get Ions?

With many molecules that dissolve in water, the atoms making up the molecules come apart in the water. This dissociation in water is called **ionization**[11]. When the atoms in the molecules come apart, they do so as charged atoms called **ions**[12]. There are always positively charged ions and negatively charged ions when ionization occurs. The positively charged ions are called **cations**[13], and the negatively charged ions are called **anions**[14].

[11] Ionization – The formation of ions by splitting molecules or electrolytes in solution.

[12] Ion – An atom or group of atoms that carries a positive or negative electric charge as a result of having lost or gained one or more electrons.

[13] Cation – A positively charged ion.

[14] Anion – A negatively charged ion.

Examples of Ionization

A good example is the ionization that occurs when table salt, sodium chloride, dissolves in water:

$NaCl$ sodium chloride	↔	Na^{+} sodium ion (cation)	+	Cl^{-} chloride ion (anion)

Another example is the ionization of calcium carbonate:

$CaCO_3$ calcium carbonate	↔	Ca^{+2} calcium ion (cation)	+	CO_3^{-2} carbonate ion (anion)

The table below shows some of the common ions found in water:

Ion	Symbol
Hydrogen	H^+
Sodium	Na^+
Potassium	K^+
Copper – Cuprous	Cu^+
Silver	Ag^+
Ammonium	NH_4^+
Fluoride	F^-
Chloride	Cl^-
Bromide	Br^-
Iodide	I^-
Hydroxide	OH^-
Nitrate	NO_3^-
Nitrite	NO_2^-
Hypochlorite	OCl^-
Bicarbonate	HCO_3^-
Permanganate	MnO_4^-
Magnesium	Mg^{+2}
Calcium	Ca^{+2}
Copper-Cupric	Cu^{+2}
Iron-Ferrous	Fe^{+2}
Zinc	Zn^{+2}
Oxide	O^{-2}
Sulfide	S^{-2}
Sulfite	SO_3^{-2}
Sulfate	SO_4^{-2}
Carbonate	CO_3^{-2}
Dichromate	$Cr_2O_7^{-2}$
Aluminum	Al^{+3}
Iron-Ferric	Fe^{+3}
Phosphate	PO_4^{-3}

Water's Ability to Dissolve

Since water is a polar substance, it dissolves other polar substances better than non-polar substances. Mineral acids, bases, and salts are polar and easily dissolved. Non-polar substances such as oils, fats, and many organic compounds do not dissolve as easily in water.

Electricity and Water

Pure water will not conduct electrical current. But when compounds release ions into the water, the charged ions make electrolytes that can conduct electrical current. The more ions there are in a solution, the more easily the current flows. The ability to conduct electrical current is called conductivity and can be used to indirectly estimate the amount of total **dissolved solids**[15] in the water.

[15] Dissolved Solids -The material in water that will pass through a glass fiber filter and remain in an evaporating dish after the water has evaporated.

[16] Saturated Solution – The physical state in which a solution will no longer dissolve more of the dissolving substance (solute).

The Impact of Temperature

Polar substances will dissolve in water up to a point. At a given temperature, water will dissolve only so much solute. When that limit is reached, the resulting solution is said to be saturated. If you add more solute to a **saturated solution**[16], it will not dissolve. If a solution contains less solute than required to reach saturation, the solution is unsaturated. In the case of solids dissolved in water, if the temperature of the solution is increased, the amount of solute (solid) required to reach saturation increases. Can you think of some solutions you have made during the last week? What were the solvent and the solute in each case? Were the solutions unsaturated or saturated?

Solution Strength

The strength of a solution is determined by the amount of solute dissolved in a certain amount of water. If you dissolve more solute, you make the solution stronger. We express solution strength in a variety of ways:

- **Parts per million (ppm)** and **milligram per Liter (mg/L)** are essentially equal and used interchangeably. A 1 ppm or 1 mg/L solution contains 1 milligram of solute per Liter of solution.
- **Percent concentration** is parts of the solute dissolved in 100 parts of solution on a weight basis. One gram of solute dissolved in 100 grams of solution is a 1 percent solution.
- **Molarity (M)** and **normality (N)** are solution concentration expressions used almost exclusively in the lab. They are based on the molecular weight of the solute. A 10 M solution is 10 times stronger than a 1 M solution. A 0.1 N solution is four times stronger than a 0.025 N solution.

Review

1. Water is said to be a ___________ molecule because one end is positively charged, and the other end negatively charged.

2. Water exists in what three physical states?

3. A(n) _______________ is formed when water dissolves material.

Constituents in Water

As we can see from the previous discussion, natural water can contain a number of substances. In the waterworks industry, these substances are called constituents or impurities. When a constituent can cause a negative impact to the health of the water user, it is called a contaminant. As you will see in the lesson on regulations, federal and state agencies have set limits on those items considered to be contaminants. The following is a brief discussion of some of the more common constituents of water.

Suspended Solids

Definition

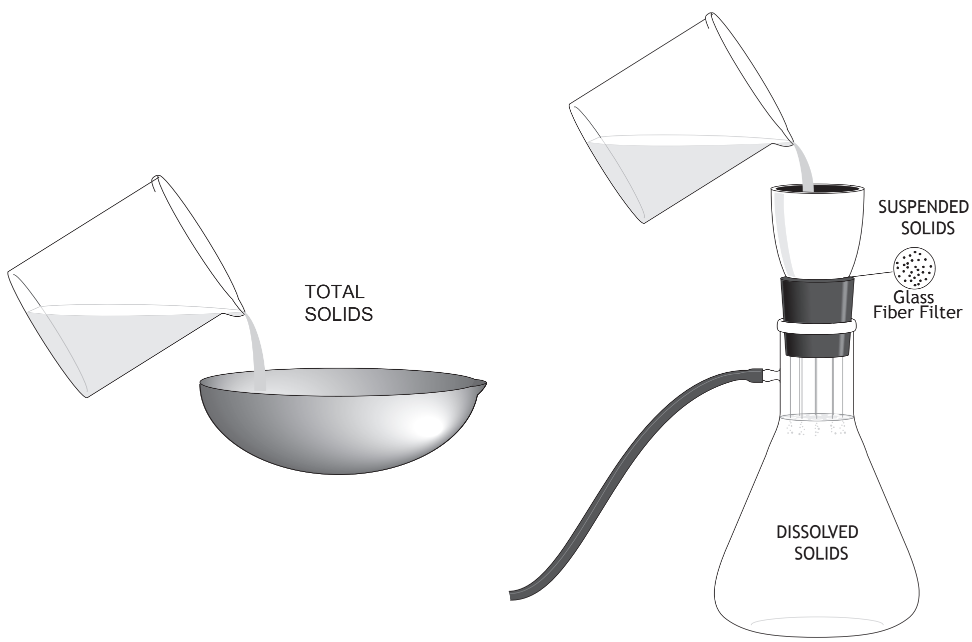
Natural water carries a lot of solids that are not dissolved. These solids are mainly non-polar substances and particles of silt and other in-organic material that just won't dissolve. These solids are referred to as **suspended solids**[17]. If the water is allowed to sit quietly, as it does in a sedimentation basin or clarifier, most of the suspended solids will settle out.

[17] Suspended Solids – The quantity of material deposited when a quantity of water, sewage, or other liquid is filtered through a glass fiber filter.

Types of Solids

In the water business, **total solids**[18] are those solids, both suspended and dissolved, that remain behind when the water is removed by evaporation. Suspended solids are defined as those that can be filtered out in the suspended solids laboratory test. The material that passes through the filter is defined as dissolved solids. These definitions are not technically accurate from a chemical point of view because some finely suspended material can actually pass through the filter.

[18] Total Solids – The solids in water, sewage, or other liquids; it includes the suspended solids (those largely removable by a filter) and filterable solids (those that are able to pass through a filter).



Colloidal Solids

Definition

Colloidal[19] solids are suspended solids so small they will not settle even if allowed to sit quietly for days or weeks. They are not dissolved, but even though they are extremely tiny, they often make the water cloudy. In general, anything less than one micron (1/ 1000 of a millimeter) is considered a colloidal particle. Fine silt, tiny particles of vegetation, and **bacteria**[20] are examples of colloidal particles.

[19] Colloidal – Any substance in a certain state of fine division in which the particles are less than one micron in diameter.

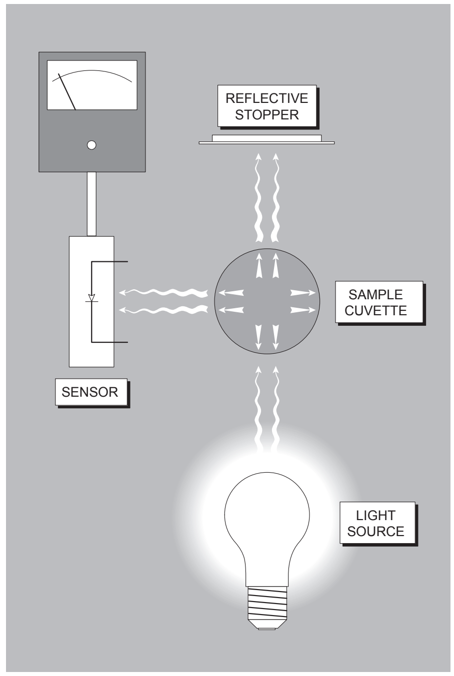
[20] Bacteria – Living organisms, microscopic in size, that consist of a single cell. Most bacteria use organic matter for their food and produce waste products as the result of their life processes.

Turbidity

Definition

Turbidity in water is caused by suspended solids, usually particles of colloidal size. Turbidity is defined as that property of water that causes light to be scattered or absorbed. Whereas high turbidity water appears cloudy, low turbidity water often sparkles with clarity. Water with low turbidity can still have dissolved solids because dissolved solids do not cause light to be scattered or absorbed. Materials that cause turbidity can cause taste and odor in drinking water and can provide a place for **microorganisms**[21] to hide and avoid disinfection.

NEPHELOMETRIC TURBIDIMETER



[21] Microorganisms – Minute organisms, either plant or animal, invisible or barely visible to the naked eye.

Color

Two Types

Color is considered an aesthetic quality in water and has no direct health impact. Color is divided into two general categories:

- **True color** – Color that is the result of dissolved chemicals, such as humic acid (from alder leaves), is called true color. It cannot be removed by passing the water through a filter.
- **Apparent color** – Color that is contributed to the water as a result of suspended material, such as clay, silt, or sand carried in the water. The yellow color in the Yellowstone River is the result of the yellow clay carried by the stream.

Dissolved Gases

What Gases?

Gases can also be dissolved in water. Gases such as oxygen, carbon dioxide, hydrogen sulfide, and nitrogen are examples of gases that dissolve in water. Not all gases dissolve to the same extent; some dissolve easily and others not as well. Oxygen and carbon dioxide are two dissolved gases important to water operations.

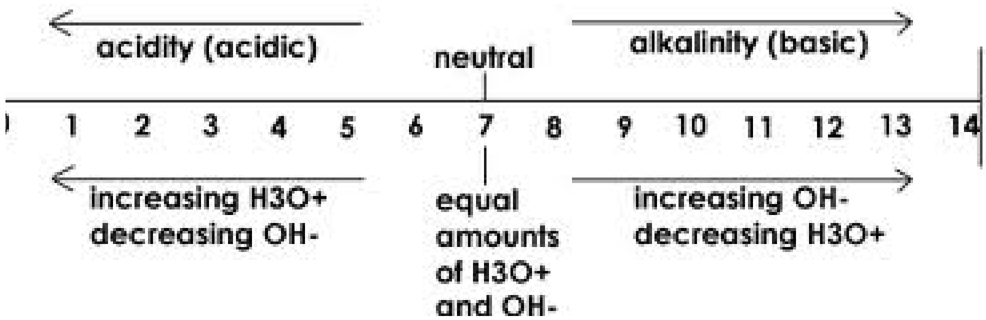
The Impact of Dissolved Oxygen

Dissolved oxygen (D.O.) is important to most aquatic organisms. It is of particular importance in streams and reservoirs as an indicator of water quality. Like other solutions, water at a given temperature can be saturated with the solute: the oxygen. And as with solid solutes, the amount of oxygen that can be dissolved at saturation depends upon temperature of the water. However, the effect is just the opposite: the higher the temperature, the lower the saturation level; the lower the temperature, the higher the saturation level.

The Impact of Carbon Dioxide

Carbon dioxide is important because of the role it plays in pH and alkalinity. Carbon dioxide is released into the water by microorganisms and consumed by algae and aquatic plants. Carbon dioxide is only slightly soluble in water. Most of the carbon dioxide reacts with the water to form carbonic acid. So as dissolved carbon dioxide levels increase, the system becomes more acidic.

CO_2	+	H_2O	↔	H_2CO_3
(carbon dioxide)		(water)		(carbonic acid)



Metals in Water

The Impact of Metals in Water

Water often carries metal impurities. Although most of the metals are not harmful at normal levels, a few metals can cause taste and odor problems or, more seriously, be toxic to humans, animals, and microorganisms. Most of these metals enter the water as part of compounds that ionize to release the metals as positive ions. When someone says they have iron in their water, this really means they have iron ions. Under specific conditions, the metal will come out of solution, and a **precipitate**[22] will be formed. Examples of metal precipitates are the reddish-brown iron rust and bluish-green copper stain. The following table lists some metals commonly found in water and their potential health hazards.

[22] Precipitate – A solid substance that can be dissolved but is separated from solution as a result of a chemical reaction or change in conditions, such as pH or temperature.

Metal	Health Hazard
Barium	Effects circulatory system and increases blood pressure.
Cadmium	Concentrates in the liver, kidneys, pancreas, and thyroid.
Copper	Damages nervous system and effects kidneys, toxic to infants.
Lead	Same as copper.
Mercury	Causes central nervous system disorders and effects the kidneys.
Nickel	Affects nervous system and causes skin sensitization.
Selenium	Affects nervous system.
Silver	Turns the skin gray.
Zinc	Causes taste problems, but not a health hazard.

Review

1. Solids that can be captured on a filter are called ______________ solids, and solids that pass through the filter are called ________________ solids.

2. A solids that is less than 1 µ in size is called a _______________.

3. Turbidity is the property of water that causes light to be ______________ and _______________.

4. There are two categories of color: ______________ color and _______________ color. Color caused by decaying alder leaves is _______________ color.

5. When carbon dioxide dissolves in water, it tends to _____________the pH of the water.

6. Metals dissolving in water can be a nuisance by causing taste and ____________ problems, and sometimes they can be _________________ to humans.

Organic and Inorganic Chemicals

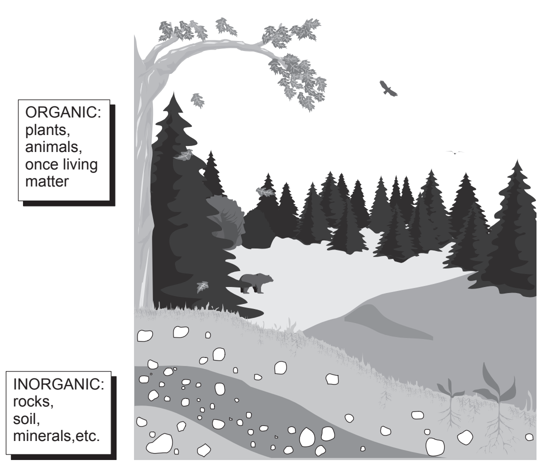
Two Categories

Chemistry divides chemical compounds into two large categories:

- **Organic compounds** are those that contain the element carbon and are derived from material that was once alive.
- **Inorganic compounds** are just the opposite. They do not contain carbon and are not derived from living material. There are a couple exceptions. Carbon dioxide, carbonate ions, and bicarbonate ions, although containing carbon, are considered inorganic.

Organic Compounds

These two large groups of compounds have very different characteristics. Organic compounds are usually large, non-polar molecules that do not dissolve well in water. They often provide large amounts of energy as food for animals and microorganisms. Some synthetic organic compounds, such as pesticides and herbicides, are extremely toxic at very low concentrations. Organics include fats, proteins, carbohydrates, fuels, cotton, wood, plastics, dyes, soaps, rubber products, and explosives.



Inorganic Compounds

Inorganic compounds are usually smaller, polar molecules that dissolve well in water. Although some specialized bacteria can use inorganics as an energy source, they are not considered a high-energy source for as many organisms. The inorganics include the acids, bases, salts, oxides, sulfate, phosphates, etc.

pH

Definition

pH is a measure of the hydrogen ion (H^+) concentration. The pH scale ranges from 0 to 14, with 7 being the center or neutral value. Low pH values are considered acidic, and high pH values are basic. The pH scale is actually an inverse logarithmic scale. What that means is that low pH values are actually high H^+ concentration, while high pH values are low H^+ concentration. It also means that the difference between any two pH values means a ten-fold difference in H^+ concentration.

Importance of pH

The pH of a solution is important to chemical reactions in water. Metal toxicity is also influenced by pH. High or low pH can inhibit growth of microorganisms.

Pure Water pH

Pure water has a neutral pH. Even pure water ionizes slightly, releasing equal numbers of H^+ and OH^- ions.

$$H_2O \leftrightarrow H^+ + OH^-$$

Acids

Acids can be defined as compounds that release hydrogen ions (H^+) when added to water. As an acid is added to the water, additional H^+ ions are released, so the H^+ ion concentration goes up, and the pH value goes down. Hydrochloric acid (HCl) is a good example of an acid:

$$HCl \leftrightarrow H^+ + Cl^-$$

It is easy to recognize acids because their formula starts with hydrogen (H). Some common acids include the following:

Hydrochloric acid	HCl
Sulfuric acid	H_2SO_4
Phosphoric acid	H_3PO_4
Carbonic acid	H_2CO_3
Nitric acid	HNO_3
Hydrofluoric acid	HF
Acetic acid	$HC_2H_3O_2$
Hypochlorous acid	$HOCl$

Bases

One characteristic of bases is that they release hydroxide ions (OH^-) when added to water. The OH^- ions combine with H^+ ions in the water, which reduces the concentration of free H^+ and raises the pH.

Sodium hydroxide is a good example of a base:

$NaOH \leftrightarrow Na^+ + OH^-$

It is easy to recognize bases because their formula contains (OH). Some common bases include the following:

Sodium hydroxide	$NaOH$
Calcium hydroxide (hydrated lime)	$Ca(OH)_2$
Ammonium hydroxide	NH_4OH

Salts

Salts are technically defined as the results of a neutralization reaction that combines an acid with a base. Salts are neither acid nor bases because they do not release either hydrogen ions (H+) or hydroxide ions (OH-). Here is an example of a neutralization reaction that produces a salt:

$2NaOH + H_2SO_4 \leftrightarrow Na_2SO_4 + 2H_2O$

Alkalinity

Definition

Alkalinity is a measure of water's ability to neutralize an acid. Alkalinity can also be defined as a buffer, a chemical system that tends to stabilize and prevent fluctuations in pH. It is usually beneficial to have significant alkalinity in water because it tends to prevent quick changes in pH. Quick changes in pH interfere with the effectiveness of the common water treatment processes. Low alkalinity contributes to corrosive tendencies of water. When alkalinity is below 80 mg/L, it is considered low.

What Causes Alkalinity?

Alkalinity is the result of carbonate (CO_3^{-2}), bicarbonate (HCO_3^-), and hydroxide (OH^-) ions in the water. Alkalinity should not be confused with pH. Even water with an acid pH can contain alkalinity. Typical water treatment chemicals that can be used to increase alkalinity are quick lime (calcium oxide, CaO), hydrated lime (calcium hydroxide, $Ca(OH)_2$), and soda ash (sodium carbonate, Na_2CO_3).

Hardness

Impact of Hardness

Classification	mg/L $CaCO_3$
Soft	60
Moderately Hard	61 – 120
Hard	121 – 180
Very Hard	Over 180

Hardness is caused by the presence of magnesium (Mg) and calcium (Ca) ions in water. Hardness causes soaps and detergents to be less effective and contributes to scale formation in pipes and boilers. Although there are no known health hazards to high hardness, water that contains excessive hardness must often be softened by lime precipitation or ion exchange. Low hardness contributes to the corrosive tendencies of water. Hardness and alkalinity often occur together because some compounds can contribute both alkalinity and hardness ions. However, hardness can be present when the alkalinity is low and vice versa.

Review

1. Compounds that are derived from material once living are called __________________ compounds.
2. Compounds that do not contain carbon are called ______________ compounds.
3. The pH scales ranges from __________ to ____________.
4. A pH of 4 would be considered _______________.
5. A pH of 7 would be considered _______________.
6. Acids are chemicals that release _____________ ions in water.
7. NaOH is a example of a:
8. Salts are formed by a neutralization reaction between an ______________ and a ________________.
9. ________________ is a measure of a water ability to neutralize and acid.
10. Hardness is caused by _______________ and _______________ ions.

Chlorine and Other Disinfectants

The element chlorine (Cl) is one of the most commonly used chemicals. As a pure element and in compounds, chlorine is the most frequently used disinfectant in water and wastewater treatment. Pure chlorine is a greenish-yellow colored gas at room temperature. It is a dense gas, 2.5 times heavier than air. It has a strong, pungent odor, is very corrosive to most metals, and is lethal if inhaled in sufficient quantity.

When chlorine gas is added to water, it reacts with water to form hypochlorous acid (HOCl).

$$Cl_2 + H_2O \rightarrow HOCl + HCl$$

The hypochlorous acid immediately ionizes to release hydrogen ions (H^+) and hypochlorite ions (OCl-).

$$HOCl \leftrightarrow H^+ + OCl^-$$

When present in water, hypochlorous acid (HOCl) and hypochlorite ion (OCl^-) are know as free chlorine residual.

Chlorine compounds are also used as disinfectants. Liquid sodium hypochlorite (NaOCl) solution, also known as bleach, and calcium hypochlorite [$Ca(OCl_2)$], a

crystal or powder, are common disinfectants. Chlorine dioxide (ClO_2), a gas, is also used as a disinfectant.
Bromine (Br_2) and iodine (I_2), both closely related chemically to chlorine, also have disinfection properties. Bromine is sometimes used to disinfect pools and spas, and iodine is used in tablet form for emergency disinfection of small volumes of drinking water.

Iron and Manganese

Iron (Fe) and manganese (Mn) are present in many water supplies, particularly groundwater. Neither is a health hazard, although both can affect water quality by causing taste and odor problems and by staining sinks, toilet bowls, and other fixtures. Iron and manganese are closely related chemically, and if iron is present, manganese will usually also be present.

Iron and manganese can be soluble (dissolved) or insoluble (undissolved particles), depending upon the conditions. In ground water, both tend to be dissolved. But when exposed to air, they are converted to the insoluble form. Soluble forms of iron are ferrous forms (also noted as Fe^{+2}). When exposed to air (such as a dripping faucet), the soluble form is converted to the insoluble ferric form (noted as Fe^{+3}), and the particles stick to the sink as a reddish-brown, rusty stain. Manganese also has soluble and insoluble forms. The insoluble manganese causes a dark greenish-black stain.

Iron can be removed by ion exchange systems or by chemical precipitation and filtration. Chemical oxidizing agents, such as chlorine and potassium permanganate, can be used to convert the soluble forms of iron and manganese to the insoluble forms.

Be careful not to confuse manganese (Mn) with magnesium (Mg). They have similar names and symbols but quite different chemical properties.

Lead and Copper

Lead (Pb) and copper (Cu) are often mentioned together because their presence in drinking water is usually the result of corrosive water leaching lead and copper out of household plumbing system pipes. Lead can be a health hazard, causing damage to the brain, red blood cells, and kidneys if it builds up in the body over time. Acute exposures to copper can cause nausea and diarrhea. Lead and copper can also cause taste and odor problems.

Corrosive water can leach lead and copper out of copper and lead pipe, out of lead-based solder, and other lead-based materials used in distribution systems. Water systems control the levels of lead and copper by treating drinking water to reduce the corrosive tendency of the water being provided to consumers.

Fluoride

Fluoride is the ion of the element fluorine (F). Fluorine compounds occur naturally in low concentrations in many water supplies. At levels of about 1 mg/L, fluoride has been shown to reduce cavities. Some communities choose to add fluoride to their drinking water to achieve this benefit.

Sodium fluoride (NaF) and sodium fluorosilicate (Na_2SiF_6) are examples of fluoride-containing compounds used as drinking water additives. Fluoride compounds must be handled carefully because the chemical powder is hazardous if inhaled. Carefully controlled addition of fluoride solution to drinking water is critical because overdosing can be toxic to consumers.

Arsenic

Arsenic (As) is a notorious poison that affects a number of organ systems in the body. It is more prevalent in groundwater than surface water, but many water systems must remove the arsenic to be within acceptable limits. A variety of technologies can be used including coagulation/filtration, ion exchange, and nanofiltration.

Lime

Lime is added to water during treatment to raise the pH and to increase alkalinity and hardness. There are two forms of lime:

- **Calcium oxide** – CaO (quick lime)
- **Calcium hydroxide** – $Ca(OH)_2$ (hydrated or slaked lime)

$Ca(OH)_2$ is CaO that has be mixed with water in a process called hydrating or slaking.

$$CaO + H_2O \rightarrow Ca(OH)_2$$

Quick lime (CaO) is hazardous to handle because it reacts vigorously with any moisture, including the moisture in your skin. Although cheaper, it must be hydrated before it can be fed into the water system. Dry, hydrated lime [$Ca(OH)_2$] is mixed with water to make a slurry and then fed into the system.

Raising the pH and increasing the alkalinity and hardness by adding lime tends to lower the corrosive tendency of the water to which it is added. Lime is often added to optimize alkalinity levels during the coagulation/flocculation treatment process.

Soda Ash

Soda ash (sodium carbonate – Na_2CO_3) is added to water to raise the pH. It also contributes to alkalinity but does not affect hardness. It does not have as strong an effect on pH as lime.

Coagulants

Coagulants are chemicals added to water to facilitate the removal of very finely suspended particles, such as colloidal particles. Most coagulants are aluminum- and iron-containing compounds. Common coagulants include aluminum sulfate or alum -$Al_2(SO_4)_3$ and ferric sulfate – $Fe_2(SO_4)_3$.

Polymers

Polymers are large, synthetic organic molecules created to optimize coagulation, flocculation, and filtration. Three general types are available:

- Cationic – having a general overall positive charge
- Anionic – having a general overall negative charge
- Non-ionic – having a general overall neutral change

Many proprietary types are available. Each water supply is carefully tested to determine which polymer will be the most effective. Polymers can be used to enhance coagulation by helping colloidal particles stick together. They can be used to help coagulated particles flocculate and become large enough to settle, and they can increase the effectiveness of the filtration process.

Radioactivity

Water supplies may contain material with low levels of radioactivity. These materials may enter the water supply from natural geological deposits or in the waste streams from industrial, research, and medical facilities. Alpha particle, beta particle, and photon radiation are all types of radiation with varying degrees of potential health implications. Different materials emit different types and intensities of radiation. Water systems are now required to monitor for radioactive uranium, radium, gross alpha particle, beta particle, and photon radioactivity.

Radon (Rn) is a colorless, odorless, radioactive gas formed by the natural radioactive decay of uranium in rock, soil, and water. It can be present in drinking water and indoor household air and is of increasing concern for water suppliers.

Chemical Characteristics of Water Quiz

Review

1. When chlorine gas reacts with water, it forms two acids: hydrochloric acid (HCl) and ___________________ acid.

2. The hypochlorite, also known as bleach, is _______________ hypochlorite.

3. Soluble iron can be converted to an insoluble form by contact with:

4. A reddish-brown stain is most likely caused by insoluble ________________ particles.

5. Lead and copper can enter consumers drinking water from household plumbing because the water is too:

6. CaO is the formula for _______________. $Ca(OH)_2$ is the formula for ________________.

7. Na_2CO_3 is the formula for:

8. ______________ and polymers are used in the coagulation/flocculation/filtration water treatment process.

9. Radioactive material can enter water sources from natural geological formations, from industrial discharges, from research facilities, and from:

1. Matter that maintains a constant volume but that will change shape to fit the shape of its container is a:
   A. Gas
   B. Liquid
   C. Solid
   D. Colloid

2. When a change takes place in matter where new substances are formed that have entirely different properties than the original, it is said to be a ______________ change.
   A. Nuclear
   B. Physical
   C. Chemical
   D. Biological

3. All matter is made up of 94 pure substances called:
   A. Molecules
   B. Compounds
   C. Elements

D. Radicals

4. The smallest piece of an element is called a(n):
   A. Atom
   B. Molecule
   C. Compound
   D. Radical

5. Which is the correct symbol for calcium?
   A. CA
   B. ca
   C. Ca
   D. Cal

6. The Periodic Table:
   A. Shows the pH of all aquatic compounds.
   B. Lists all of the common acids used in water treatment.
   C. Lists the common radicals.
   D. Lists the elements.

7. The smallest component of a compound is called a(n):
   A. Atom
   B. Molecule
   C. Element
   D. Radical

8. The compound $FeSO_4$ has how many atoms of sulfur?
   A. 1
   B. 2
   C. 3
   D. 4

9. A chemical ____________________ is a shorthand way to show how chemicals react.
   A. Balance
   B. Formula
   C. Equation
   D. Equilibrium

10. The main characteristic of water that makes it an exceptional solvent is its:
   A. Viscosity
   B. Polarity
   C. Surface tension
   D. Clarity

11. In a solution, the substance that is dissolved is called the:
   A. Solvent

B. Solution
C. Solute
D. Colloid

12. When many molecules dissolve in water, they dissociate to release charged particles called:
A. Atoms
B. Neutrons
C. Electrons
D. Ions

13. Positively charged ions are called:
A. Radicals
B. Protons
C. Anions
D. Cations

14. Which of the following is not an expression of solution concentration?
A. mg/L
B. ppm
C. Molecular weight
D. Molarity (M)

15. Solids in water that can be filtered out are called ______________ solids.
A. Total
B. Dissolved
C. Suspended
D. Colloidal

16. Solids that are so small they won't settle (about 1 µ) but are not actually dissolved are called _____________ solids.
A. Total
B. Dissolved
C. Suspended
D. Colloidal

17. The property of water that causes light to be scattered or absorbed is called:
A. Color
B. Turbidity
C. Light interference
D. Clarity

18. Chemical compounds that contain carbon and are derived from material that was once living are called ________________ compounds.
   A. Macro
   B. Inorganic
   C. Organic
   D. Energy

19. Which of the following represents an acid pH?
   A. 12
   B. 9
   C. 7
   D. 5

20. Which of the following compounds is a base?
   A. HCl
   B. NaOH
   C. NaCl
   D. H_2SO_4

21. ___________________ is the result of carbonate, bicarbonate, and hydroxide ions in the water.
   A. pH
   B. Hardness
   C. Alkalinity
   D. Turbidity

22. __________________ is the result of Mg^{+2} and Ca^{+2} ions in the water.
   A. pH
   B. Hardness
   C. Alkalinity
   D. Turbidity

23. When chlorine gas reacts with water, what compound is formed?
   A. Sulfuric acid
   B. Sodium hydroxide
   C. Hypochlorous acid
   D. Chlorine dioxide

24. A reddish-brown stain on a white porcelain sink would likely be caused by _____________ precipitate.
   A. Calcium
   B. Magnesium
   C. Iron
   D. Manganese

Biological Characteristics of Water

25. Unacceptable levels of lead and copper at a consumer's faucet would most likely be caused by:
    A. Lead and copper in the raw water source.
    B. Having chlorine residual levels too high.
    C. Corrosive water.
    D. Bacteriological activity.

26. What is the formula for soda ash?
    A. CaO
    B. $Ca(OH)_2$
    C. Na_2CO_3
    D. NaCl

Microorganisms and Disease

Today we know that disease-causing microorganisms can be carried in water and that their presence in drinking water is a serious hazard to human health. But that knowledge is relatively new. In 1676 a Dutch scientist was able to see bacteria using a very primitive microscope, but it wasn't until the mid and late 1800s that we began to understand that bacteria caused disease and that they can be carried in water. Microorganisms that cause disease by transmission through contaminated water are called **waterborne pathogens**[23].

One of the main jobs of water system operators is to control potentially pathogenic microorganisms. So it is important that they are familiar with the different types of microorganisms and their characteristics.

Microbiology

Definition

Microbiology is the study of microorganisms, of small living things. Although some forms of organisms studied by microbiologists can be seen with the naked eye, most of the things that microbiologists are interested in require the use of a microscope to see clearly. Microorganisms of interest to the water industry include the following:

- Bacteria
- Protozoa
- **Viruses**[24]
- Algae
- **Fungi**[25]

What to Study

To understand how to minimize growth and control pathogens, you must study the structure and characteristics of the microorganisms. In the sections to follow, we will look at size, shape, types, nutritional needs, and control of each of the major groups of microorganisms. We will also discuss some of the specific waterborne pathogens.

Bacteria

Most Common Microorganism

Bacteria are among the most common microorganisms in water. Bacteria are primitive, single-celled organisms with a variety of shapes and nutritional needs.

[23] Waterborne Pathogens – Bacteria, virus, and protozoa that cause disease and are carried by water.

[24] Virus – A submicroscopic organism that passes through filters capable of removing bacteria.

[25] Fungi – Non-chlorophyll-bearing plants that lack roots, stem, or leaves, that occur in water, sewage or sewage effluents, and that grow best in the absence of light.

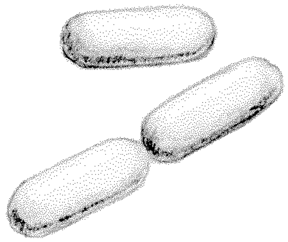
Size Range

Bacteria range in size from 0.5 to 2 microns in diameter and about 0.5 to 5 microns in length. A micron is a metric unit of measurement equal to one-millionth of a meter or one-thousandth of a millimeter. Another way to visualize the size of bacteria is to consider that it would take about 1000 bacteria, lying side-by-side, to reach across the head of a straight pin.

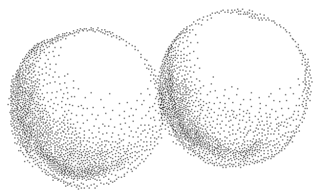
Three Shapes

There are three general groups of bacteria based on their physical shape:

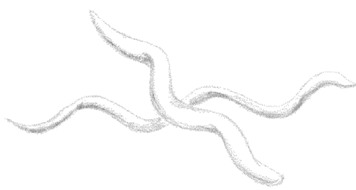
- **Rod-shaped bacteria** are called bacilli.
- **Spherical-shaped bacteria** are called cocci.
- **Spiral-shaped bacteria** make up the third group.



Bacilli



Cocci



Spiral-shaped bacteria

Within these three groups, there are many different arrangements. Some exist as single cells, others as pairs, as packets of four or eight, as chains, and as clumps.

Food Requirements

Most bacteria require organic food to survive and multiply. This food comes from plant and animal material that gets into the water where the bacteria exist. The bacteria convert the food to energy and use the energy to make new cells. Some bacteria can use inorganics (such as iron) as an energy source. These bacteria can exist and multiply even where organic pollution is not present.

Temperature Requirements

Temperature affects the rate at which bacteria grow. The warmer the environment, the faster the rate of growth. Typically, for each increase of 10° C, the growth rate doubles. This means that bacteria will multiply more quickly when it is warm, and more chlorine may be required to obtain proper disinfection.

pH Requirements

pH affects bacteria growth. Most bacteria grow best at a neutral pH. Extreme acidic or basic conditions will inhibit growth. Other materials, such as metal ions (cop-

[26] Aerobic – A condition in which "free" or dissolved oxygen is present in the aquatic environment.

[27] Anaerobic – A condition in which "free" or dissolved oxygen is not present in the environment.

[28] Facultative – Microorganisms that can switch from aerobic to anaerobic growth or can grow in an anaerobic or aerobic environment.

per, lead, silver), and some organics, such as pesticides and herbicides, are toxic and inhibit bacterial growth.

Oxygen Requirements

Many bacteria are **aerobic**[26]. They require free or dissolved oxygen in their aquatic environment. A few bacteria are **anaerobic**[27]. They can exist and multiply in an environment that lacks dissolved oxygen. Some bacteria that are normally aerobic can switch to anaerobic. These adaptable bacteria are said to be **facultative**[28]. One of the most troublesome bacteria in the water business is the iron bacteria, which is a facultative organism. The bacteria responsible for most of the biological treatment of wastewater are aerobic.

[29] Sterilization – The process of destroying all living organisms.

[30] Spores – A resistant, viable structure regarded as the resting stage of an organism.

How They Multiply

Under optimum conditions, bacteria grow very rapidly. They multiply by a simple dividing process referred to as binary fission. Each cell splits into two identical new cells. Bacteria growing under optimal conditions can double their number about every 20 to 30 minutes. This means that as long as nutrients hold out, even the smallest contamination can result in a sizable growth in a very short time.

Disinfection Process

The destruction of pathogenic microorganisms is called disinfection. Disinfection does not mean that all microbial forms are killed. Rather, that is **sterilization**[29]. However, disinfection does destroy most disease-causing organisms and reduces the total number to an acceptable level. Growing bacteria are fairly easy to control by disinfection. Some bacteria, however, form spores, which are much more difficult to destroy. **Spores**[30] are survival structures formed by some bacteria to resist harsh, threatening environments.

Pathogenic Bacteria

Bacteria are responsible for a number of the most infamous epidemic diseases. The bacterial pathogens responsible for these diseases enter potential drinking water supplies through fecal contamination and are ingested by humans if the water is not properly treated and disinfected.

The table below lists a number of bacterial waterborne diseases.

Bacteria	Disease
Salmonella typhi	Typhoid Fever
Shigella spp.	Gastroenteritis
Vibrio cholerae	Cholera
Campylobacter spp.	Gastroenteritis
Enteropathogenic E. coli	Gastroenteritis
Leptospira spp.	Leptospirosis

Review

1. Microorganisms that cause disease by transmission through contaminated water are called:

2. Microbiology is the study of:

3. The five groups of microorganisms of interest to the water industry:

4. _________________ range in size from 0.5 to 2 microns in diameter and about 1 to 10 microns long.

5. List the three common bacterial shapes:

Review Continued

6. Although some bacteria can use inorganic chemicals as an energy source, most bacteria require _________________ chemicals as a food source.

7. Bacteria that require an environment *with* free or dissolved oxygen are said to be:

8. Bacteria that require an environment *without* free or dissolved oxygen are said to be:

9. Bacteria that can exist in an environment *with or without* free or dissolved oxygen are said to be:

10. Some bacteria produce _________________, which are strong, resistant resting stages that make them more resistant to disinfection.

11. Three waterborne diseases caused by bacteria:

Protozoa

Definition and Size

Protozoa are one-celled animal-like organisms with a fairly complex cellular structure. The protozoa are the giants of the microbial world. They are many times larger than bacteria and range in size from 4 to 500 microns. The larger ones can almost be seen with the naked eye.

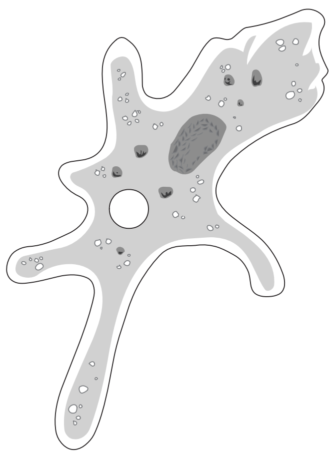
Groups of Protozoa

The major groups of protozoa are based on their method of locomotion or movement:

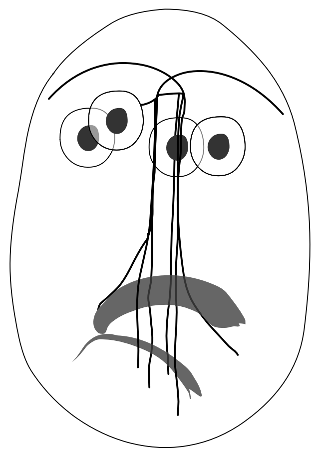
- **Amoebas** move about by a streaming or gliding action. The shape of an amoeba changes as they sort of ooze from place to place.
- **Ciliates** are covered with short hair-like projections, called cilia, which beat

rapidly and propel the ciliate through the water. Most ciliates are free-swimming, although some are attached to floating material or basin walls.

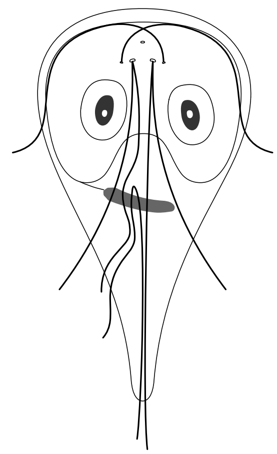
- **Flagellates** have one or more long whip-like projections, called flagella, which propel the free-swimming organisms.
- **Suctoria** are attached organisms, similar to attached ciliates, but have tentacles rather than cilia.
- **Sporozoa** are non-mobile and are simply swept along with the current of the water.



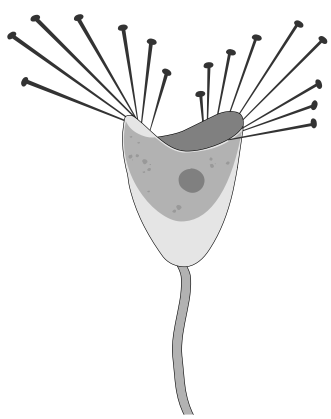
Amoeba



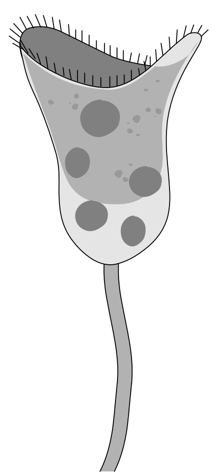
Giardia lamblia
Cyst, form



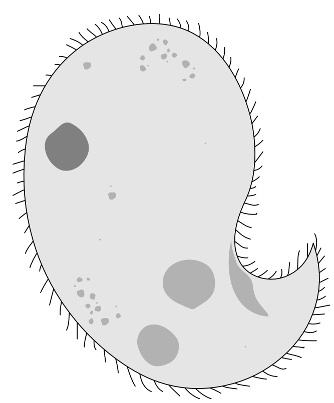
Giardia lamblia
Trophozoite, form



Suctoria



Stalked Ciliate



Free-swimming Ciliate

Food Requirements

Protozoa use organics for food. In fact, bacteria are among their favorite prey. Protozoa are mostly aerobic or facultative in regards to oxygen requirements. In the same manner as bacteria, pH, toxic materials, and temperature affect their rate of growth.

Life Cycle

Most protozoa have a complex life cycle in which they alternate between an active growth phase, when they are called trophozoites, and a resting stage, called cysts. Cysts are extremely resistant structures that protect the organism from destruction when it encounters harsh environmental conditions.

Resistance to Chlorine

Because of their relative complexity and ability to form the extremely resistant cysts, protozoa require higher disinfectant concentrations and longer contact time to control them. In fact, some types of protozoa may be almost completely resistant to disinfection by chlorination.

Waterborne Disease

Three protozoan waterborne diseases are listed in the table below.

Protozoa	Disease
Entamoeba histolytica	Amoebic dysentery
Giardia lamblia (5 to 21 μ in size)	Giardiasis
Cryptosporidia (4 to 6 μ in size)	Cryptosporidosis

Review

1. _________________ are single-celled, animal-like microorganisms, many times larger that bacteria.
2. Protozoa that move using short, hair-like projections are called:
3. Protozoa that move using long, whip-like projections are called:
4. Protozoa that move using a flowing or gliding action are called:
5. Most protozoa have an active, growing life stage called a trophozoit and a resistant, resting stage called a:
6. Three waterborne diseases caused by protozoa:

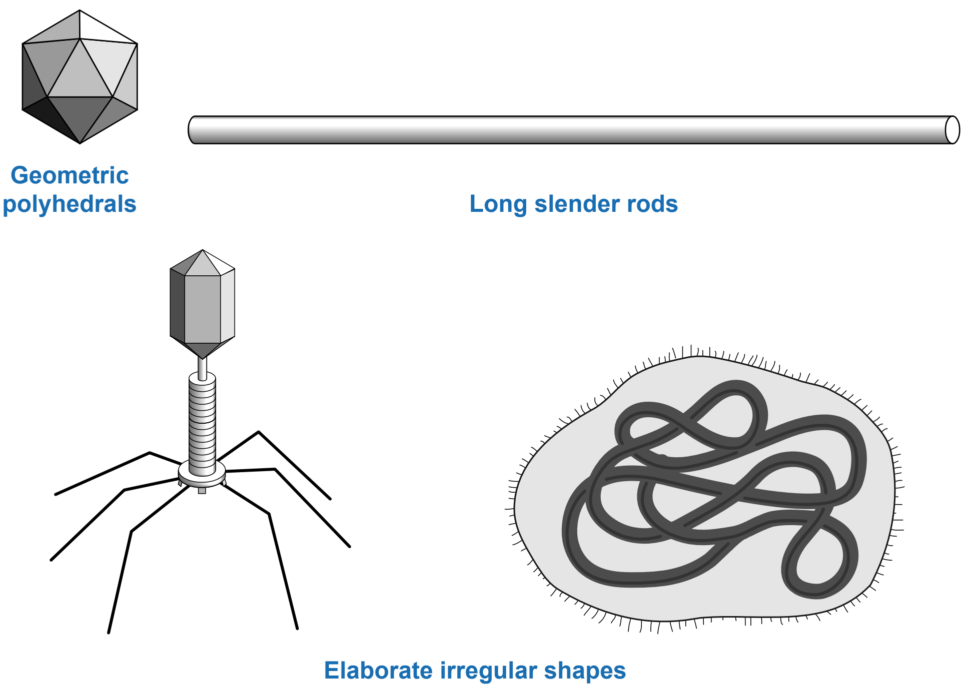
Viruses

Description and Size

Viruses are the midgets of the microbial world. They are many times smaller than bacteria. They range in size from 0.02 to 0.25 microns in diameter. Viruses are intracellular parasites that must have a host cell in which to multiply. They are extremely simple life forms. A central molecule of genetic material is surrounded by a protein shell, called a capsid, and sometimes by a second layer, called an envelope. They contain no mechanisms by which to obtain energy or reproduce on their own.

Shapes

Viruses occur in many shapes:



Need for a Host

There are almost as many kinds of viruses as there are types of other living organisms. Viruses exist that can invade virtually every kind of living cell: animals, plants, insects, fish, and even bacteria. After they invade their specific host, they take over the machinery of the host and force it to make more viruses. The host cell is then destroyed, and hundreds of new viruses are released into the environment.

Disinfection

Because they lack sensitive cellular machinery and because they have relatively tough capsids and envelopes, viruses are hard to destroy by normal disinfection practices. Increased disinfectant concentration and contact time must be used to effectively destroy viruses by chlorine disinfection.

Waterborne Diseases

Waterborne viruses can cause three diseases:

- Hepatitis
- Viral gastroenteritis
- Poliomyelitis

Review

1. ________________ are many times smaller than bacteria and are considered to be intracellular parasites.

2. Viruses lack internal cell mechanisms, so they must have a(n) ________________ cell in which to multiply.

3. Three waterborne diseases caused by viruses:

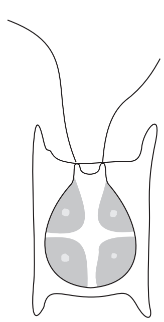
Algae

Description

Algae are a form of aquatic plants. Although in mass they are easily seen by the naked eye, many are microscopic as single cells. They exist as microscopic, single-celled forms and also as huge, multicellular forms, such as marine kelp. They occur in fresh and polluted water, as well as in salt water. Since they are plants, they are capable of using energy from the sun in the process called photosynthesis. They grow only where there is light, and they grow better where there is bright sunlight, as opposed to cloudy weather. They usually grow near the surface of the water because light cannot penetrate very far through the water.

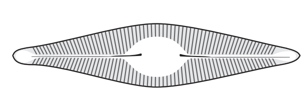
Algae are classified by their color:

- **Green algae** contain green chlorophyll and are found mostly in fresh water. This form is the green roadside ditch algae, and the type that grows on clarifier and basin walls.
- **Euglenoids** are single-celled, green-pigmented algae that resemble protozoa. They have flagella, but are considered algae because they carry out photosynthesis.
- **Diatoms** are golden-brown, single-celled forms that have a hard silica shell. The shells of millions of dead diatoms are mined commercially and known as diatomaceous earth.
- **Cyanobacterium** is bluish-green in color and undergoes photosynthesis. It was formerly called blue-green algae, but is now classified as a type of bacteria.



Euglenoids

Blue-green



Diatoms

Problems Caused by Algae

Although algae are not considered to be waterborne pathogens, they do cause some problems with water operations. They grow easily on the walls of basins and troughs, and heavy growth can cause plugging of screens and intakes. Algae release chemicals that can cause taste and odor problems in drinking water.

Control of Algae

Algae in raw water supplies can be controlled with chlorine and potassium permanganate. In raw water reservoirs, algae blooms are often controlled with copper sulfate.

Fungi

Description

Fungi are of relatively minor importance to the water business. Fungi are non-photosynthetic organisms that grow as multicellular, filamentous, mold-like forms or as single-celled, yeast-like organisms. Fungi must have organic material as a food source.

Growth Environment

Fungi like to grow in damp organic material such as drying or composting sludge. As part of their reproductive cycle, they produce spores that are so small, they can easily be carried by dust and wind. When inhaled, some of these spores can cause respiratory infections. Fungi are not considered to be waterborne pathogens.

Review

1. _____________ are a form of aquatic plants that can be either tiny, single-celled or large, multi-celled organisms.

2. Chemicals released by algae can cause _____________ and _____________ problems.

3. Algae blooms in raw water reservoirs can be controlled with:

4. _____________ are non-photosynthetic, multicellular or single-celled filamentous or yeast-like organisms that require organic material for food.

Disease and Disease Transmission

The term “disease” refers in general to an abnormal condition that impairs the victim’s function. Many different environmental factors can cause disease, such as chemical, biological, psychological, and even social factors. Waterborne pathogenic microorganisms are a major source of human disease.

Waterborne diseases are transmissible diseases because they can be passed from an infected individual to another person. The majority of the waterborne pathogens that transmit disease do so via the “feces – water – mouth” route. The pathogens exist in the intestines of an infected individual and are excreted into the environment with feces. From there they find their way into surface and groundwater supplies and to another individual through contact with or by ingesting contaminated water. Some waterborne pathogens can be acquired by breathing mist or sprays (such as in a shower). Waterborne disease can also be transmitted via a "feces – hand – mouth" route if good personal hygiene practices are not followed.

Drinking water treatment is designed to interrupt the "feces – water – mouth" cycle of transmission by removing and destroying the pathogenic microorganisms. If the treatment processes are carried out as intended, consumers should expect to have water available to them that is free of pathogens. But communities and individuals must also understand that the water can be contaminated after it is delivered to the home. Personal hygiene and sanitation practices are critical to avoiding potential waterborne disease.

Control of Microorganisms

Two terms are used in reference to the control of microorganisms:

- **Sterilization** means the complete destruction of all living forms, including single- and multi-celled microorganisms, bacterial spores, and protozoa cysts.
- **Disinfection** means the destruction of pathogenic microorganisms, but does not necessarily mean complete destruction of all life forms. Operators may sterilize glassware in the laboratory, but the addition of chlorine to treated water is a disinfection process, not sterilization.

Microorganisms can be controlled by manipulating their environment (such as applying heat or changing the pH), by limiting or removing their food supply, or by subjecting them to damaging chemical or physical processes.

Microbial growth is slowed considerably by refrigeration, by lowering the temperature. Microbial growth can also be optimized by adjusting the temperature to one that favors a particular microorganism. Higher temperatures may be sufficient to sterilize an environment. Raising the pH with lime creates conditions in which most bacteria do not grow. Limiting sunlight prevents photosynthetic algae from growing. Knowing the environmental factors that affect the growth of microorganisms helps implement strategies for control.

Limiting the food supply can control the growth of microorganisms. Since many bacteria and most protozoa require organic matter for food, removing organics from the water and keeping surfaces and basins clean and free from organic matter limit growth. The removal of minerals, such as iron, from water can also discourage the growth of bacteria that use minerals as a food source. Keeping pipes and tanks clean and free or organic sediment can help control growth in the distribution system.

A variety of chemicals and physical processes can be used to control microorganism growth. Chlorine, bromine, and iodine are well-known for their use as water disinfectants. Ozone is also an effective water disinfectant. Other chemicals, such as alcohol, formaldehyde, hydrogen peroxide, hexachlorophene, and certain heavy metals (silver and mercury) can be used to control growth. Some of these are strong and can only be used on inanimate objects. Others can be used to control microbial growth on skin and in eyes. Physical processes such as filtration, ultraviolet light, and gamma radiation are also effective.

Practicing good personal hygiene is an easy and effective way to control microorganism growth and to prevent the transmission of waterborne pathogens. Hand-washing is the most important practice. Washing hands after using the bathroom and before handling food and drinking water significantly reduces waterborne disease transmission. Coughing into the crook of an elbow, instead of into hands, can also help prevent transmission. Proper handling and disposal of human waste, and carefully cleaning up afterwards, is also important. Water system operators must practice personal hygiene conscientiously to avoid contaminating equipment and water supplies.

Indicator Microorganism

To be sure that the water supplied to consumers is free of pathogens, operators must routinely sample and test the water for indications of the presence or absence of pathogens. It is beyond the capacity of treatment plant labs to directly test for any of the pathogenic microorganisms. But operators and technicians can test for bacteria called indicators, organisms whose presence indicates the possible presence of pathogens and whose absence means that the water is free of pathogens. The indicators used are a bacterial group known as total coliforms. As a group, coliforms live in the intestines of warm-blooded animals, as well as in the soil, in natural water, and on vegetation.

Although some total coliforms are pathogenic, most are not, and harmless coliforms are normal inhabitants of all human intestinal systems. So if coliforms are found in a water sample, there is a possibility that it has been contaminated by human feces. On the other hand, since coliforms are always found in human feces, if no coliforms are found in a water sample, it is safe to conclude that it has not been contaminated with human feces. If total coliforms are found in a water sample, the sample is further tested for a more restrictive group of coliforms called fecal coliforms or for *E. coli*, a specific coliform bacterium. The tests for fecal coliforms and *E. coli* are more sensitive, but more difficult to run, so they are used to confirm the results of the total coliform test. Their presence is a stronger indication of fecal contamination that could contain waterborne pathogens.

The Safe Drinking Water Act's Total Coliform Rule specifies the frequency and procedures for sampling and testing for coliforms. Analytical laboratories running coliform tests on drinking water samples for compliance purposes must be certified by the Alaska Department of Environmental Conservation (ADEC).

Review

1. A disease that can be passed from one person to another is said to be:

2. The majority of _____________ – borne diseases are transmitted through the "feces – water – mouth" route.

3. _____________ means the complete destruction of all organisms or cells.

4. _____________ means the control of pathogenic microorganisms.

5. Manipulating a microorganism's _____________ is one way of controlling it.

6. Limiting a microorganism's _____________ supply is another way of controlling it.

7. Three chemicals, other than chlorine, that can be used to control microorganisms:

8. Practicing good personal _____________ is an easy and effective way to control microorganism growth and to prevent the transmission of waterborne pathogens.

9. A(n) _____________ is an organism whose presence indicates the possible presence of pathogens.

10. The Total Coliform Rule specifies how often water systems must sample and test for _____________ bacteria.

11. The absence of total coliform in a drinking water sample means the water is _____________ to drink.

Biological Characteristics of Water Quiz

1. Microorganisms that cause disease by transmission through contaminated water are called waterborne:
   A. Poisons
   B. Toxins
   C. Pathogens
   D. Biogens

2. Which of the following is not a microorganism of interest to the water industry?
   A. Bacteria
   B. Virus
   C. Insects
   D. Protozoa

3. Which of these is the smallest microorganism?
   A. Virus
   B. Bacteria
   C. Protozoa
   D. Algae

4. A microorganism that requires an environment with free or dissolved oxygen present is said to be an ___________________ organism.
   A. Parasitic
   B. Aerobic
   C. Anaerobic
   D. Sensitive

5. Which of the following is a bacterial waterborne disease?
   A. Polio
   B. Giardiasis
   C. Hepatitis
   D. Typhoid fever

6. The tough, resistant resting stage formed by some bacteria is called a:
   A. Capsid
   B. Cyst
   C. Spore
   D. Seed

7. The complete killing of all living cells is called:
   A. Sterilization
   B. Disinfection
   C. Sanitization
   D. Chlorination

8. The destruction of pathogenic microorganisms is called:
   A. Sterilization
   B. Disinfection
   C. Sanitization
   D. Autoclaving

9. Protozoa that move with the aid of long, whip-like tails are classified as:
   A. Amoeba
   B. Ciliates
   C. Flagellates
   D. Sporozoa

10. Protozoa that move with the aid of short, hair-like bristles are classified as:
    A. Amoeba
    B. Ciliates
    C. Flagellates
    D. Sporozoa

11. The tough, resistant resting stage of the life cycle of protozoa is called a:
    A. Capsid
    B. Cyst
    C. Spore
    D. Seed

12. Which of the following is a protozoal waterborne disease?
    A. Polio
    B. Giardiasis
    C. Hepatitis
    D. Typhoid fever

13. Which of these microorganisms are considered obligate, intracellular parasites because they lack system to reproduce on their own?
    A. Bacteria
    B. Protozoa
    C. Viruses
    D. Fungi

14. Which of the following is a viral waterborne disease?
    A. Poliomyelitis
    B. Giardiasis
    C. Cholera
    D. Typhoid fever

15. Which of the following is considered a form of aquatic plant because it is photosynthetic?
    A. Algae
    B. Protozoa
    C. Viruses
    D. Fungi

16. Diatoms belong to which group of microorganisms?
    A. Algae
    B. Protozoa
    C. Viruses
    D. Fungi

17. *Cyanobacterium*, now classified as a bacteria, used to be classified with which group of microorganisms?
    A. Algae
    B. Protozoa
    C. Viruses
    D. Fungi

18. Algae, in raw water reservoirs, can be controlled with which chemical?
    A. Sodium hypochlorite
    B. Calcium oxide
    C. Copper sulfate
    D. Soda ash

19. Diseases that can be passed from one person to another are said to be:
    A. Deadly
    B. Vectors
    C. Transmissible
    D. Toxic

20. Which of the following activities would not be considered a means of controlling microorganisms by manipulating their environment?
    A. Adding lime to raise pH
    B. Refrigeration
    C. Filtration
    D. Limiting exposure to sunlight

21. Which of the following is not used as a chemical means for controlling microorganisms?
    A. Bromine
    B. Alcohol
    C. Alum
    D. Hydrogen peroxide

22. An organism whose presence is evidence of the presence or absence of pathogens is called a(n):
    A. Pathogen
    B. Substitute
    C. Partner
    D. Indicator

23. What group of bacteria is used as an indicator for the presence of absence of waterborne pathogen in drinking water?
    A. Total coliforms
    B. Respiratory streptococcus
    C. Heterotrophs
    D. Human pathogens

Introduction to Water Sources

Chapter 3

What Is In This Chapter?

1. Definition of surface water
2. Examples of surface water
3. Advantages and disadvantages of surface water
4. Surface water hydrology
5. Raw water storage and flow measurements
6. Surface water intake structures
7. The types of pumps used to collect surface water
8. Definition of groundwater
9. Examples of groundwater
10. Advantages and disadvantages of groundwater
11. Groundwater hydrology
12. Three types of aquifers
13. Well components
14. Data and record keeping requirements
15. Transmission lines and flow meters
16. Groundwater under the direct influence of surface water

Key Words

- Aquifer
- Baseline Data
- Caisson
- Cone of Depression
- Confined Aquifer
- Contamination
- Drainage Basin
- Drawdown
- Flume
- Glycol
- Groundwater
- Impermeable
- NTU
- Parshall flume
- Permeability
- Polluted Water
- Porosity
- Raw Water
- Recharge Area
- Riprap
- Spring
- Static Water Level
- Stratum
- Surface Runoff
- Surface Water
- Unconfined Aquifer
- Water Rights
- Water Table
- Watershed
- Weir

Introduction

This lesson is a discussion of the components associated with collecting water from its source and bringing it to the water treatment plant.

Lesson Content

This lesson will focus on **surface water**[1] and **groundwater**[2], hydrology, and the major components associated with the collection and transmission of water to the water treatment plant.

[1] Surface Water – Water on the earth's surface as distinguished from water underground (groundwater).

[2] Groundwater – Subsurface water occupying a saturated geological formation from which wells and springs are fed.

Sources of Water

Three Classifications

The current federal drinking water regulations define three distinct and separate sources of water:

- Surface water
- Groundwater
- Groundwater under the direct influence of surface water (GUDISW)

This last classification is a result of the Surface Water Treatment Rule. The definition of what conditions constitute GUDISW, while specific, is not obvious. This classification is discussed later in this lesson.

Surface Water

Definition

Surface water is water that is open to the atmosphere and results from overland flow. It is also said to be the result of **surface runoff** [3]. These are two ways of saying the same thing.

[3] Surface Runoff – The amount of rainfall that passes over the surface of the earth.

Examples of Surface Water

Specific sources that are classified as surface water include the following:

- Streams, Rivers, Lakes
- Man-made impoundments (lakes made by damming a stream or river)
- **Springs**[4] affected by precipitation that falls in the vicinity of the spring (affected means a change in flow or quality)
- Shallow wells affected by precipitation (affected means a change in level or quality)
- Wells drilled next to or in a stream or river
- Rain catchments
- Muskeg and tundra ponds

[4] Spring – A surface feature where, without the help of man, water issues from rock or soil onto the land or into a body of water, the place of issuance being relatively restricted in size.

Advantages and Disadvantages of Surface Water

There are both advantages and disadvantages to surface water:

- **Advantages** – The primary advantages to using surface water as a water source include the following:
  - It is easily located. It takes no sophisticated equipment to find a surface water source.

- In many parts of the US, considerable data is available on quantity and quality of existing surface water supplies.
- Surface water is generally softer than groundwater, which makes treatment much simpler.

- **Disadvantages** – The most common disadvantages to using surface water as a water source include the following:
  - Surface waters are easily **polluted**[5] (or contaminated) with microorganisms that cause waterborne diseases and chemicals that enter the stream from surface runoff and upstream discharges.
  - The turbidity (measured as **NTU**[6]) of a surface water source often fluctuates with the amount of precipitation. Increases in turbidity increase treatment cost and operator time.
  - The temperature of surface water fluctuates with the ambient temperature. This makes it difficult to produce consistent water quality at a water treatment plant.
  - The intake structure may become clogged or damaged from winter ice, or the source may be so shallow that it completely freezes in the winter. This is a common problem with surface water sources in the arctic.
  - Removing surface water from a stream, lake, or spring requires a legal right, referred to as a water right. **Water rights**[7] in Alaska are obtained from the Department of Natural Resources (DNR).
  - For many systems in Alaska, the source water is at its worst possible quality during the time of the year when the community needs to fill or top off its storage tank. This happens late in the summer when glacially fed streams have turbidities of 1000 ntu or greater.
  - Using surface water as a source means that the purveyor is obligated to meet the requirements of the Surface Water Treatment Rule (SWTR) of the State Drinking Water Regulations. This rule requires that, in most instances, any surface water source must have a filtration system.
  - Surface waters that are high in color, especially color that is the result of decaying vegetation, have the potential to produce high levels of Total Trihalomethanes (TTHM). These chemical compounds are formed when chlorine is added to the water. The problem with the TTHM is that some of them are carcinogenic (can cause cancer) and are referred to as disinfection by-products (DBP).

[5] Polluted Water – Water than contains sewage, industrial wastewater, or other harmful or objectionable substances.

[6] NTUs – The units of measure of turbidity, Nephelometric Turbidity Units, the measurement as made with a nephelometric turbidimeter.

[7] Water Rights – The rights, acquired under the law, to use the water accruing in surface or groundwater, for a specified purpose in a given manner and usually within the limits of a given time period.

Surface Water Hydrology

Introduction

A basic understanding of the movement of water and the things that affect water quality and quantity are important to those who manage and operate water systems. The study of these items is called hydrology. The components of hydrology include the physical configuration of the watershed, the geology, soils, vegetation, nutrients, energy, wildlife, and the water itself.

Drainage Basin

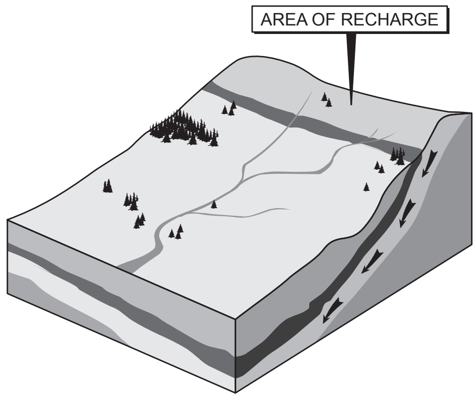
The area from which surface water flows is called a **drainage basin**[8]. With a surface water source, this drainage basin is most often called the **watershed**[9]. When we are dealing with a groundwater supply, this area is called the **recharge area**[10]. The

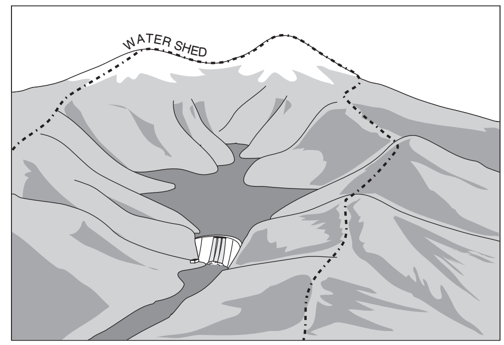
[8] Drainage Basin – An area from which surface runoff or groundwater recharge is carried into a single drainage system, also called a catchment area, watershed, or drainage area.

[9] Watershed – A drainage basin from which surface water is obtained.

[10] Recharge Area – One from which precipitation flows into the underground water sources.

drainage basin is difficult to identify when we are referring to a large river such as the Yukon. However, on a smaller river, stream or lake the area is defined by marking on a map an outline of the basin defined by the ridge of the mountains that surround the basin.





Review

1. What are the three sources of drinking water?
2. What do the letters GUDISW mean?
3. A muskeg pond is an example of what type of water source?
4. What are two of the advantages of surface water sources?
5. The study of the properties of water - its distribution and behavior - is called?
6. What is the area called that directly influences the quantity and quality of surface water?

Area Measurements

The area of the basin is commonly measured in square miles, sections, or acres. If you are taking water from a surface water source, it is desirable to know the size of the watershed.

Location of the Basin

A parcel of ground such as a drainage basin can be identified by and described by standard terms used in land descriptions and surveying. This description is based on a series of horizontal and vertical lines that form a rectangle system. The ability to describe properly the location of a drainage basin, well, or surface water intake is important when communicating with the Department of Natural Resources (DNR) and ADEC.

Baseline Data

Gathering precipitation and flow data plus water quality data is called **baseline data**[11]. This data is essential for long-term planning and determining the impact of activities in a drainage basin.

[11] Baseline Data – The water quality data, precipitation data, and stream flow data accumulated from a drainage basin or groundwater supply when there is little or no activity in the area.

[12] Raw Water – Water that has not been treated and is to be used, after treatment, for drinking water.

Raw Water Storage

Purpose

Raw water[12] storage areas are constructed to meet peak demands and/or to store water to meet demands when the flow of the source is below the demand.

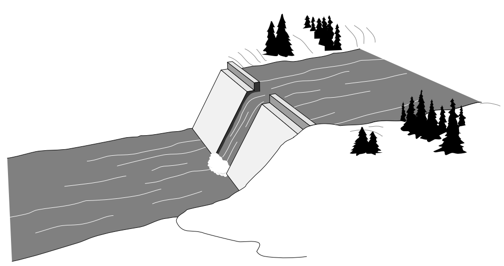
Natural Storage

Natural storage can be found in lakes like the one used by Haines and large rivers like the Yukon used by St. Mary's. Natural storage includes muskeg and tundra ponds used by logging camps in the Southeast, in oil field camps, and by resorts in the arctic region.

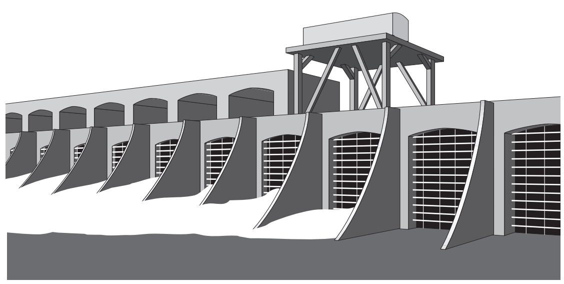
Man-made Storage

In many areas, there are no natural storage areas, and dams must be built. These dams can be either masonry or embankment dams. There are three different concrete masonry dam designs:

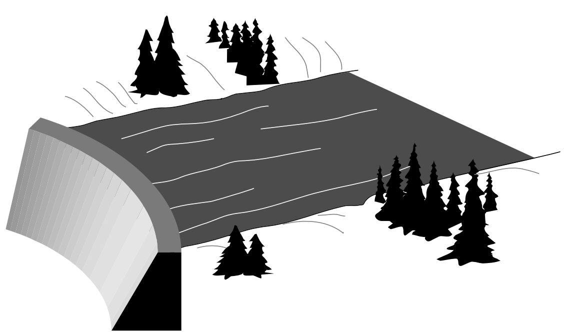
- Gravity dam
- Buttress dam
- Arched dam



Gravity dam



Buttress dam



Arched dam

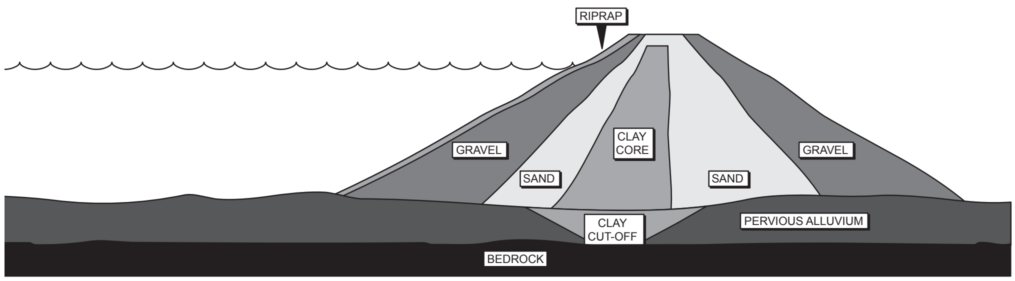
In Alaska, the most common dam used for potable water is a concrete gravity dam less than 30 feet in height. Examples of concrete dams can be found at the City of Craig and Port Alexander.

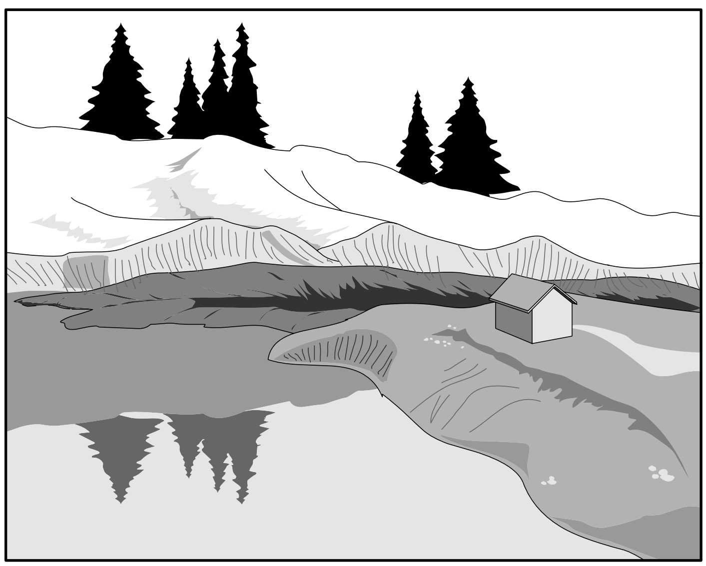
Embankment Dams

Embankment dams are made from local materials. The key to an embankment dam is a tightly compacted **impermeable**[13] clay core. This core is held in place either by rock or earth. When rock is used, the dam is called a rock fill embankment dam. **Riprap**[14] is placed on the face of the dam to prevent erosion by the water. The major advantage to this type of construction is its ability to give with small movements of the earth.

[13] Impermeable – Not allowing, or allowing only with great difficulty, the movement of water.

[14] Riprap – Broken stones or boulders placed compactly or irregularly on dams, levees, dikes, etc. for the protection of earth surfaces against the action of the water.



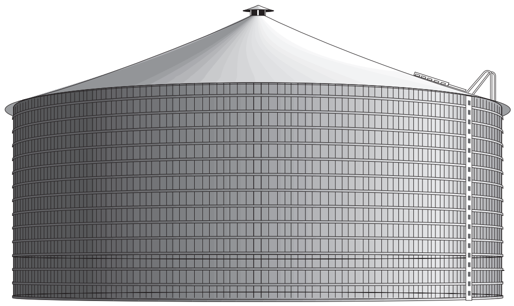


Man made impoundment resulting from an embankment dam

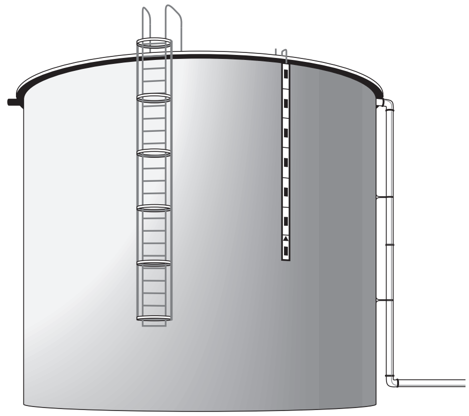
An example of an embankment dam is the village of Saxman, which uses a small embankment dam for holding its drinking water.

Raw Water Storage Tanks

In many locations in the arctic region, it is common to use a large man-made storage tank to store raw water for use during the winter months. These structures normally hold one million gallons or more and are made of wood or steel.



Wood tank



Steel tank

Flow Measurements

Introduction

The flow in a stream or river can be measured using primary devices such as **weirs**[15] and **flumes**[16] on small streams or secondary devices called current meters on larger streams.

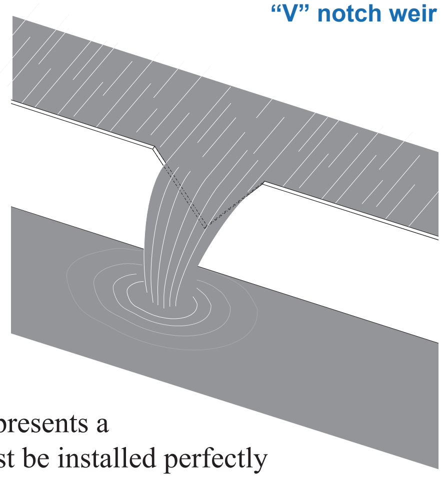
[15] Weir – A vertical obstruction, such as a wall or plate, placed in an open channel and calibrated in order that a depth of flow over the weir (head) can easily be measured and converted into flow in cfs, gpm, or MGD.

[16] Flume – An open conduit made of wood, masonry, or metal and constructed on grade that is used to transport water or measure flow.

Weirs

A weir is a plate made of wood or metal. These plates are placed in the stream plumb and level. They are identified by their shape. Typical shapes are rectangular, "V" notch, and cipolletti (a trapezoidal shaped weir), with the "V" notch and the cipolletti shapes being the most common.

"V" notch weir



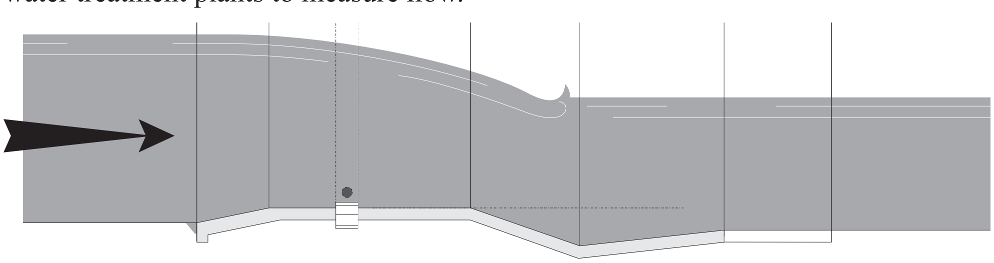
Flumes

Flumes are not as common as weirs. They are useful on very small streams and in locations where the restriction caused by the weir represents a problem to the habitat of the stream. Flumes must be installed perfectly level and plumb.

Flume Types

There are two common types of flumes used to measure stream flow: rectangular and **Parshall**[17]. The Parshall flume is the most common and is used in water and wastewater treatment plants to measure flow.

[17] Parshall Flume – A device used to measure flow in an open channel. The flume narrows to a throat of fixed dimension and then expands again. The flow is determined by measuring the difference between the head before and at the throat.



Parshall Flume

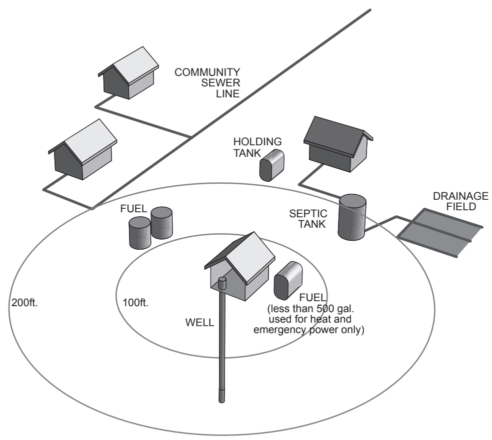
Surface Water Intake Structures

Location Criteria

Regulations and Standards

In order to protect high quality drinking water, the water works industry has developed standards and specifications for separation of the intake from potential sources of contamination. In addition, the Alaska Department of Environmental Conservation has established minimum separations distances from sources of contamination. The following listing includes industry standard practices as well as those items included in the ADEC regulations:

- There can be no wastewater disposal systems, including septic tanks and drain fields, within 200 feet of the intake for CWS, NTNCW, or TNCWS systems and 150 feet for Class C systems.
- There should be no community sewer line, holding tanks, or other potential sources of contamination within 200 feet of the intake of a CWS, NTNCW, or TNCWS system or within 100 feet in a Class C system.
- Fuel not used for on-site emergency pumping equipment or heating cannot be stored within 100 feet of the well for a CWS, NTNCW, or TNCWS system or within 75 feet of the well for a Class C system.
- Fuel for onsite emergency generators or building heating system can be stored onsite if the total volume is less than 500 gallons.



Recommendations

The following are recommendations and not regulations:

- The water purveyor should own or have a restricted area within 200 feet radius of the intake.
- There should be no roads within 100 feet of the intake.

Structures

The intake structure is used to collect the raw water from the source and place it into the transmission line. The types of intake structures used in the water industry vary greatly to meet the specific needs and construction conditions of each site. The following discussion will explore a few of the most common types as they apply to small streams, lakes, rivers, and reservoirs.

Small Streams

Small Dam

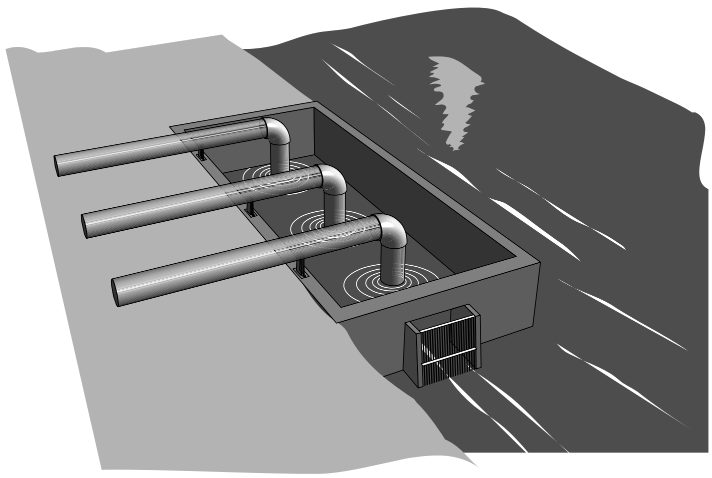
One of the most common intake structures on a small stream is a small gravity dam placed across the stream. Water behind the dam can be removed by a gravity line or pumps. This type of system is susceptible to ice damage in the winter.

Diversion in Stream

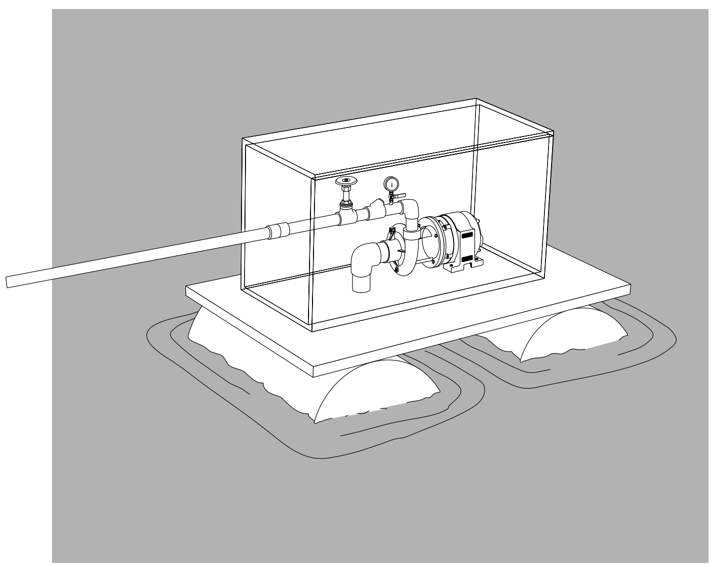
A second common intake for a small stream is a diversion of some type built next to the stream. Water is collected in the diversion and either carried away by gravity or pumped from a caisson. This type of intake is sometimes called a submerged intake.

River Float

A common intake on small and large streams is to use an end-suction centrifugal pump or submersible pump placed on a float. The float is secured to the bank, and water is pumped to a storage area. In the winter, the float is replaced with a hole in the ice and a platform for holding the pump controls.



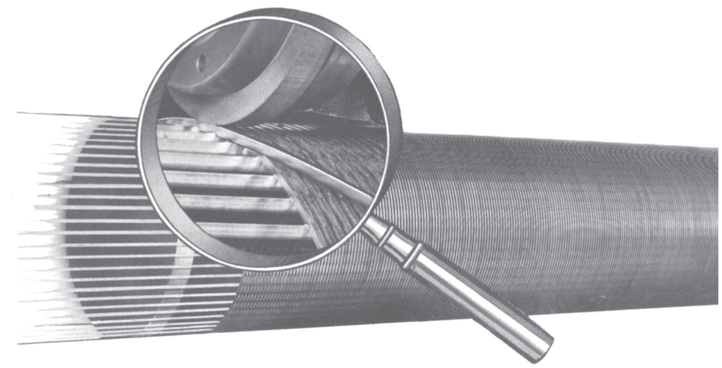
Submerged intake



Floating intake

Johnson Screen

One of the simple intake structures used on muskeg ponds and small streams is a section of Johnson screen placed on the end of a swing joint. The operator can select the best location of the pipe, raising and lowering it by a mechanical arm attached to the swing joint.

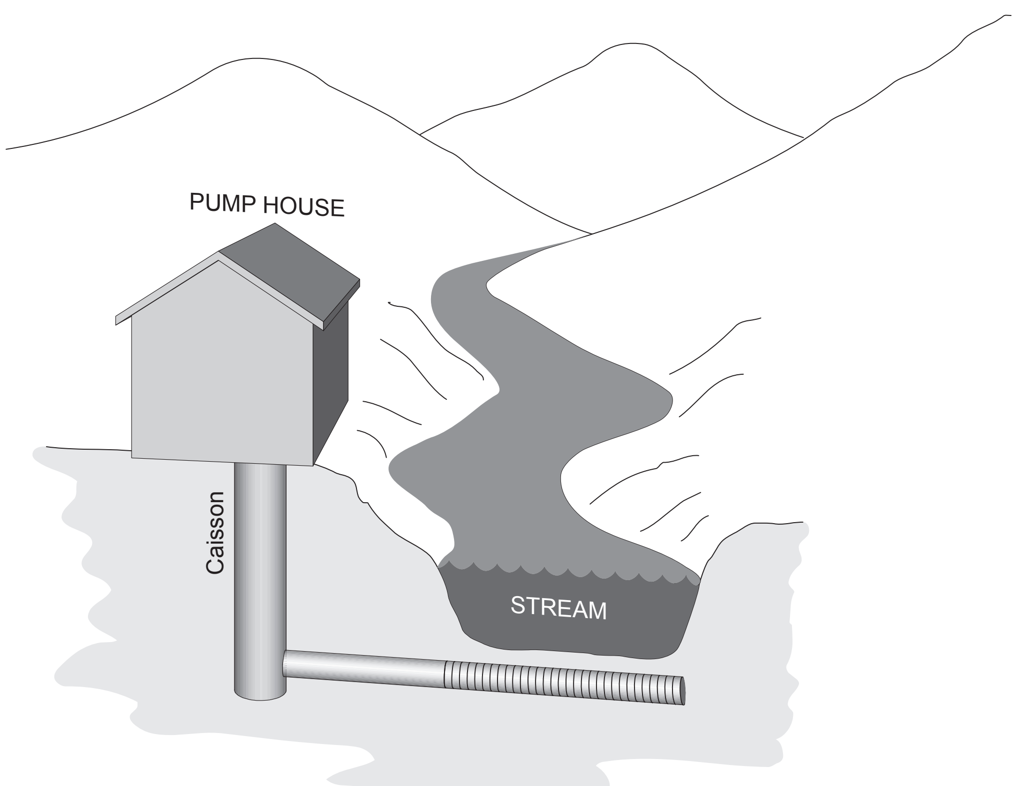


Johnson screen

Infiltration Gallery

Description

There are several uses and designs for the infiltration gallery. These include intake structures for a spring and intake structures placed in the bed of a stream. The most common infiltration galleries are built by placing Johnson well screens or perforated pipe into the streambed or water-bearing strata. The pipe is covered with clean graded gravel. As water percolates through the gravel, a portion of the turbidity and organic material is removed.



Infiltration gallery

[18] Caisson – Large pipe placed in a vertical position.

Infiltration – Caisson

The water collected by the perforated pipe flows to a caisson placed next to the stream. The water is removed from the **caisson**[18] by gravity or pumping.

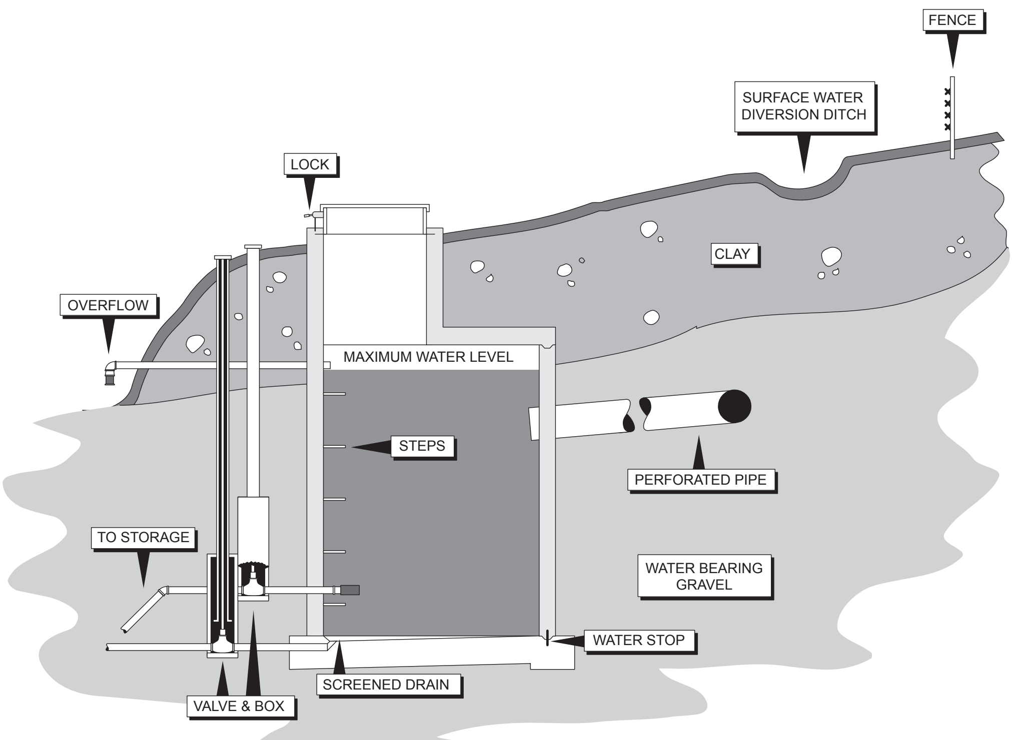
Other Intakes

Springs

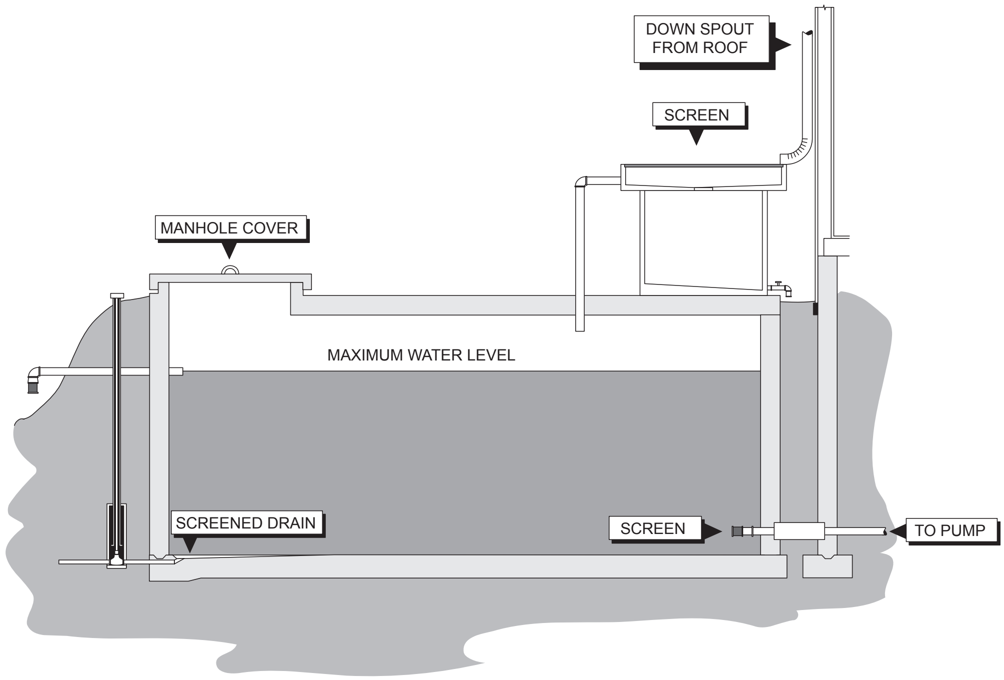
A common method of collecting water from a spring is to dig back into the mountain and place Johnson screens or perforated pipe into the water-bearing strata. This is then covered with clean washed rock and sealed with clay. The outlet is piped into a spring box.

Roof Catchments

In various parts of the world, including Southeast and Southwest Alaska, a primary source of water is rainwater. Rainwater is collected from the roof of buildings with a device called a roof catchment.



Spring box

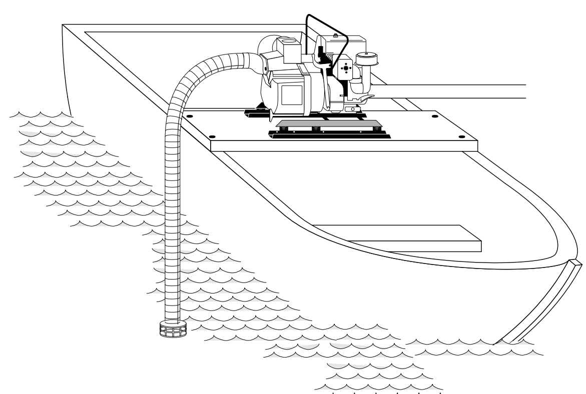


Roof catchment

Screens

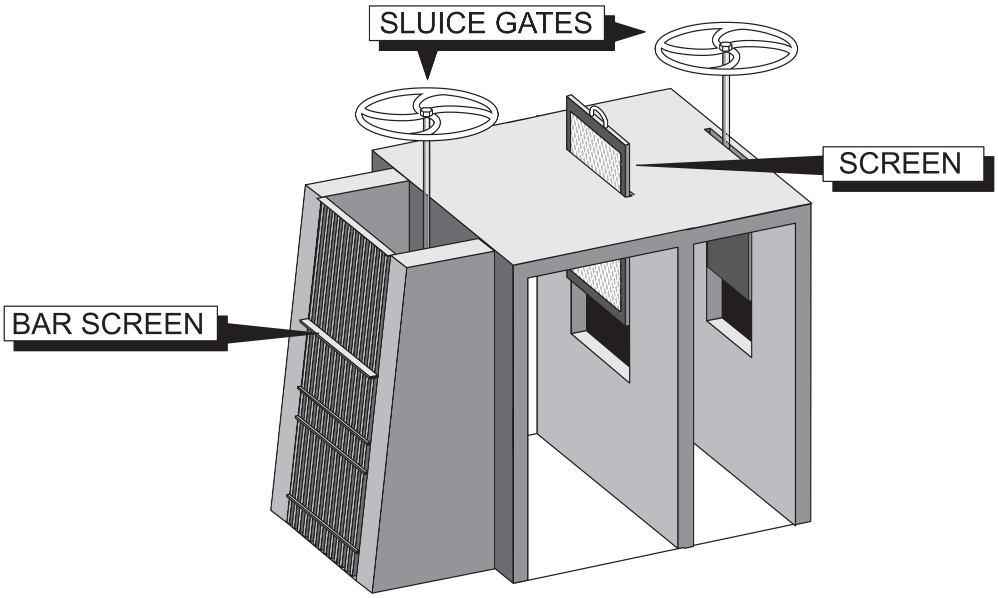
Bar Screens

The intake pumps, valves, and piping need to be protected from debris that would normally be drawn into the intake. One of the primary protection devices are large steel or concrete bars set vertically in the flow. This is called a bar screen and is designed to protect against large material.



Screens

After the bar screens is usually a smaller screen, designed to remove leaves and other small material that can clog the pumps and valves. The screens can be either self-cleaning or manually cleaned. Manually cleaned screens often require daily cleaning during certain times of the year.



Pumps

Gas Powered Units

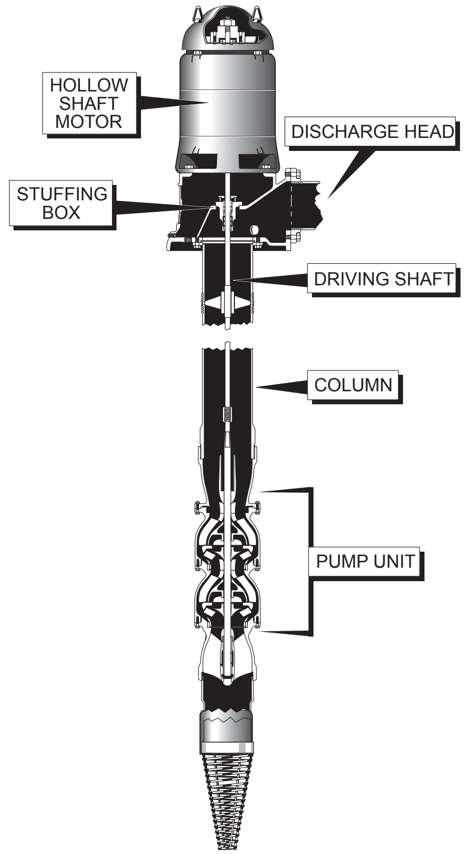
In many small villages that use the fill and draw process, a gas powered, end-suction centrifugal, self-priming pump is used to remove the water from the stream, muskeg, or tundra pond.

Lineshaft Turbines

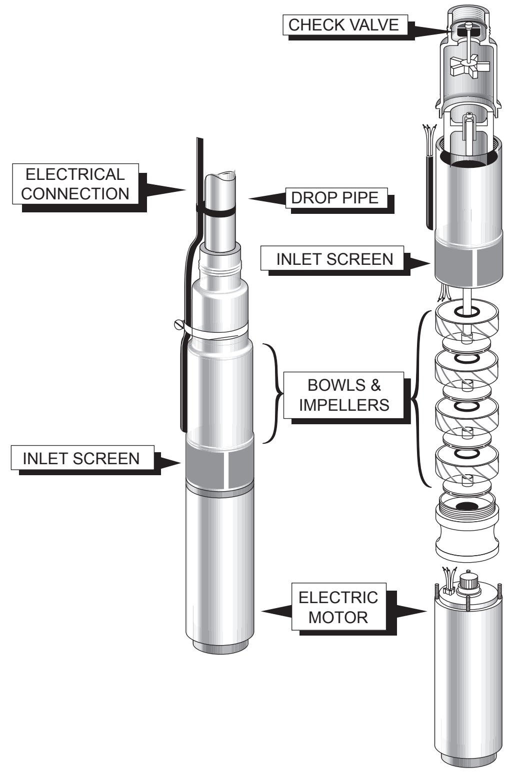
While not common in Alaska, one of the most common surface water intake pumps in other parts of the country is the lineshaft turbine. These are frequently used in larger facilities and are installed inside a protective caisson. This type of pump cannot be used as a portable device because it must remain in a perfectly plumb vertical position when it is in operation.

Submersible Turbine

The submersible turbine is used in a caisson on small streams and in river floats and set through the ice in the winter. The pump operates best and has the longest life if it can be kept in a nearly vertical plumb position when it is operating.



Lineshaft turbine



Submersible turbine

Review

1. The ______________ prevents an embankment dam from leaking.

2. What is the function of the bar screen at a surface water intake?

3. The two most common pumps found in small water system surface water and groundwater intakes are the ______________,______________ and the submersible.

Safety Concerns

Electrical

Anytime you are working with electricity, there is a safety concern. A 200-milliamp shock from arm to arm is enough to kill an average person. This current is less than what would run through your body if shocked by 120 volts. To prevent shock, always wear insulated gloves, and never wear metal jewelry or metal eyeglass frames when working with electricity. Latch the panel door open when working inside the panel. Turn the power off when making repairs, and always STOP AND THINK TWICE BEFORE TOUCHING AN ELECTRICAL COMPONENT.

Lock-Out/Tag-Out

When working on a pump, be sure to shut the power off, and "lock-out" the breaker with a padlock. Place a tag-out on the padlock with a note indicating when and why the unit was turned off.

Noise

When using gas or diesel powered equipment, you should be aware of the noise level. If the noise in the area in which you are working is above 85 db, you should wear hearing protection. Damaged hearing cannot normally be repaired. For instance, a gas-powered pump installed in a caisson or on a boat requires hearing protection anytime you are in or directly above the caisson when the pump is running.

Confined Spaces

Most caisson and valve boxes associated with intake structures are confined spaces and therefore, require the following:

- A written permit before you enter
- The use of an air ventilation system
- Monitoring the air quality with an oxygen and combustible gas meter every 15 minutes

Carbon Monoxide

When running the gas-powered pump in a caisson, take special care to ensure that the exhaust is out of the caisson. However, the wind can easily blow carbon monoxide back into the caisson. Check for oxygen and combustible gases before entering the caisson.

Records and Data Collection

To properly operate and maintain a surface water system, you should keep the following records:

- As-built drawings of all facilities
- Copy of the water rights certificate
- Copy of the watershed management use agreement
- Map of drainage basin showing land ownership, potential or existing **contamination**[19] sites, activity sites, and location of any water system structures
- Baseline quality and quantity data
- Water quality survey reports
- Water monitoring reports

[19] Contamination – The introduction into water of toxic materials, bacteria, or other deleterious agents that make the water unfit for its intended use.

Recommended Activities

To properly operate and maintain a surface water system, you should routinely obtain the following data and/or perform the following tasks: (Note: The test frequency described below is for CWS or NTNCWS systems and depends on particular system and monitoring summary.)

- Test turbidity
- pH and temperature (Daily)
- If there is color in the water (Daily)
- Test for bacteriological quality (Monthly)
- Collect a sample and have it tested for inorganic contaminants (Yearly)
- Collect a sample and have it tested for organic contaminants (Yearly)
- Inspect the intake structure (Frequency depends on type of structure but at least weekly)

- Make an on-site investigation of the drainage basin and waterway looking for existing or potential contamination (Yearly). This contamination can be natural or man-made. This process is called a water quality survey.
- Collect stream flow and precipitation data (Weekly)

Groundwater

Definition

Groundwater is considered to be water that is below the earth's crust, but not more than 2500 feet below the crust. Water between the earth's crust and the 2500-foot level is considered usable fresh water.

Examples of Groundwater

Groundwater is obtained from the following:

- Wells
- Springs that are not influenced by surface water or a local hydrologic event

Under the Influence

When a well or spring is influenced by an adjacent surface water source or by a local hydrological event, the supply is said to be groundwater under the direct influence of surface water (GUDISW).

Advantages and Disadvantages of Groundwater

There are both advantages and disadvantages to groundwater.

- Advantages – The advantages of groundwater sources in relationship to surface water include the following:
  - Groundwater is not as easily contaminated as surface water.
  - The quality of groundwater, while not always as good as would be preferred, is stable throughout the year.
  - Groundwater sources are generally lower in bacteriological count than surface water sources.
  - Groundwater is available in most locations throughout the continental US and Alaska.
- Disadvantages – When comparing groundwater sources with surface water, the following are disadvantages to using groundwater:
  - Once a groundwater source is contaminated, it is difficult for it to recover. There is no easy way to remove the contaminants.
  - Groundwater usually contains more minerals than surface water, including increased levels of hardness. Because groundwater is in contact longer with minerals, there is more time to bring them into solution.
  - Removal of groundwater normally requires a pump, thus increasing operation cost.
  - Groundwater is more susceptible to long-term contamination from fuel spills.
  - Groundwater supplies often have high levels of iron and manganese, thus increasing treatment cost and/or causing stains on plumbing and the clothing of customers.
  - Wells in the coastal areas are subject to salt water intrusion into the **aquifer**[20] and well. This contamination is difficult to predict and costly to treat.
  - Sources of contamination can be hidden from sight.

[20] Aquifer – A porous, water-bearing geologic formation from which surface water is obtained.

Groundwater Hydrology

Source
Groundwater, like surface water, is part of the hydrologic cycle. Groundwater is found in saturated layers under the earth's surface called aquifers. There are different names given to aquifers, depending upon their type.

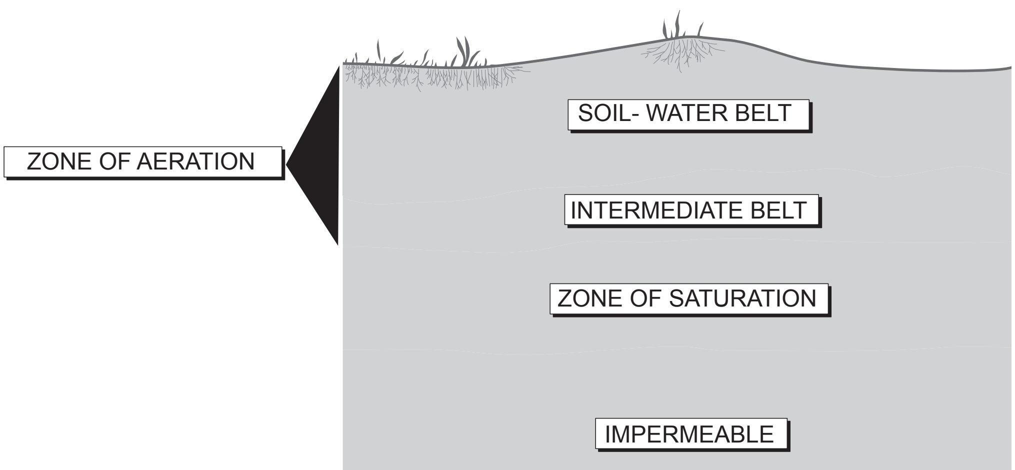
Three Types of Aquifers
There are three types of aquifers: unconfined, confined, and springs. The following is a brief description of the differences between these types of aquifers.

Unconfined Aquifers
Definition
The zone of saturation is an **unconfined aquifer**[21]. It is not contained, except on the bottom. An unconfined aquifer depends on local precipitation for recharge. This type of aquifer is often called a water table aquifer.

[21] Unconfined Aquifer – An aquifer that sits on an impervious layer but is open on the top to local infiltration. The recharge for an unconfined aquifer is local and is called a water table aquifer.

Zones and Belts
Unconfined aquifers are composed of unconsolidated strata that are divided into two zones:

- The zone of aeration contains two belts: the soil-water belt, where plants obtain their water, and the intermediate belt, where there is a mixture of air and water.
- The zone of saturation is an unconfined or water table aquifer. The top of this zone of saturation is called the **water table**[22].



[22] Water Table – The average depth or elevation of the groundwater over a selected area. The upper surface of the zone of saturation, except where that surface is formed by an impermeable body.

Unconfined Aquifer Wells
Wells drilled in an unconfined aquifer are normally called shallow wells and are subject to local contamination from hazardous and toxic material, such as fuel and oil, agricultural runoff containing nitrates and microorganisms, and septic tank discharge of increased levels of nitrates and microorganisms.

Groundwater Under the Influence
Water taken from wells drilled in an unconfined aquifer is not considered desirable

as a public drinking water source. This type of well may be classified as groundwater under the direct influence of surface water (GUDISW) and therefore require treatment for control of microorganisms.

Confined Aquifers

Definition

At various locations in the earth's crust are layers of saturated material that are contained between two layers of impermeable material such as rock, clay, or permafrost. This type of aquifer is called a **confined aquifer**[23].

[23] Confined Aquifer – An aquifer surrounded by formations of less permeable or impermeable material.

Artesian Aquifers

Confined aquifers are also called artesian aquifers. Naturally a well drilled in an artesian aquifer is called an artesian well. An artesian well is described as any well where the water in the well casing rises above the saturated strata. There are two types of artesian wells: flowing and non-flowing.

Water Quality – Confined Aquifers

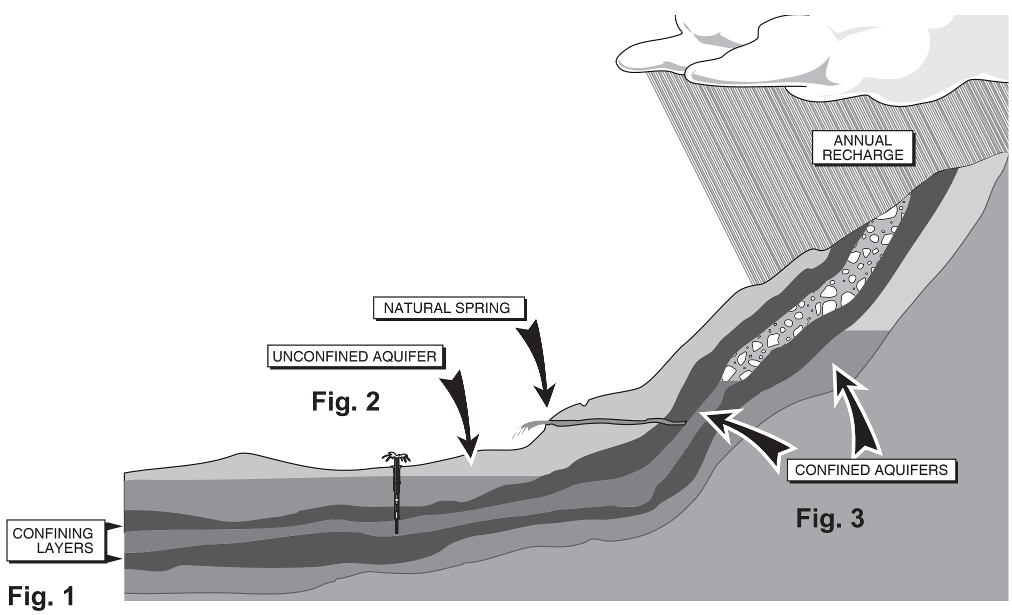
Confined aquifers commonly yield large quantities of high-quality water. One exception is water confined by permafrost layers. This water is very poor quality. The aquifer may be relatively short or may extend several hundred miles into the mountains.

Recharge of Confined Aquifers

A confined aquifer is recharged by snow or rain in the mountains where it is close to the surface of the earth. Because the recharge area is away from the area of contamination, the possibility of contamination of a confined aquifer is very low. However, once contaminated, it may take hundreds of years before it recovers.

Wells in Confined Aquifers

A well in a confined aquifer is normally referred to as a deep well. If the well is properly installed, the water quality is not impacted by local hydrological events.



Springs

Types

Water that naturally exits on the crust of the earth is called a spring. The water in a spring can originate from a water table aquifer or from a confined aquifer. When a spring comes from a confined aquifer, it is commonly the result of a geological fault (a break in the confining layer). Only water from a confined aquifer spring is considered desirable for a public water system.

Water Movement Through an Aquifer

Composition of an Aquifer

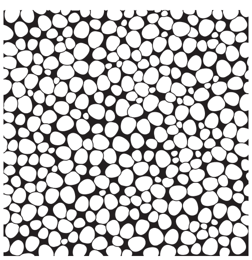
An aquifer is made up of a combination of solid material, such as rock and gravel, and open spaces called pores. Regardless of the type of aquifer, the water in the aquifer is in motion. This motion is caused by gravity or by pumping. The flow of water through the aquifer is influenced by the size of the material, the number of pores, and the connection between the pores.

Volume of Water

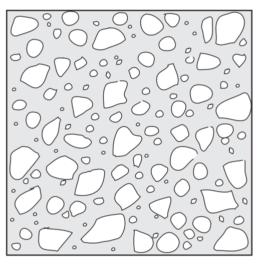
The volume of water in an aquifer is dependent upon the amount of space available between the various grains of material that make up the aquifer. The amount of space available is called **porosity**[24].

[24] Porosity – The ratio of pore space to total volume. That portion of a cubic foot of soil that is air space and therefore can contain moisture.

All grains approximately the same size.
High Porosity



Mixed grain sizes.
Low Porosity

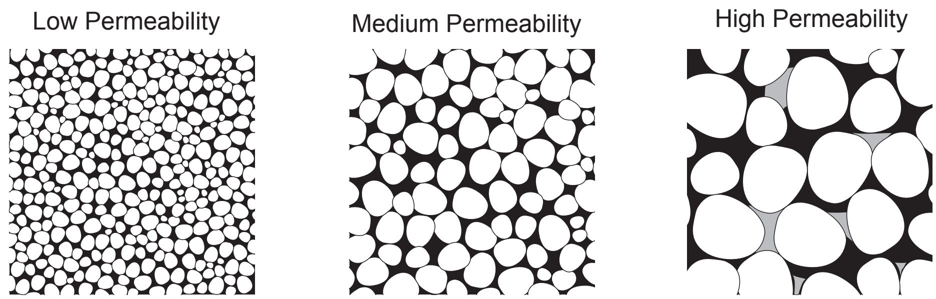


Interconnecting pores
High Porosity

Ease of Movement

Some material, such as clay, can hold a greater amount of water due to a high porosity, but the pores are not connected. It is therefore difficult for the water to move through the clay. The ease of movement through an aquifer is dependent upon how well the pores are connected. Below are three sections of different aquifers. The porosity of all three is the same. Figure three (3) offers far less friction to the water and thus allows greater flow. The ability of an aquifer to pass water is called **permeabillty**[25].

[25] Permeability – The property of a material that permits appreciable movement of water through it when it is saturated and the movement is actuated by hydrostatic pressure of the magnitude normally encountered in natural subsurface water.



[26] Stratum – A layer of the earth's crust.

[27] Cone of Depression – The depression, roughly conical in shape, produced in a water table or other piezometer surface by the extraction of water from a well at a given rate.

Water Quality

The most ideal public water system is one that offers high quality and high quantity. This is commonly an aquifer composed of a mixture of sand and gravel. This provides adequate quantity and filters out unwanted material.

Cone of Depression

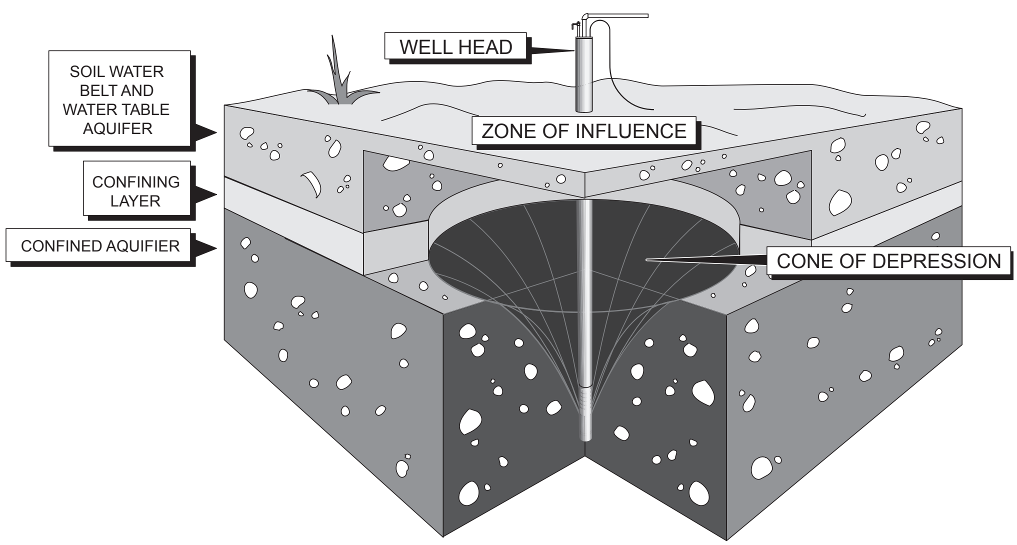
Whenever a well is placed in a water-bearing **stratum**[26] and pumped, water will flow toward the center of the well. In a water table aquifer, this movement causes the water table to sag toward the well. This sag is called the **cone of depression**[27].

Shape of the Cone

The shape and size of the cone depends on the relationship between the pumping rate and the rate at which water can move toward the well. If the permeability is high, the cone will be shallow, and its growth will stabilize. If the permeability is low, the cone will be sharp and continue to grow in size.

Zone of Influence

The area that is included in the cone of depression is called the zone of influence. Any contamination in this zone will be drawn into the well.



[28] Static Water Level – The water level in a well when the pump is not running.

[29] Drawdown – The distance between the static level and the pumping level.

Static Water Level

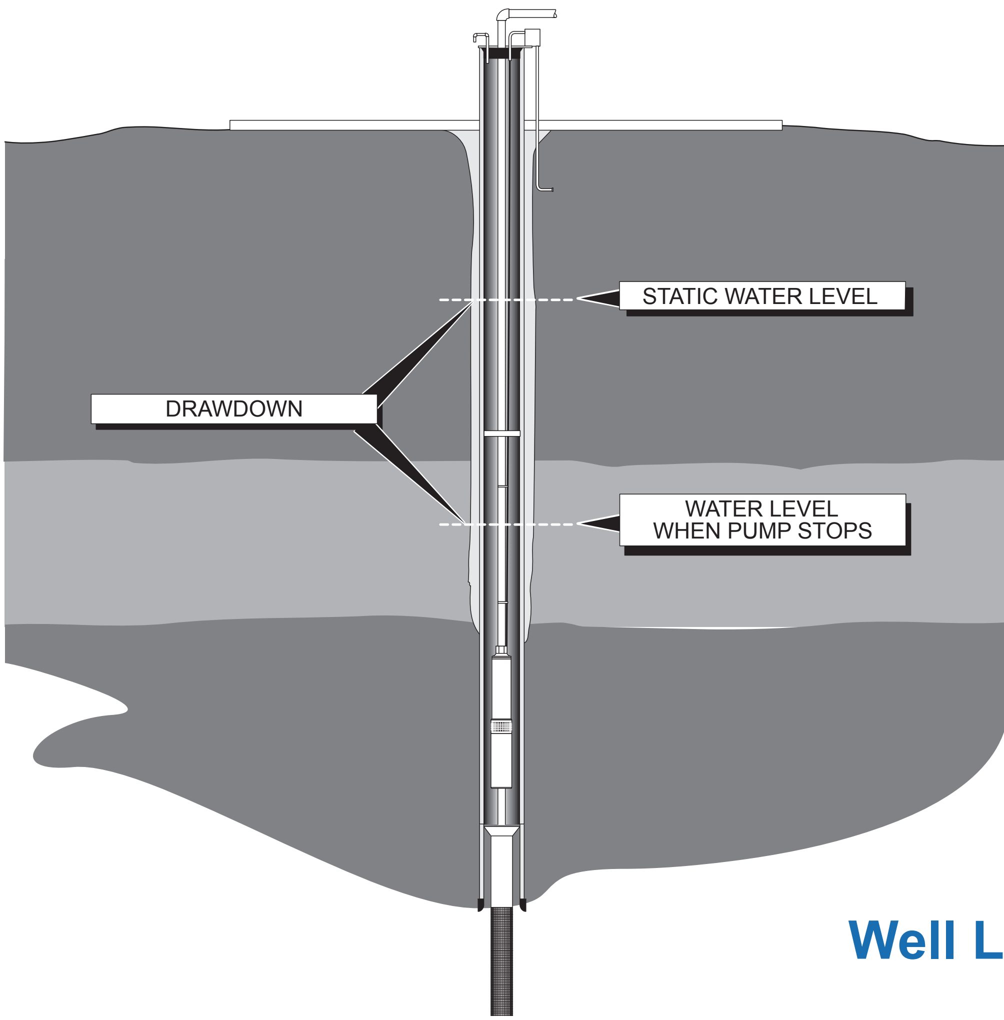
As a pump operates in a well, the depth of water will move up and down. If the pump were shut off for several hours and that water level allowed to recover and stabilize, the level would be called the **static water level**[28].

Drawdown

When a well pump operates, the level of water in the well drops. The difference between the static level and the level that a pump operates to is called the **drawdown**[29].

Specific Yield

The drawdown level depends on the pumping rate and the transmissibility of the aquifer. One standard test that is used to compare the performance of a well from year to year is to determine the specific yield of the well. This is done by pumping the well at a set rate for a specific period of time and measuring the drawdown. The flow is then divided by the drawdown to give a value in gpm/ft of drawdown.



Well Location Criteria

Regulations and Standards

In order to protect the groundwater source and provide high quality safe water, the water works industry has developed standards and specifications for wells. In addition, the Alaska Department of Environmental Conservation has established minimum construction criteria for municipal wells. The following listing details industry standard practices as well as those items included in the ADEC regulations:

- There can be no wastewater disposal systems, including septic tanks and drain fields, within 200 feet of the well for CWS, NTNCW, or TNCWS systems and 150 feet for Class C systems.
- There should be no community sewer line, holding tanks, or other potential

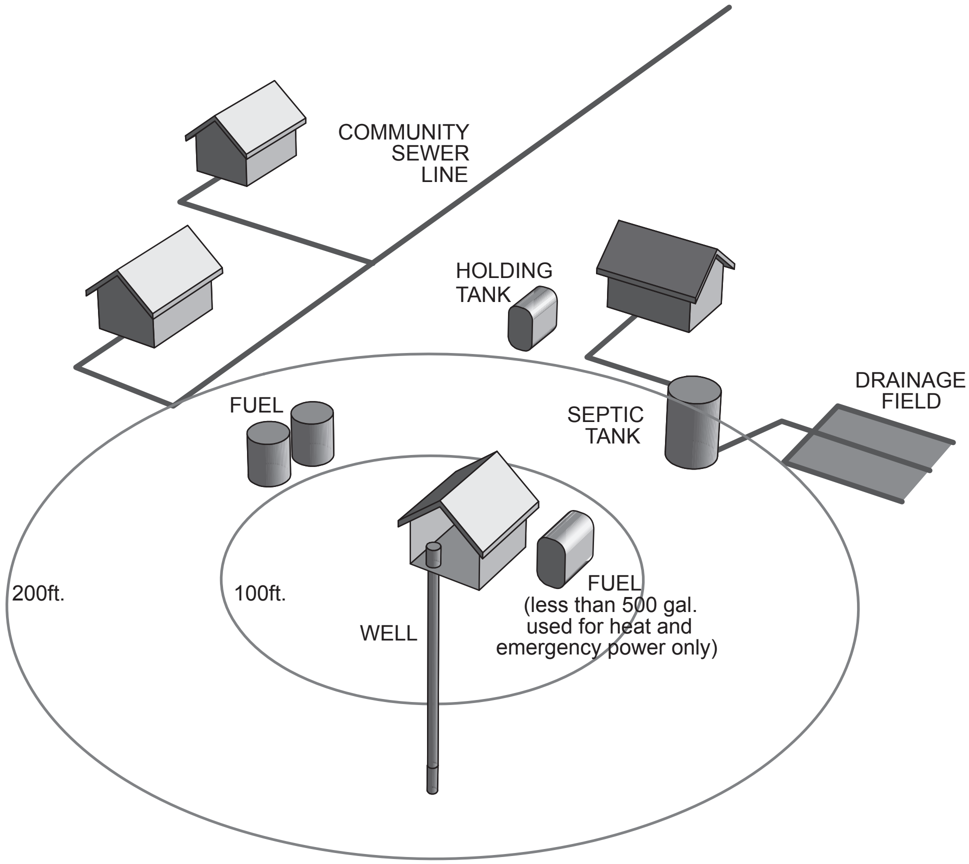
sources of contamination within 200 feet of the well in a CWS, NTNCW, or TNCWS system or within 100 feet of the well in a Class C system.
- Fuel not used for onsite emergency pumping equipment or heating cannot be stored within 100 feet of the well for a CWS, NTNCW, or TNCWS system or within 75 feet of the well for a Class C system.
- Fuel for onsite emergency generators or building heating system can be stored onsite if the total volume is less than 500 gallons.
- The well casing must extend one foot above the ground.
- The top of the well casing must extend 12 inches above the well house slab.
- The ground around the well must be sloped away from the well 10 feet in all directions.
- The well must have a sanitary seal.
- The well casing must be grouted for at least 10 feet within the first 20 feet below the surface.
- The well head must be protected against flooding. Well pits are prohibited.

Recommendations

The following are recommendations and not regulations:

- To reduce the possibility of the well being classified as being under the influence of surface water, it should not be located within 200 feet of a surface water source.
- The water purveyor should own or have a restricted area within 200 feet radius of the well.
- There should be no roads within 100 feet of the well.
- If the well is drilled within 100 feet of a road, the well must be protected against contamination from runoff from the road.
- To avoid the well being classified as GUDISW, you should review the determination criteria and discuss the location with the ADEC.

Well Components



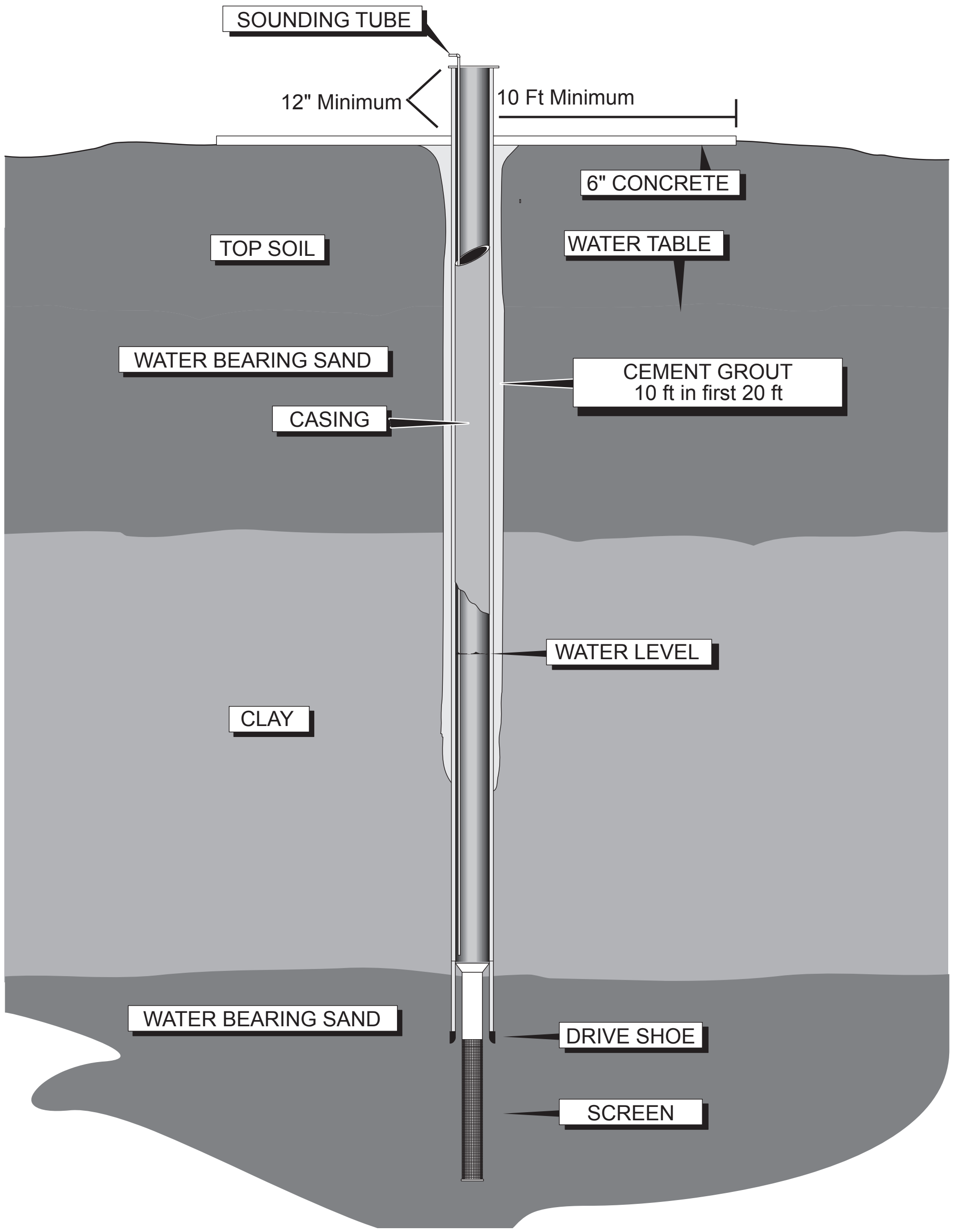
Overview

The components that make up a well system can be divided into three categories: the well itself, the building and the pump, and the related piping system.

Well

Casing

A well is a hole in the ground called the bore hole. The hole is protected from collapsing by placing a casing inside the bore hole and securing the casing to the bore hole in a way that protects the aquifer from contamination. The most common casing material is steel. The casing should extend one foot above the ground and down into the impermeable layer above the aquifer.



Grout

To protect the aquifer from contamination, the casing is sealed to the bore hole near the surface and near the bottom where it passes into the impermeable layer. The Alaska Department of Environmental Conservation minimum is 10 feet of continuos grout within the first 20 feet of the well casing.

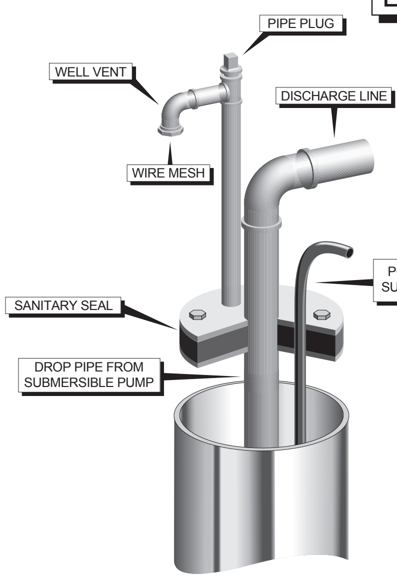
Ground Seal

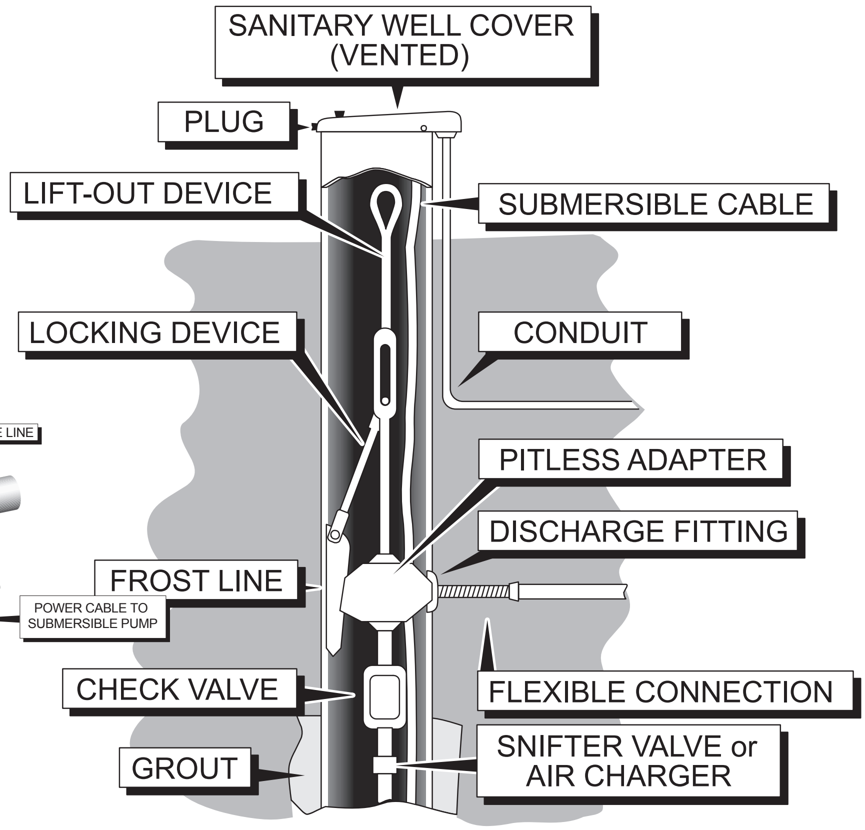
The ground around the casing is sealed with a reinforced concrete slab. This concrete is usually connected to the grout that extends down the well.

Pitless Adapter

In some instances, it is desirable to have the discharge from the well exit below ground level. This reduces the possibility of freezing and allows more flexibility in the location of the pump house. The device that allows the line to pass through the casing wall is called a pitless adapter. The casing vent is an internal part of the pitless adapter cover.

Grouting a Pitless Adapter
Wells with pitless adapters are also required to be grouted at the top. This grouting should start just below the pitless adapter and extend down at least 10 feet.





Well Head
The well head is merely the top of the well casing.

Sanitary Seal
To prevent contamination of the well, a sanitary seal is placed at the top of the casing. The type of seal varies depending upon the type of pump being used.

Sanitary Seal – Submersible Pump
For submersible turbines, the sanitary seal is typically composed of a rubber-like material placed between two pieces of metal. When bolts are tightened on the sanitary seal, the rubber is compressed and expands to seal against the casing and the pump discharge pipe.

Drop Pipe – Riser
The line leading from the pump to the well head is called a drop pipe or riser pipe. This pipe is either steel or PVC. Steel is the most desirable.

Well Screen
Screens can be installed on the end of a well casing or on the end of the inner casing on a gravel-packed well. These screens perform two functions: one is the support of

the bore hole, and the second it to reduce the amount of sand that enters the casing and the pump.

Casing Vent

The well casing must have a vent. On a typical casing, this vent is a double 90° Ell that is pointed toward the ground. The opening of the vent should be screened with a #24 mesh stainless steel screen.

Sampling Tap

A sampling tap or valve should be installed to allow for sampling raw water. This tap must be far enough from any chemical injection point so that the chemicals do not contaminate the sample.

Master Meter

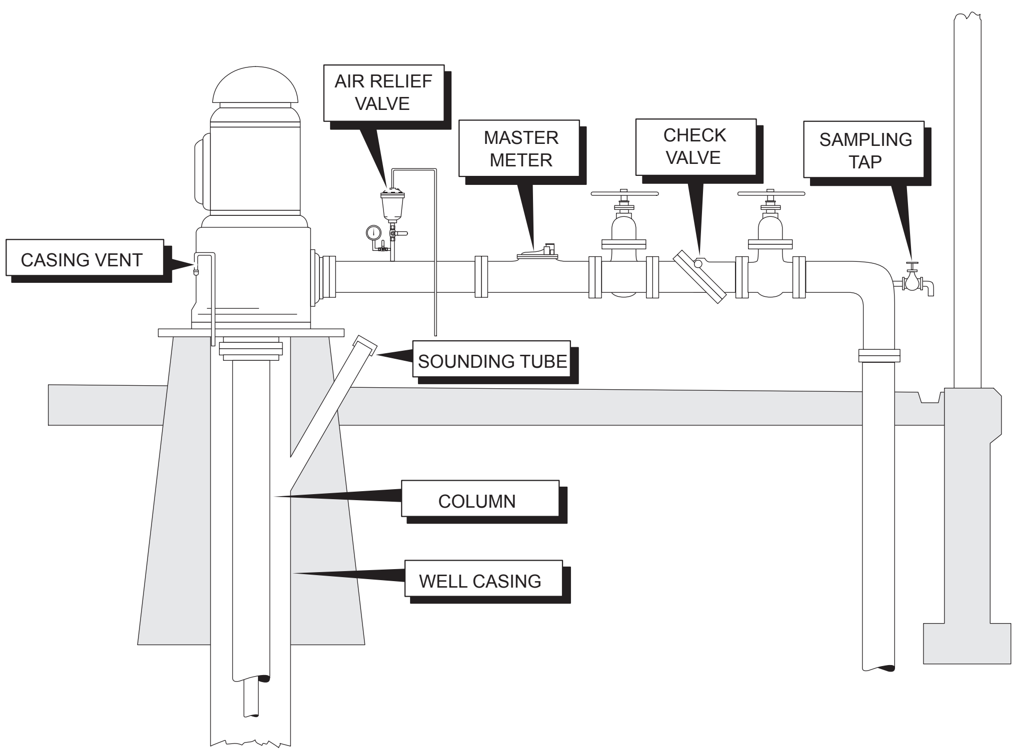
A master meter should be installed on the discharge from the well. The meter is the only reliable means of determining the production of the well.

Check Valves

On lineshaft turbines, there is commonly a check valve assembly on the discharge of the pump. The check valve prevents water from running back into the well. On small submersible pumps, there is usually a check valve at the top of the pump. On deep well submersibles, there may be additional check valves in the riser pipe. These check valves prevent water from running back through the pump and causing it to be turned in the opposite direction that could damage the pump.

Air Vacuum Relief Valve

An air vacuum relief valve is installed on the discharge line to reduce water hammer and prevent air in the column from being forced into the water. The casing is protected from collapse by a double 90° vent with #24 mesh stainless steel screen.



Check Valves and Freezing

In some cases, it may be desirable to allow a portion of the water to run back down the riser pipe on a submersible pump installation. This is accomplished by drilling a "weep hole" in the side of the pipe or in the disk of the check valve. This is done to remove water from the top of the drop pipe and thus reduce the possibility of freezing.

Building

Function of Building

The building is designed to protect the pump and piping from freezing. Protection from freezing may require the installation of heat trace tape on the drop pipe. The building should also be designed to allow easy removal and replacement of the pump and pump motor.

Electrical Equipment

All electrical components should be protected from weather damage.

Heat and Lights

The building must be heated and contain proper lighting to allow for maintenance.

Chlorine

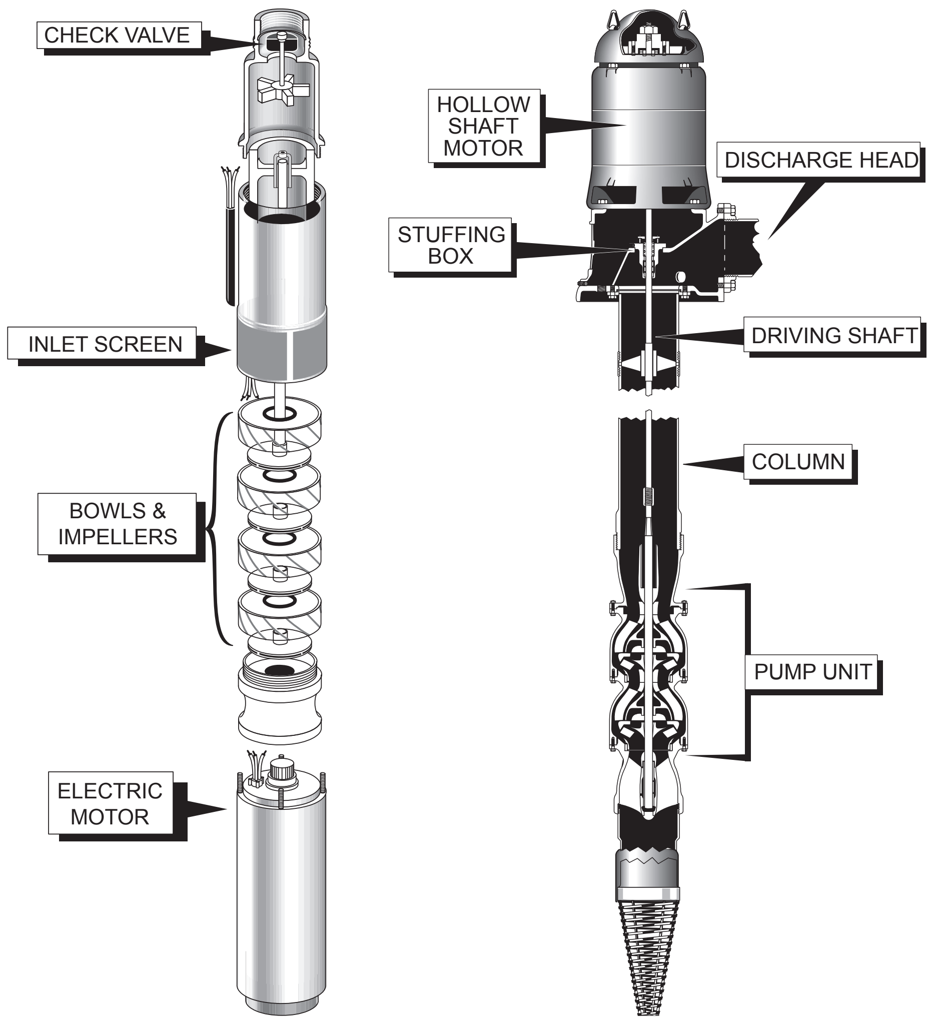
The chlorine and fluoride systems should not be in the same room with electric motors and control panels. If they must be housed with the electrical system, all the electrical fixtures and motors must be corrosion-resistant.

Pumps

Two Types

There are two types of pumps that are commonly installed in groundwater systems:

- **Submersible Turbine Components** – With the submersible turbine pumping installation, the pump motor is below the pump. The water intake is between the motor and the pump. The pump is a series of impellers called stages. Water moves from stage to stage up through the pump and into the riser pipe. Water exits the casing through the discharge head at the top of the well casing. Electrical connections are made above the casing in an electrical box. As with other types of wells, there is a casing vent installed in the sanitary seal.
- **Lineshaft Turbine Components** – With the lineshaft turbine installation, only the pump is placed into the water. The pump is similar to the submersible pump. There are a series of impellers called stages or bowls. The water flows from stage to stage up through the pump and into the column and exits the well through the discharge head. The discharge head is mounted to the base plate and sealed with a rubber-like sanitary seal. The pump is driven by a drive shaft that extends from the pump to the motor. The drive shaft is supported by bearings approximately every 20 feet. These bearings can be lubricated with water or with food-grade oil.



Submersible Turbine

Lineshaft Turbine

Data and Record-keeping Requirements

Records

A properly operated and managed water works facility keeps the following records concerning their well:

- **Well log** – Documentation of what materials were found in the bore hole and at what depth. The well log should include the depths at which water was found, the casing length and type, the depth and type of soils, testing procedure, well development techniques, and well production.
- Pump and motor name plate data, as well as maintenance history.
- Water quality data on the physical, chemical, and bacteriological testing results.
- Quantity of water pumped from the well.
- Static and drawdown water levels.

Data Collection and Testing

Treated water should be tested for the following at the stated intervals (type and frequency depends on particular system and monitoring summary):

- Temperature (Daily)
- pH (Daily)
- Amount of water pumped (Daily)
- Pumping hours (Daily)
- Pump discharge pressure (Daily)
- Iron or manganese, if a problem (Daily)
- Conductivity (Weekly)
- Total coliform (Monthly)
- Gallons per minute that pump produces (Monthly)
- Raw water fluoride, if feeding fluoride (Quarterly)
- Depth of water in well (Quarterly)
- Motor amperage and voltage (Quarterly)
- Specific yield (Twice a year – winter and summer)
- Collect sample and have it tested for Nitrate (Annually)
- Collect sample and have it tested for inorganics (Every three years)
- Collect and sample for pesticides (Every three years)
- Collect sample and have it tested for radioactivity (Every four years)
- Collect sample and have it tested for VOCs (Every five years)

Review

1. List two of the advantages of groundwater sources and two for surface water.
2. For each of the following items, give the proper separation from a well for a CWS, NT-NCW, or TNCWS system: Community sewer _______; Fuel oil, less than 500 gallons used for heating _______; Septic tank _______.
3. The well casing should extend _______ above the ground or well house floor.
4. A well casing should be grouted for at least _______ feet, within the first _______ feet.

Transmission Lines

Function

Transmission lines are installed in order to move the water between the well or intake and the treatment plant or storage tank. A transmission line is used to transfer raw water only and should have no service connections. A transmission line can serve as a chlorine contact chamber.

Types Of Transmission Lines

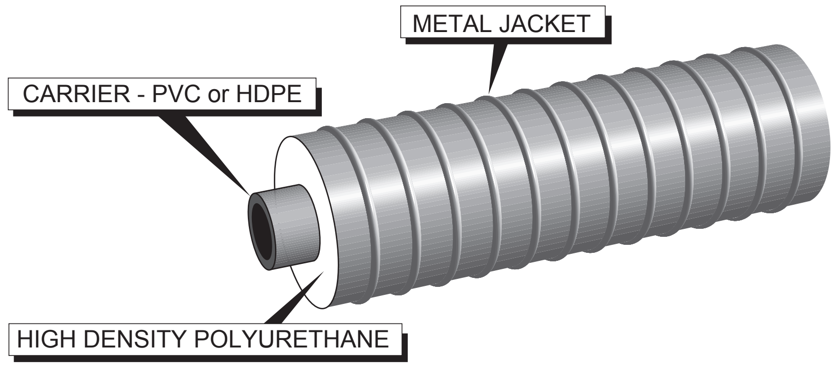
Piped

The most popular type of transmission line is the buried pipe. These lines are commonly DCIP or HDPE, although in the past, PVC, wood, and steel pipe have also been used. The City of Craig uses 12-inch DCIP from its surface water reservoir to its treatment plant seven miles away.

[30] Glycol – Common name for propylene glycol, a colorless, thick, sweet liquid used as antifreeze.

Arctic Pipe

In the arctic regions, a special piping material called arctic pipe is buried, or laid above ground in permafrost areas, instead of the standard piping material. Arctic pipe is composed of three components. The line that carries the water is called the carrier pipe and is commonly made of PVC or HDPE. HDPE is the most common in new installations. The carrier is protected with several inches of high-density polyurethane insulation and covered with a metal jacket.

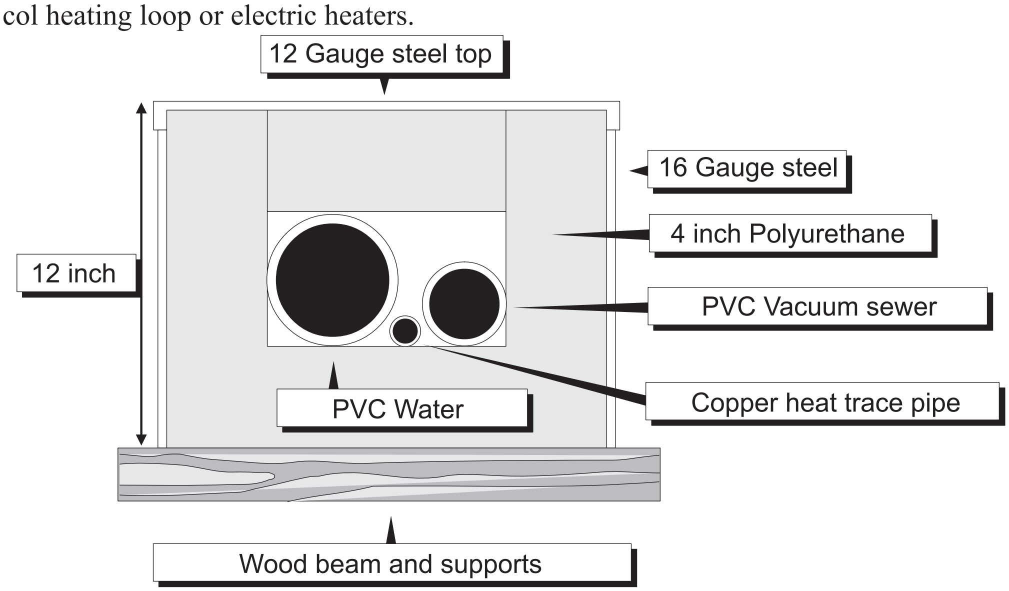


Above-Ground Utilidors

Utilidors have been used in the arctic for a number of years. The older utilidors were made of insulated plywood. The newer installations are made of large-diameter arctic pipe, insulated with high-density polyurethane or polystyrene and covered with 16- and 12-gauge steel. The carrier pipe on new utilidors is PVC or HDPE. The above-ground utilidors are commonly heated using a HDPE pipe loop of heated **glycol**[30]. The glycol is heated with a low-pressure water boiler and circulated with a pump through the loop.

Below-Ground Utilidors

Due to cost, below-ground walk-through utilidors are not very common. They can be found in Barrow, Nome, and Fairbanks. The most common below-ground utilidors are made of wood or concrete insulated with a polystyrene foam. The water, sewer, and electrical utilities are placed on racks in the utilidors. Heat is provided by a glycol heating loop or electric heaters.



Above ground utilidor

Flow Meters

Purpose

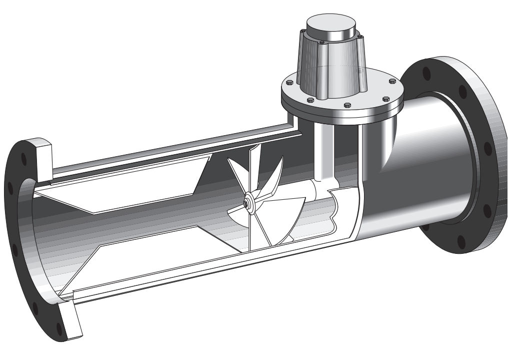
A flow meter placed in the raw water line is the only method of tracking daily use, monthly average, and peak demands. These meters can also be useful in evaluating the amount of leakage in a water system.

Types

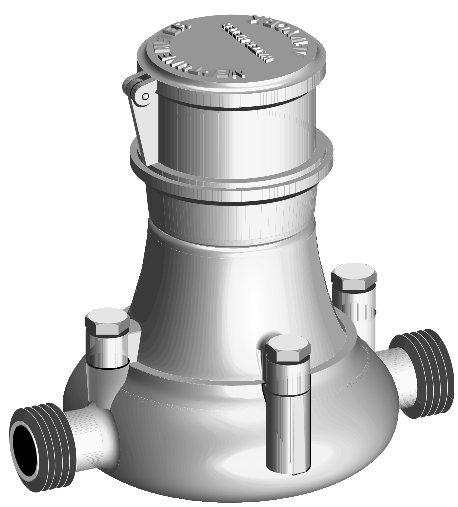
There are six types of meters used in raw water lines: propeller, turbine, magnetic, displacement, orifice, and venturi meters.

Turbine and displacement meters are the most common in the small systems in Alaska.

- Turbine – On lines 3 to 12 inches in diameter, turbine meters are common and practical. These meters use a bypass technique to divert a portion of the flow through a turbine wheel. The turbine is connected via a magnet to the register. This type of meter is quite accurate over a wide flow range and offers low headloss to the flow.
- Displacement Meters – Displacement meters are used on pipes from 3/4 inch through four inch. They are the most accurate over a wide range of flows. There are two common types of displacement meters: the rotating piston and the nutating disc. In each case, the flow of water causes a device to move in a chamber with a fixed volume. As the device moves, it rotates. The rotating device is connected by a magnet to a register that records the flow.



Turbine meter



Displacement meter

Background

When surface water can infiltrate a groundwater supply, there is a high possibility that the groundwater may be contaminated with Giardia, viruses, turbidity, and organic material from the surface water source. As a result, the Surface Water Treatment Rule of the Safe Drinking Water Act requires that each state determine which groundwater supplies are influenced by surface water. When a groundwater supply

Groundwater Under Direct Influence of Surface Water

is identified as being under the direct influence of surface water, it is no longer called a groundwater supply, but is referred to as groundwater under the direct influence of surface water (GUDISW). When a supply is designated as GUDISW, the State's surface water rules apply to the source rather than the groundwater rules.

Involvement of the ADEC

It is the responsibility of the ADEC to identify and categorize all groundwater supplies into either groundwater or GUDISW. It is the responsibility of the utility to perform the analysis required for this determination.

Evaluation Process

To determine whether a groundwater supply is under the direct influence of surface water, the EPA has developed procedures that focus on significant and relatively rapid shifts in water quality characteristics such as turbidity, temperature, and pH. When these shifts can be closely correlated with rainfall, breakup, or other surface water conditions or when certain indicator organisms associated with surface water are found, the source is said to be under the direct influence of surface water.

Procedure – More Details

The procedure for springs, infiltration galleries, and wells includes the following steps:

1. Review of records to determine the method of well construction and water quality conditions, distance from well to nearby surface water, coliform contamination history, and history of known or suspected waterborne disease outbreaks associated with organisms normally found in surface water.

2. An on-site inspection to look for evidence that surface water can enter through defects with the well head, casing, or underground connections with the aquifer.

3. An analysis of the well water to identify organisms that normally occur in surface waters but are not normally found in groundwater sources.

When Evaluation is Not Required

Utilities are not required to perform extensive evaluations if the system meets the following criteria:

- Well is deeper than 50 feet.
- Well is more than 200 feet from a surface water source.
- Well was constructed properly with screens or perforated intake below a confining layer.
- There is no history of significant shifts in water quality.
- There is no history of coliform contamination or waterborne disease outbreaks in the system.

Importance of Organisms

Although a significant and relatively rapid shift in groundwater quality can indicate the influence of surface water, it is the analysis for surface water organisms that determines whether the supply falls under the requirements of the SWTR. The intent of the analysis is to identify organisms that are likely to occur only in surface waters.

The presence of such organisms in groundwater indicates that at least some surface water has been mixed with the groundwater.

Sampling

The sampling for surface water organisms generally involves filtering 100 to 500 gallons of water through a one micron cartridge filter over a 4 to 8 hour period. At least two samples must be collected during the time the source is most susceptible to surface water influence (during heavy rainfall or runoff).

Review

1. What are the two most common arctic pipe carriers?

2. A spring and a shallow well are examples of what type of water source?

Introduction to Water Sources Quiz

1. A primary advantage of using surface water as a water source includes:
   A. Usually higher in turbidity
   B. Generally softer than groundwater
   C. Easily contaminated with microorganisms
   D. Can be variable in quality

2. Which source of water has the greatest natural protection from bacterial contamination?
   A. Shallow well
   B. Deep well
   C. Surface water
   D. Spring

3. A disadvantage of groundwater is that it is:
   A. Easily located
   B. Higher in turbidity
   C. Usually higher in minerals
   D. Not easily contaminated by microorganisms

4. What safety measure must an operator follow prior to working on electrical equipment?
   A. Lock out and tag out all electrical switches.
   B. Put on canvas gloves.
   C. Remove fuses from switch box.
   D. Tell one co-worker not to turn on the switch.

5. A weir should be used to measure water in which of the following locations?
   A. Above-ground storage tanks
   B. Household service lines
   C. Open channels
   D. Water mains

6. Infiltration galleries are more commonly used for:
   A. GUDISW systems
   B. Wells
   C. Streams or rivers
   D. Filters

7. Wells must not be located within _______ feet of a wastewater disposal system.
   A. 50
   B. 100
   C. 200
   D. 500

8. In a(n) ____________ aquifer, groundwater is under pressure.
   A. Unconfined
   B. Open
   C. Closed
   D. Confined
9. The difference between the static level and the level that a pump operates to is called the:
   A. Operating level
   B. Suction head
   C. Well yield
   D. Drawdown

10. A well casing should extend at least _______ inches above the ground.
   A. 6
   B. 8
   C. 12
   D. 24

11. The water level in a well after the pump has been shut down for a long period is called:
   A. Recovery level
   B. Drawdown level
   C. Shutdown head level
   D. Static level

12. If water is drawn out of a well, a _______________ will develop.
   A. Saturation zone
   B. Cone of depression
   C. Zone of influence
   D. Static head

13. The space between the inner or protective casing and the outer casing or drill hole should be filled with cement grout to a minimum of how many feet?
   A. 10 feet within the first 20
   B. 15 feet within the first 25
   C. 20 feet within the first 30
   D. 35 feet within the first 45

Introduction to Water Treatment

Chapter 4

What Is In This Chapter?

1. Reasons for the treatment of drinking water
2. Overview of basic water treatment processes:
    - Oxidation
    - Coagulation
    - Flocculation
    - Sedimentation
    - Granular media filtration
    - Membrane filtration
    - Adsorption
    - Disinfection
3. Application of surface water treatment systems:
    - Conventional treatment
    - Two-stage filtration
    - Direct filtration
    - Slow sand filtration
    - Diatomaceous earth
    - Membrane filtration
    - Granular activated carbon contactors
4. Application of groundwater treatment systems:
    - Conventional greensand treatment
    - Direct greensand treatment
    - Fixed bed adsorption processes
5. Application of specialized water treatment processes:
    - Hardness treatment
    - Taste and odor treatment
    - Fluoridation processes
6. Internal corrosion control
7. Water heating systems
8. Testing and reporting requirements for systems:
    - Filtration systems
    - Disinfection systems
    - Fluoridation systems
    - Water Heating systems

Key Words

- Acute
- Adsorption
- Aeration
- Aesthetics
- Agglomerate
- Aggressive Water
- Air Scour
- Alkalinity
- Alternative Filtration
- Alum
- Anionic
- Arsenate
- Arsenite
- Backwash
- Bag Filter
- Biofilms
- Breakpoint Chlorination
- Calcium Carbonate
- Cartridge Filter
- Cationic
- Chloramines
- Chlorine Demand
- Chronic
- Coagulation
- Coliform Bacteria
- Color
- Combined Chlorine Residual
- Complexed
- Contact Time
- Conventional Treatment
- Coprecipitation
- Cryptosporidium
- Demand
- Diatomaceous Earth Filter
- Differential Pressure
- Direct Filtration
- Disinfection
- Disinfection Byproducts
- Dosage
- Effective Size Turbidity Breakthrough
- Filtration
- Floc
- Flocculation
- Free Chlorine Residual
- Giardia
- Greensand
- HAA5
- Hardness
- Headloss
- Health Related
- Hydraulic Loading
- Hydrogen Sulfide Gas
- Hydrophilic
- Hydrophobic
- Hypochlorite
- Hypochlorite Ion
- Hypochlorous Acid
- Ion Exchange
- Launder
- Log Inactivation
- Membrane Cartridge Filtration
- mg/L
- Microfiltration
- Nanofiltration
- Nonionic
- Odor
- Organic Carbon
- Oxidation
- pH
- Polymeric
- Polymers
- Precipitates
- Residual
- Reverse Osmosis
- Schmutzdecke
- Sedimentation
- Septum
- Sequestering Agent
- Slow Sand Filtration
- Soda Ash
- Softening
- Soluble
- Stratify
- Total Chlorine Residual
- TTHMs
- Turbidity
- Ultrafiltration
- Zeolite

Introduction

Lesson Content

This lesson on water treatment focuses on the reasons for treatment, the basic processes associated with treatment, and the application of these processes to surface water, groundwater, and some specialized water treatment applications.

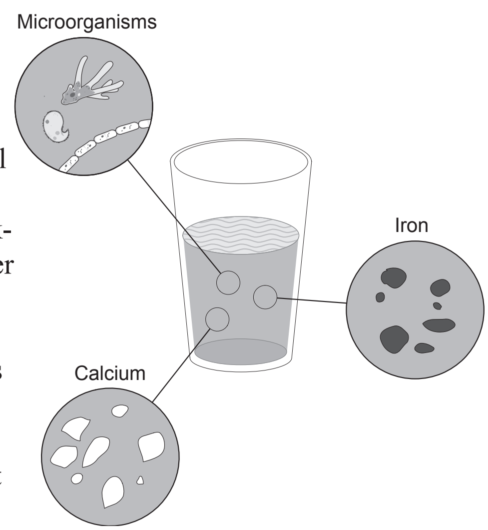
Water Treatment Overview

Treatment systems are installed for two reasons: to remove those things that can cause disease and those things that create nuisances. The basic goal is to protect public health. However, the broader goal is to provide potable water that is safe to drink, pleasant in appearance, pleasant in taste and odor, and cost-effective to produce.

While most of the concepts, processes, and systems discussed in this lesson are used in both small and large communities, the focus of this lesson will be on small systems, primarily those systems serving a population of fewer than 500 and located in rural Alaska.

Reasons for Water Treatment

The two main reasons for treating water are 1) to remove those contaminants that are harmful to health and 2) to remove contaminants that make the water look, taste, or smell bad. Since many contaminants harmful to health cannot be seen, smelled, or tasted, early water treatment efforts focused on making the water more appealing to the consumer or improving the **aesthetic**[1] qualities of the water. However, with advances in modern science, our ability to detect microorganisms and very low levels of harmful chemicals has led to advanced treatment technologies to remove **health-related**[2] contaminants that may be present in very small amounts.



Contaminants that must be removed

Aesthetic Contaminants

Aesthetic contaminants affect the appearance, taste, or **odor**[3] of the water. Most are not directly harmful to human health, but their presence may lead to problems that can indirectly result in health concerns. Aesthetic contaminants include cloudiness or **turbidity**[4], iron and manganese, **color**[5], the rotten egg odor caused by **hydrogen sulfide gas**[6], and **hardness**[7], to name a few.

Health-related Contaminants

Contaminants that can affect human health can be naturally occurring, man-made, or a result of the treatment process itself. Health-related contaminants can be further subdivided into those contaminants that can cause sickness or illness at very low levels or low exposures, the so-called **acute**[8] contaminants, or those that can cause sickness or illness only after prolonged exposure to the contaminant in drinking water, called **chronic**[9] contaminants. Health-related contaminants include pathogenic microorganisms; inorganic materials such as lead, arsenic, nitrate and nitrite; and **disinfection byproducts**[10] that can be formed during chlorination.

[1] Aesthetics – With water, the term means pleasant in appearance, odor, and taste.

[2] Health-related – Capable of influencing health.

[3] Odor – A quality that affects the sense of smell.

[4] Turbidity – A condition in water caused by the presence of suspended matter, resulting in the scattering and absorption of light rays.

[5] Color – Primarily organic colloidal particles in water.

[6] Hydrogen Sulfide Gas – A gas that results from bacterial anaerobic decay. It produces a strong rotten egg odor that can be detected at levels as low as 0.1 µg/L.

[7] Hardness – A characteristic of water caused primarily by calcium and magnesium ions. Hardness causes deposits and scale to form on pipes and fixtures.

[8] Acute – A rapid onset with low levels of exposure.

[9] Chronic – A slow onset with repeated exposures over long periods of time.

[10] Disinfection Byproducts – A chemical compound formed by the reaction of a disinfectant with contaminants in water.

Some of the more common contaminants encountered in water treatment			
Contaminant	Affects	Source	Common Treatment Options
Giardia[11]	Health	Organism	Filtration/Disinfection
Cryptosporidium[12]	Health	Organism	Filtration
Viruses	Health	Organism	Filtration/Disinfection
TTHM[13]	Health	Disinfection Byproduct	Filtration/Adsorption/Disinfectant Selection
HAA5[14]	Health	Disinfection Byproduct	Filtration/Adsorption/Disinfectant Selection
Arsenic	Health	Mineral	Co-precipitation/Adsorption
Lead	Health	Mineral/Corrosion	Corrosion Control
Copper	Health	Mineral/Corrosion	Corrosion Control
Nitrate	Health	Nitrogen	Ion Exchange/Reverse Osmosis
Manganese	Health/Aesthetic	Mineral	Oxidation/Filtration/Adsorption
Iron	Health/Aesthetic	Mineral	Oxidation/Filtration
Turbidity	Health/Aesthetic	Particle Matter	Filtration
Color	Aesthetic	Minerals or Organics	Oxidation/Filtration/Adsorption
Odor	Aesthetic	Hydrogen Sulfide	Oxidation/Aeration
Hardness	Aesthetic	Minerals	Ion Exchange/Reverse Osmosis

Basic Water Treatment Unit Processes

Water treatment requires chemical, physical, and sometimes biological processes to remove contaminants. The more common processes used in potable water treatment are the chemical and physical processes. Biological processes are primarily used for treatment of wastewater. However, the slow sand filtration process is a biological process that has been historically used to remove pathogens from potable water. The biological activated carbon (BAC) process is also a biological process that is used to remove organic contaminants from potable water.

The chemical processes involved in potable water treatment include **oxidation**[15], **coagulation**[16] and **disinfection**[17]. The physical processes include **flocculation**[18], **sedimentation**[19], **filtration**[20], **adsorption**[21], and disinfection using ultraviolet light. The types of processes that are required and the order in which they are used depend on the types and concentrations of contaminants that must be removed. Examples of this include oxidation, followed by filtration or sedimentation, followed by filtration. In the first example, the oxidation process causes the dissolved contaminants to form a **precipitate**[22], which is then removed by filtration. In the second example, sedimentation removes most of the solids by gravity and reduces the solids loading on the down stream filtration process.

[11] Giardia – A pathogenic microorganism excreted by some animals that is 6–18 micrometers in size.

[12] Cryptosporidium – A pathogenic microorganism excreted by some animals that is 4-6 micrometers in size.

[13] TTHMs (Trihalomethanes, also referred to as TTHMs or Total Trihalomethanes) – (1) Regulations – The sum of the concentrations of bromodichloromethane, dibromochloromethane, tribromomethane, and trichloromethane. (2) Compounds formed when natural organic substances from decaying vegetation and soil (such as humic and fulvic acids) react with chlorine.

[14] HAA5 – Five Haloacetic Acids including monochloroacetic acid, dichloroacetic acid, trochloroacetic acid, monobromoacetic acid, and dibromoacetic acid. Compounds formed when natural organic substances from decaying vegetation and soil (such as humic and fulvic acids) react with chlorine.

[15] Oxidation – The addition of oxygen, removal of hydrogen, or removal of electrons.

[16] Coagulation – In water treatment, the destabilization and initial aggregation of colloidal and finely divided suspended matter by the addition of a floc-forming chemical.

[17] Disinfection – The process used to control pathogenic organisms.

[18] Flocculation – The agglomeration of colloidal and finely divided suspended matter after coagulation by gentle stirring by either mechanical or hydraulic means.

[19] Sedimentation – The removal of solid particles from water by settling induced by gravity.

[20] Filtration – The process of passing liquid through a filtering medium –which may consist of granular material such as sand, magnetite, or diatomaceous earth, finely woven cloth, unglazed porcelain, or specially prepared paper–to remove suspended colloidal matter.

[21] Adsorption – The gathering of a gas or dissolved substance onto the surface of a solid.

[22] Precipitate – The material that results from precipitation – A phenomenon that occurs when a substance held in solution in a liquid passes out of solution into a solid form.

The following section provides a brief introduction to each of these basic water treatment processes. Each process will be presented in the order that they are normally used in a treatment train.

Oxidation

Chemical oxidation is used in water treatment to aid in the removal of inorganic contaminants such as iron (Fe^{2+}), manganese (Mn^{2+}), and arsenic (As^{3+}) to improve removals of particles by coagulation or to destroy taste- and odor-causing compounds. Oxidation can also be used prior to coagulation, filtration, adsorption, or sedimentation to improve the removal of inorganics, particulates, taste, or odor.

Oxidants

The most commonly used oxidants in small systems include chlorine (Cl_2) and potassium permanganate ($KMnO_4$). To a lesser extent, ozone and chlorine dioxide are also used for this purpose. Chlorine is supplied in gas, solid, and liquid forms; and potassium permanganate is usually supplied as a fine granular solid material that is dissolved in water. Ozone is a gas that is generated onsite using pure oxygen or air. The selection of the most desirable oxidant is dependent upon a number of factors, including process requirements, operational cost, chemical safety, and operational complexity.

Mixing

Oxidants are injected as a gas or a liquid. Mixing or diffusion of the gas or liquid into the water stream occurs very quickly; and therefore, mixing energy is rarely a significant issue for small systems. As a result, static or mechanical mixers are typically not required, although diffusers or injector assemblies are often used to enhance the diffusion of the oxidant into the water.

Reaction Time

Reaction time is a critical parameter when oxidants are used in the treatment process. The speed or reaction rate is dependent on the type of oxidant, type of contaminant, **pH**[23], and water temperature. As a general rule, lower pH or water temperature tends to slow the rate of oxidation.

The oxidation rate can be slowed or the oxidant demand can be increased by the presence of other contaminants, such as organic carbon, ammonia, manganese, or iron. Organic carbon can become attached to the iron or manganese, resulting in a **complexed**[24] form of the iron or manganese. This problem can be encountered when ammonia, hydrogen sulfide, and organic carbon in excess of 2 mg/L are present in water containing ferrous iron or manganous manganese. The use of chlorine as an oxidant in water containing these types of complexes can result in the formation of disinfection byproducts such as trihalomethanes (TTHM) and/or haloacetic acids (HAA5). The presence of these complexed materials may also make the removal of iron or manganese difficult unless coagulation or an appropriate membrane filtration process is used.

Ammonia will cause competing demands for chlorine and will result in the formation of chloramines unless breakpoint chlorination is used to obtain a free chlorine residual. Chloramines are a much weaker oxidant than free chlorine and significantly slow the oxidation of iron and manganese.

[23] pH – An expression of the intensity of the basic or acidic strength of water. pH may range from 0 to 14, where 0 is most acid, 14 most alkaline, and 7 neutral. Natural waters usually have a pH between 6.5 and 8.5. Mathematically, $pH = -\log_{10}[H^+]$.

[24] Complexed – A bound form of two or more substances.

Typical oxidant demands for chlorine and potassium permanganate		
Oxidant	Contaminant	Demand
Chlorine	Fe^{2+}	0.64 mg Cl_2/mg Fe^{2+}
	Mn^{2+}	1.29 mg Cl_2/mg Mn^{2+}
	As^{3+}	0.95 mg Cl_2/mg As^{3+}
Potassium Permanganate	Fe^{2+}	0.94 mg $KMnO_4$/mg Fe^{2+}
	Mn^{2+}	1.92 mg $KMnO_4$/mg Mn^{2+}
	As^{3+}	1.26 mg $KMnO_4$/mg As^{3+}

Operational Considerations

The control of the oxidation process is usually a manual operation for small systems. When chlorine is used, the proper dosage can be determined using a free chlorine test kit. The presence of free chlorine after a prescribed amount of time indicates that enough oxidant has been added to satisfy the oxidant demand. A visual test for oxidant demand is often used for potassium permanganate. The proper dosage will result in a slight pink color remaining after a period of time. When the water contains large amounts of iron, the proper dosage of permanganate is often indicated by a salmon color or a slight pink color, depending on levels of iron in the oxidized water. Similar tests for chlorine or potassium permanganate demand can be used for arsenic oxidation as well.

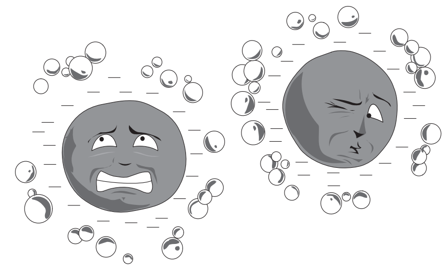
Coagulation

Most organic and inorganic material suspended in water and not dissolved will settle out if given enough time. However, the main materials that contribute to color and turbidity are either dissolved or too small to settle. The basic problem comes from material that is less than one micrometer (0.001 mm) in size, called colloidal material.

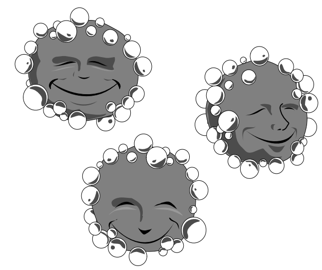
Particle Diameter mm	Representative Particle	Time Required to Settle in 1 ft. (0.3 m) Depth
		Settleable
10	Gravel	0.03 sec
1	Coarse Sand	3 sec
0.1	Fine Sand	38 sec
0.01	Silt	33 min
		Considered Nonsettleable
0.001 (1 µ)	Bacteria	55 hours
0.0001	Color	230 days
0.00001	Colloidal Particles	6.3 years
0.000001	Colloidal Particles	63 year minimum

Colloids do not settle in a reasonable length of time due to electrical charges on their surface. At one micrometer (also stated as 1 µm) in size, the influence of the surface charges offsets gravity, and the particles stay suspended. For instance, a particle 0.01 mm in diameter will settle one foot in 33 minutes, but a particle 0.0001 mm in diameter (a colloid) will settle only one foot in 230 days.

There are two types of colloidal material:



- **Hydrophobic**[25] – Hydrophobic means water-fearing. Hydrophobic colloidal material is mostly inorganic material that contributes to turbidity and carries a negative electrical surface charge.



- **Hydrophilic**[26] – Hydrophilic means water-loving. Hydrophilic colloidal material is mostly composed of organic material that is the common source of color in water. Hydrophilic compounds are surrounded by water molecules that tend to make these particles negatively charged as well.

Organic material that will pass through a 0.45 micrometer membrane filter is considered to be dissolved. These materials include humic and fulvic acids that can cause color in water and are measured as **organic carbon**[27]. Total organic carbon (TOC) includes the materials that are both larger and smaller than 0.45 micrometers in size. Dissolved organic carbon (DOC) is the fraction of organic material that is smaller than 0.45 micrometers. These acids carry a negative charge.

Coagulants

There are two opposing forces that impact the removal of colloidal material:

- Stability factors – Stability factors are those factors that help to keep colloids dispersed.
- Instability factors – Instability factors are those factors that contribute to the natural removal of colloids.

The process of decreasing the stability of the colloids in water is called coagulation. Coagulation results from adding salts of iron, aluminum, or cationic **polymer**[28] to the water. Some common coagulants include the following:

- Aluminum Sulfate (**Alum**[29]) $Al_2(SO_4)_3 \cdot 18H_20$
- Sodium Aluminate – $NaAlO_2$
- Ferric Sulfate – $Fe_2(SO_4)_3 \cdot 9H_20$
- Ferrous Sulfate – $FeSO_4 \cdot 7H_20$
- Ferric Chloride – $FeCl_3$
- Polyaluminum Chloride (PAC)
- Cationic Polymers

[25] Hydrophobic – Water-fearing. In water, hydrophobic refers to inorganic colloidal particles that contribute to turbidity.

[26] Hydrophilic – Water-loving. In water, hydrophilic refers to organic colloidal particles that contribute to color.

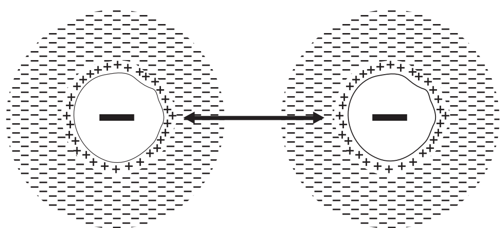
[27] Organic Carbon – A carbon substance that comes from plant or animal sources.

[28] Polymer – High-molecular-weight synthetic organic compound that forms ions when dissolved in water. Also called polyelectrolytes.

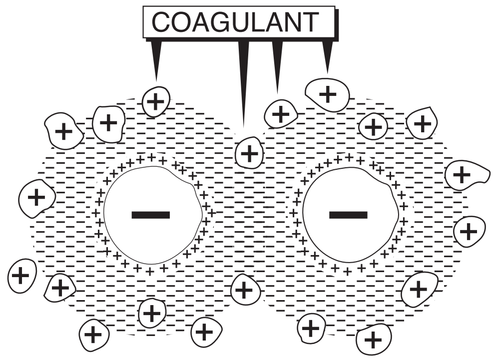
[29] Alum – Trade name for the common coagulant aluminum sulfate: $Al_2(SO_4)_3 \cdot 18H_20$.

The addition of metal salts or polymers to water containing negatively charged contaminants may result in a process called coagulation. The simplest coagulation process to explain occurs between alum and water. When alum is placed in water, a chemical reaction occurs that produces positive charged aluminum ions. The positively charged aluminum ions then become attached to the surface of the negatively charged colloid. The overall result is the reduction of the negative surface charges and the subsequent formation of **agglomerate**[30] (floc). This destabilizing factor is the major contribution that coagulation makes to the removal of turbidity, color, and microorganisms.

[30] Agglomerate – Gathered into a mass.



Hydrophobic particles



Hydrophobic particles after coagulation

There are a number of factors that influence the coagulation process. Four of the most important are pH, turbidity, temperature, and **alkalinity**[31]. The degree to which these factors influence coagulation depends upon the type of coagulant used. When metal salts are used as the primary coagulant, these factors can have a significant effect on the performance of the chemical in removing contaminants. The performance of cationic polymers, however, is less influenced by these factors.

[31] Alkalinity – A measure of waters ability to neutralize an acid.

Polyelectrolytes, or polymers, as they are commonly called, can be used as a primary coagulant or as an aid to coagulation when metal salts are used. Polymers are long string-like (chain) molecules with charges placed along the string. There are three common types of polymers:

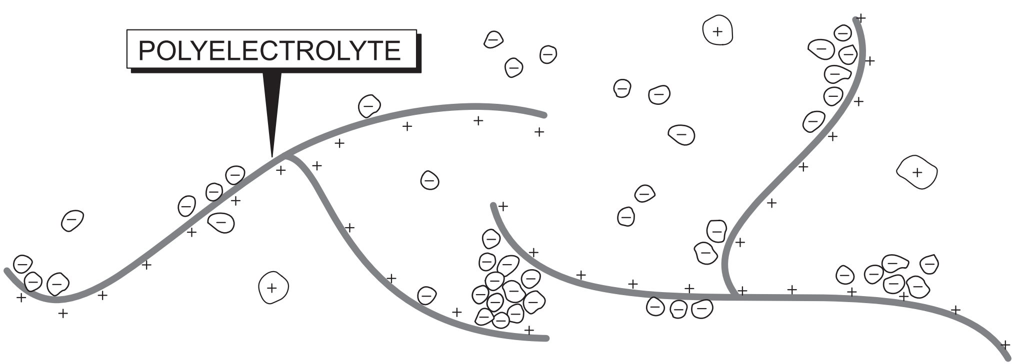
- Positively charged **polymeric**[32] substances called **cationic**[33] polymers,
- Negatively charged polymeric substances called **anionic**[34] polymers
- Polymeric substances with no charge called **nonionic**[35] polymers

[32] Polymeric – A material constructed of small molecules.

[33] Cationic – An ion or group of ions with a positive charge.

[34] Anionic – An ion or group of ions with a negative charge.

[35] Nonionic – An ion or group of ions with no charge.



Polyelectrolyte molecule

Flash Mixing/Rapid Mixing

Effective dispersion of the coagulant into the raw water stream ensures efficient and effective treatment. Flash mixing is very important when metal salts are used. Metal salts must be thoroughly dispersed into the stream within 1-2 seconds for effective treatment. The performance of polymers, on the other hand, is less influenced by flash mixing energy and is minimally affected by dispersion times as long as several seconds.

Pump diffusion and inline static mixers are the most common types of flash mixers:

- The pump diffusion system uses jets to inject the coagulant into the raw water stream. The advantage of a pump diffusion flash mixer is that it produces no additional **headloss**[36]. The disadvantages are the additional electrical power consumption and added maintenance.
- Inline static mixers are very simple devices that can be used to provide effective mixing as well. The advantages of the inline static mixer are that it requires no electrical power and very little maintenance. The disadvantages are that mixing efficiency varies with flow rate and that headloss can be on the order of two feet or more.

[36] Headloss – As it applies to a water filter, the difference between the pressure or head between two points.

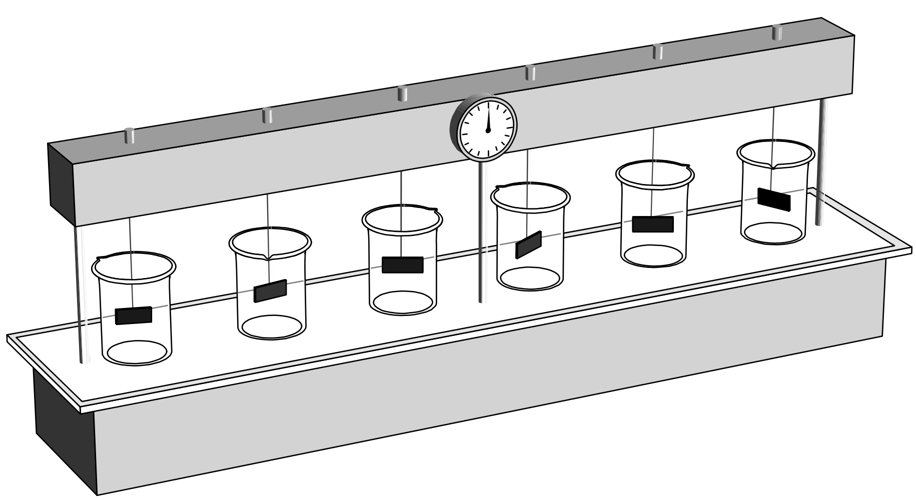
Detention Time

Appropriate detention times are required for the coagulation process to proceed to completion before the water is filtered or additional chemicals are added. The mixing energy that should be used during the reaction period depends on the type of water treatment process that is being used and the type of coagulant. Detention times on the order of 10-20 minutes are common. Detention occurs in the piping, in reaction vessels, and in the head space in the filter located above the media.

Operational Considerations

To determine the correct chemical dosage, a device called a gang mixer or jar test apparatus is used. The most common is composed of six mixers connected together and six one-liter beakers. Samples of the water, along with various dosages of the coagulant, are added to the jars. The jars are stirred in an attempt to duplicate the flash mix of the plant and then slowly stirred to duplicate the mixing time and mixing energy of the plant. The proper dosage is determined by observing the best forming **floc**[37], and the pH and turbidity of a settled or filtered sample.

[37] Floc – Small gelatinous masses formed in a liquid by the reaction of a coagulant added thereto.



Gang stirrer used for jar tests

Other types of devices are also available to indicate optimum coagulation and to control the coagulation process automatically. A coagulant charge analyzer can be used for bench testing, or a streaming current detector can be used for online measurement and control. Both devices use the net charge density of the water to indicate when optimum coagulation has been achieved. In other words, these instruments are used to measure when enough positively charged coagulant has been added to neutralize the negative surface charges of the contaminants.

Review

1. What are three contaminants that must be removed?

2. Name the three chemical processes involved in potable water treatment.

3. As a general rule, lower pH or water temperature tends to __________the rate of oxidation.

4. The two types of colloidal material are _______________and _______________.

Flocculation

Flocculation is a physical process of slowly mixing the coagulated water to increase the probability of particle collision. This process forms the floc. Floc is a snowflake-looking material that is made up of the colloidal particles, microorganisms, and precipitate.

Flocculants

Flocculation can occur with the addition of only the primary coagulant. However, additional chemicals can be added to improve the settling or filtering characteristics of the coagulated materials (floc). Anionic polymers are often used to aid in the formation of good floc for settling. These polymers can increase the speed of floc formation, the strength of the floc, and the weight of the floc. These polymers work through inter-particle bridging and rely on the presence of positive surface charges on the coagulated floc to create bonds with the negatively charged polymer chains. The optimum dosage of the anionic polymer is directly related to the amount of coagulated material that is present in the water.

Mixing Energy

The two most common types of mixers that are used for flocculation include baffled channels or paddles. In some cases, pipelines are also used to provide flocculation.

- Baffled channel mixers rely on hydraulics to provide the necessary flocculation (mixing) energy. Flocculation energy in baffled channel mixers varies with changes in water flow rate or temperature.
- Paddle mixers provide the greatest level of operational control. The speed of the paddles can be changed to compensate for changes in water temperature, turbidity, or flow rate.

Tapered energy is critical in preparing the flocculated material for efficient filtration or sedimentation. The type of floc that is formed depends on the type of chemicals that are used and the mixing energy that is provided. Higher mixing energies form smaller denser floc that is ideal for filtering. In contrast, lower mixing energies form larger heavier floc that is ideal for settling.

Detention Time

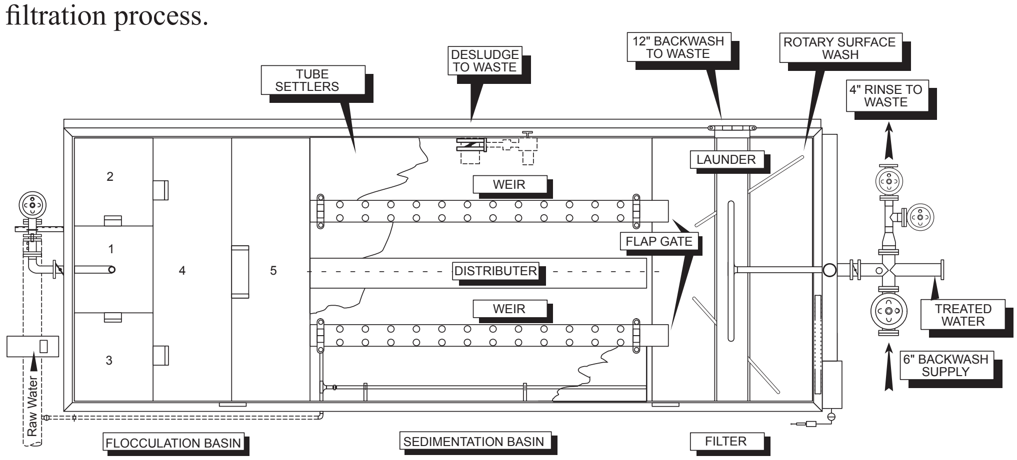
The flocculation process requires 15 to 45 minutes of mixing. The time is based on the chemistry of the water, the water temperature, and the mixing intensity. The temperature is the key component in determining the amount of time required for good floc formation.

Operational Considerations

The jar test apparatus is also used to determine the proper dosage of flocculant (anionic polymer). Proper timing between the addition of the coagulant and flocculant is very important when anionic polymers are used. Adding the flocculant at the point when a pin floc is formed can produce remarkable results. Adding the flocculant too early or too late will reduce its effectiveness. Determining the proper dosage and timing is mainly a visual test, but instruments such as a turbidimeter can be used to aid the process. The addition of too little polymer will not adequately remove the turbidity from the settled water. The addition of too much polymer will result in flocculated material settling in the jars, even as the jar stirrer paddles continue to rotate. Flocculated material will also settle in the flocculation tanks of a full-scale system if too much anionic polymer is added.

Clarification and Sedimentation

Clarification of water involves removing contaminants through simple gravity sedimentation or through solids contact processes that operate in either a down-flow or up-flow configuration. The three most common types of clarifiers used in small systems include gravity sedimentation, up-flow sludge blanket clarification, or down-flow contact clarification. The down-flow contact clarification process uses large-diameter media, and the up-flow contact process may use floating media or simply the sludge blanket itself. In small systems, gravity sedimentation and sludge blanket clarification are generally proprietary systems designed and constructed as part of a conventional packaged water treatment system. Presently, contact clarifiers are more commonly custom-designed and resemble a roughing filter or prefilter in a two-stage filtration process.



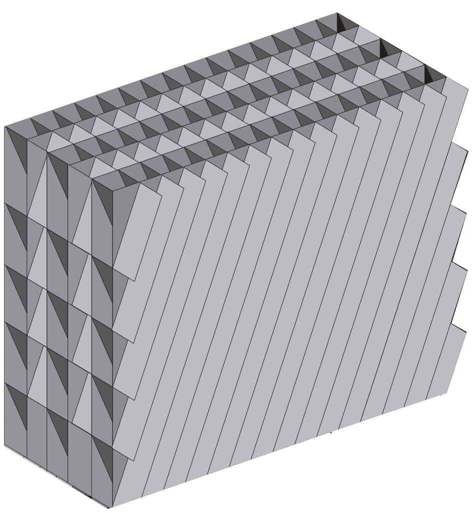
Top view of conventional filtration package treatment plant

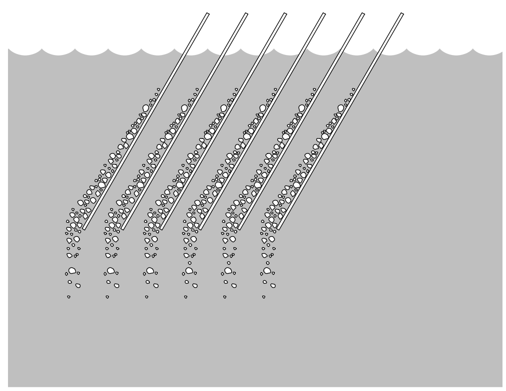
Types of Clarifiers

Today, gravity sedimentation units generally incorporate tube settlers to improve removal efficiencies. Tube settlers are typically two-inch-square or oval-shaped tubes placed on a 7.5° to 60° angle in the top two feet of the gravity sedimentation basin. The flow direction is up through the tubes. The angled tubes increase efficiency because a particle has to fall only a short distance in order to be intercepted by the sludge blanket. As water flows up through the tubes, the settled sludge moves down the tubes into the bottom of the basin.

One method of improving the efficiency of the sedimentation process is to use the sludge blanket itself as a solids contact media. In this type of clarification process, a sludge blanket is maintained in the bottom one third of the sedimentation basin. The flow of water is up through the sludge blanket. The sludge in the blanket increases the frequency of collision of the coagulated particles, and thus increases flocculation and improves solids removals. The sludge blanket works very much like a big net and is used to improve solids removals.

Down-flow contact clarifiers use large diameter media placed in a filter vessel ahead of the final filter in a two-stage configuration. The term roughing filter is often used to describe a down-flow contact clarifier. The media used in a down-flow contact clarifier is generally 2 mm - 3 mm in diameter and can consist of sand, anthracite or some proprietary media. This size media provides ample storage volume for flocculated material while being fine enough to remove or filter the flocculated particles. The allowable hydraulic loading rate of the down-flow contact clarifier depends on the relative strength of the flocculated particles and the temperature of the water.





Tube settlers

Operational Considerations

The up-flow velocity in the sedimentation basin depends on the settling characteristics of the flocculated particles and the temperature of the water. The term used to describe the up-flow velocity is surface loading. The surface loading rate for a sedimentation basin that incorporates inclined tube settlers is expressed as gallons per minute per square foot of water surface area and usually ranges between 2 - 3.5 gpm/ft^2.

When gravity sedimentation is used, the settled particles form sludge that must be removed from the basin and discharged to waste. The rate of removal depends on the rate of solids accumulation. Sludge must be removed to prevent solids from rising to the surface of the clarifier, either because it is entering the tube settlers or because gas is forming on the settled floc and buoying it to the surface. Drains are provided on the bottom of the settling basin, and settled sludge is discharged from the clarifier at specified intervals. Automatic valves with timed actuators optimize the clarification process and ensure consistent performance.

Down-flow contact clarifiers are designed based on the flow rate of the water through the unit. The loading rate on the unit is referred to as the hydraulic loading and is expressed in gallons per minute per square foot of media/bed area. The hydraulic loading rate for contact clarifiers can vary from less than 1 gpm/ft^2 to over 8 gpm/ft^2. The optimum loading rate is based on the amount and strength of flocculated material being applied to the unit. The application of contact clarifiers is limited to coagulated waters with a low solids loading. Finally, the down-flow contact clarification process has the advantage of being less complicated and less costly to operate than a gravity sedimentation unit.

Like the gravity sedimentation or up-flow sludge blanket clarification processes, the accumulated solids must be removed from the down-flow contact clarifier. This removal process is accomplished by backwashing at set intervals or when the turbidity of the effluent from the contact clarifier begins to rise. Backwashing rates are significantly higher than what is required for typical sand and anthracite (dual media) filters. Air scour followed by an up-flow **backwash**[38] of 25 - 35 gpm/ft^2 is required to dislodge and remove accumulated solids.

[38] Backwash – The reversal of flow through a filter in order to clean the filter by removing material trapped by the media in the filtration process.

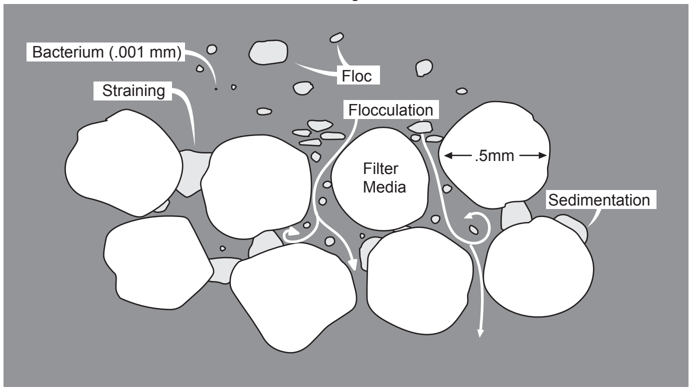
The objective of clarification is to reduce the solids loading on the down stream processes (filters) and thus increase the length of the filter cycle. The performance of the clarifier can be measured by the turbidity of the clarifier effluent or visual observation of the clarified water. The process control variables include the use of flocculant aids, the type of flocculant aid used, the location where the flocculant aid is added, the timing between coagulant injection and flocculant aid addition, the mixing energy provided during flocculation, and the **hydraulic loading**[39] being applied to the clarifier.

[39] Hydraulic Loading – The flow rate per surface or cross-sectional area.

Granular Media Filtration

Filtration is a physical process of separating suspended and colloidal particles from water by passing the water through a filter media. Filtration involves a number of physical processes. Among these are straining, settling, and adsorption. As particle contaminants pass into the filter, the spaces between the filter grains become clogged, which reduces the openings. Some contaminants are removed merely because they settle onto a media grain. Others are adsorbed onto the surface of individual filter grains. This adsorption process helps to collect the contaminants (floc) and thus reduces the size of the openings between the media grains.

Water being filtered



Adsorption of floc onto individual filter grains

As water and particles (floc) enter the filter, they begin to settle, adsorb, and collect in the upper portion of the filter media. This increases the pressure above the particles, driving them down into the media. As the floc penetrates into the filter bed, the openings get smaller, and the bed becomes clogged. This increases the friction between the water and the filter bed. As a result, there is an increase in the difference between the pressure at the top of the filter and the pressure at the bottom of the filter. This difference in pressure is called **differential pressure**[40].

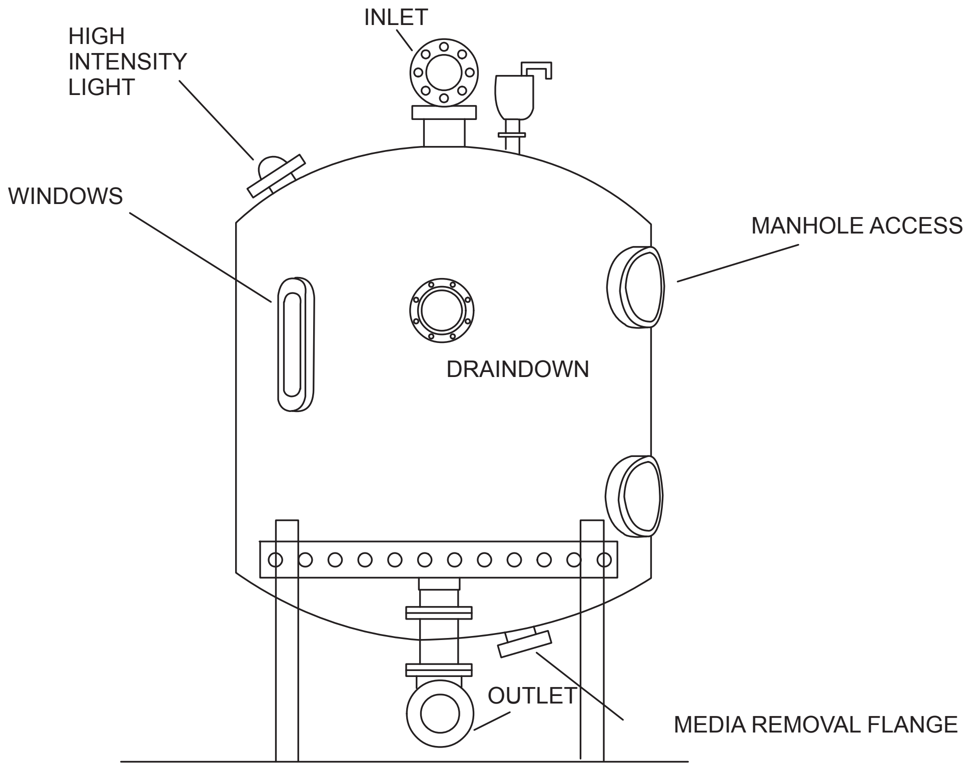
Types of Filters

The two main types of filters used in small systems include gravity filters and pressure filters.

- **Gravity filters** rely on the depth of water above the filter media to provide the driving force to pass water through the media as it clogs. The amount of available driving force or water depth (head) is limited by the sidewall height of the filter tank above the surface of the filter media. The sidewall height is thus limited by the ceiling height in the building.
- **Pressure filters** are enclosed in pressure vessels and can operate with much higher driving forces. In general, most gravity filters operate with 4 - 6 feet of available head, and pressure filters operate with 10 - 20 feet of head. A major advantage of the pressure filter is that water can be treated under pressure and pumped to a water storage tank at a higher elevation without the need to pump the water after filtration. One disadvantage of the pressure filtration system is the inability to visually observe the condition of the filter media and the backwash process. However, new pressure filters now incorporate windows for visual inspection and light to illuminate the tank interior and filter bed.

[40] Differential Pressure – The difference in water pressure between two points.

[41] Stratify – To place into layers.



Pressure filter

Filter Media

Filter media can consist of silica sand, greensand, anthracite coal, activated carbon, and many other types of media. These media can be used by themselves as a single media filter or mixed to provide improved filtration characteristics. The two most common types of granular media filters include dual-media filters and tri-media (mixed media) filters. Dual-media filters consist of anthracite coal and silica sand; and tri-media filters have anthracite coal, silica sand and fine garnet. The general goal in the filtration process is to provide coarse-to-fine filtration. Water passes through the larger anthracite media at the top of the filter first and finally through the finer grained sand located at the bottom of the filter. This design provides increased solids removals as the water progresses through the filter. The densities of the filter media are selected to allow the media to **stratify**[41] during the up-flow backwash cycle, thus placing the larger anthracite coal media on the top of the filter bed. The filter then operates in a down-flow configuration.

Greensand media is typically used in conjunction with anthracite coal in a dual-media configuration. This type of media is used to remove inorganic contaminants such as manganese and iron. The principle of course to fine filtration also applies to the greensand filter. These filters will be discussed in greater detail in the sections on inorganic adsorption and groundwater treatment.

Activated carbon can be used as a topping for silica sand as well but is more commonly used as a single media. The main purpose of activated carbon is not to remove solids but to adsorb organic contaminants. These types of filters are called contactors. These will be discussed in more detail in the sections dealing with organic adsorption and surface water treatment.

[41] Stratify – To place into layers.

Hydraulic Loading

Filter design is based on hydraulic loading and the treatment capacity of the filters. Slow sand filtration utilizes a single fine-grained sand bed. The hydraulic loading for this process varies from as little as 0.04 gpm/ft^2 to as much as 0.08 gpm/ft^2. Although higher loading rates up to 0.20 gpm/ft^2 have been used. This process is essentially a biological process, and the type of water that can be successfully treated is limited by the turbidity of the source water.

Rapid sand filters use higher loading rates and can successfully treat a wide range of raw water conditions. These filters can be used as a post treatment after clarification or without clarification in what is referred to as **direct filtration**[42]. The recommended hydraulic loading rates for rapid sand filters range from 1 gpm/ft^2 to 5 gpm/ft^2 (typical for packaged plants). These filters use medium-sized sand with an **effective size**[43] of approximately 0.5 mm. Filters using larger diameter media can operate at loading rates up to 10 gpm/ft^2. The use of high hydraulic loading rates in the filtration process is analogous to driving a car fast. The filtration process, like the car, becomes more difficult to control at higher velocities (hydraulic loading rates). However, the use of higher hydraulic loading rates allows the life of older facilities to be extended or smaller treatment system footprints to produce larger amounts of water.

[42] Direct Filtration – A gravity or pressure filter system involving coagulation, flocculation, filtration, and disinfection.

[43] Effective Size – The diameter of particles for which 10 percent of the total grains are smaller and 90 percent are larger.

Operational Considerations

One of the major keys to proper water treatment plant operation is to clean the filter before the floc penetrates completely through the filter bed resulting in **turbidity breakthrough**[44]. For most filters, this cleaning point is when effluent turbidity begins to rise and approaches the maximum value allowed by regulations. In the past, headloss through the filter governed the filtration cycle or filter run. However, turbidity limits are usually reached in most systems before terminal headloss is reached. This effluent turbidity value is typically reached after 12 to 72 hours of filter operation. The cleaning process is accomplished by allowing water to flow up through the filter bed at an appropriate velocity to expand the bed and remove the contaminants (floc) trapped by the media. This process is called "backwashing the filter." An auxiliary wash process is used to agitate the media and breakup the accumulated floc prior to the backwash process. The auxiliary wash process can be accomplished by injecting air up through the media or agitating the surface of the media with jets of water. Injecting air is the most beneficial auxiliary wash system because it thoroughly agitates the entire media bed throughout its depth. Injecting air up through the media in this manner is referred to as **air scour**[45].

[44] Turbidity Breakthrough – A rapid rise of turbidity in the effluent from a filter.

[45] Air Scour – The agitation of filter media by the injection of compressed air.

Membrane Filtration

Membrane processes commonly used in water treatment include **membrane cartridge filtration**[46] (MCF), **microfiltration**[47] (MF), **ultrafiltration**[48] (UF), **nanofiltration**[49] (NF), and **reverse osmosis**[50] (RO). The MCF process includes using **Bag Filters**[51] and **Cartridge Filters**[52] and is used to remove larger pathogens such as Giardia and Cryptosporidium. The MF and UF processes are effective at removing turbidity, particles, and pathogens from water. The NF process provides a higher level of treatment than the MF/UF processes and has the added capability of removing dissolved organic contaminants. The RO process provides the highest level of treatment of the membrane processes and is also effective in removing salts from brackish water or seawater. Membrane processes are classified based on effective size range.

[46] Membrane Cartridge Filtration – Bag or cartridge filters capable of removing giardia and cryptosporidium.

[47] Microfiltration – Membrane filters capable of removing pathogenic organisms larger than 0.1 micrometers in size.

[48] Ultrafiltration – Membrane filters capable of removing pathogenic organisms larger than 0.005 micrometers in size.

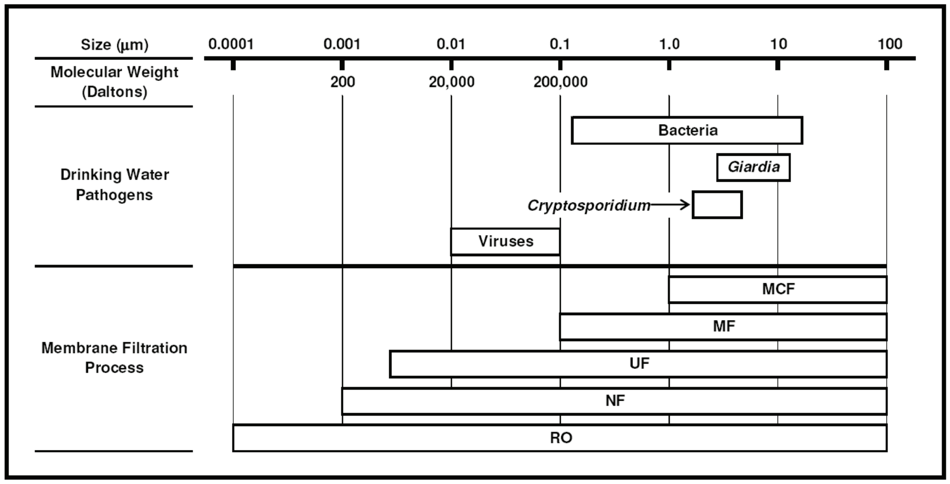
[49] Nanofiltration – Membrane filters capable of removing pathogenic organisms and dissolved organic contaminants larger than 0.001 micrometers in size.

[50] Reverse Osmosis – Membrane filters capable of removing pathogenic organisms, dissolved organic, and salts contaminants larger than 0.0001 micrometers in size.

[51] Bag Filter – A membrane filter shaped like a bag.

[52] Cartridge Filter – A membrane filter in the form of a cartridge.

The figure below, taken from the *EPA Membrane Filtration Guidance Manual*, illustrates the ability of each type of membrane process to remove various drinking water pathogens and provides the filtration size range of each process.



As noted earlier, the MCF process includes bag filters and cartridge filters. These filters are essentially a course membrane filter designed specifically to remove Giardia and Cryptosporidium. They are marginally effective at reducing turbidity and minimally effective at removing organic contaminants. Therefore, the application of these types of filters is limited to low turbidity water with minimal levels of organic contaminants. These types of membrane filters are rated for removal of Giardia and Cryptosporidium based on a maximum filtration flow rate and differential pressure. They are also certified for use in a specific filter housing. Bag or cartridge filters are considered to be **Alternative Filtration**[53] devices and must be approved by the Alaska Department of Environmental Conservation (ADEC).

[53] Alternative Filtration – A filtration technology other than diatomaceous earth filtration, conventional or direct filtration, or slow sand filtration that is used to meet the requirements of the Surface Water Treatment Rule.

Operational Considerations

The amount of pressure required to force water through membrane filters can vary significantly based on the type of membrane used. In general, the pressure required to pass water through the membrane starts at some lower value and increases as the membrane becomes clogged. Required pressures can be as low as 20 psi for bag or cartridge filters to more than 1,000 psi for reverse osmosis.

When a bag or cartridge filter becomes clogged, it is discarded. For the other types of membranes listed above, the filter is either backwashed when the cutoff pressure has been reached or chemically cleaned. Backwashing membranes may also require using chemicals to extend the time between cleanings. Chemical cleaning is used to control membrane fouling. Chemical cleaning is the primary means of restoring the membranes because they cannot be effectively cleaned by backwash alone. Over time, however, even chemical cleaning of the membranes cannot restore the required capacity, and the membranes must then be replaced.

In some cases, pretreatment to remove or reduce contaminant loading on the membranes may be required. Careful consideration must be given when selecting a membrane process for a specific application. Pilot testing may be required for unusual membrane applications.

Adsorption

Organic and inorganic contaminants can be removed from water through the adsorption process. Adsorption of a substance involves its accumulation onto the surface of a solid called the adsorbent. Adsorbents can include stationary media, such as activated carbon, ion exchange resins, or metal oxides. Adsorbents can also include aluminum or ferric chloride floc that forms during coagulation. This floc can adsorb organics such as organic carbon and inorganics such as arsenic.

Organic Adsorption

Activated carbon can be used to remove hundreds of different types of organic contaminants. It can be injected into the water as a powder, or it can be placed in a vessel in granular form for the water to flow through it. The powdered form is known as powdered activated carbon (PAC) and the granular form is known as granular activated carbon (GAC). Greater process control and adsorptive capacities can be achieved with the GAC.

GAC is placed in a vessel that resembles a filter. Two vessels are normally used and are typically operated in series. Series operation is used to ensure nearly 100 percent of the adsorption capacity of the GAC is used. The media is replaced only in the lead vessel each time, and the lead vessel is then switched to become the lag vessel. In other words, the contactor with the oldest media operates as the lead contactor, and the following contactor contains the new media and operates as a polishing contactor.

Contactors are design based on contact time. Generally, 10 minutes to 20 minutes of contact is required to obtain the desired removals and to optimize the adsorption capacity of the media.

The useful life of GAC media is a function of its ability to adsorb the target contaminant. When the media is new, nearly 100 percent of the target contaminant can be removed. As the use of the contactor progresses, less and less contaminant is removed until a maximum acceptable effluent contaminant concentration is reached. The adsorption capacity of the media at the top of the contactor can be nearly 100 percent utilized while the adsorption capacity of the media at the bottom of the contactor is only partially consumed. As a result, contactors are operated in series to fully exhaust the media in the lead contactor. The exhausted media is then removed and discarded or sent back to a facility to be regenerated.

Inorganic Adsorption

Some inorganic contaminants can be removed through the adsorption process as well. Adsorption can be on to the surface of a filter media or on to the surface of floc. Common adsorption media includes ferric oxide or activated alumina. Inorganic contaminants that can be removed by adsorption include arsenic, manganese, fluoride, as well as many others.

Arsenic is almost always a contaminant that is associated with groundwater. Arsenic can exist as either **arsenite**[54] (As^{3+}) or **arsenate**[55] (As^{5+}). Arsenite is difficult to remove using the adsorption process without first converting it to arsenate. Converting arsenite to arsenate can be accomplished through oxidation using chlorine or potassium permanganate. Once the arsenic is oxidized, it can then be removed by adsorption onto the surface of an iron floc or onto the surface of an iron oxide-coated filter media.

[54] Arsenite – Arsenic (III), the dissolved form of arsenic.

[55] Arsenate – Arsenic (V), the oxidized form of arsenic.

Arsenite can be removed from groundwater supplies in conjunction with the iron and manganese removal process. The concentration of iron must be at least 50 times greater than the concentration of the arsenic to obtain acceptable removals of the arsenic. This process is called **coprecipitation**[56]. The iron and the arsenic are oxidized simultaneously by chlorine or potassium permanganate. The natural iron forms a ferric (iron) floc when it is oxidized, and the arsenic is then adsorbed onto the surface of the floc.

[56] Coprecipitation – Simultaneous precipitation of more than one substance containing impurities within its mass.

Operational Considerations

Operation of an adsorption process using fixed media such as activated carbon or an iron-based granular media is based on breakthrough of the contaminant into the finished water. As noted earlier, the amount of water that can be treated through the process is a function of the concentration of the target contaminant and any other interfering agents. Pilot tests must be completed to determine the amount of water that can be effectively treated through the process. Change out frequency of the media is then a function of the quantity of water that can be treated.

Operation of a process using coprecipitation can be based on either breakthrough of the contaminant or clogging of the filter media. When the filter clogs or contaminant levels in the filter effluent begin to rise, the filter is then backwashed, and the process is started over.

Disinfection

Disinfection is defined as the process used to control waterborne pathogenic organisms and thus prevent waterborne disease. The goal of proper disinfection in a water system is to inactivate all disease-causing organisms. Disinfection should not be confused with sterilization, which is the complete killing of all living organisms. An example of the difference between disinfection and sterilization is the difference between placing alcohol on the skin before a shot (disinfection) and boiling surgical instruments (sterilization).

The effectiveness of disinfection in a drinking water system is measured by testing for the presence or absence of **coliform bacteria**[57]. Coliform bacteria that are found in water are generally not pathogenic, but they are a good indicator of contamination. Their absence indicates the possibility that the water is potable. Their presence indicates the possibility of contamination.
Coliform bacteria have been selected as the indicator of bacteriological water quality for several reasons:

[57] Coliform Bacteria – The coliform group of bacteria is a bacterial indicator of contamination. This group has the intestinal tract of human beings as one of its primary habitats. Coliforms may also be found in the intestinal tract of warm-blooded animals and in plants, soil, air, and the aquatic environment.

- They survive longer than most pathogenic organisms in the water environment.
- They are easy to test for. That is, the testing process has been perfected, and it is not excessively expensive or difficult.
- They are less sensitive to disinfection than many of the pathogens.

The requirements for testing the effectiveness of disinfection are to sample and test the distribution system. In order for the water to be potable, there should be a chlorine residual in all parts of the system and a complete absence of coliform in each and every sample. The presence of a single organism is cause to resample and retest.

The most commonly used disinfection alternatives in small systems today include chlorine, chloramines, ultraviolet light, and ozone. Disinfectants can be described as primary disinfectants or secondary disinfectants:

- Primary disinfectants are used to inactivate pathogenic organisms.
- Secondary disinfectants are used to maintain a disinfectant residual in the distribution system. Generally, secondary disinfectants include free chlorine or monochloramine because they can provide a persistent and detectable residual.

Chlorine

Chlorine is the most common method of disinfection used in the United States today. Despite problems, it remains our standard method of disinfection because 1) it costs less than most of the other methods, and 2) we have more knowledge about chlorine than any other disinfectant.

One of the major advantages of using chlorine is the effective residual that it produces. A residual indicates that disinfection is completed, and the system has an acceptable bacteriological quality. Maintaining a residual in the distribution system provides another line of defense against pathogenic organisms that can enter the distribution system. A residual in the distribution system helps to prevent regrowth of microorganisms injured but not inactivated during the initial (primary) disinfection stage.

Chemical Alternatives

There are two chlorine products used to disinfect drinking water: gas and **hypochlorites**[58]. Hypochlorites can be in either a liquid or powder form. The liquid is sodium hypochlorite. Household bleach is sodium hypochlorite. Powdered hypochlorite is calcium hypochlorite. HTH™ is a brand name for one of the common calcium hypochlorite products.

Gas chlorine is provided in 100 lb, 150 lb, or 1-ton containers. Chlorine is placed in the container as a liquid. The liquid boils at room temperature, producing a gas and pressure in the cylinder. At a temperature of 70° F, a chlorine cylinder will have a pressure of 85 psi. Chlorine gas is 100 percent chlorine.

Combining chlorine with either calcium or sodium produces hypochlorites. Calcium hypochlorites are available in either powder or tablet form and can contain chlorine concentrations up to 67 percent. Chlorine concentrations of household bleach range from 4.75 percent to 5.25 percent. Sodium hypochlorite is a liquid such as bleach. Sodium hypochlorite is found in concentrations up to 15 percent.

There are differences between the reactions of chlorine gas and hypochlorite compounds in water that must be considered. When chlorine gas is added to water, it tends to consume alkalinity and lower the pH through the formation of hydrochloric acid. On the other hand, the addition of hypochlorite to water tends to raise the pH from the addition of calcium or sodium hydroxide.

Chlorine Disinfection

There are several things that can interfere with or have a negative impact on the ability of chlorine to disinfect. Among these are pH, temperature, type of organisms, type of residual, quantity of interfering agents, and **contact time**[59].

[58] Hypochlorites – Compounds containing chlorine that are used for disinfection. They are available as liquids or solids and in barrels, drums, and cans.

[59] Contact Time – The amount of time in minutes that the disinfectant, measured as a free residual, is in contact with the water before the water is delivered to the first customer.

Hypochlorous acid (HOCl) is the best of the disinfection products. Hypochlorous acid is 100 to 300 times better than the hypochlorite ion (OCl^-) as a disinfectant. It requires five to 20 times more combined residual to do the same job as free residuals.

As the temperature of the water rises, chlorine compounds will evaporate or dissipate faster from the surface of the water. Thus at higher water temperatures, a higher dosage is required to maintain the same level of disinfection.

Not all organisms are affected in the same way by chlorine. For instance, viruses are much harder to kill than bacteria and require higher chlorine dosages. Also, some protozoa form cysts, or hard shells, that are difficult for chlorine to penetrate. Examples include the protozoan Cryptosporidium, which is extremely resistant to chlorine, and the cysts of Giardia, which are difficult but not impossible to inactivate with chlorine.

As we described previously, free chlorine residual is the best of the disinfectants. To maintain an effective line of defense against pathogenic organisms, State regulations require a residual of 0.2 mg/L of disinfectant at the point where the water enters the distribution system and a trace of disinfectant residual at all points in the distribution system. Due to limitations in contact time, higher residuals may be necessary to achieve proper disinfection.

Chlorination Practice

One of the major difficulties new operators have with the chlorination process is to understand the terms used to describe the various reactions and processes used in chlorination. The following table provides a brief description of the common terms used in chlorination.

Definition of Chlorination Terms	
Term	Description
Dosage	Dosage[60] is the amount of chlorine added to the system. The units used to describe dosage can be either milligrams per liter (mg/L) or pounds per day. The most common is mg/L.
Demand	Demand[61] is the amount of chlorine that is used by iron, manganese, turbidity, algae, organics, and microorganisms in the water. Because the reaction between chlorine and organic contaminants is not instantaneous, the measurable demand increases with time. For instance, the measurable demand five minutes after applying chlorine will be less than the demand after 20 minutes. Demand, like dosage, is expressed in mg/L.
Residual	Residual[62] is the amount of chlorine remaining after the demand is satisfied. Residual, like demand, is based on time. The longer the time after dosage, the lower the residual will be until all of the demand has been satisfied. Residual, like dosage and demand, is expressed in mg/L. There are three types of residual: free, combined, and total.
Free Residual	Free chlorine residual[63] is the number obtained when testing for the presence in water of chlorine gas, hypochlorous acid[64] (HOCI), and the hypochlorite ion[65] (OCI^-). Free chlorine is a stronger disinfectant than combined chlorine.
Combined Residual	Combined chlorine residuals[66] is the result of combining free chlorine with nitrogen compounds. Combined residuals are also called chloramines. There are three common chloramines: monochloramines, dichloramines, and trichloramines.
Total Chlorine Residual	Total chlorine residual[67] is the mathematical combination of free and combined residuals. Total residual can be determined directly with standard chlorine residual test kits. Total residual is the normal test required at wastewater treatment facilities.
Pre-Chlorination	Pre-Chlorination is the addition of chlorine prior to a unit process. In water treatment, pre-chlorination usually means the application of chlorine prior to any other treatment.
Post-Chlorination	Post-Chlorination is the addition of chlorine after a unit process. In water treatment, this is considered to be the chlorination of the water after treatment. The addition of chlorine to a treatment plant clearwell is post-chlorination.
Super-Chlorination	Super-Chlorination is the addition of a chlorine dosage so large that the water must be dechlorinated prior to use. There is no set value that is accepted as indicating super chlorination.
Dechlorination	Dechlorination is the reduction of the residual to an acceptable level. Dechlorination can be accomplished with the use of chemicals such as sulfur dioxide and sodium bisulfite.
Chloramines	If there are nitrogen compounds in the water, the hypochlorous acid will combine with them to form chloramines. Nitrogen compounds include inorganic nitrogen such as ammonia and organic nitrogen like protein and amino acids.

[60] Dosage – When related to chlorine, the amount of chlorine added to the system.

[61] Demand – When related to chlorine, the amount of chlorine utilized by iron, manganese, algae, and microorganisms in a specified period of time.

[62] Residual – What is remaining in the water after a set period of time.

[63] Free Chlorine Residual – The amount of chlorine available as dissolved gas, hypochlorous acid, or hypochlorite ion that is not combined with an ammonia or other organic compounds. It is 25 times more powerful than the combined chlorine residual.

[64] Hypochlorous Acid – An usable strongly oxidizing but weak acid (HOCI) obtained in solution along with hydrochloric acid by reaction of chlorine with water.

[65] Hypochlorite Ion – An ion that results from the reaction of chlorine gas and water. Hypochlorite ion (OCl^-), along with hypochlorous acid, are called free chlorine residual. However, the hypochlorite ion is not as powerful a disinfectant as hypochlorous acid.

[66] Combined Chlorine Residual – The amount of chlorine available as a combination of chlorine and nitrogen.

[67] Total Chlorine Residual – The sum of the combined and free chlorine residuals.

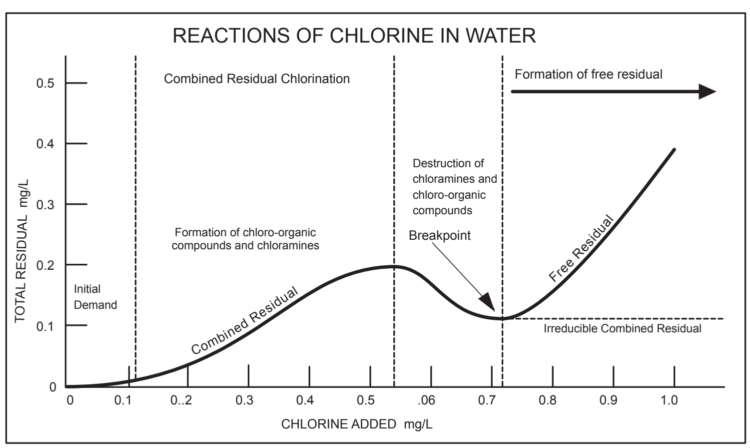
Breakpoint Chlorination

The concept of **breakpoint chlorination**[68] is extremely important for the operator to understand. The chlorine breakpoint can be determined only by experimentation. This experiment is not difficult to perform. It requires twenty 1000 mL beakers and a solution of chlorine. The water is placed in the beakers and dosed with progressively larger amounts of chlorine. For instance, you might start with zero in the first beaker, then 0.5 mg/L, and 1.0 mg/L, and so on. After a period of time, say 20 minutes, each beaker is tested for total chlorine residual and the results plotted.

[68] Breakpoint Chlorination – The point at which near-complete oxidation of nitrogen compounds is reached. Any residual beyond breakpoint is mostly free chlorine.

Components of the Breakpoint Curve

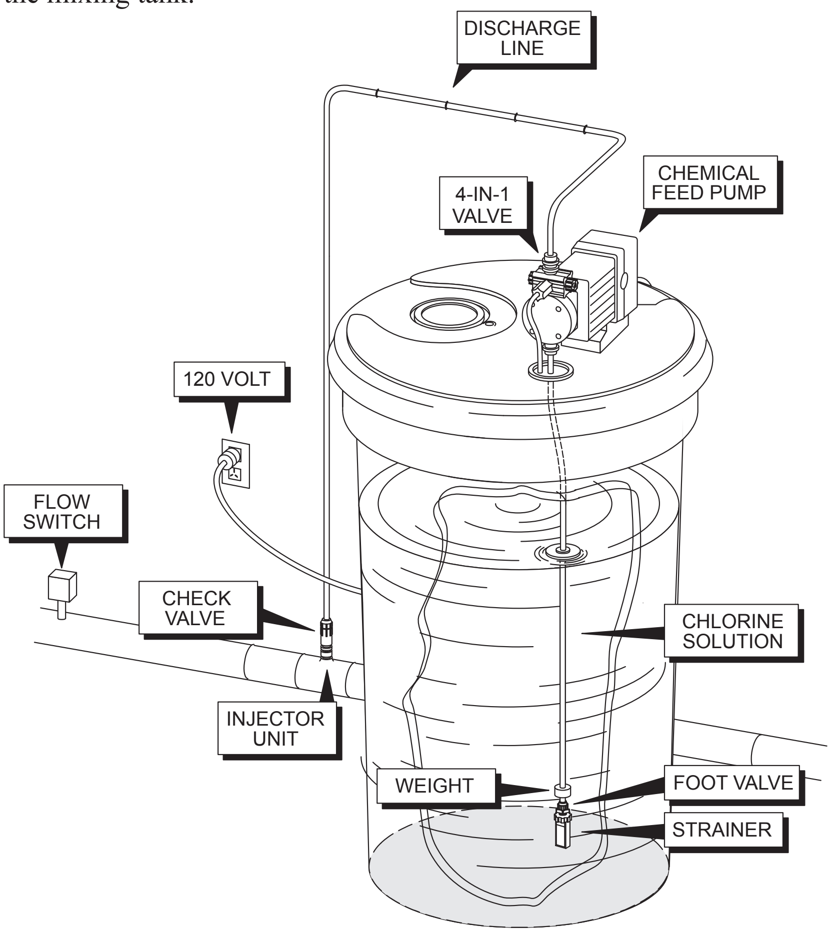
Curve Component	Explanation
Initial Demand	When the curve starts, there is no residual, even though there was a dosage. This is called the initial demand and is the result of the chlorine being used by microorganisms and interfering agents.
First Rising Leg	After the initial demand, the curve slopes upward. This part of the curve is produced by chlorine combining to form chloramines. All of the residual measured on this part of the curve is combined residual (monochloramine).
Dropping Curve	At some point, the curve will begin to drop back toward zero. This portion of the curve results from a reduction in combined residuals. This occurs because enough chlorine has been added to destroy (oxidize) the nitrogen compounds that were being used to form combined residuals (chloramines).
Breakpoint	The breakpoint is the point where the downward slope of the curve breaks upward. At this point, all of the nitrogen compounds that could be destroyed have been destroyed.
Second Rising Leg	After breakpoint, the curve starts upward again, usually at a 45° angle. It is only on this part of the curve that free residuals can be found.
Irreducible Combined Residual	The distance that the breakpoint is above zero is a measure of the remaining combined residual that will be in the water. This combined residual exists because some of the nitrogen compounds cannot be oxidized by chlorine. If irreducible combined residual is more than 15 percent of the total residual, chlorine odor and taste complaints will be high.



Chlorination Equipment

The gas chlorine feed equipment used in a water system is rated in pounds per day (the maximum amount of chlorine that the system can feed in a day). All of the units sold today are vacuum-operated. This is a safety feature. If there is a break in one of the components in the chlorinator, the vacuum will be lost and the chlorinator will shut down without allowing gas to escape.

The most common hypochlorinator system is composed of a 20 to 50 gallon corrosion-proof tank (usually plastic) in which a hypochlorite solution is mixed. This solution is pumped into the system using a chemical feed pump. To protect the pump, a strainer is placed on the end of the suction line. Also on the suction line is a weight and foot valve. The weight keeps the line in the solution, and the foot valve helps to maintain the prime on the pump. On the end of the discharge line is a check valve. This valve prevents the water in the system from flowing back through the pump into the mixing tank.



Typical hypochlorination feed equipment

Sodium hypochlorite can be generated onsite using high-grade, high-quality salt, water, and electricity. The strength of the sodium hypochlorite solution produced using this equipment is around 0.8 percent. The process water must have less than 17 mg/L hardness, and in many cases in Alaska, the water must be heated. The sodium hypochlorite solution at 0.8 percent is very stable. However, because of the low chlorine concentration of the solution, a relatively large injection pump is required to deliver the needed dosage. Lastly, a by-product of onsite sodium hypochlorite generation includes the production of hydrogen gas H_2. Safe disposal of this gas must be considered for this application.

Chloramines

Chloramines[69] have been used as a disinfectant in drinking water treatment since the beginning of the 20th century. Chloramines are produced when chlorine is added to water containing nitrogen compounds such as ammonia nitrogen. This reaction is detailed above in the breakpoint chlorination example. There are three types of chloramines that are produced, including monochloramines, dichloramines, and trichloramines. From the water treatment perspective, the desired form of chloramine is monochloramine because of its biocidal properties and minimal taste and odor production. Dichloramines and trichloramines are less desirable because of the chlorinous tastes and odors that they produce.

[69] Chloramines – Compounds produced when chlorine and ammonia react. A weak oxidant or disinfectant.

The major benefits of monochloramines include their tendency to produce fewer disinfection by-products such as TTHMs and HAA5s, minimal chlorinous tastes and odors, persistence to reach distant areas of the distribution system, and effectiveness as a secondary disinfectant in penetrating **biofilms**[70] in distribution systems.

[70] Biofilms – A colony of tiny microorganisms.

Chloramines are less effective as a biocide than free chlorine for inactivating pathogenic microorganisms. For this reason, chloramines are generally not used as a primary disinfectant. Chloramines are, however, an excellent secondary or final disinfectant because they form a very stable and persistent residual.

Chloramination Equipment

The equipment required to produce chloramines is essentially the same equipment required for chlorination systems. Chlorine can be injected as a gas or a liquid, and ammonia can also be injected as a gas or a liquid. In addition, both chlorine and ammonia are also available in liquid form or in granular form that can be dissolved in water. Great care must also be taken to ensure that concentrated chlorine and ammonia are never mixed because they will form nitrogen trichloride, a potentially explosive compound.

Ultraviolet Light (UV)

One of the numerous forms of energy is electromagnetic. UV light is in the electromagnetic spectrum between X-rays and visible light. Practical UV disinfection in water treatment occurs primarily at a wavelength between 200 nanometers (nm) and 300 nm. A mercury-based UV lamp will produce ultraviolet light at 253.7 nm.

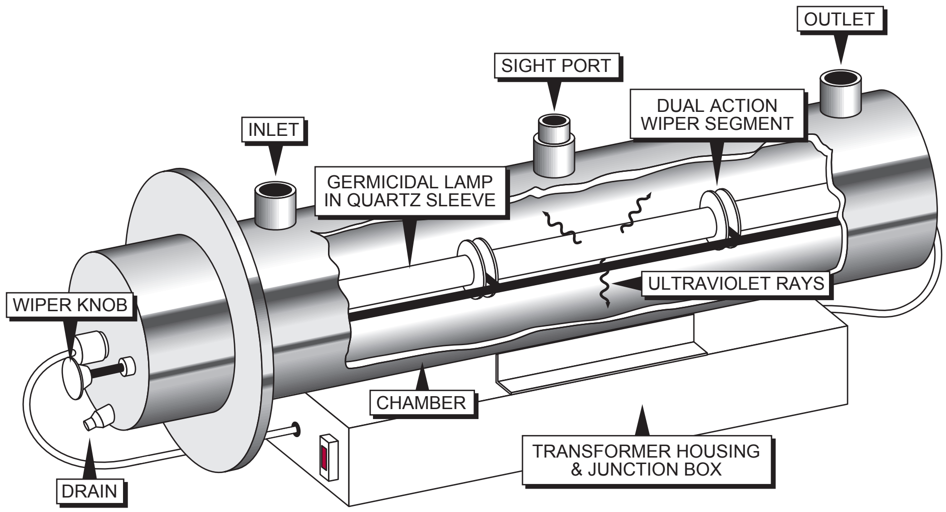
Ultraviolet Disinfection

Disinfection by UV light is very different from the mechanisms of chemical disinfection using chlorine, chloramines, or ozone. Chemical disinfectants inactivate microorganisms by damaging cellular structures, interfering with metabolism, and hindering growth. UV light inactivates microorganisms by damaging their nucleic acid and preventing them from replicating, thus making it impossible for the organisms to infect the host.

The UV dosages required to inactivate viruses are substantially higher than those required to inactive Cryptospordium and Giardia. UV leaves no residual and thus requires the addition of chlorine or some other secondary disinfectant to maintain a residual in the system.

Ultraviolet Disinfection Equipment

UV reactors must consistently deliver the dosage of UV radiation necessary to inactivate the target pathogens. Factors that interfere in the delivery of the proper dosage include poor water quality such as high turbidity, absorbance of the light by organics, low bulb light output (caused by slime buildup or bulb degradation), or an increase in the water flow rate past the light source. To ensure proper treatment, commercial UV reactors are equipped with UV sensors, temperature sensors, flow meters, and cleaning mechanisms for the bulbs.



UV disinfection system

Ozone

Ozone (O_3) is a colorless gas with a characteristic odor reminiscent of a lightning storm. Ozone has been used in drinking water treatment for many years in France, Germany, and Canada. Its use in the United States has been increasing as concerns about chlorinated by-products have increased. Because of the reactivity of ozone, residuals cannot be maintained for more than a few minutes. As a result, ozone is considered to be a primary disinfectant and requires the use of chlorine or chloramines as a secondary disinfectant.

Ozone Disinfection

Ozone is a very powerful disinfectant. The concentration and reaction times are substantially lower than those required for free chlorine. Required CT values for inactivation of Giardia by ozone are on the order of 1/10th of those required for free chlorine.

Ozone Disinfection Equipment

Because of its extreme reactivity, ozone gas must be produced onsite. It is a product of the action of electrical fields on oxygen. The oxygen can be derived from air or shipped to the site as pure oxygen in compressed gas cylinders. After the ozone is generated, it is piped to a contactor. Ozone is then injected at the bottom of the contactor tank into a diffuser, and the fine bubbles rise through the water as the water flows downward into the tank. Ozone is transferred from the gas phase into the water through this process, where it is free to react with the contaminants.

The CT Concept

One of the keys in predicting the effectiveness of a chemical disinfectant on microorganisms is CT. The disinfectant residual concentration is the "C," and the contact time is the "T." CT is calculated based on a specified disinfectant residual being maintained prior to the first customer: Concentration (mg/L) x Contact time (minutes).

Experimentation has shown that specific CT values are necessary for the inactivation of viruses and Giardia. The required CT value will vary depending on the disinfectant, pH, temperature, and the organisms that must be inactivated. Charts and formulas are available to make this determination.

Tables in the EPA's *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources* list the required CT values for various types of disinfectants.

[71] Log Inactivation – A mathematical relationship relating percent inactivationtologarithmicinactivation. Common inactivations are three log or 99.9 percent and four log or 99.99 percent.

CT Values for Various Disinfectants

Disinfectant	Disinfectant Concentration	Log Inactivation*	Microorganism	pH	Water Temperature	Required CT
Free Chlorine	0.6 mg/L	1	Giardia	7.0	<34° F	67
	Varies	3	Viruses	6-9	<34° F	9
Chloramines	Varies	1	Giardia	6-9	<34° F	1,270
	Varies	3	Viruses	N/A	<34° F	2,063
Ozone	Varies	1	Giardia	---	<34° F	0.97
	Varies	3	Viruses	---	<34° F	1.4

***Log inactivation**[71] is related to the percentage of organisms inactivated. One log is equal to 90 percent; two logs equal 99 percent; and three logs equal 99.9 percent inactivation.

Surface Water Treatment Systems

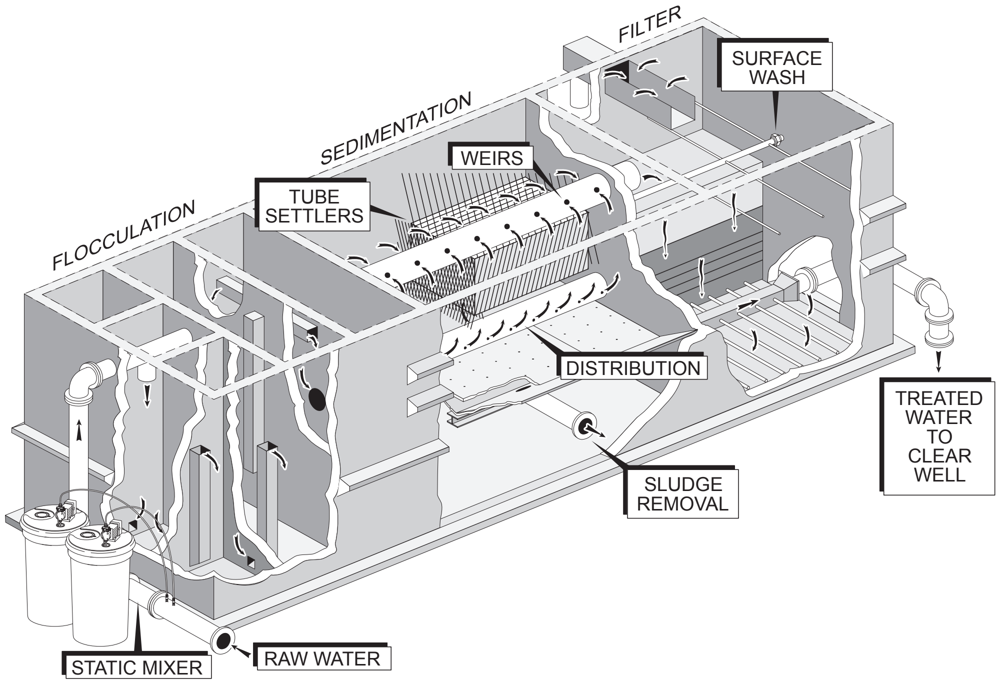
The control of turbidity, color, microorganisms, and, to some extent, taste and odor is commonly accomplished through some type of filtration system. The Surface Water Treatment Rule describes five different types of filtration systems: **conventional treatment**[72], direct filtration, **slow sand filtration**[73], **diatomaceous earth filtration**[74], and alternate filtration technologies such as bag filters and cartridge filters.

[72] Conventional Treatment – A standard treatment process involving coagulation, flocculation, sedimentation, filtration, and disinfection.

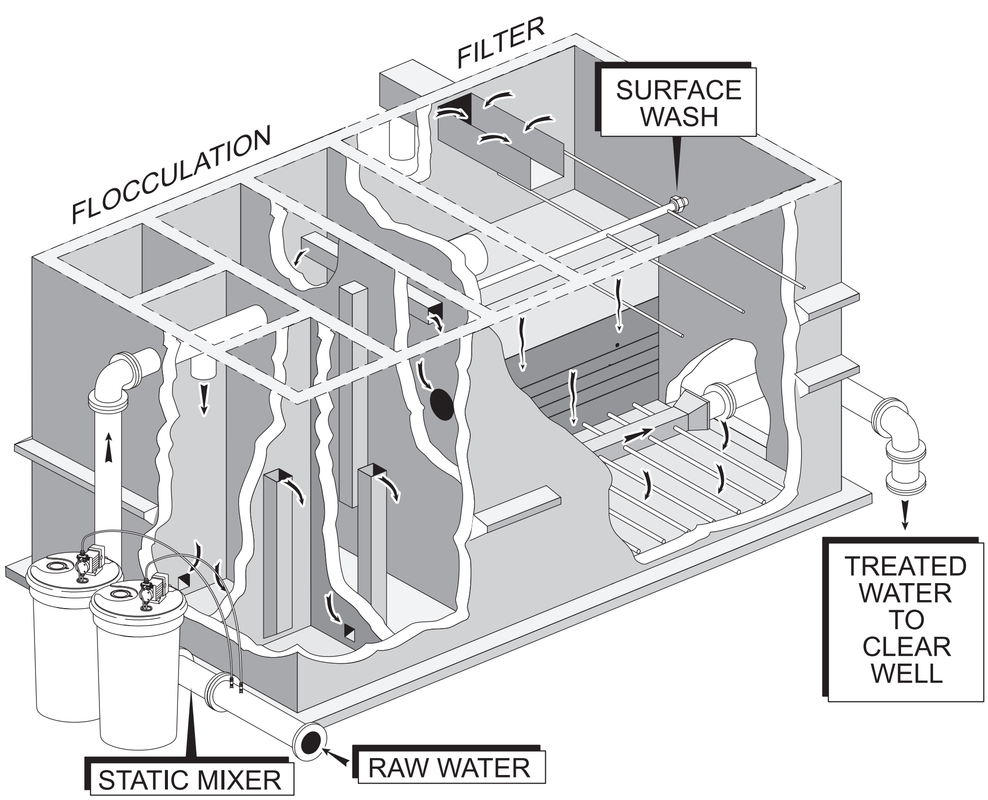
[73] Slow Sand Filtration – A method of filtration that uses a layer of microorganisms and sand media to remove contaminants.

[74] Diatomaceous Earth Filter – A pressure filter utilizing a media made from diatoms.

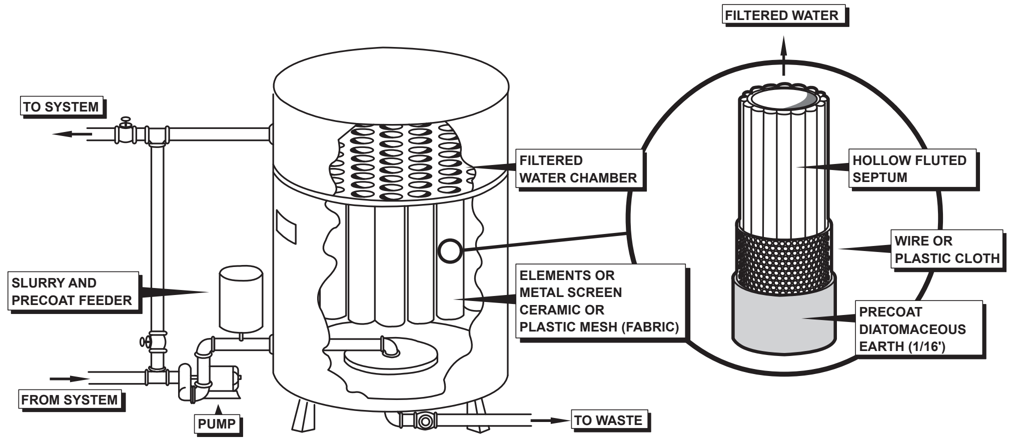
Conventional treatment includes rapid gravity filters, either built on-site or provided as a skid-mounted packaged system with flocculation and sedimentation units. Direct filtration is similar to conventional treatment with the exception that there is no sedimentation unit. The third type of filtration is called slow sand filtration and the fourth is diatomaceous earth filtration. In addition, the regulations allow the use of "alternate filtration technologies." Alternate filtration includes cartridge filters or bag filters. Membranes have also been identified as a technology to address the Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR). Membranes are an option that can meet not only the requirements of the SWTR, but also the cryptosporidium removal requirements of the LT2ESWTR.



Typical conventional package treatment plant



Direct Filtration - gravity filter system



Diatomaceous earth filter

There are common variations of the conventional treatment and direct filtration processes that can be used to meet regulatory water treatment goals, to improve process efficiency, and to reduce the operational complexity of surface water treatment processes. These include two-stage filtration and pressure filtration.

One of the main goals in operating a surface water treatment system is to achieve efficient filter runs. The more water a filter produces before a backwash is required, the lower the percentage of treated water lost to backwash. In other words, backwashing a properly designed filter requires about the same amount of water each time it is cleaned. The water that is used for backwash must be potable water from the water storage tank. Potable water is used to avoid injecting contaminants or debris into the filter underdrains. Generally, filtration efficiencies greater than 95 percent are considered acceptable. Efficiencies substantially less than 95 percent are cause for further investigation. Filtration efficiency is calculated as follows:

Filter efficiency (%) = 100 – (Backwash water volume/Water produced during the filter run)

It should be noted that a water source may be treated using direct filtration if backwash water waste can be limited to an acceptable level. High contaminant concentrations can substantially shorten filter runs and thus reduce efficiencies below an acceptable level. The addition of pretreatment such as a clarifier must be provided to reduce solids loading on the filters if this occurs. In this situation, conventional treatment is the preferred process. However, conventional treatment should not be used when a clarifier is not required.

Applied Water Quality

The quality of water from the source should determine the most appropriate type of treatment. Water quality issues that must be considered include the amount of turbidity, organics, algae, and total dissolved solids (TDS).

As a general rule of thumb, the higher the levels of contaminants in the raw water, the greater the level of treatment that is required prior to filtration. The filtration process is usually the final removal process in a water treatment system. Pretreatment processes such as flocculation, sedimentation, contact clarification, roughing filters, etc. are simply used to reduce the solids load on the final filters.

The table below provides general guidelines of applicable raw water quality for some of the basic water treatment processes:

	Conventional Treatment	Two-Stage Filtration	Direct Filtration	Alternative Filtration
Turbidity (NTU)	<5000	<50	<15	<1.5
App. Color (CU)	<3000	<50	<20	<15
Algae (ASU/mL)	<10000	<5000	<500	<100
TTHMF (mg/L)	<0.20	<0.16	<0.13	<0.08
HAA_5F (mg/L)	<0.15	<0.12	<0.10	<0.06

Note

1. The above criteria are general recommendations. Exceptions may be possible under certain conditions.
2. The criteria presented for direct filtration is also applicable to pressure filtration and slow sand filtration.
3. Alternative Filtration is also referred to as a membrane process specifically defined as Membrane Cartridge Filtration (MCF) in the US EPA Membrane Filtration Guidance Manual. Both cartridge filters and bag filters are used in this process.
4. Total Trihalomethane Formation (TTHMF) and Five Haloacetic Acid Formation (HAA_5F) are the levels of disinfection by-products that would be produced under typical chlorination and distribution system operating conditions.
5. ASU stands for Areal Standard Unit.
6. Presedimentation may be required for turbidities over 1000 NTU.

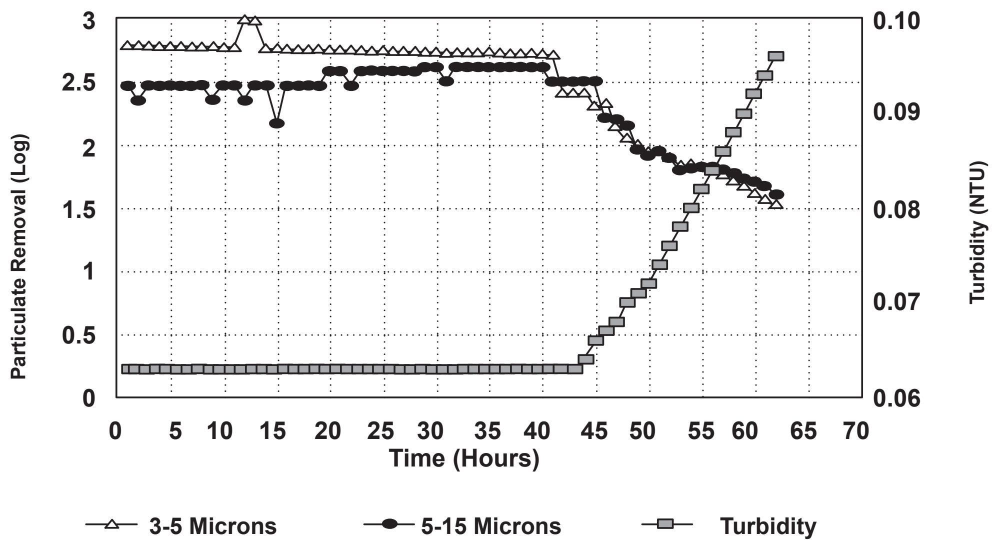
Review

1. What is the process of separating suspended and colloidal particles from water by passing the water through a filter media?
2. Name the four tpes of membrane filtration.
3. How much time is generally required to obtain the desired removals and to optimize the adsorption capacity of the media?
4. During dissenfection when does the destruction of chloraminnes and chlor-organic compuonds occur.
5. What is considered one of the keys in predicting the effectiveness of a chemical disinfectant on mirro-organisms?

Operational Control

The issue of operational control of surface water treatment systems has become increasingly important as water treatment regulations have become more stringent. Water treatment systems must consistently produce water compliant with the required removals of microorganisms and disinfection inactivations. To do this, turbidities must be maintained within very narrow tolerances, and disinfection must be consistently applied. Instrumentation has become mandatory equipment to ensure proper operation of the water treatment system and to allow accurate reporting of performance.

At a minimum, online turbidimeters and recorders are now required to consistently monitor process turbidities and to allow reporting of turbidities at the required intervals. Turbidimeters can also be configured to shut the system down in order to prevent high turbidity water from entering the system and thus prevent a violation of regulatory requirements. Particle counters are also available for online monitoring of process performance; however, these units are expensive, and there are no regulatory requirements or standards for their use.



Filter run

Automated control of the coagulation process is also available through the use of a Streaming Current Detector (SCD). A SCD measures the net charge density in the water and can be used to determine when the optimum amount of coagulant has been added. The contaminants in raw water have a highly negative net charge. Optimum coagulation occurs when the net charge nears a value of zero as measured by the SCD. Most SCDs are equipped with a signal output capability that can be used to provide online control of a coagulant feed pump. This automated control can ensure consistent optimization of the coagulation process.

Online chlorine analyzers are also available for monitoring disinfectant residuals. The devices can be configured to provide automated control of the chlorine injection pump. This type of instrument can ensure that proper disinfection is consistently maintained.

Conventional Treatment

The basic unit processes employed in a conventional treatment system include coagulation, flocculation, sedimentation, and filtration. Typically, conventional treatment systems are capable of producing a final effluent turbidity of less than 0.1 NTU. Filtration rates for conventional treatment ranges from 2 to 6 gpm/ft^2, with 4 gpm/ft^2 as the most common.

The conventional treatment system starts with the chemical feed system. This system can include dry or liquid feeders for alum, ferric salts, lime, **soda ash**[75], potassium permanganate, and/or polymers. The chemical is fed into the raw water just prior to or directly into some type of flash mixing unit. The flash mixer quickly mixes the

[75] Soda Ash – A common name for commercial sodium carbonate. A salt used in water treatment to increase the alkalinity or pH value of water or to neutralize acidity.

chemical with the water. Flash mix systems include static or mechanical mixers. Static mixers are more common on small package plants, and mechanical mixers are more common on the larger facilities.

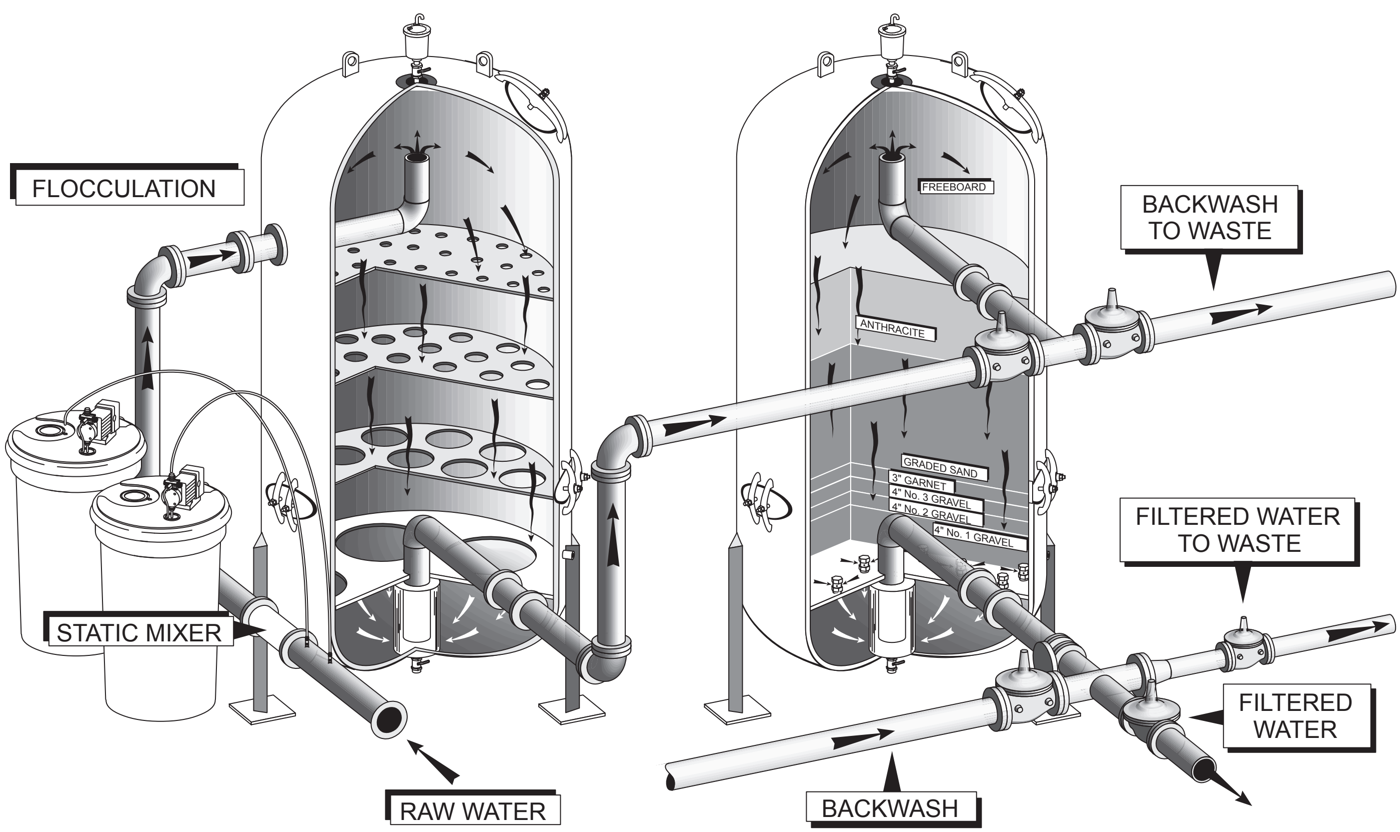
Flocculation systems vary from simple hydraulic systems using baffled chambers to mechanical mixers that resemble a paddle wheel that slowly rotates through the water. Small package plants commonly use hydraulic systems, and mechanical mixers are used for the larger facilities.

The sedimentation basins come in a wide variety of shapes: round, square, and rectangular. The most common are rectangular. Most basins used in small facilities have an inlet distributor or area designed to allow for a smooth entry of the water into the basin. The water travels up through the basin, possibly into the tube settlers, and then into collection devices called weirs or effluent **launders**[76].

[76] Launder – Sedimentation tank effluent troughs.

Sludge is removed from the clarifier by gravity in the smaller facilities and by mechanical means in larger facilities. The large facilities may use scraper arms that move the sludge to a collection point or vacuum devices that lift the sludge from the bottom of the clarifier and deposit it into a channel. The sludge is then piped to a pond or settling facility and then to land disposal.

Water passes from the sedimentation basin into the filters. The filter is composed of a box, with an underdrain system, support gravel, and filter media. The underdrain system is designed to collect the water as it passes through the filter and to distribute backwash water evenly through the filter.



Direct filtration - pressure filter system

Most filter systems have a surface wash system or an air scour system to provide agitation of the media prior to backwash. The surface wash system consists of a series of nozzles attached to an arm or grid. The nozzles are pointed down, so they will break up the accumulation of flocculated material on the filter bed surface and thus increase the life of the media by preventing mudballs from forming and sinking into to the bed.

The air scour system is also used to agitate the media through the injection of air up through the entire depth of the bed. Air scour provides a more thorough cleaning than the surface wash because it agitates all of the media aggressively.

Two-stage Filtration

A two-stage filtration system can be housed in open tanks and operate as gravity filters or enclosed in vessels and operated as pressure filters. Two-stage filtration systems consist of two filters operated in series. The first filter contains large-diameter media and functions as either a clarifier or a flocculator, depending on the size of the media and flow rate. In general, media smaller than about 2 mm is required for clarification, and media larger than 4 mm is required for flocculation. Water treatment objectives and the nature of the contaminants determine the most appropriate media configuration. A more thorough discussion regarding two-stage filtration is given earlier in the section covering basic water treatment unit processes.

In a two-stage system, both clarification and, to some extent, flocculation are carried out in the first stage filter. The size of the media, as noted earlier, determines which process is predominantly performed by the first stage filter. The hydraulic loading on the first stage filter is a function of the process that it is to perform. Lower loadings are used if it is to function primarily as a clarifier, and higher loadings are used if it is to function primarily as a flocculator. The second stage filter is designed as a standard dual media or mixed media filter. The function of the second stage, or final filter, is similar to that in a conventional treatment system.

The chemical amendments used in a two-stage system can include either or both metal salts and polymers. In general, cationic polymers are used either in conjunction with metal salts or alone to improve the shear strength of the floc. Metal salts alone produce a very weak floc, which can be broken up by the **hydraulic shear**[77] in these types of treatment units. Anionic polymers can also be used as chemical amendments; however, the amount of chemical that is injected must be minimized in order to reduce clogging of the media in the first stage filter.

[77]Hydraulic Shear – The shear force of water flowing past an object.

The first stage filter must be cleaned periodically during the filtration cycle. The requirement for cleaning can be based on differential pressure across the filter (how much the filter is clogged) or on the turbidity of the effluent. The cleaning process is accomplished by first air scouring the media followed by an up-flow backwash. Because of the large media size, air scour is mandatory. Additionally, the backwash water flow rate per square foot of media area is also substantially higher than the flow rate required for the second stage filter.

Direct Filtration

A direct filtration system is simply a conventional treatment system without the clarifier. Direct filtration plants can also operate with either gravity or pressure filters.

Direct filtration is used for treating high-quality source waters with low levels of turbidity and organic contaminants. The upfront processes such as clarification are simply not required because of the low contaminant loading on the filters. Efficient filter runs can be attained because of the pristine source water and minimal solids loading on the filter. These systems are less complicated to operate because fewer unit processes are involved.

When raw water is pumped or piped from the source to a gravity filter, the head (pressure) is lost as the water exits the filter. Depending on the location of the water treatment plant, it is usually necessary to pump water from the plant to an elevated or pressurized water storage tank. One way to reduce pumping is to enclose the filter in a pressure vessel and thus maintain the head (pressure) of the pump or source. This type of arrangement is called pressure filtration.

Pressure filtration systems have been designed and installed in many communities throughout Alaska. The systems include a minimum of two filters, a static mixer and piping designed to provide flocculation. Hydraulic flocculation is also provided in the head space in the filter vessel above the media.

The preferred chemical amendments for direct filtration are cationic polymers. These coagulants provide a very strong floc that can withstand the hydraulic shear encountered in the filter media. In direct filtration, the filter media must remove all of the floc. Metal salts, such as aluminum sulfate or ferric sulfate, produce a weak floc that will break up in the media and result in high turbidities in the filter effluent within a relatively short period of time after the filter run begins. Cationic polymers, on the other hand, can produce long, efficient filter runs. Polymers are more expensive than metal salts, and the amount that can be injected is limited by the EPA. However, because the water that can be applied to a direct filtration system has lower levels of contaminants, it also has a lower coagulant demand, thus making the use of polymers cost-effective.

Slow Sand Filtration

Both small and large communities use slow sand filters to remove turbidity and microorganisms. They are effective when the color and turbidity of the source are low. Their operational cost is much lower than conventional treatment. However, they require large areas of ground and, in most locations in Alaska, must be enclosed in a heated building. Moreover, slow sand filters are difficult to operate when the raw water quality deteriorates.

A slow sand filter is composed of a filter bed of sand that is 24 to 42 inches deep. This bed is placed over an underdrain system. Water passes through the filter bed, and contaminants are removed from the water by a biological process. The filter bed contains microorganisms that enable the filters to remove bacteria, reduce organic matter, and reduce turbidity. The active biological layer on top of the filter media is referred to as the **Schmutzdecke**[78]. Periodically, the top one or two inches of the media must be removed in order to maintain satisfactory water production.

[78] Schmutzdecke – A thin organic mat that grows on a sand filter.

Diatomaceous Earth Filtration

Diatomaceous earth (DE) filters are not commonly used in Alaska in drinking water systems. They are, however, often used to filter swimming pool water. Diatomaceous earth is a white material made from the skeletal remains of diatoms. The skeletons are microscopic and, in most cases, porous. There are different grades of diatomaceous earth, and the grade is selected based on the filtration requirements.

[79] Septum – Filter media on which diatoms are collected during filtration with a diatomaceous earth filter. Usually made of nylon, plastic, stainless steel, or brass.

The DE is mixed in a water slurry and fed onto a fine screen called a **septum**[79]. This septum is usually made of stainless steel, nylon, or plastic. Coating the septum with diatoms gives the filter the ability to remove very small microscopic material. A slurry of diatoms is fed with the raw water during filtration in a process called body feed. The body feed prevents premature clogging of the septum cake. These diatoms are caught on the septum, which increases the headloss and prevents the cake from clogging too rapidly by the particles being filtered. While the body feed does increase headloss, it is more gradual than if body feed were not used. When the diatoms have built up to a depth of approximately 1/16 of an inch, they are removed by backwashing the filter.

In the past, operating costs, the inability to consistently produce low turbidity water, difficulty in maintaining a proper cake, and cake disposal problems have limited the diatomaceous filter's popularity. However, recent technological improvements have led to a resurgence in the use of this process.

Membrane Filtration

Membrane filtration systems can treat a wide array of contaminants, depending on the process that is selected. The processes defined in the *EPA Membrane Filtration Guidance Manual* include membrane cartridge filtration (MCF), microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO). The capabilities of each process to remove selected contaminants are detailed in the previous discussion on membrane filtration.

Membrane systems are subject to fouling and may require pretreatment for certain troublesome contaminants. For the MCF process, pretreatment may include only a roughing filter to reduce the solids loading on the down stream MCF (bag or cartridge) filter/pathogen barrier. In the more sophisticated systems, an entire conventional treatment system may precede an RO system for reduction of TDS. Other problematic contaminants are detailed in the previous discussion on membranes.

Alternative filtration is the term used by ADEC to describe the use of bag or cartridge filters for the removal of Giardia and Cryptosporidium. The application of alternative filtration is limited to pristine water containing very low levels of turbidity, organics, and algae. In these systems, cartridge or bag filters are made of a synthetic media that is contained in a housing. These systems are normally installed in a series of three or four filters. Each housing contains media successively smaller than the previous media. The filters are arranged in series so that the more expensive Giardia and Cryptosporidium barriers are protected by the less expensive prefilters. The filters are rated at a certain flow rate and maximum differential pressure. The filters are discarded when they become clogged.

All membrane filters, regardless of the type, must be replaced in time as they become fouled beyond the point where output can be recovered through backwashing and chemical cleaning. In general, bag and cartridge filters must be replaced on a monthly basis or even more frequently, depending on raw water quality. Well-maintained MF, UF, NF, and RO membrane filters can last 3-5 years on the average. Replacement of the membranes can be very expensive costing thousands of dollars every few years.

Granular Activated Carbon (GAC) Contactors

Granular activated carbon (GAC) contactors are used as a polishing step in the removal of organic contaminants. They are typically used to reduce DBPs or to control taste and odor. Contactors are usually installed in series in order to obtain the maximum utilization of the activated carbon media.

The type of process used ahead of GAC treatment can have a significant effect on the performance of the GAC and the amount of water that can be effectively treated before the media requires replacement. The use of coagulation and filtration ahead of a GAC adsorption process can serve both to reduce the amount of organic contaminants that must be removed by the GAC and to condition the organic contaminants, allowing greater removal efficiencies by adsorption.

The type of contaminant that must be removed determines the selection of the most appropriate GAC media. Manufacturers are available to help with the selection process. GAC media is typically supplied in bags. The media is then loaded into the contactor vessels, usually by hand.

The use of GAC in Alaska is limited by the high cost of shipping and large volumes of the media that must be supplied. Many communities are remote, and shipping large quantities of materials is expensive. In other areas of the country, the media can be returned to the manufacturer for regeneration, although in Alaska the media must be discarded because it is not cost-effective to return the media for regeneration. However, in some cases, the use of GAC is cost-effective in fill and draw type systems because of the low quantities of water that is used.

Operation of a GAC contactor is based on the amount of water that can be filtered before contaminants begin to break through the filter. The replacement of the media is governed by the amount of contaminant that can be tolerated in the filtered water. This target is typically set as a percentage of the contaminant entering the contactor. Pilot testing must be conducted to determine the performance of the GAC in removing the target contaminants as well as the GAC usage rate with respect to the volume of water that can be treated before media replacement is required.

Groundwater Treatment Systems

Iron, manganese, arsenic, carbon dioxide, and hydrogen sulfide are contaminants that commonly occur in groundwater and require some level of treatment for removal. Iron and manganese are found as naturally occurring **soluble**[80] minerals in the soil. By means not totally understood, bacteria and other natural conditions convert the insoluble iron and manganese into soluble forms and release them into the water. The primary problem with iron and manganese is that they stain fixtures and clothing. While they do not directly cause odor and taste problems, when there is an excess of soluble iron in the water, bacteria, referred to as "iron-reducing bacteria," will utilize the soluble iron and produce by-products that give the water a metallic taste.

Carbon dioxide and hydrogen sulfide are gases that can cause treatment problems or odor production respectively. Carbon dioxide gas tends to reduce pH and can cause gas binding in gravity filters. Hydrogen sulfide gas produces a strong rotten egg odor that can be detected at levels as low as 0.1 μg/L.

[80] Soluble – A substance that is easily dissolved.

[81] Sequestering Agent – A chemical compound or polymer that chemically ties up (sequesters) other compounds or ions so that they cannot be involved in chemical reactions.

[82] Aeration – A treatment process bringing air and water into close contact in order to remove or modify constituents in the water.

The Safe Drinking Water Act lists iron and manganese as secondary contaminants. The MCL is 0.3 mg/L for iron and 0.05 mg/L for manganese. In 2006, the US EPA lowered the MCL for arsenic from 0.05 mg/L to 0.01 mg/L. Carbon dioxide and hydrogen sulfide gas are not regulated contaminants; however, they can affect pH or odor, which are considered by ADEC to be secondary contaminants.

Applied Water Quality

The level of iron and manganese can have a major effect on the type of treatment process that is selected. In general, similar options exist for groundwater treatment also used for surface water treatment. The conventional treatment process is used when high concentrations of iron and manganese must be removed prior to filtration. The direct filtration process is appropriate when lower concentrations of these contaminants are present in the source water. As a rule of thumb, when iron concentrations exceed about 10 mg/L, conventional treatment should be considered.

When the water contains very low concentrations of iron, the addition of a **sequestering agent**[81], such as hexametaphosphate, can be successful in keeping the iron in solution. Sequestering agents do not remove the iron, but bind it chemically so that it is not easily oxidized.

Air can also be used to oxidize iron and manganese. The air is either pumped into the water, or the water is allowed to fall over an **aeration**[82] device. The air oxidizes the iron and manganese, which are then removed by a filter. Lime is often added to raise the pH in order to speed the oxidation process.

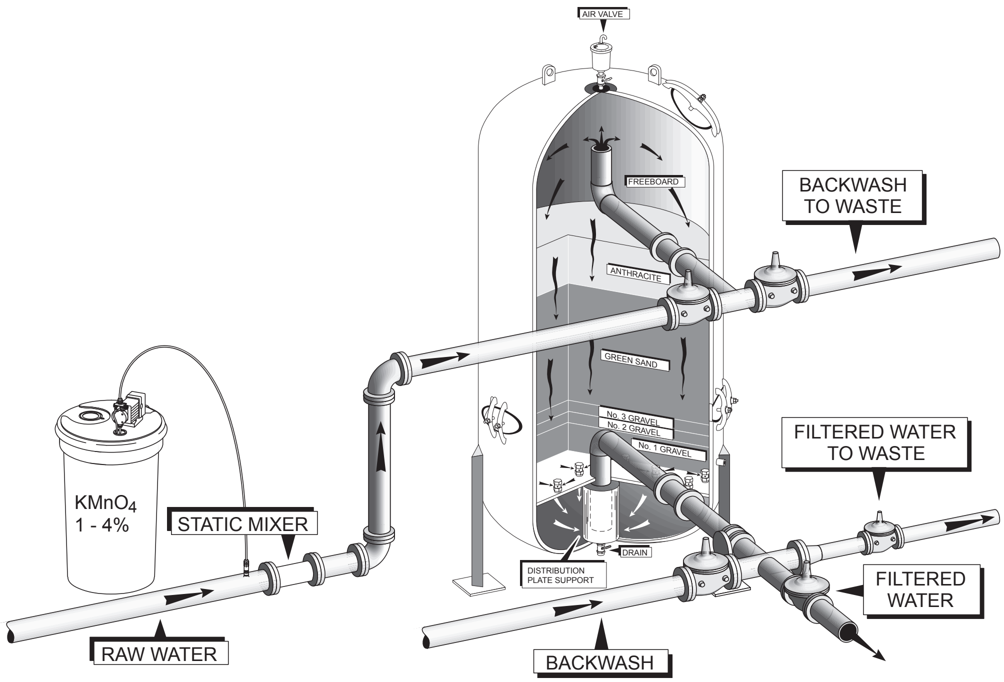
Treatment for arsenic has been previously discussed. The most common and successful options include coprecipitation with natural iron, iron hydroxide adsorption using ferric sulfate or ferric chloride, and fixed bed adsorption using an iron-based media. Carbon dioxide can be particularly troublesome in the gravity filtration process. When conventional treatment is being considered, the presence of carbon dioxide must be carefully evaluated in the equipment selection process. Gas binding can occur in gravity filters, resulting in very short and inefficient filter runs. The use of pressure filtration after clarification can be employed in conventional treatment to overcome this problem.

[83] Zeolite – Natural or man-made minerals that collect from a solution certain ions (sodium or $KMnO_4$) and either exchange these ions, in the case of water softening, or use the ions to oxidize a substance, as in the case of iron or manganese removal.

[84] Greensand – Naturally occurring silicates of sodium and aluminum that respond as a natural ion exchange medium. Commonly used as the primary filter medium in a potassium permanganate, greensand, iron, and manganese removal process.

Conventional Greensand Treatment

The conventional greensand treatment system that is used in groundwater treatment is designed very similar to a surface water treatment system. The major difference is the use of a natural **zeolite**[83] media called manganese **greensand**[84] in place of the silica sand in the filter.



Greensand filter system

When conventional greensand treatment is used, the continuous regeneration process is employed. In this process, an oxidant is continuously fed into the raw water as it enters the plant. Chemical amendments for conventional greensand treatment include chlorine or potassium permanganate for oxidation of iron and manganese to form precipitates. If organically complexed iron or manganese is present, the use of a cationic polymer or a metal salt may be required. Lastly, an anionic polymer is usually added to improve the settling characteristics of the iron floc and thus improve the efficiency of the sedimentation process.

A conventional greensand treatment system is operated in much the same way as a conventional surface water treatment system. The accumulated solids (iron and manganese) in the sedimentation basin must be periodically removed, and the filter must be backwashed to flush out accumulated contaminants. In conventional greensand treatment, the length of the filter run is usually determined by differential pressure (clogging of the media with precipitate).

Arsenic removal through the conventional greensand process is accomplished by coprecipitation. Coprecipitation occurs with iron that is naturally available or with iron that is supplemented through the addition of ferric sulfate or ferric chloride. The ratio of iron to arsenic must be at least 50:1 to provide enough sites (precipitated iron) for the arsenic to adsorb. Lastly, the arsenic must be oxidized completely before it can be adsorbed onto the surface of the iron floc.

Direct Greensand Filtration

The most common method of iron and manganese removal in Alaska is a process called the continuous regeneration manganese greensand process. This process consists of a filter filled with greensand and is typically used when concentrations of iron are less than about 10 mg/L. The filter can be configured as a pressure filter or a gravity filter. Pressure filters are the most common.

The direct filtration greensand process can also be operated in an intermittent regeneration mode. In the intermittent regeneration mode, the greensand is soaked (regenerated) using either chlorine or potassium permanganate after the filter is backwashed. The filter is then started, and contaminants are adsorbed onto the surface of the media. This process is used to treat relatively low levels of iron below about 2 mg/L.

With continuous regeneration, oxidation is carried out using either chlorine or potassium permanganate. The chlorine or potassium permanganate oxidizes the iron and manganese, turning it from a soluble to an insoluble precipitate that is filtered out by the greensand media. Besides filtering the precipitate, when using potassium permanganate, any excess potassium permanganate is adsorbed onto the greensand and acts to regenerate the media. This allows the greensand to act like a “sponge,” soaking up any excess potassium permanganate and providing oxidation in times when the dosage of potassium permanganate is insufficient to oxidize all of the iron and manganese. In this process, issues involving organic complexes of iron and manganese are addressed through the addition of a cationic polymer. However, when chlorine is used as an oxidant, a free chlorine residual must be maintained in the influent to the filter. The use of chlorine as an oxidant should be carefully considered due to the potential to form DBPs. In addition, the slower reaction times of chlorine, when compared to potassium permanganate, can result in inadequate removals of the contaminants.

In the continuous regeneration process, the filter is backwashed after a differential pressure of 6 psi is reached or when levels of iron or manganese begin to increase in the filter effluent. Differential pressures greater than 6 psi should be avoided due to the potential to fracture the surface coating of manganese dioxide on the individual media grains. Other media are available such as GreensandPlus™ or pyrolusite that can be used to withstand much higher differential pressures.

Air scour should be used for auxiliary agitation of the greensand media prior to backwash. The use of air scour enhances the removal of contaminants as well as improves the length of filter runs and the useful life of the media. Surface wash is another method of providing auxiliary agitation of the media. However, it should be noted that surface wash only agitates the surface of the media, whereas air scour agitates the entire bed throughout its depth.

In direct filtration, arsenic removal can be accomplished using coprecipitation as well. This process is limited to lower concentrations of arsenic because of the lack of a sedimentation process prior to filtration. Large amounts of precipitated materials will clog a filter quickly. The ability of the floc to withstand the hydraulic shear is also an important parameter because precipitated iron can breakup in the filter and pass through carrying the attached arsenic with it. As a result, ferric chloride is used if supplemental iron is needed for arsenic adsorption because it can form a strong filterable floc.

Fixed Bed Adsorption

In a fixed bed adsorption process, the media is used to remove the contaminants. Adsorbents include hydrous metal oxides such as activated alumina, iron, or manganese. The removal of a number of contaminants is possible with these processes. However, the following discussion will focus on the removal of the more common contaminants such as iron, manganese, and arsenic.

Iron and Manganese Removal

Greensand is coated with manganese dioxide. Greensand can be used as a fixed bed adsorption media when operated in an intermittent regeneration mode. The intermittent regeneration greensand process is limited to water containing relatively low levels of iron and when manganese removal is the primary objective. In this process, the filter is backwashed to remove accumulated contaminants and then soaked in 100 mg/L of chlorine or 60 grams of potassium permanganate per cubic foot of media for a prescribed period of time. The filter is then rinsed and placed back into operation. The length of the filter run is based on a set volume of water, which is determined based on the concentrations of contaminants present in the source water.

Arsenic Removal

Iron oxide media can be used to remove arsenic from water in a fixed bed adsorption mode. Unlike greensand, though, the media is typically not regenerated. The spent media is simply discarded, and fresh media is loaded into the vessel. Other media-like activated alumina can be used as well; however, the iron-based medias have removal capacities greater than activated alumina and also have a wider range of optimum pH levels. The adsorptive capacity of the iron-based media is affected by pH, although it is not as sensitive to pH as activated alumina. The optimum pH level for activated alumina is 5.5, compared to iron-based media that has an optimum pH range of 5.5 to 8.5. Other required water quality parameters are detailed by the manufacturers of the media. The amount of water that can be treated before the media is replaced depends on the concentration of contaminants in the source water and the amount of other competing contaminants that are present. Estimates of the volume of water that can be treated per bed change out may be provided by the media supplier. Actual performance should be determined in the field through pilot testing before a commitment is made to select this process for full-scale implementation.

Specialized Water Treatment Processes

Specialized treatment systems include those that can apply to either groundwater or surface water. They address areas such as hardness, taste and odor, fluoridation, corrosion control, and processes specific to cold regions such as heating the raw water to improve treatment.

Hardness Treatment

Hardness is most often associated with groundwater supplies. However, it can also be a problem in some surface water sources. Hardness results from calcium (Ca) and magnesium (Mg) ions. The amount of hardness in water is expressed as an equivalent amount of **calcium carbonate**[85] ($CaCO_3$). This means that regardless of the amount of the various components that make up hardness, they can be related to a specific amount of calcium carbonate.

The objection of customers to hardness is often dependent on the amount of hardness that they are used to. A person who routinely uses water with a hardness of 20 mg/L might think that a hardness of 100 mg/L is too much. On the other hand, a person who uses water with a hardness of 200 mg/L might think that 100 mg/L is very soft.

[85] Calcium Carbonate – The principle compound of hardness. The term used as an equivalent for hardness and alkalinity. Symbolically represented as $CaCO_3$.

The following table provides common classifications of hardness:

Classification	mg/L CaCO3
Soft	0 - 60
Moderately Hard	61-120
Hard	120-180
Very Hard	Over 180

[86] Ion Exchange – A reversible chemical reaction between an insoluble solid and a solution during which ions may be interchanged.

There are two common methods used to reduce hardness: the lime-soda ash process and **ion exchange**[86]. Because the lime-soda process is applicable only to larger facilities, it will not be discussed here.

Ion exchange is accomplished by charging a resin with sodium ions and allowing the resin to exchange the sodium ions for calcium and/or magnesium ions. Common resins include synthetic zeolite and polystyrene resins. These resins are placed in a pressure vessel. A salt brine (NaCl) is flushed through the resins. The sodium ions in the salt brine attach to the resin. The resin is then said to be charged. Water is passed through the charged resin; and the resin exchanges the sodium ions attached to the resin for calcium and magnesium ions, thus removing them from the water. After a specified period of time, the resin is regenerated using a brine solution, and the calcium and magnesium ions are flushed out of the system.
The ion exchange process of **softening**[87] water removes all or nearly all of the hardness and adds sodium ions to the water. One of the results is the water may become more corrosive than before. Another concern is that addition of sodium ions to the water may increase the health risk of those with high blood pressure.

[87] Softening – The process of control or destruction of hardness.

The ion exchange process is used in small systems where lime soda ash systems are not practical. This process is also used to produce soft water for making calcium hypochlorite solutions and for package saturators.

Review

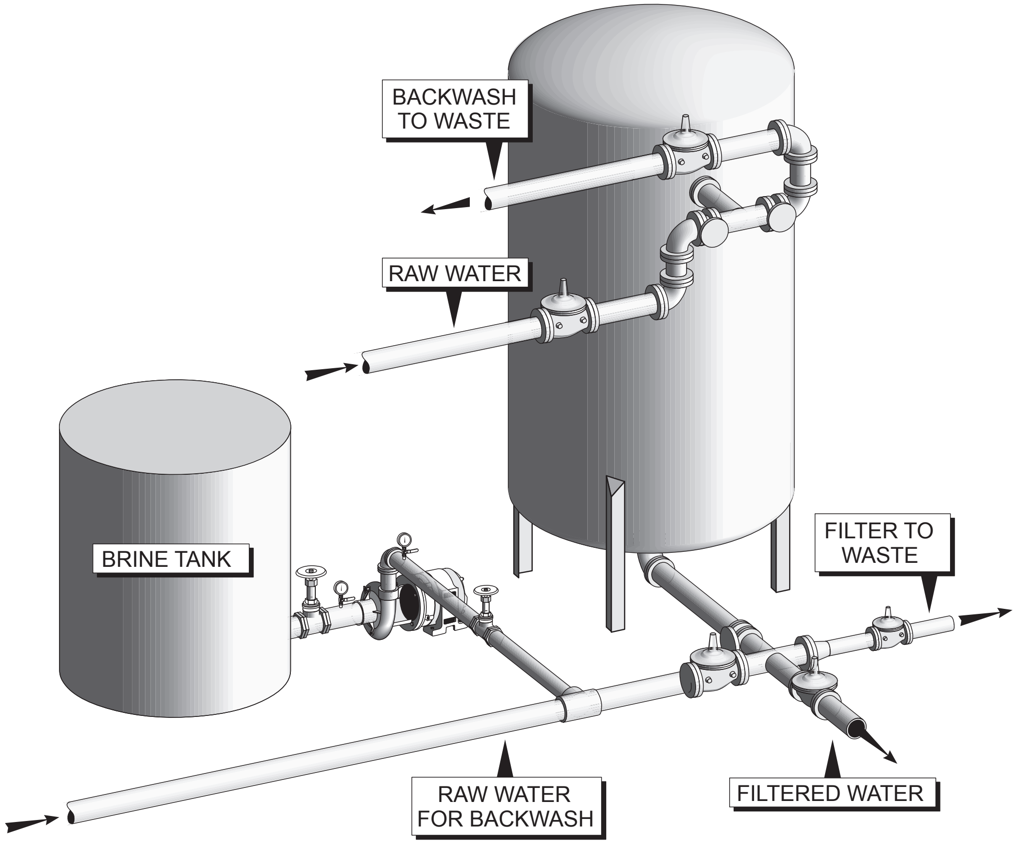
9. What are the four basic unit processes of conventional treatment?

10. When treating high-quality source waters with low levels of turbidity and organic contaminants a ______________ _____________ system could be used.

11. What is the active bilogical layer on top of the filter media is referred to as the ______.

12. What does hardness result from?

13. Treatement for taste and odor issues is commonly solved through the use of _________ ______________ _______________.



Ion exchange system

Taste and Odor Treatment

Taste and odor can be caused by a wide variety of constituents. Among them are biological slimes on the inside of pipes and well screens, algae, diatoms, chemicals, and minerals in the water. Taste and odor do not directly represent a health hazard, but they can cause the customer to seek water that tastes and smells good, but may not be safe to drink. Therefore, taste and odor has a secondary MCL of 3 TON (Threshold of Odor Number).

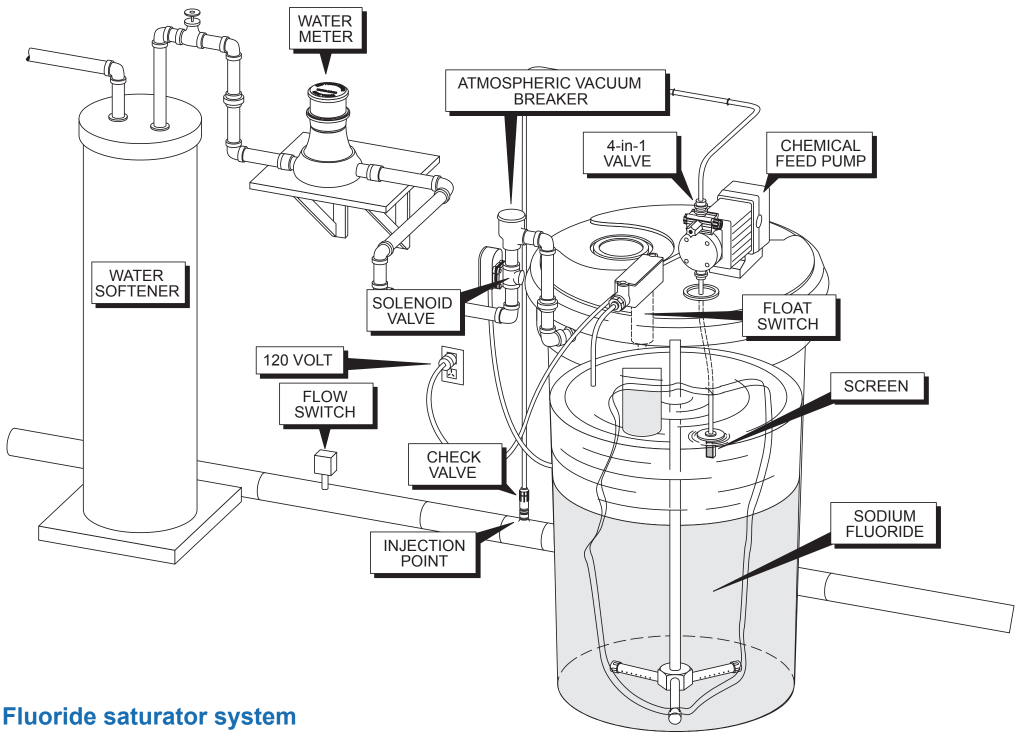
One of the common methods used to remove taste and odor is to oxidize the materials that cause the problem. Oxidants such as chlorine, ozone, or potassium permanganate are commonly used. The main problem with using chlorine for this task is that disinfection by-products can be formed if organic contaminants are present.

Another common treatment method is to use an adsorption process such as granular activated carbon (GAC). The use of these types of systems is discussed in the section on Organic Adsorption and Granular Activated Carbon Contactors. Pilot testing should be conducted before this method of treatment is selected.

Fluoridation

In certain populations in the Midwestern portion of the United States, it was discovered that those that drank water with natural levels of fluoride above 1 mg/L had drastically reduced occurrence of tooth decay from what was normal. As a result of this research, many communities have decided to artificially control the fluoride level in their drinking water by adding fluoride. However, increased levels of fluoride can cause a disease called fluorosis. The most common symptom is spotting of the teeth (brown spots). Therefore, a secondary limit of 2.0 mg/L has been established to prevent this problem from occurring. A primary MCL of 4.0 mg/L has also be established for fluoride. Exceeding this level can cause skeletal fluorosis, which is a deterioration of the bones. Fluoride is the only chemical that has both a secondary MCL (SMCL) and a primary MCL.

Fluoride is added to drinking water systems to reduce tooth decay. The process used in most of Alaska is to mix a four percent solution of sodium fluoride and feed it into the water system. The amount that is fed depends on the air temperature and on the natural fluoride levels in the raw water. The goal is to feed enough fluoride to maintain a residual of 0.8 to 1.2 mg/L.



Fluoride saturator system

There are numerous methods available to feed fluoride into a system. In rural Alaska, the most common fluoride feed system is the upflow saturator. The system uses a 50-gallon plastic tank. Sodium fluoride is placed in the tank, and the tank is filled with clean water. The solution above the fluoride crystals will become saturated with sodium fluoride at four percent (40,000 mg/L). The fluoride solution is then injected into the water system using a chemical feed pump.

The water level in the tank is maintained by a float and solenoid valve control system. The amount of water used is determined by a water meter on the water supply. Backsiphonage into the water system is prevented by a vacuum breaker on the water supply line to the saturator. A screen, float, and foot valve are placed on the suction line to the pump. To prevent water from flooding the feed tank, a check valve is installed on the discharge line where the pump discharge tubing connects to the water system.

Safety Equipment

To prevent the accidental overdose of fluoride, special safety features are built into the fluoride system:

- Wiring the fluoride feeder so that it can obtain power only when the system pump is operating.

- Placing a special plug on the fluoride feed pump electrical cord so that it cannot be plugged into any outlet other than the one that is controlled by the pumping system or flow switch.
- Placing a flow indicator in the system flow line and wiring this flow indicator so that flow must pass through the line before the fluoride feed pump can be energized.
- Installing a special valve, called a four-function valve, on the feed pump to prevent a sudden drop in system pressure from siphoning the contents of the saturator into the system.

Corrosion Control

The causes of corrosion are very complicated and not well understood. Corrosion in potable water systems can cause health-related problems, piping failures, staining and taste issues, and operational problems. Many natural waters can be corrosive. Ironically, very soft, clean water with high dissolved oxygen is desirable as a drinking water. However, this same water is said to be very aggressive. That is, minerals can be easily dissolved into the water. Two contaminants of special concern are lead and copper. Both of these are found in the piping in homes. Aggressive water can cause the levels of lead and copper to increase, representing a potential health hazard. In addition, corrosive water deteriorates the metal components of a water system and thus reduces its useful life. Surface water, such as that found in Southeast and South central Alaska, is known to be **aggressive**[88] and contributes to the blue copper stains often found on white fixtures. This aggressiveness or corrosivity of the water is the basis for the Lead and Copper rule.

[88] Aggressive – Aggressive waters are those that are high in dissolved oxygen, are neutral to low pH, and have low (below 80 mg/L) alkalinity. These conditions allow water to easily dissolve metals such as iron, copper, and lead.

Iron bacteria, which are found in most waters, can attach themselves to the walls of pipe and fittings. They form colonies that seal over in little bumps called incrustations. These colonies produce hydrogen sulfide gas that dissolves into the water and forms sulfuric acid. The acid attacks the pipe and fittings causing pits or pinholes to form.

Corrosive waters can cause the cement lining of iron pipe to dissolve into the water, leaving the pipe wall rough and increasing headloss. They can also cause asbestos to leach into the water from asbestos cement (AC) pipe. Aggressive and corrosive waters increase the cost to the customer both directly and indirectly. The customers' water heaters and faucets deteriorate faster than normal. Ultimately, the cost resulting from the deterioration of the water distribution system is shared by all.

The most common means of determining whether water is corrosive is through the use of a corrosivity index such as the Langlier Saturation Index (LSI). The LSI is a means of evaluating water quality data such as pH, total dissolved solids, temperature, hardness, and alkalinity to determine whether the water is corrosive. If the LSI is greater than 0, the water is supersaturated and tends to deposit a calcium carbonate scale layer; if the LSI is equal to 0, the water is considered to be in equilibrium and will not precipitate nor dissolve calcium carbonate; and if the LSI is less than 0, the water is undersaturated and tends to dissolve calcium carbonate. An LSI of less than 0 indicates that the water may be corrosive and that corrective action should be considered.

One method used to reduce the corrosive nature of water is to add lime or soda ash to raise the pH to 8.5. In most cases, corrosion control chemicals are fed after other treatment is completed. Most waters are not corrosive once the pH is raised to above 8.5. However, this high pH reduces the disinfection capability of chlorine.

A second method that is available to address corrosion is the use of zinc orthophosphate or polyphosphate. These chemicals coat the inside of the pipelines and protect the pipe materials from the corrosive water. The use of these chemicals involves a balancing act by the operator to not add too much or too little. If too little is added, the corrosion will continue, and if too much is added, the piping can become clogged.

Water Heating Systems

Water systems in the arctic heat their water directly or indirectly to prevent it from freezing and to enhance treatment. Heat may be applied to the water at one or more points in the system. Typical heat addition points include the following:

- Raw water prior to the treatment plant
- Directly after treatment
- In the distribution system loop as water is circulated through the distribution system
- To a heat line that is placed next to a water line in a utilidor

From a treatment perspective, heating the raw water can speed the rate of oxidation or other chemical reactions and can thus ensure that treatment is completed thoroughly within the time that is available prior to the next unit process. The physical aspects of treatment are also impacted by water temperature because of the changes in the density of the water. A change in density affects mixing energy, settling characteristics, and filtration characteristics. Thus treatment processes can be optimized by controlling water temperature. In addition, the rate of disinfection is also impacted by water temperature. In general, increasing water temperature reduces the time required to disinfect the water.

Testing and Reporting

At a properly operated water treatment plant, the following minimum records and data need to be collected:

Water Filtration Systems

1. Turbidity – raw and finished water
2. pH – raw and finished water
3. Alkalinity – raw and finished water
4. Temperature – raw and finished water
5. Amount of chemicals used
6. Chemical dosage
7. Gallons of water produced
8. Length of filter runs
9. Quantity of backwash used
10. Power consumption
11. Hours required for operation and maintenance
12. Cost per 1000 gallons produced

Water Disinfection Systems

1. Disinfectant residual
2. Quantity of disinfectant used
3. Disinfectant dosage
4. Check pump and appurtenances

Water Fluoridation Systems

1. Fluoride residual
2. Quantity of fluoride used
3. Fluoride dosage
4. Check fluoride tank, fill valve, check valve, and anti-siphon protection
5. Check pump and appurtenances

Introduction to Water Treatment Quiz

Water Heating Systems

1. Boiler temperature
2. Circulation pump pressure
3. Circulation loop temperature
4. Water temperatures

Additional information on testing your drinking water can be found in Chapter 1.

1. Water that is safe to drink is called ________________ water.
   A. Potable
   B. Palatable
   C. Good
   D. Clear

2. The type of organisms that can cause disease are said to be ________________ microorganisms.
   A. Bad
   B. Pathogenic
   C. Undesirable
   D. Sick

3. The basic goal for water treatment is to ________________.
   A. Protect public health
   B. Make it clear
   C. Make it taste good
   D. Get stuff out

4. Four types of aesthetic contaminants in water include the following:
   A. Odor, turbidity, color, hydrogen sulfide gas
   B. Pathogens, microorganisms, arsenic, disinfection by-products

5. What does mg/L stand for?
   A. Microorganisms/Liter
   B. Milligrams/Loser
   C. Milligrams/Liter
   D. None of the above

6. Disinfection by-products are a product of:
   A. Filtration
   B. Disinfection
   C. Sedimentation
   D. Adsorption

7. Acute contaminants are those that can cause sickness after:
   A. Prolonged exposure
   B. Low levels or low exposure

8. Chronic contaminants are those that can cause sickness after:
   A. Prolonged exposure
   B. Low levels or low exposure

9. TTHMs and HAA5s can affect:
   A. Health
   B. Aesthetics
   C. Color
   D. Odor

10. Oxidation, coagulation, and disinfection are ________________ processes.
   A. Physical
   B. Chemical
   C. Biological
   D. Mechanical

11. Flocculation, sedimentation, filtration, and adsorption are ________________ processes.
   A. Physical
   B. Chemical
   C. Biological
   D. Mechanical

12. A precipitate can be formed after which one of the following processes:
   A. Oxidation
   B. Flocculation
   C. Filtration
   D. Adsorption

13. Giardia and cryptosporidium are a type of:
    A. Mineral
    B. Organism
    C. Color
    D. Bird

14. The chemical oxidation process in water treatment is typically used to aid in the removal of :
    A. Organic contaminants
    B. Inorganic contaminants
    C. Large contaminants
    D. None of the above

15. The process of decreasing the stability of colloids in water is called:
    A. Flocculation
    B. Coagulation
    C. Sedimentation
    D. Clarification

16. Slowly agitating coagulated materials is the process of:
    A. Flocculation
    B. Coagulation
    C. Sedimentation
    D. Filtration

17. The sedimentation portion of water treatment is also called a(n):
    A. Clarifier
    B. Filter
    C. Adsorber
    D. Water treater

18. Particles that are less than 1 μm in size and will not settle easily and are called:
    A. Light particles
    B. Colloidal particles
    C. Colored particles
    D. Flat particles

19. One micrometer is also equal to:
    A. 0.1 mm
    B. 0.0001 mm
    C. 0.001 mm
    D. 1 m

20. Particles less than 0.45 µm in size are considered to be:
    A. Dissolved
    B. Really little
    C. Colored particles
    D. Flat particles

21. Turbidity is measured as:
    A. Mg/L
    B. mL
    C. gpm
    D. NTU

22. $Al_2(SO_4)_3 \cdot 18H_20$ is the chemical formula for:
    A. Alum
    B. Iron
    C. Manganese
    D. Lead

23. A(n) _________________ polymer is commonly used as a coagulant.
    A. Anionic
    B. Cationic
    C. Nonionic
    D. Ionic

24. A(n) _________________ polymer is used to enhance flocculation.
    A. Anionic
    B. Cationic
    C. Nonionic
    D. Ionic

25. The concentration of a chemical added to the water is measured in:
    A. mL
    B. mg
    C. mg/L
    D. Liters

26. The quantity of chlorine remaining after primary disinfection is called a _________________ residual.
    A. Chlorine
    B. Permaganate
    C. Hot
    D. Cold

27. Primary disinfectants are used to ________________ microorganisms.
    A. Hurt
    B. Inactivate
    C. Burn up
    D. Evaporate
28. Secondary disinfectants are used to provide a ________________ in the distribution system.
    A. Color
    B. Chemical
    C. Smell
    D. Residual

29. What type of polymer is used to improve the efficiency of the sedimentation process?
    A. Cationic
    B. Nonionic
    C. Anionic
    D. All of the above

30. When operating a filter, one of the operational concerns is the difference between the pressure or head on top of the filter and the pressure or head at the bottom of the filter. This difference is called ________________ pressure.
    A. Different
    B. Differential
    C. High
    D. Low

31. List the basic processes, in the proper order, for a conventional treatment plant.
    A. Coagulation, flocculation, sedimentation, filtration
    B. Flocculation, coagulation, sedimentation, filtration
    C. Filtration, coagulation, flocculation, sedimentation
    D. Coagulation, sedimentation, flocculation, filtration

32. The four most common oxidants include:
    A. Chlorine, potassium permanganate, ozone, chlorine dioxide
    B. Chlorides, soap, air, coagulants
    C. Air, chemicals, sodium, chloride
    D. Flocculants, coagulants, sediments, granules

33. When comparing conventional treatment with direct filtration, what process unit is in the conventional treatment plant that is not in the direct filtration plant?
    A. Filter
    B. Clarifier
    C. Mixer
    D. Detention

34. In a typical water treatment plant, alum would be added into the ________________ mixer.
    A. Speed
    B. Large
    C. Slow
    D. Flash

35. The process of cleaning a filter by pumping water up through the filter media is called ________________ the filter.
    A. Backwashing
    B. Rewashing
    C. Purging
    D. Lifting

36. Bag and cartridge filters are used to remove which two pathogenic microorganisms?
    A. Viruses and giardia
    B. Giardia and cryptosporidium
    C. Viruses and bacteria
    D. None of the above

37. List the five types of membrane filtration processes commonly used in water treatment.
    A. MCF, MF, UF, NF, and RO
    B. MNF, MOF, UOF, NOF, and ROO
    C. CFM, FM, FU, FN, and OR
    D. None of the above

38. What is a method of reducing hardness?
    A. Softening
    B. Hardening
    C. Lightning
    D. Flashing

39. Adsorption of a substance involves its accumulation onto the surface of a:
    A. Solid
    B. Rock
    C. Pellet
    D. Snow ball

40. The solid that adsorbs a contaminant is called the:
    A. Adsorbent
    B. Adsorbate
    C. Sorbet
    D. Rock

41. The adsorption process is used to remove:
   A. Organics or inorganics
   B. Bugs or salts
   C. Organisms or dirt
   D. Color or particles

42. Describe two primary methods used to control taste and odor?
   A. Oxidation and adsorption
   B. Filtration and sedimentation
   C. Mixing and coagulation
   D. Sedimentation and clarification

43. In order to determine the effectiveness of disinfection, it is desirable to maintain a disinfectant residual of at least ________________ mg/L entering the distribution system.
   A. 0.10
   B. 0.5
   C. 0.3
   D. 0.2

44. A ________________ residual of chlorine is required throughout the system.
   A. Large
   B. High
   C. Trace
   D. Hot

45. The test used to determine the effectiveness of disinfection is called the:
   A. Coliform bacteria test
   B. Color test
   C. Turbidity test
   D. Particle test

46. Name two methods commonly used to disinfect drinking water other than chlorination.
   A. Ozone and ultraviolet light
   B. Soap and agitation
   C. Filtration and adsorption
   D. Salt and vinegar

47. Name the two types of hypochlorites used to disinfect water.
   A. Chloride and monochloride
   B. Sodium and calcium
   C. Ozone and hydroxide
   D. Arsenic and manganese

48. Free chlorine can only be obtained after ________________ point chlorination has been achieved.
    A. Breakpoint
    B. Fastpoint
    C. Softpoint
    D. Onpoint

49. The meaning of the "C" and the "T" in the term CT stands for:
    A. Concentration and time
    B. Color and turbidity
    C. Calcium and tortellini
    D. Chlorine and turbidity

50. Chloramine is most affective as a ________________ disinfectant.
    A. Primary
    B. Secondary
    C. Third
    D. First

51. List the five types of surface water filtration systems.
    A. Bag filtration, cartridge filtration, fine filtration, coarse filtration, media filtration
    B. Conventional treatment, direct filtration, slow sand filtration, diatomaceous earth filtration, membrane filtration
    C. Turbidity filtration, color filtration, bag filtration, fine filtration, media filtration
    D. None of the above

52. GAC contactors are used to reduce the amount of ________________ contaminants in water.
    A. Inorganic
    B. Turbidity
    C. Particle
    D. Organic

53. Greensand can be operated in either ________________ regeneration or ________________ regeneration modes.
    A. Continuous or intermittent
    B. Fast or slow
    C. Hot or cold
    D. Constant or unusual

54. The two most common types of chlorine disinfection by-products include:
    A. TTHM and HAA5
    B. TTHA of HMM5
    C. Turbidity and color
    D. Chloride and fluoride

55. What is the purpose of adding fluoride to drinking water?
    A. Increase tooth decay
    B. Reduce tooth decay
    C. Make teeth white
    D. Government conspiracy

Introduction to Water Distribution Systems

Chapter 5

What Is In This Chapter?

1. Functions of a distribution system
2. Types of distribution systems
3. Common distribution piping materials
4. Common distribution system fittings
5. Major components of piped systems
6. Distribution system pipe installation
7. Common household service equipment and materials
8. Common reservoirs and their components
9. Typical utilidor components and operation
10. Basic operation and maintenance requirements of a distribution system
11. Common methods to control cross connections

Key Words

- "C" Factor
- Air Gap
- Altitude Valve
- Appurtenances
- AWWA
- Backflow
- Backsiphonage
- Butterfly Valve
- Compression Hydrant
- Cross Connection
- Double Check
- HDPE
- Hydrant Bury
- Invert
- Mechanical Joint
- MVO
- NSF
- Peak Demand
- PVC
- Reservoir
- RPZ
- Seal Water
- Slide Gate Hydrant
- Thrust Block
- Toggle Hydrant
- Vacuum Breaker
- Water Hammer

Introduction

Lesson Content

This lesson on the introduction to distribution systems is focused on the description of the various components of a distribution system, their function, and their purpose. Some details on the proper operation and maintenance of components in a distribution system are covered here, but you may want to consult additional manuals for a more detailed discussion.

Cost Factors

In most communities, the water distribution system is their largest single capital investment. To preserve this investment, careful attention should be paid to the proper operation and maintenance of the system. This starts with a good understanding of the components and their function.

Primary Function and Design

The basic function of a water distribution system is to transport the water from the treatment facility to the customer. In addition, distribution systems may also provide storage, as well as provide flow and pressure adequate for fire protection. Typically, the size of water mains, pump station capacity, and storage reservoir volume is determined by fire suppression needs. The volume of water necessary to fight fires is much greater than domestic and commercial water demand in most communities.

System Criteria

To provide this basic function in a proper manner, criteria have been established for distribution systems. Distribution systems should provide adequate and reliable water to the customer. Adequate means providing all the water the customer needs at a pressure not less than 20 psi. Adequate also means that the water provided meets the customer's needs for quality. Reliable means that customers can expect to obtain all the water they need, anytime they need it. In other words, they can expect that there will be water at the tap. As part of being adequate and reliable, the system must be operated in a way so that the quality of the water does not deteriorate between the treatment facility and the customer.

In many communities, the customer expects that adequate reserves are present for fire prevention. If there are fire hydrants on the system, the customer has every right to make this assumption, and the purveyor has the responsibility for meeting this expectation by providing adequate flow, pressure, and storage volume.

Types of Systems

In many villages in Alaska and Canada, watering points substitute for a normal distribution system. These are systems with one or more specific points in the village where the customer can obtain water. This is the modern version of the community well. In some villages, there is a combination circulating system and watering points. The watering points are used by those customers who have homes away from the piped system.

Another type of system found in Alaska and Canada is the haul system. With the haul system, water is delivered using a truck and tank or a snow machine and tank. The water is delivered on order in much the same manner as fuel oil is delivered.

The most traditional water distribution system is the piped system. There are two types of piped systems: the conventional system and the completely looped circulating system. The circulating system is common in the arctic.

Review

1. List the three primary functions of a water distribution system.
2. What are the two criteria for a water distribution system?
3. The pressure in a water distribution system should never drop below ___________ psi.

Watering Point System

Description

A watering point is a location in a village where customers can access the water supply. In some villages, the only source of water for customers is from the watering point. There may be more than one watering point in the village, depending on its population.

Treatment

The treatment process for a watering point system is the same as for a piped system.

Equipment

A storage reservoir may or may not be necessary for a watering point system, depending on source production. The reservoir may be close to or inside the treatment plant. Standard reservoir designs are used in these systems. The reservoirs may be steel, concrete, or wooden gravity tanks or steel hydropneumatic systems.

When the watering point is near or adjacent to the treatment plant, the piping material used is the same as would be used in the treatment plant; copper, galvanized steel, **PVC**[1], and **HDPE**[2] are common. When the watering point is away from the treatment plant, the piping material is the standard material used in piped distribution systems for that particular climate.

There are as many methods of obtaining water from the watering point as there are watering points. The most common of these techniques is to use a flexible hose and automatic hose reel. The hose must consist of **NSF**[3]-approved material, not a garden hose. In cold climates, reinforced, arctic-grade, heat-traced hose with a PVC liner may be provided. A means of **backflow**[4] prevention must be provided to protect the public system from potential contamination.

In some instances, the watering point may contain a coin, key, or coupon-operated dispensing system and a meter. Each coupon will allow a set volume of water to be delivered. The coupon system allows the village to obtain a fair payment for the cost of treating the water, as well as operating and maintaining the watering point.

[1] PVC – Polyvinyl Chloride. A plastic pipe made by forcing heated plastic through a die.

[2] HDPE – High-density polyethylene.

[3] NSF – National Sanitation Foundation.

[4] Backflow – A reverse flow condition, created by a difference in water pressures, which causes nonpotable water to flow into a potable water system.

Haul System

Description

A haul delivery system may be supplemented or used in conjunction with a standard piped system, such as in Fairbanks and Barrow, or may be the only means of water being delivered to the customer.

Treatment

The treatment process for a haul system is the same as for a piped system or watering point.

Equipment

The most common haul systems use a high-quality tank mounted on a truck or snow machine. The water in the tank is prevented from freezing by using the heat from the engine exhaust system.

The methods used to get water from the truck to the customer's holding tank is typically 1¼-inch or larger NSF-approved flexible pipe. In cold climates, a reinforced arctic-grade, heat-traced hose with a PVC liner may be used. Sometimes a dispensing pipe is elevated so that haul trucks can park beneath the water pipe. A means of backflow prevention must be provided to protect the public system from potential contamination.

The delivery tank should be cleaned and disinfected with a chlorine solution similar to the disinfection process used for a reservoir. Hauling tanks should not be used for other purposes such as pesticide or sewage hauling.

Piped Distribution System

Description

A piped system can vary from simple to extremely complicated. Most piped systems have the same basic components: pipes, valves, fire hydrants, service connections, and reservoirs. Piped systems may also have pumping stations. The following describes the various components that can be found in a piped system, excluding pumping.

Main Line Piping Materials

Gray Cast Iron Pipe (GCIP)

Gray cast iron pipe used in the waterworks industry is manufactured to meet **AWWA**[5] standard C-106. This is some of the oldest piping material in use today. Over 200 cities in the United States have pipe installed that has been in use for over 100 years. Gray cast iron pipe was first manufactured using a process called pit casting. In this process, the molten iron was poured into a mold and allowed to cool. In 1925, a process called spin casting was developed. In this process, molten iron is injected into a spinning mold. The result is a pipe of consistent diameter and wall thickness.

[5] AWWA (American Water Works Association) – An association of waterworks personnel, equipment manufacturers, suppliers, and engineers.

Ductile Cast Iron Pipe (DCIP)

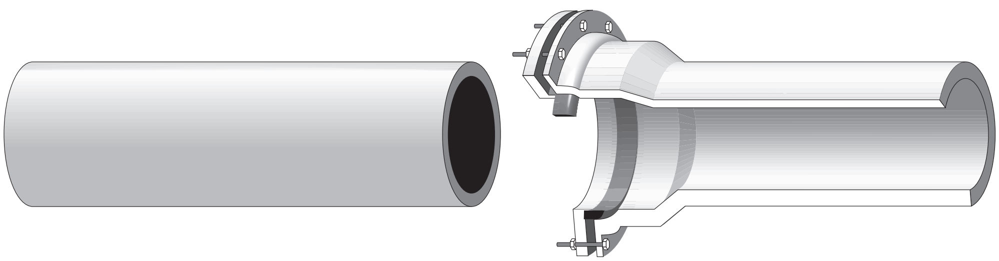
Ductile cast iron is not an alloy. It is formed by injecting magnesium into molten cast iron. The treatment changes the carbon structure of cast iron from a flake to a spherical shape. This alteration results in a material of high strength. It can withstand high impacts, both internally and externally; it has great beam strength (won't break easily); and it is much better in resisting corrosion than gray cast iron.

Ductile cast iron pipe is commonly manufactured using the spin cast system. In this process, molten cast iron is injected into either a metal or sand-lined spinning mold. DCIP pipe is available in sizes ranging from three inches to 54 inches and comes in 18-foot and 20-foot lengths. Lining it with a thin coating of cement mortar enhances the hydraulic capabilities and corrosion resistance of the pipe. Under these conditions, the Hazen and Williams **"C" Factor**[6] for the pipe is 140.

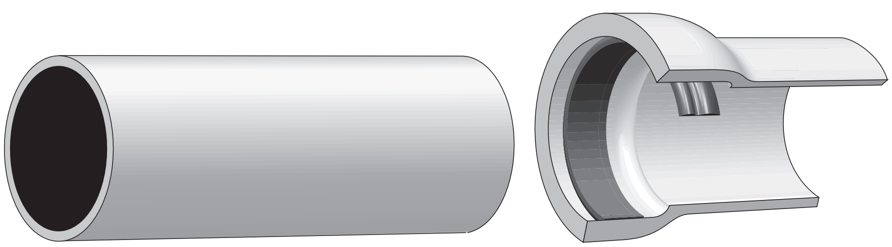
Ductile cast iron pipe is commonly connected using **mechanical joints**[7] (M.J.), flanges or the various common rubber ring push-on joints. Fittings used are commonly made of gray or ductile cast iron and use M.J. or hub joints. Push-on joints are typically used for buried pipe installed below grade because they are quickly assembled and the least expensive. Service taps are made by directly tapping the line or using service saddles.

[6] "C" Factor – The factor used in the Hazen and Williams equation for determining headloss. The "C" Factor is a representation of the hydraulic roughness of the pipe. The larger the number, the smoother the pipe is hydraulically.

[7] Mechanical Joint – A joint used on cast iron valves, fittings, fire hydrants, and cast iron pipe. The joint consists of a rubber gasket and follower ring held to a flange by a row of bolts. The gasket is compressed between the follower ring and the flange seat.



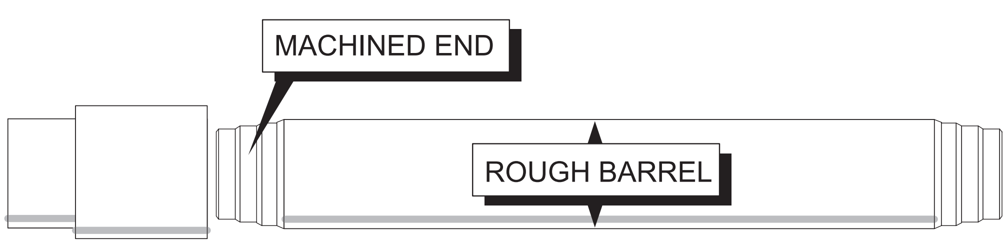
Mechanical joint



Rubber ring push-on joint

Asbestos Cement (A.C.) Pipe

A.C. pipe is also referred to as Transite™, which is the trademark of the Johns-Manville Corporation, one of the first U.S. manufacturers of the material. The pipe is made by spraying a solution of portland cement, long fibrous asbestos, silica sand, and water onto a spinning anvil. The pipe is then shaped and placed in an autoclave to dry.



A.C. pipe

A.C. pipe is available in sizes from three inches to 36 inches and comes in a standard length of 13 feet. There are two common dimensions associated with A.C. pipe. The outside dimension of the pipe itself is referred to as the "rough barrel." The outside dimension where the coupling fits is referred to as the "machined end." To reduce the amount of field machining required during construction, the manufacturers make short sections of pipe that are three feet, three inches and six feet, six inches in length. When the short sections are manufactured similar to the regular pipe, they are referred to as MEE (machined each end). However, short sections are also manufactured with machined end dimensions as the outside diameter. This type of section is referred to as MOA (Machined Over All).

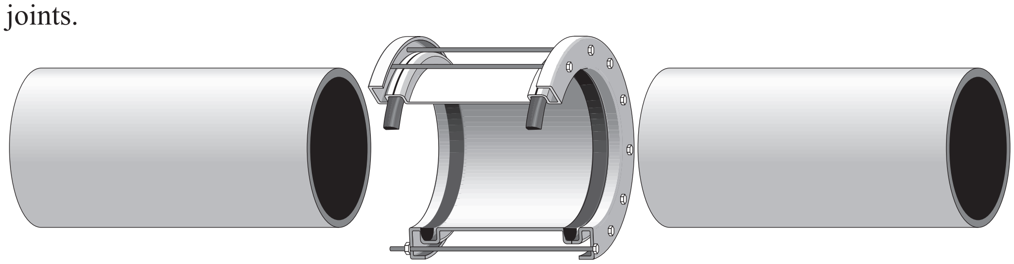
The material is connected together using a double bell coupling with a rubber ring in each end. Fittings and valves used on AC pipe are commonly made of cast iron using a rubber push-on ring for connection. Service line connections may be made by direct tapping of the line or by using a service saddle.

Steel Pipe

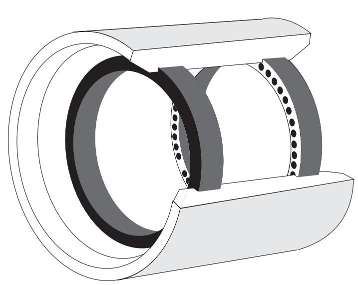
Steel pipe used in the waterworks industry in sizes greater than six inches is manufactured to meet AWWA C-200 standard. Smaller diameter lines used are NSF-approved. These materials may be manufactured by anyone using a variety of means. These materials fall into two categories: mill pipe and fabricated pipe. Typically steel pipe is used in the construction of large-diameter water mains.

Steel mill pipe is available in sizes from 1/8 inch to 36 inches and commonly comes in 21-foot lengths. Two of the most common mill pipes used in the waterworks industry are Standard Weight and Scheduled Pipe. The two common Scheduled Pipes are Schedule 40 and Schedule 80. In sizes from 1/8 inch through 10 inches, standard weight and Schedule 40 pipe are the same OD and wall thickness. From 12 inches through 24 inches, the wall thickness of the standard weight pipe remains constant, while the schedule 40 pipe wall thickness increases with an increase in diameter.

Steel pipe is coupled by a variety of methods: threaded couplings, welded couplings, Dresser™-type couplings, Victaulic™ couplings, flanges, and rubber ring push-on joints.



Dresser™-type coupling

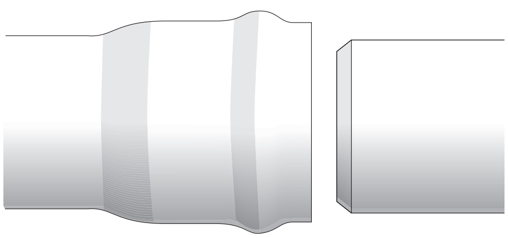


Double bell coupling

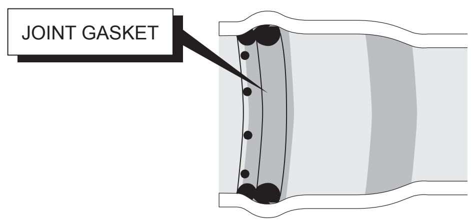
PVC (Polyvinyl Chloride) Pipe

PVC water pipe is made from unplasticized polyvinyl chloride. The material is heated and shaped by forcing it through a die in a process called extrusion. Although the material was introduced into the U.S. in the late 1940s, it gained wide acceptance from the larger water systems only when a thicker walled material was developed and an AWWA standard was adopted. The standard that governs most of this thick-walled PVC pipe is called C-900. This distinguishes it from other PVC water pipe that has a thinner wall.

The material is lightweight and easy to install. It is virtually corrosion-free and therefore has gained relatively wide acceptance as a major pipeline material. One disadvantage to PVC pipe is installation in contaminated soils, where fuel oils, gasoline, and other organic compounds may permeate the pipe wall.



PVC integral bell and spigot joint



PVC integral bell cross section

PVC used for water lines is generally available in sizes of 1/2 inch through 16 inches. There are three common types of PVC used:

- Schedule pipe
- Pressure pipe
- Class pipe

The chief differences among these various pipe types are wall thickness, outside diameter, and burst strength.

Schedule pipe is available in sizes from 1/8 inch through 24 inches, Pressure pipe is available in sizes from 1.5 inches through 12 inches, and Class pipe is available in sizes from four inches through 12 inches. All three types are available in standard 20-foot lengths. PVC pipe has a Hazen and Williams "C" factor of 150. PVC pipe is available in various wall thicknesses and outside diameters. This has resulted in considerable confusion about which pipe is which. In the discussion below, we offer some clarification.

PVC Class and Pressure pipe can be connected using either an integral bell and spigot process or a double-ended bell. In either case, the gasket is a rubber material, and the joints are made by lubricating the pipe and pushing it into the coupling or bell.

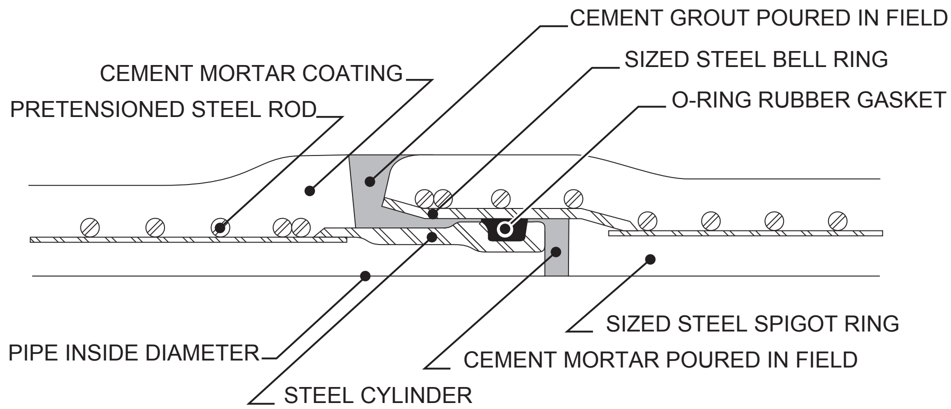
Concrete Pipe

Concrete pipe used in the waterworks industry is manufactured in accordance with AWWA standards C-301 and C-302. This piping material is used primarily for large-diameter lines. Several types of concrete pressure pipe are used; however, the most common types of concrete pipe used are manufactured by wrapping a wire around a steel cylinder and using a cement coating to cover the steel cylinder both internally and externally.

Concrete cylinder pipe is also available in various prestressed forms. The prestressed pipe is made similar to the pretensioned, except the wire wrap is much smaller and under much higher tension (up to 170,000 psi). This material is usually used only on large-diameter lines, commonly 36 inches to 240 inches.

One of the most common concrete pressure pipes is referred to as pretensioned concrete cylinder pipe. (A cross-section of this pipe is shown below.) This pipe starts from a steel cylinder. The cylinder is wrapped with a steel rod that is under tension. The interior and exterior of the pipe is coated with cement mortar. The cement is then cured in an autoclave. Concrete cylinder pipe is an extremely durable material with high hydraulic capabilities.

Pretensioned concrete cylinder pipe is available in sizes from 12 inches to 42 inches and in standard sections of 32-foot and 40-foot lengths.



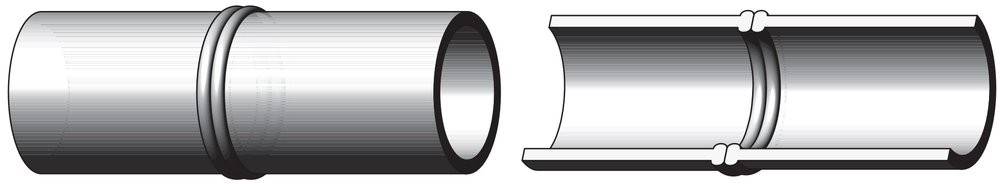
Pretensioned concrete cylinder pipe cross section

This pipe is connected by bell and spigot rubber ring push-on joints. Once the joint has been connected, the exposed steel must be coated with concrete to protect the steel cylinder from corrosion.

High-Density Polyethylene (HDPE) Pipe

High-Density Polyethylene (HDPE) is manufactured using a heat extrusion process and polyethylene resins. The material is used for water services lines and main lines. There are a wide variety of HDPE piping materials manufactured. The primary material used for drinking water is manufactured to meet ASTM standards D1248 and AWWA C-906. The designation used to identify the resin used to produce this piping material is ASTM, and the PPI (Plastic Pipe Institute) designation is PE 3408.

HDPE, PE 3408 is manufactured in pressure ratings from 65 psi to 220 psi. The most common material used in Alaska has a pressure rating of 160 psi. HDPE pipe is available in sizes of 3/4 inch through 16 inches. Sizes of 3/4 inch through 1.5 inches are available in rolls of up to 500 feet, and a two-inch size is available in 350-foot coils. Larger sizes, three inches and up, are available in 20-foot and 40-foot lengths. All material used for drinking water is manufactured to IPS (Iron Pipe Size) outside dimensions. The wall thickness of the pipe increases with an increase in pipe diameter. The wall thickness is selected to maintain a ratio of pipe OD divided by wall thickness of 11. This is called the SDR (Standard Dimension Ratio).

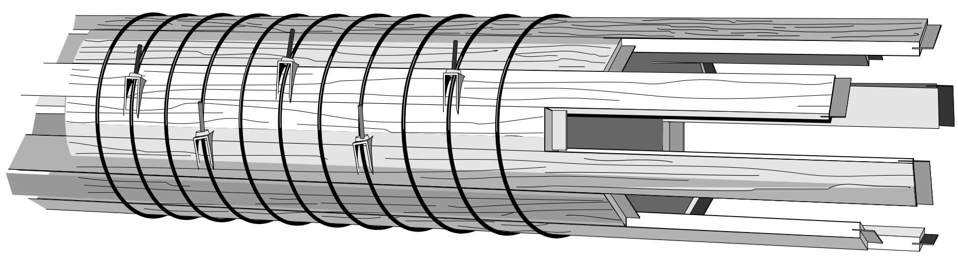


HDPE heat fused welded joint

The most common connection for HDPE pipe is a heat-fused weld. The pipe is commonly connected using a butt welding process. The welding of HDPE takes special equipment and special training. Small diameter (less than two inches) can be connected using compression fittings and stainless steel or brass insert fittings. There are special stainless steel adapters that allow the pipe to be connected using the Victaulic type of coupling. Flanged connections can be made by welding a butt or socket weld flange to the pipe. Repairs can be made to the pipe using typical cast iron couplings, provided that a special stainless steel insert is placed in the pipe to prevent collapsing of the pipe.

Wood Pipe

Wood pipe was at one time used quite extensively in the Pacific Northwest. For the most part, it has been replaced with one of the more common pipe materials previously described.



Continuous stave wood pipe

Purple Pipe

A special purpose for pipelines may be the distribution of reclaimed water. It is becoming more and more common for utilities to treat their wastewater to a high standard so that it can be reused for irrigation of athletic fields and golf courses, snowmaking at ski slopes, wetland enhancement, and commercial or industrial process water. Distribution pipe used to transport reclaimed water is either tinted or painted purple to distinguish it from potable water lines.

PIPE SIZE	Scheduled Pipe				PVC Pressure Pipe						PVC Class Pipe					
inches	40		80		125		160		315		100		150		200	
	ID	OD	ID	OD	ID	OD	ID	OD	ID	OD	ID	OD	ID	OD	ID	OD
1/2	0.612	0.840	0.546	0.840					0.716	0.84						
1	1.049	1.315	0.957	1.315	1.211	1.315	1.195	1.315	1.189	1.315						
2	2.067	2.375	1.939	2.375	2.229	2.375	2.193	2.375	2.149	2.375						
4	4.026	4.5	3.826	4.5	4.224	4.5	4.154	4.5	4.072	4.5	4.39	4.80	4.23	4.80	4.07	4.80
6	6.065	6.625	5.76	6.625	6.217	6.625	6.115	6.625	5.993	6.625	6.30	6.90	6.09	6.90	5.86	6.90
8	7.981	8.625	7.625	8.625	8.095	8.625	7.961	8.625	7.803	8.625	8.25	9.05	7.98	9.05	7.68	9.05
10	10.02	10.75	9.56	10.75	10.08	10.75	9.924	10.75	9.73	10.75	10.16	11.10	9.79	11.10	9.42	11.10
12	11.93	12.75	11.374	12.75	11.964	12.75	11.77	12.75	11.43	12.75	12.08	13.20	11.65	13.20	11.20	13.20
16	15.0	16	14.31	16			16.01	17.4								
20	18.81	20	17.938	20			19.87	21.6								
24	22.64	24	23.0	24			23.74	25.8								
36																
38																

PIPE SIZE	AC						DCIP Thickness Pipe			
inches	100		150		200		51		52	
	ID	OD	ID	OD	ID	OD	ID	OD	ID	OD
1/2										
1										
2										
4							4.28	4.80	4.22	4.80
6	6	7.16	5.80	7.12	5.70	7.36	6.34	6.90	6.28	6.90
8	8	9.32	7.80	9.44	7.60	9.68	8.45	9.05	8.39	9.05
10	10	11.46	10.0	11.85	9.60	11.88	10.46	11.10	10.40	11.10
12	12	13.70	12.0	14.11	11.44	14.11	12.52	13.20	12.46	13.20
16	15.5	17.50	16.0	18.65	15.50	18.74	16.66	17.40	16.6	17.40
20	20	22.50	20.0	23.54			20.82	21.60	20.76	21.60
24	24	27.17	24.0	28.22			24.98	25.80	24.92	25.80
36							37.34	38.30	37.24	38.30
38							49.64	50.80	49.5	50.80

Inside and outside dimensions for common piping materials

Fittings

Fittings are used to connect other **appurtenances**[8] and change the direction or size of the waterline. Some of the more common fittings are tees, wyes, bends, crosses, adapters, reducers, and increasers.

[8] Appurtenances – Portions of a main structure necessary to allow it to operate as intended, but not considered part of the main structure: hydrants, valves, tees, elbows, etc.

Fittings used in water distribution systems are made out of cast iron, PVC, HDPE, stainless steel, and fiberglass. The material selected is based on the piping material and local conditions.

The connections on cast iron fittings can be flanged, mechanical joint, or hub (with a rubber ring). Cast iron fittings are also available with combinations of any two connections. For instance, it is possible to obtain a cast iron fitting that is mechanical joint on one end and hub on the other end. Cast Iron fittings are typically used with PVC, AC, DCIP, and wood pipe.

Connections for steel fittings can be threaded, hub, flange, butt, or socket welded. Steel fittings are used with steel pipe.

Stainless steel fittings can be threaded, hub, flange, butt, and socket welded. Stainless steel fittings are used with PVC and stainless steel pipe.

PVC fittings are made for PVC pipe and are either glued or hub. PVC pipe can be joined with tees, elbows, or other fittings manufactured for ductile iron pipe. HDPE fittings are made for HDPE pipe and are either socket welded or butt welded.

Review

1. What type of hose should be used on haul trucks and watering points?
2. What are two common piping materials used in distribution systems?
3. What are the two most common DCIP joints?
4. In what lengths is the for four-inch diameter HDPE pipe available?
5. How is HDPE pipe connected?
6. What type of piping material can be connected using a glue technique?

Pipe Installation

Distribution System Layout

Water distribution mains may be laid out in grids, loops, or branches much like a tree. Grid or loop systems provide greater flow for fire protection and reduce the number of dead-end lines. Branch layouts result in a number of dead-end lines that can lead to bacteriological, taste, and odor problems. In addition, they require more frequent flushing, which increases the production of waste water.

Depressurization of a water line can lead to contamination if the surrounding soil is saturated with sewage or other groundwater contaminants. Water mains installed parallel to sewer mains must be at least 10 feet apart horizontally, and the water main must be one foot higher than any nearby sewer line. Water mains should never be laid in the same trench with sewer lines. In addition, water mains should be installed at least 25 feet horizontally from wastewater soil absorption systems (leach fields), cesspools, seepage pits, and septic tanks. In all situations, the location of water mains must meet the standards of the Alaska Department of Environmental Conservation and local or regional health agencies if applicable.

Prior to excavating, operators must determine the location of all buried water, sewer, electrical, gas, telephone, cable, and storm drain lines. The Alaska Digline is a one-number, centralized call center established to provide information regarding underground utilities: 1-800-478-3121 or 1-907-278-3121. Alaska Digline agents use a database to pinpoint a reported area of activity and then send a standardized information packet to subscribers within two working days.

Whenever excavation is necessary for repairs or new construction, shoring may be needed to protect operators. A framework of metal and/or wood is placed in the trench to prevent a cave-in. Shoring components may consist of the following:

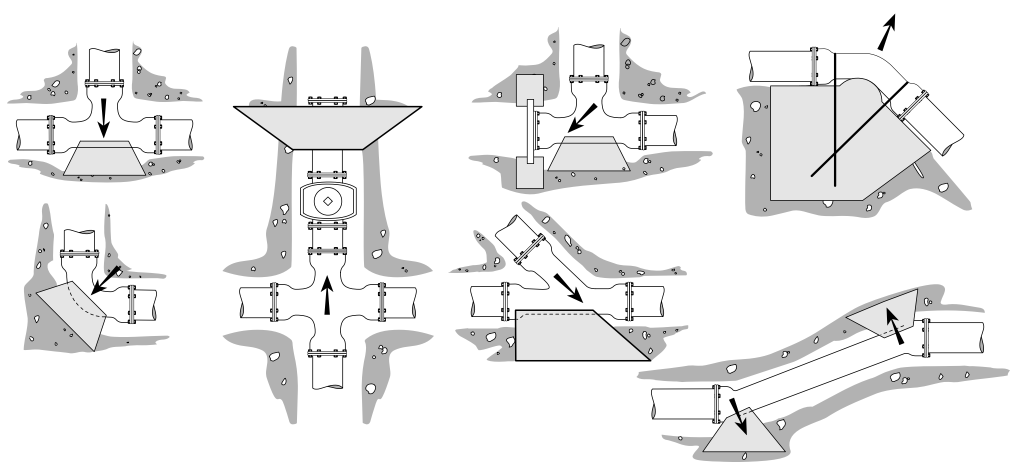
- Sheathing
- Upright braces
- Horizontal jacks or cross braces
- Longitudinal braces or stringers

Often, a prefabricated aluminum trench box is used. The Alaska Department of Labor has specific safety rules regarding shoring that are discussed in another chapter of this manual.

Bedding is a granular material placed in the bottom of a pipe trench to support the pipe. A lack of proper uniform support can lead to "beam" breakage of the pipe. Types of bedding include pea gravel, sand, and select native soil material. If a trench encounters bedrock, it must be over-excavated six inches before bedding is used to bring the trench up to the desired gradeline of the pipe. If the proper soil is available, some types of pipe, such as ductile iron, may be laid directly on the trench bottom. It is important to have an even pipe bedding and backfill over the pipe with soil that will not abrade the pipe walls. The backfill material must be adequately compacted with material that has sufficient moisture content.

Thrust forces are created in a pipeline where it changes direction, changes size, or dead-ends or at valve and hydrant locations. To prevent pipe joints from uncoupling and other damage from internal pressure or water hammer, a **thrust block**[9] may be used. Thrust blocks are often made of concrete and steel reinforcement rods cast in place or large precast concrete blocks. It is important that thrust blocks rest against undisturbed soil with sufficient bearing area. There are standard engineering formulas to determine the thrust exerted within a pipeline and the size of thrust block necessary for a given type of soil.

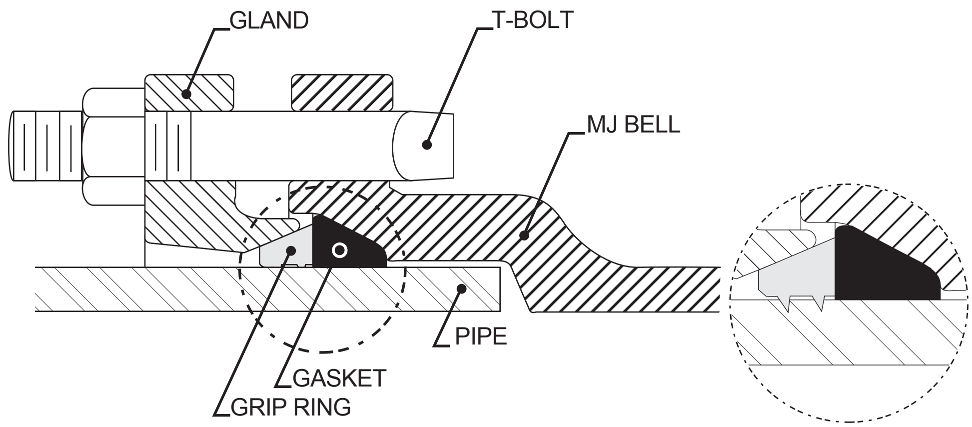
[9] Thrust Block – A concrete wedge placed between a fitting and the trench wall, used to transfer the force from the fitting to the trench wall, and thus prevent the fitting from being pushed away from the pipe.



Thrust blocks

Restrained joint fittings and short pieces of pipes called spools are designed to allow the connection of fire hydrants and branch valves to a distribution line without using a thrust block.

The most common restraining joints use a mechanical joint with some type of restraining device. One of these utilizes a snap ring placed into ductile cast iron or PVC pipe. The M.J. follower is machined to fit over the snap ring and hold the pipe and fitting in place. There are also a wide variety of proprietary fittings using various types of locking devices.



Grip ring

Pressure Testing and Disinfection

Water should be delivered to the consumer at a minimum pressure of 35 psi measured at the property line or meter. A typical working pressure in most systems is 60 psi. The absolute minimum pressure at all points in the distribution system is 20 psi, while 100 psi is the maximum pressure desirable. Excess pressure will potentially damage water heaters, fixtures, and appliances.

Whenever a new pipeline is put into place and often after repairs are made, a leakage test is conducted. A valved-off section of the main line is slowly filled with water as air is expelled through a corporation stop or hydrant. After sitting idle for 24 hours, the pipe is brought up to a pressure 50 percent higher than the normal working pressure for the line, or 150 psi, whichever is larger. This pressure is maintained for four hours, after which pressure is observed for a drop that would indicate leakage.

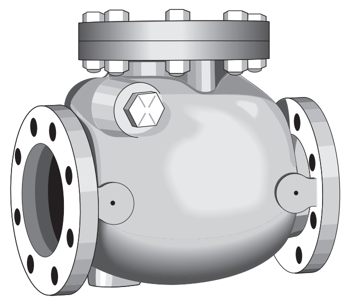
The amount of water needed to refill the pipe is measured and compared to an allowable leakage rate calculated based on size and type of pipe. Leaks determined using this method along with any visible leaks are then repaired or replaced before the pipe is disinfected and flushed. Typically a hypochlorite solution of 25 to 50 mg/L is introduced into the pipe and allowed to sit for 24 hours prior to flushing. If calcium hypochlorite tablets are used for disinfection, the minimum contact time is 24 hours. The American Water Works Association (AWWA) has developed standards for conducting leakage/pressure testing and disinfection of water mains.

Valves

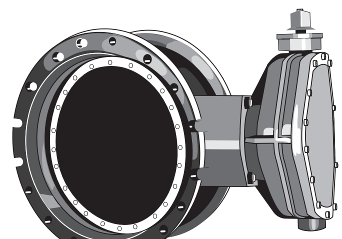
Valve Types

The types of valves used in distribution systems include gate, butterfly, globe, plug, ball, air control, vacuum breakers, check valve assemblies, and reduced pressure zone backflow prevention assemblies.

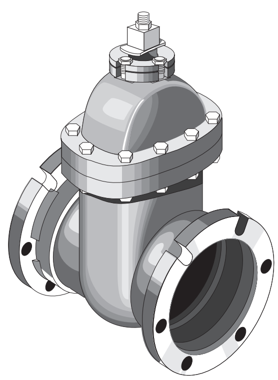
Check valves are used to prevent water from reversing direction in a line or flowing in two directions. The most common check valve used is the swing check, which has a simple design with a cast iron body and bonnet, a brass seat ring, and a movable disc. Flow forces the valve open, and when the flow is reversed, the flow closes the valve. Check valves are not adequate to control backflow or backsiphonage.



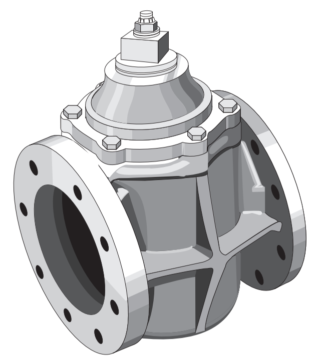
Swing check valve



Butterfly valve



Gate valve



Plug valve

Function of Valves

Valves are used in a water system to control pressure, control flow, regulate levels in **reservoirs**[10], isolate sections of line, release air, prevent vacuum in a distribution line, and prevent backflow and **backsiphonage**[11]. Globe valves are commonly used to regulate flow and pressure. Ball and plug valves are found in service lines. Both butterfly and gate valves are used in the main lines and hydrant lead lines in the distribution system. When butterfly or gate valves are used for isolation, they should be located at every intersection and intervals of not more than 800 feet so that small sections of the water main may be shut down for maintenance.

[10] Reservoir – A tank used to hold water.

[11] Backsiphonage – A form of backflow caused by a negative or below-atmospheric pressure within the water system.

Connections

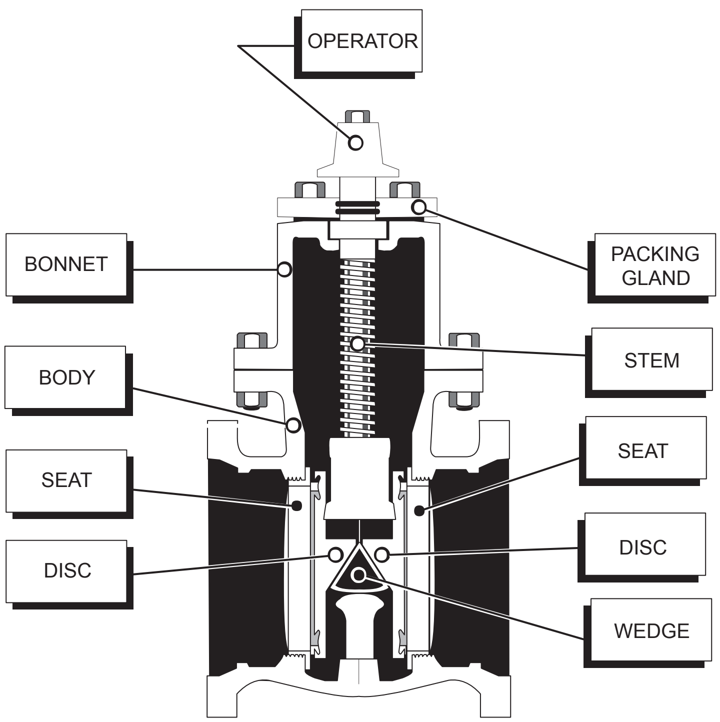
Connections on valves two inches and smaller are typically threaded, glued, or soldered, depending on the type of pipe. For larger valves, flange, mechanical joint, and hub are the most common connections. Valves can be purchased with a combination of connections. For instance, a mechanical joint by flange connection is fairly common.

Gate Valves

The lower portion of the gate valve, called the body, houses the connections and the seat that the movable closure comes up against. The closure is moved up and down by an operating stem. When in an open position, the closure is stored in the bonnet of the valve. The bonnet also holds the stuffing box, and the stuffing box contains the packing or “O” ring, which controls leakage around the stem.

The common movable closures are single disc, double disc, and resilient seat:

- Single disc – The single disc closure is wedge-shaped. When the valve is closed, the disc is forced down and against the seats on either side. This type of valve works only on low-pressure systems. When high pressure is applied to one side of the valve, it becomes very difficult to open.
- Double disc – The common movable closure used in the waterworks field is the double disc. The two discs are parallel to each other as are the two seats. When this valve is closed, a wedge of some type that rests between the two discs forces the two valve faces outward toward the two seats. When this valve is opened, the turning of the shaft causes the wedge to be relaxed and the two discs to move away from the seats, thus making it much easier to open the valve.
- Resilient seat – A recent addition to the gate valve market is a resilient seat valve. This valve uses a movable closure coated with a rubber-like material. The resiliency of the material allows for the use of a wedge-shaped single disc closure. Because of the resilient nature of the closure, the valve opens easily under high pressure.



Cutaway of gate valve double disc

The stem found on a gate valve may either be rising or non-rising. Non-rising stems are used in most underground installations. In this valve, the disc moves up the stem, and only the stem rotates in the bonnet.

Rising stem gate valves are also called outside stem & yoke (OS & Y) gate valve. These are used in valve pits and on either side of control valves. They allow easy determination of whether the valve is open or closed.

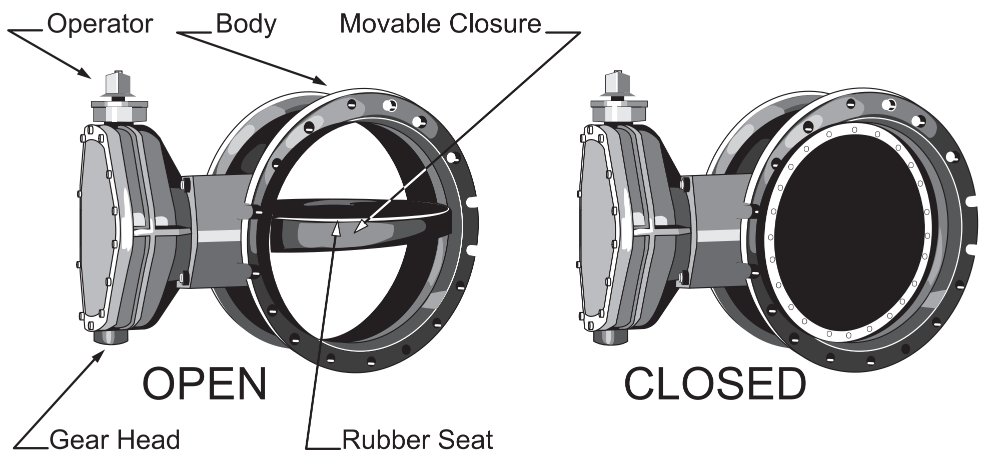
The device used to turn the stem is called a valve operator. Common operators are two-inch square nuts on underground installations and hand wheels on valve pit installations.

Butterfly Valves

[12] Butterfly Valve – A valve whose movable closure rotates 90° around a shaft that is set through the center of the closure and the center of the flow path.

The **butterfly valve**[12] has a movable closure that rotates on a shaft inside of the valve body. The body holds the inlet connections and valve seat. When closed, the movable closure seats against a rubber-like seat that is set into the valve body or fastened to the closure. The butterfly valve is not 100 percent watertight when closed.

The valve stem usually passes into a gear train. The common gear train is a 90° gear train, which allows the valve to be mounted sideways. When installed in the ground, the operator is commonly a two-inch square nut. A wheel is used when the valve is installed in an open valve pit.



Butterfly valve operation

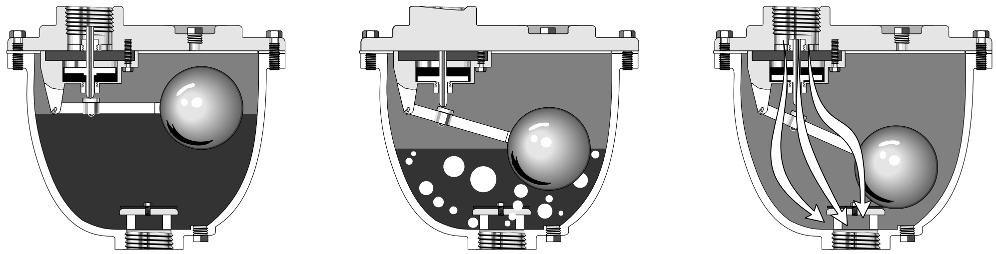
Butterfly valves offer some restriction to flow, which increases headloss. They are, however, much easier to open and close in large lines than gate valves.

Air Valves

There are three common air valves used in a distribution system: air vacuum, air relief (release) and combination valves. Each valve has its own unique function:

- Air and vacuum valves – Air and vacuum valves are designed to allow the escape of air while the line is being filled. Once the line is filled, the pressure in the valve keeps the valve from opening even if air accumulates in the valve. When the line is drained and the internal pressure drops below atmospheric, the valve opens, allowing air in preventing the pipe from collapsing. These valves are also referred to as air relief valves.
- Air relief valves – Air release valves are commonly installed at high points in a system and are designed to collect and release air that accumulates in the system. An accumulation of air in a pipe will reduce its flow capacity. Another application of an air relief valve is to vent air that has accumulated in the well column when a well was not in use.
- Combination valves – There are two types of combination valves. The most common is the combination of air release and vacuum relief, a combination of the two valves described above and shown in the diagram below. This type of valve is often referred to simply as an air vac valve. The second combination valve is one designed with two orifices, one for high airflow and one for low airflow. This is a combination air relief valve.

Combination air vac valves are installed at high points in the line to allow air in and out of the line. Allowing air out of the line reduces problems with low flows due to a blockage by air. Allowing air into the line during times when the line may be being emptied prevents the low internal pressure from drawing a joint gasket into the pipe and thus causing a leak.



Combination air vacuum valve

Air vac valves are installed on top of the line usually through a two-inch corp stop with a two-inch gate valve placed between the corp stop and the valve. The entire setup is normally placed in a valve pit.

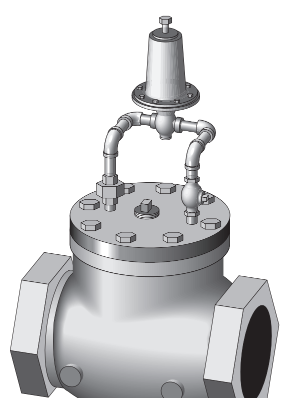
Globe Valves

The globe valve is used to reduce or control pressure in a portion of a system, to throttle or control flow from a pump, to reduce **water hammer**[13] at a pump, and to control the level of water in a reservoir. When a valve is used to control the level of water in a reservoir, it is called an **altitude valve**[14]. A specialized globe valve used to dampen water hammer is a pressure-relief valve.

[13] Water Hammer – The result of the conversion of velocity head to pressure head. The pressure spike created by suddenly stopping the flow of water.

[14] Altitude Valve – A valve that automatically opens and closes to maintain the level of water in a reservoir. Most commonly a wide body globe valve.

Globe valves have a movable closure that moves up and down inside of the valve body. The movable closure is usually attached to a shaft that is positioned by two guides. The movable closure either seats against a resilient face, or the closure has a resilient face that seats against a solid valve seat. The position of the movable closure is controlled by pressure on a diaphragm or piston at the top of the valve. The diaphragm pressure is obtained directly or indirectly from the water system. The control of this pressure is usually regulated through a pilot valve. Most of the globe valves used for flow and pressure control and as altitude valves use flange connections on each side.



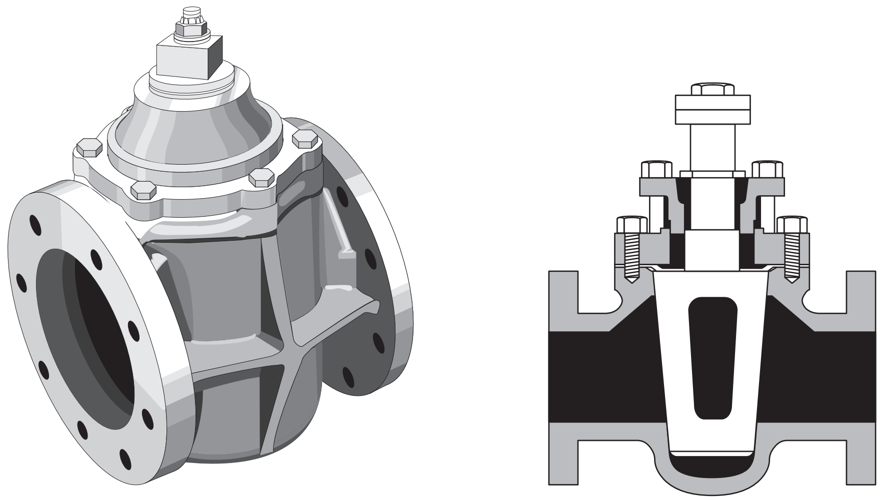
Pressure relief valve

Plug Valves

Plug valves can be found in a wide variety of sizes. In a water system, they are commonly used as the isolation valves on the customer service lines. In this instance, they are usually made of brass and have threaded or copper tubing connections.

The plug valve is the simplest of all valves. The movable closure has a hole through which water is permitted to pass. A ¼ turn turns the valve from open to closed.

Older plug valves control leakage between the movable closure and the valve body by the close tolerance between the two components. This close tolerance makes it difficult to open and close these valves. In recent years, plug valves have been manufactured with Teflon™ and "O" ring seals. These valves are much easier to operate.

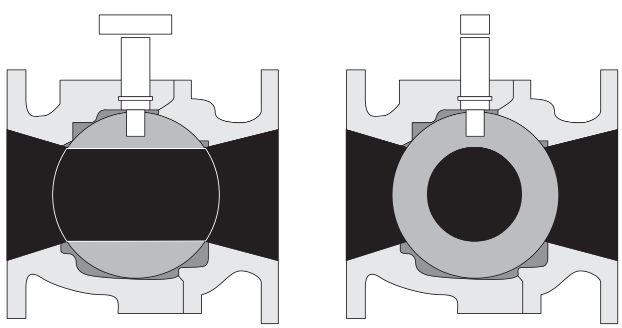


Plug valve

Ball Valves

Ball valves are found on small lines (less than two inches), in and around the treatment plant, and on some customer service lines. They are manufactured from brass or PVC. They offer an advantage over the plug valve because they are much easier to operate. Large ball valves (greater than three inches) are used as flow and pressure control valves on pumping systems. These large ball valves are commonly manufactured from cast iron with a steel movable closure.

The ball valve is similar to the plug valve. The movable closure has a hole in its center through which water passes. Closing or opening the valve is accomplished by a simple ¼ turn of the handle. The ball valves movable closure is prevented from leaking by seals placed in the valve body.



Ball valve open and closed

Foot Valves

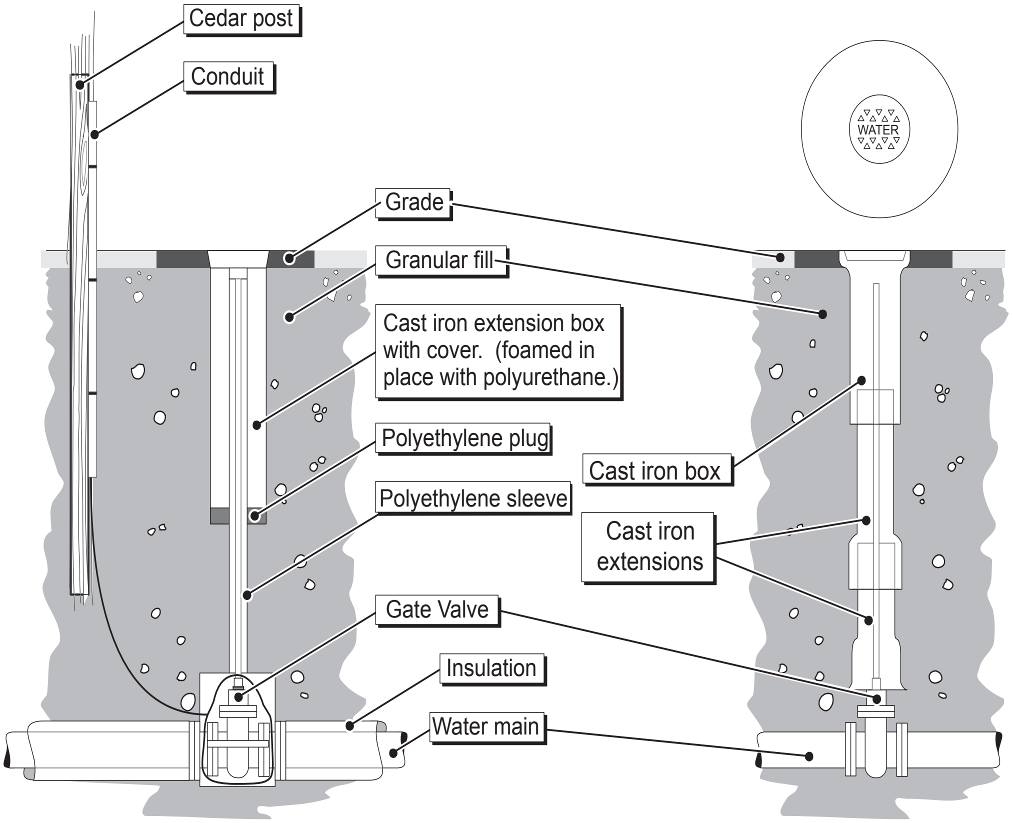
Foot valves may be installed at the bottom of a well discharge line or the end of the intake pipe in a suction lift pumping situation. The function of this valve is to prevent the water column from discharging back into a well or wetwell and to maintain prime to the pump.

Valve Boxes

Access to main line valves on piped systems is through a valve box. Valve boxes are made of cast iron, concrete, or PVC with a cast iron lid.

Valve Maintenance

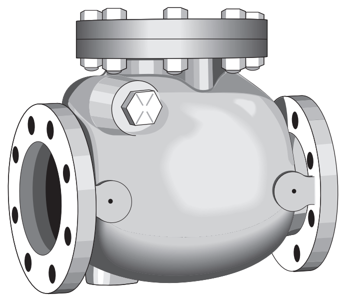
All valves in the main lines of the distribution system should be located and exercised once each year. This is best done in early summer to allow repair before winter.



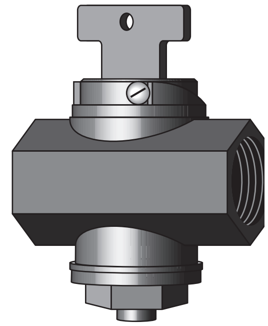
Arctic valve box installation using a cast iron valve box

Identification

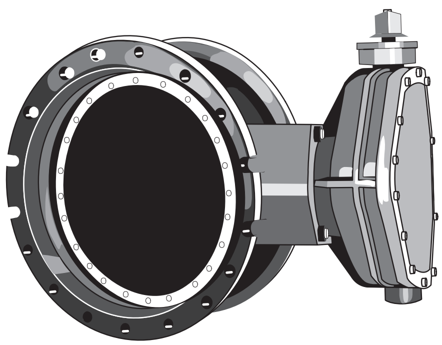
1. Identify the valves below.



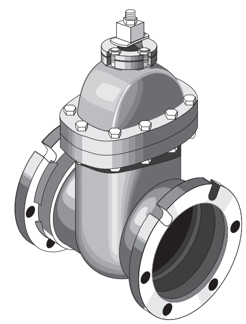
1. ______________________



2. ______________________



3. ______________________

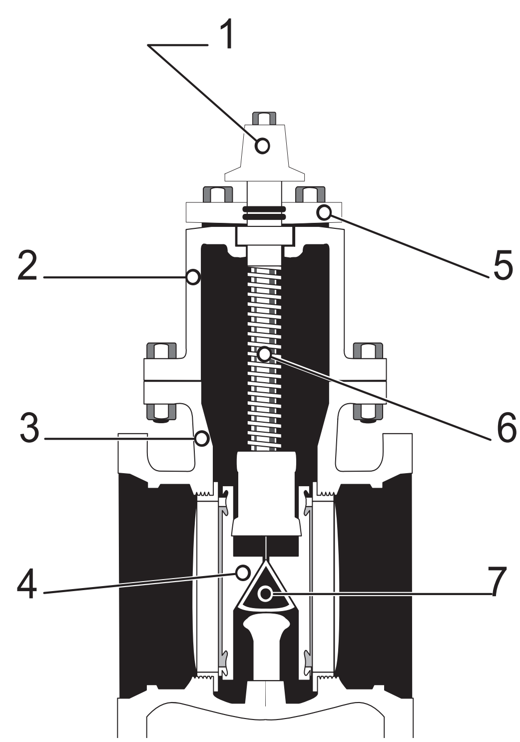


4. ______________________

Identification

1. Identify the valve components below.

1. ______________________
2. ______________________
3. ______________________
4. ______________________
5. ______________________
6. ______________________
7. ______________________



Fire Hydrants

Purpose

The primary function of a fire hydrant is to provide access to water for fire suppression. Fire hydrants can also be used in the following secondary functions:

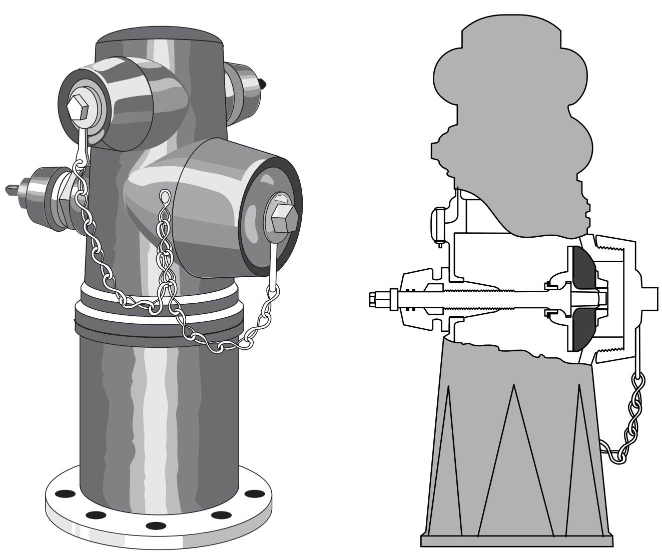
- Access to water for construction
- Access to water for other utilities, such as street cleaning and sewer cleaning
- Access point for testing the distribution system's flow capabilities

Hydrant Types

Two classifications of hydrants are made in the United States: the wet barrel and the dry barrel. These are manufactured in accordance with AWWA standards C-502 and C-503:

- Wet barrel – Wet barrel hydrants have the operating valve in the nozzle section of the hydrant and are operated by rotating the operating stem on each of the outlets. These hydrants are used in warm climates where it rarely freezes. Their main advantage is the ease of connecting a second fire truck. Each discharge port is independently valved.

- Dry barrel – Dry barrel hydrants have the operating valve installed below ground. The hydrant is equipped with a special drain valve that allows the above ground portion to automatically drain when not in use. The dry barrel hydrant is widely used in colder climates. Its main advantage is that it is less likely to freeze, and when hit by a vehicle, it does not normally lose water.



Wet barrel fire hydrant

Four Types of Dry Barrel

Four types of dry barrel fire hydrants are used in the United States. Two of the types are called compression hydrants. There is one type of **compression hydrant**[15] that opens with the flow, and one that opens against the flow. A third type of dry barrel hydrant is called the **toggle hydrant**[16], and the fourth type is the **slide gate hydrant**[17]. All of these hydrants are opened by turning an operating nut on the top of the hydrant. On both of the compression hydrants, the main valve, which is made of a soft

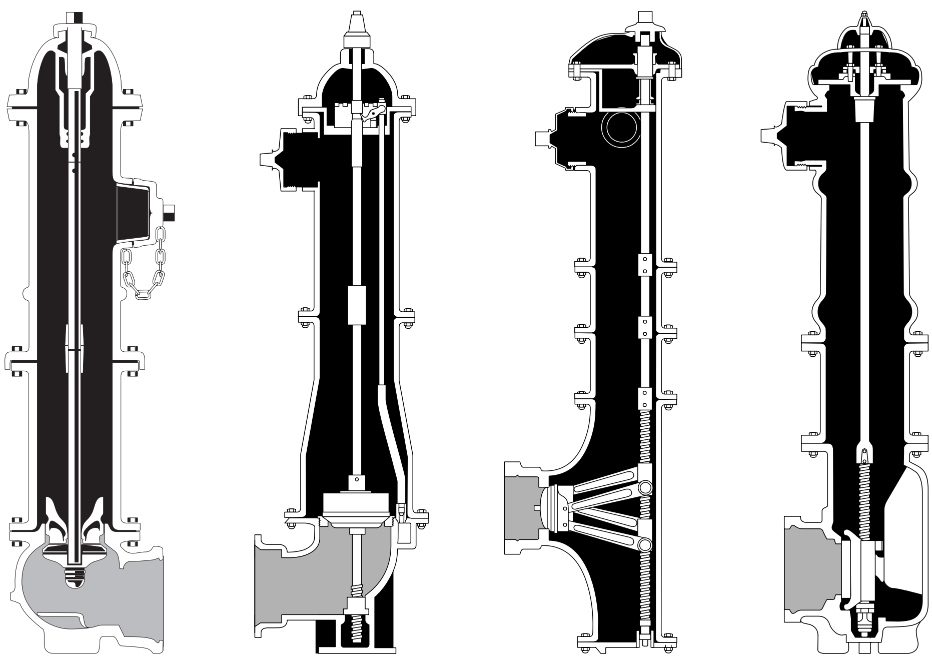
[15] Compression Hydrant – A fire hydrant where the main valve moves reciprocally on a vertical axis is against a seat located in the hydrant base. The valve moves against the seat to close and away from the seat to open.

[16] Toggle Hydrant – A fire hydrant where the main valve moves reciprocally on a horizontal axis against or away from a vertical seat located in the base of the hydrant. The main valve is moved by means of a vertical stem. Rotation of the stem causes the arms of the toggle mechanism to move the main valve.

[17] Slide Gate Hydrant – A fire hydrant where the main valve moves vertically by means of a threaded stem. When the stem is rotated, the internally threaded gate moves. The gate is forced against the valve seat by a wedging mechanism.

material, is moved up or down away from a bronze seat. The toggle hydrant uses a sideways action to move the valve against a bronze seat. The slide gate works more like a single disc gate valve. The gate is forced down by the stem and sideways against a seat by a wedge.

Compression hydrants — Toggle hydrant — Slide gate hydrant

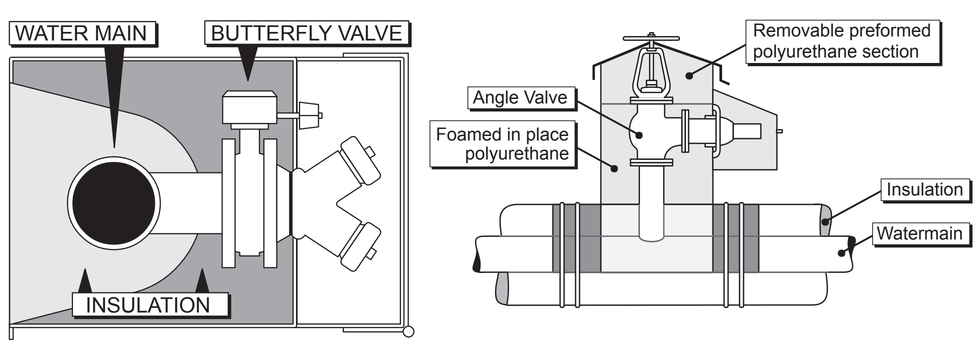


Opens against flow — Opens with flow

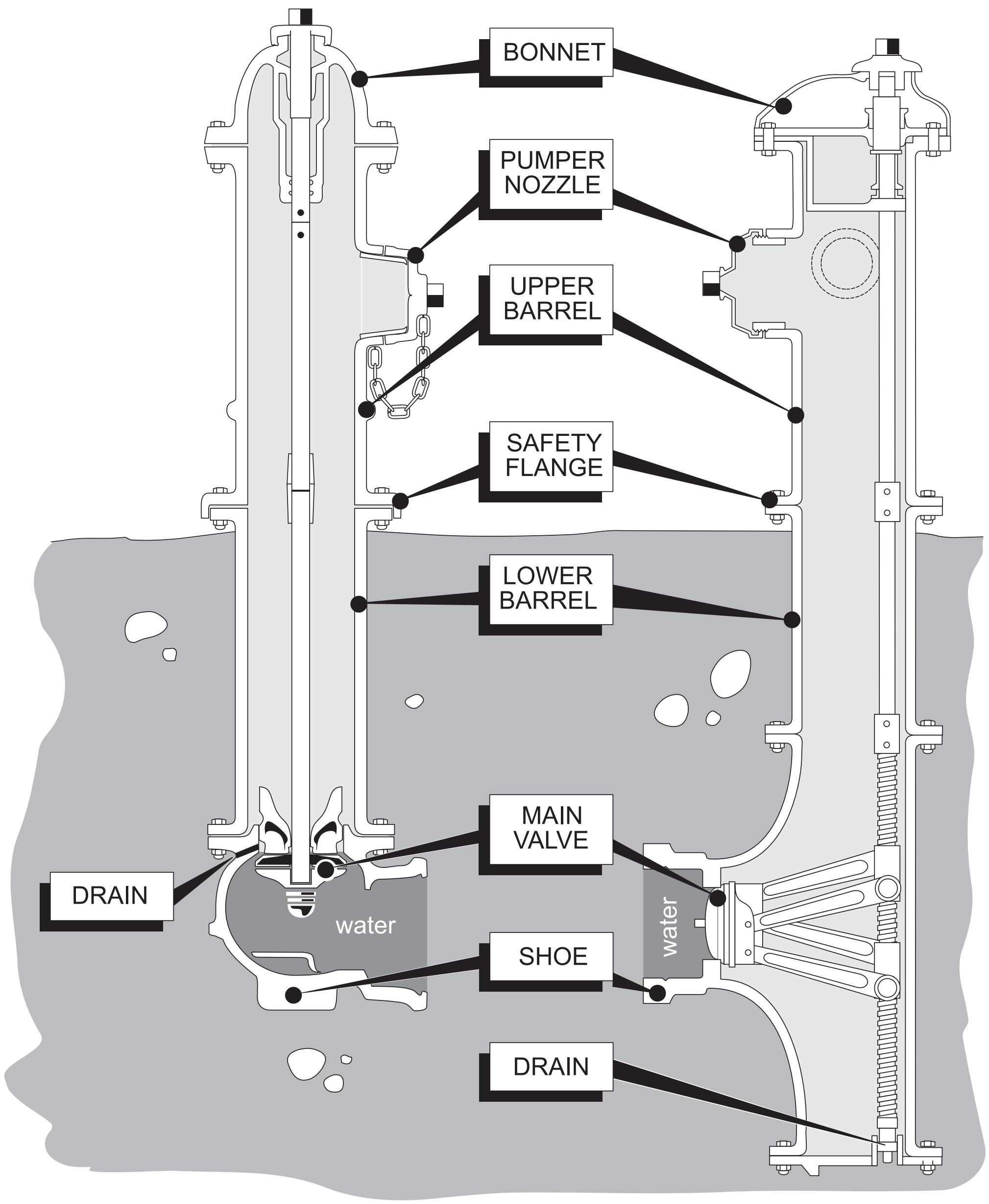
Hydrants are also classified by whether they are post or flush hydrants. The hydrant that we commonly think about is a post hydrant. A flush hydrant sits flush with the surface of the ground and is used in airports, on bridges, and other places where the exposure of the hydrants is more of a hazard than the difficulty of connecting to a ground-level hydrant.

For safety purposes, hydrants can also be designed to break at the ground line with a minimum amount of damage. This type of hydrant is referred to as a traffic model hydrant.

Special methods have been devised to allow access to above and below-ground utilidor systems. One such method uses an angle globe valve connected to the main line. While this does not meet the AWWA standards for a fire hydrant, it does function as a fire hydrant.



Arctic hydrants



Hydrant Components

If you examine the hydrant from the top down, the major components are identified as follows:

1. Bonnet – On top of the upper barrel sits the bonnet. The bonnet protects the packing and the operating nut mechanism.
2. Upper barrel – The upper barrel contains the outlet nozzles and a plate that holds packing or "O" rings, which prevent water from entering the top of the hydrant. Common nozzle configurations include two 2 ½-inch hose nozzles and one pumper nozzle that may be any size from four through six inches. Some hydrants do not have packing plates and are referred to as wet barrel hydrants.
3. Lower barrel – The next section is the lower barrel. This section determines the height or **bury**[18] of the hydrant. The bury is the distance from the bottom of the inlet connection (**invert**[19]) to a point four inches below the flange that connects the lower barrel to the upper barrel.

[18] Hydrant Bury – The distance from the invert of the hydrant lead to a point four inches below the flange between the upper and lower barrels of a hydrant.

[19] Invert – The bottom inside surface of a pipe.

4. Shoe – The shoe is where the inlet connection is made. The inlet connection can be either a four- or six-inch M.J., hub, flange, or screwed connection. The shoe also changes the direction of the flow from horizontal to vertical. On most compression hydrants, the main valve is housed either in the shoe or directly on top of it. The size of the main valve is referred to as the main valve opening (**MVO**[20]). This is the inside diameter of the valve seat. Sizes ranging from four through six inches are common. The shoe also usually contains the drain valve assembly, which is used to drain the hydrant when it is closed.

[20] MVO (Main Valve Opening) – The inside diameter of the bronze main valve seat of a fire hydrant.

Hydrant Maintenance

Fire hydrants should be inspected for leakage and proper operation and exercised at least once each year. This is best done in early summer so that any necessary repairs can be made before winter.

Customer Service Materials

Meters

While not all communities install meters on customer services, meters serve at least two functions:

1. They provide a method to fairly distribute the cost of providing water service.
2. Having meters allows the operator to determine the amount of unaccounted-for water lost by the system. High percentages of unaccounted-for water indicates excessive leakage in the system.

Customer services are divided into at least three categories: household, commercial, and fire. The type of meter used often depends upon the type of service.

Household

The standard meters for household services are 5/8 inch to one inch in size and provide at least 20 to 30 gpm at 40 psi. A household meter has a register that records the quantity of water used, a magnetic connection to a rotating device, a measuring chamber, a body, and, in some cases, a bottom plate that will break when frozen to prevent damage to the meter.

There are three types of household meters. They are described by their different measuring chambers. The nutating disk and oscillating piston meters are called displacement meters. With these meters, water causes a piston or disk to be moved, displacing the water and causing the rotating assembly to rotate, which indicates flow on the register. The turbine meter uses a vaned wheel that is rotated by the flow of water. The wheel is attached to the register, thus indicating water use.

Household meters are installed in meter boxes in the sidewalk in locations where the frost depth is only two or three feet. In locations where meters are apt to freeze each winter, they are installed in the house.

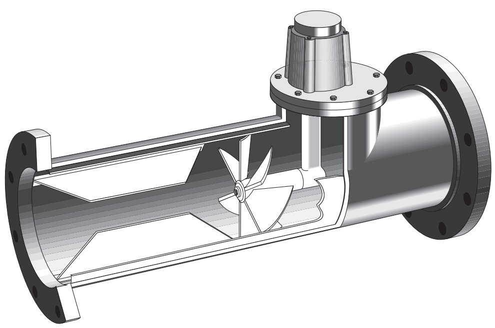
In Alaska's small communities, Badger, Rockwell, and Neptune are the most common brands of household meters used.

Commercial

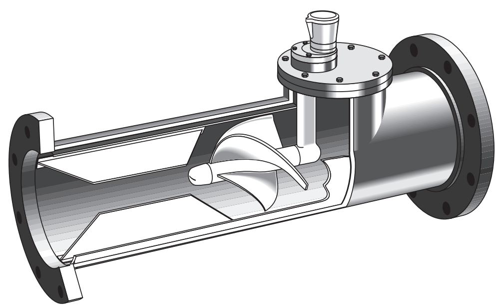
Commercial services are usually considered any services serving something other than a single household and having a service line one inch or larger in size.

There are three common commercial meters:

- Compound meters – The compound meter has two measuring chambers: one for low flow and one for high flow. The low flow chamber typically uses a displacement meter, while the high flow chamber uses a turbine or propeller meter.
- Turbine meters – Turbine meters typically use a pinwheel mounted on a vertical shaft. Turbine meters in large sizes have low accuracy.
- Propeller meters – Propeller meters use a prop blade mounted on a horizontal shaft in the flow. Propeller meters work best over a narrow flow range and are used on services where the flow does not vary widely.



Turbine meter



Propeller meter

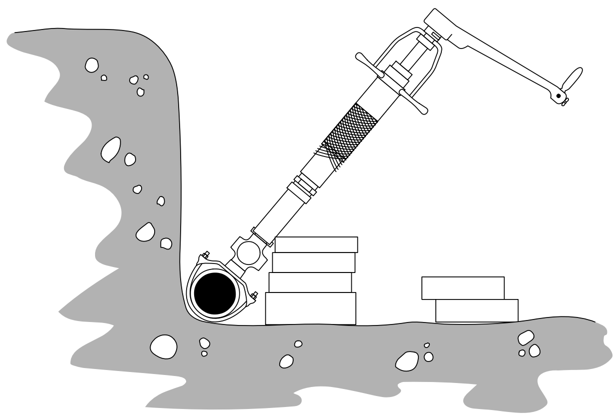
Fire

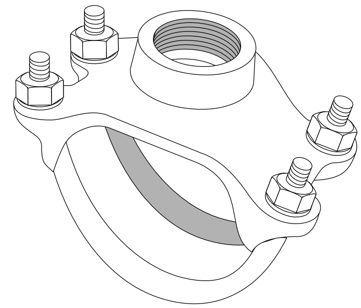
Meters installed on fire sprinkler lines are called fire service meters or check meters. The most common contains a large swing check valve and a small displacement meter. When there is a fire, the check opens and a small amount of water is diverted through the small meter, indicating that there has been a flow in the line.

Service Fittings

Services can be connected to an existing main line without shutting the line off. This is done using a special tapping machine. The tapping machine allows direct connection to ductile cast iron pipe or connection to AC, PVC, and HDPE through a saddle, a malleable iron or brass device that is clamped around the line. A gasket prevents leakage between the saddle and the pipe.

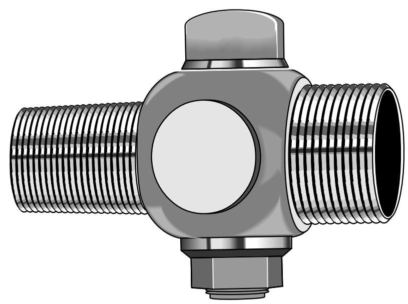
Services are connected to the main line through a brass plug valve called a corporation stop. The corporation stop may be threaded into a tee, tapped directly into a cast iron pipe, or threaded into a saddle. The tapping machine can be connected to the corporation stop, and a drill bit can be used to tap the main.





Service saddle

Tapping machine



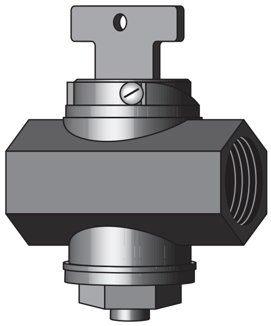
Corporation stop

When the meter is installed in the house or when there is no meter, the utility needs a way to shut off the service. This is accomplished with a brass plug valve called a curb stop. The curb stop is placed in the service line in a location that allows access through a curb stop valve box from outside the house. A connection to the curb stop is often the location of leaks in older service installations.

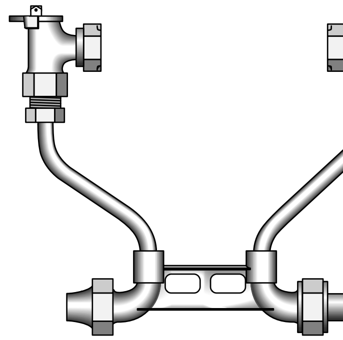
The brass valve that is fastened to the meter is called an angle stop or straight stop, depending upon its obvious shape. This valve is used to shut off the service. The outlet side of the meter is installed with either a customer valve or a tail piece and a customer valve. The tail piece is an adapter from the meter threads to pipe thread.

One of the ways to maintain the proper distance between the meter fittings when a meter is being changed is to use a meter setter. This brass and copper device also allows the service line to be buried at a safe depth and still have the meter within reasonable reach of the top of the meter box.

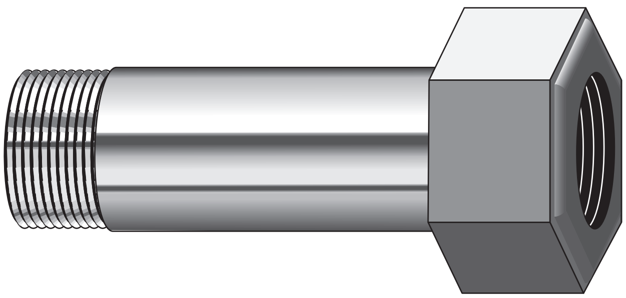
Household services are connected to the main using copper tubing, polyethylene pipe, PVC, galvanized steel, or HDPE pipe. In rural Alaska, HDPE is the most popular. Commonly household services are installed using ¾ or one-inch service lines. A flexible service line has the advantage of allowing a small amount of movement with shifting or settling soil conditions. Copper, plastic, and old lead pipe service lines are flexible, but galvanized iron pipe does not flex. Copper service lines installed inside a building are typically soldered in place. PEX (cross-linked polyethylene) is a newer type of plastic pipe material that has gained widespread acceptance. It can be connected with press-on crimped fittings.



Curb stop

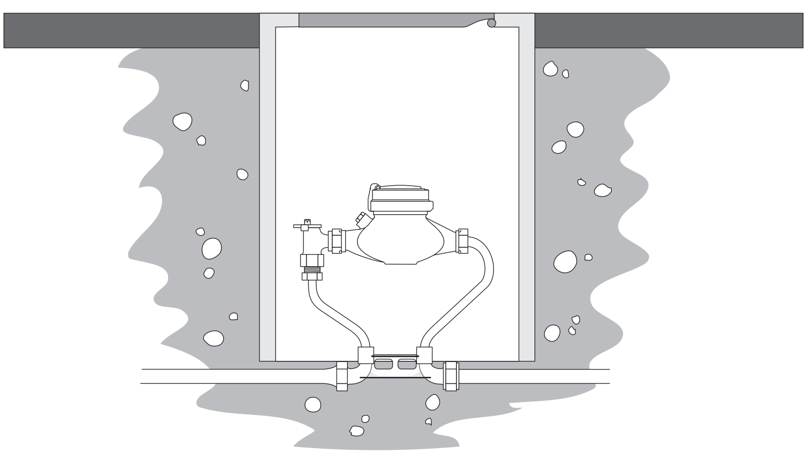


Meter Setter



Tail Piece

When the meter is installed in the sidewalk area, a meter box gives access for the meter reader. Boxes are commonly made from cast iron, concrete, and plastic. In some instances, large-diameter insulated PVC pipe with a cast iron lid is used as a meter box.



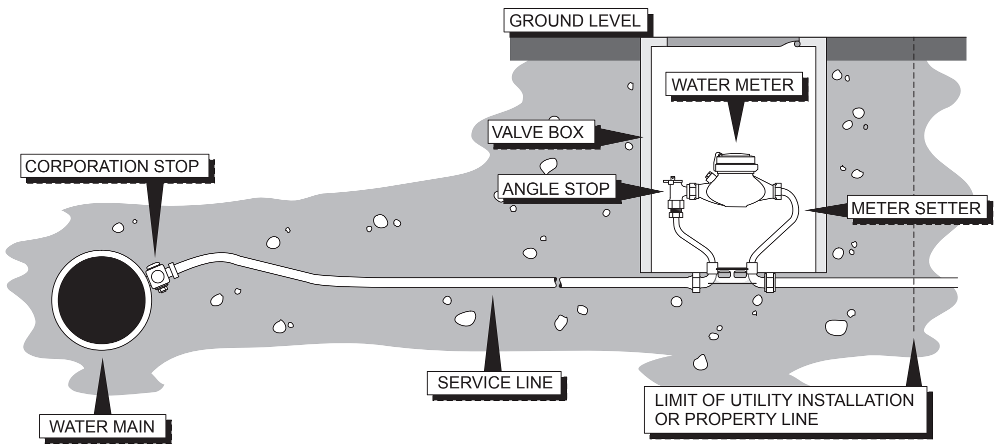
Meter box

To speed the reading of meters and to make it easier to install meters inside of the house, special meter-reading devices have been developed. These include remote registers that secure to the side of the house or a post and automatic readers that allow the meter reader to obtain the data electronically.

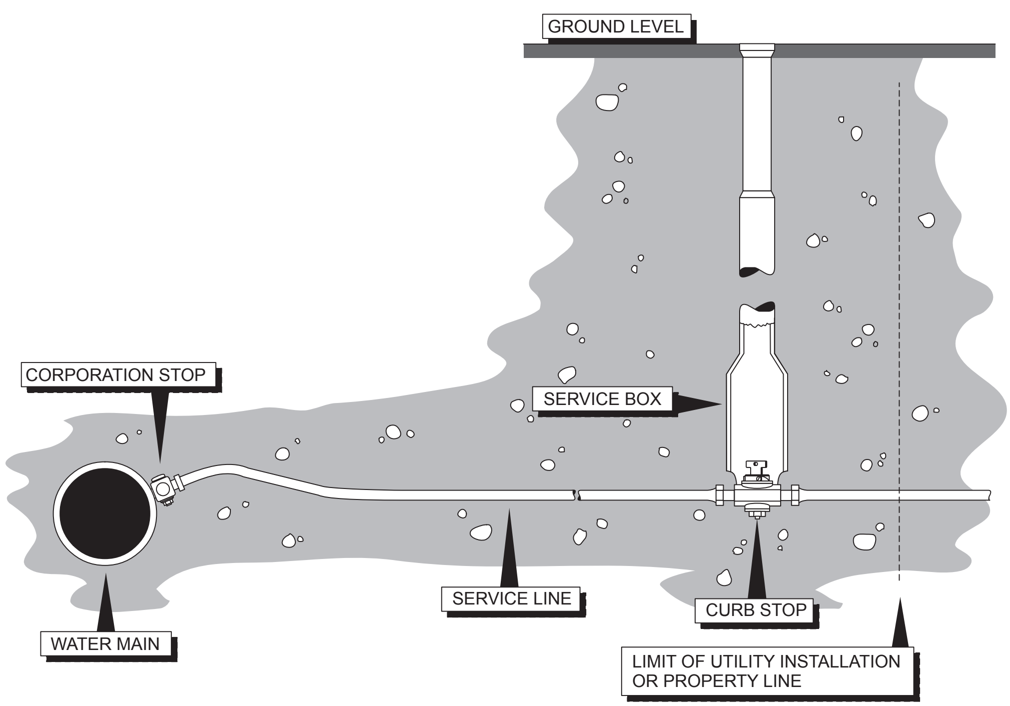
Meter Installations

The type of meter installation depends upon the environmental conditions of the area. In most of the U.S., a standard meter setting is used. In the Arctic, special circulation systems are required.

The most common meter installation is the standard setting. In this setting, a single service line is run from the corporation stop to the meter or from corporation stop to the curb stop and then to the meter.



Meter box installation



Curb stop installation

Finished Water Storage

Function

There are at least six functions that a storage reservoir can serve in a water distribution system:

1. Maintain pressure on the system – In many systems, the elevation of the reservoir determines the pressure in the system.
2. Provide flow during **peak demand**[21] – In many water systems, it is not economical to construct a treatment facility or well that has large enough capacity to meet the peak hourly or daily demand. The water in the reservoir can be drawn into the system to satisfy these peaks.
3. Provide fire demand.
4. Provide surge relief – To reduce the surge associated with stopping and starting pumps, systems can be designed so that the pump discharges directly into a reservoir.
5. Level out pumping demand – To keep pumps from running 24 hours a day, systems are often designed to allow the pumping system to fill the reservoir to a specific level. The pumps then shut off, and water is drawn from the reservoir until the level drops to a predetermined point at which time the pumps restart.
6. Provide or increase detention time – This is done to provide chlorine contact time and satisfy the desired CT values requirements.

[21] Peak Demand - the maximum momentary flow required for a water treatment plant, pumping station or distribution system. The demand is usually the maximum average flow in one hour or less.

Reservoir Types

There are four basic types of reservoirs:

- Built with all or most of the reservoir below ground
- Built at ground level
- Elevated above the ground (elevated tanks or standpipes)
- Hydropneumatic tanks (tanks that are pressurized with air)

Steel Tanks

One of the materials used to construct reservoirs is steel. There are two types of steel tanks: welded and bolted. Because of cost, the bolted tanks are the most common in rural Alaska. Steel tanks are typically installed above ground or elevated. Elevated tanks are also called standpipes. Steel tanks are placed on a concrete pad or on an oil-soaked sand pad. The oil reduces deterioration of the bottom of the steel tank.

Concrete Tanks

There are two types of concrete tanks:

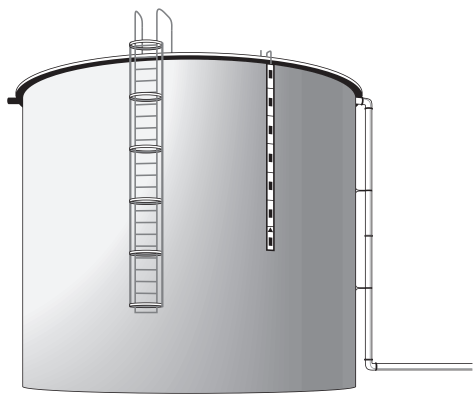
- **Cast-in-place tanks** are installed below ground or above ground. The concrete is poured into forms much like the walls of a home basement, but with more reinforcement.
- **Prestressed tanks** are commonly installed above ground. A prestressed tank is made by wrapping a wire or cable tightly around the tank, stressing the concrete. This wire is covered with concrete to prevent deterioration. The concrete in a prestressed tank is in a relaxed condition when the tank is full. This commonly extends the life of the tank.

Wood Tanks

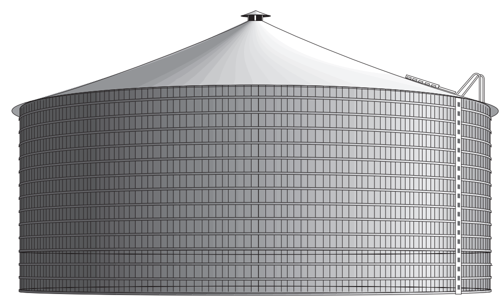
In many rural areas, including southeast Alaska, wood reservoirs are very common. The insulation capabilities of the wood, along with the low cost of construction, make wood a good choice for the small community. The most common wood tanks are made from vertical tongue-and-groove Douglas Fir or Redwood slats. The slats are held in place by steel bands, which may be galvanized or covered by polyethylene to prevent rusting.

One of the major operational problems with wooden tanks is preventing bacteria that are already in the wood from causing positive bacteriological samples. Special cleaning and chlorination practices are required to reduce this problem.

Wood tanks are installed with either wood or concrete floors. Concrete floors are poured directly on compacted soil. Wood floors are protected from the ground by being installed on concrete or wood pilings.



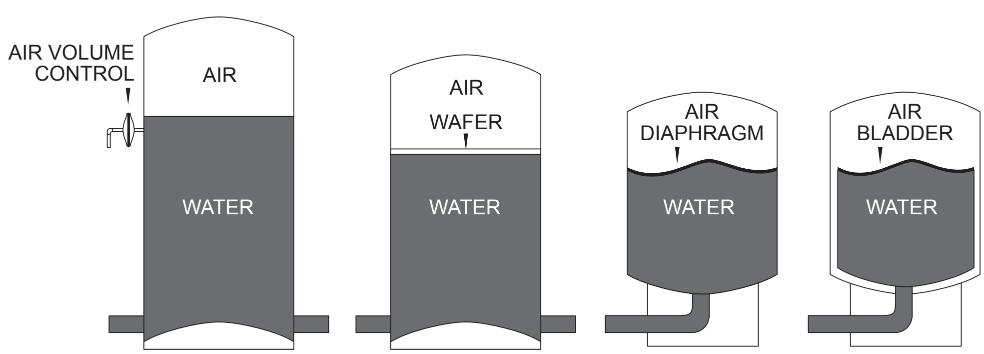
Steel tank



Wood reservoir (storage tank)

Hydropneumatic Tanks

Hydropneumatic tanks, or pressure tanks, are constructed of steel or fiberglass. These tanks are pressurized by a pump or a pump and air compressor. The tanks commonly contain 1/3 air and 2/3 water. The air is compressed when the tank is filled, acting like a big spring. When the pump shuts off, the air is used to push the water out of the tank.

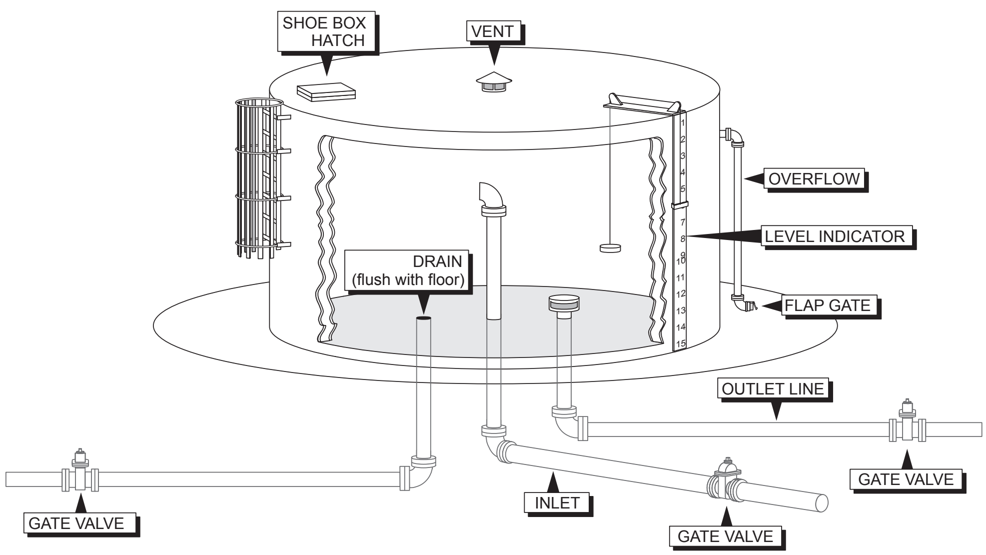


Hydropneumatic tanks

Valves and Piping

The reservoir water level is controlled by one or more of several popular techniques, each of which control the flow into the tank:

- Float valves – A float valve works very much like the float in a toilet bowl and can be installed on the inlet line. As the level of water in the tank changes, the position of the movable closure in the valve changes, which adjusts the amount of water flowing into the reservoir.
- Electric controls – Electric controls include electrodes, floats, pressure switches, and sonic devices used to sense the level of water in the reservoir and turn a pump on or off. They can also be used to operate chemical feed pumps.
- Altitude valves – These are commonly wide body globe valves. The valve senses the water level in the tank by one of many techniques. A signal, associated with the water level, is sent to the chamber on top of the valve. This changes the position of the movable closure.
- Isolation – Regardless of the type of inlet control system, each reservoir must be equipped with an isolation valve on the inlet. This may be a butterfly or gate valve.



Typical reservoir piping

The outlet normally extends a few inches above the floor to prevent silt, which may enter the tank, from flowing out of the tank. The outlet is commonly screened and includes some type of isolation valve.

The drain line should be installed at floor level to allow complete drainage and cleaning of the tank. To prevent rodents from entering the drain, a screen or flap gate is installed at the end of the drain line.

The inlet and outlet piping (and sometimes baffling) should be installed to minimize short-circuiting when using the reservoir for chlorine contact time.

It is important that each reservoir be installed with some type of by-pass piping and valving. This allows the reservoir to be taken offline for cleaning without interrupting service to customers.

Auxiliary Equipment

One of the methods used to prevent the interior of a steel tank from deteriorating due to corrosion is to install a protective system called cathodic protection. Sacrificial zinc anodes are placed in the water and a direct current applied to the anodes. This assures that the current flow through the tank is in a direction that will cause the anodes, not the tank, to deteriorate. The zinc placed on an outboard motor to reduce corrosion is an example of this process.

The entrance hatch should be in a position so that it is easy to access. To reduce the possibility of unauthorized entry and possible contamination, the hatch should remain locked except when in use. The best hatches are of the “shoe box” design, where the lid overlaps the hatch opening. This prevents rain from entering the reservoir.

Confined Space

A storage reservoir is a confined space. Entry for inspection should only be done in accordance with the confined space entry requirements.

Ladders are installed on the outside of the tank to allow access to the hatch. These ladders are usually locked, or access is restricted by raising the end of the ladder several feet above the ground to deter vandalism. The ladder on a storage reservoir may require special fall protection to prevent injury.

To reduce access to the reservoir, it is common practice to surround the reservoir with a six-foot-high chain link fence with a gate that remains locked, except when maintenance is being performed on the tank.

To prevent the collapse of a reservoir when all of the water is drawn out, one or more vents are installed. These vents should be screened to prevent the entrance of birds, rodents, and insects.

A storage reservoir is a confined space. Entry into this space requires that you follow the confined space entry permit requirements. When spraying a chlorine solution, you should wear chemical safety goggles, a cartridge respirator, rubberized gloves, and protective clothing.

Cold-Climate Distribution Systems

Utilidors

Utilidors are used in some arctic locations to house and protect water distribution and sewer collection systems. The utilidor also provides access for maintenance to piping, valves, and fire hydrants.

There are three types of utilidors—those made with concrete, those made with wood, and those made with arctic pipe:

- Concrete utilidors – Concrete utilidors are usually installed underground, such as in Fairbanks. Concrete utilidors are not very common because of their cost. They usually contain a large variety of utilities such as water, sewer, electricity, phone, TV cable, and commercial heat.

- Wood utilidors – Wood utilidors are more popular than concrete, but still not very common. The cost of construction is their major disadvantage. There are two types of wooden utilidors: those constructed of plywood and insulated on the inside with high-density polyurethane or polystyrene and those made of laminated planks and insulated on the outside, such as in Barrow. Wood utilidors can be installed above or below ground. One of the major problems with below-ground utilidors is flooding from a water or sewer line failure or leakage from the outside during spring and summer months.
- Arctic pipe utilidors – Among the most common utilidor systems are those made with arctic pipe. Standard arctic pipe made with PVC or HDPE carrier and 16-gauge corrugated steel coating is used. The water line is laid inside of the carrier. The carrier may also contain sewer lines and heating lines or heat trace tape. Arctic pipe utilidors may be installed above or below ground.

Utilidors are commonly heated with a hot water or a glycol loop from a low-pressure boiler and heat exchanger, from a forced air heating system, or from self-regulating heat trace tapes.

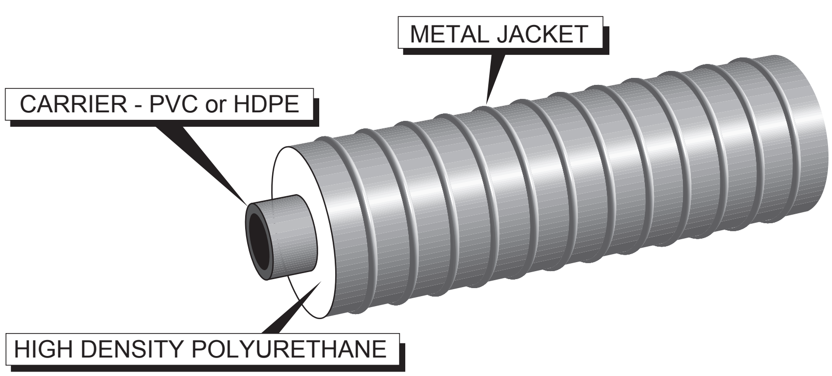
Arctic Pipe

Arctic pipe is a general name given to piping material that is made of three components:

- An inside pipe, called a carrier
- Several inches of high-density polyurethane or polystyrene insulation that protects the carrier
- An outside protective layer

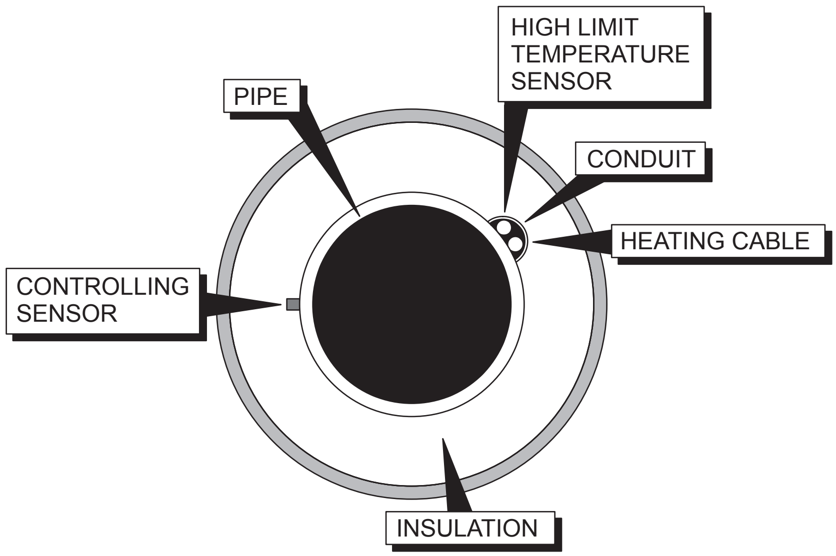
The most common carriers are made of PVC or HDPE. The outside cover can be made from a variety of materials. The two most common are polyvinyl chloride butyl rubber and 16-gauge corrugated steel or aluminum. The polyvinyl chloride butyl rubber coating is commonly used in underground installations, and the corrugated steel is the most commonly used in above-ground installations.

Arctic pipe can be purchased with a built-in heat trace tape designed to prevent freezing in extreme conditions. This tape can be installed in the field or at the factory. The tape is placed against the carrier, and electrical connections should be made at each joint.



Arctic pipe

Size is relative to the component being discussed. The arctic pipe industry makes insulated pipe from all of the popular materials and in the ranges normally manufactured. In Alaska's rural communities, the most common carriers are 160 psi, two inches through six inches HDPE. Insulation thickness varies from one to three inches, depending on the expected temperature around the pipe. As mentioned earlier, the exterior material varies from a 20 mil laminated polyvinyl chloride butyl rubber coating to 16-gauge steel or aluminum.



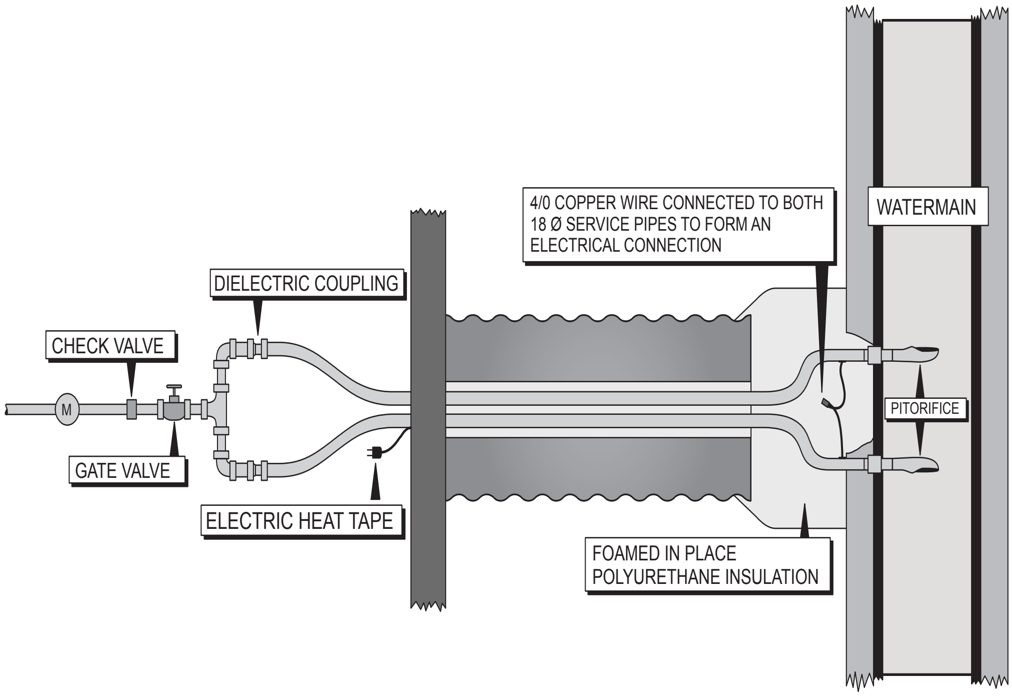
Arctic pipe with heat trace system

The joints for the carrier are made in the same manner as if the carrier were not associated with the arctic pipe. The joints for the polybutyl cover are made by installing insulation, wrapping the insulation with the tape, and covering the tape with an epoxy. Joints for the corrugated cover are made by use of a split cover that is placed around the joint and bolted together.

Circulation Systems

Many arctic water distribution systems are designed with circulating water mains constructed as loops. The water may be heated to a temperature above freezing (40 to 45°F) by means of a heat exchanger at the water treatment plant and then pumped through a service area zone and returned to the treatment building. Oil-fired, low-pressure, hot water boilers are a common source of energy for the heat exchanger. If a water-glycol mixture is used for the exchanger, propylene glycol that is non-toxic should be used.

In the circulation system, there are two taps and two lines: an entry line and a return line. The corporation stops are the pitorifice type. This device is a standard corporation stop with a Pitot tube bend on the inlet. The inlet pitorifice is pointed into the flow, and the outlet pitorifice is pointed away from the flow. The service line loops into and out of the house. If there is a meter, it is attached to a tee on the top of the loop. In some instances, a small pump is installed in the service line to assure constant movement. In order for the pitorifice to work properly, the service line cannot be over 60 feet in length, and the velocity in the main line must be at or above two feet per second (two ft/sec).



Dual pitorifice installation designed to assure continuous circulation of water

Heat trace tape is occasionally installed in conjunction with circulating systems.

If the meter is installed using copper piping, a wire with clips must be placed across the meter before the meter is removed. This protects the operator in case the electrical system is grounded to the water system.

Service connections from the utilidor to the customer are made using arctic pipe containing all of the services. The arctic pipe is sealed to the utilidor.

To reduce the potential of water freezing in them, steel tanks are often covered with three inches of polystyrene or polyurethane boards or spray. The insulation is then covered with metal or fiber coating to protect the insulation from damage.

Cold Weather Operation

A common problem in arctic environments is frozen water lines. There are three acceptable methods used to thaw these lines.

Electrical

While electrical thawing has been used to thaw frozen steel and copper lines, its use is discouraged. For quite some time, it has been recognized that electrical thawing of water mains can be quite dangerous. Many communities no longer allow metal utility pipe for use as a ground. There have been instances where if the voltage and amperage are not controlled, home circuits may be damaged or destroyed, and, in extreme cases, the entire home may be destroyed by fire. The popular use of HDPE and PVC pipe do not lend themselves to electrical thawing. The exception to this rule are plastic pipelines installed with a heat-tracing conductor suitable for maintaining flow and thawing if feasible.

High Pressure

One of the common effective methods of thawing small diameter lines is with the use of a high-pressure washer or jet unit. This device produces a pressure of 2200 psi at a flow of 5.2 gpm. The water can be heated with an inline heater to 50°F to 180°F. The water is pumped at high pressure through a small-diameter line that is hand-fed into the frozen line. The pressure and heat are used to thaw the line. This unit has been effective at temperatures as low as -10°F.

Steam

A steam unit, similar to the high-pressure unit, is also commonly used to thaw water lines. A positive displacement pump is used to pump 500°F steam at 1.5 gpm through a small line. The small line is hand-fed into the frozen pipe. The steam is produced by an oil-fired boiler that uses kerosene or No. 1 fuel oil. Steam should not be used on plastic or HPDE pipe unless the temperature can be reduced to under 230°F.

Hot Water

In many cold-climate regions, a hot water technique is used to thaw frozen water mains and services. This may be done by breaking the service in the home and feeding a ¼ to 3/16-inch tube into the service line. The tube is advanced to the point of blockage, and then hot water is fed through the tube as it advances until the blockage is melted. Since this procedure may form a cross connection with the potable water system, action must be taken to protect the public supply by using disinfected water or a backflow assembly.

Operation and Maintenance of Distribution Systems

The proper O & M of distribution systems is part of the overall O & M of the water facility and includes the following activities:

- Collecting bacteriological samples
- Testing for chlorine residuals
- Finding and repairing leaks
- Testing system pressure at various locations on a systematic basis
- Flushing the main lines at least once a year
- Inspecting fire hydrants twice a year (fall and spring)
- Locating and exercising in-line valves at least once a year
- Cleaning the storage reservoir once a year
- Inspecting the storage reservoir, screens, valves, and hatches once a year
- Replacing pilot valves and valve seats and inspecting the main valve seat on all pressure-reducing valves and altitude valves once a year.

Water Distribution System Quality

The following is the six-Step program for maintaining “Good” water in the distribution system:

1. Maintain a positive pressure of at least 20 psi.
2. Manage the “age” of the water.
3. Maintain a chlorine (or other disinfectant) residual.
4. Keep the pipelines clean.
5. Provide treatment so that the water does not degrade in the water distribution system.
6. Set up Water Quality Goals, and test the water frequently.

The minimum pressure should be 20 psi throughout the distribution system. If the pipelines are designed to carry fire flow, the 20-psi minimum pressure should be maintained at the location of the fire, plus all service points in the system during the fire. Care should be used when opening and closing fire hydrants because a surge may cause a drastic fluctuation in high and low pressure in the system. Hydrants valves should always be turned SLOWLY.

Manage storage tanks and pumps to reduce the age of the water and keep the water moving in the distribution system as much as possible. Water should not sit stagnant in the system for more than five days. Water movement can be improved by eliminating dead-end pipes and re-configuring pressure zones. Dead-end water mains are often the source of taste and odor complaints from customers.

Often, storage tanks are oversized to provide fire protection or water for future growth. Water may fail to “turnover” in the tank because of low flow or layering due to temperature differences. Reservoir turnover can be improved by changing the drawdown levels in the tank to draft more water or by adding a recirculation pump. When tank water level controls are altered, system pressure should not be decreased below minimum levels. Additionally, some tanks may have been designed to meet chlorine contact time using a set volume. Good mixing of water can be achieved in a tank by using a small recirculation pump, turbulent inflow, diffusers, or all three of these methods.

Regulations typically require that only a trace of chlorine residual be maintained in the distribution system, but a recordable quantity, such as 0.2 mg/L measured as a free residual, is suggested throughout the system including dead-end lines.

Pipelines can be maintained in a “clean” condition by removing particles or sediment through adequate treatment prior to distribution. Before a new water main is placed into service, it should be flushed and disinfected and flushed again per AWWA standards. The rehabilitation and repair of water mains are common activities that pose a risk of contamination if not performed properly. Main breaks should be isolated and backflushed to remove debris, then disinfected and tested for coliform before being placed back into service. Along with cleaning, pigging, and routine flushing of water mains, a good maintenance program includes scheduled replacement of old, deteriorated piping.

Flushing may include conventional or unidirectional methods:

- Conventional flushing consists of random drawing of water from hydrants without associated valve isolation. The direction of water flow and velocity are not controlled. Deposits may be stirred up, and some are removed, but other sediment may only be moved to another point in the pipeline.
- Unidirectional flushing requires prior planning of sequential valve and hydrant operation to move water from the source out toward the extremities of the system. The operator controls water flow and velocity. Velocity is sufficient to remove sediment and biofilm from the pipe interior. The process may include several measurements, such as velocity, chlorine residual, pH, turbidity, and coliform or TTHM sampling. A typical two-person crew can flush one mile of pipeline in an eight-hour shift.

Treatment of the water source prior to distribution may be necessary not only to meet turbidity and coliform standards, but also as a means to reduce chlorine demanding substances that could lead to TTHM and HAA5 formation. Often the source water must be treated to reduce its corrosiveness or to remove taste and odor. Consideration should be given to flushing water mains late at night to lessen traffic disruption and minimize customer complaints.

Water quality monitoring goals may include system-wide standards for heterotrophic plate count, chlorine residual, turbidity, taste and odor, or color. Often customer complaints are tracked as a means of better understanding distribution system water quality.

Leak Detection

In many water distribution systems, a significant percentage of water is lost while in transit from treatment plants to consumers. Recent technical publications indicate that the amount of lost or "unaccounted for" water is typically in the range of 20 to 30 percent of production. Although unaccounted for water is usually attributed to several causes, including leakage, metering errors, and theft, leakage is the major cause. In addition to environmental and economic losses caused by leakage, leaky pipes pose a public health risk, as leaks are potential entry points for contaminants if a pressure drop occurs in the system.

To minimize public health risks and conserve water or save on treatment costs, operators and managers may want to implement leakage control programs. There are two major steps in any systematic leakage control program:

- Water audits – Water audits involve detailed accounting of water flow into and out of the distribution system or parts of it. The audits help to identify areas having excessive leakage. Unfortunately, they do not provide information about the location of leaks. To do so, leak detection surveys must be undertaken.
- Leak detection surveys – In leak surveys, the water distribution system is checked for leaks by using acoustic equipment that detects the sound or vibration induced by water as it escapes from pipes under pressure. Acoustic equipment includes listening devices, such as listening rods, aquaphones (or sonoscopes), and geophones (or ground microphones). These are used to listen for leak sounds at contact points with the pipe, such as fire hydrants and valves. Acoustic equipment also includes leak noise correlators. These are modern computer-based instruments that have a simple field setup and work by measuring leak signals (sound or vibration) at two points that bracket a suspected leak. The position of the leak is then determined automatically based on the time shift between the leak signals calculated using the cross-correlation method. Several makes of acoustic leak detection equipment are now commercially available.

When water main breaks occur, valves are used to turn off the water so that repairs can be made. If the valves closest to the main break are inoperable, other valves must be closed, necessitating the interruption of water service to additional customers. To reduce the likelihood of this occurring, a water distribution system should be surveyed to determine where older valves should be replaced and where the installation of additional valves would enhance system control. It is recommended that all water distribution system valves be exercised by turning them completely on and off at least once each year. The operator may want to keep precise records of valve location, age, and maintenance performed, as well as the number of turns needed to open and close the valve.

In most areas, fire hydrants require annual inspections and maintenance. They normally have only a one-year warranty, but some have five-year warranties. These inspections are generally performed by the local utility, but they often do not inspect hydrants identified as private. Fire hydrant manufacturers recommend lubricating the head mechanism and restoring the head gaskets and “O” rings annually so that the fire hydrant can perform the service expected of them. Lubrication is generally done with a food-grade, non-petroleum lubricant to avoid contamination of the distribution system.

Occasionally, a stone or foreign object will mar the seat gasket. In this case, most hydrants have a special seat wrench that allows for removing the seat to replace the gasket or other broken parts without removing the hydrant from the ground. Hydrants extensions are also available for raising a hydrant if the grade around the hydrant changes. Without extending the height, the wrenches to remove caps will not clear, and the break flanges for traffic models will not be located correctly. Hydrant repair kits are also available to repair sacrificial parts designed to break when hit by a vehicle.

Many departments use the hydrants for flushing out water line sediments. When doing so, they often use a hydrant diffuser, which is a device that diffuses the water so that it doesn’t damage property and is less dangerous to bystanders than a solid stream. Some diffusers also dechlorinate the water to avoid surface water contamination.

Storage and Reservoir Inspection and Maintenance

Reservoir cleaning, leak testing, and inspection are ways to assure the integrity of a utility’s water storage facilities and to preserve overall water system reliability. Many water systems have adopted procedures from the American Water Works Association (AWWA) for inspecting steel tanks, standpipes, and reservoirs. The only exceptions are those facilities that cannot be removed from service without jeopardizing public health and welfare.

Tanks and reservoirs should be inspected externally and leak-tested annually. Primary reservoirs should be cleaned and disinfected every three years. All other reservoirs should be cleaned and disinfected every five years. Interior inspection should be no fewer than every five years, or whenever routine cleaning and disinfection is completed. After cleaning, if the reservoir was drained, it should be disinfected by spraying the walls with a five percent chlorine solution. If the reservoir is full of water, sufficient chlorine may be added to bring the residual to 10 mg/L for a 24-hour holding period.

Leakage test results and applicable reservoir or tank inspection information may be documented on a reservoir inspection form, signed, dated, and kept in a permanent maintenance file. This form should note the condition of interior paint or coating, interior pitting or cracking, any repairs made, and the condition of structural components.

Review

1. Arctic pipe is composed of three components. Name these three components.
2. What gauge metal is used on the outside of arctic pipe?
3. What standard pipe sizing is used for the OD of HDPE pipe?
4. What is a pitorifice?
5. Describe two methods of heating a utilidor.
6. Describe three methods for thawing frozen water lines.

Cross Connection Control

Health Risk

The plumbing at schools, water treatment plants, wastewater plants, and other public and private facilities can be so complicated that the potable water piping can be unintentionally connected to a source of contamination. If this happens, a health risk is created. There are hundreds of incidents each year where contaminated material enters a water system through cross connections.

In small communities, possible sources of contamination are associated with swimming pools and wastewater treatment plants where chemicals such as chlorine, fluoride, and boiler additives are used.

A health risk can exist if the drinking water system is connected directly or indirectly to contaminated sources. This can happen when a chemical is mixed and the hose is placed in the mixing tank or the drinking water system is connected to the **seal water**[22] supply on a sewage pump. This direct or indirect connection is called a **cross connection**[23].

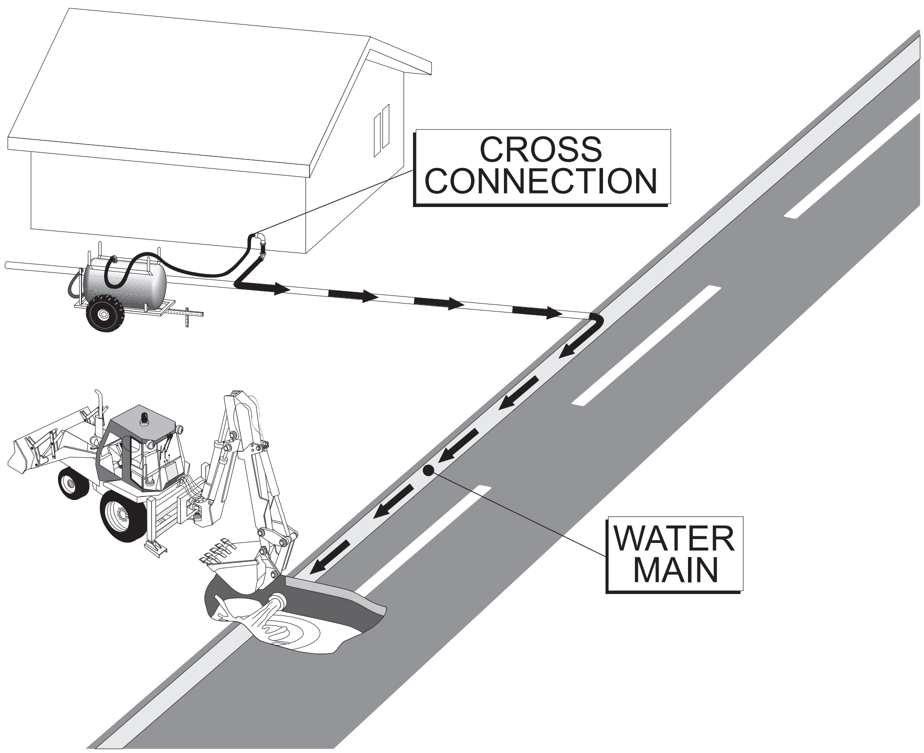
[22] Seal Water – The water supplied to the stuffing box to lubricate and flush the packing or the mechanical seal.
[23] Cross connection – Any physical arrangement whereby a public water supply is connected, directly or indirectly, with a non-potable or unapproved water supply or system.

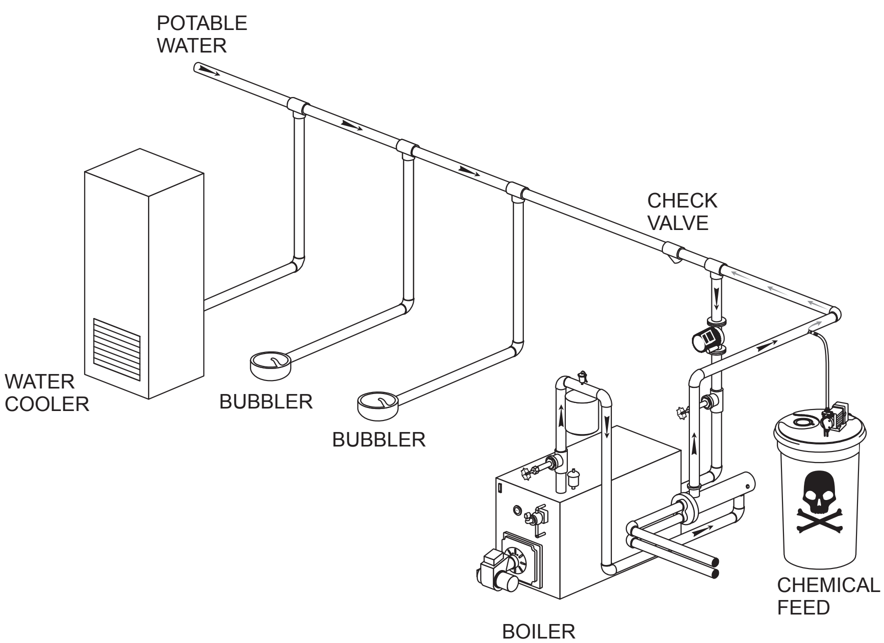
The cross connection can only cause a problem if there is a reversal of flow in the system. This reversal of flow is called backflow. Backflow exists anytime water moves backward through the system.

There are two ways that backflow can occur:

- Backsiphonage occurs when the pressure in the system drops below atmospheric pressure and the water distribution system is connected to a nonpotable source that is open to the atmosphere. This can happen if the distribution system pressure is lowered as a result of a main break or heavy use, such as during a fire.

- Backpressure exists any time the pressure in the contaminated source exceeds the pressure in the distribution system. This can happen as a result of a booster pump in a heating system or excessive pressures in a boiler improperly connected to the potable water supply.





Backpressure condition

Each state's drinking water regulations indicate that a known cross connection cannot be allowed to exist. Because inspection of facilities is difficult, time-consuming, and not always possible, the waterworks industry has taken a preventive approach to cross connection control. Under this approach, facilities that have a high potential of cross connection or that handle highly hazardous materials are required to protect the water system. This is accomplished by installing special devices in the facility and on the water service connection where it enters the facility.

Assemblies

The assemblies used to prevent backflow from a potential cross connection include the following:

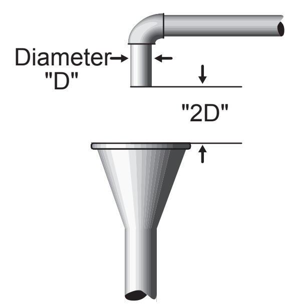
- Air gaps
- Atmospheric vacuum breakers
- Pressure vacuum breakers
- **Double check valve assemblies**[24]
- Reduced pressure zone backflow prevention assemblies

[24] Double Check Valve Assembly – An assembly of two independently acting check valves with shut-off valves on each side of the check valves and test ports for checking the water tightness of each check valve.

The assembly to be used should be selected based upon the degree of hazard, plumbing arrangement in the facility, and the use of additional devices within the facility.

A high-hazard facility would include a sewage treatment plant or lift station. A low level of hazard would be a situation where the odor and taste of the water might be affected, but there is no health risk.

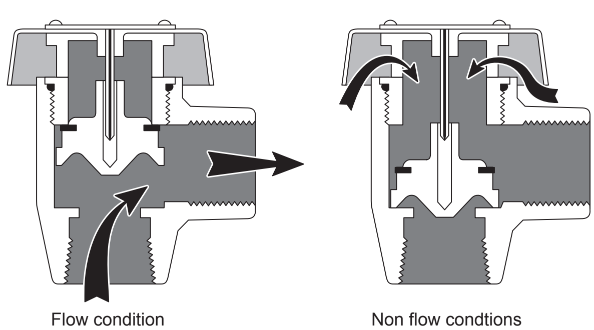
The most protective of the assemblies is the **air gap**[25]. The air gap is easy to observe and inspect. The air gap is a positive way to protect the water supply from a chemical vat. The requirements are that the air gap between the two water sources be twice the diameter of the outlet of the supply line but no less than one inch from the rim of the tank. Air gaps can be used on high-hazard conditions.



[25] Air Gap – A positive means of preventing a cross connection. An air gap should be twice the diameter of the discharge pipe or a minimum of 1 inch above the rim of the tank.

Atmospheric vacuum breakers are used on low-degree hazard conditions, such as janitor sinks, lawn sprinkler systems, and supply lines on low-concentration chemical vats, such as chlorine and fluoride solutions. Atmospheric vacuum breakers open any time there is a backsiphonage and allow air to be drawn into the line, preventing a backflow of the downstream solution. They will not prevent backflow as a result of backpressure. A downstream valve cannot be installed on an atmospheric **vacuum breaker**[26].

[26] Vacuum Breaker – A mechanical device that prevents backflow due to siphoning action created by a partial vacuum that allows air into the piping system, breaking the vacuum.



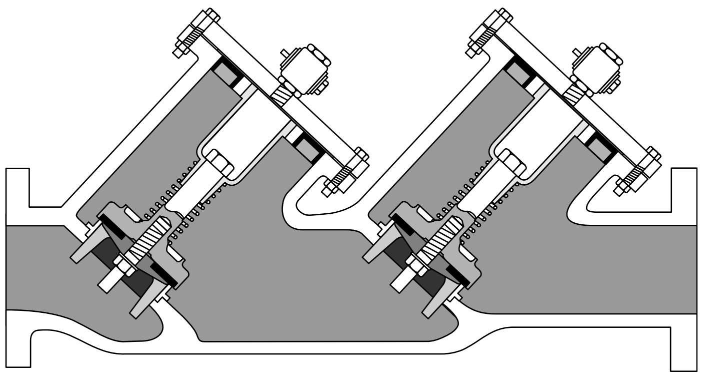
Atmospheric vacuum breaker

Pressure vacuum breakers are used for the same functions as an atmospheric vacuum breaker. There are only three differences:

- The pressure vacuum breaker has an internal spring that helps it to open.
- There are valves to allow the assembly to be tested.
- A valve can be placed in the downstream line.

They are not designed for connections where backpressure may exist.

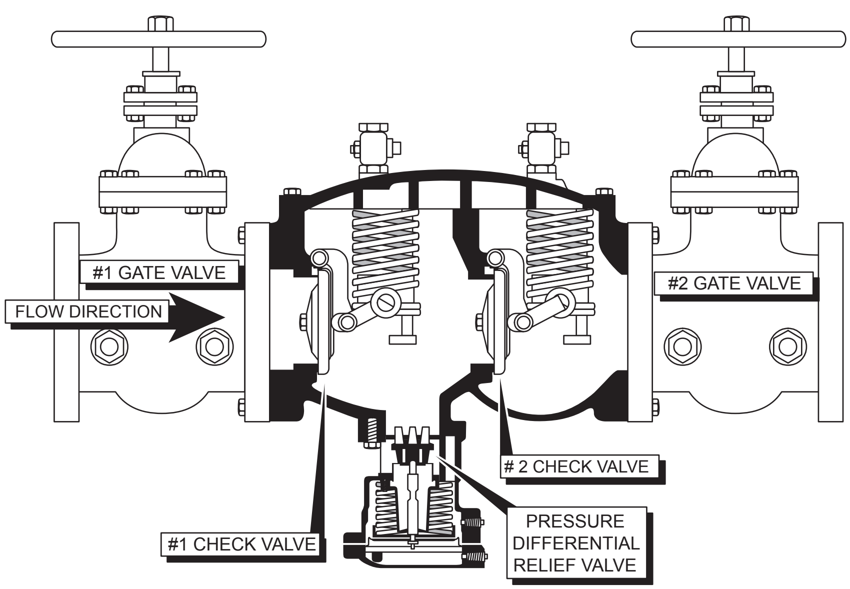
A double check valve assembly (DCVA) is composed of two independent internally weighted check valves (springs), isolation valves on each side of the assembly, and test ports on the assembly that allow a tester to determine that the check valves are watertight. DCVAs protect against backpressure or backsiphonage on low-hazard conditions.



Double check valve assembly

High-hazard conditions require an air gap or a **reduced pressure zone backflow prevention assembly (RPZ)**[27]. It is composed of two independent, internally weighted check valves separated by a reduced pressure zone valved to the atmosphere. The assembly also has an isolation valve on each end, as well as test ports to determine the proper operation of the assembly. The valve is designed so that the valve on the reduced pressure zone will open when the pressure in the zone gets to within two psi of the supply pressure. For backflow to occur through this valve, the two check valves, as well as the reduced pressure zone valve, would all have to fail at the same time.

[27] RPZ (Reduced Pressure Zone Backflow Prevention Assembly) – A backflowpreventionassemblycontaining two check valves, a differential relief valve located between the two check valves, shut-off valves on each end of the assembly, and test ports for checking the water tightness of the check valves and the operation of the relief valve.



Rockwell Model 701 RPZ assembly

Only approved assemblies may be installed in a water system. For an assembly to be approved, it must undergo extensive testing by a private testing laboratory. ADEC maintains a listing of approved assemblies. Contact the regional ADEC representative for a listing of these devices.

A certified backflow prevention device tester must test the assemblies once each year. To obtain a certification as a backflow prevention assembly tester, you must attend a school and pass a written and practical exam. To maintain your certification, some states require an annual refresher course, proof that you have tested devices in the past year, and a certificate indicating that your test instruments have been tested within the past year.

Review

1. Describe the terms backsiphonage and backpressure.
2. Name the proper cross connection control device for a sewage treatment plant, clinic, and a boiler feed water to a glycol system.
3. Cross connection control devices should be tested how often?

Water Distribution Systems Quiz

1. Which of the following primarily determines the size of water mains, pumping stations, and storage tanks?
   A. Maximum day demand during the 24-hour period during the previous year
   B. Population served
   C. Per-capita water use
   D. Fire protection requirements

2. Which of the following is a measure of the smoothness of pipe?
   A. S factor
   B. C factor
   C. Hazen-Williams formula
   D. T factor

3. The primary purpose of check valves is to prevent:
   A. Excessive pump pressure
   B. Priming
   C. Water from flowing in two directions
   D. Water hammer

4. Why is excessive water pressure to residential homes objectionable?
   A. Increases particulate matter reaching the customer
   B. Causes erosion of the copper plumbing due to the high velocities, giving the water a metallic taste
   C. Decreases the life of the water heaters and other water-using appliances
   D. Causes foaming from faucets

5. What is the best time to perform a flushing program on the mains?
   A. Spring when the weather is usually mild
   B. Fall when water usage is low and the weather not yet harsh
   C. Late at night to lessen traffic disruption and minimize customer complaints
   D. Summer when many residents are on vacation

6. Large full storage tanks are typically disinfected with a chlorine residual of which of the following?
   A. 3 mg/L
   B. 10 mg/L
   C. 25 mg/L
   D. 50 mg/L

7. Which one of the following service line materials is not flexible?
   A. Copper
   B. Galvanized iron
   C. Lead
   D. Plastic

8. What is the term for a framework of wood or metal installed to prevent caving of trench walls?
   A. Sheeting
   B. Sloping
   C. Shielding
   D. Shoring

9. Which type of pipe is typically used in the construction of very large water mains?
   A. Asbestos-cement
   B. Steel
   C. Plastic
   D. Galvanized

10. Air-relief valves are installed for which of the following reasons?
    A. Release some of the energy created by water hammer
    B. Stop flow completely when the tank is full
    C. Vent air that has accumulated in the well column while the well is not in use
    D. Turn off pressure during hydrant main maintenance without disrupting service to customers

11. After a new water main is installed and pressure tested, it should be:
    A. Flushed with clean water for 24 hours and put into service
    B. Filled with a solution of 25 ppm to 50 ppm free chlorine for at least 24 hours prior to flushing
    C. Filled with clean water and allowed to sit for five days at full pressure before turning the water into the system
    D. Photographed so that mapping can be avoided until the system is complete

12. Which type of hydrant has no main valve but has a separate valve for each nozzle?
    A. Wet-barrel
    B. Warm-climate
    C. Dry-barrel
    D. Breakaway

13. Which of the following type of valve is used in maintaining prime to a pump?
    A. Foot
    B. Suction
    C. Vacuum header
    D. Butterfly

14. Which of the following metals make the best anode?
    A. Brass
    B. Cast iron
    C. Zinc
    D. Copper

15. A six-inch pipeline needs to be flushed. If the desired length of pipeline to be flushed is 316 feet, how many minutes will it take to flush the line at 31 gpm?
    A. 10 minutes
    B. 15 minutes
    C. 30 minutes
    D. 60 minutes

16. Why should the operator contact area companies with underground utilities before starting an underground repair job?
    A. To determine if there have been recent excavations in that location
    B. To ask the companies to locate and mark the location of their utilities in the area of the repair job
    C. To determine if they also have excavating to do in the area
    D. To ask if they will help route traffic while you are doing the repair job

17. What is the area of a trench that is 22.4 feet long and 3.3 feet wide?
    A. 26 sq ft
    B. 74 sq ft
    C. 143 sq ft
    D. 187 sq ft

18. Interior copper tubing is usually joined by:
    A. Solder
    B. Flare
    C. Compression
    D. Union

19. Which type of piping is most resistant to corrosion?
    A. Plastic
    B. Stainless steel
    C. Concrete
    D. Asbestos-cement

20. What is the minimum contact time when using the chlorine tablet method of disinfecting water mains?
    A. 6 hours
    B. 12 hours
    C. 18 hours
    D. 24 hours

21. A pipeline that contains reclaimed water should be tinted or painted what color?
    A. Orange
    B. Yellow
    C. Purple
    D. Red

22. What is the diameter of a tank with a circumference of 408.2 ft?
    A. 31 ft
    B. 130 ft
    C. 260 ft
    D. 1,282 ft

23. Fuel oils, gasoline, and other organic compounds may permeate which type of piping?
    A. Plastic
    B. Asbestos-cement
    C. Fiberglass
    D. Concrete

24. Why should isolation valves be installed at frequent intervals in the distribution piping?
    A. To stop water from flowing backward through a pump that is not in operation
    B. To throttle flow and maintain a lower pressure in the lower distribution system zone
    C. So that air that accumulates at high points in pipes can be automatically vented
    D. So that small sections of water main may be shut off for maintenance

25. What water quality problem is most likely to occur at dead-end water mains?
    A. Dirty water
    B. Taste and odor
    C. Milky water due to air bubbles
    D. Dirty clothes due to manganese

26. What type of concrete tank is made like a home basement but with more reinforcement?
    A. Cast-in-place concrete
    B. Hydraulically applied concrete-lined
    C. Circular prestressed-concrete
    D. Prestressed concrete-wire-wound

27. PVC pipe can use tees, elbows, and other fittings from what other type of pipe?
    A. Prestressed concrete cylinder
    B. Ductile iron
    C. Concrete
    D. Asbestos-cement

28. What type of ductile-iron pipe joint is quickly assembled and is the least expensive?
    A. Flanged joint
    B. Mechanical joint
    C. Push-on joint
    D. Ball-and-socket joint

29. Where is the most common location of leaks on old service connections?
    A. Household plumbing
    B. Connections to the curb stop
    C. Connections to the gate valve
    D. Pressure regulator

30. Dry-barrel fire hydrants are used in what type of environment?
    A. Dry
    B. Wet
    C. Freezing
    D. Hot

31. The supply or fill hose for a Watering Point System must be tested and approved by:
    A. The American Water Works Association (AWWA)
    B. The Association of State Drinking Water Administrators (ASDWA)
    C. The National Sanitation Foundation (NSF)
    D. The Society of Professional Engineers (SPE)

32. Which of the following is the best type valve to use to dampen a water hammer?
    A. Pressure-relief
    B. Needle
    C. Pressure-reducing
    D. Pinch

33. Which of the following valves can be used to control pressure?
    A. Globe
    B. Butterfly
    C. Gate
    D. Plug

34. Which of the following valves is best to use in throttling flow?
    A. Globe
    B. Butterfly
    C. Gate
    D. Ball

35. What is the pressure head at a fire hydrant in feet, if the pressure gauge reads 121 psi?
    A. 52 ft
    B. 86 ft
    C. 141 ft
    D. 280 ft

36. Which of the following types of valve is the best to use for maintaining the water level in a storage tank?
    A. Altitude
    B. Tapping
    C. Butterfly
    D. Needle

37. A joint that consists of a rubber gasket and follower ring held to a flange by a row of bolts is called a:
    A. Bell and spigot
    B. Caulder coupling
    C. Mechanical joint
    D. Victaulic coupling

38. Water mains should be separated from sewer mains by:
    A. At least 24 inches vertically and 60 inches horizontally
    B. A horizontal distance of 10 ft and vertical distance of 12 inches above the sewer main
    C. A vertical distance of 5 ft above the sewer and 5 ft horizontally
    D. A PVC curtain at least 6 mil in thickness extending to a depth of 4 ft below the invert of the sewer main

39. A thrust block or restrained joint should be installed in a water distribution system:
    A. At a change in direction, size, dead end, or valve and hydrant locations
    B. At the apex or high point of every water main to prevent water hammer
    C. Wherever there is a change in velocity head due to friction
    D. Whenever a wet tap is made at a point between the curb stop and tapping saddle

40. A special corporation stop design used in arctic climates that enhances circulation through a service connection loop to the home is the:
    A. Recirculating ball valve
    B. Heat traced curb device
    C. Arctic insulated curb stop
    D. Pitorifice

Introduction to Pumping Systems

Chapter 6

What Is In This Chapter?

1. The function of pumping systems
2. Common pump types
3. The basic theory of operation of centrifugal pumps
4. The basic theory of operation of diaphragm pumps
5. The major components of a pumping system, including the building and piping system
6. Terms used to identify common pumps and their components
7. The weight of a cubic foot of water
8. How to convert between cubic feet and gallons
9. The difference between force and pressure and what impacts them
10. How to convert between psi and feet of head
11. The difference between psi and feet of head
12. The relationship between flow in cubic feet per second and gallons per minute
13. The terms used to describe static and dynamic hydraulic conditions
14. Headloss and its causes
15. The terms used to describe pumping conditions

Key Words

- Amperage
- Axial Flow Pumps
- Can Turbine Pumps
- Cavitation
- Centrifugal Force
- Centrifugal Pump
- Close-coupled Pumps
- Concentric Reducer
- Displacement Pumps
- Dynamic Pumps
- Eccentric Reducer
- End Suction Centrifugal Pumps
- Energy
- Foot Valve
- Force
- Frame-mounted Pumps
- Headloss
- Horsepower
- Impeller
- Inertia
- Line Shaft Turbine Pumps
- Mechanical Seal
- Packing
- Pressure
- Pump Bowl
- Seal Water
- Shroud
- Split Case Pumps
- Static
- Stuffing Box
- Submersible Turbine Pumps
- Suction Head
- Suction Lift
- Total Dynamic Head
- Velocity Head
- Vertical Turbine Pumps
- Volute

Lesson Content

This lesson provides an overview of the major pumping-related components found in small water systems. The lesson focuses on descriptions of components, common names, and general function.

Pump Stations

Functions

Pumping stations in small communities are used for the following purposes:

- Remove water from a source, such as a river, lake, reservoir, well, spring, or muskeg pond.
- Move water from the treatment plant to the distribution system or reservoir.
- Circulate water through a distribution system.
- Maintain pressure in the distribution system.
- Circulate glycol through a heat exchanger or heating loop.
- Pump chemicals into the system.

Major Components

A pump station is composed of four sets of components:

- The building
- The hydraulic system: the pump and related piping
- The electrical system: the motor and its related components
- The control system: pressure, flow, and level switches

Pump Station Buildings

Introduction

In medium-to-large facilities, pumping stations are usually separate buildings. In small systems, while they can be separate buildings, they are normally associated with the treatment plant, watering point, or other buildings.

Basic Consideration

Regardless of the design, most pumping station buildings are designed with the door opening out to allow access should there be a broken water line in the building. In addition, the buildings should be vandal-resistant, well-heated in the winter, and properly vented in the summer.

Hydraulic System

Pump Types

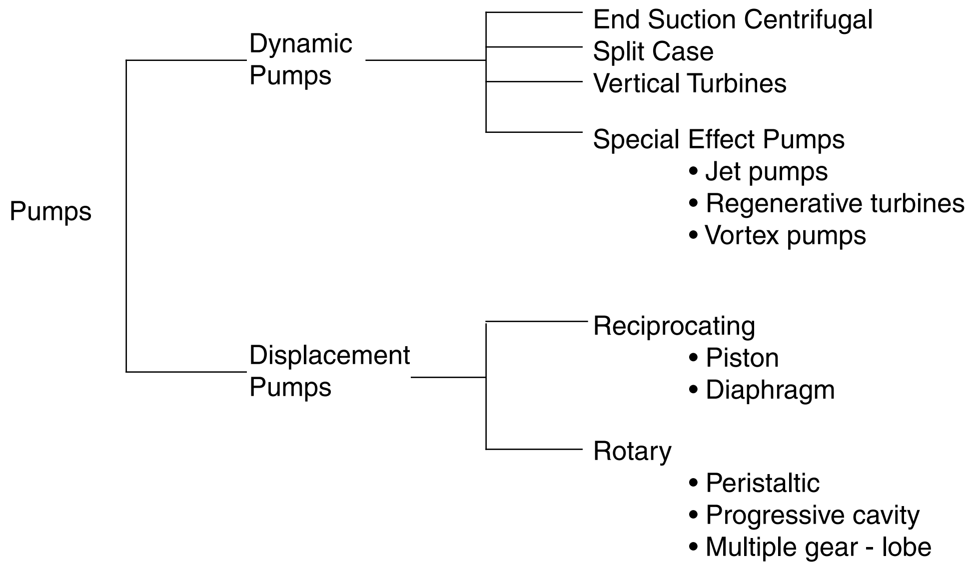
The pumps used in small water systems can be divided into two general categories. The basic difference between the two types is their response to changes in discharge pressure.

- **Dynamic pumps**[1] – Dynamic pumps are used in conditions where high volumes are required and a change in flow is not a problem. As the discharge pressure on a dynamic pump is increased, the quantity of water pumped is reduced. One type of dynamic pump, centrifugal pumps, are the most common pump used in water systems. Dynamic pumps can be operated for short periods of time with the discharge valve closed.
- **Displacement pumps**[2] – Displacement pumps are used in conditions where relatively small, but precise, volumes are required. Displacement pumps will

[1] Dynamic Pumps – Pumps in which the energy is added to the water continuously and the water is not contained in a set volume.

[2] Displacement Pumps – Pumps in which the energy is added to the water periodically and the water is contained in a set volume.

not change their volume with a change in discharge pressure. Displacement pumps are also called positive displacement pumps. The most common positive displacement pump is the diaphragm pump used to pump chlorine and fluoride solutions. Operating a displacement pump with the discharge valve closed will damage the pump.



Centrifugal Pumps - Pumping Theory

Energy Input Device

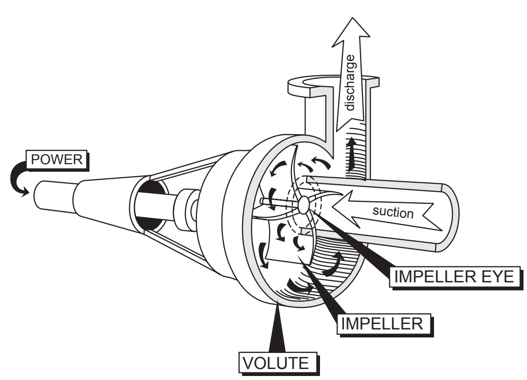
A pump is a device that puts **energy**[3] into the water. This energy can be expressed in two ways: an increase in pressure or an increase in flow.

Centrifugal Pumps – Energy Input

If you were to cut a section out of the top of a pipe and use a canoe paddle to move the water, you would have a pump. It would not be very efficient, but you would be inputting energy into the water. If you reshaped the paddle into an **impeller**[4], you would be able to place more energy into the water. The energy would be transferred from the impeller to the water due to the friction between the impeller and the water. However, water would splash out onto the floor. This is because **centrifugal force**[5] causes the water to fly outward away from the impeller.

The Pump Case

If you surrounded the impeller with a case, you could control the water and obtain a more efficient energy transfer. The case that you would use is volute (spiral-shaped). **Volute**[6] is a geometrical shape, like a circle or a square. For example, a snail shell is volute-shaped. The shape of the case helps to determine the direction of rotation of the pump.



[3] Energy – The ability to do work. Energy can exist in several different forms, such as heat, light, mechanical, electrical, or chemical. Energy can neither be created nor destroyed, but can be transferred from one form to another. Energy exists in one of two states: potential or kinetic.

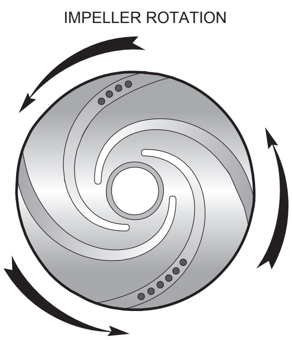
[4] Impeller – A rotating set of vanes designed to impart rotation to a mass of fluid.

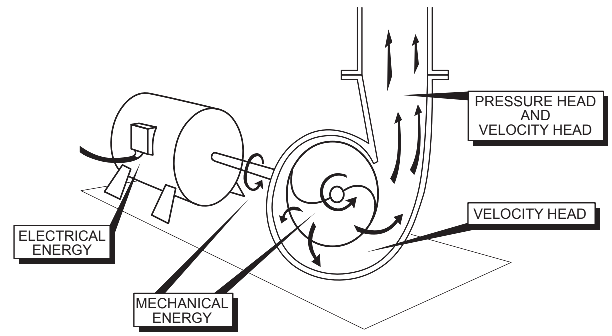
[5] Centrifugal force – The force that when a ball is whirled on a string, pulls the ball outward. On a centrifugal pump, it is the force that throws water from the spinning impeller.

[6] Volute – The spiral-shaped casing surrounding a pump impeller that collects the liquid discharged by the impeller.

Pump Rotation

The direction of rotation can be determined when looking into the suction side of the volute case. For example, in the case below, the direction of rotation is counter-clockwise.





In summary, there are two theories that explain how a **centrifugal pump**[7] works:

- Energy transfer – the transfer of energy from the shaft to the impeller and from the impeller to the water.
- Centrifugal force – the force used to throw the water from the impeller.

[7] Centrifugal Pump – A pump consisting of an impeller fixed on a rotating shaft and enclosed in a casing, and having an inlet and discharge connection. The rotating impeller creates pressure in the liquid by the velocity derived from centrifugal force.

Centrifugal Pumps Configuration

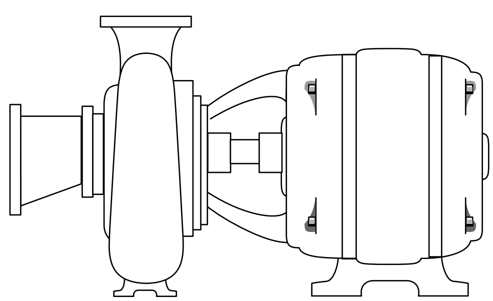
Three Different Configurations

Centrifugal pumps can be divided into one of three classifications based on their configuration: **end suction centrifugal**[8], **split case**[9], and **vertical turbines**[10].

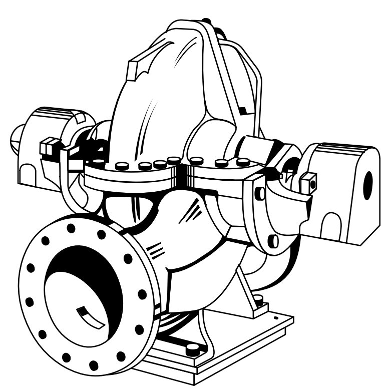
[8] End Suction Centrifugal Pumps – The most common style of centrifugal pump. The center of the suction line is centered on the impeller eye. End suction centrifugal pumps are further classified as either frame-mounted or close-coupled.

[9] Split Case Pumps – A centrifugal pump designed so that the volute case is split horizontally. The case divides on a plane that cuts though the eye of the impeller.

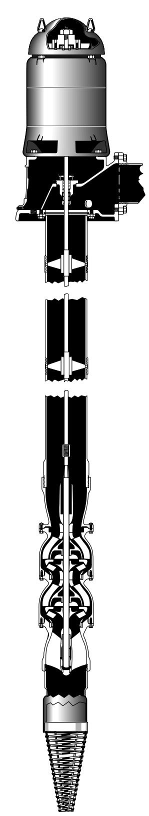
[10] Vertical Turbine Pumps – A classification of centrifugal pumps that are primarily mounted with a vertical shaft; the motor is commonly mounted above the pump. Vertical turbine pumps are either mixed or axial flow devices.



End suction centrifugal



Split case

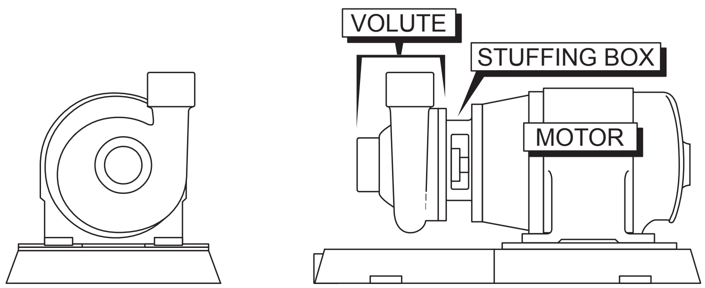


Vertical turbine

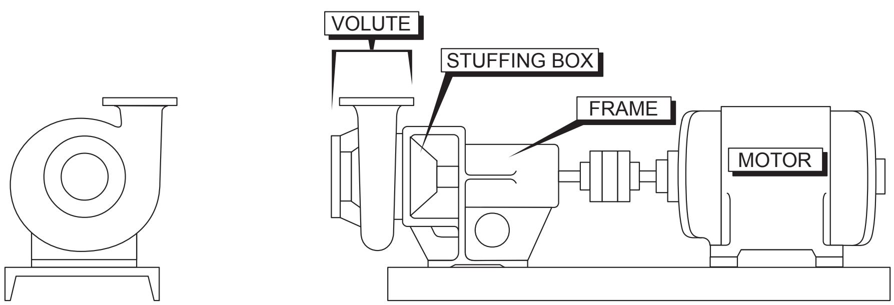
End Suction Centrifugal - Types

The end suction centrifugal pump is the most common centrifugal pump and the one we have in mind when we think about centrifugal pumps. There are two types of end suction pumps:

- **Close-coupled**[11] – A close-coupled pump has only one shaft and one set of bearings: the motor shaft and bearings. The pump impeller is placed directly onto the motor shaft. Close-coupled pumps require less space and are less expensive than frame-mounted pumps.



- **Frame-mounted**[12] – A frame-mounted pump has a shaft and bearings separate from the motor. A coupling is required to get the energy from the motor to the pump.



For safety purposes, couplings should have guards installed.

Split Case Pumps

Split case pumps are unique. The case has a row of bolts that allow half of the case to be removed, providing access to the entire rotating assembly for inspection or removal. These pumps are normally found as fire service pumps and circulation pumps in medium-to-large communities. The circulation pumps in Nome and Fairbanks are split case pumps.

Vertical Turbines

There are four styles of vertical turbines: **line shaft**[13], **axial flow**[14], **can turbine**[15] and the **submersible turbine**[16]. The vertical turbine and the submersible turbine are found in rural communities in Alaska. The primary difference between the vertical turbine and the submersible turbine is the position of the motor. The pumping assembly is the same. Submersible turbine pumps in Alaska can range from 5 gpm to 100 gpm or more.

[11] Close-coupled Pumps – End suction centrifugal pumps in which the pump shaft and motor shaft are the same. The pump bearings and motor bearings are also the same. The impeller is attached directly onto the end of the motor shaft.

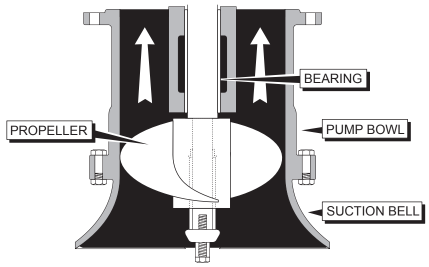
[12] Frame-mounted Pumps – End suction centrifugal pumps designed so that the pump bearings and pump shaft are independent of the motor. This type of pump requires a coupling between the pump and the motor in order to transfer energy from the motor to the pump.

[13] Line Shaft Turbine Pumps – A type of vertical turbine. In this type of vertical turbine, the motor is mounted above the ground, and the pump unit is mounted below the water surface. A column extends from the pump to a discharge head found just below the motor. A shaft extends on a straight line from the center of the motor to the pump. The pump may be mounted a few feet to several hundred feet away from the motor.

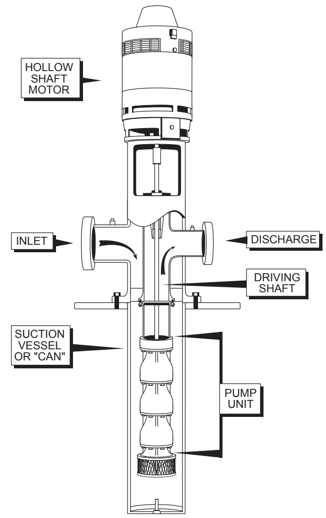
[14] Axial Flow Pumps – A type of vertical turbine that uses a propeller instead of an impeller. In axial flow pumps, the energy is transferred into the water so that the direction of the flow is directly up the shaft.

[15] Can Turbine Pumps – A type of line shaft turbine. The pump assembly is mounted inside of a sealed can. The inlet is mounted opposite the outlet on the discharge head. The can must always be under pressure.

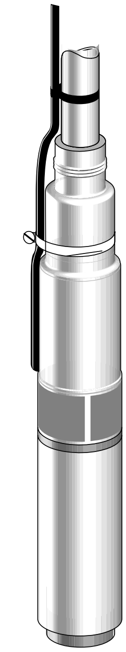
[16] Submersible Turbine Pumps – A style of vertical turbine pump in which the entire pump assembly and motor are submersed in the water. The motor is commonly mounted below the pump.



Axial flow turbine



Can turbine



Submersible turbine

End suction Centrifugal and Split Case Components

Shaft and Bearings

The shaft is used to transfer energy from the motor to the impeller. The most common shaft materials are high carbon steel and stainless steel. Each shaft is supported by bearings that support loads along the shaft, called thrust loads, and loads at right angles to the shaft, called radial loads. The bearings may or may not be part of the motor.

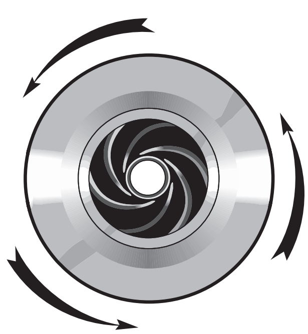
Impellers

The energy is transferred from the shaft to the impeller and from the impeller to the water. There are three types of impellers, based on the number of **shrouds**[17]:

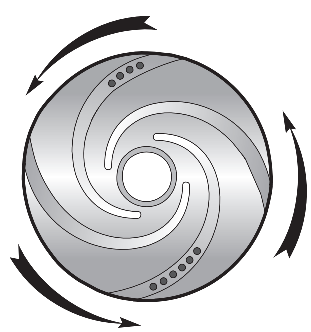
- Closed impeller – When an impeller has a shroud in the front and in the back.
- Semi-open impeller – When there is only a shroud in the back of the impeller.
- Open impeller – When there are no shrouds.

The impeller type is selected by the pump manufacturer to meet specific conditions.

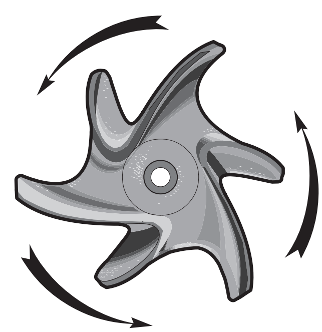
[17] Shroud – The front and/or back of an impeller.



Closed



Semi-open



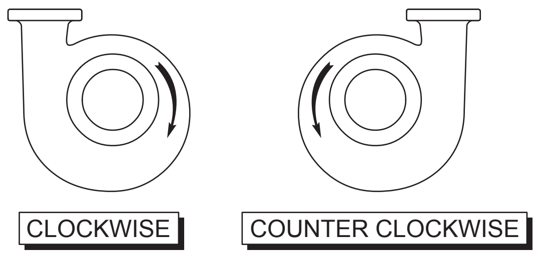
Open

Wear Rings

With closed impellers, the impeller fits very close to the case. As a result, the case is worn by material passing from the high-pressure side to the low-pressure side of the impeller. To protect the case, brass or stainless steel wear rings are inserted into the case.

Volute Case

Around the impeller is the volute case. The volute case gathers the water thrown from the impeller and directs it in a single direction.



Backing Plate

Behind the volute case is the backing plate. The backing plate seals the back of the volute case area.

Stuffing Box

Attached to, and sometimes part of, the backing plate is the **stuffing box**[18]. The stuffing box is where material that controls the leakage of water from around the shaft is placed. The material placed in the stuffing box is either **packing**[19] or a **mechanical seal**[20].

Packing/Mechanical Seals

Packing and mechanical seals serve the same purpose: they control leakage through the stuffing box. Packing is composed of some type of fiber, like cotton, and some type of lubricant, like graphite or Teflon™. A mechanical seal is composed of two finely machined surfaces, one hard and one soft, that prevent water from passing. When installing packing, joints should be staggered.

Packing Gland

In order to control leakage with packing, pressure must be placed on the packing. This pressure is applied by the packing gland, two pieces of metal at the back of the stuffing box. There should be a slow drip from the stuffing box to show lubrication between the shaft and the packing.

Lantern Ring

It is often desirable to lubricate and cool the packing with external water or oil. When water is used, it is called **seal water**[21] or flush water. The seal water is distributed into the stuffing box through the lantern ring, which is commonly a brass ring with holes that allow the water to easily pass.

Shaft Sleeve

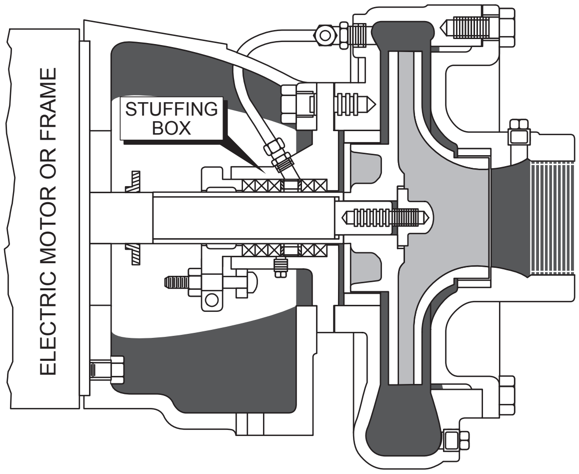
To protect the shaft from damage due to the packing, a shaft sleeve can be installed. A shaft sleeve is a brass or stainless steel sleeve that fits tightly over the shaft.

[18] Stuffing Box – That portion of the pump that houses the packing or mechanical seal. Usually referred to as the dry portion of the pump. The stuffing box is located in back of the impeller and around the shaft.

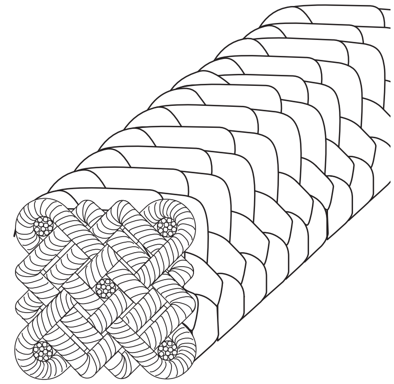
[19] Packing – Material made of woven animal, plant, mineral, or metal fiber and some type of lubricant, placed in rings around the shaft of a pump and used to control the leakage from the stuffing box.

[20] Mechanical Seal – A mechanical device used to control leakage from the stuffing box of a pump and usually made of two flat surfaces, one of which rotates on the shaft. The two flat surfaces are of such close tolerances as to prevent the passage of water between them.

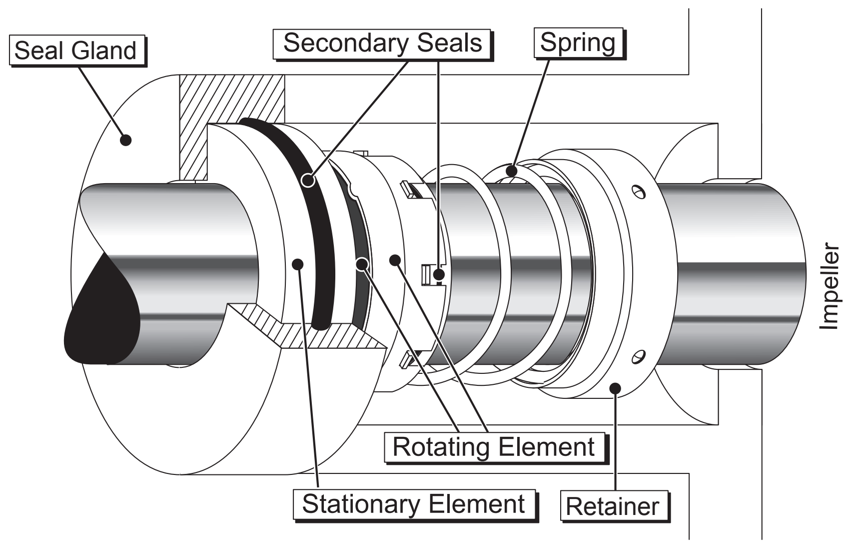
[21] Seal Water – The water supplied to the stuffing box to lubricate and flush the packing or the mechanical seal.



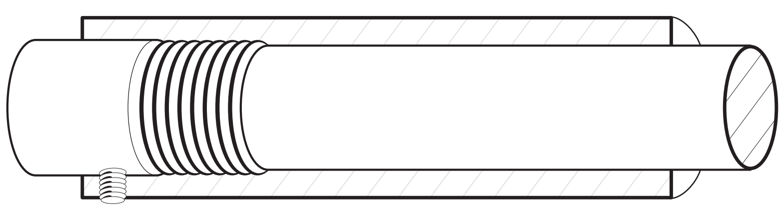
Stuffing box



Packing



Mechanical seal



Shaft sleeve threaded to shaft

Review

1. List the two major categories of pumps.
2. How is energy transferred from the impeller of a centrifugal pump to the water?
3. The energy placed into the water by a pump can be expressed as an increase in ________________ and an increase in ________________.

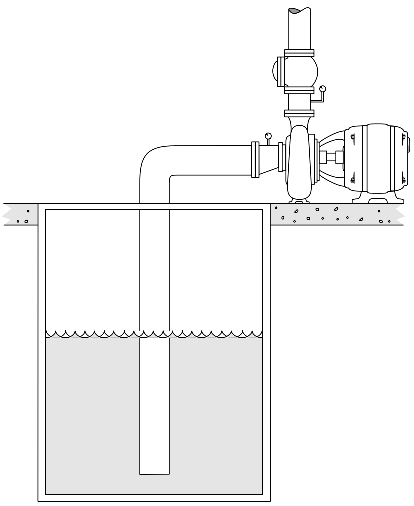
End suction Centrifugal and Split Case Piping

Suction Conditions

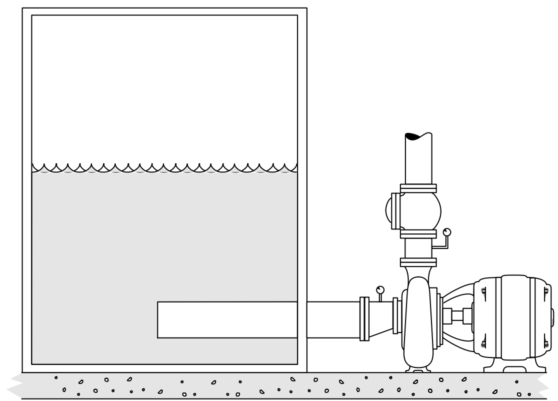
End suction and split case pumps can be installed in **suction lift**[22] or **suction head**[23] conditions. (See Hydraulics section for a more detailed explanation.) The piping system associated with the pump varies slightly depending on the suction conditions. Since the suction lift condition is the most difficult, it is used in the following description.

[22] Suction Lift – A pumping condition where the eye of the impeller of the pump is above the surface of the water from which the pump is pumping.

[23] Suction Head – A pumping condition where the eye of the impeller of the pump is below the surface of the water from which the pump is pumping.



Suction lift



Suction head

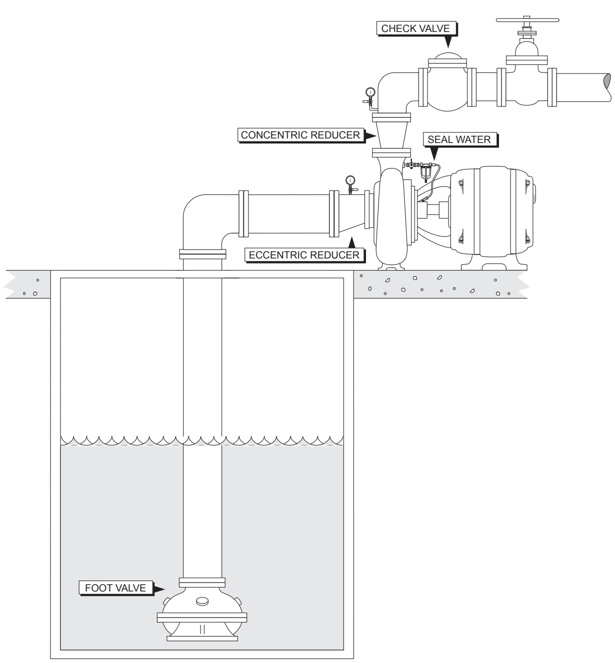
Suction Piping

Most pumps in a suction lift condition require a **foot valve**[24] on the end of the suction line to prevent the pump from losing prime. Most foot valves are large globe valves. The suction piping is usually designed one pipe size larger than the inlet of the pump with smooth piping material and fittings. Isolation valves on the suction side of a pump should only be gate or ball valves. Butterfly valves cause high **headloss**[25]. As the piping reaches the pump, it is reduced to meet the pump connection using an **eccentric reducer**[26]. The eccentric reducer prevents air accumulation in the piping.

[24] Foot Valve – A one-way valve placed at the entrance of a suction line that is opened by the flow of water. The purpose of the valve is to prevent reverse flow.

[25] Headloss – The loss of energy as a result of friction, commonly expressed in feet. The loss is actually a transfer to heat.

[26] Eccentric Reducer – A device used to connect a large pipe to a smaller pipe so that one edge of both pipes is aligned.



Discharge Piping

The discharge side of a pump usually starts with a **concentric reducer**[27], which takes the pipe up to one pipe size larger than the pump discharge. An isolation valve, preferably a gate or ball valve, is normally installed on the discharge. To reduce repair costs, a flange-by-flange spool or expansion joint is placed between the isolation valve and the pump.

[27] Concentric Reducer – A device used to connect a large pipe to a smaller pipe so that the center lines of both pipes are aligned.

Controlling Flow and Pressure

Ball valves and wide body globe valves are used to control flow and pressure from a pump as well as reduce water hammer during shutdown.

Check Valve

To prevent the flow of water back through the pump, a check valve is often placed in the discharge line. If there is a flow or pressure control valve, then a check valve is not necessary.

Gauges

To evaluate pump operating conditions, pressure gauges are placed on the suction and discharge sides of a pump. Ball valves are installed at the base of the gauges to allow easy replacement and to shut the gauges off when not in use, thus extending their life.

Seal Water

Seal water is usually supplied from the discharge of the volute case. If the seal water is obtained from some other source, a pressure gauge should be installed in the seal water line in order to assure that flow is in the correct direction, and backflow protection should be provided with an air gap.

Vertical Turbine Components

Line Shaft and Submersible

Vertical turbines, as discussed here, include line shaft and submersible turbines.

Inlet

Water enters the vertical turbine through the suction bell. It then passes into the **pump bowl**[28]. The bowl serves the same function as the volute case on an end suction centrifugal. This is where energy is transferred to the water by the impellers.

[28] Pump Bowl - The case that functions as a volute case on a mixed flow vertical turbine.

Impellers

Most line shaft and submersible turbines have more than one impeller. Each impeller and pump bowl is referred to as a pump stage. Adding stages increases the discharge pressure of the pump, but not its flow.

Column

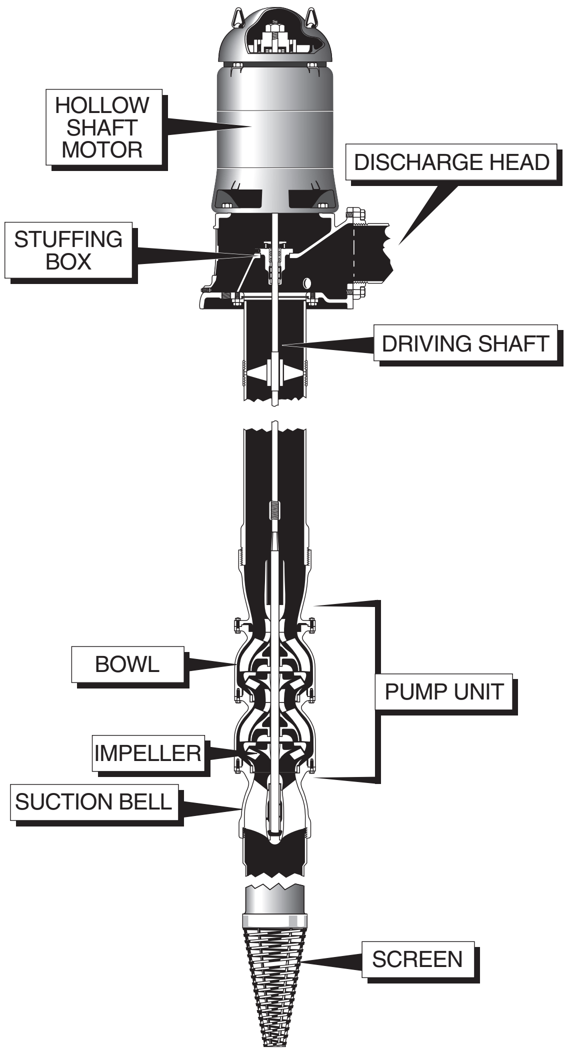
Water passes out of the pump bowl assembly and into the column. In the center of the column is the pump shaft, which may be lubricated with water or oil.

Discharge Head

The large cast iron component at the top of the pump is the discharge head. It is here that the direction of flow is changed from vertical to horizontal. The discharge head also contains the stuffing box and the mechanical seal or packing.

Motor

On top of the discharge head is the pump motor. The motor can be removed from the pump by removing a nut on the pump shaft located on the top of the motor. The motor can then be lifted off the pump shaft for maintenance.



Lineshaft turbine

Vertical Turbine Special Piping

Reversal of Flow

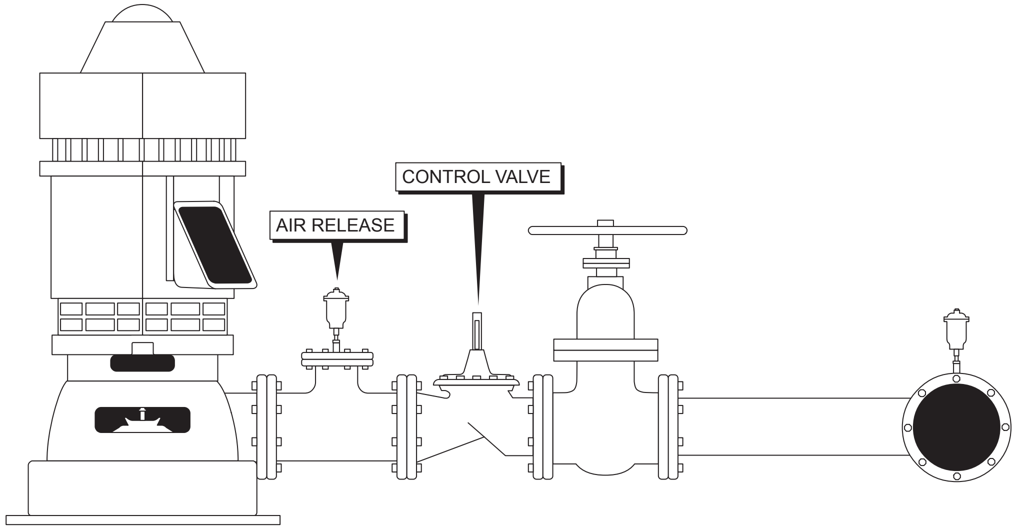
When a vertical turbine is shut down, water runs back down the column or drop line. Line shaft turbines have special non-reversing ratchets built into the motor to prevent the pump from spinning backwards. Small submersible turbines are installed with a check valve at the top of the pump to prevent water from running backwards through the pump.

Air Control

To prevent contamination from entering the discharge line through the stuffing box, an air valve is placed on the discharge line. This valve allows air in and, when the pump starts, allows the air out.

Flow – Pressure Control

Like the end suction centrifugal, flow and pressure control with vertical turbines is accomplished using wide body globe valves and butterfly valves.



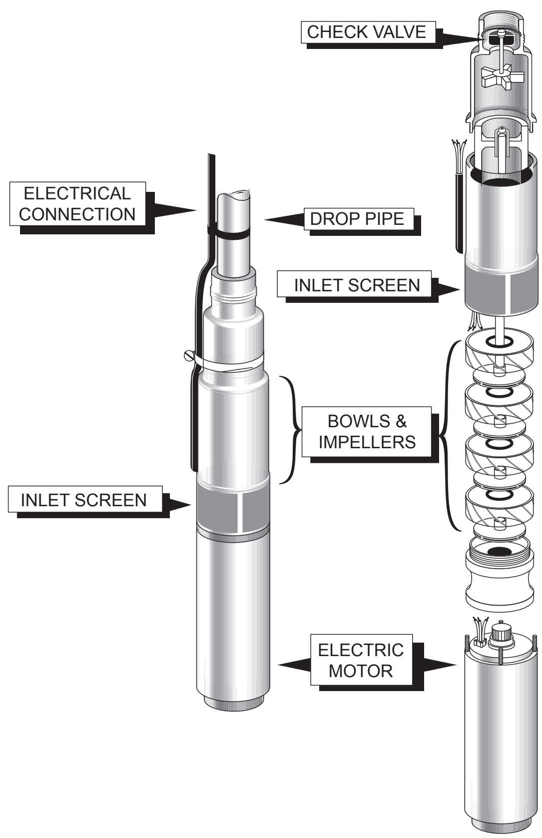
Submersible Turbine Components

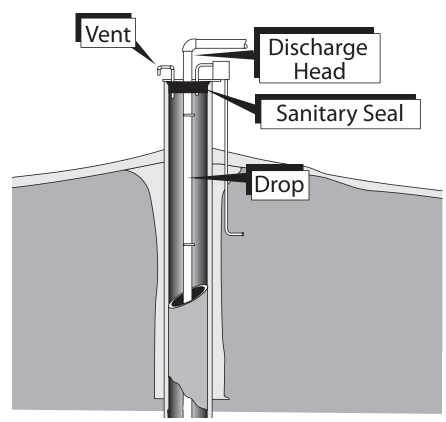
Inlet

The water inlet into a submersible turbine is between the pump and the motor. Water moves through pump bowls that are, in most cases, identical to those of the line shaft turbine.

Drop Pipe

Water moves up from the submersible turbine, through the drop pipe, and out the discharge head.





Cavitation
Cavitation is the condition where vapor bubbles are formed in a flowing liquid when the pressure of the liquid falls below its vapor pressure. Once the bubbles reach an area where the pressure increases above vapor pressure, the bubbles collapse thereby creating small areas of high temperature and emitting shock waves.

Cavitation in a centrifugal pump occurs when the inlet pressure falls below the design inlet pressure or when the pump is operating at a flow rate higher than the design flow rate. When the inlet pressure in the flowing liquid falls below its vapor pressure, bubbles begin to form in the eye of the impeller. Once the bubbles move to an area where the pressure of the liquid increases to above its vapor pressure, the bubbles collapse thereby emitting a "shock wave." These shock waves can pit the surface of the impeller and shorten its service life. The collapse of the bubbles also emits a pinging or crackling noise that can alert the operator that cavitation is occurring.

Cavitation is undesirable because it can damage the impeller, cause noise and vibration, and decrease pump efficiency.

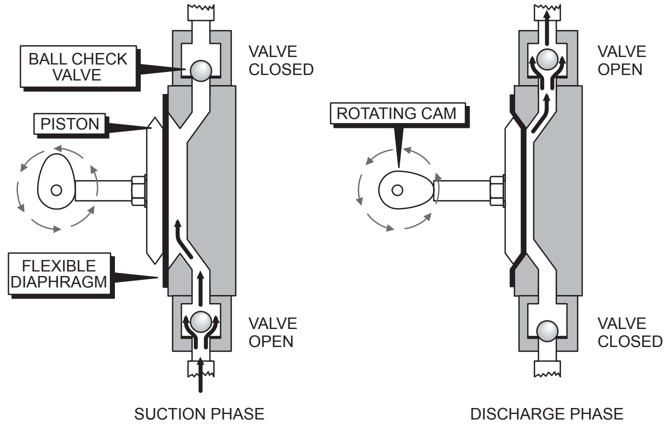
Positive Displacement Pumps

Major Components
While there are several different types of positive displacement pumps available, this section is limited to those commonly used in small water systems.

Never pump against a closed discharge or suction valve when using any positive displacement pump. This could result in severe damage to personnel and/or equipment.

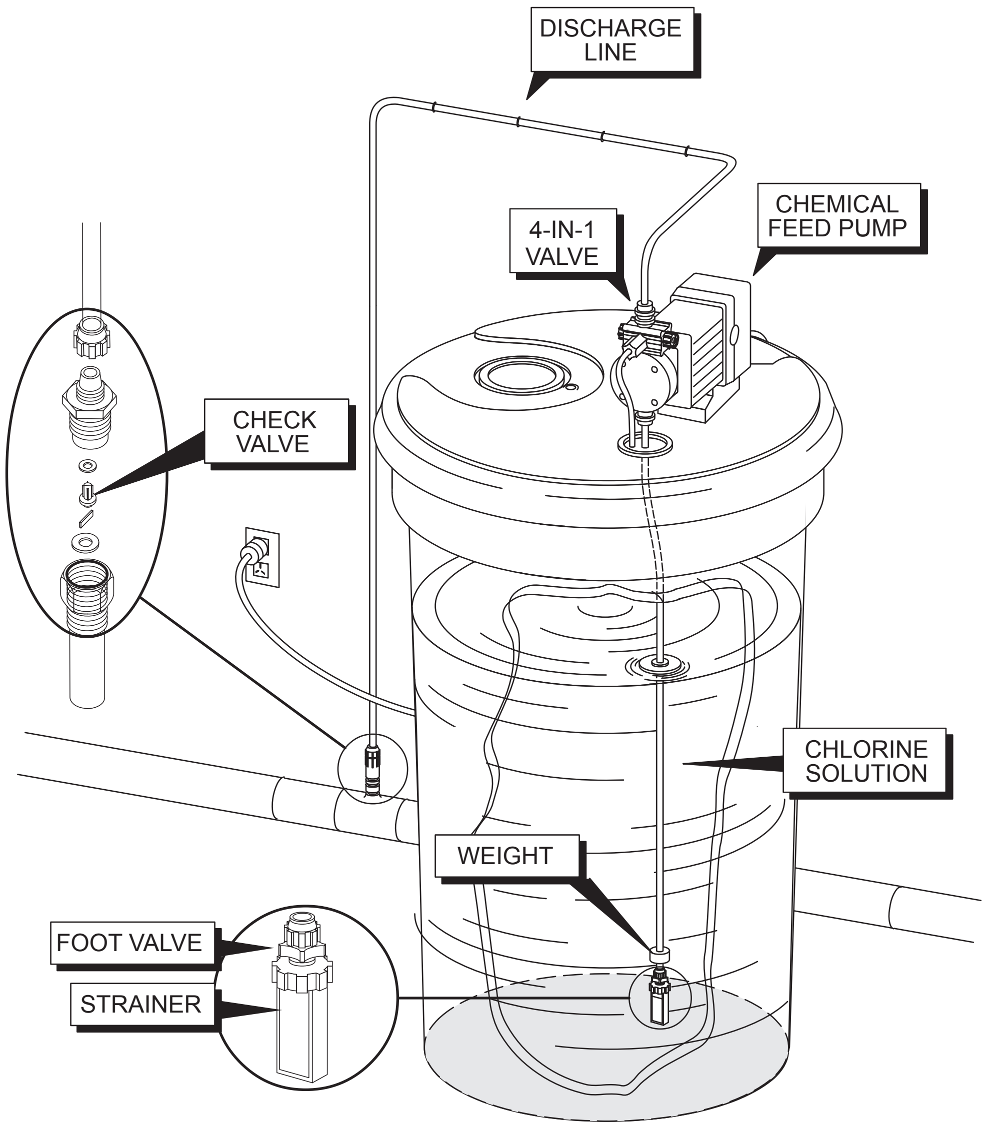
Diaphragm Pumps
The diaphragm pump is composed of the following:
- A chamber used to pump the fluid
- A diaphragm operated by either electric or mechanical means
- Two valve assemblies: a suction valve assembly and a discharge valve assembly

When the diaphragm is pulled back, a vacuum is created in the chamber in front of the diaphragm. This vacuum causes the discharge valve to be forced closed against its seat. The vacuum allows atmospheric pressure to push fluid up against the outside of the suction valve, opening the valve and filling the chamber. When pressure is returned to the diaphragm, forcing it toward the front of the chamber, the increased pressure causes the suction valve to be forced closed and the discharge valve to be forced open. The fluid is pushed out of the chamber, and the pumping cycle starts over.



Piping System

The piping system for diaphragm pumps used to pump chemicals is relatively simple. There are a foot valve and screen on the suction line and a check valve on the end of the discharge line. The foot valve prevents loss of prime. The discharge check valve prevents the system water from flowing back into the chemical feed tank.



Piping System

Peristaltic Pumps

A peristaltic pump is a type of positive displacement pump used for pumping a variety of fluids, such as chemicals and sludges. The fluid is contained within a flexible tube fitted inside a circular pump casing. A rotor with a number of rollers (or shoes) is attached to a rotating arm that compresses the flexible tube. As the rotor turns, the part of tube under compression closes, thus forcing the fluid to be pumped through the tube. This works much like squeezing toothpaste out of a tube.

Since they have no moving parts in contact with the fluid, peristaltic pumps are inexpensive to manufacture. Their lack of valves, seals, and glands makes them comparatively inexpensive to maintain, and the use of a hose or tube makes for a relatively low-cost maintenance item compared to other pump types.

It is important to select tubing with appropriate chemical resistance towards the liquid being pumped. Types of tubing commonly used in peristaltic pumps include polyvinyl chloride (PVC), silicone rubber, and fluoropolymer. Trade names include Tygon™ and Viton™.

Progressive Cavity Pumps

A progressive cavity pump moves fluid by means of a rotary screw or rotor turning within a stationary stator. The flow rate is proportional to the rotation rate of the pump. Progressive cavity pumps are designed to transfer fluid or fluids with suspended solids. They are frequently used to pump sludge, but can be used to meter large volumes of chemicals in a precise manner.

Operation

As the rotor turns, "humps" built into the rotor move within cavities in a synthetic rubber stator. This action squeezes material out of the end of the pump in much the same way as with peristaltic pumps. These pumps should always run with a fluid inside to lubricate the pump. A progressive cavity pump should never be operated against a closed valve.

Basic Hydraulic Terms and Concepts

This brief discussion on hydraulics is intended as a background necessary to understand the pumping and piping systems at a beginning level. The lesson is divided into two parts; 1) basic hydraulic terms and concepts and 2) pumping hydraulics.

Weight-Volume Relationship

Weight per Cubic Foot

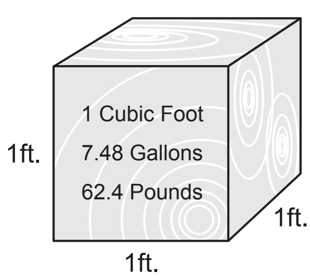
Cubic feet and gallons are both used to describe a volume of water. There is a defined relationship between these two methods of measurement. The specific weight of water is defined relative to a cubic foot. One cubic foot of water weighs 62.4 pounds. This relationship is true only at a temperature of 4°C and at a **pressure**[29] of one atmosphere (called standard temperature and pressure). However, the weight varies so little that for practical purposes we use this weight from a temperature of 0°C to 100°C.

[29] Pressure – The force exerted on a unit area. Pressure = Weight x Height. In water, it is usually measured in psi (pounds per square inch). One foot of water exerts a pressure of 0.433 pounds per square inch.

$1\ ft^3\ H_2O = 62.4\ lbs$

Volume per Cubic Foot

At standard temperature and pressure, one cubic foot of water contains 7.48 gallons. With these two relationships we can determine the weight of one gallon of water. This is accomplished by dividing the weight (62.4 lbs) by the volume in gallons (7.48 gallons per cubic foot).



$$\text{wt of gal of water} = \frac{62.4\ \text{lbs}}{7.48\ \text{gal}} = 8.34\ \text{lbs/gal}$$

Summary
1 ft^3 H_2O = 7.48 gallons
1 gallon H_2O = 8.34 pounds

Conversion ft^3 to gallons
With this information we can convert cubic feet to gallons by simply multiplying the number of cubic feet by 7.48 gal/ft^3.

Example – Conversion ft^3 to gallons

Find the number of gallons in a reservoir that has a volume of 668.5 ft^3.

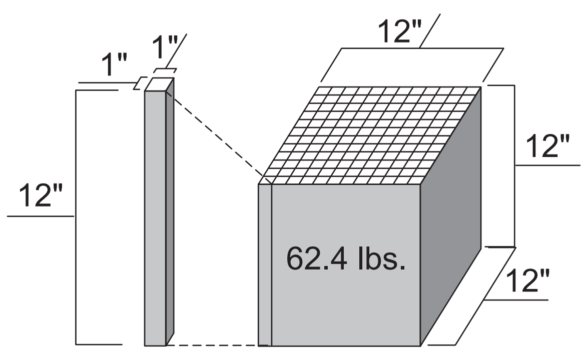
668.5 ft^3 x 7.48 gal/ft^3 = 5,000 gallons

Force and Pressure

Force
In the English system **force**[30] and weight are often used in the same way. The weight of the cubic foot of water is 62.4 pounds. The force exerted on the bottom of the one foot cube is 62.4 pounds. If we have two cubes stacked on top of one another, the force on the bottom will be 124.8 pounds.

[30] Force – Influence (as a push or pull) that causes motion. Physics - The mass of an object times its acceleration: F = ma.

Pressure
Pressure is a force per unit of area, pounds per square inch or pounds per square foot are common expressions of pressure. The pressure on the bottom of our cube is 62.4 pounds per square foot. It is normal to express pressure in pounds per square inch (psi). This can be accomplished by determining the weight of one square inch of our cube one foot high. Since the cube is 12 inches on each side, the number of square inches on the bottom surface of the cube is 12 x 12 = 144 in^2. Now by dividing the weight by the number of square inches we can determine the weight on each square inch.



$$psi = \frac{62.4 \text{ lbs/ft}}{144 \text{ in}^2} = 0.433 \text{ psi/ft}$$

This is the weight of a column of water one inch square and one foot tall. If the column of water were two feet tall and the pressure would be 2 ft x 0.433 psi/ft = 0.866 psi.

1 ft of water = 0.433 psi

Conversion feet to psi
With the above information we can convert feet of **head**[31] to psi by multiplying the feet of head times 0.433 psi/ft.

[31] Head – The measure of the pressure of water expressed as height of water in feet: 1 psi = 2.31 feet of head.

Example – Conversion feet to psi

A reservoir is 40 feet tall. Find the pressure at the bottom of the reservoir.

40 ft x 0.433 psi/ft = 17.3 psi

Conversion of psi to feet

The conversion of psi to feet is simply made by dividing the psi by 0.433 psi/ft.

Example – Conversion of psi to feet

Find the height of water in a tank if the pressure at the bottom of the tank is 12 psi.

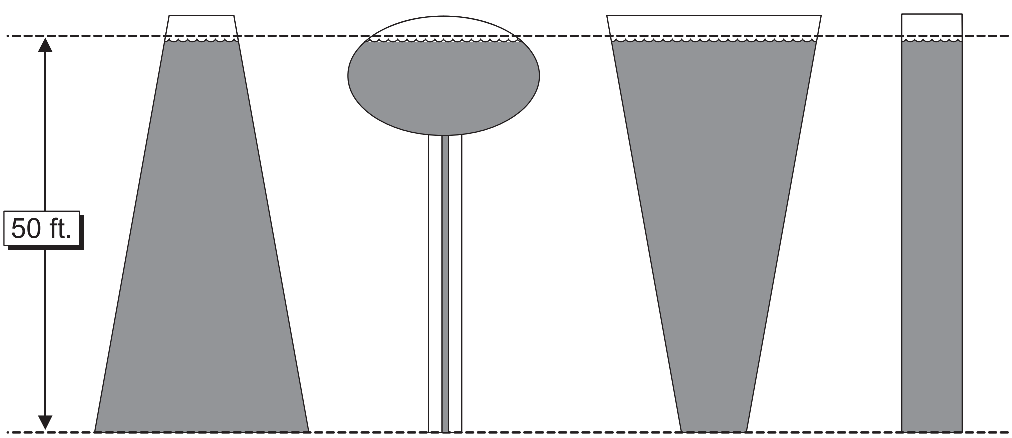
12 psi ÷ 0.433 psi/ft = 27.7 ft

Pressure and Head

Pressure is directly related to the height of a column of fluid. This height is called head or feet of head. From the discussion above we see there is a direct relationship between feet of head and pressure. The relationship is that for every one foot of head there is a pressure of 0.433 psi.

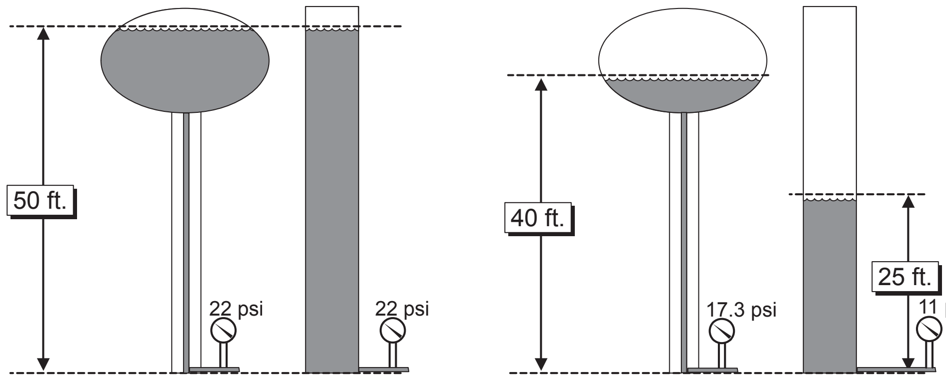
Pressure Relative to Container Size

The pressure at the bottom of a container is affected only by the height of water in the container and not by the shape of the container. In the drawing below there are four containers all of different shapes and sizes. The pressure at the bottom of each is the same.



Pressure and Volume

The pressure exerted at the bottom of a tank is relative only to the head on the tank and not the volume of water in the tank. For example, below are two tanks each containing 5000 gallons. The pressure at the bottom of each is 22 psi. If half of the water were drained from the tanks the pressure at the bottom of the elevated tank would be 17.3 psi while the pressure at the bottom of the standpipe would be 11 psi.



Velocity and Flow

Velocity

Velocity is the speed that the water is moving along a pipe or through a basin. Velocity is usually expressed in feet per second, ft/sec.

Flow

Flow is commonly expressed in gallons per minute (gpm) and/or cubic feet per second (cfs). There is a relationship between gallons per minute and cubic feet per second. One cubic foot per second is equal to 448.8 gallons per minute.

1 cfs = 448.8 gpm

Flow Equation

The basic equation for determining flow is as follows:

$$Q = V \times A$$

Where:
Q = cfs (ft^3/sec)
V = ft/sec
A = ft^2

Static and Dynamic Conditions

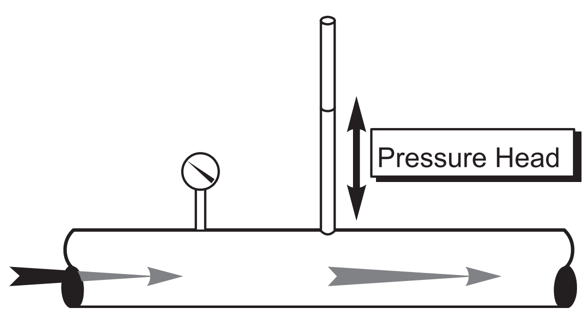
Static Pressure

The pressure measured when there is no water moving in a line or the pump is not running is called **static**[32] pressure. This is the pressure represented by the gauges on the tanks in the discussion above.

[32] Static – A non-moving condition.

Dynamic Pressure

When water is allowed to run through a pipe and the pressure (called pressure head) measured at various points along the way we find that the pressure decreases the further we are from the sources.



Headloss
The reason for this reduction in pressure is a phenomenon called headloss. Headloss is the loss of energy (pressure) due to friction. The energy is lost as heat.

Explanation
When we hear that the headloss in a certain pipe is 25 feet, that means the amount of energy required to overcome the friction in the pipe is equivalent to the amount of energy that would be required to lift this amount of water straight in the air 25 feet.

Factors Contributing to Headloss
In a pipe, the factors that contribute to headloss include the following:

- Roughness of pipe
- Length of pipe
- Diameter of pipe
- Velocity of water

Comparison of Factors
In general, if the roughness of a pipe were doubled the headloss would double. If the length of the pipe were doubled the headloss would double. If the diameter of a pipe were doubled the headloss would be cut in half and if the velocity of the water in a pipe were doubled the headloss would be increased by about four times. It should be apparent that velocity, more than any other single factor, affects headloss. To double the velocity we would have to double the flow in the line.

Example – Headloss

500 feet of four inch line with a flow of 110 gpm has a headloss of 7.5 feet. At a flow of 220 gpm, the headloss jumps to 26 feet or an increase of 3.5 times.

Fittings and Headloss
Each type of fitting has a specific headloss depending upon the velocity of water through the fitting. For instance the headloss though a check valve is two and one quarter times greater than through a ninety degree elbow and ten times greater than the headloss through an open gate valve.

Pumping Hydraulics

Basic Terms

Static Head
Static head is the distance between the suction and discharge water levels when the pump is shut off. Static head conditions are often indicated with the letter Z.

Suction Lift
Suction lift is the distance between the suction water level and the center of the pump impeller. This term is only used when the pump is in a suction lift condition. A pump is said to be in a suction lift condition any time the eye (center) of the impeller is above the water being pumped.

Suction Head

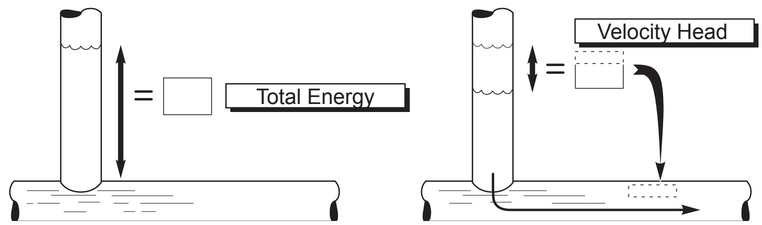
Suction head is the distance between the suction water level and the center of the pump impeller when the pump is in a suction head condition. A pump is said to be in a suction head condition any time the eye (center) of the impeller is below the water level being pumped.

Velocity Head

Velocity head[33] is the amount of energy required by the pump and motor to overcome **inertia**[34] and bring the water up to speed. Velocity head is often shown mathematically as $V^2/2g$. (g is the acceleration due to gravity – 32.2 ft/sec^2).

[33] Velocity Head – The amount of energy required to bring a fluid from standstill to its velocity. For a given quantity of flow, the velocity head will vary indirectly with the pipe diameter.

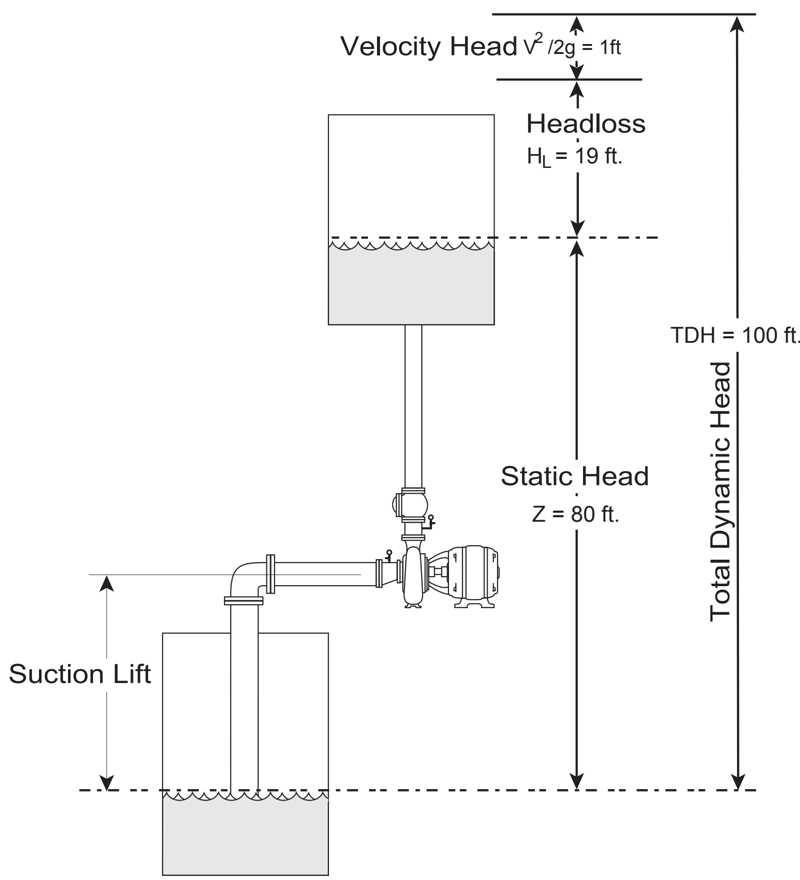
[34] Inertia – The tendency of matter to remain at rest or in motion



Total Dynamic Head

Total dynamic head[35] (TDH) is a theoretical distance. It is the static head, velocity head and headloss required to get the water from one point to another.

[35] Total Dynamic Head (TDH) – The total energy needed to move water from the center line of a pump (eye of the first impeller of a lineshaft turbine) to some given elevation or to develop some given pressure. This includes the static head, velocity head and the headloss due to friction.



Components of total dynamic head

[36] Horsepower – A measurement of work, 33,000 foot pounds per minute of work is 1 horsepower.

Horsepower

Horsepower[36] is a measurement of the amount of energy required to do work. Motors are rated in horsepower. The horsepower of an electric motor is called brake horsepower. The horsepower requirements of a pump are dependent on the flow and the total dynamic head.

[37] Amperage – The measurement of electron flow.

Horsepower and Amperage

The horsepower output of an electric motor is directly reflected to the **amperage**[37] that the motor draws. Any increase in horsepower requirements will give a corresponding increase in amperage.

Pump Response

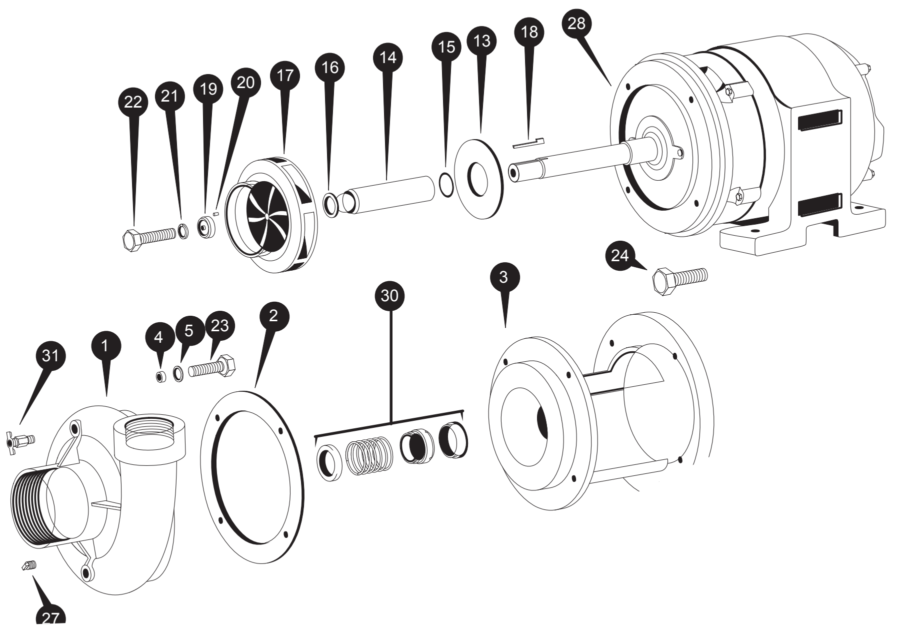
For centrifugal pumps, as the total dynamic head is increased the pump will pump less water and will require less horsepower.

Identification

Identify the components indicated in the drawing below.

______ A. Volute case ______ B. Mechanical seal ______ C. Impeller

______ D. Stuffing box ______ E. Shaft sleeve



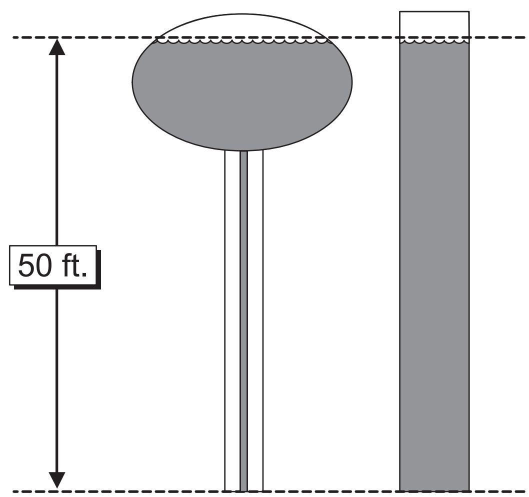
Review

1. One cubic foot of water weighs__________ pounds, and contains ___________ gallons.

2. One gallon of water weighs _____________lbs.

3. Looking at the two reservoirs below, will the pressure at the bottom be:

   A. The same
   B. Greater in the tank on the left
   C. Greater in the tank on the right



4. A tank contains 500 cubic feet. This converts to how many gallons?

5. A flow of one cubic foot per second is equivalent to __________ gpm.

6. Headloss is the result of _____________. The energy given off as a result of headloss is given off as _____________.

7. What term is used to describe the difference between the level of water in a well and the level of water in the reservoir when the pump is shut down?
   ____

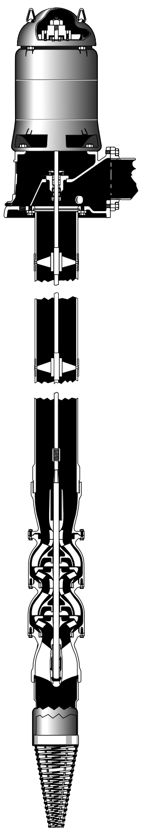
8. What units are used to measure the energy required to do the work of pumping water?
   ____

9. It is 60 feet in elevation from the level of water at the top of the reservoir to the pump house. What is the static water pressure at the pump house?

Identification

Identify the three pumps below by configuration.

1.



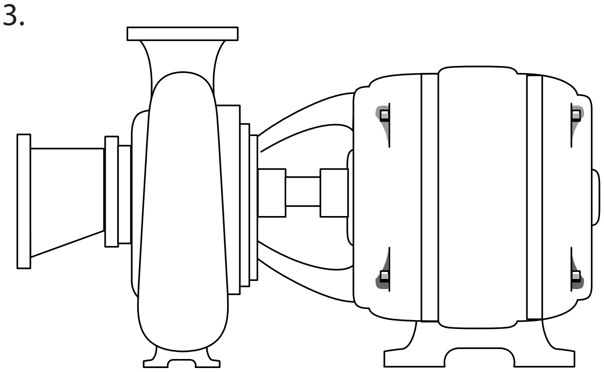
2.

1. ______________________________

2. ______________________________

3. ______________________________

3.



Identify the components indicated in the drawing below.

A. ____________________

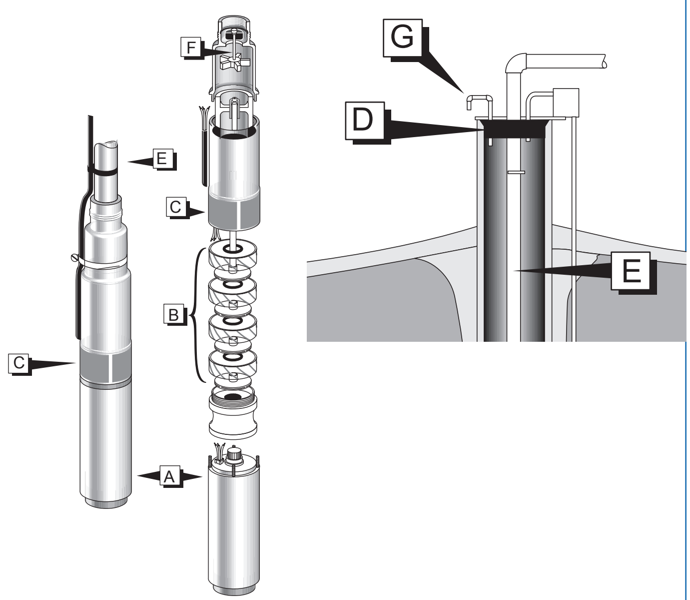
B. ____________________

C. ____________________

D. ____________________

E. ____________________

F. ____________________



Introduction to Pumping Systems Quiz

1. Which type of pump is frequently used to pump water from wells?
   A. Progressive cavity pumps
   B. Submersible turbine pumps
   C. Reciprocating pumps
   D. Circulating pumps

2. What is the purpose of pump mechanical seals?
   A. Keep leakage off slippery floors
   B. Prevent leakage between the pump casing and shaft
   C. Provide an effective backflow prevention device
   D. Seal water to maintain pump prime

3. What is the primary purpose of priming a pump?
   A. Ensure the pump operates freely
   B. Fill the volute with water
   C. Prevent backflow
   D. Start the seal water flow

4. The component of a centrifugal pump sometimes installed on the end of the suction pipe is called the:
   A. Volute
   B. Foot valve
   C. Impeller
   D. Packing

5. Positive displacement pumps should never be operated:
   A. Backward
   B. With a closed discharge or suction valve
   C. Without supervision
   D. Without a concentric reducer

6. Pumps that are used to feed chemicals should:
   A. Never be run in auto
   B. Never be run dry
   C. Always be controlled by a flow switch
   D. Always be controlled by a level sensor

7. Packing should be adjusted when:
   A. Excessive leakage from the discharge pipe is noticed
   B. Excessive leakage from the stuffing box is noticed
   C. Pump prime is lost
   D. The pump is shut down

8. Closed impellers should be used for:
   A. When the pump is used to pump sludge
   B. When the pump is used to circulate glycol
   C. When the pump is used to pump chemicals
   D. When the pump is used to boost pressure

9. Check valves are used to:
   A. Control leakage from the stuffing box
   B. Ensure pump is isolated from the system for maintenance
   C. Prevent water from flowing in reverse
   D. Fill water storage tanks

10. Pump couplings are used to:
   A. Ensure pump is properly connected to discharge piping
   B. Connect the motor to the pump
   C. Provide cooling water for the stuffing box
   D. Keep the pump primed

11. One cubic foot of water weighs ______________ pounds and contains ______________ gallons.
   A. 8.34 lbs, 7.48 gallons
   B. 7.48 lbs, 62.4 gallons
   C. 11.3 lbs, 5 gallons
   D. 62.4 lbs, 7.48 gallons

12. One gallon of water weighs ______________ lbs.
   A. 3.42 lbs
   B. 7.48 lbs
   C. 8.34 lbs
   D. 4.56 lbs

13. A tank contains 500 cubic feet. This converts to how many gallons?
   A. 3740 gallons
   B. 66.8 gallons
   C. 4170 gallons
   D. 59.9 gallons

14. A flow of one cubic foot per second is equivalent to ______________ gpm.
   A. 62.4
   B. 179.5
   C. 7.48
   D. 448.8

15. Headloss is the result of ______________. The energy given off as a result of headloss is given off as ______________.
    A. Pressure, head
    B. Friction, heat
    C. Flow, electricity
    D. Weight, noise

16. What term is used to describe the difference between the level of water in a well and the level of water in the reservoir when the pump is shut down?
    A. Drawdown
    B. Static head
    C. Well yield
    D. Dynamic head

17. Describe Total Dynamic Head (TDH).
    A. Total pressure a pump will pump
    B. Composed of headloss, velocity head, and static head.
    C. Amount of pressure in a well
    D. A toilet on a submarine

18. What is the difference between suction lift and suction head?
    A. Total dynamic head in the pumping system
    B. Static head between the pump suction and discharge.
    C. Relationship between the eye of the impeller of the pump and the surface water from which the pump is pumping.
    D. There is no difference

19. What units are used to measure the energy required to do the work of pumping water?
    A. Microns
    B. Horsepower
    C. Foot-pounds
    D. Gallons per minute

20. It is 60 feet in elevation from the level of water at the top of the reservoir to the pump house. What is the static water pressure at the pump house?
    A. 500.4 psi
    B. 25.98 psi
    C. 138.6 psi
    D. 448.8 psi

Basic Electricity and Motor Controls

Chapter 7

What Is In This Chapter?

1. The basic components of an atom
2. Basic electrical units and symbols
3. The difference between a conductor and an insulator
4. The difference between open and closed circuits
5. The difference between AC and DC power
6. An explanation of single and three phase power
7. How electromagnets work
8. The function of common electrical components found in small water systems
9. Common pump electrical control components

Key Words

- AC
- Amperage
- Atom
- Brake Horsepower
- Conductor
- DC
- Electromagnetism
- Electron
- EMF
- Heater
- Hertz
- Horsepower
- Insulator
- Magnetic Breaker
- Magnetic Starter
- Neutron
- Proton
- Resistance
- Sine Wave
- Single Phase Power
- Three Phase Power
- Voltage

Electrical Basics

In order to develop a basic understanding of how electrical equipment and motor controls work, we need to review basic electrical theory. And since electrical theory is based on atomic theory, we need to begin with a review of how atoms work.

Atomic Theory

The Atom – Nucleus

If we break matter into its smallest component, the base unit is the **atom**[1]. An atom is composed of three components: the center is called the nucleus and contains two types of particles, protons and neutrons. The protons have a positive charge and the **neutrons**[2] have a neutral or zero charge.

[1] Atom – The smallest part of an element that still retains the properties of that element.

[2] Neutron – A neutrally charged particle in the nucleus of an atom. This particle has the same weight as a proton, an atomic weight of 1.

The Electron

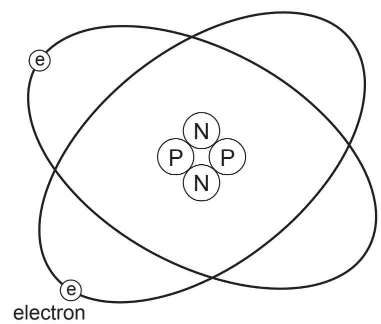
Orbiting around the nucleus are one or more electrons. The **electron**[3] is extremely small. It travels at nearly the speed of light and has an electrical charge that is negative. This charge is equal in value to the positive charge of the **proton**[4].

[3] Electron – A negatively charged particle that travels around the nucleus of an atom.

[4] Proton – A positively charged particle in the nucleus of an atom. This particle has an atomic weight of 1 and an atomic charge of plus 1.

Stability of the Atom

The electrons remain a constant distance from the nucleus of the atom. There are two forces that hold them in this position. One is the electrical attraction between the negative electrons and the positive protons. This has the tendency to pull the electrons into the nucleus. The second force is centrifugal force. Centrifugal force tries to make the electrons fly away from the nucleus. The two forces counteract each other and hold the electrons stable in their orbits.



Electron Shells

The electrons in an atom form shells (or orbits) around the nucleus. Each shell has a precise number of electrons. Each element has a different number of electrons. The atoms of the heavier elements have multiple shells. Regardless of the element, atoms are most stable when they have eight electrons in their outermost shell.

Fewer than Eight

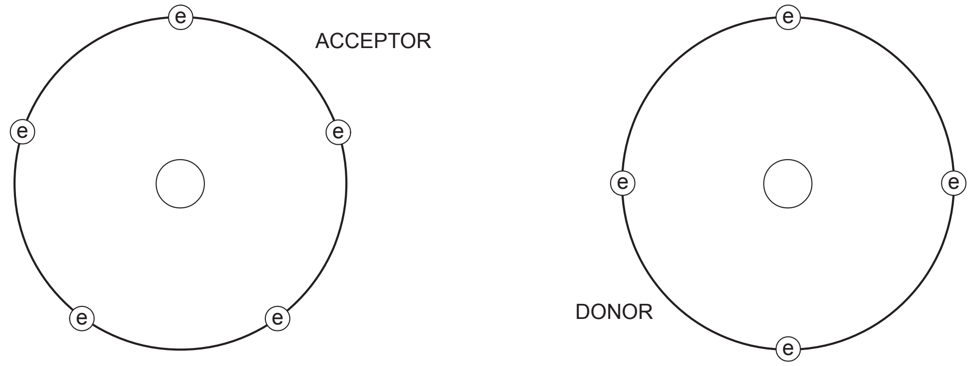
When an atom has five or more, but fewer than eight, electrons in its outer shell, the atom prefers to gather more electrons to be satisfied. This type of material is called an acceptor. Electrically, materials that are acceptors are called **insulators**[5]. They do not allow the flow of electrons easily. Examples of insulators include but are not limited to glass, plastic, porcelin, carbon, air, wood and rubber.

[5] Insulator – A substance, body, or device that prevents the flow of electrical current.

Fewer than Five

When an atom contains fewer than five electrons in its outer shell, it is easier for it to give up the excess than to gain more electrons. Atoms with fewer than five electrons are called donors. Electrically, materials that have fewer than five electrons are called **conductors**[6]. These atoms allow electrical current to flow easily. Examples of conductors include but are not limited to copper, gold, aluminum, silver, and iron.

[6] Conductor – A substance, body, device, or wire that readily conducts or carries electrical current.

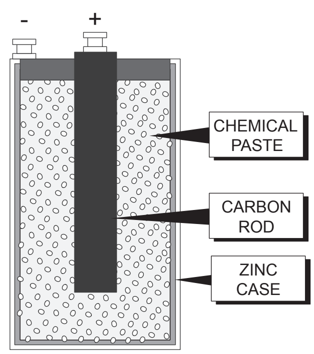


Making Electrons Move

In order to cause the electrons of a donor material to leave the atom, sufficient energy must be applied to cause the electron to speed up enough to overcome the attraction of the proton. Energy can be applied mechanically by a generator, by light, by pressure, by chemical reactions, and by heat.

Battery

The simplest way to look at electrical energy is with a battery. A dry cell battery is made from a chemical paste and two electrodes. The chemical reaction between the chemical paste and the electrodes causes an excess of electrons to accumulate on one post, which creates an electrical charge difference between the two posts. If a conductor is connected between the two posts, electrons will flow from one post to another.



Measurements of Electricity

Pressure

The battery can be viewed as an electrical pump. There is an electrical force difference between the two poles. This electrical difference is called electromotive force or **EMF**[7] for short. If the battery were visualized as a water pump, this difference would be the difference in pressure between the suction and discharge of the pump.

[7] EMF (Electromotive Force) – The electrical pressure (voltage) that forces an electric current through a conductor.

Pressure –Volts

Electrical pressure is called **voltage**[8]. The units of measurement are volts. The symbol for volts can be "E" (for EMF) or "V" (for volts). Voltage is measured with a volt meter. A common volt meter used by operators is a VOM (Volt, Ohm, Milliamp Meter).

[8] Voltage – The measurement of EMF between two points.

Flow

The flow of electrons from one point to another is called current. Current is measured as amperage (amps for short). Current or amps is similar to flow in gallons per minute in a water line. The electrical symbol for amps is "I" or "A." Amperage is measured using an amp meter.

Resistance

The **resistance**[9] to the flow of electrons is similar to headloss in a water line. Resistance is measured as ohms. Electrically, the symbol for resistance is "Ω" (the Greek letter omega) or "R."

[9] Resistance – The opposition offered to the flow of electrical current. Usually measured as Ohms.

Electrical Measurement	Units	Symbols	Water Equivalent	Water Units
Pressure (EMF)	Volts	E or V	Pressure	psi
Current	Amps	I or A	Flow	gpm
Resistance	Ohms	Ω or R	Headloss	feet

Review

1. The particle that rotates around the nucleus of an atom is the ______________.

2. The ______________ and the ______________ can be found in the nucleus of an atom.

3. Examples of good electrical conductors include:

4. ______________ is the electrical unit that is related to pressure; ______________ is the electrical unit that is related to flow; and ______________ is the electrical unit that is related to headloss.

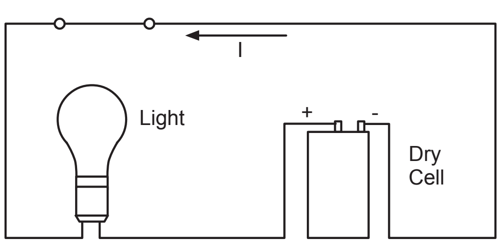
5. The symbol for voltage is ______________ or ______________; the symbol for amperage is ______________ or ______________; and the symbol for resistance is ______________ or ______________.

6. EMF stands for ______________ force and is the same as ______________.

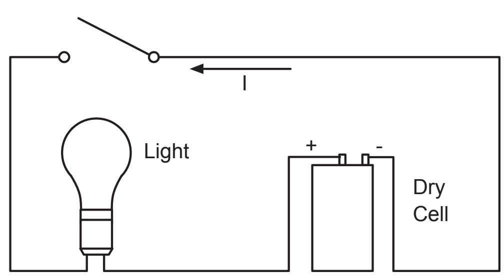
Types of Circuits

There are two types of electrical circuits that we need to be concerned with:

- Open Circuit – An open circuit is similar to having the light switch in the "off" position. There is no electrical current flow. There is no connection between the light and the power system; thus there is no flow of electrons.
- Closed Circuit – A closed circuit is similar to having the light switch in the "on" position. Electrons can flow from the power sources to the light, and the light comes on.



Closed Circuit



Open Circuit

Types of Power

There are two basic types of power—direct current (**DC**[10]) and alternating current (**AC**[11]):

- Direct Current – With direct current, the electrons are always flowing in a single direction. This is the type of current available from a battery similar to the 12v battery in your vehicle. Most electronic equipment, such as computers, the TV, and stereos, use direct current internally making the electricity easier to control.
- Alternating Current – The current we are most familiar with is alternating current (AC). This is what is available at the electrical outlets in the room, it is typically 120v, it is used to operate the pumping control system and electrical motor. With AC current, the electrons flow back and forth in the line because the potential on the circuit is constantly switched from positive to negative and negative to positive.

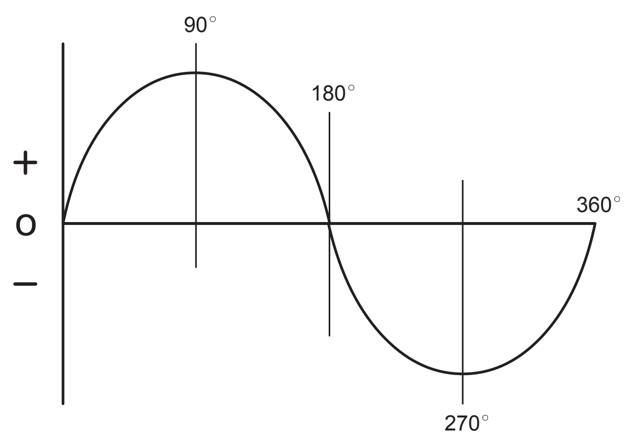
[10]DC (Direct Current) – A flow of electrons in a single direction at a constant rate so that the value remains stable.

[11]AC (Alternating Current) – An electric current of constantly changing value that reverses direction of flow at regular intervals.

Sine Wave

If we could see the pattern produced by DC, it would be a straight line. AC, on the other hand, produces a pattern called a **sine wave**[12]. A sine wave shows the oscillation from positive to negative and back to positive. A "complete" sine wave is the representation of one cycle resulting from switching from positive to negative and back to positive.

[12] Sine Wave – The wave traced by the sine of an angle as the angle is rotated through 360°. Alternating current values follow a sine wave with respect to time.



Frequency

Frequency is the number of complete sine wave cycles that are produced in one second. The units of frequency are **Hertz**[13]. Normal household current alternates at 60 hertz or 60 times per second.

[13] Hertz – The frequency at which a cycle repeats within one second. For instance, a repeat of a cycle at a rate of 60 times per second is called 60 Hertz.

Sine Wave and Time

The distance from one end of a sine wave to the other is a measure of time and is marked off in degrees. When the frequency is 60 hertz, the distance in time from one end of a sine wave to the other is l/60th of a second. This 1/60 of a second is then divided into 360 equal parts called degrees.

Converters

It is possible to convert DC to AC and AC to DC. This is accomplished using an electrical circuit called an inverter. The most common conversion is from AC to DC. We convert AC to DC for electronic equipment, such as computers, the TV, and stereo.

Single and Three Phase Power

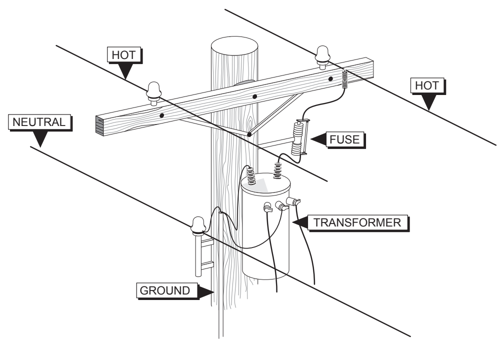
When we talk about pumping stations, we often ask, "is it **single**[14] or **three phase**[15]?" Without some background, these terms can have very little meaning. Electricians use the terms as though we all have this understanding. This is not really true. The following is a brief introduction into the difference between single phase and three phase power.

[14] Single Phase Power – A circuit or generator in which only one alternating current is produced.

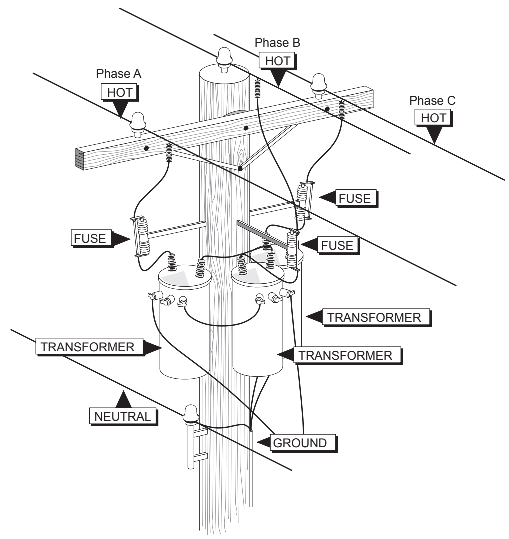
[15] Three Phase Power – A circuit or generator in which three power sources 120° out of phase with each other are produced.

Single Phase

Phases can be equated to sources. With single phase power, there is a single source of power. There would be two wires leading to the building, one that is called the hot lead and one that is called the neutral. Most homes have three lines leading to the weather head. There are two hot leads and one neutral. While this is really two phase power, it is called single phase.



Single phase



Three phase

Three Phase

Three phase power can be equated to three power sources. Each source is a different phase. At a pump station or treatment plant, three phase power would have four wires coming from the pole transformer to the weather head. There would be three hot leads and one neutral.

What is Phase?

Phase is a common term in electricity used to describe timing. With three phase power, each phase is energized a fraction of a second later in time. That is, the voltage applied to each phase starts later in time. The common description is that each phase starts 120° later in time. This is easier to see if we think about degrees as time. Remember, 360° is 1/60th of a second.

Advantage of Three Phase

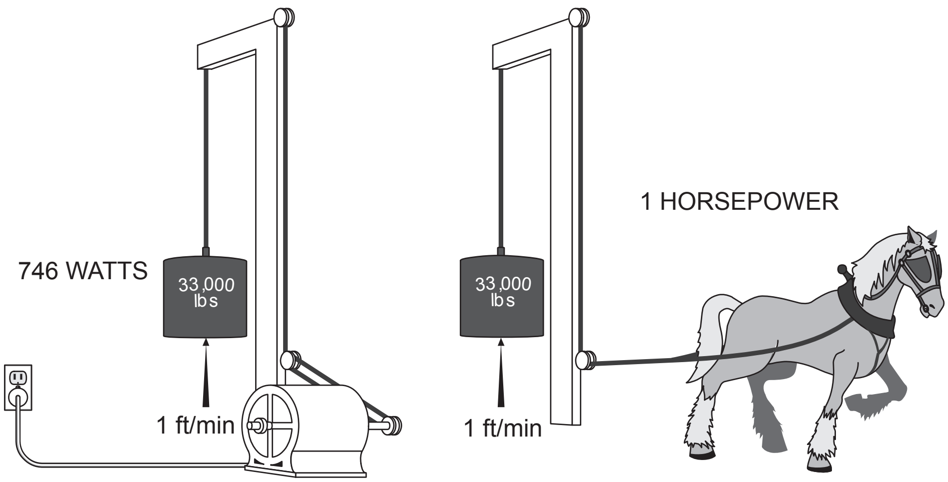
Because each phase is a predictable amount of time out of phase with the others, we can use these phenomena to easily start an electrical motor without the use of switches or capacitors. This reduces motor manufacturing and maintenance cost.

Horsepower[16]

Doing Work

Moving water from one location to another is defined as work and requires energy. One of the ways to measure the amount of energy required to do work is in foot-pounds. One foot pound of work is the amount of energy required to lift one pound of water one foot in elevation. In pumping situations, the amount of work done will be in the thousands of foot-pounds. Because we do not like to use large numbers, we have defined another term for work.

[16] Horsepower – When 33,000 foot-pounds of work is performed in one minute.



Electric Motors

Electric motors are rated in horsepower. The output of the motor is the name plate horsepower and is called **brake horsepower**[17].

[17] Brake Horsepower – The output horsepower of an electric motor. The representation of the amount of work that the motor can perform. Providing work of 33,000 foot pounds per minute is equivalent to one horsepower.

Horsepower to Electricity

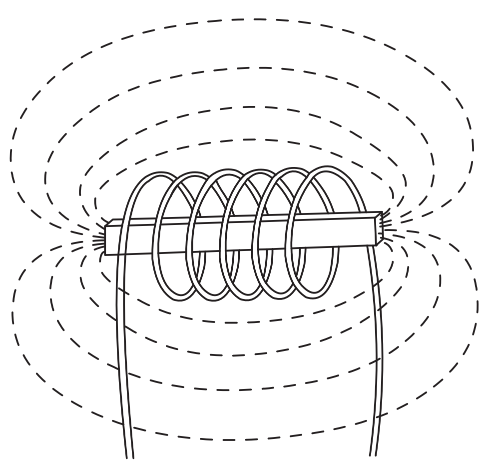
In order to provide the horsepower required, electricity is needed. The amount of electricity used is a combination of the voltage and the amperage and is the amount of work or power performed by electricity. It is given in units called watts. There is a relationship between horsepower and watts.

1 HP = 746 watts   1 HP = 0.746 kilowatts

Electromagnetism[18]

Electromagnetic Field

When current is passed through a conductor, an electromagnetic field is developed around the conductor. This field is very much like the field that exists between the north and south poles of a permanent magnet. It makes no difference if the current passed through the wire is AC or DC; the same electromagnetic field is produced.



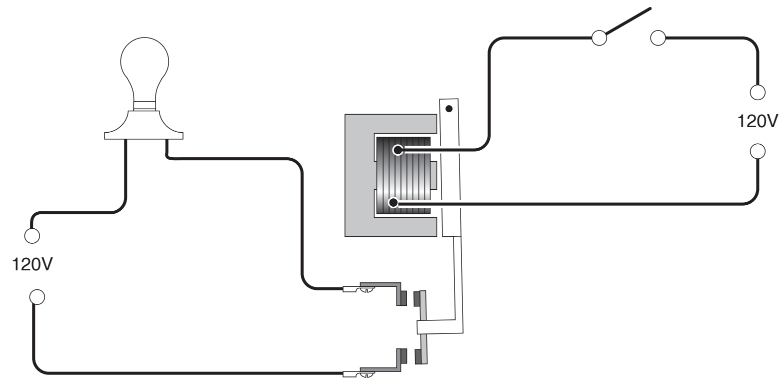
Making a Magnet

If we wind a wire around a piece of metal and pass a current through the wire, the piece of metal will become a magnet with a north and south pole.

[18] Electromagnetism – (1) The magnetic force produced by an electric current or (2) the science that studies the interrelation of electricity and magnetism.

Turning the Magnet into a Switch

Let's now use the electromagnet to operate a switch. A simple switch can be made by placing a bar close to the end of the magnet. If we connect the bar to one side of an electrical supply, connect a second bar and light to the other side of an electrical source, and close the switch, the light will come on. When power is applied to the electromagnet, the bar is pulled down by the electromagnetic field, and the light is energized.

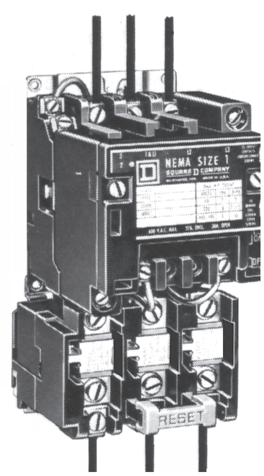


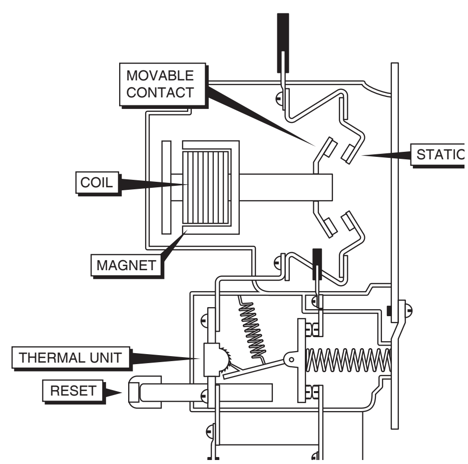
Contactors

There are numerous electromagnetic devices in an electrical panel. These are called relays, contactors, or contact relays. These simple electromagnets are used to close a switch. These same devices are also available to open a switch. There are contractors available with multiple contacts that can turn equipment and lights on and at the same instant turn other equipment and lights off. All of this can be done with a single contactor.

Magnetic Starters

A magnetic starter is nothing more than a large contactor. The switch that provides power to the electric motor is closed by applying power to an electromagnet (the coil). In most instances, the power to the motor is much higher voltage (240, 460, 480, etc.) than the power applied to the electromagnet (the coil), which is typically 120 volts.





Major Electrical Components

Transformers

Transformers are found on the electrical pole and in some control panels. Transformers are electrical devices that change voltage. They can be used to step voltage up or step voltage down. The transformer on the pole outside of the pumping station or treatment plant is most likely a step down transformer. In most instances, there is a second step down transformer in the control panel to step the voltage down from that needed for the motors to 120 volts for the control system.

Contacts

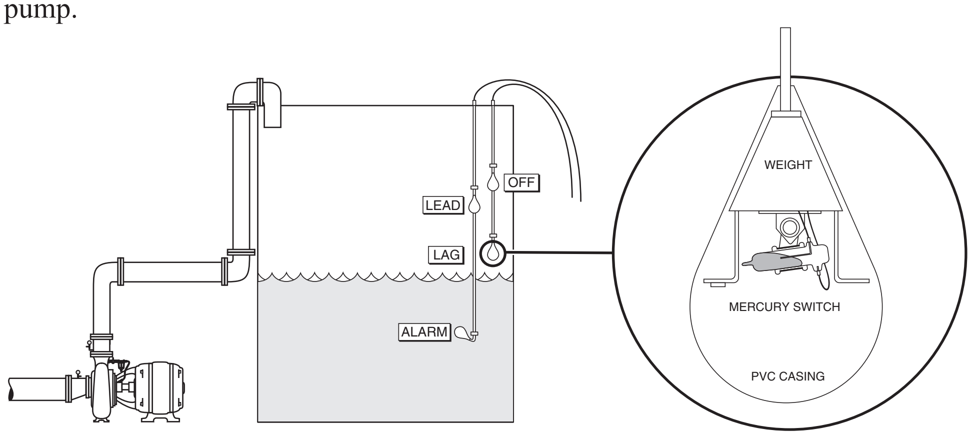
Contactors, coils, relays, contact relays, and magnetic starters are electromagnetic switches.

Switches

There is a wide variety of switches in use in treatment plants and pumping stations. Some of the most common in the small system are float switches, probes, flow switches, and pressure switches.

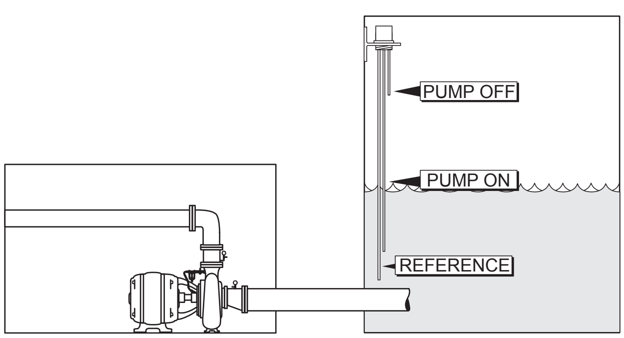
Float Switches

The most common float switch is the mercury float. The float contains a glass vial with two electrodes and a puddle of mercury. When the float is tripped, the mercury runs across the electrodes, and the circuit is closed. This may be used to start or stop a pump.



Probes

Electrical probes are often used to determine the level of water in a tank and turn pumps on or off. For probes to work, there must be at least two probes. When both probes are in the water, the circuit is closed. When the water level reaches the lower probe, the pump turns on and pumps until the water level reaches the upper (pump off) probe.

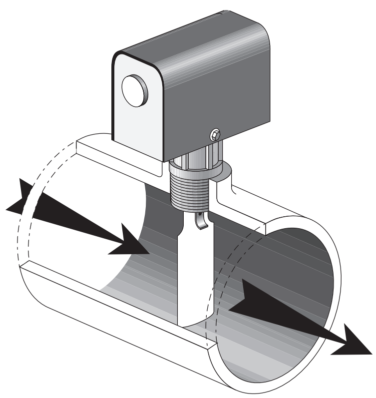


Flow Switch

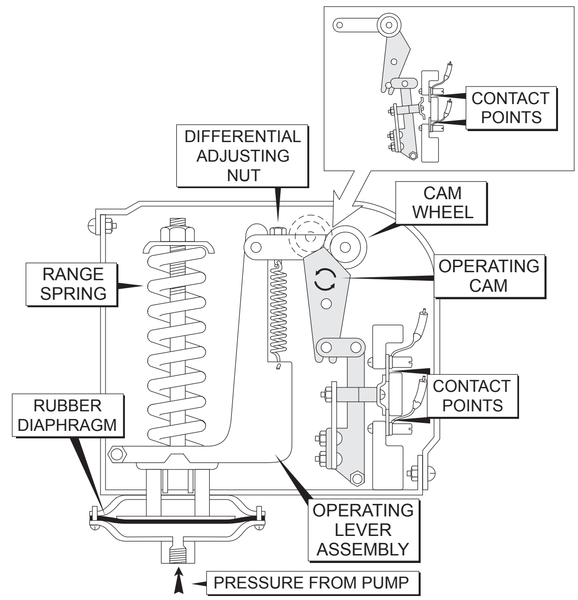
A typical switch in a fluoride system is a flow switch. This switch has a reed or paddle that is in the path of the flow. The forward flow of the water bends the reed and closes a pair of contacts, completing the circuit.

Pressure Switch

Tank systems often use pressure switches. These switches are made of a diaphragm and a series of levers and springs. Increases in pressure cause the diaphragm to flex, opening a contact, opening the circuit, and stopping the pump.
When the pressure falls, the diaphragm flexes to allow a contact to close, completing the circuit and starting the pump.



Flow switch



Pressure switch

Pumping Electrical Systems

The electrical system associated with pumping systems is composed of two independent but associated systems: the power system and the control system.

Power System

Transformers and Drop

The power system starts at the power company's transformer. The primary side (inlet) of the transformer is fused to prevent a short in the pump station from causing excessive damage to the power system. The lines leading from the transformer to the pumping building are called the drop. The drop connects to the weather head and mast at the pump house.

Disconnect and Breaker

The wires lead down the mast to the disconnect. The disconnect is used to disconnect the power from the entire system. From the disconnect, power goes to the **magnetic breaker**[19] or fuses. In some cases, the disconnect and the magnetic breaker may be the same. The magnetic breaker and fuses both serve the same purpose: over current protection. They prevent a fire in the building or wiring as a result of a short circuit in the wiring system.

[19] Magnetic Breaker – An electrically operated mechanical device used for over current protection.

Magnetic Starter

From the breaker, power is wired to the **magnetic starter**[20]. The magnetic starter is an electrically operated switch. The switch is closed when an electromagnet is energized. When the electromagnet is de-energized, a spring disconnects the switch. Power to operate the electromagnet is supplied through the control circuit.

[20] Magnetic Starter – An electrically operated mechanical switch used to connect power to an electric motor.

Heaters – Thermal Overload

At the bottom of the magnetic starter is the thermal overload or **heater**[21] assembly. The heaters sense the amount of amperage flowing through the starter by sensing the heat created by this amperage. The electrical controls of the heaters are in the control circuit. Heaters provide overload protection. If the motor draws high current, the heaters will heat up and disconnect the control circuit stopping the motor before it burns up.

[21] Heater – A device designed for overload protection of electric motors. The device is heat-sensitive and placed in the power circuit with an electrical connection to the control circuit.

Review

1. The frequency of alternating current is measured in what units?
2. Three phase power is like having:
3. Work in water is measured as horsepower. In electricity, this same work is measured a:
4. The device used to operate a magnetic starter is the:
5. What is the name used to identify magnetic starters, contact relays, motor starters, and relays?
6. The ________________ is used to protect the motor from current draw, and the ________________ is used to protect the building and wiring from a short circuit.

Control Circuit

Power Source

The power for the control circuit comes from one leg of the power circuit. This control voltage is usually tapped into the circuit above the magnetic starter. The voltage above the station is usually greater than the 120 volts desired for the control circuit. A step-down transformer is used to obtain the 120 volts.

Switches

From the transformer in the panel, the power leads to a switch or switches. Most pumping stations have a Hand-Off-Auto (H-O-A) switch. In the hand position, all of the remote sensing system is disconnected. From the H-O-A switch, power goes to the control switch in the heater assembly.

Control

The control circuit includes all of the control system: pressure-sensing switches, flow switches, level sensing switches, and float switches. These switches are primarily used to turn pumps on and off.

Control Panel

The control panel may also contain lights that indicate the status of the pumps, various alarm conditions, and hour meters.

Maintenance Considerations

Basic Routines

The maintenance requirements associated with each pumping installation are unique to the installation. However, there are general considerations that can be applied to most pumping installations. These include performing the following activities and gathering the following data at the specified intervals:

- Suction and discharge pressure - Daily
- Number of hours operated from the hour meter - Daily
- Inspect stuffing box for leakage - Daily
- Flow - Monthly
- Replace packing - Annually
- Amperage and voltage measurements - Quarterly

Basic Electricity and Motor Controls Quiz

1. What is the name for the flow of electrons in an electric circuit?
   A. Voltage
   B. Resistance
   C. Capacitance
   D. Current

2. What is the basic unit of electric current?
   A. The volt
   B. The watt
   C. The ampere
   D. The ohm

3. Which instrument is used to measure electric current?
   A. An ohmmeter
   B. A wavemeter
   C. A voltmeter
   D. An ammeter

4. What is the name of the pressure that forces electrons to flow through a circuit?
   A. Magnetomotive force, or inductance
   B. Electromotive force, or voltage
   C. Farad force, or capacitance
   D. Thermal force, or heat

5. What is the basic unit of electromotive force (EMF)?
   A. The volt
   B. The watt
   C. The ampere
   D. The ohm

6. How much voltage does an automobile battery usually supply?
   A. About 12 volts
   B. About 30 volts
   C. About 120 volts
   D. About 240 volts

7. How much voltage does a wall outlet usually supply in the U.S.?
   A. About 12 volts
   B. About 30 volts
   C. About 120 volts
   D. About 480 volts

8. Which instrument is used to measure electric potential or electromotive force?
   A. An ammeter
   B. A voltmeter
   C. A wavemeter
   D. An ohmmeter

9. What limits the current that flows through a circuit for a particular applied DC voltage?
   A. Reliance
   B. Reactance
   C. Saturation
   D. Resistance

10. What is the basic unit of resistance?
    A. The volt
    B. The watt
    C. The ampere
    D. The ohm

11. Which instrument is used to measure resistance?
    A. An ammeter
    B. A voltmeter
    C. An ohmmeter
    D. A wavemeter

12. What are three good electrical conductors?
    - A. Copper, gold, mica
    - B. Gold, silver, wood
    - C. Gold, silver, aluminum
    - D. Copper, aluminum, paper

13. What are four good electrical insulators?
    - A. Glass, air, plastic, porcelain
    - B. Glass, wood, copper, porcelain
    - C. Paper, glass, air, aluminum
    - D. Plastic, rubber, wood, carbon

14. What does an electrical insulator do?
    - A. It lets electricity flow through it in one direction.
    - B. It does not let electricity flow through it.
    - C. It lets electricity flow through it when light shines on it.
    - D. It lets electricity flow through it.

15. Before attempting to work on any electrical appliance you should?
    - A. Have proper training
    - B. Observe all state and local safety codes
    - C. Check for improper shorts or grounds
    - D. All of the above

Introduction to Water System Safety

Chapter 8

What Is In This Chapter?

1. Major elements of a safety program
2. General description of safety considerations associated with water systems:
   - Electrical measurements
   - Traffic control
   - Hazardous material communication
   - Competent person/shoring
   - Confined space
   - Lockout/Tagout
   - Handling chemicals
   - How to lift a load properly
   - First aid for exposure to chlorine
   - General hygiene to prevent contracting waterborne diseases
   - Types of fires and methods of handling them

Key Words

- Adjacent
- Cave-in
- Competent Person
- Confined Space
- Excavation
- Lockout/Tagout
- MSDS
- OSHA
- Permit-required Confined Space
- Trench

Introduction

Accidents don't just happen. They are caused. Most accidents are caused by an unsafe act and/or an unsafe condition. The following information is a brief discussion of the major components of a water utility safety program. This material is not intended as a comprehensive review of safety, but as an introduction to the more important aspects of a water utility safety program.

Responsibility

Everyone is responsible for providing safe working conditions, including the operator, superintendent, and management. The management has the responsibility to develop a safety program, set policy, provide rewards, and provide safety equipment. The superintendent has the responsibility to see that the safety program is carried out, that operators use safety equipment, and that unsafe conditions are identified and corrected. The operator has the responsibility to use safety equipment properly, follow safety policies and procedures, and provide information to the superintendent when an unsafe condition is identified. Remember, only YOU can be responsible for your own safety.

Regulations – Federal

[1] OSHA – Occupational Safety and Health Act.

The Williams-Steiger Occupational Safety and Health Act of 1970 (**OSHA**[1]) required the federal government to establish minimum health and safety standards. The standards and regulations developed under this act require that employers furnish employees a place of employment free from recognized hazards that are likely to cause death or serious physical harm. The act provides for up to one year of prison and up to $70,000 penalty on conviction of a violation of the regulations associated with this act.

Regulations – State of Alaska

The State of Alaska Department of Labor is responsible for implementing most of these regulations. In some cases, the Alaska regulations are more stringent than the federal regulations. These regulations pertain to private and public employers alike. An excellent resource for developing and maintaining your safety program is the Department of Labor web site: http://labor.state.ak.us/lss/oshhome.htm. Here you can find information you need to develop your own safety program and the required recordkeeping requirements.

Workplace Injury and Illness Prevention Program

Every organization is required to have a safety program, or as it is officially called, a Workplace Injury and Illness Prevention Program. Why have a safety program? Taking risks is a part of running any business, particularly for small water utility. Some risks are just not worth the gamble. One of these is risking the safety and health of those who work with you.

Accidents Cost Money

Safety organizations, states, small business owners, and major corporations alike now realize that the actual cost of a lost workday due to injury is substantial. For every dollar spent on the direct costs of a worker's injury or illness, much more will be spent to cover the indirect and hidden costs.

Consider what one lost workday injury costs:
- Productive time lost by an injured employee
- Time to hire or to retrain other individuals to replace the injured worker until his/her return
- Time and cost for repair or replacement of any damaged equipment or materials
- In addition to compensation, the cost of continuing all or part of the employee's wages
- Reduced morale and perhaps lower efficiency among employees
- Increased workers' compensation insurance rates
- Cost of completing paperwork generated by the incident

Injury and Illness Prevention Program

Your Injury and Illness Prevention Program must be a written plan that includes policies and procedures and is put into practice. These key elements are required:
- Management commitment/assignment of responsibilities
- Safety communications system with employees
- System for assuring employee compliance with safe work practices
- Scheduled inspections/evaluation system
- Accident investigation
- Procedures for correcting unsafe/unhealthy conditions
- Safety and health training and instruction
- Record keeping and documentation

Management Commitment/Assignment of Responsibilities

The person or persons with the authority and responsibility for your safety and health program must be identified and given management's full support. Your management must commit itself and your agency by building an effective Injury and Illness Prevention Program and integrating it into your entire operation. This commitment must be backed by strong organizational policies, procedures, incentives, and disciplinary actions as necessary to ensure employee compliance with safe and healthful work practices.

Safety Communications

Your program must include a system for communicating with all employees - in a form readily understandable by all affected employees - on matters relating to occupational safety and health, including provisions designed to encourage employees to inform the employer of hazards at the worksite without fear of reprisal. This is usually in the form of monthly safety meetings designed to discuss and advise management on safety and health issues.

Schedule general employee meetings at which those present may freely and openly discuss safety. Such meetings should be regular, scheduled, and announced to all employees so that maximum employee attendance can be achieved. Many employers find it cost-effective to hold such meetings at shift change time, with a brief overlap of schedules to accomplish the meetings. If properly planned, effective safety meetings can be held in a 15 to 20-minute time frame.

Concentrate on:

- Occupational accident and injury history at your own worksite, with possible comparisons to other locations in your company.
- Feedback from the employee group.
- Guest speakers from your workers' compensation insurance carrier or other agencies concerned with safety.
- Brief audio-visual materials that relate to your industry.

Controlling meetings:

- Stress that the purpose of the meeting is safety. Members of management should attend this meeting.
- Training programs are excellent vehicles for communicating with employees.
- Posters and bulletins can be very effective ways of communicating with employees. You may obtain useful materials from OSHA, the Alaska Department of Labor, your workers' compensation insurance carrier, the National Safety Council, or other commercial and public service agencies.
- Newsletters or similar publications devoted to safety are also very effective communication devices. If you cannot devote resources to an entire publication, make safety a featured item in every issue of your agency's newsletter.
- Provide a safety suggestion box for employees, anonymous if desired, to communicate their concerns to management.
- Publish a brief company safety policy or statement informing all employees that safety is a priority issue with management, and urge employees to actively participate in the program for the common good.
- Communicate your concerns about safety to all levels of management.
- Document all communication efforts, as you will be required to demonstrate that a system of effective communication is in place.

Hazard Assessment and Control

Periodic inspections of the workplace and procedures for correction of safety hazards provide a method of identifying existing or potential hazards in the workplace, as well as eliminating or controlling them. Hazard control is the heart of an effective Injury and Illness Prevention Program. Hazards that occur or recur reflect a breakdown in the hazard control system. The hazard control system is also the basis for developing safe work procedures and injury/illness prevention training.

A qualified person must make the required hazard assessment inspection of your workplace. This survey can provide the basis and guide for establishing your hazard assessment and control system. The inspection can produce knowledge of hazards that exist in the workplace, as well as conditions, equipment, and procedures that could be potentially hazardous.

An effective hazard control system will identify hazards that exist or develop in your workplace, how to correct those hazards, and steps you can take to prevent their recurrence. If you have an effective system for monitoring workplace conditions, you will be able to prevent many hazards from occurring through scheduled and documented self-inspections. Make sure established safe work practices are being followed and any unsafe conditions or procedures are identified and corrected properly.

Scheduled inspections are in addition to the everyday safety and health checks that are part of the routine duties of managers and supervisors. The frequency of these inspections depends on the operations involved, the magnitude of the hazards, the proficiency of employees, changes in equipment or work processes, and the history of workplace injuries and illnesses. Inspections should be conducted by personnel who, through experience or training, are able to identify actual and potential hazards and understand safe work practices.

Management and/or the agency's safety committee must review written inspection reports. The review should assist in prioritizing actions and verify completion of previous corrective actions, and the overall inspection program results should be reviewed for trends.

Employees should be encouraged to tell their supervisors of possibly hazardous situations, knowing their reports will be given prompt and serious attention without fear of reprisal. When everyone knows that the situation was corrected (or why it was not hazardous), you create a system by which employees continue to report hazards promptly and effectively.

Workplace equipment and personal protective equipment should be maintained in safe and good working condition. In addition, your own program monitors the operation of workplace equipment and can also verify that routine preventive maintenance is conducted and personal protective equipment is reliable. Proper maintenance not only makes good safety sense, it can prevent costly breakdowns and undue exposures.

Hazards should be corrected as soon as they are identified. For any that cannot be immediately corrected, set a target date for correction based on such considerations as the probability and severity of an injury or illness resulting from the hazard; the availability of needed equipment, materials, and/or personnel; time for delivery, installation, modification, or construction; and training periods.

Provide interim protection to employees who need it while the correction of hazards is proceeding. A written tracking system such as a log helps you monitor the progress of hazard correction. You should review and prioritize your program based on the severity of the hazard.

Accident Investigation

A primary tool you should use in an effort to identify and recognize the areas responsible for accidents is a thorough and properly completed accident investigation. It should be in writing and adequately identify the cause(s) of an accident or near-miss incident.

Accident investigations should be conducted by trained individuals whose primary focus is to understand why the accident or near miss occurred and what actions can be taken to prevent recurrence. In smaller organizations, the responsibility may lie directly with the supervisor responsible for the affected area or employee.

Questions to ask in an accident investigation include the following:

- What happened? The investigation should describe what took place that prompted the investigation: an injury to an employee, an incident that caused a production delay, damaged material, or any other conditions recognized as having a potential for losses or delays.

- Why did the incident happen? The investigation must obtain all the facts surrounding the occurrence: what caused the situation to occur; who was involved; whether the employee(s) was/were qualified to perform the functions involved in the accident or near miss; whether they were properly trained; whether proper operating procedures were established for the task involved; whether these procedures were followed, and if not, why not; where else this or a similar situation might exist; and how it can be corrected.
- What should be done? The person conducting the investigation must determine which aspects of the operation or processes require additional attention. It is important to note that the purpose here is not to assess blame, but to determine what type of constructive action can eliminate the cause(s) of the accident or near miss.
- What action has been taken? Action already taken to reduce or eliminate the hazard being investigated should be noted, along with any hazards remaining to be addressed. Any interim or temporary precautions should also be noted. Any pending corrective action and reason for delaying its implementation should be identified.

Corrective action should be identified in terms of not only how it will prevent a recurrence of the accident or near miss, but also how it will improve the overall operation. This will assist the investigator in reporting his/her solutions to management. The solution should be a means of not only achieving accident control, but also improving overall operations.

If you have a safety committee, its members should review investigations of all accidents and near-miss incidents to assist in recommending appropriate corrective actions to prevent similar recurrence.

Thorough investigation of all accidents and near misses will help you identify causes and needed corrections, as well as can help you determine the reasons accidents occur, the locations where they happen, and any accident trends. Such information is critical to preventing and controlling hazards and potential accidents.

Safety Planning, Rules, and Work Procedures

Planning for safety and health is an important part of every business decision, including purchasing, operations, changes in work processes, and planning for emergencies.

Your safety and health planning are effective when your workplace has the following:

- Rules written to apply to everyone and address such areas as personal protective equipment, appropriate clothing, expected behavior, and emergency procedures. You and your employees should periodically review and update all rules and procedures to make sure they reflect present conditions.
- Rules and procedures written for new exposures when they are introduced into the workplace.
- Safe and healthful work practices developed for each specific job.
- Discipline or reward procedures to help assure that safety rules and work procedures are put into practice and enforced. Reward or positive reinforce-

ment procedures such as bonus, incentive, or employee recognition programs should provide positive motivation for compliance with safety rules and procedures.

- A written plan for emergency situations. Your plan must include a list of emergencies that may arise, as well as a set of procedures to respond to each situation. Some emergency procedures, such as those covering medical emergencies or fire evacuation, are mandated by OSHA regulations.
- If you have operations involving hazardous substances, procedures, or processes, you must designate emergency response teams to be specifically trained and equipped to handle possible imminent hazards.

Safety and Health Training

Training is one of the most important elements of any Injury and Illness Prevention Program. It allows employees to learn their job properly, brings new ideas into the workplace, reinforces existing ideas and practices, and puts your program into action.

Employees benefit from safety and health training through fewer work-related injuries and illnesses, as well as reduced stress and worry caused by exposure to hazards. The agency benefits from reduced workplace injuries and illnesses, increased productivity, lower costs, and a more cohesive and dependable work force.

An effective Injury and Illness Prevention Program includes training for both supervisors and employees. Training for both is required by OSHA safety orders. You may need outside professionals to help you develop and conduct your required training program. Help is available from the OSHA Consultation Service, the Alaska Department of Labor, your workers' compensation insurance carrier, private consultants, and vendor representatives.

Outside trainers should be considered temporary. Eventually you will need your own in-house training capabilities, so you can provide training that is timely and specific to the needs of your workplace and your employees.

To be effective and also meet OSHA requirements, your training program needs to:

Let your supervisors know:

- They are key figures responsible for the establishment and success of your Injury and Illness Prevention Program.
- The importance of establishing and maintaining safe and healthful working conditions.
- They are responsible for being familiar with safety and health hazards to which their employees are exposed; how to recognize these hazards; the potential effects these hazards have on their employees; and the rules, procedures, and work practices for controlling exposure to those hazards.
- How to convey this information to employees by setting a good example, instructing them, and making sure they fully understand and follow safe procedures.
- How to investigate accidents and take corrective and preventive action.

Let your employees know:

- The success of the company's Injury and Illness Prevention Program depends on their actions as well as yours.
- The safe work procedures required for their jobs and how these procedures protect them against exposure.
- When personal protective equipment is required or needed, as well as how to use and maintain it in good condition.
- What to do if emergencies occur in the workplace.

A safety and health-training program must, at a minimum, provide training and instruction:

- To all employees when your program is first established.
- To all new employees.
- To all employees given new job assignments for which training has not been previously received.
- Whenever new substances, processes, procedures, or equipment are introduced to the workplace and present a new hazard.
- Whenever you or your supervisors are made aware of a new or previously unrecognized hazard.
- For all supervisors to assure they are familiar with the safety and health hazards to which employees under their immediate direction and control may be exposed.

Safety and Health Recordkeeping

No operation can be successful without adequate recordkeeping, which enables you to learn from past experience and make corrections for future operations. Records of accidents, work-related injuries, illnesses, and property losses serve a valuable purpose.

Under OSHA recordkeeping requirements, information on accidents is gathered and stored. Upon review, causes can be identified and control procedures instituted to prevent the illness or injury from recurring. Keep in mind that any inspection of your workplace may require you to demonstrate the effectiveness of your program.

Injury and Illness Records

Injury and illness recordkeeping requirements under OSHA require a minimum amount of paperwork. These records give you one measure for evaluating the success of your safety and health activities: success would generally mean a reduction or elimination of employee injuries or illnesses during a calendar year.

You must report industrial deaths and accidents to the Alaska Division of Labor Standards and Safety. Alaska Statute 18.60.058 requires employers to report to the Division of Labor Standards and Safety any employment accident that is fatal to one or more employees or that results in the overnight hospitalization of one or more employees. The report, which must be made immediately but no later than eight hours after the employer learns that the accident has occurred, must relate the circumstances of the accident, the number of fatalities, and the extent of the injuries.

Additional information on recordkeeping can be found on the Department of Labor web site at:

http://labor.state.ak.us/lss/oshhome.htm

During the year, regularly review these records to see where your injuries and illnesses are occurring. Look for any patterns or repeat situations. These records can help you to identify hazardous areas in your workplace and to pinpoint where immediate corrective action is needed. Since the basic OSHA records are for reportable injuries and illnesses only, you may expand your system to include all incidents relating to workplace safety and health, even those where no injury or illness resulted. Such information can assist you in pinpointing unsafe acts, conditions, or procedures.

Exposure Records

Injury and illness records may not be the only records you need to maintain. OSHA standards concerning toxic substances and hazardous exposures require records of employee exposure to these substances and sources, physical examination reports, employment records, and other information.

Documentation of Your Activities

Essential records, including those legally required for workers' compensation, insurance audits, and government inspections must be maintained for as long as required. For most employers, OSHA standards also require that you keep records of steps taken to establish and maintain your Injury and Illness Prevention Program:

- Records of scheduled and periodic inspections as required by the standard to identify unsafe conditions and work practices. The documentation must include the name(s) of the person(s) conducting the inspection, the unsafe conditions and work practices identified, and the action taken to correct the unsafe conditions and work practices. The records are to be maintained for at least one year. However, employers with fewer than 10 employees may elect to maintain the inspection records only until the hazard is corrected.
- Documentation of safety and health training required by standards for each employee. The documentation must specifically include employee name or other identifier, training dates, type(s) of training, and the name of the training provider. These records must also be kept for at least one year, except that training records of employees who have worked for less than one year for the employer need not be retained beyond the term of employment if they are provided to the employee upon termination of employment.

In addition, employers with fewer than 10 employees can substantially comply with the documentation provision by maintaining a log of instructions provided to the employee with respect to the hazards unique to the employees' job assignment when first hired or assigned new duties. Keeping such records fulfills your responsibilities under General Industry Safety Order 3203. It also affords an efficient means to review your current safety and health activities for better control of your operations and to plan future improvements.

Review

1. The department in Alaska responsible for implementing OSHA regulations is the Department of :

2. What eight key elements must be in a safety program?

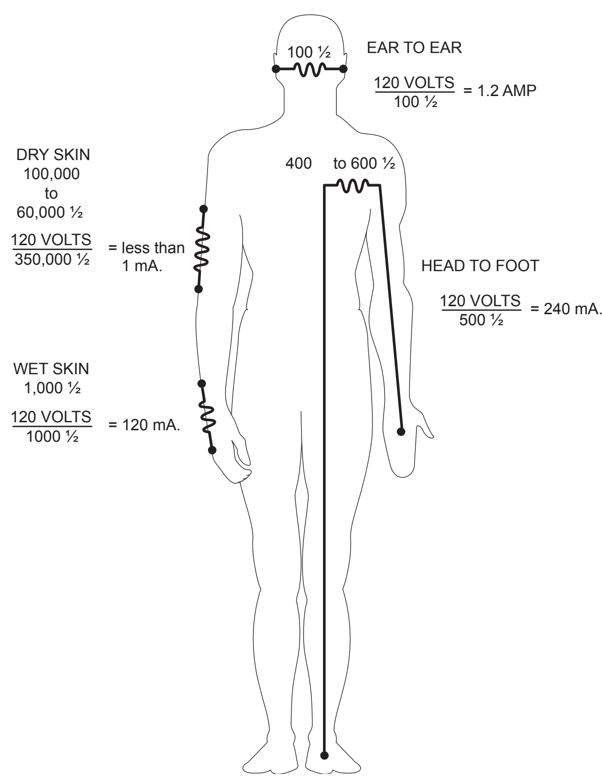
Major Safety Concerns

The following is a brief discussion of major safety concerns in small water utilities.

Electrical Measurements

Electrical measurements should be taken by a qualified electrician. When one is not available and the operator has to make these measurements, the following safety precautions should be followed:

- Remove all jewelry, including earrings, rings, watches, necklace, metal-rimmed glasses, and large belt buckles
- Wear shirts with tight-fitting sleeves
- Fasten the panel door open
- Wear safety goggles
- Wear electrical safety gloves
- Have a second person standing by when making the measurements
- Make the measurements with one hand; keep the second hand in your pocket



Amperage flow through various portions of the body with 120 volts applied

Traffic Control

Introduction

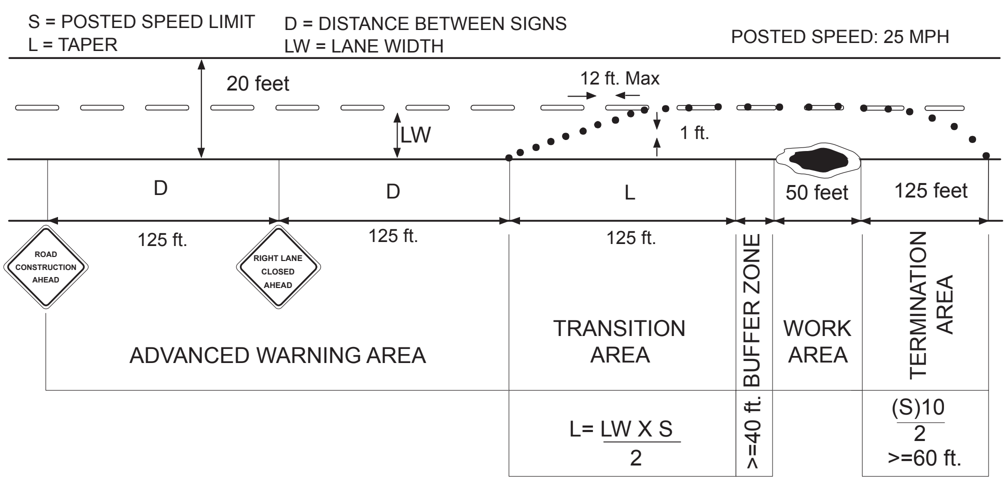
Traffic control includes protection for vehicles, snow machines, ATVs, and pedestrians. When work is being performed on a street or sidewalk, the proper number of signs and cones should be in place. The number of signs and cones needed depends on the speed of the traffic.

Zones

When setting up traffic control, you should consider the following four zones:

- Advance Warning Zone – The zone prior to the work site. Here signs such as UTILITY WORK AHEAD, RIGHT LANE CLOSED, and CONSTRUCTION AHEAD are used.

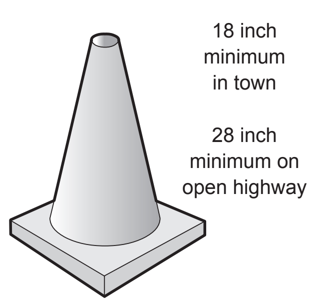
- Transition Zone – The zone used to move the traffic away from the work area and into a selected lane. Cones are often used to define the transition zone.
- Buffer and Work Area – A buffer area of 40 to 50 feet is desirable in front of the work area. This allows the placement of equipment without being in the traffic area.
- Termination Zone – The area after the work area where traffic is allowed to come back into its normal flow pattern.



Sign Placement

When the traffic speed is 25 mph or less, a typical traffic control setup would include the following:

- At least two advanced warning signs 125 feet apart
- Cone taper of 125 to 150 feet
- Twelve cones
- Cones spaced 12 feet apart



TRAFFIC CONE

Review

1. Describe four safety precautions to follow when making electrical measurements.

2. Traffic control means to control what?

3. How far apart should the advance warning signs be when the posted speed is 25 mph? How far apart should the cones be placed?

Hazardous Material Communication

OSHA has developed a hazardous communication standard to make sure that the proper information on handling hazardous materials reaches each worker required to handle the material. This program addresses five main areas:

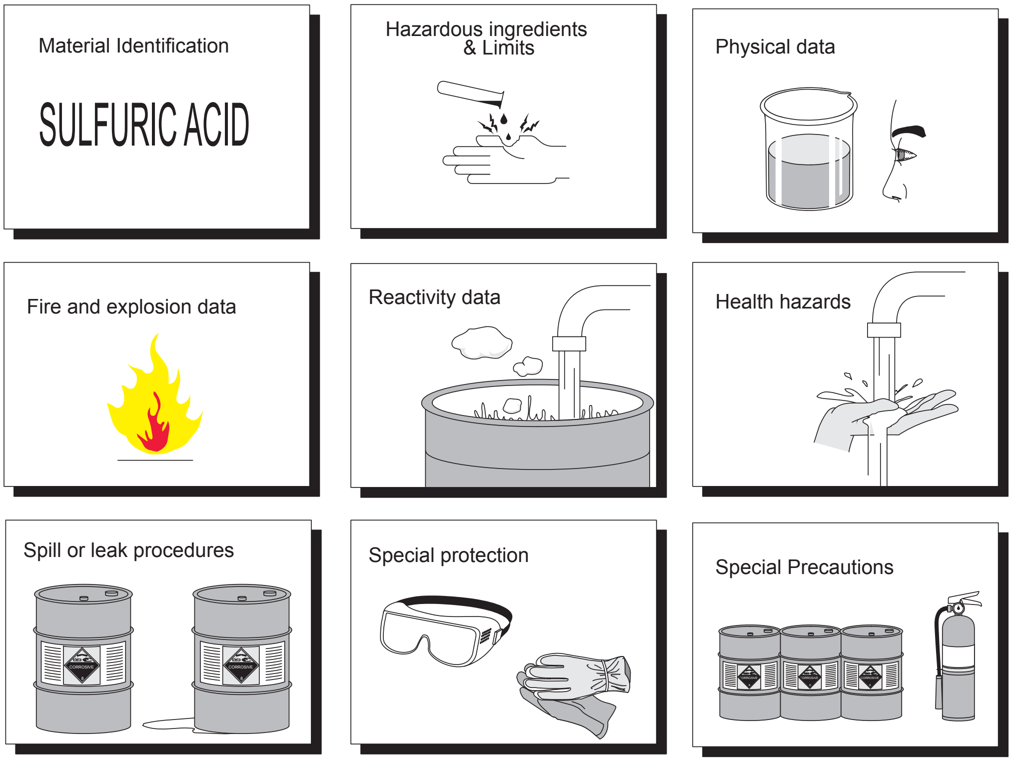
- The identification of hazardous chemicals
- A product warning label system
- The development of **Material Safety Data Sheets (MSDS[2])**
- The development by each organization of a hazard communication program
- Employee training program on how to handle hazardous materials and how to read the hazardous material labels and MSDS

[2] MSDS (Material Safety Data Sheet) – Written material produced by the chemical manufacturer describing properties and safe-handling procedures.

MSDS Components

An MSDS is a written document provided by the manufacturer and supplier of the chemical. Each chemical (alum, chlorine, paint, cleaners, etc.) must have a MSDS. Your organization is required to have available copies of the MSDS for the chemicals handled by the workers. Each MSDS has information concerning nine specific areas:

- Chemical identification information
- Hazardous ingredients and safe exposure levels
- Physical data
- Fire and explosion data, including flash point and how to extinguish a fire
- Health hazards, including first aid requirements
- Reactivity data – the incompatibility and instability of the material with other chemicals
- How to handle a spill or leak
- Special protective equipment required for handling
- Special precautions concerning posting, handling, and clean-up

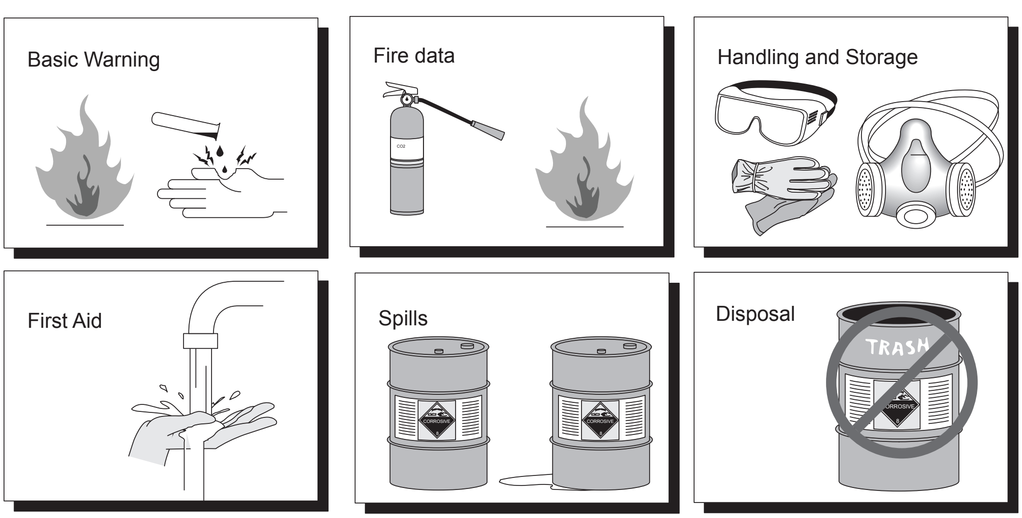


Label Components

Each manufacturer of a chemical is required to place a label on the container of that chemical. The label contains information on six specific areas:

- Basic warnings, including chemical name, hazardous ingredients, and name and address of manufacturer
- First aid for exposure to the chemical
- How to handle a fire involving the chemical
- How to handle a spill of the chemical
- Equipment necessary for proper handling and storage of the chemical
- Cautions regarding proper disposal of the container

In addition, a placard indicating special precautions is commonly included. Typical placards are for flammable, corrosive, oxidizer, poison, irritant, explosive, and combustible.



Written Program Content

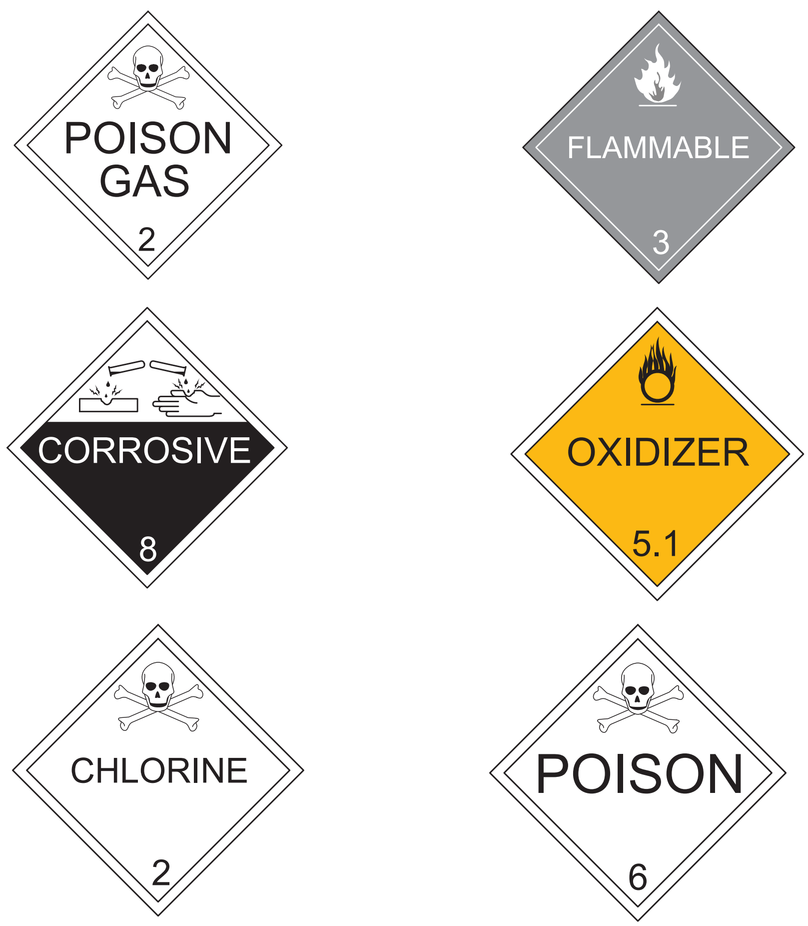
Each organization is required to have a written program that contains the following elements:

- A listing of all hazardous chemicals in the workplace
- How the needed labels will be provided
- The location of MSDS
- How employee training will be provided
- How employees will be informed of hazards from unlabeled pipes
- How workers will be told the hazards of non-routine tasks

Training Requirements

The training program must contain the following elements:

- How to detect the release of a hazardous chemical
- The hazards of all chemicals in your work area and the dangers of any job you may have to do
- How to protect yourself from these dangers
- The details of the Hazardous Communication Program developed by the employer

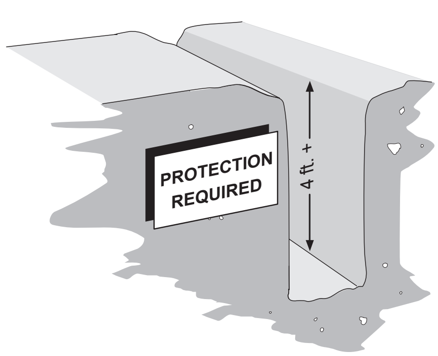


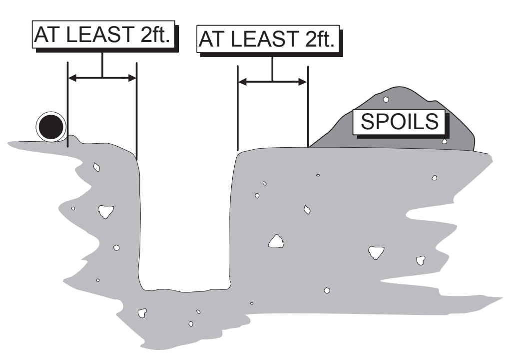
Competent Person/Shoring

When a **trench**[3] is dug for construction or repair, a person with the proper training to be considered a **competent person**[4] must be on hand to do the following:

- Inspect the site for potential hazards, and re-inspect regularly.
- Test the soil to determine its classification.
- Determine the proper method of preventing a **cave-in**[5]. Any trench in Alaska that is four feet deep or deeper is required to have some form of cave-in protection.
- Assure that no materials that may present a hazard to those in the trench are on the surface **adjacent**[6] to the trench.
- Determine that all other underground utilities in the vicinity of the **excavation**[7] are located.
- Determine that proper access and egress is available for workers to enter and exit the trench. A ladder must be within 25 feet of any person working in a trench that is three feet deep or deeper.
- Determine that all traffic control is properly installed.
- Assure that no load can fall on those working in the trench.
- Ensure that back-up warning systems are in place and working on all equipment at the work site.
- Make sure that workers are protected from the accumulation of water.
- Ensure that all adjacent structures are stable and do not represent a hazard to the workers.
- Make sure that the spoils are placed at least 2 feet back of the trench wall.
- Assure that adequate protection to prevent persons from falling into the excavation is in place.
- Ensure that proper procedures are used to test the trench for the presence of combustible and toxic gasses in addition to oxygen. The oxygen level must remain above 19.5 percent. This includes keeping internal combustion engines far enough away to avoid CO accumulation in the trench.
- Assure that proper emergency rescue equipment is on the job site.

The "competent person" should inspect the excavation at least once a day and record the findings of that inspection.





[3] Trench – A narrow excavation made below the surface of the ground. In general, the depth is greater than the width, but the width of a trench should not be greater than 15 feet.

[4] Competent Person – One who is capable of identifying existing and predictable hazards in the surroundings or working conditions which are unsanitary, hazardous, or dangerous to employees and who has authorization to take prompt corrective measures to eliminate them.

[5] Cave-in – 1) The separation of a mass of soil or rock material from the side of an excavation or 2) the loss of soil from under a trench shield or support system and its sudden movement into the excavation, either by falling or sliding, in sufficient quantity so that it could entrap, bury, or otherwise injure or immobilize a person.

[6] Adjacent – As used with trench protection systems, the area within a horizontal distance from the edge of the trench equal to the depth of the trench.

[7] Excavation – Any man-made cavity or depression in the earth's surface, including its sides, walls, or faces, formed by earth removal and producing unsupported earth conditions by reason of the excavation.

Review

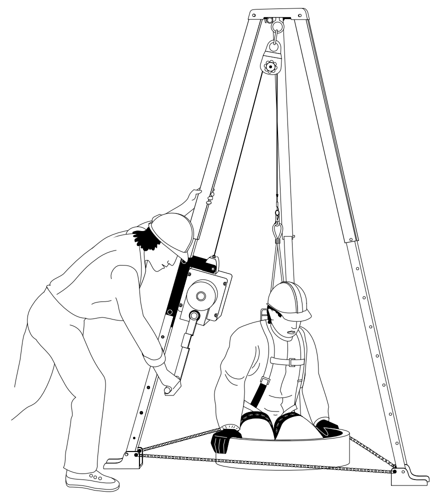
1. What is the function of the MSDS?

2. What is the function of the Hazardous Material Communication Program?

3. In Alaska, the soils associated with any trench must be tested by a ______________ ______________ if the trench is more than ______________ deep, and protection must be provided.

Confined Space

A **confined space**[8] is any space where the entrance and exit is restricted, is not made for human habitation, and may have a hazardous atmosphere. A **permit-required confined space**[9] is a confined space that 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 contains any other recognized serious safety hazard. Always assume a space is a permit-required confined space until proven otherwise!



Typical confined spaces include manholes, valve pits, the inside of a pressure filter, wet well of a sewage lift station, and reservoirs. In Alaska, any trench 3 feet deep or deeper is considered a confined space. When an area is identified as a permit-required confined space, the following must be in place:

- The organization must have a written policy, procedure, and permit system for confined spaces.
- Entrance can be gained only if a permit is obtained and signed by the entry supervisor.
- The air must first be tested for explosive and hazardous gases, then for oxygen concentration.
- It is best to ventilate the confined space for at least 10 minutes before entering and to maintain the ventilation system during occupancy.
- The air in the confined space should be tested every 30 minutes for combustible and toxic gases.
- There must be two people on hand to enter a confined space: the entrant and an attendant. The two must be in constant communication with each another.
- In most confined spaces, the entrant must use a safety harness connected to a retrieval tripod.

[8] Confined Space – As defined by NIOSH, a space that by design has limited openings for entry and exit; has unfavorable natural ventilation that could contain or produce dangerous air contaminants; and that is not intended for continuous employee occupancy.

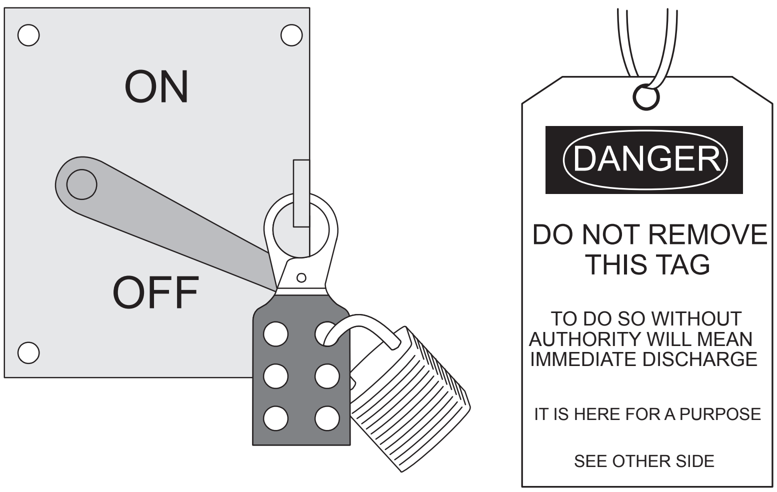
[9] Permit-required confined space – A confined space that contains or has the potential to contain a hazardous atmosphere, that contains a material that has the potential for engulfing an entrant, that has an internal configuration such that an entrant could be trapped, or that contains any other recognized serious safety hazard.

Lockout/Tagout

All energy sources that supply motors, valves, air compressors, and other equipment need to be secured and locked-out and tagged-out prior to any maintenance work on this equipment. This is typically done at breaker panels to secure electrical energy, but any source of energy, such as air or water pressure, spring tension, or steam, must be secured also. A **lockout/tagout**[10] program must include the following:

- A written policy and procedure
- Individual keyed locks for each person who may shut down a piece of equipment
- Tags that allow the individual to identify who locked out the device as well as when and why it was locked out

[10] Lockout/Tagout – A process of physically locking and tagging hazardous energy sources to prevent energy during maintenance.



Handling Chemicals

The most common chemicals handled by small water system operators include the following:

- Gas chlorine
- Aluminum sulfate (alum)
- Lime
- Soda ash
- Calcium hypochlorite
- Sodium hypochlorite
- Potassium permanganate
- Sodium fluoride

The chemicals should be stored and marked in accordance with the MSDS.

General Guidelines for Personal Protective Equipment

The following are general guidelines for personal protective equipment for these common chemicals. For more detailed information, see the MSDS for the specific chemical.

Safety Equipment	Chemical
Chemical Safety Goggles	Required for all but gas chlorine
Cartridge Respirator	Calcium hypochlorite, sodium hypochlorite, potassium permanganate, and sodium fluoride
Dust Mask	Alum, lime, and soda ash
Rubberized Gloves	Calcium and sodium hypochlorite, potassium permanganate, and sodium fluoride
Self-Contained Breathing Apparatus	Gas chlorine

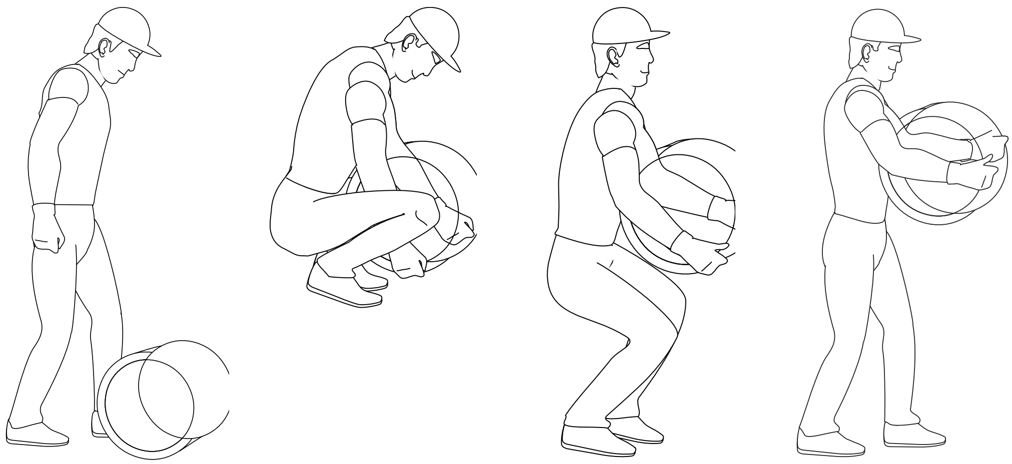
Gluing PVC

The cleaning solvent used to prepare PVC for gluing contains Methyl Ethyl Ketone (MEK). This solvent can enter the blood stream by passing directly through the skin or by breathing the fumes. Butyl rubber gloves and a cartridge respirator are recommended when using this material.

Lifting

Working in a water system, by its nature, requires lifting. We all tend to lift too much and ignore the proper techniques of lifting. The result is a high rate of back injuries in people who perform construction work. Here are a few simple steps that, if followed, will reduce the possibility of a back injury:

1. Get on firm, flat footing. Keep your knees apart and your toes pointed slightly out.
2. Bend at the knees, not at the hips.
3. Tighten your stomach muscles. This will help to support your back.
4. Lift with your legs. This puts less pressure on your back.
5. Keep the load close to your body.
6. Think before your start the lift. Here are a few basic questions to ask:
    - What is the size of the load?
    - Can I safely lift this load?
    - Can I get help if the load is beyond by capabilities? A “He-Man” is of very little value with a bad back!
    - Is there a better way?
    - Can I use a hand truck, backhoe, or other device to do this job?
    - Is the pathway clear? Most accidents in this industry are slips, trips, and falls.
7. Keep in shape. Exercising at least three times a week will keep both your back and stomach muscles in tone and thus will reduce the possibility of back injury.



First Aid

The following is a brief review of common first aid practices for accidents likely to occur in the water works industry.

Chlorine on Skin

For exposure of your skin to sodium hypochlorite, calcium hypochlorite solution, or gas chlorine, flush the area for 15 minutes with clean fresh water. If burning persists, see a doctor.

Chlorine in Eye

If sodium hypochlorite, calcium hypochlorite solution, or gas chlorine enters the eye, flush the eye for 15 minutes with clean, warm fresh water. See a doctor.

Overcome by Chlorine Gas

If someone is overcome by gas chlorine, remove the person from the contaminated area, and treat for shock. If the person is not breathing, give mouth-to-mouth resuscitation. If their heart has stopped, give CPR.

Shock

In the case of shock due to injury, illness, or poison, the symptoms will be a pale, mottled face, cold sweat, fast breathing, and a weak pulse. Keep the person warm and lying down with their feet raised. Do not give fluids or food.

Frostbite

Among the symptoms of frostbite are skin that is flushed before changing to white or grayish yellow, blisters, coldness, numbness, and pain. Do not rub the area. Quickly warm by immersing the area in tepid water (102° F to 105°F).

Burns

The symptoms of burns are redness and pain. Moderate burns will blister. A severe burn will show tissue destruction. Treat small burns with ice. Use cool water (not ice) for big burns. Wash with cool water and soap. Apply a sterile dressing but no ointment. Do not remove clothing stuck to a burn. Seek medical help if there is extensive blistering or if the skin is white, dry, and painless.

Electric Shock

The symptoms of electric shock are unconsciousness and pale, blushed skin that is clammy and mottled in appearance. If the victim is not breathing, give mouth-to-mouth. If there is no pulse, give CPR, but only if you are trained to do so. Elevate feet and keep warm.

Mouth-to-Mouth Resuscitation

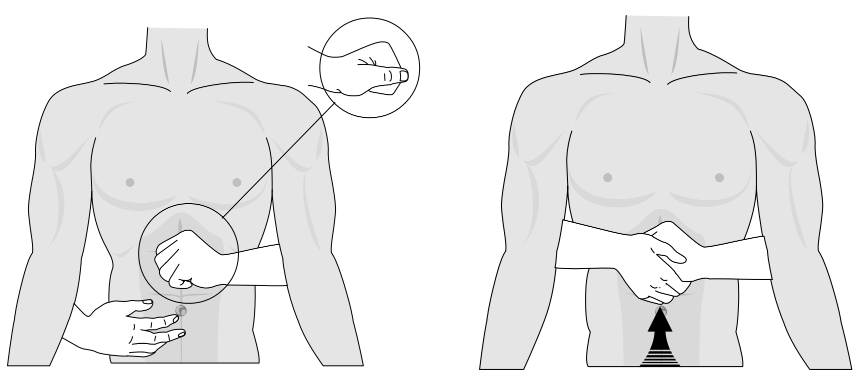
Use this procedure only when the victim is not breathing. Lack of consciousness is not a symptom that breathing has stopped.

1. Remove any foreign matter from the mouth.
2. Tilt the victim's head backward so that their chin is pointing upward. This is accomplished by placing one hand under the person's neck and lifting while placing your other hand on their forehead and pressing. Tilt the head without closing the person's mouth.
3. Move their tongue away from the back of their throat to provide an open airway.
4. While maintaining a backward head-tilt position, pinch the person's nostrils with the fingers of the hand that is pressing on their forehead to prevent leakage of air.
5. Open your mouth wide, take a deep breath, seal your mouth tightly around the person's mouth in a wide-open circle, and blow.
6. Watch the victim's chest. When you see it rise, stop inflation, raise your mouth, turn your head to the side, and listen for exhalation. Watch the chest to see that it falls.
7. Repeat this process at a rate of one breath every five seconds for adults (12 per minute), one every three seconds for infants and small children (20 per minute).

Choking

This procedure is commonly used when a person is choking but still conscious:

1. Stand behind the victim.
2. Wrap your arms around their waist.
3. Make a fist with one hand, and place the thumb side against the person's abdomen in the midline slightly above their navel and well below the tip of their sternum.
4. Grasp your fist with your other hand.
5. Press into the victim's abdomen with a quick upward thrust. Each thrust should be distinct and delivered with the intent of relieving the airway obstruction. Exert no pressure against their rib cage with your forearms.



Review

1. In order to protect your back, you should always lift with your:
2. What is the first aid for a spill of chlorine on your skin?
3. What is the key condition that will tell you it is all right to give mouth-to-mouth to a person?

General Hygiene

Disease Potential

People are one of the most significant carriers of diseases. In fact, most of the waterborne diseases discussed in this text are carried by people. Often operators of water systems in small communities must also operate the wastewater facility and make repairs to pipes in soils that are contaminated by human waste.

Protection

There are precautions that you can take to maintain a level of protection from diseases such as hepatitis and gastroenteritis:

- When possible, use rubberized gloves to handle contaminated material.
- Never smoke while working in a contaminated area.
- Never eat food in a contaminated area.
- Keep your hands away from your face while working in a contaminated area.
- Wash with soap and water after handling contaminated material.
- Always wash your hands with soap and water after using the rest room.
- If possible, shower and change clothes before going home.

Bloodborne Pathogens

In 1992, OSHA Bloodborne Pathogens Standards (BBPS) became law. Bloodborne Pathogens are pathogenic microorganisms that are present in human blood and other body fluids and can cause disease in humans. These pathogens include, but are not limited to, Hepatitis B Virus (HBV) and Human Immunodeficiency Virus (HIV). Other potentially infectious materials include the following human body fluids: mucus, semen, vaginal fluid, saliva, and any body fluid that is visibly contaminated with blood.

Although the Center for Disease Control (CDC) has determined that HIV and other bloodborne pathogens are not waterborne diseases, the CDC warns that persons who provide emergency first aid/CPR could become contaminated. For example, if a worker finds another worker or other person unconscious and not breathing, the worker could become contaminated with a bloodborne pathogen disease if the worker renders CPR to the victim without proper personal protection. If a worker attempts to aid another worker or other person who is bleeding, again the worker could become contaminated with a bloodborne pathogen disease.

To protect employees from bloodborne pathogens (HIV and Hepatitis B), all employers must do the following:

- Train all employees on the hazards of bloodborne pathogens.
- Equip all first aid kits with rescue barrier masks to prevent mouth-to-mouth contact, with latex protective gloves to prevent contact with body fluids, and with eye protection and a biohazard bag to dispose of cleanup materials.
- Provide the exposed employee medical attention, including immunizations for self-protection, such as the Hepatitis B vaccine, at no cost to the employee as mandated by 29 CFR 1910.1030.

Fire Safety

Classification of Fires

There are four classifications of fires based on the type of material involved:

Classification	Material Involved
CLASS A	A Class A fire is ordinary combustibles or fibrous material, such as wood, paper, cloth, paper, and some plastics.
CLASS B	A Class B fire is flammable or combustible liquids such as gasoline, diesel, kerosene, paint, paint thinners, and propane.
CLASS C	A Class C fire is energized electrical equipment, such as motors, motor controls, switches panel boxes, and power tools.
CLASS D	A Class D fire is certain combustible metals, such as magnesium, titanium, potassium, and sodium. These metals bum at high temperatures and give off sufficient oxygen to support combustion. They may react violently with water or other chemicals and must be handled with care.

Extinguishing Small Fires

Classification	Method of Extinguishing
CLASS A	Extinguish with pressurized water, foam, or multipurpose dry chemical extinguishers. Do not use carbon dioxide or ordinary dry chemical extinguishers on Class A fires.
CLASS B	Extinguish Class B fires by removing oxygen, by preventing vapors from reaching ignition sources, or by inhibiting the chemical chain reaction. Use foam, carbon dioxide, ordinary dry chemical, multipurpose dry chemical, and halon extinguishers.
CLASS C	Extinguish Class C fires by using carbon dioxide, ordinary dry chemical, multipurpose dry chemical, and halon-free extinguishers.
CLASS D	Extinguish Class D fires by using dry powder extinguishers made especially for this type of fire.

Special Note: Production of Halon has been banned since January 1, 1994 because Halon contributes to ozone depletion. Its reuse is still permitted.

Introduction to Water System Safety Quiz

1. What is the intent of this safety chapter?
   A. To determine how to be in compliance with safety regulations.
   B. To provide you with standard procedures for working safely.
   C. To make you aware of the hazards that may be encountered at your workplace.
   D. To present approved rules.

2. Who has the responsibility for your safety?
   A. Safety director
   B. OSHA
   C. You
   D. Your supervisor

3. Which type of ladder should never be used when working around electrical equipment?
   A. Fiberglass
   B. Metal
   C. Plastic
   D. Wooden

4. What is a "non-permit required confined space"? A confined space that
   A. Contains a material that has the potential for engulfing an entrant
   B. Contains or has the potential to contain a hazardous atmosphere
   C. Does NOT contain or have the potential to contain any atmospheric hazard capable of causing death or serious physical harm
   D. Has an internal configuration such that an entrant could be trapped or asphyxiated by inwardly converging walls

5. When testing the atmosphere in a confined space, which is the correct testing sequence?
   A. First test for combustible gases and vapors, then oxygen, and then toxic gases and vapors
   B. First test for explosive and hazardous gases and then oxygen concentration
   C. First test for oxygen, then combustible gases and vapors, and then toxic gases and vapors
   D. First test for toxic gases and vapors, then oxygen, and then combustible gases and vapors

6. If someone is suffering from electric shock, what are their typical symptoms?
   A. Pale, blushed skin that is clammy and mottled in appearance
   B. Rapid, shallow breathing
   C. Bleeding from ears
   D. Uncontollable seizures.

7. What type of fire extinguisher should be provided in a pumping station?
   A. All-purpose, ABC chemical type
   B. Gas type
   C. Portable type
   D. Water-fed extinguisher type

8. When any piece of electrical equipment is being worked on, the circuit breaker should be:
   A. Painted when repair is complete
   B. Recorded for future reference
   C. De-energized and locked out/tagged out
   D. Replaced

9. What is the only acceptable breathing device to wear while handling gas chlorine leaks?
   A. Activated carbon canister type
   B. Potassium tetroxoide canister type
   C. Self-contained breathing apparatus
   D. Organic filter respirator

10. Of the following types of extinguishers, which should be used on electrical fires?
    A. Water
    B. Soda-acid
    C. Blanket
    D. Carbon dioxide

11. Wear safety goggles when:
    A. Handling acid
    B. In the office
    C. Driving vehicles
    D. Measuring turbidity

12. OSHA is the acronym for:
    A. Organization for Safe Health Administration
    B. Occupational Safety and Health Administration
    C. Occupation, Safety, and Health Act
    D. Organization of State Health Administrators

13. The spoils from a trench must be placed how far back from the trench wall?
    A. 5 Feet
    B. 10 Feet
    C. 2 Feet
    D. 1 Foot

14. When handling fluoride chemicals, personnel should wear a respirator or mask approved by:
    A. OSHA
    B. MSA
    C. EPA
    D. NIOSH

15. What information must be on a warning tag attached to a breaker that has been locked out?
    A. Name of the person who locked out the breaker
    B. Exact time the breaker was locked out
    C. Date the breaker can be unlocked
    D. Name of the shift supervisor

16. When a permit is required to enter a confined space, who may sign the permit?
    A. Entrant
    B. Anyone at the job site
    C. Entry supervisor
    D. OSHA representative

17. What type of personal protective equipment (PPE) should an operator wear when handling hypochlorites?
    A. Reflective vest
    B. Dust mask
    C. Ear plugs
    D. Eye goggles

18. When testing a trench for the presence of oxygen, the level must remain above _______?
    A. 19.5 percent
    B. 19.0 percent
    C. 20.5 percent
    D. 21.0 percent

19. Under any soil conditions, cave-in protection is required for trenches or excavations that are how many feet deep?
    A. 2 feet
    B. 3 feet
    C. 4 feet
    D. 5 feet

20. Material Data Safety Sheets (MSDS) are required for:
    A. All chemicals used in the workplace, regardless of hazard
    B. Only chemicals with known health hazards
    C. Only flammable or explosive chemicals
    D. Only chemicals with suspected health hazards

21. All occupied trenches three or more feet deep must provide exits at:
    A. 15-feet intervals
    B. 20-feet intervals
    C. 25-feet intervals
    D. 30-feet intervals

22. What class of fire involves oil or grease?
    A. Class A
    B. Class B
    C. Class C
    D. Class D

23. What type of information is available on a Material Safety Data Sheet (MSDS)?
    A. Effects of exposure
    B. Flammability rating
    C. Safe exposure level
    D. Where to purchase the chemicals

24. Which items should NOT be accomplished by a formal hazard communication training program?
    A. Explain how to read and interpret MSDS forms.
    B. Train employees on basic safety rules.
    C. Inform employees of the measures they can take to protect themselves from the physical and health hazards of chemicals in the work area.
    D. Make employees aware of the hazard communication standard and its requirements.

25. In Alaska, the agency that regulates safety in the workplace is:
    A. Alaska Department of Environmental Conservation
    B. Environmental Protection Agency
    C. Rural Utility Business Advisor
    D. Alaska Department of Labor

26. Which OSHA program requires the employer to provide the Hepatitis B vaccination to employees?
    A. Hazardous Infectious Disease (HID) Program
    B. Personal Protective Exposure (PPE) Program
    C. Bloodborne Pathogen (BBP) Program
    D. Carcinogen Protection (CPP) Program

Regulations and Monitoring

Chapter 9

What Is In This Chapter?

1. Why compliance is important
2. The Safe Drinking Water Act
3. Drinking water standards
4. Drinking water contaminants
5. Public water system classification
6. Monitoring, sampling and reporting
7. Alaska's sampling and testing schedules
8. Total Coliform Rule
9. Sample siting plan
10. Surface Water Treatment Rule
11. Interim Enhanced Surface Water Treatment Rule
12. Long Term 1 Enhanced Surface Water Treatment Rule
13. Long Term 2 Enhanced Surface Water Treatment Rule
14. Filter Backwash Recycling Rule
15. Ground Water Rule
16. Arsenic Rule
17. Lead and Copper Rule
18. Stage 1 Disinfectants and Disinfection Byproducts Rule
19. Stage 2 Disinfectants and Disinfection Byproducts Rule
20. Variances and Exemptions
21. Public Notification Rule
22. Consumer Confidence Reports

Key Words

- MCL
- MCLG
- Coliform
- Primacy
- Sample Siting Plan

Introduction

As a small water system operator, you are busy operating and managing your system. Complying with current regulations gives you plenty to do, and you may feel overwhelmed by the thought of having to comply with new regulations. You want to do what is best for your customers, but new regulations may mean costly improvements - and higher water rates.

As the operator of a small drinking water system, only you can take the necessary steps to comply with safe drinking water regulations and protect your customers' health. Compliance takes planning and preparation!

Please note that this chapter contains only a general introduction to the United States Environmental Protection Agency (EPA) regulations governing public water systems. The EPA regulations described in this document contain legally binding requirements. The general description provided here does not substitute for those regulations, nor is this text a regulation itself. It does not impose legally binding requirements on anyone, but rather is intended to provide general information only. As a result, you will need to be familiar with the details of the rules that are relevant for your system; you cannot rely solely on this text for compliance information. Additionally, Alaska may have different or more stringent requirements than the EPA's, so you will need to learn what state laws and regulations apply to your system in addition to the ones described here. And like everything else, regulations change! Be sure to contact your local ADEC office for the most current information. They can assist and advise you about what regulations apply to your system.

Why Compliance is Important

Drinking water systems have an enormous impact on public health, and the public health benefits of a well-run system cannot be overstated. Millions of Americans receive high-quality drinking water every day from their public water systems (which may be publicly or privately owned). Nonetheless, drinking water safety cannot be taken for granted. There are a number of threats to drinking water: improperly disposed chemicals, animal wastes, pesticides, human wastes, wastes injected deep underground, and naturally occurring substances all can contaminate drinking water. Likewise, drinking water that is not properly treated or disinfected or that travels through an improperly maintained distribution system may also pose a health risk. Customers rely on their water systems to provide safe water for drinking, bathing, cleaning, and cooking. High-quality drinking water is a major contributor to the high standard of living and health enjoyed by Americans.

Yet since 1971, more than 600 waterborne disease outbreaks have been recorded in the United States. In most cases, these outbreaks result in nausea, diarrhea, and cramps. In some cases, they result in very serious illness and even death. These outbreaks serve as a constant reminder of the critical importance of ensuring safe drinking water.

The Multiple Barrier Approach

Drinking water professionals have long known that the most effective way to protect consumers from the risk of contamination and waterborne disease is through a multiple barrier approach. This approach sets up a series of technical and managerial barriers that ensure a safe drinking water supply and guard against waterborne disease outbreaks. These barriers include the following:

- Source water protection
- Treatment
- Distribution system integrity
- Public information

For each of these barriers, you can choose from a number of options to improve your system and further protect the health of your customers. Your best option will depend on the unique challenges and opportunities facing your system.

Small Systems and the Multiple Barrier Approach

Small systems face many challenges in providing safe, reliable, and affordable drinking water. Implementation of effective multiple barriers of protection requires technical, financial, and managerial resources that some systems may lack. Such systems benefit from State "Capacity Development" programs. Through these programs, systems have access to assistance in developing the financial capabilities and the institutional knowledge and structures to reliably and consistently apply multiple barriers of protection. Contact your local ADEC office for more information.

The Safe Drinking Water Act

The Safe Drinking Water Act (SDWA) applies to every public water system (PWS) in the United States. There are currently more than 160,000 public water systems providing water to almost all Americans at some time in their lives. The responsibility for making sure these public water systems provide safe drinking water is divided among the EPA, states, tribes, water systems, and the public. The SDWA provides a framework in which these parties work together to protect this valuable resource.

The SDWA was originally passed by Congress in 1974 to protect public health by regulating the nation's public drinking water supply. The law was amended in 1986 and 1996 and requires many actions to protect drinking water and its sources: rivers, lakes, reservoirs, springs, and ground water wells. The SDWA does not regulate private wells or any water system that serves fewer than 25 individuals.

The SDWA authorizes EPA to set national health-based standards for drinking water to protect against both naturally occurring and man-made contaminants that may be found in drinking water. The EPA, states, and water systems then work together to make sure that these standards are met.

Originally, the SDWA focused primarily on treatment as the means of providing safe drinking water at the tap. The 1996 amendments greatly enhanced the existing law by recognizing source water protection, operator training, funding for water system improvements, and public information as important components of safe drinking water. This approach ensures the quality of drinking water by protecting it from source to tap.

The most direct oversight of water systems is conducted by state drinking water programs. States and Native Tribes can apply to the EPA for **primacy**[1], the authority to implement the SDWA within their jurisdictions, if they can show that they will adopt

[1] Primacy – The primary responsibility for administering and enforcing regulations.

standards at least as stringent as the EPA's and make sure water systems meet these standards.

States, or the EPA acting as a primacy agent, make sure water systems test for contaminants, review plans for water system improvements, conduct on-site inspections and sanitary surveys, provide training and technical assistance, and take action against water systems not meeting standards. The EPA has granted the ADEC full primacy for 10 federal drinking water rules.

The ADEC has, in recent years, adopted federal SDWA regulations by reference. When federal regulations are adopted by reference, ADEC requires compliance with regulations already issued by the EPA. The federal regulations are frequently amended, and the State must adopt the federal regulations or develop its own set of equivalent regulations to maintain primacy for administering the program within Alaska.

National Drinking Water Standards

Drinking water standards apply to public water systems, which provide water to at least 15 connections or 25 persons at least 60 days out of the year. Most cities, towns, schools, businesses, campgrounds, and shopping malls are served by public water systems.

EPA sets national standards for drinking water based on sound science to ensure consistent quality and protect against health risks, with consideration of available technology and costs. These National Primary Drinking Water Regulations (NPDWRs or primary standards) set enforceable maximum contaminant levels (**MCLs**[2]) for particular contaminants in drinking water or required ways to treat water to remove contaminants. Each standard also includes requirements for water systems to test for contaminants in the water to make sure standards are achieved.

[2] MCLs (maximum contaminant levels) – The maximum level of certain contaminants permitted in drinking water supplied by a public water system as set by the EPA under the federal Safe Drinking Water Act.

The EPA prioritizes contaminants for potential regulation based on risk and how often they occur in water supplies. The EPA sets a health goal based on risk, including risks to the most sensitive people such as infants, children, pregnant women, the elderly, and the immuno-compromised. The EPA then sets a legal limit for the contaminant in drinking water or a required treatment technique. This limit or treatment technique is set to be as close to the health goal as feasible. The EPA also performs a cost-benefit analysis and obtains input from interested parties when setting standards.

National drinking water standards are legally enforceable, which means that both the EPA and states can take enforcement actions against water systems not meeting safety standards. The EPA and states may issue administrative orders, take legal actions, or fine utilities. The EPA and states also work to increase the owners and operators of water systems' understanding of, and compliance with, standards.

The EPA also sets Secondary Drinking Water Regulations (secondary standards), which are non-enforceable guidelines for contaminants that may cause cosmetic effects (such as skin and tooth discoloration) or aesthetic effects (such as taste or odor). Water systems are not required by the EPA to adopt these secondary standards; however, states may choose to adopt and enforce them. The ADEC requires a public water system to meet the secondary MCLs if the Department determines that public health is threatened or that exceeding a secondary MCL is not in the public interest.

Drinking Water Standards and Health Effects

Adverse health effects from contaminants that may occur in drinking water include acute effects that may immediately impact health and chronic effects that may occur if contaminants are ingested at unsafe levels over many years.

- Acute effects – People can suffer acute health effects from almost any contaminant if they are exposed to extraordinarily high levels, such as in the case of a contamination event like a cross connection or oil spill. In drinking water, microbes, such as bacteria and viruses, are the contaminants with the greatest chance of reaching levels high enough to cause acute health effects. Drinking water that meets EPA health-based standards is generally safe. People who are not healthy as a result of illness, age, or weakened immune systems are more likely to be at risk from certain contaminants that may be found in drinking water.
- Chronic effects – Chronic effects occur after people consume a contaminant at levels over EPA's safety standards for many years. The drinking water contaminants that can have chronic effects are chemicals (such as disinfection by-products, solvents, and pesticides), radionuclides (such as radium), and minerals (such as arsenic). Examples of these chronic effects include cancer, liver or kidney problems, or reproductive difficulties.

For a list of current drinking water standards, information on potential health effects of specific contaminants, and guidance to persons with severely compromised immune systems, see the EPA web site (www.epa.gov/safewater/dwhealth.html) or call the Safe Drinking Water Hotline at 1-800-426-4791.

The Contaminant Candidate List

The 1996 Amendments to the SDWA require that every five years the EPA establish a list of contaminants that are known to or anticipated to occur in public water systems and that may require future regulations under the SDWA. The list is developed with significant input from the scientific community and other interested parties. After establishing this contaminant candidate list, the EPA identifies contaminants that are priorities for additional research and data gathering. The EPA then uses this information to determine whether a regulation is appropriate. This process is repeated every five years for each list.

Drinking Water Contaminants

There are two basic groups of contaminants: primary and secondary. The EPA has set standards for 90 chemical, microbiological, radiological, and physical contaminants in drinking water. The EPA's web site (http://www.epa.gov/safewater/contaminants/index.html) provides a complete table of the currently regulated contaminants, potential health effects, and sources. The site lists the legally enforceable standards that apply to public water systems as well as the non-enforceable guidelines for secondary standards.

Primary Contaminants

The primary contaminants have known health effects and are divided into the following groups:

- Microorganisms
- Disinfectants
- Disinfection Byproducts
- **Inorganic Contaminants**[3]
- Organic Chemicals
- Radioactive Contaminants (Radionuclides)

[3]IOCs (Inorganic Contaminants) – Inorganic contaminants are compounds or chemicals that are considered contaminants by the EPA. As a result, the terms "compound," "chemical," and "contaminant" are often used interchangeably to describe IOCs.

Microorganisms

Coliform bacteria are common in the environment and are generally not harmful. This type of bacteria is not a health threat in itself. Rather, it is used to indicate whether other potentially harmful bacteria may be present. Coliforms are naturally present in the environment as well as in feces.

Fecal coliforms and *E. coli* come only from human and animal fecal waste. Fecal coliform and *E. coli* are bacteria whose presence indicates that the water may be contaminated with human or animal wastes. Disease-causing microbes (pathogens) in these wastes can cause diarrhea, cramps, nausea, headaches, or other symptoms. These pathogens may pose a special health risk for infants, young children, and people with severely compromised immune systems. The presence of fecal coliform or *E. coli* is a danger alarm that a system is likely contaminated with human or animal fecal waste.

Cryptosporidium is a parasite commonly found in lakes and rivers, especially when the water is contaminated with sewage and animal wastes. Cryptosporidium is very resistant to disinfection, and even a well-operated water treatment system cannot ensure that drinking water will be completely free of this parasite. Cryptosporidium has caused several large waterborne disease outbreaks of gastrointestinal illness, with symptoms that include diarrhea, nausea, and/or stomach cramps.

Giardia lamblia is a microorganism frequently found in rivers and lakes and if not treated properly may cause diarrhea, fatigue, and cramps after ingestion.

Turbidity is a measure of the cloudiness of water. It is used to indicate water quality and filtration effectiveness (for example, whether disease-causing organisms are present). Turbidity has no health effect; however, it can interfere with disinfection and provide a medium for microbial growth. Turbidity may indicate the presence of disease-causing organisms. These organisms include bacteria, viruses, and parasites that can cause symptoms such as nausea, cramps, diarrhea, and associated headaches.

Disinfectants and Disinfection Byproducts

Chemicals such as chlorine, chloramines, and chlorine dioxide are disinfectants commonly added to a water supply to kill microorganisms such as Giardia and *E. coli* and have a maximum allowable residual level. Disinfection byproducts (DBPs) form when the disinfectants added to drinking water react with naturally occurring organic and inorganic matter in water. Regulated disinfection byproducts include trihalomethanes (TTHM), haloacetic acids (HAA5), bromate, and chlorite.

Inorganic Contaminants (IOCs)

IOCs are mineral-based compounds such as metals, nitrates, and asbestos. These contaminants are naturally occurring in some water, but can also get into water through farming, chemical manufacturing, and other human activities. The EPA has set legal limits on 15 inorganic contaminants.

Organic Chemicals

Organic chemicals are carbon-based chemicals, such as solvents and pesticides that can get into water through runoff from cropland or discharge from factories. The EPA has set legal limits on 56 organic contaminants.

- Volatile Organic Compounds (VOCs) – Sources of VOCs entering a water supply can include discharge from factories, leakage from gas storage tanks, and leaching from landfills. VOCs include industrial and chemical solvents, such as benzene and toluene.
- Synthetic Organic Chemicals (SOCs) are carbon-based compounds of man-made origin that can get into water through runoff from croplands or discharge from factories. SOCs include, among other compounds, pesticides and herbicides, such as atrazine, alachlor, endrin, and lindane. Some SOCs are volatile; others tend to stay dissolved in water instead of evaporating.

Radionuclides

Most drinking water sources have very low levels of radioactive contaminants ("radionuclides") that are not considered to be a public health concern. Of the small percentage of drinking water systems with radioactive contaminant levels high enough to be of concern, most of the radioactivity is naturally occurring. Certain rock types have naturally occurring trace amounts of "mildly radioactive" elements (radioactive elements with very long half-lives) that serve as the "parent" of other radioactive contaminants ("daughter products"). These radioactive contaminants, depending on their chemical properties, may accumulate in drinking water sources at levels of concern. The EPA has set legal limits on four radionuclide contaminants.

Secondary Contaminants

The secondary contaminants have associated impacts that are not directly related to health, such as taste and staining. The EPA recommends secondary standards to water systems but does not require systems to comply. However, states may choose to adopt them as enforceable standards.

Secondary Contaminants	
• Aluminum • Chloride • Color • Copper • Corrosivity • Fluoride • Foaming Agents • Iron	• Manganese • Odor • pH • Silver • Sodium • Sulfate • Total Dissolved Solids • Zinc

Knowing Which Regulations Apply to You

When faced with the full set of SDWA regulations, the responsibility of keeping your system in compliance can seem overwhelming. However, the task can be made much easier if you understand a few basics about how EPA and SDWA regulations categorize drinking water systems. Certain rules apply only to certain kinds of systems. This means that your system will be regulated according to its size, PWS category, source water, and treatment steps. Once you understand how your system is categorized within a regulation, you will be better equipped to talk to regulators and get the information you need in order to keep your system in compliance.

Classification of Public Water Systems

Water systems are defined by EPA/ADEC regulations. As stated earlier in the chapter, drinking water standards apply only to PWSs that provide water to at least 15 connections or 25 persons at least 60 days out of the year. The EPA classifies PWSs according to the number of people they serve, the source of their water, and whether they serve the same customers year-round or on an occasional basis. Each system has a unique Public Water System Identification Number (PWSID), history, and record with ADEC.

The EPA has defined three types of public water systems:

- Community Water System (CWS) – A public water system that supplies water to the same population year-round. Examples are communities like Anchorage and Nulato.
- Non-Transient Non-Community Water System (NTNCWS) – A public water system that regularly supplies water to at least 25 of the same people at least six months per year, but not year-round. Some examples are schools, factories, office buildings, and hospitals that have their own water systems.
- Transient Non-Community Water System (TNCWS) – A public water system that provides water in a place such as a gas station or campground where people do not remain for long periods of time.

The EPA also classifies water systems according to the number of people they serve:

- Very Small water systems serve 25-500 people.
- Small water systems serve 501-3,300 people.
- Medium water systems serve 3,301-10,000 people.
- Large water systems serve 10,001-100,000 people.
- Very Large water systems serve 100,001+ people.

ADEC Class C

A Class C system is a PWS that serves fewer than 25 people. It is a unique ADEC designation. There is no comparable EPA term; this class system is an ADEC-defined and regulated entity. The EPA does not regulate systems this small.

Drinking Water Watch

The ADEC Drinking Water Program has developed a tool whereby owners, operators, and consumers can access specific information about a water system. The program is called Drinking Water Watch and can be queried for sampling information, monitoring summaries, violation information, water systems contact, and general information.

To find information on your system, visit the Drinking Water Watch web site (http://dec.alaska.gov:8080/DWW/)

This site is very important to the PWS operator and system owner for understanding their PWS status and current and future drinking water sampling and reporting. Operators must familiarize themselves with this site and the PWS they are working with. Be sure to explore all the screens and understand how the information applies to your system. Check this data record for accuracy. The ADEC uses this site for determining compliance using operator and laboratory reporting. If you do not have Internet access, contact ADEC staff, and they may send this information to you by mail or fax or simply give you results as they are listed.

Monitoring, Sampling, and Reporting

It is the responsibility of each water system to test for possible contaminants in its water supply.

Although each regulation has its own, sometimes complex, set of requirements, every regulation affects your system in the same basic way. In general, you will have to do the following:

- Monitor for a contaminant and report the results to the State.
- Make compliance decisions based on your monitoring results and the outcome of any State review.
- Take action to reduce any health risks that have been identified through monitoring.
- Provide the public information about water quality and public health risks.

System Monitoring

Typically, the first thing you will need to do to comply with a regulation is monitor for the contaminant of concern to determine whether it is present in your water and, if so, at what level. Sometimes, you may be able to use previously collected monitoring data to comply with the monitoring requirements of new regulations.

System Decision-Making

After your monitoring data has been collected, you will be able to better assess your situation. ADEC will also review the data to determine where your system stands in regards to compliance and will be able to direct you on what to do if your system appears to have a compliance problem.

System Actions

Possible system actions may involve installing a new treatment process, modifying an existing process, replacing failing pumps or pipes, or using a new source of water. After exploring a variety of options, you should choose an option that is viable for your system and put that option into action. Extensive technical and financial resources are available to help you along in these tasks.

General Monitoring Requirements

Two monitoring requirement summaries are provided on the following pages. These do not replace the current drinking water regulations. ADEC drinking water regulations Articles 3 and 4 contain most of the standards and monitoring requirements that apply to PWS. In some instances, you must refer to the EPA Quick Reference Guides and Code of Federal Regulations (CFR) to obtain the complete documentation.

System-Specific Monitoring Summary

The ADEC Drinking Water Watch web site tells you what (the contaminants), when (the frequency), and where (the location) to sample. The ADEC uses certain criteria to assign water-sampling requirements for a PWS:

- Population served
- Hours/seasonal/full time water delivery service operation
- Water source type: groundwater, surface water, GUDISW, purchased water
- Disinfection practiced or use of oxidants
- Rule (which SDWA Rule: TCR, SWTR, etc.)
- Piped system or community haul, watering point, washeteria source
- Water storage tanks in use
- Historic sample results
- Type of treatment
- Level of regulated contaminants in raw or treated water
- Whether MCLs are being met in the treated water
- History or special circumstances and whether you are special

Sample Locations

Sample location is an important part of taking a water sample. The major categories are listed below

During Treatment

Certain rules and/or the ADEC may require water to be sampled during treatment to document the performance of the treatment process. Data is recorded, properly documented, and/or reported to the ADEC/EPA. Archiving and storing this data is a significant responsibility of the operator. Some of the required sampling/testing/recording include turbidity, disinfectant residual, contaminant value for process controls, or other chemical injection. This list may vary due to system layout or other unusual conditions. The ADEC Drinking Water Watch site will identify the regulatory values/frequency data your system must collect and record.

After Treatment

MCLs apply to the water being served to the public so samples are taken after treatment. Almost all samples come from the entry point to the distribution systems. The PWS may also be required to take disinfection residual values of the water entering the distribution system and other ADEC-established parameters (fluoride, corrosion chemicals, pH, etc.). These samples are taken before the first customer. Samples for inorganic chemicals, VOCs, pesticides, turbidity, and radioactivity are usually collected after treatment at the entry point to the distribution system, but each system is unique, so you should consult the appropriate references.

Each rule has a specific sample requirement. Consult the EPA Quick Reference Guides, ADEC staff, and the Drinking Water Watch for assistance.

Distribution System

TTHM/HAA5s and coliform bacteria samples are taken in the distribution system at specific locations. If the system chlorinates or chloraminates, a chlorine residual test is required at the same place and time as a coliform sample.

Customer/Consumer Home

Lead and copper tests are taken from customer faucets, and there are many specific procedures to take this sample. Follow the “sample protocol” carefully.

The following Alaska public drinking water supply sampling and testing schedules for surface water, GUDISW and groundwater depend on your type of system and monitoring summary.

Surface Water and GUDISW
- **Community Water Systems (CWS)**
- **Non-Transient Non-Community Water Systems (NTNCWS)**
- **Transient Non-Community Water System (TNCWS)**

This summary does not replace the current drinking water regulations.

TCR/ Nitrate/Nitrite		CWS	NTNCWS	TNCWS
Sanitary Survey		Every 3 years	Every 5 years	Every 5 years
Total Coliform Bacteria[1]		Monthly	Monthly	Monthly
Nitrate (NO_3)		Quarterly[2]	Quarterly[2]	Annually
Nitrite (NO_2)		1 sample record	1 sample record	1 sample record
Reporting		CWS	NTNCWS	TNCWS
Turbidity		Continuous or grab samples	Continuous or grab samples	Continuous or grab samples
		(Frequency determined by population and filtration type.)		
Fluoride – if added		Daily	Daily	
Entry Point Chlorine – if chlorine is added		Continuous or grab samples	Continuous or grab samples	Continuous or grab samples
		(Pop determines how many times a day chlorine is measured.)		
Distribution System Chlorine[3]		Monthly	Monthly	Monthly
Consumer Confidence Report		Annually	Annually	
Disinfection/Disinfectant Byproducts		CWS	NTNCWS	TNCWS
Total Trihalomethanes[1] (TTHM/HAA5)	Pop < 500	Annually	Annually	Annually
	Pop 500 - 9,999	Quarterly[2]	Quarterly[2]	Quarterly[2]
	Pop ≥10,000	Quarterly[2]	Quarterly	Quarterly
TOC and Alkalinity		Monthly[2]	Monthly[2]	
Bromate (Ozone plants only)		Monthly	Monthly	
Inorganic Chemicals		CWS	NTNCWS	TNCWS
All Primary		Annually	Annually	
Arsenic		Annually	Annually	
Asbestos		Once per period	Once per period	
Lead and Copper[1]		Every 6 months[2]	Every 6 months[2]	
Organic Chemicals		CWS	NTNCWS	TNCWS
Pesticides (SOCs) and Other Organics		Quarterly[2]	Quarterly[2]	
Volatile Organic Chemicals (VOCs)		Quarterly	Quarterly	
		Annually	Annually	
Radionuclides		CWS	NTNCWS	TNCWS
Gross Alpha Radioactivity		Quarterly		
Radium 226, Radium 228, Uranium		Quarterly		

[1] Number of samples is based on population. [2] May be reduced if certain criteria are met.

[3] Distribution point chlorine test is required at the same time and location as total coliform samples are collected.

Cycle – 3 years; Period – 9 years

Alaska Public Drinking Water Supply Sampling and Testing Schedules

Groundwater
- **Community Water Systems (CWS)**
- **Non-Transient Non-Community Water Systems (NTNCWS)**
- **Transient Non-Community Water System (TNCWS)**

This summary does not replace the current drinking water regulations.

TCR/ Nitrate/Nitrite		CWS	NTNCWS	TNCWS
Sanitary Survey		Every 5 years	Every 5 years	Every 5 years
Total Coliform Bacteria[1]		Every month	Every month	Every quarter
Nitrate (NO_3)		Annually	Annually	Annually
Nitrite (NO_2)		1 sample record	1 sample record	1 sample record
Reporting		CWS	NTNCWS	TNCWS
Fluoride – if added		Daily	Daily	Daily
Entry Point Chlorine – if chlorine is added		Continuous or grab samples	Continuous or grab samples	Continuous or grab samples
		(Pop determines how many times a day chlorine is measured.)		
Distribution Chlorine[2] – if chlorine is added		Monthly	Monthly	
Consumer Confidence Report		Annually		
Disinfection/Disinfectant By-products		CWS	NTNCWS	TNCWS
Total Trihalomethanes[1] (TTHM/HAA5)	Pop < 500 – 9,999	Annually	Annually	
	Pop ≥10,000	Quarterly	Quarterly	
Bromate (Ozone plants only)		Monthly	Monthly	
Inorganic Chemicals		CWS	NTNCWS	TNCWS
All Primary		Once per period	Once per period	
Arsenic		Once per period	Once per period	
Asbestos		Once per cycle	Once per cycle	
Lead and Copper[1]		Every 6 months[3]	Every 6 months[3]	
Organic Chemicals		CWS	NTNCWS	TNCWS
Pesticides (SOCs) and Other Organics		Every quarter[3]	Every quarter[3]	
Volatile Organic Chemicals (VOCs)		Every quarter	Every quarter	
		Annually	Annually	
Radionuclides		CWS	NTNCWS	TNCWS
Gross Alpha Radioactivity		Every quarter		
Radium 226, Radium 228, Uranium		Every quarter		

[1] Number of samples is based on population.
[2] Distribution point chlorine test is required at the same time and location as total coliform samples are collected.
[3] May be reduced if certain criteria are met.
Cycle – 3 years
Period – 9 years

Alaska Public Drinking Water Supply Sampling and Testing Schedules

Current Regulations To Control Microbial Contaminants

In drinking water, microbes are the contaminants with the greatest chance of reaching levels high enough to cause acute health effects. The following major rules are intended to control this risk:

- Total Coliform Rule
- Surface Water Treatment Rule
- Interim Enhanced Surface Water Treatment Rule
- Long Term 1 Enhanced Surface Water Treatment Rule
- Long Term 2 Enhanced Surface Water Treatment Rule
- Filter Backwash Recycling Rule
- Ground Water Rule

Total Coliform Rule (TCR)

The TCR applies to all public water systems and serves to improve public health protection by reducing fecal pathogens to minimal levels through control of total coliform bacteria, including fecal coliform and Escherichia coli (*E. coli*). This rule establishes a maximum contaminant level (MCL) based on the presence or absence of total coliforms, modifies monitoring requirements including testing for fecal coliforms or *E. coli*, requires use of a sampling plan, and requires sanitary surveys for systems.

Important Elements of This Rule

The number of routine samples required each month depends on system size. Samples must be collected at sites representative of water quality throughout the distribution system according to an approved **Sample Siting Plan**[3]. Depending on the results (not present, positive, too old to analyze, fecal coliform present, etc.), there are procedures the operator must follow.

[4] Sample Siting Plan – A plan that specifies where in the distribution system routine samples will be drawn in order to ensure that they are "representative" of the water supplied to every customer.

As mentioned previously, the presence of total coliforms is a warning sign that your system is vulnerable to contamination. It does not necessarily mean that your system is contaminated. If any of your routine samples test positive for the presence of total coliforms, you must do both of the following:

- Immediately collect a set of repeat samples per positive routine sample to assess the extent of the problem.
- Collect five routine samples the next month.

For every total coliform-positive sample, a set of repeat samples must be collected **within 24 hours** of the system being notified of the positive result. The minimum number of repeat samples required is based on the number of routine samples collected.

TCR Major Provisions

ROUTINE Sampling Requirements

- Total coliform samples must be collected 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.
- Samples must be collected at regular time intervals throughout the month except groundwater systems serving 4,900 persons or fewer may collect them on the same day.
- Monthly sampling requirements are based on population served.
- A reduced monitoring frequency may be available for systems serving 1,000 persons or fewer and using only ground water if a sanitary survey within the past 5 years shows the system is free of sanitary defects. (The frequency may be no fewer than 1 sample/quarter for community and 1 sample/year for non-community systems.)
- Each total coliform-positive routine sample must be tested for the presence of fecal coliforms or E. coli.
- If any routine sample is total coliform-positive, repeat samples are required.

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 coliforms:

- One REPEAT sample must be collected from the same tap as the original sample.
- One REPEAT sample must be collected within five service connections upstream.
- One REPEAT sample must be collected within five service connections downstream.
- Systems that collect 1 ROUTINE sample per month or fewer must collect a fourth REPEAT sample.

If any REPEAT sample is total coliform-positive:

- The system must analyze that total coliform-positive culture for fecal coliforms or E. coli.
- The system must collect another set of REPEAT samples, as before, unless the MCL has been violated and the system has notified the State.

Additional ROUTINE Sampling Requirements

A positive ROUTINE or REPEAT total coliform result requires a minimum of five ROUTINE samples be collected the following month the system provides water to the public, unless waived by the State.

Public Water System ROUTINE Monitoring Frequencies

Population	Minimum Samples/ Month	Population	Minimum Samples/ Month	Population	Minimum Samples/Month
25-1,000*	1	21,501-25,000	25	450,001-600,000	210
1,001-2,500	2	25,001-33,000	30	600,001-780,000	240
2,501-3,300	3	33,001-41,000	40	780,001-970,000	270
3,301-4,100	4	41,001-50,000	50	970,001-1,230,000	300
4,101-4,900	5	50,001-59,000	60	1,230,001-1,520,000	330
4,901-5,800	6	59,001-70,000	70	1,520,001-1,850,000	360
5,801-6,700	7	70,001-83,000	80	1,850,001-2,270,000	390
6,701-7,600	8	83,001-96,000	90	2,270,001-3,020,000	420
7,601-8,500	9	96,001-130,000	100	3,020,001-3,960,000	450
8,501-12,900	10	130,001-220,000	120	≥ 3,960,001	480
12,901-17,200	15	220,001-320,000	150		
17,201-21,500	20	320,001-450,000	180		

* Includes PWSs that have at least 15 service connections, but serve < 25 people.

Other Provisions

Systems collecting fewer than five ROUTINE samples per month . . .	Must have a sanitary survey every five years (or every 10 years if it is a non-community water system using protected and disinfected ground water).**

TCR Major Provisions	
Other Provisions Continued	
Systems using surface water or groundwater under the direct influence of surface water (GWUDI) and meeting filtration avoidance criteria . . .	Must collect and have analyzed one coliform sample each day the turbidity of the source water exceeds one NTU. This sample must be collected from a tap near the first service connection.
** As per the IESWTR, states must conduct sanitary surveys for community surface water and GWUDI systems in this category every three years (unless reduced by the State based on outstanding performance).	
How is Compliance Determined	
• Compliance is based on the presence or absence of total coliforms. • Compliance is determined each calendar month the system serves water to the public (or each calendar month that sampling occurs for systems on reduced monitoring). • The results of ROUTINE and REPEAT samples are used to calculate compliance.	
A Monthly MCL Violation is Triggered if:	
A system collecting fewer than 40 samples per month . . .	Has greater than 1 ROUTINE/REPEAT sample per month that is total coliform-positive.
A system collecting at least 40 samples per month . . .	Has greater than 5.0 percent of the ROUTINE/REPEAT samples in a month total coliform-positive.
An Acute MCL Violation is Triggered if:	
Any public water system . . .	Has any fecal coliform- or E. coli-positive REPEAT sample or has a fecal coliform- or E. coli-positive ROUTINE sample followed by a total coliform-positive REPEAT sample.
Public Notification and Reporting Requirements	
For a Monthly MCL Violation	• The violation must be reported to the State no later than the end of the next business day after the system learns of the violation. • The public must be notified within 30 days after the system learns of the violoation. [2]
For an Acute MCL Violation	• The violation must be reported to the State no later than the end of the next business day after the system learns of the violation. • The public must be notified within 24 hours after the system learns of the violation. [2]
Systems with ROUTINE or REPEAT samples that are fecal coliform- or E. coli-positive . . .	Must notify the State by the end of the day they are notified of the result or by the end of the next business day if the State office is already closed.

Developing a Sample Siting Plan

The TCR requires each PWS to sample for coliform according to a written plan, which must be made available to the Primacy Agency. Having a written sample collection protocol helps ensure that all sampling is done correctly, even when assignments of water system personnel change.

The plan specifies where in the distribution system routine samples will be drawn to ensure that they are "representative" of the water supplied to every customer. Representative samples that accurately reflect the quality of the finished water are crucial because if coliforms are in the water supply, they may not be found uniformly throughout the distribution system. The sampling plan also designates repeat sampling sites to be used if a sample drawn from a routine sampling point tests positive for coliforms. Remember, the purpose of sampling is not to draw "clean" samples, but to identify any coliform contamination so that it can be dealt with promptly. Because of this, it is important to identify dead ends and trouble spots in the distribution system for sampling locations.

Sampling sites specified in the sampling plan should be selected carefully throughout the distribution system to represent the varying conditions that occur there. It is especially important to identify and include in the sampling plan areas that may adversely affect the microbiological quality of the water. The details of a sampling plan depend on the characteristics of the system for which it is developed and on the requirements of the Primacy Agency. Contact the ADEC for complete requirements. Factors to consider when preparing a site-sampling plan include the following:

- The location and type of water sources, treatment facilities, storage tanks, pressure stations, and service connections
- The location of dead-end pipes, main and branch lines, loops, and other aspects of the piping system's configuration
- Cross-connection hazards and shared connections
- Areas of low water pressure and slow water movement
- Varying population densities
- Hydrants (for flushing schedule)

A basic site-sampling plan may have three components: a map of the distribution system, a narrative description of the plan, and a maintenance program.

Sampling Sites

Customers' faucets and specially installed sampling taps are the two most common types of sampling sites. Customer faucets may not always be conveniently accessible. In addition, samples from a customer's faucet may not accurately reflect distribution system conditions for reasons that have to do with the customer's plumbing that are not under the water supplier's control. If customers' faucets are to be used, each faucet should be examined carefully to ensure its suitability. Some examples of undesirable conditions include the following:

- Swivel-type faucets that have a single valve for hot and cold water
- Faucets that have leaky packing material around the stem
- Faucets that supply areas, such as janitorial or commercial sinks, where bacterial contamination is likely
- Faucets close to or below ground level
- Faucets that point upward
- Faucets that have threads on the inside of their spouts

- Faucets that have aerators (If such faucets are to be used, the aerators must be removed before a sample is collected.)
- Outside hose bibs

To avoid the problems inherent with customer faucets, many water suppliers collect water samples for coliform analysis from special taps connected directly to distribution pipes. These special taps can simply be a faucet at the end of a riser pipe connected to the distribution line or a more sophisticated manufactured sampling station installed at the water meter or into the distribution main.

Sample Collection Techniques

It is essential that the proper techniques be used to eliminate the possibility of contamination of the sample while it is being collected. There are critical techniques and methods to this sampling event. If you get it right from the beginning, there will be fewer problems. Quality control must be practiced. The cost of sloppy samples is wasted money, wasted labor, and poor customer relations. It is the operator's responsibility to assure the customer that the water is safe.

1. Wash your hands thoroughly before handling supplies. Assemble all of the sampling supplies before you begin.
2. DO NOT RINSE OUT THE SAMPLE BOTTLE. The powder in the bottle is meant to be there and will not contaminate your sample. The powder is sodium thiosulfate which eliminates chlorine in the sample.
3. Remove any aerators, strainers, or hoses that are present because they may harbor bacteria. If possible, avoid using a faucet that swivels.
4. Disinfect the faucet by dipping the end in a cap full of bleach before running the water. This is optional but a good idea.
5. Open the cold water tap for about two to three minutes before collecting the sample. (You may want to time this step–three minutes is a long time.) This clears the service line.
6. While waiting, collect the required chlorine residual if your system disinfects, and record it on the lab form.
7. Adjust the flow to about the width of a pencil. Check for steady flow. Do not change the water flow once you have started sampling. It could dislodge microbial growth.
8. Remove the bottle cap (stopper, etc.). Be careful not to touch the inside with your fingers.
9. Position the bottle under the water flow. Hold the bottle in one hand and the cap in the other. Do not lay the cap down or put it in a pocket. Take care not to contaminate the sterile bottle or cap with your fingers or permit the faucet to touch the inside of the bottle.
10. Fill the bottle to at least the fill line (100 ml). Do not fill it all the way up to the top. Allow 1" head space.
11. Place the cap on the bottle, and screw it down tightly. Take special care not to touch the inside of the cap or bottle. If you do, start with a new bottle.

12. Turn the tap off. Replace the aerator, strainer, or hose.

13. Keep the sample cool, but do not freeze.

14. Fill out label, tag, and lab form in waterproof ink. Make sure the label is dry before writing on the label.

15. Check that the information on the label is correct, and keep a copy for your files. Pack the sample in a Styrofoam container or bubble wrap, so the bottle does not break, and put in the mail.

16. Ensure the samples reach the laboratory within 30 hours of collection.

The result of a coliform test is relied upon to be accurate and representative. There is great concern when a bacterial sample is positive; this indicates possible contamination, which is very serious because of possible health affects.

The TCR is complicated. When results are negative (no coliform detected), everyone is happy. When results are positive (coliform present), there will be a lot of action/reaction to analyze more water samples and to understand the cause and the possible public health impact. Consult with the ADEC during a response incident for a coliform positive result. There will be a lot to do on a strict timeline.

The Surface Water Treatment Rule (SWTR)

Surface water treatment plants are classified according to the type treatment process or treatment technique (TT) used. These include avoidance of filtration, conventional, direct, slow sand, alternative (cartridges, membrane, diatomaceous earth), bank filtration, and other variations as recognized by the EPA and ADEC. The type of water source and water source characteristics may also be used.

The Surface Water Treatment Rule, promulgated in June 1989, seeks to prevent waterborne diseases caused by viruses, Legionella, and Giardia lamblia. These disease-causing microbes are present at varying concentrations in most surface waters. The rule requires that water systems filter and disinfect water from surface water sources to reduce the occurrence of unsafe levels of these microbes.

The SWTR applies to all PWSs using surface water or GUDISW, otherwise known as "Subpart H systems." (Subpart H refers to the section of the Code of Federal Regulations (CRF) 141, National Primary Drinking Water Regulations that is the Surface Water Treatment Rule.) This water, which most of the country's large water systems use, is in rivers, lakes, and reservoirs. Surface water is particularly susceptible to microbial contamination from sewage treatment plant discharges and runoff from storm water and snow melt. These sources often contain high levels of fecal microbes that originated in wild animals, livestock waste, or septic systems.

Important Elements of This Rule

The rule sets non-enforceable health goals, or **Maximum Contaminant Level Goals (MCLGs)**[4], for Legionella, Giardia, and viruses at zero because any amount of exposure to these contaminants represents some health risk. In establishing legal limits for contaminants in drinking water, the EPA can set either a legal limit (MCL) and require monitoring for the contaminant in drinking water, or, for those contaminants that are difficult to measure, establish a treatment technique (TT) requirement. Since measuring disease-causing microbes in drinking water is not considered to be feasible, the EPA established a treatment technique in this rule.

[5] MCLGs (Maximum Contaminant Level Goals) – The maximum level of a contaminant that is associated with no adverse health effects from drinking water containing that contaminant over a lifetime.

All systems must filter (unless filter avoidance criteria are met) and disinfect their water to provide a minimum of 99.9 percent combined removal and inactivation of Giardia and 99.99 percent of viruses. The adequacy of the filtration process is established by measuring turbidity (a measure of the amount of particles) in the treated water and determining if it meets the EPA's performance standard.

To assure adequate microbial protection in the distribution system, water systems are also required to provide continuous disinfection of the drinking water entering the distribution system and to maintain a detectable disinfectant level within the distribution system.

SWTR Residual Disinfectant Monitoring and Reporting Requirements

Location	Concentration	Monitoring Frequency	Reporting (Reports due 10th of the following month)
Entry to distribution system	Residual disinfectant concentration cannot be < 0.2 mg/L for more than 4 hours.	Continuous, but state may allow systems serving 3,300 or fewer persons to take grab samples from one to 4 times per day, depending on system size.	Lowest daily value for each day, the date and duration when residual disinfectant was < 0.2 mg/L, and when state was notified of events where residual disinfectant was < 0.2 mg/L.
Distribution system – same location as total coliform sample location(s)	Residual disinfectant concentration cannot be undetectable in greater than 5 % of samples in a month, for any 2 consecutive months. Heterotrophic plate count (HPC) ≤ 500/mL is deemed to have detectable residual disinfectant.	Same time as total coliform samples.	Number of residual disinfectant or HPC measurements taken in the month resulting in no more than 5 % of the measurements as being undetectable in any 2 consecutive months.

Interim Enhanced Surface Water Treatment Rule (IESWTR)

The Interim Enhanced Surface Water Treatment Rule, promulgated in December 1998, amends the existing SWTR to improve control of microbial contaminants, particularly *Cryptosporidium*, including provisions specifically to address *Cryptosporidium*, and to address risk trade-offs with disinfection byproducts in systems using surface water or GUDISW that serve 10,000 or more persons. The rule builds upon the treatment technique requirements of the SWTR. In addition, systems must continue to meet existing requirements for *Giardia lamblia* and viruses.

Important Elements of This Rule

Specifically, the rule includes the following:

- Maximum contaminant level goal (MCLG) of zero for *Cryptosporidium*
- 2-log *Cryptosporidium* removal requirements for systems that filter
- Strengthened combined filter effluent turbidity performance standards
- Individual filter turbidity monitoring provisions
- Disinfection profiling and benchmarking provisions
- Systems using ground water under the direct influence of surface water now

subject to the new rules dealing with *Cryptosporidium*
- Inclusion of *Cryptosporidium* in the watershed control requirements for unfiltered public water systems
- Requirements for covers on new finished water reservoirs
- Sanitary surveys conducted by states for all surface water systems, regardless of size

The rule, with tightened turbidity performance criteria and individual filter monitoring requirements, is designed to optimize treatment reliability and to enhance physical removal efficiencies to minimize the Cryptosporidium levels in finished water. Turbidity requirements for combined filter effluent remains at least every four hours, but continuous monitoring is required for individual filters. In addition, the rule includes disinfection profiling and benchmarking provisions to assure continued levels of microbial protection while facilities take the necessary steps to comply with new DBP standards.

IESWTR Major Provisions	
Regulated Contaminants	
Cryptosporidium	• Maximum contaminant level goal (MCLG) of zero. • 99 percent (2-log) physical removal for systems that filter. • Include in watershed control program for unfiltered systems.
Turbidity Performance Standards	Conventional and direct filtration combined filter effluent: • $\leq$ 0.3 nephelometric turbidity units (NTU) in at least 95 percent of measurements taken each month. • Maximum level of 1 NTU.
Turbidity Monitoring Requirements (Conventional and Direct Filtration	
Combined Filter Effluent	Performed every 4 hours to ensure compliance with turbidity performance standards.
Individual Filter Effluent	Performed continuously (every 15 minutes) to assist treatment plant operators in understanding and assessing filter performance.
Additional Requirements	
• Disinfection profiling and benchmarking. • Construction of new uncovered finished water storage facilities prohibited. • Sanitary surveys, conducted by the State, for all surface water and ground water under the direct influence of surface water systems regardless of size (every 3 years for community water systems and every 5 years for non-community water systems).	
Profiling and Benchmarking	
Public water systems must evaluate impacts on microbial risk before changing disinfection practices to ensure adequate protection is maintained. The three major steps include the following: • Determine if a public water system needs to profile based on TTHM and HAA5 levels (applicability monitoring). • Develop a disinfection profile that reflects daily *Giardia lamblia* inactivation for at least a year. (Systems using ozone or chloramines must also calculate inactivation of viruses.) • Calculate a disinfection benchmark (lowest monthly inactivation) based on the profile and consult with the State prior to making a significant change to disinfection practices.	

Long Term 1 Enhanced Surface Water Treatment Rule

The Long Term 1 Enhanced Surface Water Treatment Rule (LT1), promulgated in January 2002, strengthens control of microbial contaminants, particularly *Cryptosporidium*, for small systems–those systems serving fewer than 10,000 people. This rule builds upon the framework established for larger systems in the IESWTR.

Important Elements of This Rule

The rule requires PWS that use surface water or GUDISW and serve fewer that 10,000 people to meet strengthened filtration requirements. It also requires systems to calculate levels of microbial inactivation to ensure that microbial protection is not jeopardized if systems make changes to comply with requirements of the Stage 1 Disinfectants and Disinfection Byproducts.

<table>
<tr><th colspan="2">LT1 Major Provisions</th></tr>
<tr><th colspan="2">Control of Cryptosporidium</th></tr>
<tr><td colspan="2">The maximum contaminant level goal (MCLG) is set at zero.
Filtered systems must physically remove 99% (2-log) of Cryptosporidium.
Unfiltered systems must update their watershed control programs to minimize the potential for contamination by Cryptosporidium oocysts.
Cryptosporidium is included as an indicator of GWUDI.</td></tr>
<tr><th colspan="2">Combined Filter Effluent (CFE) Turbidity Performance Standards</th></tr>
<tr><td colspan="2">Specific CFE turbidity requirements depend on the type of filtration used by the system.

Conventional and direct filtration:
$\leq$ 0.3 nephelometric turbidity units (NTU) in at least 95% of measurements taken each month.
Maximum level of turbidity: 1 NTU.
Slow sand and diatomaceous earth (DE) filtration:
Continue to meet CFE turbidity limits specified in the SWTR:
1 NTU in at least 95% of measurements taken each month.
Maximum level of turbidity: 5 NTU.
Alternative technologies (other than conventional, direct, slow sand, or DE):
Turbidity levels are established by the State based on filter demonstration data submitted by the system.
State-set limits must not exceed 1 NTU (in at least 95 percent of measurements) or 5 NTU (maximum).</td></tr>
<tr><th colspan="2">Turbidity Monitoring Requirements</th></tr>
<tr><td>Combined Filter Effluent</td><td>Performed at least every 4 hours to ensure compliance with CFE turbidity performance standards.[1]</td></tr>
<tr><td>Individual Filter Effluent (IFE) (for systems using conventional and direct filtration only)</td><td>Since the CFE may meet regulatory requirements, even though one filter is producing high turbidity water, the IFE is measured to assist conventional and direct filtration treatment plant operators in understanding and assessing individual filter performance.
Performed continuously (recorded at least every 15 minutes).
Systems with two or fewer filters may conduct continuous monitoring of CFE turbidity in place of individual filter effluent turbidity monitoring.
Certain follow-up actions are required if the IFE turbidity (or CFE for systems with two filters) exceeds 1.0 NTU in 2 consecutive readings or more (additional reporting, filter self-assessments, and/or comprehensive performance evaluations - CPEs).</td></tr>
<tr><td colspan="2">[1] This frequency may be reduced by the State to once per day for systems using slow sand/alternative filtration or for systems serving 500 persons or fewer, regardless of the type of filtration used.</td></tr>
<tr><th colspan="2">Disinfection Profiling and Benchmarking Requirements</th></tr>
</table>

LT1 Major Provisions
Community and non-transient non-community public water systems must evaluate impacts on microbial risk before changing disinfection practices to ensure adequate microbial protection is maintained. This is accomplished through a process called disinfection profiling and benchmarking. What are the disinfection profiling and benchmarking requirements? • Systems must develop a disinfection profile, which is a graphical compilation of weekly inactivation of Giardia lamblia, taken on the same calendar day each week over 12 consecutive months. (Systems using chloramines, ozone, or chlorine dioxide for primary disinfection must also calculate inactivation of viruses.) Results must be available for review by the State during sanitary surveys. • A state may deem a profile unnecessary if the system has sample data collected after January 1, 1998–during the month of warmest water temperature and at maximum residence time in the distribution system–indicating TTHM levels are below 0.064 mg/L and HAA5 levels are below 0.048 mg/L. • Prior to making a significant change to disinfection practices, systems required to develop a profile must calculate a disinfection benchmark and consult with the State. The benchmark is the calculation of the lowest monthly average of inactivation based on the disinfection profile.

SWTR – Requirements for Unfiltered Systems

- Applies to all public water systems using surface water or ground water und er the direct influence of surface water; otherwise known as " subpart H systems".
- Requires all Subpart H systems to disinfect.
- Requires Subpart H systems to filter unless specific filter avoidance criteria are met.
- Requires unfiltered systems to perform source water monitoring and meet site specific conditions for control of microbials.

Some public water supplies that have pristine sources may be granted a waiver from the filtration requirement. These supplies must provide the same level of treatment as those that filter; however, their treatment is provided through disinfection alone. Systems must meet source water quality and site specific conditions to remain unfiltered. If any of the filtration avoidance criteria are not met, systems must install filtration treatment within 18 months of the failure.

System Reporting Requirements for Unfiltered Systems	
Report to State:	• What to Report:
Within 10 days after the end of the month:	• Source water quality information (microbial quality and turbidity measurements). • In addition to the disinfection information above, systems must report the daily residual disinfectant concentration(s) and disinfectant contact times(s) used for calculating the CT value(s).
By October 10 each year:	• Report compliance with all watershed control program requirements. • Report on the on-site inspection unless conducted by the State, in which the State must provide the system a copy of the report.
Within 24 hours:	Turbidity exceedances of 5 NTU and waterborne disease outbreaks.

System Reporting Requirements for Unfiltered Systems	
As soon as possible but no later that the end of the next business day:	Instance where the residual disinfectant level entering the distribution system was less than 0.2 mg/L.

SWTR – Requirements for Systems Using Conventional or Direct Filtration

- Requires all Subpart H systems to disinfect.
- Requires Subpart H systems to filter unless specific filter avoidance criteria are met.
- Requires individual filter monitoring and establishes combined filter effluent (CFE) limits.
- Applies a treatment technique requirement for control of microbials.

There are two ways turbidity is measured: Combined Filter Effluent (CFE) and Individual Filter Effluent (IFE).

Turbidity, Monitoring and Reporting Requirements for Systems Using Conventional or Direct Filtration

Turbidity Reporting Requirements Reports due by the 10th day of the following month the system serves water to the public.	**Monitoring/ Recording Frequency**	**SWTR As of June 29, 1993**	**IESWTR ≥ 10,000 people As of Jan 1, 2002**	**LT1ESWTR < 10,000 people As of Jan 1, 2005**
CFE 95 percent Value Report total number of CFE measurements and number and percentage of CFE measurements ≤ 95th % limit.	At least every 4 hours*	≤ 0.5 NTU	≤ 0.3 NTU	≤ 0.3 NTU
CFE Maximum Value Report date and value of any CFE measurement that exceeded CFE maximum limit.	At least every 4 hours*	5 NTU Contact state within 24 hours	1 NTU Contact state within 24 hours	1 NTU Contact state within 24 hours.
IFE Monitoring Report IFE monitoring conducted and any follow-up actions.	Continuously every 15 minutes	None	Monitor-exceedances require follow-up actions	Monitor-exceedances require follow-up actions. Systems with 2 or fewer filters may monitor CFE continuously in lieu of IFE.

*Monitoring frequency may be reduced by the state to once per day for systems serving 500 or fewer people.

IFE Follow-Up and Reporting Requirements

Condition	IESWTR (≥ 10,000)			LT1ESWTR (< 10,000) **		
	Action	Report	By	Action	Report	By
Two consecutive recordings > 0.5 NTU taken 15 minutes apart at the end of the first 4 hours of continuous filter operations after backwash/offline:	Produce filter profile within 7 days (if cause not known).	• Filter # • Turbidityvalue • Date • Cause (if known) or report profile was produced	10th of the following month			
Two consecutive recording > 1.0 NTU taken 15 minutes apart:	Produce filter profile within 7 days (if cause not known).	• Filter # • Turbidityvalue • Date • Cause (if known) or report profile was produced			• Filter # • Turbidity value • Date • Cause (if known)	10th of the following month
Two consecutive recordings > 1.0 NTU taken 15 minutes apart at the same filter for 3 months in a row:	Conduct filter self-assessment within 14 days.	• Filter # • Turbidityvalue • Date • Report filter assessment produced	10th of the following month	Conduct a filter self-assessment within 14 days. Systems with 2 filters that monitor CFE in lieu of IFE must do both filters.	Date filter self-assessment triggered and completed	10th of the following month (or within 14 days of filter self-assessment being triggered if triggered in last four days of the month)
Two consecutive recordings > 2.0 NTU taken 15 minutes apart at the same filter for two months in a row:	Arrange for CPE within 30 days and submit report within 90 days.	• Filter # • Turbidityvalue • Date	10th of the following month	Arrange for a CPE within 60 days and submit CPE report within 120 days.	Date CPE triggered	10th of the following month
		Submit CPE report	90 days after exceedance		Submit CPE report	120 days after exceedance

** Systems serving fewer than 10,000 people must begin complying with these requirements beginning January 1, 2005.

IFE performance is measured in systems using conventional or direct filtration. The performance of each individual filter is critical to controlling pathogen breakthrough. The CFE turbidity results may mask the performance of an individual filter since the individual filter may have a turbidity spike of a short duration not detected by four-hour CFE readings.

The IESWTR and LT1ESWTR created more stringent CFE turbidity standards and established a new IFE turbidity monitoring requirement to address Cryptosporidium. These new turbidity standards assure conventional and direct filtration systems will be able to provide 2-log Cryptosporidium removal.

SWTR – Requirements for Systems Using Slow Sand, Diatomaceous Earth, or Alternative Filtration

- Requires all Subpart H systems to disinfect.
- Requires Subpart H systems to filter unless specific filter avoidance criteria are met.
- Applies a treatment technique requirement for control of microbials.

Turbidity

Turbidity is measured as Combined Filter Effluent (CFE) for slow sand, diatomaceous earth, and alternative filtration. The CFE 95th percent value and CFE maximum value for slow sand and diatomaceous earth were not lowered in the IESWTR and LT1ESWTR since these filtration technologies are assumed to provide 2-log Cryptosporidium removal with the turbidity limits established by SWTR. Alternative filtration technologies (defined as filtration technologies other than conventional, direct, slow sand, or diatomaceous earth) must demonstrate to the State that filtration and/or disinfection achieve 3-log Giardia and 4-log virus removal and/or inactivation. The IESWTR and LT1ESWTR also require alternative filtration technologies to demonstrate 2-log Cryptosporidium removal.

Turbidity, Monitoring and Reporting Requirements for Systems Using Slow Sand, Diatomaceous Earth or Alternative Filtration

Turbidity Reporting Requirements (Reports due by the 10th day of the following month the system serves water to the public)		**Monitoring/ Recording Frequency**	**SWTR As of June 29, 1993**	**IESWTR ≥ 10,000 people As of Jan 1, 2002**	**LT1ESWTR < 10,000 people As of Jan 1, 2005**
Slow Sand & Diatomaceous Earth	CFE 95%	At least every 4 hours*	≤ 1 NTU	Regulated under SWTR	Regulated under SWTR
	CFE Max	At least every 4 hours*	5 NTU	Regulated under SWTR	Regulated under SWTR
Alternative • **Membranes** • **Cartridges** • **Other**	CFE 95%	At least every 4 hours*	≤ 1 NTU	Established by the state	Established by the State (not to exceed 1 NTU)
	CFE Max	At least every 4 hours*	5 NTU	Established by the state	Established by the State (not to exceed 5 NTU)

* Monitoring frequency may be reduced by the State to once per day for systems using slow sand or alternative filtration. Monitoring frequency may be reduced by the State to once per day for systems serving 500 or fewer people, regardless of type of filtration used.

CFE Turbidity: Reporting Requirements			
Report to State:	**SWTR Measurements**	**IESWTR Measurements**	**LT1ESWTR Measurements****
Within 10 days after the end of the month:	Total number of monthlymeasurements	Total number of monthlymeasurements	Total number of monthlymeasurements
	Number and percent less than or equal to designated 95th percentile turbidity limits	Number and percent less than or equal to designated 95th percentile turbidity limits	Number and percent less than or equal to designated 95th percentile turbidity limits
	Date and value exceeding 5 NTU	Date and value exceeding 5 NTU for slow sandanddiatomaceous earth or maximum level set by state for alternative filtration	Date and value exceeding 5 NTU for slow sandanddiatomaceous earth or maximum level set by the State for alternative filtration
Within 24 hours:	Exceedances of 5 NTU for CFE	Exceedances of 5 NTU for slow sand and diatomaceous earth or maximum CFE level set by state for alternative filtration	Exceedances of 5 NTU for slow sand and diatomaceous earth or maximum CFE level set by the state for alternative filtration
** Systems serving fewer than 10,000 people must begin complying with these requirements beginning January 1, 2005.			

Disinfection Profiling and Benchmarking Requirements

A disinfection profile is the graphical representation of a system's microbial inactivation over 12 consecutive months. A disinfection benchmark is the lowest monthly average microbial inactivation value. The disinfection benchmark is used as a baseline of inactivation when considering changes in the disinfection process.

The purpose of disinfection profiling and benchmarking is to allow systems and states to assess whether a change in disinfection practices creates a microbial risk. Systems should develop a disinfection profile that reflects Giardia lamblia inactivation (systems using ozone or chloramines must also calculate inactivation of viruses), calculate a benchmark (lowest monthly inactivation) based on the profile, and consult with the State prior to making a significant change to disinfection practices.

This rule is large, complex, prescriptive, wide-ranging and inherently challenging. It describes treatment plant performance, monitoring, record keeping, reporting, archiving of data, and much more. The ADEC drinking water regulations has a good section on this subject, but EPA literature must be consulted for recently adopted SDWA regulations and to complement ADEC regulations. Literally hundreds of pages of regulation are written to describe the rules and how they are applied.

Disinfection Profiling and Benchmarking Requirements Under IESWTR and LT1ESWTR		
Requirement	**IESWTR**	**LT1ESWTR**
Affected Systems:	Community, non-transient non-community, and transient systems	Community and non-transient non-community systems only.
Begin Profiling By:	April 1, 2000	• July 1, 2003 for systems serving 500-9,999 people • January 1, 2004 for systems serving fewer than 500 people.
Frequency & Duration:	Daily monitoring for 12 consecutive calendar months to determine the total logs of Giardia lamblia inactivation (and viruses, if necessary) for each day in operation.	Weekly inactivation of Giardia lamblia (and viruses, if necessary) on the same calendar day each week over 12 consecutive months.
Disinfection Benchmark Must Be Calculated If:	Systems required to develop a disinfection profile and are considering any of the following: • Changes to the point of disinfection. • Changes to the disinfectant(s) used. • Changes to the disinfection process. • Any other modification identified by the State. Systems must consult the State prior to making any modifications to disinfection practices.	Same as IESWTR, and systems must obtain state approval prior to making any modifications to disinfection practices.
State may waive disinfection profiling requirements if certain criteria are met.		

Long Term 2 Enhanced Surface Water Treatment Rule

The purpose of the Long Term 2 Enhanced Surface Water Treatment Rule (LT2), promulgated in December 2005, is to reduce illness linked with the contaminant *Cryptosporidium* and other disease-causing microorganisms in drinking water.

Important Elements of This Rule

The LT2 applies to all PWSs that use surface water or GUDISW and will supplement the existing regulations by targeting additional *Cryptosporidium* treatment requirements to higher risk systems. This rule also contains provisions to reduce risks from uncovered finished water reservoirs and to ensure that systems maintain microbial protection when they take steps to decrease the formation of disinfection byproducts that result from chemical water treatment.

Critical Deadlines

Monitoring starting dates are staggered by system size. The largest systems (serving at least 100,000 people) began monitoring in October 2006, and the smallest systems (serving fewer than 10,000 people) began monitoring in October 2008. After completing monitoring and determining their treatment bin, systems generally have three years to comply with any additional treatment requirements. Systems must conduct a second round of monitoring six years after completing the initial round to determine if source water conditions have changed significantly. Systems may use previously collected (Grandfathered) data in lieu of conducting new monitoring, and systems are not required to monitor if they provide the maximum level of treatment required under the rule. Contact the ADEC to determine deadlines and requirements for your system.

LT2 Major Provisions

Control of *Cryptosporidium*	
Source Water Monitoring	Filtered and unfiltered systems must conduct 24 months of source water monitoring for *Cryptosporidium*. Filtered systems must also record source water *E. coli* and turbidity levels. Filtered systems will be classified into one of four "Bins," based on the results of their source water monitoring. Unfiltered systems will calculate a mean *Cryptosporidium* level to determine treatment requirements. Systems may also use previously collected data (Grandfathered data). Filtered systems providing at least 5.5 log of treatment for *Cryptosporidium* and unfiltered systems providing at least 3-log of treatment for *Cryptosporidium* and those systems that intend to install this level of treatment are not required to conduct source water monitoring.
Installation of Additional Treatment	Filtered systems must provide additional treatment for *Cryptosporidium* based on their bin classification (average source water *Cryptosporidium* concentration), using treatment options from the "microbial toolbox." Unfiltered systems must provide additional treatment for Cryptosporidium using chlorine dioxide, ozone, or UV.
Uncovered Finished Water Storage Facility	Systems with an uncovered finished water storage facility must either: • Cover the uncovered finished water storage facility. • Treat the discharge to achieve inactivation and/or removal of at least 4-log viruses, 3-log for Giardia lamblia, and 2-log for Cryptosporidium.

Disinfection Profiling and Benchmarking

After completing the initial round of source water monitoring, any system that plans on making a significant change to their disinfection practices must do the following:

- Create disinfection profiles for *Giardia lamblia* and viruses.
- Calculate a disinfection benchmark.
- Consult with the state prior to making a significant change in disinfection practice.

Bin Classification for Filtered Systems

Cryptosporidium **Concentration (oocysts/L)**	**Bin Classification**	**Additional *Cryptosporidium* Treatment Required**			**Alternative Filtration**
		Conventional Filtration	**Direct Filtration**	**Slow Sand or Diatomaceous Earth Filtration**	
< 0.075	Bin 1	No additional treatment required	No additional treatment required	No additional treatment required	No additional treatment required
0.075 to < 1.0	Bin 2	1 log	1.5 log	1 log	(1)
1.0 to < 3.0	Bin 3	2 log	2.5 log	2 log	(2)
≥ 3.0	Bin 4	2.5 log	3 log	2.5 log	(3)

(1) As determined by the State (or other primacy agency) such that the total removal/inactivation > 4.0-log.
(2) As determined by the State (or other primacy agency) such that the total removal/inactivation > 5.0-log.
(3) As determined by the State (or other primacy agency) such that the total removal/inactivation > 5.5-log.

Inactivation Requirements for Unfiltered Systems

Cryptosporidium Concentration (oocysts/L)	Required Cryptosporidium Inactivation
≤ 0.01	2-log
> 0.01	3-log

Filter Backwash Recycling Rule (FBRR)

The Filter Backwash Recycling Rule was developed to improve public health protection by assessing and changing, where needed, recycle practices for improved contaminant control, particularly microbial contaminants.

The FBRR applies to PWSs that use surface water or GUDISW; practice conventional or direct filtration; and recycle spent filter backwash, thickener supernatant, or liquids from dewatering processes. The FBRR requires systems that recycle to return specific recycle flows through all processes of the system's existing conventional or direct filtration system or at an alternate location approved by the State. This is typically to a backwash lagoon or sewer lagoon.

The Ground Water Rule (GWR)

The EPA published the Ground Water Rule in November 2006 to improve your drinking water quality and provide increased protection against microbial pathogens, while minimizing public health risks of disinfectants and disinfection byproducts (DBPs). The GWR builds upon the Total Coliform Rule by addressing the health risks of fecal contamination. The rule establishes a risk-based approach to target ground water systems that are vulnerable to fecal contamination. Ground water systems that are identified as being at risk of fecal contamination must take corrective action to reduce potential illness from exposure to microbial pathogens. The rule applies to all systems that use ground water as a source of drinking water. The rule includes provisions for monitoring for systems with sources at risk and actions to remove or inactivate contaminants, if found, to prevent them from reaching drinking water consumers.

Important Elements of This Rule

The rule addresses risks through a risk-targeting approach that relies on four major components:

1. Periodic sanitary surveys of ground water systems that require the evaluation of eight critical elements and the identification of significant deficiencies (for example, a well located near a leaking septic system). States must have completed the initial survey by December 31, 2012, for most community water systems (CWSs) and by December 31, 2014, for CWSs with outstanding performance and for all non-community water systems.

2. Source water monitoring to test for the presence of E. coli, enterococci, or coliphage in the sample. There are two monitoring provisions:

   - Triggered monitoring for systems that do not already provide treatment that achieves at least 99.99 percent (4-log) inactivation or removal of viruses and that have a total coliform-positive routine sample under Total Coliform Rule sampling in the distribution system.

   - Assessment monitoring – As a complement to triggered monitoring, a state has the option to require systems, at any time, to conduct source water assessment monitoring to help identify high-risk systems.

3. Corrective actions required for any system with a significant deficiency or source water fecal contamination. The system must implement one or more of the following correction action options:
   - Correct all significant deficiencies.

- Eliminate the source of contamination.
- Provide an alternate source of water.
- Provide treatment that reliably achieves 99.99 percent (4-log) inactivation or removal of viruses.

4. Compliance monitoring to ensure that treatment technology installed to treat drinking water reliably achieves at least 99.99 percent (4-log) inactivation or removal of viruses.

GWR Compliance Dates

The GWR is scheduled for implementation over several years. Most of the GWR requirements took effect December 1, 2009, and states have two years from promulgation and up to two years under an extension to adopt the rule. The compliance date for triggered monitoring (and associated corrective actions) and compliance monitoring is December 1, 2009. There are no timeframes associated with the assessment monitoring because it is at the option of the State. States must complete their initial round of sanitary surveys by December 31, 2012, for most community water systems. States will have until December 31, 2014, to complete the initial sanitary survey for community water systems identified by the State as outstanding performers and non-community water systems.

Please consult the ADEC or EPA for how the GWR may impact you. The role of sanitary surveys is greatly emphasized in this rule; expect increased scrutiny of the condition of your system, records, and performance. The sanitary conditions of your system and type of water source will be relevant to the impact of this rule.

Current Regulations To Control Chemical Contaminants

The following major rules are intended to control this risk:

- Arsenic Rule
- Lead and Copper Rule (LCR)
- Stage 1 Disinfectants/Disinfection By-products Rule (Stage 1 D/DBPR)
- Stage 2 Disinfectants/Disinfection By-products Rule (Stage 2 D/DBPR)
- Radionuclides
- Radon Rule

The Arsenic Rule

Arsenic is a semi-metal element in the periodic table. It is odorless and tasteless. It enters drinking water supplies from natural deposits in the earth or from agricultural and industrial practices. Arsenic has been linked to cancer of the bladder, lungs, skin, kidney, nasal passages, liver, and prostate. Non-cancer effects can include thickening and discoloration of the skin, stomach pain, nausea, vomiting, diarrhea, numbness in hands and feet, partial paralysis, and blindness.

Important Elements of This Rule

The EPA has set the arsenic standard for drinking water at 0.010 parts per million (10 parts per billion) to protect consumers served by public water systems from the effects of long-term, chronic exposure to arsenic.

The PWS must sample for arsenic to record current values and have a sufficient number of sample results on hand to understand the system's compliance with the new arsenic MCL of 10 parts per billion. After sufficient samples are on record, the PWS sampling interval for arsenic is placed into the Standardized Monitoring Framework. Surface water and groundwater systems have different sampling timelines.

Monitoring Requirements for Total Arsenic (1)	
Compliance Determination (IOCs, VOCs, and SOCs)	
1. Calculate compliance based on a running annual average at each sampling point. 2. Systems will not be in violation until one year of quarterly samples have been collected (unless fewer samples would cause the running annual average to be exceeded). 3. If a system does not collect all required samples, compliance will be based on the running annual average of the samples collected.	
Initial Monitoring	
One sample after the effective date of the MCL (January 23, 2006). Surface water systems must take annual samples. Ground water systems must take one sample between 2005 and 2007.	
Reduced Monitoring	
If the initial monitoring result for arsenic is less than the MCL . . .	• Ground water systems must collect one sample every three years. • Surface water systems must collect annual samples.
Increased Monitoring	
A system with a sampling point result above the MCL must collect quarterly samples at that sampling point, until the system is reliably and consistently below the MCL.	
(1) All samples must be collected at each entry point to the distribution system, unless otherwise specified by the State	

Standardized Monitoring Framework for Inorganic, VOCs, SOC, Arsenic

EPA literature is the primary source for details on this rule. This rule applies to all regulated PWS. It addresses sampling for inorganic contaminants, VOCs, synthetic organics (pesticides), radionuclides, nitrate, nitrite, asbestos. It describes required sample history and reduced monitoring provisions for regulated chemicals after sufficient data is recorded. This reduced monitoring schedule can save PWSs a lot of money. This rule, and the availability of waivers for certain chemicals, is reasonable and worthy of operator attention.

The EPA understands that most water sources and treatment plants have consistent (historic) values on record of regulated contaminants. The values for a great number of the regulated contaminants do not change much over time; this condition is acknowledged in this rule. It lays out the sampling criteria for a whole series of regulated contaminants by system size, source type, measured values, etc. It is a very important rule to be familiar with. The ADEC and the PWS should be using this rule as appropriate to minimize unnecessary sampling and concentrating available resources on contaminants of real concern.

The Lead and Copper Rule (LCR)

The Lead and Copper Rule was published in June 1991 to protect public health by minimizing lead and copper levels in drinking water. The health effects of lead are most severe for infants and children. For infants and children, exposure to high levels of lead in drinking water can result in delays in physical or mental development. For adults, it can result in kidney problems or high blood pressure.

Most regulations require sampling at entry points to the distribution system. Because lead and copper in drinking water is due primarily to the corrosion of distribution and household plumbing materials, tap water samples are collected at kitchen or bathroom taps of residences and other buildings. This requirement significantly complicates sample collection, requiring you, the water system operator, to coordinate with the people you serve.

Tap monitoring results are the primary factor for determining your ongoing monitoring requirements and whether you need to undertake any of the following treatment technique requirements:

- Corrosion control treatment
- Source water treatment
- Public education
- Lead service line replacement

Important Elements of This Rule

Lead and copper tap monitoring applies to all CWSs and NTNCWSs. The regulations divide these systems into three broad size categories: large, medium, and small. System size is a factor in determining the number of samples that must be collected, as well as the applicability and timing of some of the provisions.

There is no MCL for lead or copper. The LCR establishes an action level (AL) of 0.015 mg/L for Lead (Pb) and 1.3 mg/L for Copper (Cu) based on 90th percentile level of tap water samples. An AL exceedance is not a violation but can trigger other requirements that include water quality parameter (WQP) monitoring, corrosion control treatment, source water monitoring/treatment, public education, and lead service line replacement.

Lead and Copper Rule

Tap Sampling Requirements

- First draw samples must be collected by all CWSs and NTNCWSs at cold water taps in homes/buildings that are at high risk of Pb/Cu contamination as identified in 40 CFR 141.86(a).
- Number of sample sites is based on system size (Table 1).
- Systems must conduct monitoring every six months unless they qualify for reduced monitoring (Table 2).

Table 1: Pb and Cu Tap and WQP Tap Monitoring

Size Category	System Size	# of Pb/Cu Tap Sample Sites		# of WQP Tap Sampling Sites	
		Standard	Reduced	Standard	Reduced
Large	> 100K	100	50	25	10
	50,001 – 100K	60	30	10	7
Medium	10,001 – 50K	60	30	10	7
	3,301 – 10K	40	20	3	3
Small	501 – 3,300	20	10	2	2
	101 – 500	10	5	1	1
	≤ 100	5	5	1	1

Table 2: Criteria for Reduced Pb/Cu Tap Monitoring*

Can Monitor ...	If the System ...
Annually	1. Serves ≤ 50,000 and is ≤ both ALs for 2 consecutive six-month monitoring periods; or 2. Meets Optimal Water Quality parameter (OWQP) specification for 2 consecutive 6-month monitoring periods.
Triennially	1. Serves ≤ 50,000 and is ≤ both ALs for 3 consecutive years of monitoring, or 2. Meets OWQP specifications for 3 consecutive years of monitoring; or 3. Has 90th percentile Pb levels ≤ 0.005 mg/L and 90th percentile Cu level ≤ 0.65 mg/L for 2 consecutive 6-month periods (accelerated reduced Pb/Cu tap monitoring), or 4. Meets the 40 CFR 141.81(b)(3) criteria.
Once Every 9 Years	Serves ≤ 3,300 and meets monitoring waiver criteria found at 40 CFR 141.86(g).
* Samples are collected at reduced number of sites. (See Table 1 above.)	
Treatment Technique and Sampling Requirements if AL is Exceeded	
- Water Quality Parameter (WQP) Monitoring - Public Education (PE) - Source Water Monitoring and Treatment - Corrosion Control Treatment	
If the system continues to exceed the AL after installing CCT and/or SOWT...	
- Lead Service Line Replacement	

The Stage 1 Disinfectants and Disinfection Byproducts Rule (Stage 1 DBPR)

The Stage 1 Disinfectants and Disinfection Byproducts Rule, published in December 1998, reduces exposure to disinfection byproducts for customers of CWSs and NTNCWSs that add a disinfectant to the drinking water during any part of the treatment process and TNCWSs that use chlorine dioxide.

Important Elements of This Rule

The Stage 1 DBPR was the first of a staged set of rules that reduced the allowable levels of DBPs in drinking water. The rule established seven new standards and a treatment technique of enhanced coagulation or enhanced softening to further reduce DBP exposure. The rule establishes maximum residual disinfectant level goals (MRDLGs) and maximum residual disinfectant levels (MRDLs) for three chemical disinfectants: chlorine, chloramines, and chlorine dioxide. It also establishes MCLGs and MCLs for total trihalomethanes, haloacetic acids, chlorite, and bromate.

Stage I Disinfectants and Disinfection Byproducts Rule

Stage 1 Regulated Contaminants/Disinfectants					
Regulated Contaminants	MCL (mg/L)	MCLG (mg/L)	Regulated Disinfectants	MRDL* (mg/L)	MRDLG* (mg/L)
Total Trihalomethanes (TTHM)	0.080		Chlorine	4.0 as Cl_2	4
Chloroform Bromodichloromethane Dibromochloromethane Bromoform		 zero 0.06 zero			
Five Haloacetic Acids (HAA5)	0.060		Chloramines	4.0 as Cl_2	4
Monochloroacetic acid Dichloroacetic acid Trichloroacetic acid Bromoacetic acid Dibromoacetic acid		 zero 0.3	Chlorine dioxide	0.8	0.8
Bromate (plants that use ozone)	0.010	zero	*Stage 1 DBPR includes maximum residual disinfectant levels (MRDLs) and maximum residual disinfectant level goals (MRDLGs), which are similar to MCLs and MCLGs, but for disinfectants.		
Chlorite (plants that use chlorine dioxide)	1.0	0.8			

Treatment Technique			
Enhanced coagulation/enhanced softening to improve removal of DBP precursors for systems using conventional filtration treatment.			
Routine Monitoring Requirements			
	Coverage	Monitoring Frequency	Compliance
TTHM/HAA5	Surface and GUDISW serving ≥ 10,000	4/plant/quarter	Running annual average
	Surface and GUDISW serving 500 – 9,999	1/plant/quarter	Running annual average
	Surface and GUDISW serving < 500	1/plant/year in month of warmest water temp **	Running annual average of increased monitoring
	Ground water serving ≥ 10,000	1/plant/quarter	Running annual average
	Ground water serving < 10,000	1/plant/year in month of warmest water temp **	Running annual average of increased monitoring
	Ozone plants	Monthly	Running annual average
Bromate	Ozone plants	Monthly	Running annual average
Chlorite	Chlorine dioxide plants	Daily at entrance to distribution system; monthly in distribution system	Daily/follow-up monitoring
Chlorine dioxide	Chlorine dioxide plants	Daily at entrance to distribution system	Daily/follow-up monitoring
Chlorine/ Chloramines	All systems	Same location and frequency as TCR sampling	Running annual average
DBP Precursors	Conventional filtration	Monthly for total organic carbon and alkalinity	Running annual average

** Systems must increase monitoring to one sample per plant per quarter if an MCL is exceeded.

The Stage 2 Disinfectants and Disinfection Byproducts Rule (Stage 2 DBPR)

The Stage 2 Disinfectants and Disinfection Byproducts Rule, published in December 2005, is an extension of the Stage 1 DBPR. Systems must also continue to comply with the other requirements of the Stage 1 DBPR in addition to meeting the requirements of the Stage 2 DBPR. This includes compliance with the MCLs for bromate (for systems using ozone) and chlorite (for systems using chlorine dioxide), the MRDLs for chlorine or chloramine (depending on the residual disinfectant used), as well as TOC removal requirements.

Important Elements of This Rule

This final rule strengthens public health protection for customers by tightening compliance monitoring requirements for two groups of DBPs: TTHM and HAA5. The rule targets systems with the greatest risk and reduces potential health risks related to DBP exposure and provides more equitable public health protection. The rule also requires some systems to complete an Initial Distribution System Evaluation (IDSE) to characterize DBP levels in their distribution systems and identify locations to monitor DBPs for Stage 2 DBPR compliance. The Stage 2 DBPR is being released simultaneously with the LT2 ESWTR to address concerns about risk trade-offs between pathogens and DBPs.

This rule applies to CWSs and NTNCWSs that add and/or deliver water that is treated with a primary or residual disinfectant other than ultraviolet light. NTNCWSs serving < 10,000 people do not need to complete any of the IDSE options, but must conduct Stage 2 DBPR compliance monitoring.

Stage 2 DBPR Compliance Dates

The EPA or the State should supply the system operator with a compliance schedule. If the system owner or operator did not receive a schedule, they should contact the local ADEC office.

The Stage 2 DBP rule builds incrementally on existing DBP rules. Many systems have already made significant progress in lowering their DBP levels. The Stage 2 DBP rule takes a risk-based targeted approach to require treatment changes by only those public water systems that are identified as having the greatest remaining risk. The first step is a multi-year process for systems to determine where higher levels of DBPs are likely to occur in their distribution system. These locations will become the system's new DBP monitoring sites.

If the DBP levels at these locations are too high (above the MCL), the system will start to take corrective actions. These actions could range from simple, quickly implemented management or operational changes to major construction. Any changes made by systems must be well studied and planned before execution. This planning, obtaining funding and permits for construction, designing, and finally constructing new facilities take time. The time to completion will vary depending on what they need to do. Depending on system size and the extent of needed construction, systems will begin the first year of compliance monitoring between 2012 and 2016 and must be in compliance with the Stage 2 DBP rule MCLs at the end of a full year of monitoring.

Stage 2 Disinfectants and Disinfection Byproducts Rule		
Stage 2 Regulated Contaminants		
Regulated Contaminants	**MCLG (mg/L)**	**MCL (mg/L)**
Total Trihalomethanes (TTHM)		0.080 LRAA (Locational Running Annual Average)
Chloroform Bromodichloromethane Dibromochloromethane Bromoform	0.07 zero 0.06 zero	
Five Haloacetic Acids (HAA5)		0.060 LRAA
Monochloroacetic acid Dichloroacetic acid Trichloroacetic acid Bromoacetic acid Dibromoacetic acid	0.07 zero 0.02	
IDSE Requirements**		
IDSE Option	**Description**	
Standard Monitoring	Standard monitoring is one year of increased monitoring for TTHM and HAA5 in addition to the data being collected under Stage 1 DBPR. These data will be used with Stage 1 DBPR data to select Stage 2 DBPR TTHM and HAA5 compliance monitoring locations. Any system may conduct standard monitoring to meet the IDSE requirements of the Stage 2 DBPR.	
System Specific Study (SSS)	Systems that have extensive TTHM and HAA5 data (including Stage 1 DBPR compliance data) or technical expertise to prepare a hydraulic model may choose to conduct a system specific study to select Stage 2 DBPR compliance monitoring locations.	
40-30 Certification+	The term "40/30" refers to a system that during a specific time period has all individual State 1 DBPR compliance samples less than or equal to 0.040 mg/L for TTHM and 0.030 mg/L for HAA5 and has no monitoring violations during the same time period. These systems have no IDSE monitoring requirements, but will still need to conduct Stage 2 DBPR compliance monitoring.	
Very Small System (VSS) Waiver+	Systems that serve fewer than 500 people and have eligible TTHM and HAA5 data can qualify for a VSS Waiver and would not be required to conduct IDSE monitoring. These systems have no IDSE monitoring requirements, but will still need to conduct Stage 2 DBPR compliance monitoring.	
** NTNCWSs serving < 10,000 people do not need to complete any of the IDSE options. + Systems that are notified by the EPA or the State that their VSS Waiver or 40/30 certification has not been approved will need to complete Standard Monitoring or SSS.		

Stage 2 Disinfectants and Disinfection Byproducts Rule			
Compliance with Stage 2 DBPR MCLs (Routine Monitoring)			
Source Water Type	**Population Size Category**	**Monitoring Frequency[1]**	**Total Distribution System Monitoring Locations Per Monitoring Period [2]**
Subpart H	< 500	per year	2
	500 – 3,300	per quarter	2
	3,301 – 9,999	per quarter	2
	10,000 – 49,999		4
	50,000 – 249,999		8
	250,000 – 999,999		12
	1,000,000 – 4,999,999		16
	≥ 5,000,000		20
Ground Water	< 500	per year	2
	500 – 9,999		2
	10,000 – 99,999	per quarter	4
	100,000 – 499,999		6
	≥ 5,000,000		8
Operational Evaluation			
System must begin complying with the operational evaluation provisions of the Stage 2 DBPR.			

[1] All systems must monitor during month of highest DBP concentrations.
[2] Systems on a quarterly monitoring must take dual sample sets every 90 days at each monitoring location, except for subpart H systems serving 500–3,300. Systems on annual monitoring and subpart H systems serving 500 – 3,300 are required to take individual TTHM and HAA5 samples (instead of a dual sample set) at the locations with the highest TTHM and HAA5 concentrations, respectively. If monitoring annually, only one location with a dual sample set per monitoring period is needed if highest TTHM and HAA5 concentrations occur at the same location and month.

Other Regulations

Variances and Exemptions Rule

States or the EPA may grant variances to allow public PWSs to use less costly technology. Exemptions under the SDWA allow public water systems more time to comply with a new NPDWR. Variances under the SDWA allow a public water system to deviate from the maximum contaminant level of a national primary drinking water regulation (NPDWR) under certain conditions when exceptionally poor source water conditions prevent compliance with that NPDWR. When operating under variances or exemptions, water systems must still provide drinking water that protects public health.

There are two types of variances:

1. General variances are intended for systems that are not able to comply with a NPDWR due to their source water quality. General variances require compliance as expeditiously as practicable and in accordance with a compliance schedule determined by the State.
2. Small system variances are intended for systems serving 3,300 persons or fewer that cannot afford to comply with a NPDWR (but may be allowed for

systems serving up to 10,000 persons). Small system variances require compliance within three years (with a possible two-year extension period).

Systems with exemptions must achieve compliance as expeditiously as practicable and in accordance with the schedule determined by the State. In addition:

- Initial exemptions cannot exceed two years.
- Systems serving < 3,301 persons may be eligible for one or more additional two-year extension periods (not to exceed six years).
- Excluded Contaminants
- General variances may generally not be granted for the maximum contaminant level (MCL) for total coliforms or any of the treatment technique (TT) requirements of Subpart H of 40 CFR 141.
- Small system variances may not be granted for NPDWRs promulgated prior to 1986 or MCLs, indicators, and TTs for microbial contaminants.
- Exemptions from the MCL for total coliforms may generally not be granted.

Exclusions

- Systems that have received a small system variance are not eligible for an exemption.
- Small system variances may not be granted for NPDWRs that do not list a small system variance technology (SSVT).
- Systems that have received an exemption are generally not eligible for a variance.

Water system owners and operators should familiarize themselves with the Variances and Exemptions Rule. There are many rule-related activities and responsibilities associated with this rule.

Public Notification Rule

Public notification is intended to ensure that consumers will always know if there is a problem with their drinking water. These notices immediately alert consumers if there is a serious problem with their drinking water that may pose a risk to public health. They also notify customers if their water does not meet drinking water standards, if the water system fails to test its water, or if the system has been granted a variance (use of less costly technology) or an exemption (more time to comply with a new regulation).

The Public Notification Rule (PNR), as revised in 2000, applies to all PWS and requires faster notice in emergencies and fewer notices overall. The notices provide better communication of potential health risks from drinking water violations and how to avoid such risks. Water systems are able to better target notices to the seriousness of the risk and make the existing notification process less burdensome for water suppliers and make notices easier for consumers to read.

Notices must be sent within 24 hours, 30 days, or one year, depending on the tier to which the violation is assigned. The clock for notification starts when the PWS learns of the violation. Notices must be provided to persons served, not just billing customers.

The Public Notification Rule
Tier 1 Public Notice – Immediate Notice, Required Within 24 Hours
• Fecal coliform maximum contaminant level (MCL) violation or failure to test for fecal contamination after total coliform test is positive • Nitrate/nitrite/or total nitrate and nitrite MCL violation or failure to take confirmation sample • Chlorine dioxide maximum residual distribution level (MRDL) violation in distribution system or failure to take repeat samples in distribution system • Exceedance of maximum allowable turbidity level resulting in an MCL or treatment technique (TT) violation, when the State or EPA determines a Tier 1 notice is warranted • Special public notice for non-community water systems with nitrate exceedances between 10 mg/L and 20 mg/L, when allowed to exceed MCL (10 mg/L) by the State • Waterborne disease outbreak or other waterborne emergency • Other situations as determined by the primacy agency
Tier 2 Public Notice – Notice as soon as practical, Required Within 30 Days (Unless extended to 90 days by State)
• All other MCL, MRDL, and TT violations not identified as a Tier 1 notice • Monitoring and testing procedure violations, when the primacy agency requires a Tier 2 (rather than Tier 3) notice • Failure to comply with variance and exemption (V&E) conditions
Tier 3 Public Notice – Required Within 30 Days (Annual)
• All other monitoring or testing procedure violations not already requiring a Tier 1 or Tier 2 notice • Operation under a Variance and Exemption • Special public notices (exceedance of the fluoride secondary maximum contaminant level (SMCL); announcing the availability of unregulated contaminant monitoring results)
Contents of a Notice
Unless otherwise specified in the regulations,* each notice must contain: 1. A description of the violation or situation, including contaminant levels, if applicable 2. When the violation or situation occurred 3. Any potential adverse health effects (Using standard health effects language from Appendix B of the public notification rule or the standard monitoring language. See below.) 4. The population at risk 5. Whether alternative water supplies should be used 6. What actions consumers should take 7. What the system is doing to correct the violation or situation 8. When the water system expects to return to compliance or resolve the situation 9. The name, business address, and phone number of the water system owner or operator 10. A statement (see below) encouraging distribution of the notice to others, where applicable
* These elements do not apply to notices for fluoride SMCL exceedances, availability of unregulated contaminant monitoring data, and operation under a variance or exemption. Content requirements for these notices are specified in the rule. **Standard Monitoring Language** – We are required to monitor your drinking water for specific contaminants on a regular basis. Results of regular monitoring are an indicator of whether or not our drinking water meets health standards. During [period] we [did not monitor or test/did not complete all monitoring or testing] for [contaminant(s)] and therefore cannot be sure of the quality of the drinking water during that time. **Standard Distribution Language** – Please share this information with all the people who drink this water, especially those who may not have received this notice directly (for example, people in apartments, nursing homes, schools, and businesses). You can do this by posting this notice in a public place or distributing copies by hand or mail.

PNR Reporting and Record-keeping

- PWSs have 10 days to send a certification of compliance and a copy of the completed notice to the primacy agency.
- PWS and primacy agency must keep notices on file for three years.
- Primacy agencies must report public notification violations to the EPA on a quarterly basis.

The Consumer Confidence Report (CCR) Rule

The Consumer Confidence Report Rule requires all CWSs to prepare and distribute a brief annual water quality report summarizing information regarding water sources used, any detected contaminants, compliance, and educational information. The reports are due to customers by July 1 of each year for water quality data in the previous calendar year.

There are well-established templates to use for completing your CCR. This information is available by contacting your local ADEC office.

Summary

The drinking water regulations and monitoring requirements are subject to frequent changes in response to new federal requirements. It is important for the operator to establish contact with the ADEC drinking water specialist assigned to their PWS in order to remain up-to-date with new regulations and monitoring requirements. The ADEC drinking water specialist can provide the most current information and provide you with a monitoring summary of the water system you are working on/with.

Remember, it is your responsibility as the treatment plant operator to know what the regulations are and be in compliance with those regulations. Your customer's health depends on it. There are numerous resources available to you regarding drinking water regulations. If you have access to the Internet:

- http://www.epa.gov
- http://www.dec.alaska.gov/eh/dw/index.htm

If you do not have access to the Internet, contact your local ADEC office or the EPA's Safe Drinking Water Hotline at 1-800-426-4791.

Regulations and Monitoring Quiz

1. The most important responsibility of a water operator is to provide:
   A. Adequate water pressure
   B. Palatable drinking water
   C. Adequate amounts of water
   D. Safe drinking water

2. What information does a "public notification" supply?
   A. Notifies water consumers of a positive BacT sample
   B. Notifies water consumers of additional charges for water
   C. Notifies water consumers that water will be turned off for maintenance
   D. Notifies water consumers that the water tests were acceptable

3. What is the purpose of the bacteriological site sampling plan?
   A. To have a map showing where BacT samples are drawn
   B. In case of a positive Bac T sample, the operator will know where to take the four repeat samples
   C. The state will know where you are taking your repeat samples
   D. All of the above

4. To ensure that the water supplied by a public water system meets state requirements, the water system operator must regularly collect samples and:
   A. Have water analyzed at an approved water testing laboratory
   B. Determine a sampling schedule based on state requirements
   C. Send all analyses results to the state
   D. All of the above

5. Samples taken for routine bacteriological testing should be preserved by:
   A. Freezing
   B. Boiling
   C. DPD preservative
   D. Refrigeration

6. How many coliform samples are required per month for a water system serving a population between 25 and 100?
   A. 1
   B. 2
   C. 3
   D. 4

7. Before taking a bacteriological (BacT) water sample from a faucet, you should:
   A. Wash hands thoroughly
   B. Remove the faucet aerator
   C. Flush water until you're sure water is from the main, not the service line
   D. All of the above

8. Monthly BacT samples should be taken from:
   A. The well pump house
   B. The distribution system
   C. The treatment plant
   D. An outside hose spigot

9. If your BacT sample test is positive, how long do you have to collect four repeat samples and deliver them to the lab?
   A. 12 hours
   B. 24 hours
   C. 48 hours
   D. 72 hours

10. A positive total coliform test indicates that:
   A. Disease-causing organisms may be present in the water supply
   B. The water is safe to consume
   C. The water supply has high iron levels
   D. There is nothing to be concerned about

11. Which two types of analysis must be done on all public water supplies?
   A. Bacteriological and chemical
   B. Chlorine residual and trihalomethanes
   C. Bacteriological and hardness
   D. Chemical and turbidity

12. A major source of error when obtaining water quality information is improper:
   A. Sampling
   B. Preservation
   C. Tests of samples
   D. Reporting of data

13. What is commonly used as an indicator of potential contamination in drinking water samples?
   A. Viruses
   B. Coliform bacteria
   C. Intestinal parasites
   D. Pathogenic organisms

14. If you have questions about when or where you need to take water samples, what organization should you contact?
   A. United States Environmental Protection Agency
   B. Alaska Department of Environmental Conservation
   C. State Department of Health
   D. Safe Drinking Water Act Agency

15. A sample siting plan describes:
    A. Where the well(s) are located
    B. Where coliform samples are to be taken
    C. Where future improvements will take place
    D. None of the above

Testing Your Drinking Water

Chapter 10

What's In This Chapter?

1. Common equipment used in a water laboratory
2. How to use the meniscus to properly measure a liquid volume
3. The basic laboratory techniques of pipetting and titration
4. Common laboratory safety procedures and techniques
5. The three different types of samples
6. A description of a good sample location
7. Which tests are best determined from grab samples
8. The hold time and temperature for biological samples
9. The three cardinal rules to sampling.
10. When in the daily flow cycle chlorine residuals should be taken
11. The basic procedure for
    - Alkalinity
    - Chlorine residual
    - pH
    - Fluoride
    - Bacteriological sampling
12. The function and use of QAQC
13. Proper recordkeeping procures

Key Words

- Fecal Coliform
- NFR
- QAQC

Introduction

Level of Material
The material in this lesson is presented at a beginning level. There has been no assumption that the reader is familiar with water laboratory equipment or procedures. Only a general discussion is provided for routine laboratory testing. There has been no attempt to provide step-by-step procedures for the tests discussed in this lesson. The goal is to provide the user with a general understanding of the common laboratory procedures used in a typical water laboratory in a small treatment plant.

Reference Text
There are numerous reference books available that provide step-by-step procedures for all of the laboratory tests that are normally conducted by an operator. Contact EPA, the American Water Works Association or the local state regulatory agency for information on these books.

Commercial Laboratories
Many small systems prefer to utilize a commercial laboratory to perform the testing that is required by ADEC. However, there are lab tests that help an operator control their treatment process (process control testing). A basic understanding of both types of testing can be useful for the entry level operator.

Content
This lesson contains the following sections:

- Equipment
- Laboratory techniques
- Laboratory safety
- Sampling procedures
- Types of samples
- Testing
- **QA/QC**[1]
- Record keeping

[1] QA/QC - Quality Assurance - Quality Control - The formal process of assuring the laboratory is performing testing in the most accurate and precise manner possible in order to comply with specified regulations.

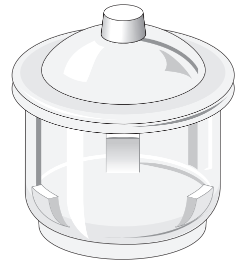
Equipment

Limitations
A typical laboratory could contain a wide variety of special equipment. The following discussion provides information on only that equipment discussed in the test procedures provided in this lesson.

Hardware
Water Bath Incubator
The incubator required to perform the fecal coliform test must be capable of maintaining a temperature of 44.5°C within 0.2°C. A water bath incubator is frequently used. This device looks like a rectangular metal basin. Water is placed inside the basin. The temperature is maintained by a heating element at the bottom of the basin and a lid that keeps the heat from escaping. This type of incubator is capable of maintaining the strict temperature requirement for the fecal coliform test.

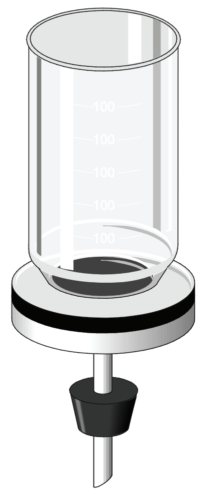
Drying Oven
A small oven that looks like a rectangular metal box is used to maintain the proper temperature to dry filters for the suspended solids and total solids tests.

Desiccator
A desiccator is a glass or plastic device that looks similar to a salad bowl with a lid. The device is used to allow heated samples to cool without taking on moisture from the air. To prevent moisture from entering the samples a material called desiccant is placed in the bottom of the desiccator. This material absorbs moisture.



Desiccator

Fecal Filter Apparatus
A special stainless steel or plastic funnel and filter holder are used to run the **fecal coliform**[2] test. The bottom of this device is mounted in a rubber stopper that will fit into a filter flask. The top of the funnel secures to the bottom by a 1/4 turn twist or a magnet.



Funnel

[2] Fecal Coliform - The Fecal coliform group of bacteria is a bacterial indicator of contamination. This group has as one of its primary habitats the intestinal tract of human beings. Coliforms also may be found in the intestinal tract of other warm-blooded animals. Also called E. Coli or Escherichia Coli.

Autoclave
In order to sterilize the equipment needed to perform bacteriological testing an autoclave is needed. This device allows the development of high temperatures and pressures needed to kill all microorganisms. An autoclave is very similar to a pressure cooker.

Glassware
Volumetric Flasks
In order to measure large volumes of liquid accurately, a volumetric flask is used. These devices have only one measurement point. This point is a line etched on the neck of the flask. Various sizes are available.

Pipettes
In order to measure small volumes of liquids accurately a pipette is used.

Burettes
In order to deliver precise volumes of fluid at a controlled rate a long glass tube called a burette is used. This tube is fastened into a stand and filled from the top. The flow is controlled by a small valve on the bottom.

Graduated Cylinders
Graduated cylinders are glass or plastic cylinders that have a scale marked to the nearest milliliter etched onto their sides. Graduated cylinders are used to measure sample volumes. While fairly accurate, they are not as accurate as volumetric flasks.

Beakers
Beakers are glass or plastic containers used in a laboratory. While they have a scale on the side that indicates their volume they are the least accurate of all of the glassware. They are used to hold samples, mix solutions and other general tasks in the lab.

Erlenmeyer Flasks
A special flask called an Erlenmeyer flask is used to titrate samples. (See titration discussion). These flasks have a large flat bottom and taper to a narrow top to prevent spilling when the contents are mixed.

Vacuum Flask

Vacuum flask are used in the fecal coliform and suspended solids test. The vacuum flask is made like an Erlenmeyer flask except there is a connection near the top of the flask for a vacuum source.

Gooch Crucible

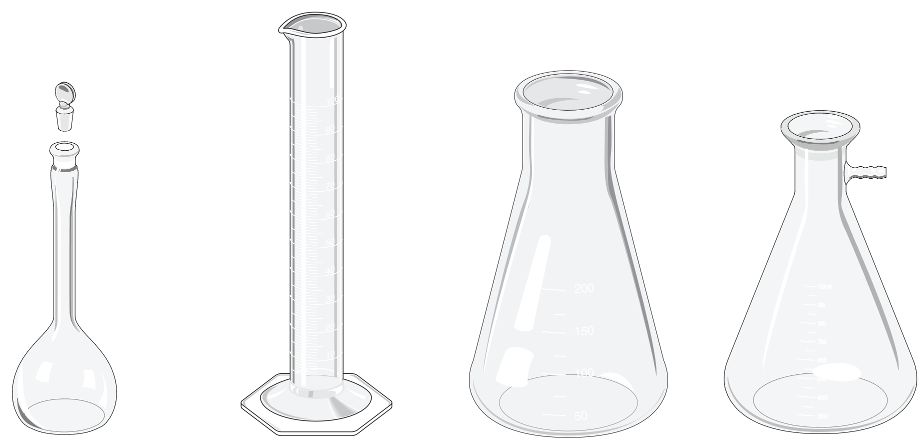
One of the suspended solids test procedures requires the use of a ceramic device called a Gooch Crucible. This device is funnel shaped with small holes in the lower end. The Gooch is placed in a rubber holder in a vacuum flask and a glass fiber filter is placed inside.

Buchner Funnel

The Gooch crucible is too small to allow filtration of a large volume sample that contains a high concentration of solids. To measure suspended solids a buchner funnel is used. This is a large ceramic or plastic funnel with holes in a plate that has been formed inside the funnel. A glass fiber filter is placed on the plate and the funnel placed in a rubber holder in a vacuum flask.

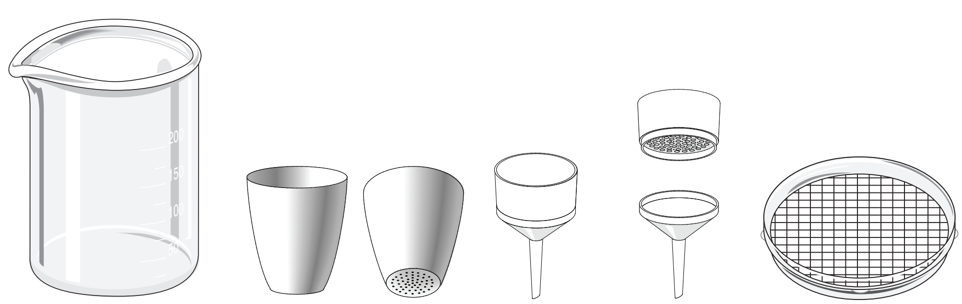
Petri Dish

A petri dish is a small flat glass or plastic dish with a lid. Media and bacteriological samples are placed in the petri dish which is placed in an incubator. There are a wide variety of petri dish sizes available.



Volumetric flask | Graduated cylinder | Erlenmeyer flask | Vacuum flask

Pipette



Beaker | Gooch crucible | Buchner funnel | Petri dish

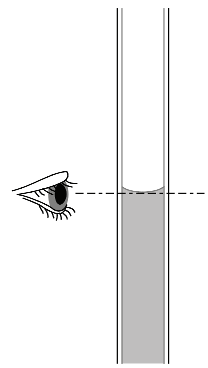
Basic Laboratory Techniques

In order to understand the following laboratory testing procedures it is necessary to explain three basic laboratory techniques. These are pipetting, titrating and reading liquid volumes.

Pipetting

Liquid is drawn into a pipette by use of a vacuum placed on the top of the pipette. This vacuum is commonly created with a rubber bulb that is placed over the end of the pipette. The flow of liquid out of the pipette is controlled by placing the end of one finger over the opening at the end of the pipette. While this sounds easy it takes considerable practice to be able to perform this task with high accuracy.

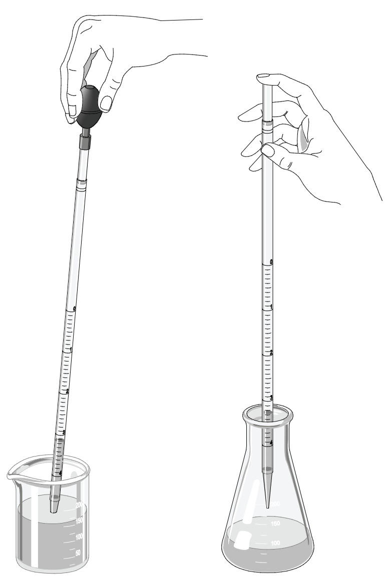
Reading volumes



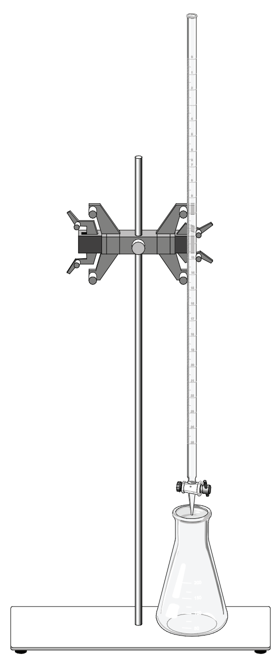
When a fluid is placed in a glass measuring device such as a graduated cylinder, volumetric flask, pipette or burette the quantity must be recorded. Most fluids adhere to the side walls of a glass container. In doing this the surface becomes concaved. This concaved surface is called a meniscus. To properly read the level of fluid in a glass device, read along the bottom of the meniscus.

Titrating

Titrations are performed in many of the test procedures. This process requires a burette and erlenmeyer flask. A sample and some chemical are placed in the flask. A second chemical is placed in the burette. When the two chemicals mix a color is developed or they cause a color to disappear. The normal procedure is to twirl the flask while allowing a controlled rate of flow from the burette to enter the flask. When a specific color point is reached the volume used is determined from the burette and used to calculate the concentration in the flask.



Pipetting



Titration technique

Laboratory Safety

Preventing Hazards

The laboratory is not necessarily a dangerous place. However, when the laboratory is used by inexperienced and/or careless operators accidents can easily happen. The basic tests covered in this manual require a minimum of laboratory experience and are not highly hazardous as long as basic safety precautions are observed.

Proper procedures and techniques can be placed into two general groups:

1. Personal protection
2. Proper handling of chemicals and bacteriological materials.

Personal Protection

The most important aspect of laboratory safety is to protect yourself and others around you.

Eye Protection

Eyes must be protected from splashing chemicals, chemical dust, high pressure water and broken glass. Protection is provided by wearing chemical safety glasses or goggles any time the operator is performing laboratory tests, handling glassware or chemicals.

Safety Equipment

Each laboratory should be equipped with the following safety equipment:

- Fire extinguisher - dry chemical or CO_2
- Fully equipped first-aid cabinet
- Fire blanket
- Chemical eye-wash

Operators should be trained in the use of this equipment and know its location.

Pipetting

When transferring chemicals or measuring a sample with a pipette, always use a pipette fill bulb. Never suck the solution into the pipette with your mouth.

Handling Samples

Samples should not be handled with bare hands. Use disposable latex gloves to protect against infections.

Wash-Up

To prevent the transfer of chemicals to the eyes and the transfer of disease, wash hands with hot water and soap after handling sewage samples.

Eating

To prevent accidental intake of chemicals or ingesting pathogenic organisms, never use laboratory glassware for serving food or drink. Never smoke in a laboratory. Never eat or drink in a laboratory.

Labels

Containers of chemicals received from a manufacturer have the proper labeling. When a chemical is transferred to a storage bottle the following information must be placed on the label:

- Name of chemical
- Chemical formula - if known
- Concentration
- Date
- Initials of the person preparing the container

In addition it is desirable to place an **NFR**[3] label on the container. If the container is removed from the treatment plant the NFR label must be on the chemical.

[3] NFR - National Fire Rating System This system provides the users of chemicals with a four diamond placard that indicates the health concern, flammability, and reactivity levels of the chemical.

Handling Chemicals and Samples

The operator may be required, as part of the job, to handle a variety of hazardous materials. It is beyond the scope of this manual to discuss all of the chemicals an operator may encounter in the lab. Caution: chemicals which are handled improperly, or randomly mixed together can produce heat, toxic fumes or even explode. In order to properly handle, control and dispose of these materials it is important that the operator review the Material Safety Data Sheets (MSDS) for each chemical used with care. The following is a brief and general discussion of handling precautions. However, this information does not substitute for the MSDS.

MSDS

A current MSDS must be on-site for each chemical that is in the laboratory. It is the responsibility of the employer to see that each person who may use a chemical is aware of the location of the MSDS and has been trained in how to read the MSDS.

Corrosive Chemicals

Acids

Operators may handle sulfuric, hydrochloric, nitric and glacial acetic acids. All acids are classified as corrosive and may cause burns to the skin, if contacted.

Spills

The specifics on how to handle a spill are found in the MSDS. However, in general the spill may be controlled by dilution with large and immediate quantities of water or neutralized with sodium bicarbonate. The spill area should then be cleaned and dried.

Contact with Skin

Contact with acids can quickly cause severe burns to the skin. The area should be immediately washed with large quantities of cool water and neutralized with sodium bicarbonate.

Pipetting

As with other materials, acids should only be pipetted using a pipette bulb.

Diluting with Water

When diluting an acid with water, always add the acid to the water. Never add the water to the acid.

Bases
Operators and laboratory technicians may handle sodium hydroxide, potassium hydroxide, and ammonium hydroxide. These are all strong bases that are corrosive to clothing and can cause burns to the skin. First aid is provided by immediately washing the area with large quantities of cool water.

Infectious Material
While it is unlikely that an operator would contract a disease while handling water or wastewater samples, the possibility does exist. An operator can prevent disease by following a few simple rules.

Open Wounds
Untreated water samples may contain bacteria, viruses and protozoa that can cause disease. One of the methods of contacting these microorganisms is through breaks in the skin. Keep wounds covered by wearing disposable latex gloves when handling all samples.

Ingestion
When handling fecal coliform plates it is easy to transfer microorganisms to the hands and then transfer them to your mouth while eating or smoking. Therefore, wash your hands thoroughly after handling samples, even if latex gloves are worn.

Clothing
In the performance of routine laboratory work the operator can easily collect pathogenic microorganisms onto their clothes. These microorganisms can then be transferred to the home. Therefore, change clothing at the plant and wash up before going home. If a shower is available, it is a good idea to shower and change clothes before leaving the plant.

Sampling Procedures

Must Be Representative
Sampling is often the most neglected technique in laboratory control testing. A sample must accurately represent the body of water intended for study. Although a test may be performed carefully and accurately, the result is meaningless if the sample is not representative of the water source from which it was taken.

Obtaining Representative Samples
Over the years operators and technicians have developed specific sampling techniques and procedures that, when used properly, provide representative samples. These are called the principles of sampling.

Principles of Sampling
Three Cardinal Rules
Water samples are taken from a wide variety of locations under many different conditions. Sampling sites should be selected to meet the requirements of the information desired. Sampling methods should be carefully considered. Regardless of the site or method chosen, there are Three Cardinal Rules that apply to all samples. They are cleanliness, documentation, and preservation.

Cleanliness
All containers including caps and measuring devices with which the sample comes in contact must be cleaned. Process control samples should be taken in containers washed in soap and water. Total coliform and fecal coliform samples must be taken in a special sterilized container.

Documentation
Water sample labels should note:

- The type of sample
- Source the sample is collected from
- Location of sampling point
- The date and hour sampled
- Name of sampler
- The temperature of the sample
- Recent weather conditions
- Flow at time of sampling

Location Expanded
A sample is only a representation of the conditions at the point of sampling. For example, the conditions in a sedimentation basin may vary greatly from one end of the basin to the other. Therefore, it is imperative that the exact basin sample location be included in the documentation. For example, we would write "east end of basin two feet back of overflow weir." We would not write "sample taken from sedimentation basin."

It is often helpful to identify standard sample sites within the plant and distribution system with a number or other identifying title. The exact description of that sample point can be detailed on a sample site plan or standard sampling plan.

Preservation
Samples may contain living organisms which continue to grow unless the life processes are slowed by lowering temperatures or halted by addition of chemicals. In addition, chemical degradation can also occur if samples are not properly preserved and stored prior to testing.

Preservation Methods
The correct form of preservation must be practiced, and will vary with the type of sample. In general, samples containing living organisms (bacteriological samples) may be preserved up to 6 hours if refrigerated at 4˚C. Chemical samples may need to be stored out of the light or have a specific chemical added.

Chain of Custody
If a sample is sent off site for analysis, a proper chain of custody procedure should be followed. A chain of custody provides a paper trail that documents each person that handles the sample from sampling to disposal. This procedure ensures proper quality control of the sample when data validation is necessary.

Other Sampling Considerations
Representative Location
Samples must be selected from a location that is representative of the conditions. Typically, this is a location where the flow is well mixed. Dead ends and corners of tanks and basins are not usually representative of the entire flow.

Number and Volume
In order for the sampling to be representative, there must be the proper number and volume of samples collected.

Large Particles
Large particles should be excluded from the sample. They are not representative of the sample stream.

Deposits and Growths
Deposits and growths that have accumulated at the sampling site must be avoided in the sample. This includes slime or algae growing on sample lines and faucets.

Aseptic Conditions
The process of maintaining the quality of a bacteriological sample is called aseptic handling. This means avoiding contamination from skin, clothing, equipment, water, and adjacent surfaces.

Data
Unless the proper data is recorded with the sample the sample is not valid.

Mixing
Always mix the sample before removing a portion.

Time Frame
Samples should be tested as soon as possible – always within the permissible time interval after sampling.

Summary
A good sample location is one where the flow is well mixed, easily accessible, and representative of the overall flow conditions.

Types of Samples

There are three types of samples collected by plant operators:

1. Grab samples
2. Composite samples
3. Proportional composite samples

Each type of sample has its proper function.

Grab Samples
A "grab" sample is a single sample that is taken at one particular time. Grab samples are taken because they are required or because there is a lack of time to collect composite samples. For some tests, grab samples are preferred.

Use of Grab Samples
Tests such as residual chlorine, dissolved oxygen, and pH are determined from grab samples because they cannot be preserved and a grab sample is the most representative.

Sampling and Flow - Chlorine

If only one chlorine residual sample can be taken per day, it is best to take this sample at peak flow. Chlorine residuals are normally at their lowest during peak flow. This is because; even with flow proportional chlorinators the feed rate is not increased at an exact proportion to flow. If at all possible chlorine residual samples should be taken at minimum and at peak flows. This will provide the operator with a view of the residual ranges found in the system. The required minimum CT must be maintained in the distribution system to ensure proper disinfection has taken place. The minimum CT is calculated based on chlorine residuals at peak flow when there is the lowest contact time in the system.

Sampling and Flow - Total Coliform

Because total coliform numbers in the water system are related to chlorine levels it is best to sample for total coliform at the same time that samples are collected for chlorine residuals.

Sampling for pH

In order for pH readings to be representative of the plant conditions they should be taken at maximum and minimum flows. If, due to time constraints, they can only be taken once a day, then they should be taken at the same time each day.

Composite Samples

A composite sample is a series of grab samples poured together to make one sample. The simplest type of composite sample consists of grabs of equal volume and is applicable only to situations of uniform flow.

Use of Composite Samples

A composite sample is only representative if the flow at the point of sampling remains constant throughout the sampling period. The sampling period is typically 24 hours but may be more or less depending on the constituent to be tested for.

Flow Proportional Composite Samples

In proportional composite samples, the volume of each portion is adjusted to the flow at the time the portion is collected. All portions are mixed together to produce a final sample representative of the flow during that particular collection period. Composite samples are representative of the character of the flow over a period of time. The effects of intermittent changes in strength and flow are eliminated. The portion collected should be obtained with sufficient frequency to obtain average results.

Required Lab Testing

Requirements

The Alaska Department of Environmental Conservation (ADEC) monitoring summary specifies which lab tests will be required of a specific system. This section covers the some of the common tests an operator may perform. All water systems are required to perform and report specific laboratory tests.

The following material is a discussion and description of the listed tests, no intent for step-by-step instruction is implied. Always follow the instructions for the specific test kit used.
Water systems must use EPA-approved analytical methods when analyzing samples

to meet federal monitoring requirements or to demonstrate compliance with drinking water regulations. Approved methods are listed in the Code of Federal Regulations after publication in a final rule or as part of an expedited approval. Approved methods are developed by EPA, other government agencies, universities, consensus methods organizations, water laboratories, and instrument manufacturers.

Analytical Method

An analytical method is a procedure that determines the concentration of a contaminant in a water sample. Analytical methods generally describe:

- How to collect, preserve, and store the sample.
- Procedures to concentrate, separate, identify, and quantify contaminants present in the sample.
- Quality control criteria the analytical data must meet.
- How to report the results of the analysis.

In general, an analytical method:

- Is applicable to routine analyses of samples.
- Is suitable for measuring the drinking water contaminant in the concentration range of interest.
- Provides data with the necessary accuracy and precision to demonstrate compliance or meet monitoring objectives in a wide variety of drinking waters.
- Includes instructions for all aspects of the analysis from sample collection to data reporting.
- Incorporates appropriate quality control criteria so that acceptable method performance is demonstrated during the analysis of samples.

Sampling

For Screw-cap Bottles

To collect water samples using screw-cap sample bottles, use the following procedures:

- Label the bottle with the site number, date, and time.
- Remove the cap from the bottle just before sampling. Avoid touching the inside of the bottle or the cap. If you accidentally touch the inside of the bottle, use another one.
- Leave a 1-inch air space. Do not fill the bottle completely (so that the sample can be shaken just before analysis). Recap the bottle carefully, remembering not to touch the inside.
- Fill in the bottle number and/or sample site number on the appropriate label. This is important because it tells the lab which bottle goes with which site.
- If the samples are to be analyzed in the lab, place them in the cooler for transport to the lab.

For Whirl-pak® Bags

To collect water samples using Whirl-pak® Bags, use the following procedures:

- Label the bag with the site number, date, and time.
- Tear off the top of the bag along the perforation above the wire tab just prior to sampling. Avoid touching the inside of the bag. If you accidentally touch the inside of the bag, use another one.
- Fill the bag no more than 3/4 full!
- Pull on the wire tabs to close the bag. Continue holding the wire tabs and flip the bag over at least 4-5 times quickly to seal the bag. Don't try to squeeze the air out of the top of the bag. Fold the ends of the wire tabs together at the

top of the bag, being careful not to puncture the bag. Twist them together, forming a loop.

- Fill in the bag number and/or site number on the appropriate label. This is important! It is the only way the lab knows which bag goes with which site.

Total Alkalinity

Alkalinity is a measure of the capacity of water to neutralize acids. The total alkalinity analysis involves titration. In this test, titration is the addition of small, precise quantities of sulfuric acid (the reagent) to the sample until the sample reaches a colorimetric end point corresponding to a specific pH (known as an endpoint). The amount of acid used corresponds to the total alkalinity of the sample.

Sampling and Storage

Collect samples in clean plastic or glass bottles. Fill completely and cap tightly. Avoid excessive agitation or prolonged exposure to air. Samples should be analyzed as soon as possible after collection but can be stored at least 24 hours by cooling to 4 °C (39 °F) or below. Warm to room temperature before analyzing.

Equipment

For total alkalinity, use a portable test kit, such as a Hach model AL-DT using a Digital titrator. Digital titrators have counters that display numbers. A plunger is forced into a cartridge containing the reagent by turning a knob on the titrator. As the knob turns, the counter changes in proportion to the amount of reagent used. Alkalinity is then calculated based on the amount used. Digital titrators allow for much more precision and uniformity in the amount of titrant that is used.

Procedure

Follow the instructions for specific brand and model test kits you use. The following is a general procedure for the Hach test kit.

1. Collect the sample

2. Measure total Alkalinity:

   Select the sample volume and Sulfuric Acid (H_2SO_4) Titration cartridge corresponding to the expected alkalinity concentration as mg/L calcium carbonate ($CaCO_3$) from table in the kit instructions.

   1. Insert a clean delivery tube into the sulfuric acid titration cartridge and attach the cartridge to the titrator body.

   2. Hold the titrator, with the cartridge tip pointing up, over a sink. Turn the delivery knob to eject air and a few drops of titrant. Reset the counter to 0 and wipe the tip.

   3. Use a graduated cylinder to measure the sample volume from the table in the kit instructions. Transfer the sample into a clean 250-mL Erlenmeyer flask. Dilute to about the 100-mL mark with deionized water, if necessary.

   4. Add the contents of one Phenolphthalein Indicator Powder Pillow and swirl to mix.

   5. If the solution turns pink, titrate to a colorless end point. Place the delivery tube tip into the solution and swirl the flask while titrating with sulfuric acid. Record the number of digits required. Note: If the solution is colorless before

titrating with sulfuric acid, the Phenolphthalein (P) Alkalinity is zero; proceed with step 8.

6. Calculate: Digits Required x Digit Multiplier = mg/L $CaCO_3$ P Alkalinity
7. Add the contents of one Bromcresol Green-Methyl Red Indicator Powder Pillow to the flask and swirl to mix.
8. Continue the titration with sulfuric acid to a light greenish blue-gray (pH 5.1), a light violet-gray (pH 4.8), or a light pink (pH 4.5) color, as required by the sample composition; see kit instructions. Record the number of digits required.
9. Calculate: Total Digits Required x Digit Multiplier = mg/L as $CaCO_3$ Total Alkalinity.

Note: Carbonate, bicarbonate and hydroxide concentrations may be expressed individually using the relationships shown in kit instructions.
Note: Milligrams equivalent/L Alkalinity = mg/L as $CaCO_3$ ÷ 50.

Perform an Accuracy Check

This accuracy check should be performed when interferences are suspected or to verify analytical technique.

1. Snap the neck off an Alkalinity Standard Solution Voluette® Ampul, 0.500 N.
2. Use a TenSette® Pipet to add 0.1 mL of standard to the sample titrated in Steps 6 or 9.
3. Resume titration back to the same end point. Record the number of digits needed.
4. Repeat, using two more additions of 0.1 mL. Titrate to the end point after each addition.
5. Each 0.1 mL addition of standard should require 25 additional digits of 1.600 N titrant or 250 digits of 0.1600 N titrant. If these uniform increases do not occur, refer to kit instructions on the Accuracy Check and Standard Additions.

Interferences

Highly colored or turbid samples may mask the color change at the end point. Use a pH meter to identify the endpoints for these samples.

Chlorine may interfere with the indicators. Add one drop of 0.1 N Sodium Thiosulfate to eliminate this interference.

Chlorine Residual (Free Residual – DPD) Color Comparator Method

The amount of free chlorine present in a distribution system is important because these chlorine molecules provide additional protection against waterborne diseases, should contamination enter the distribution system.

DPD Method

The DPD method is the only acceptable procedure for measuring free chlorine residual in water distribution systems. N,N-diethyl-p-phenylenediamine (DPD) is added to a sample and, through a series of reactions, a chemical is produced that is red in color. The color intensity correlates to the residual chlorine concentration. The sample color is compared to colors on a color wheel to determine chlorine residual.

Storage of Samples

Chlorine in solution is very reactive and very unstable. Because of this it is impossible to preserve a sample for residual chlorine. Any sample taken for residual chlorine analysis must be tested immediately. According to EPA, this means the sample must be tested within fifteen minutes of collection.

There are also other concerns when sampling for residual chlorine. Exposure to sunlight and sample agitation reduces the chlorine to ineffective forms. Additionally, a dirty sample collection bottle, whether glass or plastic, can create a chlorine demand. All these interferences will give you lower residual chlorine values than what may actually be present in the field. All of these interferences can also be avoided with proper sample collection and handling.

Equipment

Hach Model #CN - 66 or comparable Wallace & Tiernan or LaMotte comparators

Reagents

DPD Free Chlorine Powder Pillow - Hach #14070-99

Special Instructions

Each brand of color comparator has its own peculiarities. This procedure will be for the HACH comparator. Special instructions will be added in the right hand column of each step for the other comparators.

Procedure - Free Chlorine Residual

1. Clean comparator glass cells

   Periodically wash the cells with hot soapy water and a soft test tube brush. Rinse thoroughly with distilled water. Let the cells drain dry.

2. Rinse glass cells with sample

   Do this each time the cells are used. The rinse will remove any remaining chemical and accumulated dust.

3. Fill left sample tube

   Place 5 mL of sample in the left-hand cell/tube. This is referred to as the blank. The purpose of this step is to compensate for any color or turbidity in the sample.
   Note: The Wallace & Tiernan comparator calls for 15 mL of sample. The LaMotte does not use a blank.

4. Fill right sample tube

   Place 5 mL of sample in the right-hand cell/tube. This is the portion of the sample to be tested.

5. Add reagents to tube

   Add contents of powder pillow to right-hand cell. DPD tablets may be substituted for the powder pillow.
   Note: Be sure the reagent pillow has DPD Free printed on it. Do not use DPD Total!

6. Insert rubber stoppers

These will prevent loss of sample during mixing.
Note: Rubber stoppers are a possible source of contamination. Gentle swirling should achieve adequate mixing, making the stoppers unnecessary.

7. Stir by swirling the test cell

   Do not place thumb or finger on the top of the test cell - this could contaminate the sample.

8. Wait 30 seconds

   Read color within one minute.

9. Adjust the comparator wheel

   Hold the comparator up to a light source and look through the viewing windows in the back of the comparator. Rotate the color wheel until the color in the test window matches the color in the blank window.

   With the LaMotte, move the test cell until it matches the color in one of the vials.

10. Read the residual

    Read the test results on the scale at the bottom of the comparator. The residual will be indicated mg/L.

11. Record the results

    The results should be recorded as mg/L of free chlorine residual.

12. Rinse the test cells

    Rinse each tube twice with distilled water, invert the tubes, and place in the comparator to dry. If there is no distilled water, rinse with sample water, invert, and allow the cells to dry.
    Note: DPD powder comes in small foil envelopes rather than plastic pillows. However, they are still referred to as pillows. These envelopes are impervious to sunlight, thus extending their shelf life over the pillows.

Chlorine Residual (Free Residual 0-2 mg/L - DPD) Spectrophotometer

The DPD method is the only acceptable procedure for measuring free chlorine residual in water distribution systems. N,N-diethyl-p-phenylenediamine (DPD) is added to a sample and, through a series of reactions, a chemical is produced that is red in color. The color intensity correlates to the residual chlorine concentration. In this test, a spectrophotometer is used to more accurately measure this intensity of the red color instead of a color wheel.

Equipment

HACH Pocket Colorimeter II Chlorine Test Kit(Cat. No. 5870000) Borosilicate glass sample container with screw-on top.

Reagents

DPD Free Chlorine Powder Pillow - HACH # 1407099.

Procedure

1. Fill a 10-mL cell with sample

2. Press the POWER key. The arrow should indicate the low range channel (LR). For residuals in the 0 to 2.00 mg/L range, the instrument should be in low (LO) range. This allows the result to be read in the hundredths. To change modes, consult owners manual.

3. Calibrate the meter:

   Remove the meter cap. Place the blank in the cell holder with the diamond mark facing the keypad. Fit the meter cap over the cell compartment to cover the cell. Note: Wipe excess liquid and finger prints off sample cells.

   Press ZERO/SCROLL. The display will show "- - - -" then "0.00". Remove the blank from the cell holder.

4. Fill a second 10-mL cell to the 10-mL line with sample.

5. Add DPD reagent:

   Add the contents of one DPD Free Chlorine Powder Pillow to the sample cell (the prepared sample).

6. Cap and shake:

   Firmly screw cap onto sample bottle and shake gently for 20 seconds.
   Note: Shaking dissipates bubbles that may form in samples with dissolved gases.
   Note: A pink color will develop if chlorine is present.

7. Place sample in instrument:

   Carefully wipe the outside of the sample bottle to remove any liquid, dirt, and/or fingerprints. Arrange the sample bottle so the white diamond is facing the operator. Within one minute after adding DPD reagent, place the mixed sample into the cell holder. Note: Accuracy is not affected by undissolved powder.

8. Place light shield:

   Place the instrument cap over the sample. The cap should fit snugly, with the smooth side of the cap facing the operator.

9. Read and record:

   Press READ/ENTER. The instrument will show "- - - -" followed by the results in mg/L chlorine. Note: If the sample temporarily turns yellow after reagent addition, or if the display shows over range, dilute a fresh sample and repeat the test. A slight loss of chlorine may occur because of the dilution. Multiply the result by the appropriate dilution factor.

Fluoride Residual - Low Range (0-2 mg/L)

Fluoride is fed into water distribution systems as a means of reducing dental cavities in children.

Method

The method described in this procedure is for the HACH Fluoride Pocket Colorimeter II with SPADNS 2 (Arsenic-free) Kit.

Storage of Samples

Since fluoride is very stable, samples for testing can be stored for seven (7) days provided that the sample is cooled to 4°C. The storage container should be polypropylene or borosilicate glass. Warm samples to room temperature before analysis.

Equipment

Fluoride Pocket Colorimeter II with SPADNS 2 (Arsenic-free) Kit (Cat. No. 2513100)

Polypropylene or borosilicate glass sample container with screw-on top.

Reagents

- Distilled water
- Accuvacs Non-Arsenic SPADNS Reagent ampuls or SPADNS 2 (Arsenic-free) Fluoride Reagent Solution, 1 L

Ampuls or Pipets?

Fluoride test may be conducted using accuvac© ampuls or pipets. This procedure is for SPADNS AccuVac® Method* USEPA Accepted.

Procedure

1. Press the POWER key

   The arrow should indicate channel 2.
   Note: See instructions for information on selecting the correct range channel.

2. Collect sample

   Collect at least 40 mL of sample in a 50-mL beaker. Fill another 50-mL beaker with at least 40 mL of deionized water. Note: The sample and water should be the same temperature (± 1 °C).

3. Fill the Ampuls

   Fill a SPADNS Fluoride AccuVac Ampul with sample. Fill another SPADNS Fluoride AccuVac Ampul with deionized water (the blank).
   Note: Keep the tip of the ampul immersed until the ampul fills completely.

4. Mix the Ampuls

   Quickly invert the ampuls several times to mix.
   Note: Wipe off any liquid or fingerprints.

5. Wait 1 minute

6. Read the Blank

   Place the blank in the cell holder and cover the blank with the instrument cap.

7. Press ZERO/SCROLL

   The display will show “- - - -” then 0.0. Remove the blank from the cell holder.

8. Read the Sample

   Place the prepared sample in the cell holder and cover the sample cell with the instrument cap.

9. Press READ/ENTER

   The display will show “- - - -”, followed by results in mg/L fluoride (F-). Note: If the instrument shows a flashing 2.2 (over range), dilute the sample with an equal volume of water and repeat the test. Multiply the result by 2. **Important:** The primary MCL for Fluoride is 4.0 and the secondary MCL is 2.0.

Accuracy Check - Standard Solutions Method
Use a 1.00 mg/L fluoride standard solution in place of the sample. Perform the procedure as described above.

Safety Concern
Older reagents used in previous Hach test kits contained sodium arsenite. Final solutions remaining after the test contained arsenic in sufficient concentration to be regulated as a hazardous waste for Federal RCRA. Operators should use the newer arsenic-free reagents.

pH
pH is a measure of hydrogen ion (H+) concentration and is generally used to describe a system as being acidic or basic. It is not to be confused with alkalinity or acidity, which are entirely different tests. pH measurements are taken at various points throughout a treatment plant, and any abnormal readings can be an indication of a change in water quality.

Sampling
You must measure the pH within 2 hours of the sample collection. This is because the pH will change due to the carbon dioxide from the air dissolving in the water, which will tend to lower the pH of the sample.

Equipment
pH Meters
A pH meter measures the electric potential (millivolts) across an electrode when immersed in water. This electric potential is a function of the hydrogen ion activity in the sample. Therefore, pH meters can display results in either millivolts (mV) or pH units.

A pH meter consists of a potentiometer, which measures electric current; a glass electrode, which senses the electric potential where it meets the water sample; a reference electrode, which provides a constant electric potential; and a temperature compensating device, which adjusts the readings according to the temperature of the sample (since pH varies with temperature). The reference and glass electrodes are frequently combined into a single probe called a combination electrode.

There is a wide variety of meters, but the most important part of the pH meter is the electrode. Buy a good, reliable electrode and follow the manufacturer's instructions for proper maintenance. Infrequently used or improperly maintained electrodes are subject to corrosion, which makes them highly inaccurate.

pH "Pocket Pals" and Color Comparators
pH "pocket pals" are electronic hand-held "pens" that are dipped in the water and provide a digital readout of the pH. They can be calibrated to one pH buffer (lab meters, on the other hand, can be calibrated to two or more buffer solutions and thus are more accurate over a wide range of pH measurements).

Color comparators involve adding a reagent to the sample that colors the sample water. The intensity of the color is proportional to the pH of the sample. This color is then matched against a standard color chart. The color chart equates particular colors to associated pH values. The pH can be determined by matching the colors from the chart to the color of the sample.

Procedure

The procedure for measuring pH is the same whether it is conducted in the field or lab. If you are using a "pocket pal" or color comparator, follow the manufacturer's instructions. Use the following steps to determine the pH of your sample if you are using a meter.

1. Rinse the electrode well with deionized water.
2. Place the pH meter or electrode into a 7.0 buffer solution. Read and record the pH and adjust the pH meter to read 7.0.
3. Rinse the electrode well with deionized water.
4. Read and record the pH of the sample. Rinse the electrode well with deionized water
5. Place the pH electrode into pH 7.0 buffer solution. The probe should be continuously soaked in the buffer which has the pH value closest to the suspected pH of the sample to be measured, typically 7.0 for most water treatment plants.

Note: Although the pH buffer or sample should be well mixed, excessive agitation can trap extra CO_2 and lower the pH of the solution being tested. Samples containing large amounts of dissolved CO_2 must be measured quickly since the CO_2 can escape into the atmosphere.

Turbidity - (Nephelometric Method)

Description

Turbidity is an expression of the optical properties of water which cause light to be scattered and absorbed rather than be transmitted in a straight path. The measurement of light scattered at a 90 degree angle is performed with a nephelometer. As the turbidity increases, the amount of light scattered will increase.

Sources of Turbidity

This turbidity is usually caused by finely divided suspended matter such as clay, silt, plankton and other organic and inorganic material.

Relationship to TSS

Attempts to correlate turbidity to suspended solids is impractical due to the fact that turbidity is related to particle size, shape and refractive index, as well as quantity.

Application

The procedure outlined below is general and can be applied to several brands of nephelometers. Be sure to read carefully the manufacturer's operation manual for your particular instrument.

Equipment

Several nephelometers and turbidimeters have been approved by the USEPA. Manufacturers include Hach, HF Instruments and Turner Designs.

Reagents

Due to the precision necessary for this instrument, it is recommended that standards be purchased rather than prepared. One standard must be on hand for each range used. These purchased standards are called Primary Standards.

Standards purchased after 1992 are very stable and will need to be replaced only when the glass shows any visual sign of scratching. Under normal use these standards should be replaced once a year.

Procedure

1. Calibrate the instrument

   Be sure to check the manufacturer's instruction for warm-up time and calibration. A separate standard must be used to calibrate each scale used.

2. Collect sample

   Collect a representative sample in a clean container. Samples may be stored up to 24 hours in the dark. The sample should be thoroughly mixed by shaking 15 times through a one-foot arc. The air bubbles should be allowed to dissipate before testing. Fill a sample cell to the line (about 15 mL), taking care to handle the sample cell by the top. Cap the cell.

3. Prepare the sample cell

   Wipe the cell with a soft, lint-free cloth to remove water spots and fingerprints. Apply a thin film of silicone oil. Wipe with a soft cloth to obtain an even film over the entire surface.

4. Press: I/O

   The instrument will turn on. Place portable instruments on a flat, sturdy surface. Do not hold the instrument while making measurements.
   Insert sample cell

5. Insert the sample cell in the instrument cell compartment so the diamond or orientation mark aligns with the raised orientation mark in front of the cell compartment. Close the lid.

6. Select range to be measured

   Select manual or automatic range selection by pressing the RANGE key. The display will show AUTO RNG when the instrument is in automatic range selection.

7. Signal averaging

   Select signal averaging mode by pressing the SIGNAL AVERAGE key. The display will show SIG AVG when the instrument is using signal averaging. Use signal average mode if the sample causes a noisy signal (display changes constantly)

8. Press: READ

   The display will show - - - - NTU, then the turbidity in NTU. Record the turbidity after the lamp symbol turns off. NTU = Nephelometric Turbidity Units

9. Discard sample and clean sample cell

Cold Water Problems

When the water is cold the heat from the turbidimeter may cause condensation to develop on the outside of the glass or gas bubbles to form on the inside of the glass. Either condition will give a false, high turbidity reading. It may be necessary to either read the results quickly or allow the sample to warm slightly before proceeding.

Bacteriological Sampling

Description

Sampling of water distribution systems for bacterial contamination is an essential procedure for determination of water safety. It is, therefore, essential that the proper techniques be used to eliminate the possibility of contamination of the sample while it is being collected. In addition, a chlorine residual test must be performed at the same time as collecting a bacterial sample in order to comply with the Disinfectant/Disinfection Byproduct Rule.

Equipment

On-Site Testing: When collecting samples for on-site testing, use sterilized borosilicate glass and wide-mouth bottles with ground glass stoppers arid with a minimum capacity of 120 mL.

When to Sample

It is best to sample at the first of the month. This allows a chance for a second sample, should the first one be lost or damaged in shipping.

Mailing

When mailing samples the following sterilized containers are acceptable:

- Heat-resistant polypropylene bottle with plastic screw-on top with 120 mL capacity.
- Borosilicate glass bottle with plastic screw-on top with 120 mL capacity.
- Polypropylene plastic “whirl pack” with 125 mL capacity.

A bacteriological sample that is mailed must get to the laboratory within 30 hours after collection or the laboratory will not test the sample.

Insulation

Samples mailed or shipped by plane must be insulated and protected from damage and freezing.

Special Instructions

Elimination of Chlorine Residual

Sample bottles and “whirl packs” prepared in commercial laboratories will have sodium thiosulfate in the bottle to eliminate chlorine in the sample. The sodium thiosulfate will appear as a white powder, crystal or clear liquid. This material should not be rinsed from the container.

Do Not Reuse Containers

If, for some reason, the sample could not be shipped, dump the sample but do not reuse the bottle.

Procedure

1. Select a sample site

   Sample sites should be representative of the system. There are two types of sample locations:
   - Those that are identified on the official sample plan.
   - O & M sampling points, which include raw water, reservoirs, dead ends, low points in the system and new lines.

2. Select sample point

   Routine sample points should have been identified as part of the development of the official sampling plan. The best sample points are faucets approximately 30 inches above the ground or from inside faucets that have none of the characteristics listed below. Sample points to be avoided are:
   - Drinking fountains
   - Lawn faucets
   - Hoses
   - Kitchen faucets
   - Leaky faucets
   - Aerators
   - If a faucet with an aerator must be used, the aerator should be removed.

3. Sanitize faucet

   Wipe the outside of the faucet with a mild chlorine solution.

4. Allow water to run 5 minutes

   Or wait for a sufficient time to allow water from the distribution system to enter the sampling point.

5. Adjust the flow so that there will be no splashing

   Splashing could cause some of the sodium thiosulfate to be displaced and could cause contamination to drip into the container.

6. Open container

   Remove the lid or open the whirl pack. Keep the lid or stopper pointed down. Do not touch the inside of the container. Do no blow into the pack while open.

7. Fill the container

   One inch of head space (air) should be left in sample bottles and 2 inches in the whirl pack. This improves mixing of the sample at the laboratory. A minimum of 100 mL is necessary for each sample. Since the container holds 120 mL, leaving an air space will still provide sufficient actual sample volume.

8. Seal container

   Replace lid on bottle, pull wires of Whirl bag to flatten the top of the bag and whirl the bag over three times. Fold the wires over the bag.

9. Turn water "Off"

10. Pack for shipping

    The container should be insulated to maintain the temperature of the sample. If shipping is delayed, refrigerate the sample. If the sample cannot be shipped on the same day it was collected, then discard and resample.

11. Collect a Chlorine Residual Sample

    Collect a sample and test for free chlorine residual. Record the results.

Record Sample Data

Standard Sampling

The containers used by commercial and state laboratories are supplied with a standard sample data form. Completely fill out all portions of the form.

Essential Data

When a form is not available, as in an O & M sample, record the following information:

- Public water system number
- Sources of water, ground, surface and name of stream or lake, if surface
- Time collected
- Date sample collected
- Sample location
- Name of person collecting sample
- Was the water chlorinated?
- If the sample is mailed, time and date of mailing. If shipped by plane, date and flight number.

Copy of Data

When shipping a sample to a state or commercial laboratory, keep and file a copy of the data form that was sent with the sample.

Repeat Sample

When a positive coliform bacteriological sample is received, Repeat Samples must be collected and tested in order to determine if contamination is actually present.

Procedure

Four (4) Repeat Samples must be collected. These Repeat Samples must be collected within 24 hours of the time the notification of the positive sample was received by the utility.

Where to Sample

1. One sample must be collected from the same tap used for the positive sample.
2. One sample within five (5) customer connections upstream of the original sample location.
3. One sample within five (5) customers connections downstream of the original sample location.
4. One sample from any other location.

Same Day Collection

All Repeat Samples must be collected on the same day.

When There is Only One Sample Point

If only one sampling point exists in the system then you may:

- Collect one Repeat Sample a day for four (4) consecutive days or,
- Collect one 400 mL sample on one day from the tap.

Following Month
During the month following a positive coliform sample five (5) routine samples must be collected from the system.

Removal From The Record
There are three ways of invalidating a coliform positive sample from a routine sample.

- A coliform positive sample may be removed from the utility records (invalidated) if all repeat samples taken from the original coliform positive tap are coliform positive and all repeat samples taken from the original tap are negative. This indicates a domestic plumbing problem.
- ADEC may invalidate a sample if the laboratory establishes that lab error caused the positive result.
- The department may also invalidate a positive result if the department's representative determines that the positive result was from a situation not representative of the water quality in the distribution system. You must work closely with the local ADEC Drinking Water Program representative in these situations.

Evaluating Coliform Testing Results
Violation
The water system is in violation of the drinking water regulations if any one of the following occurs:

- If the system fails to submit the required number of samples during any one month or if required repeat samples are not collected.
- A violation exists if the system receives more than one total coliform positive sample.

Acute Health Risk: Fecal Coliform
A test that indicates the presence of fecal contamination from warm-blooded animals including humans is the test for specific coliform bacteria called a fecal coliform or E. coli.

If a routine or repeat sample is total coliform positive, the laboratory will analyze the total coliform positive culture medium to determine if fecal coliform or E. coli are present.

When a system receives more than one positive coliform sample and the confirmation test for E. coli is also positive, the system is said to have an acute risk to human health.

Public Notification
General: For all violations and situations, immediately consult with ADEC when you learn of the violation or situation. However, you must issue a public notification within the required time frame even if you are unable to contact the primacy agency.

Non-Acute Violation
When a system has an MCL violation of a total coliform rule the public must be notified. This notification must take place within 30 days of the notification from the laboratory that a sample tested positive. This would occur if both the routine sample and repeat samples were positive to total coliform.

Acute Violation

When an acute violation is received public notification must take place within 24 hours of the receipt of the notification from the laboratory that a violation has occurred. This would occur if a water system had any:

- fecal coliform or E. coli positive REPEAT sample or
- has a fecal coliform or E. coli positive ROUTINE sample followed by a total coliform positive REPEAT sample, or
- failure to test for fecal coliform or E. coli when any repeat sample tests positive for coliform.

Quality Assurance/Quality Control

Quality assurance and quality control is often referred to as QA/QC. This term refers to a program that includes methods and procedures used in the lab to guarantee the validity of the numbers reported on monitoring reports. A QA/QC program is a required component of laboratory operation and may be part of the general procedure of the laboratory. These QA/QC programs outline specific procedures and activities required to meet federal quality control requirements and also to meet some states' laboratory accreditation processes.

Examples

Some examples of quality assurance/quality control tests include:

- Checking or calibrating lab thermometers to NIST15 standard thermometers
- Running duplicates of tests to determine if results are repeatable
- Checking or calibrating turbidimeters to NIST standards

Value of QA/QC

QA/QC tests are not only required, they are a good way to check and assure the validity of test results. Lab tests take a tremendous amount of time and energy to perform. Lab results are a basis for future construction and planning. Test results need an assurance and some controls to determine their accuracy.

Recordkeeping

Required monitoring

There are many levels of recordkeeping and criteria for both preparing and storing records. The following are a few basic considerations that can apply to all recordkeeping systems.

- Keep all records in blue ink.
- Records should never be altered by erasing or white-out, but incorrect numbers should be crossed out and initialed by the operator.
- Initials or signatures should accompany all recorded readings. A listing of all initials or signatures should be on file on the premises.
- Record Retention: All records should be kept for a specific period time. The time required for record retention depends on the type of constituent. For example, bacteriological tests must be kept for 5 years. Lead and Copper tests must be kept for 10 years.

Process Control Records

While these records are not influenced by the regulations as much as the water quality records, all records should be neatly prepared, signed, and kept on site for a reasonable length of time.

Conclusion

Relationship to Sample

The overall bottom line of laboratory testing is that the test and its results are no better than the sample, or the actual portion of water that is tested. It is critical that the sample be taken and the tests run on a sample that represents the proper overall objective.

Sample Types

If a “snapshot” of what is happening at a specific moment is desired, a grab sample should be collected and the appropriate test performed. Composite sample should only be taken if required by ADEC.

Testing Your Drinking Water Quiz

1. When using a pipette to measure liquids, a vacuum is supplied by __________.
   A. Sucking on the top of the pipette by mouth.
   B. Using a rubber bulb.
   C. Using a vacuum pump.
   D. Using a centrifugal pump

2. When reading the volume of fluid in a glass measuring device such as a graduated cylinder or pipette, the liquid will stick to the walls of the container. The surface of the fluid will be concave (meniscus). To obtain an accurate volume reading, read the level at the ______ of the meniscus.
   A. Top
   B. Middle
   C. Bottom

3. MSDS stands for ___________.
   A. Minimum sample Deviation Sheets
   B. Medicinal Safety Data System
   C. Maximum Sound Deferment Supplement
   D. Material Safety Data Sheet

4. When diluting acid with water, always add the _____ to the _____.
   A. Acid, water
   B. Water, acid

5. What are the "Three Cardinal Rules" for sampling?
   A. Speed accuracy, and cleanliness
   B. Documentation, sample size, and speed
   C. Cleanliness, documentation, and preservation
   D. Location, accuracy, and preservation

6. A paper trail that documents each person that handles a sample from sampling to disposal is called a __________.
   A. MSDS
   B. Chain of custody
   C. DMR
   D. Sampling log

7. A _____ sample is one that is taken at one particular time at one location and only represents the water quality at the time of sample collection.
   A. Composite
   B. Initial
   C. Grab
   D. Final

8. A _____ sample is a combination of individual samples combined to make one sample and represents water quality over a period of time.
   A. Composite
   B. Initial
   C. Grab
   D. Final

9. ______ is a measure of the capacity of water to neutralize acids.
   A. Concentration
   B. Alkalinity
   C. pH
   D. Conductivity

10. Total alkalinity samples should be analyzed as soon as possible after collection but can be stored for up to 24 hours by cooling to ____ or below.
    A. 0° C (32° F)
    B. 37° C (99° F)
    C. 4° C (39° F)
    D. -10° C (14° F)

11. A free chlorine residual sample must be analyzed ______.
    A. Immediately
    B. Within 24 hours
    C. Within 48 hours
    D. Within 7 days

12. The DPD method is used to determine the __________ of a water sample.
    A. Dissolved oxygen content
    B. Conductivity
    C. pH
    D. Free chlorine residual

13. What color does N,N-diethyl-p-phenylenediamine (DPD) turn in the presence of chlorine?
    A. Orange
    B. Green
    C. Blue
    D. Red

14. Why is fluoride added to drinking water?
    A. For disinfection
    B. To prevent tooth decay
    C. To prevent scaling of distribution system piping
    D. To enhance the taste of drinking water

15. A fluoride residual sample can be stored for ______ days if cooled to 4°C.
    A. 14
    B. 10
    C. 8
    D. 7

16. _____ is a measure of the hydrogen ion (H+) concentration of a solution.
    A. Conductivity
    B. Alkalinity
    C. pH
    D. Turbidity

17. pH samples must be analyzed within _____ hours of collection.
    A. 2
    B. 4
    C. 6
    D. 8

18. Prior to analyzing a sample for pH, the pH probe is calibrated using a ____ buffer solution.
    A. 1.0
    B. 5.0
    C. 7.0
    D. 10.0

19. _____ is an expression of the optical properties of water which causes light to be scattered and absorbed rather than transmitted in a straight path.
    A. pH
    B. Residual
    C. Conductivity
    D. Turbidity

20. What is the minimum sample size for a bacteriological sample?
    A. One liter
    B. 500 mL
    C. 100 mL
    D. 50 mL

21. A bacteriological sample that is being mailed must get to the laboratory within ___ hours after collection; otherwise, it is an invalid sample.
    A. 10
    B. 15
    C. 20
    D. 30

22. The white powder in a bacteriological sample bottle is _________ and will eliminate any chlorine in the sample.
    A. Sodium thiosulfate
    B. Potassium Permanganate
    C. Sodium Chloride
    D. Calcium Hypochlorirte

23. Which of the following is a good sampling point for a bacteriological sample?
A. Drinking fountain
    B. Garden hose
    C. Sampling station
    D. Faucet with aerator attached

24. If a positive bacteriological sample is received, ______ repeat samples must be collected immediately.
    A. Eight
    B. Four
    C. Two
    D. One

25. Repeat samples for a positive bacteriological sample must be collected at the following sample locations:
    A. At the inlet to water treatment plant, the outlet of the water treatment plant, the inlet to the water distribution system, and the positive sample location.
    B. At the positive sample location, within five service connections upstream of the positive sample location, within five service connections downstream of the positive sample location, and one at any other location within the dis tribution system.
    C. Two samples at the positive sample location and two samples at the inlet to the water distribution system.
    D. At the water source, the outlet of the water treatment plant, the inlet to the water distribution system, and the furthest sample point in the water distribution system.

26. When there is a positive bacteriological sample on a system containing only one sampling point, the sampling requirement is _____.
    A. Collect one repeat sample a day for five consecutive days or collect one 500 mL sample on one day.
    B. Collect one repeat sample a day for three consecutive days or collect one 300 mL sample on one day.
    C. Collect one repeat sample a day for seven consecutive days or collect one 700 mL sample on one day.
    D. Collect one repeat sample a day for four consecutive days or collect one 400 mL sample on one day.

27. During the month following a positive bacteriological sample, a minimum of _____ routine samples must be collected from the system.
    A. One
    B. Five
    C. Ten
    D. Twenty

28. When an acute MCL violation of the Total Coliform Rule occurs, public notification must occur within _____ hours of receipt of the notification from the laboratory that a violation has occurred.
    A. 24
    B. 36
    C. 48
    D. 72

Management Considerations

Chapter 11

What's In This Chapter?

1. The basic responsibilities of management, operations, and customers
2. The purpose and components of Preventive Maintenance (PM)
3. The components of an Emergency Response Plan (ERP)
4. The purpose of Action Plans
5. The purpose of a good public relations program
6. The reason for maintaining daily records at a water system

Water Systems Organization

Parts of a Water System

A water system is composed of more than the physical facilities. Other major parts of the system include the customers, the federal and state regulatory agencies, the governing body, the utility manager, and system operators. Each group has a unique and important role in providing safe water.

Roles and Responsibilities

Customers

The customer is the end-user of the product and responsible for paying for the service provided and using the water in a wise manner.

Federal and State Agencies

Federal and state agencies are responsible for establishing regulations to assure that water provided by public water systems is safe to drink. In addition, these agencies provide information and technical assistance for water systems in meeting regulations.

Governing Body

The governing body may be a city or borough council or a traditional village council. The council sets policy and rates and is responsible for overseeing the entire water utility.

The governing body, as a group and sometimes as individuals, is responsible and liable for the following:

- Quality of the service
- Fair treatment of customers, employees, and vendors, including contractors
- Safety of employees
- Financial solvency and physical well being of the water utility

Utility Manager

The Utility Manager is responsible for the day-to-day operation, preventive maintenance, and emergency repairs. In small communities, the City Manager, Mayor, or City Administrator may fill the Utility Manager role.

Operator

Operators maintain and operate the water system. They are directly accountable to the Utility Manager. Because this course is focused primarily on operation and maintenance of small water systems, additional information on the responsibilities of management and the operators are provided below.

Management

Who Is Management?

The identification of who or of what level of the organization should be considered management is a local decision and will not be addressed. However, regardless of who is defined as management, there are several management functions that must be performed in a properly operated water system. It makes no difference who performs these duties, as long as they are done.

Management Tasks

Management is responsible for the following:

1. Establishing and maintaining ordinances pertaining to the management, operation, and financial policies and procedures of the utility.
2. Establishing and printing rules for customers.
3. Setting proper, equitable rates for the use of water.
4. Developing plans so that future needs can be met.
5. Establishing long-term (5 to 10-year) budgeting requirements.
6. Integrity of the financial situation, including budgeting, collecting utility bills, and paying encumbered bills.
7. Establishing and properly supporting a worker safety program.
8. Seeing that operators are properly trained.
9. Establishing proper recordkeeping systems for water quality data, billing, budgets, and operation data.
10. Communicating the needs and conditions of the system to state agencies, customers, and operators.
11. Developing and implementing a public relations/customer service program.

Operation and Maintenance

The operator of the water system is a major link in the protection of the health of the community or village. This is one of the most important responsibilities in the community. Without a properly trained operator, a valuable water system can be damaged beyond repair in just a few days of cold weather. In addition, public health can be compromised and can lead to sickness or death of water customers.

Operator Tasks

A good operator must perform the functions of mechanic, microbiologist, chemist, construction worker, janitor, public relations expert, data management expert, and a host of others. A good operator must:

- Be properly trained.
- Assist the manager in establishing an operating budget.
- Inspect equipment.
- Keep proper repair parts on hand.
- Collect adequate samples.
- Perform routine testing.
- Repair broken equipment.
- Prevent equipment breakdowns by performing preventive maintenance.
- Keep water temperature correct.
- Add proper chemicals in proper amounts.
- Prevent contamination of water sources.
- Prevent deterioration of the water system.
- Keep management aware of system problems.
- Communicate with the state, customers, and management.
- Keep quality records.
- Maintain an easy-to-retrieve record history.
- Be reliable.

Review

For each of the following, provide one major responsibility in association with water systems:

A. Customers

B. Governing body

C. State agency

D. Manager

E. Operator

Programs and Plans

To properly and successfully operate and manage a water utility, there are several programs and plans that must be developed and implemented. The following is a brief introduction to a few of these key programs.

Safety

Programs

One of the major responsibilities of management is to develop, implement, and support a worker safety program. A more in-depth discussion of some of the key elements of a safety program is discussed in the safety lesson. A properly designed program includes a written policy and written programs and procedures for at least the following areas:

- Injury and illness prevention
- General safety and first aid
- Traffic control
- Confined space entry
- Lockout/tagout system
- Shoring protection and the associated competent person program
- Fall protection
- Hazardous material handling
- Hazardous material communication
- Hearing protection
- Fire prevention
- Safety committee
- Heavy equipment operation

Training and Equipment

In nearly every case, each safety program component has a training requirement, as well as specific requirements for the selection and use of safety equipment. Current federal and state safety regulations call for the employer to supply all required safety equipment.

Training

Training costs money. Why then do successful organizations require and support personnel training? These organizations have found that training is necessary for the following reasons:

- Training provides personnel with the proper information to allow them to properly operate and maintain the system.
- Proper training can in many cases reduce operating cost.
- Training can be a motivator for all personnel.
- Some training is required to meet certification and safety requirements.
- Providing this training reduces the organization's liability exposure, improves operations, and reduces accidents.
- In critical environments such as the Arctic, properly trained personnel can prevent costly system failures.

Certification and Training

Besides the training requirements associated with the safety program, each organization has the responsibility to see that the operators and office staff are properly trained and, where appropriate, certified. Although operator certification is required for most community water systems, it is also an excellent way to motivate employees and at the same time reduce liability exposure. In addition, most states require training to maintain operator certification. Continuing Education Units (CEUs) are the national standard for measuring training. One CEU is equal to 10 contact hours of training.

Advanced Training

Research indicates that the best results are received from people who are trained at least one level above their work requirements. Therefore, it is the responsibility of management to see that each worker is involved in a regular training program. If the budget allows, at least two training and/or conference sessions per year are recommended. Both AWWA and WEF have suggested that the personnel training budget be equal to at least five percent of the amount paid for salary.

Maintenance Management

Components

A good way for the operator to plan and perform all of the required tasks is to develop a planned maintenance management system. This system includes a preventive maintenance (PM) system, data collection process, work order system, inventory control system, and monthly reports to management. This process is useful in justifying budget requests and managing personnel requirements.

Key Element

The key element of a maintenance management system is the use of a routine schedule of sampling, testing, reporting, and equipment PM. The schedule could be a calendar, index cards, or computer-generated listing of equipment maintenance requirements.

Review

1. Identify three of the safety programs that must be developed by management.

2. Why should operators be trained?

3. What is the primary function of a preventive maintenance system?

4. The key element of a maintenance management system is the schedule. What are the four items that should be on this schedule?

5. Which "program" is the most useful in justifying the operations and maintenance budget?

Emergency Response Plans (ERP)

What is an Emergency Response Plan?

An ERP is a written, well-thought-out series of planned actions that help you respond to emergencies of all types. An ERP presents clear and logical steps to take in response to possible emergencies, designates persons responsible for specific actions, provides for training and planned practice exercises, and ensures effective coordination with first responders, law enforcement, and health officials.

If your water system does not have an ERP, you should prepare one. An ERP will help you organize your response to emergencies before they happen. An emergency can happen at any time, and any problem with the drinking water supply will become a top priority for you and the affected members of your community. An emergency could generate tremendous and immediate pressures on system operators, emergency response professionals, law enforcement, local health officials, and the public. A system that has an ERP and has practiced organized emergency response exercises will have a much better chance of minimizing the effects of emergencies. Therefore, having a well-planned system response to foreseeable emergencies makes good sense.

Preparing an ERP

Preparing an ERP can take some effort. You should build an internal team of water system operators, board members, and community leaders to develop a complete ERP. The steps below can help you prepare a new ERP (or update your existing ERP). Remember that your state can be a good source of assistance should you have questions or need help in developing your ERP. In Alaska, contact the ADEC for more information. Finally, because every system is different, you may need to modify the ERP development process described below to make it work for you.

It is important to note that some states may have their own ERP requirements. Make sure you check with your state to see whether it has established specific requirements that you must address.

In developing an ERP, you should identify and form partnerships with the people and organizations whose help your system will need in an emergency:

- Local police and fire departments
- Public health officials
- Local emergency planning committees (LEPC)
- Local government/city managers
- State and federal agencies
- Nearby water utilities (for developing interconnections and mutual aid agreements)
- Health care providers
- Equipment suppliers
- News media

Core Elements

A number of core elements should be included in any ERP, including yours. These elements will help ensure that your ERP and emergency response capabilities enable you to respond to any kind of emergency or threat. At the same time, the elements are flexible enough to ensure that your ERP meets the specific needs of your system.

1. System-Specific Information

In an emergency, you should be able to provide basic technical information to personnel who will provide emergency assistance. In most cases, the organizations providing assistance will be those with which you formed partnerships while developing your ERP. To ensure that you can provide the necessary system-specific information quickly and accurately, it is important that you include it as an easily accessible part of your ERP. The basic information that you should have in this section of your ERP includes the following:

- Owner name, operator name(s), and Public Water System Identification (PWSID) number, which identifies your system to your state and to EPA
- Key information about critical system components (for example, source water, treatment plant, water and chemical storage, and distribution system)
- Population served and number of service connections in the distribution system
- How to isolate parts of your system when the need arises

2. Roles and Responsibilities

You should specify roles and responsibilities for yourself and for your partners from outside of your system. First, you should designate an Emergency Response Leader (and a back-up), who will be the main point of contact and the primary decision-maker during an emergency. Other system personnel and your partners should also understand their roles, responsibilities, and place in the chain of command. While it is important not to get bogged down in terminology and titles, it is also important that you and your Emergency Response Leader make sure all parties are clear about their roles.

Everyone should be familiar with what is known as “command structure language.” The Federal Emergency Management Agency (FEMA) and other federal agencies use the National Incident Management System (NIMS) to coordinate emergency efforts. Your state and local government may have also adopted the NIMS. The NIMS Incident Command System (ICS) is the standard organizational structure for all major domestic incidents. It helps to coordinate the efforts of many emergency responders. The NIMS will enable responders at all levels to work together more effectively to manage domestic incidents no matter what the cause, size, or complexity. You can obtain more information on the NIMS and the NIMS ICS from FEMA at http://www.fema.gov/nims.

At a minimum, your ERP should include the following basic information for your Emergency Response Leader and one back-up point of contact:

- Name
- Home telephone number
- Work telephone number
- Pager number (if applicable)
- Cell phone number (if applicable)
- Address

Remember to communicate this information to your partners verbally and in writing.

You should also identify other key individuals and partners and describe their roles, responsibilities, and places in the chain of command. This too must be communicated to your partners verbally and in writing.

3. Communication Procedures – Who, What, and When

Timely communication with a variety of audiences is an essential component of your ERP. You should plan to notify three groups of people:

- **System personnel** – Your Emergency Response Leader or backup should be the first person notified in an emergency. Other appropriate personnel should then be contacted.
- **Emergency partners** – These are the partners you identified in ERP Step 1. They should be contacted as necessary, depending on the type of emergency.
- **Public and news media** – You should designate in advance a spokesperson who will handle public and media communications during an emergency. This spokesperson should not be the Emergency Response Leader. You should also develop a plan that your spokesperson can follow in communicating with the media and the public. This plan will help your spokesperson maintain a message that is clear, accurate, and easily understood by your audience.

Your ERP should include contact information for all individuals and organizations that fall into the groups discussed above. The list should include contact names, addresses, and all phone numbers for each contact. Update this list regularly to ensure that information is current, and organize it to ensure that the highest priority calls are made first. States and technical assistance providers may have sample contact list templates you can use.

4. Personnel Safety

Protecting the health and safety of your personnel is an important part of your ERP. In your ERP, you should write out basic safety precautions, identify the location of first aid supplies, and identify locations where personnel should meet in the event of an emergency. You should also make sure that your personnel are regularly trained in all of your safety procedures. The personnel safety section of your ERP should, at a minimum, include the following:

- Directions for proper first aid and medical treatment
- Procedures for using and maintaining emergency response equipment
- Identification of evacuation routes and evacuation procedures
- Identification of assembly areas and procedures for locating all personnel

5. Identification of Alternate Sources of Water

Your ERP should identify alternate sources of water that can address short-term (hours to days) and long-term (weeks to months) outages. There are a number of different options for short-term and long-term water supplies. Short-term options include bottled water from outside sources or retailers and bulk water from a variety of sources. Long-term options may include connecting your distribution system to a neighboring system. These alternate sources should be clearly identified in your ERP, and the agreements or arrangements for accessing the alternate sources should be clearly spelled out. Your source list and the agreements with these sources should be kept up to date.

You should also plan for the impact of various public health notifications, including "boil water," "do not drink," and "do not use" notices. The different steps you may need to take to deal with each of these notifications should be addressed clearly in your ERP.

The important thing to remember is to identify short-term and long-term alternate water sources in your ERP and to establish agreements with these partners before an emergency occurs. Your ERP should list your alternate water sources, along with the relevant contact information. You should also file copies of your agreements with your ERP.

6. Equipment and Chemical Supplies

You should identify in your ERP where to find the equipment, repair parts, and chemicals needed in the event of an emergency. This section of your ERP should include an updated list of the following:

- Current equipment
- Repair parts
- Chemical supplies
- Agreements with nearby systems to share portable generators and spare parts
- Contact information for any partners who can assist you with equipment and chemical supplies

7. Property Protection

Protecting your facilities, equipment, and records is very important for getting your system running again after an emergency. Your ERP should clearly describe procedures to secure and protect important assets. In this section of your ERP, you should consider describing how you will lock down your facilities, how you will control access to the facilities, and the steps you will take to protect other crucial property and records.

8. Water Sampling

Sampling is critical to determining whether the water your system produces is safe for your customers to drink and use. In your ERP, you should address water sampling and monitoring issues that could arise during an emergency. Water sampling and analysis is critical during the detection of an incident and during recovery from an incident. When developing your ERP, you should consult with your state on water sampling and monitoring requirements, including responsibility for water quality monitoring during an emergency. Make sure you know what to do in an emergency before an emergency occurs.

Remember, the answers to these questions will most likely differ with each incident and will probably determine which parts of your ERP need to be implemented. You or your Emergency Response Leader should exercise judgment when determining how to respond to a specific threat.

Action Plans – Responding to Different Types of Emergencies

An Action Plan provides your system with quick approaches for responding to specific types of emergencies. The Action Plans that you develop should complement the general activities outlined in the core elements of your ERP and should be tailored to specific events, such as floods and tornadoes. Action Plans should be short and concise "rip and run" documents that can be detached from your ERP and taken into the field by emergency responders. The activities listed in the Action Plans should complement actions already initiated under your ERP. You should develop Action Plans for intentional acts and for natural disasters and other significant events.

Intentional Acts

Action Plans should cover the following incidents and threats of such incidents (for example, hoaxes):

- Contamination
- Intentional hazardous chemical release
- Structural damage/physical attack
- SCADA, computer, or cyber attack

Natural Disasters and Other Significant Events

You may want to incorporate or modify existing plans to deal with a variety of natural disasters and other significant events. If you do not have existing plans, it makes sense to develop new plans to cover such events that may affect your system:

- Fire
- Flood
- Wind storms
- Severe weather (snow, ice, temperature, lightning, or drought)
- Earthquake and volcanic activity
- Electrical power outage
- Mechanical failure
- Water supply interruption
- Contaminated water
- Personnel problems (loss of operator, construction accidents, or medical emergencies)
- Accidental hazardous spill/release

Remember, your Action Plans should be clear, concise, and accessible. They should be well organized to make sure that the proper Action Plan can be found quickly by the staff members who need it.

Your Action Plans should include the following basic information:

- Special notification requirements
- Special response steps necessary for the specific type of emergency
- Recovery actions to bring your system back into operation
- Remediation actions needed to make sure your system is fully restored

Follow-up Actions

Completing your written ERP is only the first step in making sure that your system is prepared to deal with an emergency. Your ERP should be a "living" document that you review and update regularly to ensure that all of your information is correct and up to date. Training in how to use your ERP is just as important as developing and updating it. Even the best ERP will be difficult to implement during an emergency if people do not know their responsibilities. You should regularly practice implementing your ERP. Orientation exercises, table-top workshops, functional exercises, and full-scale drills are all ways in which you can help to make sure that your well-planned ERP is executed properly and efficiently when a real emergency arises.

Review

1. What are the major components of an emergency response plan?

2. Who should be involved in developing an ERP for your water system?

3. What type of events/emergencies should a water system plan for?

4. What should be in an Action Plan?

5. How often should an ERP be updated?

Public Relations

Definition

Public relations is a process of providing information, of listening to and responding to the needs of the customer. There are many ways of implementing a public relations program.

Why a PR Program?

An effective public relations, customer relations program provides two advantages to the utility. First, it is the best method of determining customer expectations and level of satisfaction with the service being provided. Second, it is a viable method of developing customer support. This support is needed when the customer goes to pay their monthly bill and when the utility seeks revenue planning help for capital improvement projects.

Elements

The following is a brief listing of a few common public relations activities:

- Responding quickly to emergencies and complaints
- Providing information on service connection requirements, billing frequency, billing rates, payment requirements, and actions by the customer that can impact operating cost
- Holding an annual "coffee" information exchange or an open house at the water facilities
- Tracking and analysis of customer complaints
- Operating and maintaining the facilities in such a way as to prevent higher-than-normal operating costs
- Providing tours of the water facilities to school children and teachers

Recordkeeping Systems

Why Keep Records?

Records, or information, are maintained in a water facility for several reasons. Here is a listing of some of the more important ones:

- Helps to reduce operation and maintenance cost.
- Allows the analysis of operation and maintenance cost.
- Allows the evaluation of mechanical equipment in order to reduce maintenance cost.
- Provides information for budgeting.
- Allows engineers to evaluate the need for expansion.
- Reduces the community's, the manager's and the operator's liability exposure.
- Improves process control decisions.
- Helps to maintain a high-quality product.
- Helps to identify problems before they become a crisis.
- Meets requirements of financing agencies for giving grants or loans.

Which Records Need To Be Maintained?

Information is of no value if it cannot be retrieved. It is important that key records be maintained in a manner that allows for easy access and retrieval. This can be in a computer database or a simple index card system. The following are a few of the key information management systems needed in a water system.

Nameplate

All of the data on the nameplate of each piece of equipment should be recorded. This makes the development of a critical spare parts list much easier, as well as making it easier to order parts.

Inventory Control

A simple inventory control system that lists the critical spare parts, their numbers, when they were received, and when they were last used can be critical in resolving emergencies.

Plant Operations

The treatment process of a plant will change during the year due to changes in weather and demand. By maintaining a history and comparing the history to present conditions, the operator can often make changes in anticipation of changes in raw water quality This, if done correctly, can help to maintain a constant high-quality finished water.

Asset Value

By maintaining a listing of all assets in the system and tracking the cost of making major repairs, the organization can more accurately determine the data needed to establish proper billing rates. In addition, the organization can determine from this data the life expectancy of major components and set aside the appropriate amount of funds for their replacement.

Review

1. What is the main advantage to having an effective public relations program?

2. Why is having good customer support so important?

3. List three reasons for maintaining a recordkeeping system.

4. List four sets of records that should be maintained at a water facility.

5. Why should nameplate data be collected and maintained as a separate set of records?

Management Considerations Quiz

1. Which of the following is a major part of a water system?
   A. Manager and operators
   B. Customers
   C. Governing body
   D. All of the above

2. Who is responsible for setting rates and utility policy?
   A. Manager
   B. Operator
   C. Governing body
   D. Customer

3. Who is responsible for operating and maintaining the water system?
   A. Manager
   B. Operator
   C. Governing body
   D. Customer

4. Who is responsible for developing, implementing, and supporting a worker safety program?
   A. Manager
   B. Regulatory agencies
   C. Governing body
   D. Customer

5. Which of the following is not a benefit of personnel training?
   A. Proper training can in many cases reduce operating cost.
   B. Training can be a motivator for all personnel.
   C. Training is required in order to meet certification and safety requirements.
   D. Training wastes time and money.

6. Research indicates that the best results are received from people who are trained
   A. To the minimum necessary to pass certification exams
   B. To the minimum to qualify for the job
   C. At least one level above their work requirements
   D. To the maximum that the utility can afford

7. Which of the following is not part of a planned maintenance management system?
   A. Data-collection process
   B. Rate-setting process
   C. Work order system
   D. Inventory control system

8. An ERP should achieve the following:
   A. Present clear and logical steps to take in response to possible emergencies
   B. Designate persons responsible for specific actions
   C. Ensure effective coordination with first responders, law enforcement, and health officials
   D. Provide information for setting utility rates

9. Action Plans should include the following basic information:
   A. Remediation actions needed to make sure the system is fully restored
   B. Special response steps necessary for the specific type of emergency
   C. Recovery actions to bring the system back into operation
   D. All of the above

10. An effective public relations program:
    A. Helps in responding to the needs of the customer
    B. Is not necessary for small utilities
    C. Is the job of management only
    D. Is a security risk

11. Recordkeeping systems for small utilities usually require:
    A. Specialized training to manage
    B. Only an index card system
    C. Lots of time to keep up
    D. Clerical staff

The Alaska Operator Certification Program

Chapter 12

What Is In This Chapter?

1. System classification
2. Levels of operator certification
3. Regulatory requirements
4. Regulations

The Alaska Department of Environmental Conservation (ADEC) administers the Operator Certification Program. The purpose of operator certification is to ensure that water system operators are qualified and competent. The program requires that operators meet eligibility requirements and pass certification exams. There are 10 different exams that vary in subject matter and difficulty, depending on the type and complexity of the water system operated.

There are two elements of operator certification:

- System classification is the process by which ADEC determines the complexity of a water system. The classification of a water system determines the required level of operator certification.
- Operator certification is the process by which operators demonstrate competency at a level comparable to system classification. For example, if a water treatment system is classified as class 2, the supervising operator of the system must pass the level 2 water treatment certification exam.

System Classification

The following water systems are required to have certified supervising operators:

- **Community Water Systems (CWS)** that serve at least 25 residents or 15 service connections year-around.
- **Non-transient Non-community Water Systems (NTWCWS)** serve the same 25 people for at least six months of the year. Typical examples include community water systems, subdivisions, condo associations, schools, office buildings, and day-care centers.
- **Transient Non-community Water Systems (TNCWS)** that use a surface water source or a groundwater under the direct influence of surface water source. These systems serve 25 people per day for at least 60 day per year. Typical examples include lodges and restaurants.
- **Water distribution systems** that serve more than 500 people or more than 100 service connections. These systems are typically associated with a community system.

All of these water systems are classified into one of the following system types:

- **Small water systems** typically service fewer than 500 people and fewer than 100 service connections. In order for a system to be classified as small, there must be minimal or no treatment occurring at the system. When no chemicals are added at a small water system, the system is classified as small, untreated. When one chemical is added at a small water system, the system is classified as small, treated. Often, there will be some sort of “passive” treatment at a small water system, such as softeners or cartridge filters. Water systems with more complex treatment, such was multiple chemicals, chemically aided filtration, or membrane filtration are classified as water treatment systems.

  Example: Consider a water system serving a small office building. Groundwater is pumped from a well and run through a softener. No chemicals are added to the water. This system is classified as small, untreated because no chemicals are added to the water. The classification is not affected by the use of a softener.

- **Water treatment systems** are classified according to complexity. Complexity is determined using a point rating system. Points are assigned for the design capacity of the system, the water source, and each treatment component of the water system. Points are totaled once all components are considered. The total determines classification from class 1 to class 4, with class 4 systems being the most complex.

  Points are associated with every imaginable component of a water treatment system. The point values for various components are established in the regulations that govern the program. The ranges of points used to determine the final classification are also found in the regulations.

  Example: Consider a typical direct filtration surface water treatment system. The classification might be as follows:

Peak day design capacity (130,000 gallons per day)	9 points
Surface water as a source	6 points
pH adjustment	3 points
Coagulation (primary coagulant)	5 points
In-line static mixer used for mixing	1 point
Granular media filtration	8 points
Disinfection with powdered hypochlorites	3 points
Total	**35 points**

  Systems totaling between 31 and 55 points are classified as class 2. Thus this system is a class 2 system.

- **Water distribution systems** are classified according to the number of service connections. The classification of a water distribution system increases from 1 through 4 as the number of service connections increases. Regulations specify the number of service connections for each classification of distribution system.

  There are two caveats that will increase the classification of a water distribution system from that determined by the number of service connections. Water distribution systems with five or more pressure zones are classified one class higher. Additionally, water distribution systems where water is circulated or heated to prevent freezing in the distribution system are classified one class higher. The classification of a distribution system will increase only once, even if both conditions are present.

  Example: Consider a North Slope water distribution system with 150 service connections. Water is heated and circulated in the distribution system to prevent freezing. Water distribution systems serving 15 to 500 service connections are initially classified as class 1. However, because water is heated and circulated to prevent freezing, the classification increases by one class. Thus this is a class 2 distribution system.

Operator Certification

There is a comparable level of certification for every class of system. Operators can become certified at the following levels:

- Small, Untreated
- Small, Treated
- Water Treatment levels Provisional, 1, 2, 3, and 4
- Water Distribution levels Provisional, 1, 2, 3, and 4

An operator must take and pass a certification exam to become certified. There is an education and experience prerequisite associated with each exam. The prerequisites increase with each higher level exam. For example, an operator needs three months of experience and a high school diploma to take the small, untreated exam, whereas an operator needs four years of experience and four years of postsecondary education to take the water treatment level 4 exam. The education and experience prerequisites for each exam are described in regulations.

Small, Untreated and Small, Treated Certification

Small, untreated and small, treated exams are offered twice per year in a paper and pencil format. Alternatively, the two exams are available online, year-round at seven prearranged locations. Water treatment and water distribution exams are available twice per year in a paper and pencil format. Additionally, the provisional level exams are available in conjunction with introductory courses, which are held at different times of the year at various locations around the State.

Provisional Level Certification

The Provisional level of certification replaces what was once called operator-in-training (OIT) certification. Operators must pass the level 1 exam to receive Provisional certification. In order to test for the provisional certification, an operator must have completed high school and have three months of experience. Provisional certificates can be upgraded to level 1 once the operator meets the level 1 experience requirements. The operator is responsible for applying for a certificate upgrade. OIT certificates cannot be upgraded without taking an exam; instead, operators with OIT certificates need to pass the level 1 exam to obtain provisional or level 1 certification.

There is an education renewal requirement associated with each certification. The continuing education unit (CEU) is the recognized unit of education. One CEU is equivalent to 10 hours of continuing education. An operator must earn 0.5 CEUs (five hours) of training during the three years prior to certificate expiration in order to renew a small, untreated certificate. An operator must earn 1.0 CEU (10 hours) of training during the three years prior to certificate expiration in order to renew a small, treated certificate. An operator must earn 3.0 CEUs (30 hours) of training during the three years prior to certificate expiration in order to renew any water treatment or water distribution certificate. Information regarding continuing education can be obtained from the Operator Certification program staff.

Regulatory Requirements

The supervising operator of a regulated system must be certified at a level equal to the classification of the system under that operator's control. The regulations that govern the Operator Certification Program discuss the requirements in more detail.

Utilities that serve more than 500 people or 100 service connections typically have both a water treatment system and a water distribution system. If that is the case, the supervising operator of the water treatment system must have the appropriate water treatment certificate, while the supervising operator of the water distribution system must have the appropriate level of water distribution certification. Water systems that serve fewer than 500 people and fewer than 100 service connections have only one classification. The supervising operator of these systems must be appropriately certified.

Regulations

The Operator Certification Program is governed by the Water and Wastewater Operator Certification and Training regulations (18 AAC 74). The information found above provides a quick overview of the classification and certification process. For specific information regarding the requirements, consult the actual regulations. The following list provides the specific regulatory citation for the items discussed above.

Classification of small water systems	18 AAC 74.450
Classification of water treatment systems	18 AAC 74.120 (b) and (e)
Classification of water distribution systems	18 AAC 74.120 (a)
Prerequisites for exams	18 AAC 74.050
Certificate renewal requirements	18 AAC 74.810
Regulatory requirements for water treatment and water distribution systems	18 AAC 74.010
Regulatory requirements for small water systems	18 AAC 74.410

More Information

All questions regarding system classification and operator certification should be addressed to the Operator Certification Program. Contact information for the program is as follows:

Operator Certification Program
ADEC
410 Willoughby Ave. Suite 303
P.O. Box 111800
Juneau, AK 99811-1800
Phone: (907) 465-1139
Fax: (907) 465-5177
http://www.dec.alaska.gov/water/opcert/index.htm

Chapter 12 The Alaska Operator Certification Program Quiz

1. What state agency administers the Operator Certification Program?
   A. Department of Labor (DOL)
   B. Department of Commerce, Community and Economic Development (DCCED)
   C. Department of Environmental Conservation (DEC)
   D. Department of Health and Social Services (DHSS)

2. What is the purpose of operator certification?
   A. To ensure water system operators are qualified and competent.
   B. To allow water systems to operate without competent personnel.
   C. To ensure water system operators are not felons.
   D. To allow water systems to operate their systems without oversight.

3. What are the two elements of the Operator Certification Program?
   A. Technical assistance and sampling compliance.
   B. System classification and technical assistance.
   C. Operator certification and technical assistance.
   D. System classification and operator certification.

4. What type of water systems require operators certified at the correct level for the system?Choices: Community Water System (C), Non-transient non-community (NTNC), Transient non-community (TNC), Non public (NP)
   A. NP, NTNC, and C water systems
   B. C, NTNC, all TNC, and NP water systems
   C. C.C, NTNC, and TNC using surface water or groundwater under the influence of surface water as a source water systems
   D. NP, all TNC ,and NTNC water systems

5. A small, treated water system is a water system that is classified as a small water system and adds ________.
   A. No chemicals
   B. One chemical
   C. Two chemicals
   D. More than two chemicals

6. A small, untreated water system is a water system that is classified as a small water system and adds ________.
   A. No chemicals
   B. One chemical
   C. Two chemicals
   D. More than two chemicals

7. Water treatment systems are classified according to ________.
   A. The population served with no concern for complexity
   B. The number of faucets
   C. Complexity based on a point rating system
   D. The number of kitchen sinks

8. Water distribution systems are classified according to ________.
   A. The population served with no concern for complexity
   B. The number of service connections
   C. Complexity based on a point rating system
   D. The number of kitchen sinks

9. Water distribution systems can increase in classification if _______, but can only increase one class even if both conditions exist.
   A. There are over 100 fire hydrants or 25 sampling stations
   B. There are six or more car washes, or where water is circulated or heated to prevent freezing
   C. There is a washeteria, or five or more pressure zones
   D. There are five or more pressure zones, or where water is circu lated or heated to prevent freezing

10. Where can you find the requirements for certification and system clas sification information?
   A. 18 AAC 30 Environmental Sanitation
   B. 18 AAC 74 Water and Wastewater Operator Certification and Training
   C. 18 AAC 80 Drinking Water
   D. 18 AAC 95 Administrative Enforcement

11. Who should you contact if you have questions regarding operator cer tification or system classification?
   A. Drinking Water Program
   B. Water Quality Programs
   C. Operator Certification Program
   D. Village Safe Water

Waterworks Math – The Basics

Chapter 13

What Is In This Chapter?

1. The principles of working with fractions
2. The principles of working with decimals
3. How to round numbers
4. How to determine significant digits
5. How to read powers
6. Conversions using standard conversion factors
7. The weight of one cubic foot of water
8. The volume in gallons of one cubic foot of water
9. The number square feet in an acre
10. How to average a set of numbers
11. How to determine area of rectangles and circles
12. How to determine volume of rectangular, circular, and cone-shaped objects
13. How to convert whole numbers to percent
14. How to calculate percent
15. How to make common waterworks conversions
16. Common abbreviations found in waterworks math
17. How to convert pressure to feet of head
18. The number of gpm that equals one cfs
19. How to calculate the radius and circumference of a circle
20. How to calculate the perimeter of a rectangle
21. How to calculate flow
22. How to calculate detention time

Key Words

- Area
- Averages
- cfs
- Circumference
- Cross-sectional Area
- Cubic Feet
- Cylinder
- Demand
- Detention Time Flow
- Diameter
- Head
- MGD
- mg/L
- pi
- Radius
- Rectangle
- Velocity
- Volume

Introduction

Lesson Intent

This lesson on math basics is intended as a review and introduction to those math concepts believed to be critical and minimum to the "Certified Operator" in an Alaskan community of fewer than 500 population. This does not mean that these are the only math concepts that a competent operator needs in order to solve routine operation and maintenance problems.

Lesson Content

This lesson on basic math is a review of the principles needed for working with fractions and decimals, rounding numbers, determining the correct number of significant digits, raising numbers to powers, calculating percent, making simple conversions, calculating **flow**[1], calculating volume, and calculating **detention time**[2].

[1] Flow – To be in constant movement, typically in a single direction. In regards to water, this term typically relates to a volume per unit of time, gallons per minute, cubic feet per second, etc.

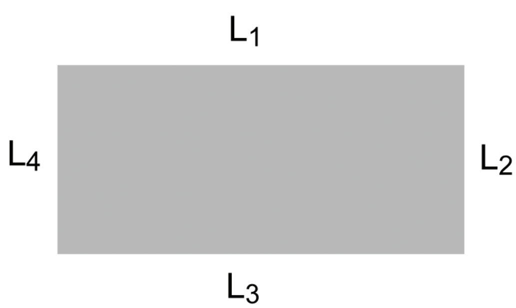
[2] Detention time – The theoretical time required to displace the contents of a tank or unit at a given rate of discharge or flow.

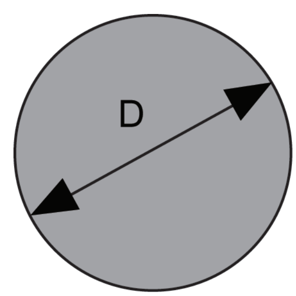
Basic Equations

The following is a listing of the basic formulas found in the math section of this text. They have been compiled here for your convenience.

Perimeter/Circumference

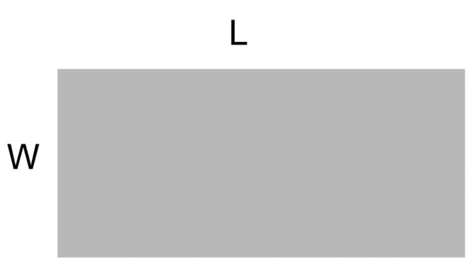
Square or Rectangle	Circle
Perimeter = L1 + L2 + L3 + L4	Circumference = πD

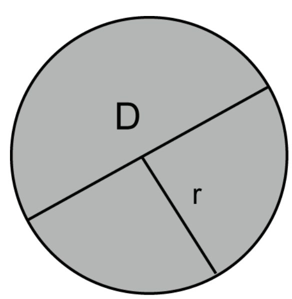




Area

Rectangle or Square	Circle
$A = L \times W$	$A = \pi r^2$ or $0.785D^2$

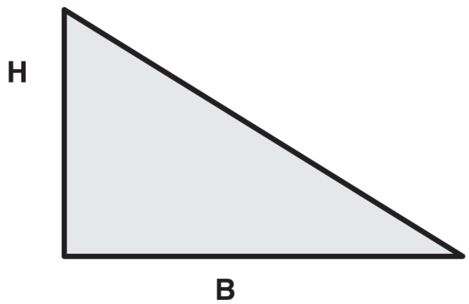




Area

Triangle

$$A = \frac{B \times H}{2}$$

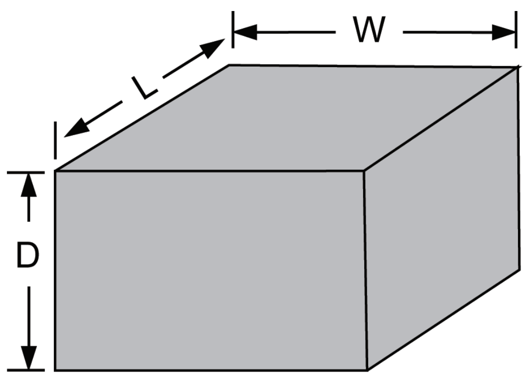


Other Equations

Volume

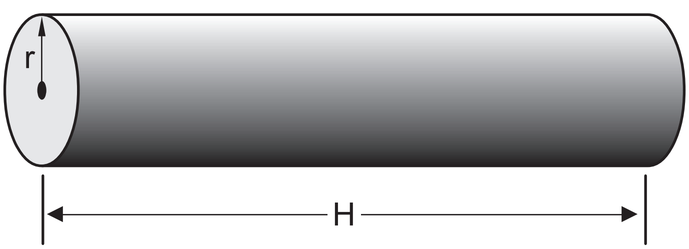
Rectangle or Square

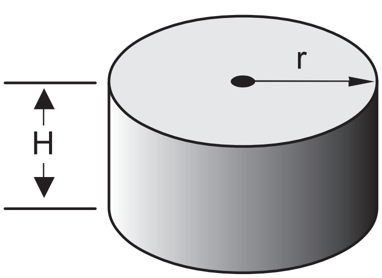
V = L x W x D



Cylinder

$V = \pi r^2 \times H$ or L

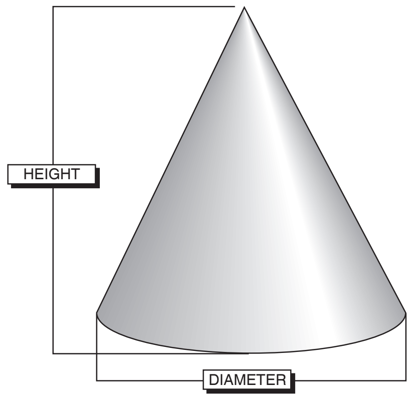




Volume

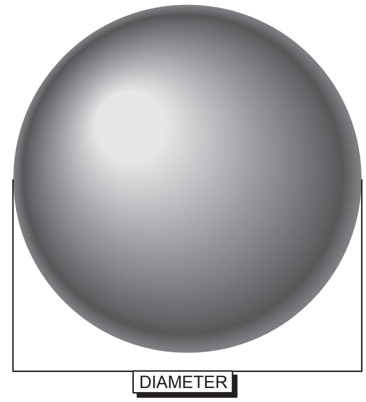
Cone

$$\frac{\pi r^2 H}{3} \quad \text{or} \quad \frac{.785\ D^2\ H}{3}$$



Sphere

$$\frac{2}{3} \times (.785\ D^2) \times D$$



Pounds

Lbs = V, MG x 8.34 lbs/gal x Conc, mg/L

Where:
Lbs = pounds
V = flow or volume in millions of gallons
Conc = concentration or dosage in mg/L

Removal Efficiency

$$\frac{\text{In - Out}}{\text{In}} \times 100 = \%\ \text{efficiency}$$

Pump Efficiency

$$\frac{\text{Output Horsepower}}{\text{Input Horsepower}} \times 100 = \%\ \text{efficiency}$$

Weir Overflow Rate

$$\text{Weir Overflow Rate (WO)} = \frac{\text{Flow rate in gpd}}{\text{Weir length in feet}} = \text{gal/day/ft}$$

Temperature

$°C = 5/9\ (°F - 32°)$ $\qquad$ $°F = (9/5 \times °C) + 32$

Detention Time

$$\text{Detention Time (DT)} = \frac{\text{Volume}}{\text{Flow}}$$

Working with Math

Steps in Solving Problems

Introduction

There are many methods that can be successfully used to solve waterworks problems. We tend to select and adapt problem-solving styles that fit our individual system. If you have selected one or more methods that are beneficial to your style, we suggest that you continue to use what has worked in the past. However, if waterworks problems have frustrated you then we suggest that you consider some version of the following procedure:

Procedure

1. When appropriate, make a drawing of the information in the problem.
2. Place the data that is available on the drawing.
3. Ask, "What is the question?"
4. Write down what you are to find. Sometimes the answer has more than one piece. For instance, you may need to find "X" and then find "Y."
5. Write down any equation that you are going to need.
6. Fill in the data in the equation.
7. Rearrange the equation, if necessary.
8. Pick up the calculator and make the calculation.
9. Write down the answer.

Word Problems

Words to Symbols

In word problems, certain words can be used to determine the correct math function or meaning. Here are a few of the basic word meaning examples:

Word	Meaning
of	multiply
and	add
per	divide
less than	subtract

Symbols to Words

In writing mathematical formulas or expressions, symbols are used to indicate an mathematical operation. Here are a few examples:

Math Operation	Symbol	Example
Multiplication	x	Q = V x A
Multiplication	•	Q = V • A
Multiplication	No space	Q = VA
Multiplication	( ) ( )	Q = (V) (A)
Division	÷	r = D ÷ 2
Division	——	$r = \frac{D}{2}$
Division	/	r = D/2

Help with the Calculator

Introduction

The calculator has made the solution of waterworks problems much easier and improved our accuracy. At the same time the calculator brings with it its own problems. The following are few hints that may make using the calculator less stressful.

Hint #1 – Type of Calculator

The calculator used by a waterworks operator is not a toy; it is a tool like any other tool. As such, it is best to purchase for quality rather than price. Quality will be easier to use and last much longer. A quality calculator used by a waterworks operator should have the following:

- The keys should be large enough to allow your fingers to be easily placed on them.
- The calculator should have a **pi**[3] (π) key. This makes calculating pipe and circular tank volumes much easier.
- Solar calculators do not offer the freedom of use that battery calculators offer.
- A protective case will add life to the calculator.
- The display should allow for 10 characters.
- A scientific calculator is more appropriate and useful than a business calculator.

[3] pi – Greek letter (π) used as a symbol denoting the ratio of the circumference of a circle to its diameter.

Hint #2 – Read the Book

The small booklet that comes with the calculator is designed to help you understand the functions of the calculator. You should read and then store the book for easy access. This allows you to use the book to help solve unique problems that show up only on occasion.

Hint #3 – Division by 2

One of the common problems confronted by operators is the proper method to solve the following:

- One incorrect method that is used is to divide 7 by 0.25 and then multiply that answer by 8.34. This will yield an incorrect answer of 233.52 **mg/L**[4] .
- A second less serious mistake is to multiply 0.25 x 8.34 and write the answer down on a piece of scratch paper (2.085). Typically the answer is rounded off to 2. The rounding reduces the accuracy, and writing the number down is a step that is not necessary.
- The CORRECT APPROACH would be to place 7 in the calculator, press the divide key (÷), enter the number 0.25 and press the divide key (÷) again. Now enter in the number 8.34, and press the equal key (=). The correct answer of 3.357 should be displayed. This can be rounded off to 3.4 mg/L. Yes, this is one more character than the correct number of significant digits. This is done not because of accuracy but because the answer is most likely larger than 3.

[4] mg/L (milligrams per Liter) – A unit of the concentration of a constituent in water. It is 0.001g of the constituent in 1,000 ml of water. mg/L has replaced the PPM (parts per million) in reporting results in water.

Math Principles

Fractions

Use

With the calculators that are available today, the need to work with fractions is not what it once was. However, the operator is often faced with routine situations that require thinking in fractions and on occasion actually working with fractions. One of the common uses for the rules governing the use of fractions in a math problem is dealing with units of a problem. The unit gpm is actually a fraction gal/min, and **cfs**[5] is actually ft^3/sec. So as you can see, understanding fractions may help you solve other problems.

[5] cfs – To be in constant movement, typically in a single direction. In regards to water, this term typically relates to a volume per unit of time, gallons per minute, cubic feet per second, etc.

Components of a Fraction

A fraction is composed of three items: two numbers and a line. The number on the top is called the numerator, the number on the bottom is called the denominator, and the line in between them means to divide.

$$\text{Divide} \longrightarrow \frac{3}{4} \begin{array}{l}\text{Numerator}\\ \text{Denominator}\end{array}$$

Principles of Working With Fractions

Introduction

Like all other math functions, how we deal with fractions is governed by rules or principles. The following is a discussion of 11 principles associated with using fractions.

Same Numerator and Denominator

When the numerator and denominator of a fraction are the same, the fraction can be reduced to 1. For example:

$$\frac{4}{4} = 1,\quad \frac{24}{24} = 1,\quad \frac{8}{8} = 1,\quad \frac{12}{12} = 1,\quad \frac{125}{125} = 1$$

Whole Numbers to Fractions

Any whole number can be expressed as a fraction by placing a "1" in the denominator. For example:

$$2 \text{ is the same as } \frac{2}{1} \text{ and } 45 \text{ is the same as } \frac{45}{1}$$

Adding Fractions

Only fractions with the same denominator can be added, and only the numerators are added. For example:

$$\frac{1}{8} + \frac{3}{8} = \frac{4}{8} \text{ and, } \frac{6}{32} + \frac{12}{32} = \frac{18}{32}$$

Subtracting Fractions

Only fractions with the same denominator can be subtracted, and only the numerators are subtracted. The denominator remains the same. For example:

$$\frac{7}{8} - \frac{3}{8} = \frac{4}{8} \text{ and, } \frac{18}{25} - \frac{6}{25} = \frac{12}{25}$$

Mixed Numbers

A fraction combined with a whole number is called a mixed number. For example:

$$4\frac{1}{8},\quad 16\frac{2}{3},\quad 8\frac{3}{4},\quad 45\frac{1}{2} \text{ and, } 12\frac{17}{32}$$

These numbers are read, four and one eighth, sixteen and two thirds, eight and three fourths, forty-five and one half, and twelve and seventeen thirty seconds.

Changing a Fraction

A fraction can be changed by multiplying the numerator and denominator by the same number. This does not change the value of the fraction, only how it looks. For instance:

$$\frac{1}{2} \text{ is the same as } \frac{1 \times 2}{2 \times 2} \text{ which is } \frac{2}{4}$$

Simplest Terms

Fractions should be reduced to their simplest terms. This is accomplished by dividing the numerator and denominator by the same number. The result of this division must leave both the numerator and the denominator as whole numbers. For instance:

$$\frac{2}{4} \text{ is not in its simplest terms, by dividing both by 2, we obtain } \frac{1}{2}$$

The number 2/3 cannot be reduced any further since there is no number that can be divided evenly into the 2 and the 3.

Practice Problems – Fractions

1. Reduce the following to their simplest terms.

   A. 4/8 = ________________________
   B. 12/18 = ________________________
   C. 3/4 = ________________________
   D. 6/8 = ________________________
   E. 24/32 = ________________________
   F. 9/18 = ________________________
   G. 15/27 = ________________________

Key to Reducing – Even Numbers

When the starting point is not obvious, do the following: if the numerator and denominator are both even numbers (2, 4, 6, 8, 10, etc.), divide them both by 2. Continue dividing by 2 until a division will no longer yield a whole number with the numerator and denominator.

Key to Reducing – Odd Numbers

When the numerator and denominator are both odd numbers (3, 5, 7, 9, 11, 13, 15), attempt to divide by three, continue dividing by 3 until a division will no longer yield a whole number with the numerator and denominator. It is obvious that some numbers such as 5, 7, and 11 cannot be divided by 3 and may in fact be in their simplest terms.

Different Denominators

To add or subtract fractions with different denominators, the denominators must be changed so that all denominators are the same. To find the "common denominator," multiply the denominators together. Then convert each fraction to a new value based on this new common denominator.

For instance, to add 1/8 and 2/3 together:

1. Start by multiplying the denominators 8 x 3 = 24.
2. Change 1/8 to a fraction with 24 as the denominator.

   $$\frac{24}{8} = 3, \qquad 3 \times 1 = 3 \text{ (the numerator), new fraction is } \frac{3}{24}$$

   Notice that this is the same as 1/8 except 3/24 is not reduced to its simplest terms.

3. Change 2/3 to a fraction with 24 as the denominator.

   $$\frac{24}{3} = 8, \qquad 8 \text{ X } 2 = 16 \text{ (the numerator), new fraction is } \frac{16}{24}$$

4. Complete the addition.

   $$\frac{3}{24} + \frac{16}{24} = \frac{19}{24}$$

Numerator Larger

Any time the numerator is larger than the denominator, the fraction should be turned into a mixed number. This is accomplished by the following procedure:

1. Determine the number of times the denominator can be divided evenly into the numerator. This will be the whole number portion of the mixed number.
2. Multiply the whole number times the denominator, and subtract from the numerator. This value, the remainder, becomes the numerator of the fraction portion of the mixed number.

$\frac{28}{12}$, 28 is divisible by 12 twice. 2 is the whole number

2 x 12 = 24

$\frac{28}{12} - \frac{24}{12} = \frac{4}{12}$ dividing top and bottom by 4 = $\frac{1}{3}$

New mixed number is 2 $\frac{1}{3}$

Multiplying Fractions

This is accomplished by the following procedure:

1. Multiply the numerators together.
2. Multiply the denominators together.
3. Reduce to the simplest terms.

   For example: Find the result of multiplying 1/8 x 2/3

$$\frac{1}{8} \times \frac{2}{3} = \frac{2}{24}, \text{ reduced } = \frac{2}{24} \div \frac{2}{2} = \frac{1}{12}$$

Dividing Fractions

This is accomplished by the following procedure:

1. Invert the denominator (turn it upside down).
2. Multiply and reduce to simplest terms. For example:
3. Divide 1/8 by 2/3.

$$\frac{1}{8} \div \frac{2}{3} = \frac{1}{8} \times \frac{3}{2} = \frac{1 \times 3 = 3}{8 \times 2 = 16} = \frac{3}{16}$$

The divide symbol can be ÷ or / or ——.

Converting Fractions to Decimals

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

Example – Converting Fractions to Decimals

$$\frac{1}{2} = 0.5, \frac{7}{8} = 0.875, \frac{7}{16} = 0.875, \frac{1}{4} = 0.25, \text{ and } \frac{2}{3} = 0.667$$

Changing Inches to Feet

To change inches to feet, multiply the number of inches by the conversion 1/12.

Example – Changing Inches to Feet

Change 3 inches to feet:

$$3 \text{ in x } \frac{1\text{ft}}{12\text{in}} = \frac{3\cancel{\text{in}} \text{ x } 1\text{ft}}{12\cancel{\text{in}}} = \frac{3\text{ft}}{12} = 0.25 \text{ ft}$$

Practice – Changing Inches to Feet

Change the following to feet:

2 inches, 4 inches, 6 inches, 8 inches

$$\frac{2}{12} = 0.167 \text{ feet}$$

$$\frac{4}{12} = 0.33 \text{ feet}$$

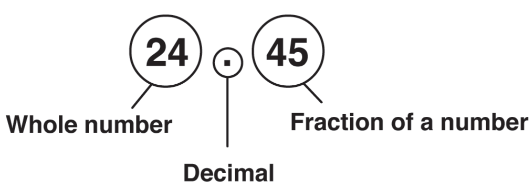
$$\frac{6}{12} = 0.5 \text{ feet}$$

$$\frac{8}{12} = 0.667 \text{ feet}$$

Decimals

The Components

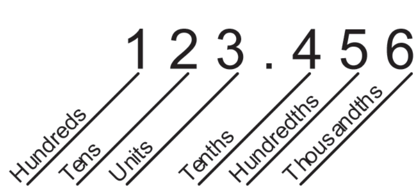
A decimal is composed of two sets of numbers: the numbers to the left of the decimal are whole numbers, and numbers to the right of the decimal are parts of whole numbers, a fraction of a number.



Fraction Component

The term used to express the fraction component is dependent on the number of characters to the right of the decimal.

- The first character after the decimal point is tenths: 0.1 – tenths
- The second character is hundredths: 0.01 – hundredths
- The third character is thousandths: 0.001 – thousandths



Principles

Calculators

With today's use of calculators, we seldom need the rules for handling decimals. As a result, when we need to make a computation manually, we often cannot remember the basic rules. Therefore, this brief review is provided.

Number Less Than One

When a number is less than one and is expressed as a decimal, place a "0" (zero) to the left of the decimal. This makes it clear that the number is less than one. For instance 0.25 is much clearer than .25.

Subtraction

When subtracting decimals, simply line up the numbers at the decimal, and subtract. For example:

$$\begin{array}{r} 28.65 \\ -\ 12.25 \\ \hline 16.40 \end{array} \qquad \begin{array}{r} 145.600 \\ -\ 13.212 \\ \hline 132.388 \end{array}$$

Addition

To add numbers with a decimal, use the same rules as subtraction: line up the numbers on the decimal, and add.

$$\begin{array}{r} 28.65 \\ +\ 12.25 \\ \hline 40.90 \end{array} \qquad \begin{array}{r} 145.600 \\ +\ 13.212 \\ \hline 158.812 \end{array}$$

Multiplication

To multiply two or more numbers containing decimals, follow these few basic steps:

1. Multiply the numbers as whole numbers. Do not worry about the decimals.
2. Write down the answer.
3. Count the total number of digits (numbers) to the right of the decimal in all of the numbers being multiplied.
4. To place the decimal in the answer, count from the right to the left the number of digits counted in the previous step.

Example – Multiplication

Multiplying 3.04 x 8.6 yields the number 26144.

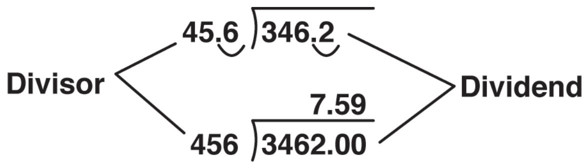
There are a total of three digits to the right of the decimal point (2 for the number 3.04 and 1 for the number 8.6). Therefore, the decimal point should be placed three places to the left from the right of the last 4.

26.144

Division

To divide a number by a number containing a decimal, the divisor must be made into a whole number by moving the decimal point to the right until you have a whole number.

1. Count the number of places the decimal needed to be moved.
2. Move the decimal in the dividend by the same number of places.
3. Make the division.



Using the Calculator

With today's calculators, this problem would simply be set up as follows:

$$\frac{346.2}{45.6} = 7.59$$

Rounding

Why Round?

Numbers are rounded to reduce the number of digits to the right of the decimal point. This is for convenience, not accuracy.

Process of Rounding

1. Start by deciding how many places you want to the right of the decimal. Remember this is done for convenience.
2. If the number to the right of the last number that you wish to report is 5 or greater than 5, increase the size of the last number by 1.
3. If the number to the right of the last number that you wish to report is less than 5, the size of the last number remains the same.

Example 1 – Rounding

A calculation has just been completed, and the answer is 24.55836. A decision is made to have two places to the right of the decimal. Two places takes you to 25.55. The next number is "8." Therefore, the last five is rounded up to a six. The number is 24.56.

Example 2 – Rounding

A calculation has just been completed, and the answer is 24.55436. A decision is made to have two places to the right of the decimal. Two places takes you to 25.55. The next number is "4." Therefore, all of the numbers to the right of the .55 are dropped. The reported number is 24.55.

Practice Problems – Rounding

1. Round the following to the nearest hundredths (the second place after the decimal).

   A. 2.4568 ________________________
   B. 27.2534 ________________________
   C. 128.2111 ________________________
   D. 364.8762 ________________________
   E. 354.777777 ________________________
   F. 34.666666 ________________________
   G. 67. 33333 ________________________

2. Round the following to the nearest tenths (the first place after the decimal).

   A. 2.4568 ________________________
   B. 27.2534 ________________________
   C. 128.2111 ________________________
   D. 364.8762 ________________________
   E. 354.777777 ________________________
   F. 34.666666 ________________________
   G. 67. 33333 ________________________

Determining Significant Digits

The Concept

Significant digits are related to rounding. We use the concept to determine the direction to round a number. The basic idea is that no answer can be more accurate than the least accurate piece of data used to calculate the answer.

Process

There are several rules used to determine whether a digit is significant:

1. Non-zero digits are significant. ie. numbers 1-9
2. Zero's appearing between non-zero digits are significant. ie. 1**0**3, 24**000**.2, 1**0**.7
3. Zero's appearing to the right of a decimal ar significant. ie. 12**.00**, 8.34**00**, 0.02**0**
4. Zero's appearing at the beginning of a number are **NOT** significant. ie **0**.4

Practice Problems – Significant Digits

For addition and subtraction the process involves two steps:

1. Determine the number of decimal places in the least accurate piece of data.
2. Round off the answer to theis position.

Example – Significant Digits

The following calculation was made:

12.27 + 45.283 = 57.553

The least accurate piece of data is number 12.27. As 12.27 has only 2 decimal places the sum can have only 2 decimal places as well. The correct answer is 57.55.

1. Round the following answers off to the most significant digit.

	Problem	Accurate Answer
A.	25.1 + 26.43 = 51.53	
B.	128.456 – 121.4 = 7.056	
C.	85-7.92432 = 77.07568	
D.	8.564+5 = 13.564	

For multiplication and division the process involves two steps:

1. Determine the number of significant figures each number has.
2. Round the final answer to the number with the least significant digits.

Example – Multiplication and Division with Significant Digits

The following calculation was made:

53.2 x 128.64 = 6,843.648

In the above problem, 53.2 has 3 significant figures and 128.64 has 5. The multiplication/division rule says the answer should be rounded to the number with the least number of significant digits; in this case three (53.2). So the correct answer is 6,840.

2.

	Problem	Accurate Answer
A.	26.34 x 124.34567 = 3,275.26495	
B.	23.58 x 34.251 = 807.63858	
C.	12,453 / 13.9 = 895.8992805755	
D.	12,457.92 x 3 = 37,373.76	

Working with Powers

Principle

Powers are used to identify **area**[6], as in square feet, and volume as in **cubic feet**[7]. Powers can also be used to indicate that a number should be squared, cubed, etc. This later designation is the number of times a number must be multiplied by itself.

[6] Area – The extent of a surface, measured by the number of squares of equal size it contains.

[7] Cubic Feet – A measurement of volume in the number of cubes that are one foot on a side.

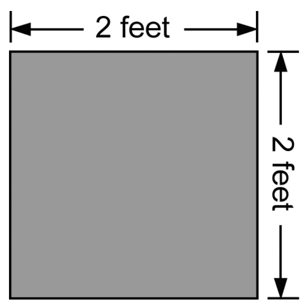
Example – Powers

We could find these two numbers:

4^2 or 4 ft^2

The number 4^2 means 4 x 4 = 16.

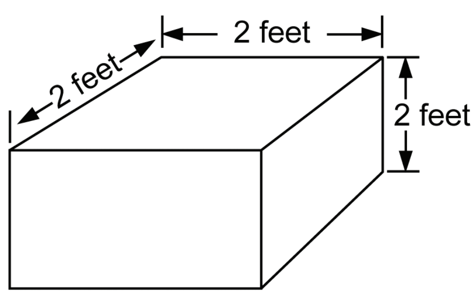
The number 4 ft^2 means four square feet, an area 2 ft x 2 ft.



Or we might see these two numbers 4^3 or 4 ft^3.

The number 4^3 means 4 x 4 x 4 = 64.

The number 4 ft^3 means 4 cubic feet, a block 2 ft x 2 ft x 1 foot deep.



Finding Averages

Use

Finding an **average**[8] of a series of numbers is accomplished by adding the numbers and dividing by the number of numbers in the group. This is an activity that is required on the monthly report for chlorine, fluoride, and turbidity readings. The average for the month is commonly figured on all chemicals added, and on most test results.

[8] Average – An arithmetic mean. The value is arrived at by adding the quantities in a series and dividing the total by the number in the series.

Example 1 – Averages

Find the average of the following series of numbers: 12, 8, 6, 21, 4, 5, 9, and 12. Adding the numbers together we get 77. There are 8 numbers in this set. Divide 77 by 8.

$\frac{77}{8}$ = 9.6 is the average of the set

Example 2 – Averages

Here is a series of daily turbidities. Obtain the average for them.

0.3, 0.4, 0.3, 0.1, 0.8

The total is 1.9. There are 5 numbers in the set. Therefore:

$\frac{1.9}{5}$ = 0.38, rounding off = 0.4

Practice Problem – Averages

1. Find the average of the following set of numbers:

0.2
0.2
0.1
0.3
0.2
0.4
0.6
0.1
0.3

Equations

Description

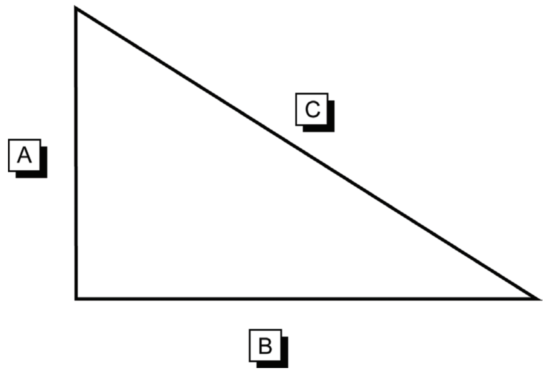
An equation is a symbolic representation of how to combine certain information in order to obtain the proper result. Equations are written using letters and symbols to represent unknown or standard values.

Use

Equations (also called formulas) are used by operators to solve a wide variety of problems associated with treatment and collection. In fact, most operators use formulas without thinking about them to solve routine problems. For instance, to determine the perimeter or distance around a building requires using a formula.

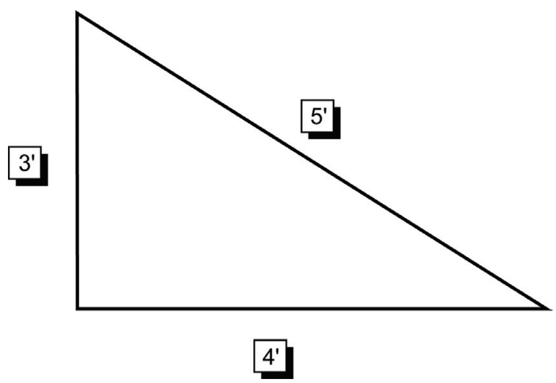
Example 1 – Equations

The equation for determining the perimeter of a triangle is P = a + b + c. P is the letter used to designate the perimeter and a, b, and c are used to identify the lengths of the sides. The mathematical symbols (=) and (+) tell the user what math functions are to be carried out. This formula says to add the lengths of all of the sides to obtain the perimeter.



Example 2 – Equations

In the example below, the numbers 3', 4', and 5' have been substituted for the letters a, b, and c. To solve the equation substitute the numbers for the appropriate letters, a = 3', b = 4', and c = 5'. Now add the three together to obtain a perimeter of 12'. The distance around this triangle is 12 feet.



Works on All Triangles

This equation will work for all triangles, regardless of the lengths of their sides.

Formulas with Symbols

Some equations such as the one for the area of a circle ($A = \pi r^2$) use symbols. The symbol π (pi) is used to represent a constant: 3.14. This is done in equations to simplify the writing of the equation.

Listing of Formulas

A listing of common equations used in water/wastewater systems can be found at the end of this chapter. In addition, equations are used in most of the other sections of this chapter.

Rearranging Equations

Types of Equations

The equations that are commonly used in water math are called linear equations (follow a straight line). To be successful in solving math problems, an operator must be able to solve a linear equation with one unknown (perimeter of a triangle, pounds formula, area of a circle are all examples of this type of equation).

Why Rearrange?

To solve a problem, an operator is often required to solve the equation for a component that is not normally part of the solution. For instance, the perimeter and the length of two sides of a triangle may be known, and you wish to solve for the length of the third side.

Two Sides

Equations have two sides that are separated by the equal sign (=) . To solve an equation, there must be only one unknown and the unknown must be on one side of the equation by itself.

Rearranging Equations with Addition and Subtraction

Rule

The rule of equality must be maintained! Thus, if you subtract a value from the right side of the equal sign, you must subtract the same value from the left side of the equal sign. The is true for adding, dividing, and multiplying.

Example – Addition and Subtraction

Solve the equation $12 = 3 + b + 5$

The first step is to rearrange the equation so that the unknown is on one side of the equation by itself. This is accomplished by subtracting 3 and 5 from both sides of the equation.

$12 – 3 – 5 = 3 + b + 5 – 3 – 5$

On the right side of the equation $3 – 3 = 0$ and $5 – 5 = 0$

The resulting new equation would look like this:

$12 – 3 – 5 = b$

The last step is to do the math. That is, subtract 3 and 5 from 12. The result is: $4 = b$

Rearranging Equations with Multiplication and Division

Process

To solve for an unknown value in an equation using multiplication or division, move the unknown value to one side of the equation by itself.

Top and Bottom

As stated above, an equation has two sides. A multiplication and division equation also has a top and bottom that are separated by a division line. When the equation is just multiplication, the division line is not shown and all of the items are above the line.

Rule

To move an item from one side of an equation to the other in a multiplication or division equation, the item is moved from the top of one side to the bottom of the other or from the bottom of one side to the top of the other.

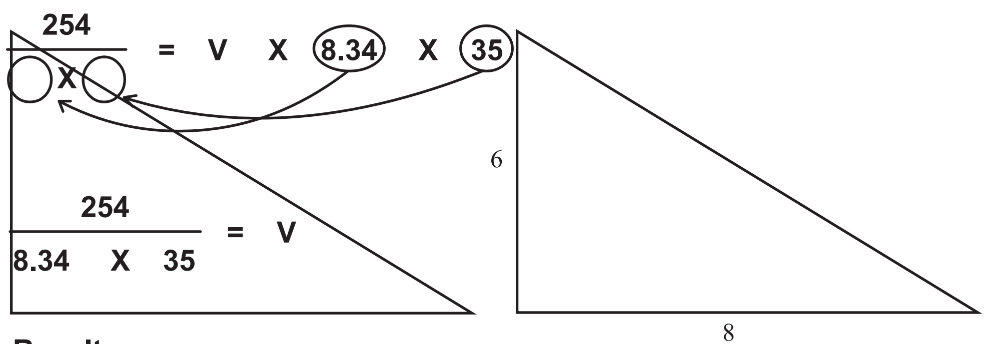
Summary

To state it another way, if the item that is being moved is on top of the equation, then it must be placed below when moved. If an item is below in the equation, then it must be placed above when it is moved.

Example 1 – Multiplication and Division

Solve this equation for V:

$$254 = V \times 8.34 \times 35$$



Result:

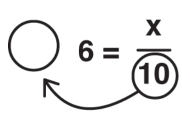
$$V = 0.87$$

Example 2 – Multiplication and Division

Solve for X in the following equation:

$$6 = \frac{x}{10}$$

Step 1 – Rearrange the equation by multiplying both sides by 10.



10 x 6 = X

Step 2 – Solve the equation.

60 = X

Special Note

Many equations are written without the use of the multiplication sign. For instance, $A = \pi r^2$ and $C = \pi D$.

πr^2 is the same as $\pi \times r^2$, or pi times r^2.

Also, $\pi (r^2)$ is the same as $\pi \times (r^2)$ or pi times r^2.

Equation Problems

Example 1 – Equation Problems

A triangle has a perimeter of 24', the length of the bottom is 8', and the length of the left side is 6'. What is the length of the long side?

Step 1 – Draw a diagram of the triangle.

Step 2 – Place the known values on the diagram.

Step 3 – Write the equation.

$P = a + b + c$

Step 4 – Fill in the known values in the equation.

$24' = 6' + 8' + c$

Step 4 – Subtract 6' and 8' from both sides of the equation.

$24' - 6' - 8' = c$

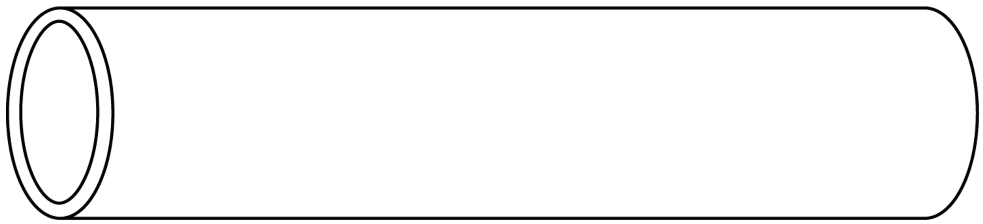
Step 5 – Solve the equation.

$10' = c$

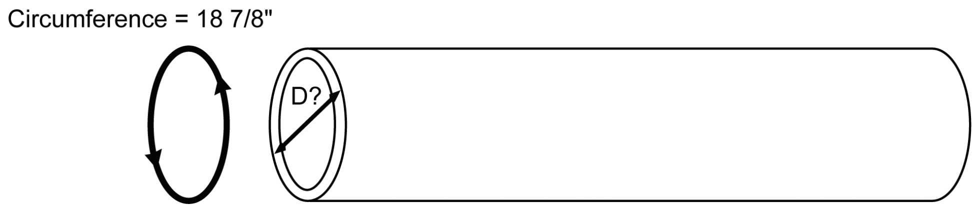
Example 2 – Equation Problems

Find the diameter of a pipe with a circumference of 18 7/8 inches.

Step 1 – Draw a diagram of the pipe.



Step 2 – Place the known values on the diagram.



Step 3 – Make any obvious conversions.

The circumference is given in inches and fractions of inches. This must be converted to a decimal before proceeding.

18 7/8" = 18.875"

Step 4 – Select an equation.

$C = \pi D$

Step 5 – Fill in the known values.

$18.75'' = \pi D$

Step 6 – Divide both sides of the equation by pi.

$$\frac{18.75''}{\pi} = D$$

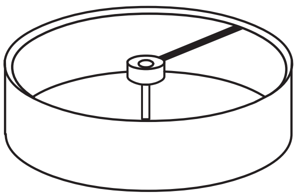
Step 7 – Solve the equation.

6" = D

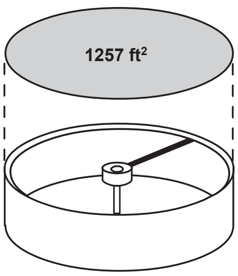
Example 3 – Equation Problems

Find the diameter of a settling basin with a surface area of 1257 ft^2.

Step 1 – Draw a diagram of the clarifier.



Step 2 – Place the known values on the diagram.



Step 3 – Select an equation.

$A = \pi r^2$

Step 4 – Fill in the known values.

$1257\ ft^2 = \pi r^2$

Step 5 – Divide both sides of the equation by pi (π).

This rearrangement will require two steps. The second step is to change the r^2 to r. This is accomplished by finding the square root of all of the values on both sides of the equation.

$$\sqrt{\frac{1257\, ft^2}{\pi}} = r$$

20 feet = r

Step 6 – Determine the diameter from the radius.

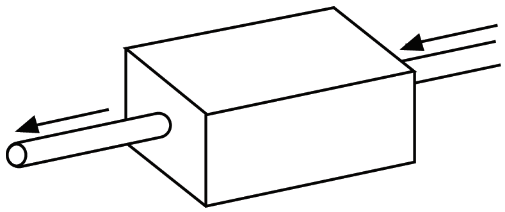
Since the radius is one half of the diameter this value must be multiplied by 2.

2 x 20 ft = 40 ft – the diameter of the clarifier

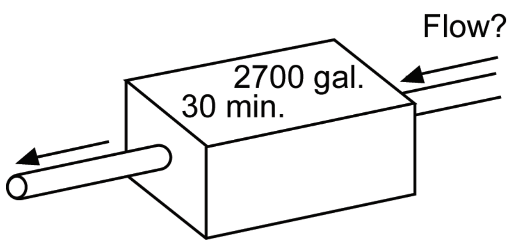
Example 4 – Equation Problems

A chlorine contact chamber holds 2700 gallons. It is desired to have a contact time of 30 minutes in the chamber. What is the maximum flow rate that can pass through this chamber at this detention time.

Step 1 – Draw a diagram of the situation.



Step 2 – Place the unknown values on the diagram.



Step 3 – Select an equation.

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

Step 4 – Place the known values in the equation.

$$30 \text{ min} = \frac{2{,}700 \text{ gal}}{\text{gpm}}$$

Step 5 – Divide both sides of the equation by 30 minutes.

$$\text{gpm} = \frac{2{,}700 \text{ gal}}{30 \text{ min}}$$

Step 6 – Solve the equation.

gpm = 90 gpm

Practice Problems – Formulas

1. Find the diameter of a settling basin that has a circumference of 126 feet.

2. Find the diameter of a pipe that has a circumference of 12 9/16".

3. Find the diameter of a settling basin that has a surface area of 113 ft^2.

4. Find the diameter of a storage tank that has a surface area of 314 ft^2.

5. The detention time in a chlorine contact chamber is 42 minutes. If the chamber holds 3200 gallons, what is the flow rate in gpm?

6. A clearwell has a detention time of 2 hours. What is the flow rate in gpm if the clearwell holds 8000 gallons?

7. A rectangular settling basin has a weir length of 10 feet. What is the weir overflow rate when the flow is 80,000 gpd?

Finding Perimeter/Circumference

Units

The perimeter is the total distance or length around an object, like a parcel of land, a building, or a box. **Circumference**[9] is the distance around a circle. Distance is a linear measurement, and therefore the standard units for linear measurements are used. Typical samples would be inches, feet, miles, etc.

Formula for a Rectangle

The perimeter of a **rectangle**[10] is obtained by adding the lengths of the four sides.

[9] Circumference – The perimeter of a circle.

[10] Rectangle – A four-sided figure with four right angles.

Formula for a Circle

The circumference of a circle is found by multiplying pi (π) times the **diameter**[11].

$C = \pi \times D$

Where:

C = Circumference π = Greek letter pi

D = Diameter $\pi = 3.1416$

[11] Diameter – The distance across a circle. A straight line passing through the center of a circle.

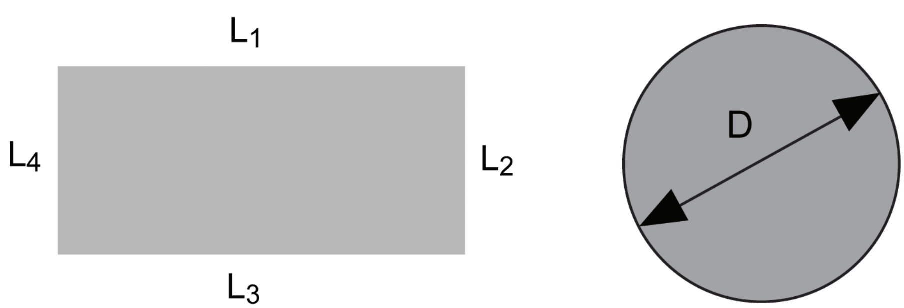
Perimeter/Circumference

Square or Rectangle

Perimeter = L1 + L2 + L3 + L4

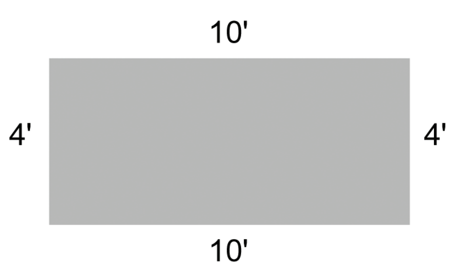
Circle

Circumference = πD



Example – Rectangle

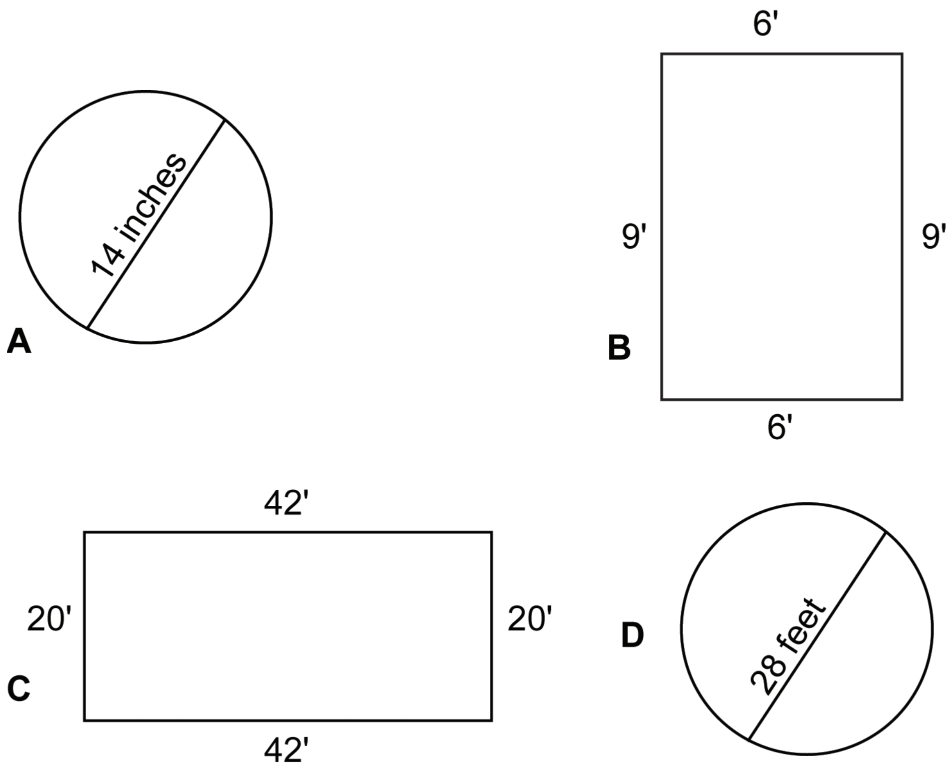
Find the perimeter of the following rectangle:



P = 10' + 4' + 10' + 4' = 28'

Practice Problems – Perimeter and Circumference

1. Find the perimeter or circumference of the following items:



[12] Cross-sectional Area – The area at right angles to the length of a pipe or basin.

[13] Radius – A line from the center of a circle or sphere to the circumference of the circle or surface of the sphere.

Finding Area

Units

Area is an expression of the square unit measurement of the surface of an item or a parcel of land. The area on top of a sedimentation basin is called the surface area. The area of the end of a pipe is called the **cross-sectional area**[12]. Area is usually expressed in squared terms such as square inches (in^2) or square feet (ft^2). Land may also be expressed in terms of sections (1 square mile) or acres (43,560 ft^2) or in the metric system as hectares (10,000m^2).

Formula for a Rectangle

The area of a rectangle is found by multiplying the length times the width.

Where:

L = length W = width

Formula for a Circle

The surface area of a circle is determined by multiplying pi times the radius squared (r^2).

Where:

A = area π = Greek letter pi

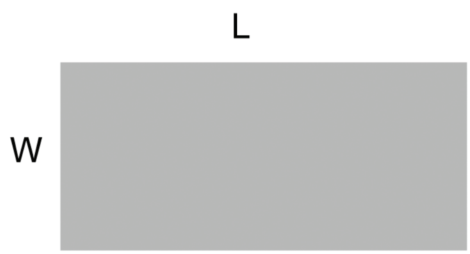
r = **radius**[13] of a circle π = 3.1416

Radius is one-half of the diameter

Area

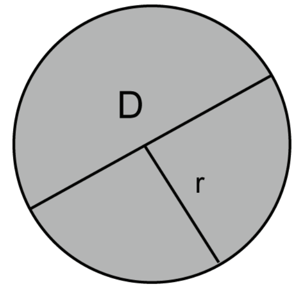
Rectangle or Square

$A = L \times W$



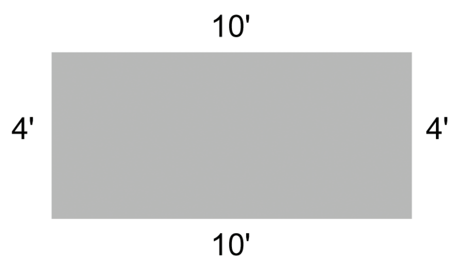
Circle

$A = \pi r^2$ or $.785D^2$



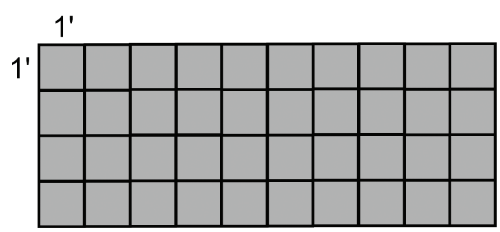
Example – Rectangle

Find the area of the following rectangle:



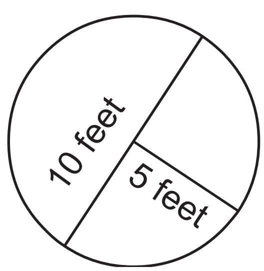
$A = 4' \times 10' = 40\ ft^2$

This is the same as saying that 40 individual pieces of paper one foot by one foot could be placed on this surface.



Example – Circle

Find the surface area of the following circle with a radius of 5 ft:



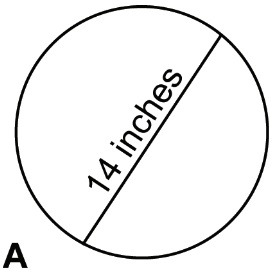
$A = \pi \times r^2$
$A = \pi \times 5^2$
$A = \pi \times 25\ ft^2$
$A = 78.5\ ft^2$

Or

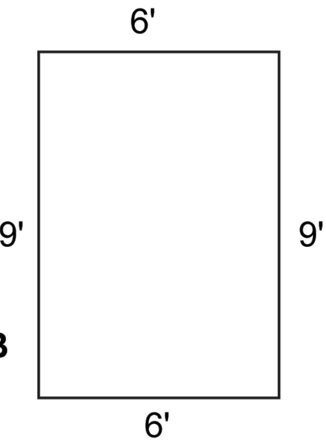
$A = .785 \times D^2$
$A = .785 \times 10^2$
$A = .785 \times 10 \times 10$
$A = 78.5\ ft^2$

Practice Problems – Area

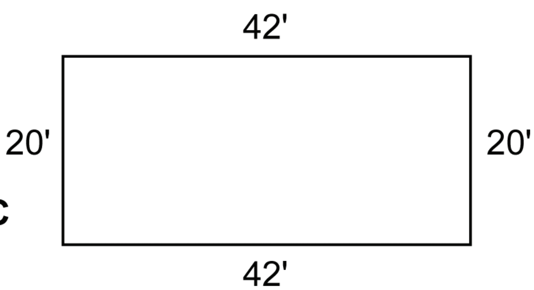
1. Find the area of the following items:



A

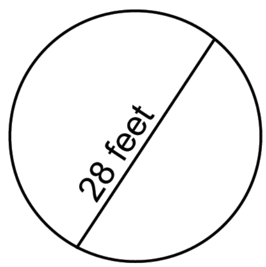


B



C

D



Finding the Volume

Units

Volume[14] is expressed in cubic units, such as cubic inches (in^3), cubic feet (ft^3), acre feet (1 Acre foot = 43,560 ft^3), etc.

[14] Volume – The amount of space occupied by or contained in an object. Measured by the number of cubes, each with an edge 1 unit long that can be contained in the object.

Formula for Rectangular Object

The volume of a rectangular object is obtained by multiplying the length times the width times the depth or height.

$$V = L \times W \times D$$

Where: L = length, W = width, D = depth or H = height

Formula for a Cylinder

The volume of a **cylinder**[15] (such as a piece of pipe or a tank) is equal to its height times pi times the radius of the cylinder squared. The length (L) and height (H) of a cylinder are the same dimension.

[15] Cylinder – A solid or hollow figure, traced out when a rectangle rotates using one of its sides as the axis of the rotation.

$$V = H \times \pi r^2$$

$$\text{or } V = H \times .785\, D^2$$

Where: $\pi = 3.1416$

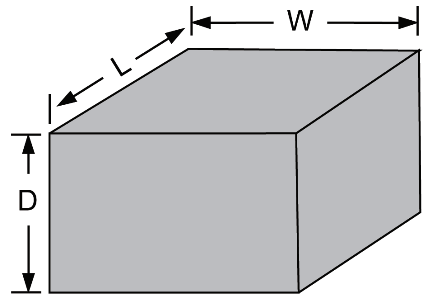
r = radius of the cylinder

H = height or length of the cylinder

Volume

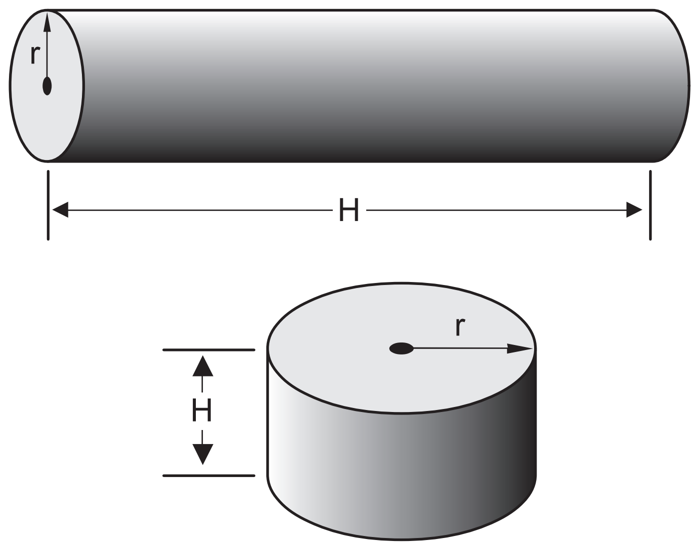
Rectangle or Square

V = L x W x D



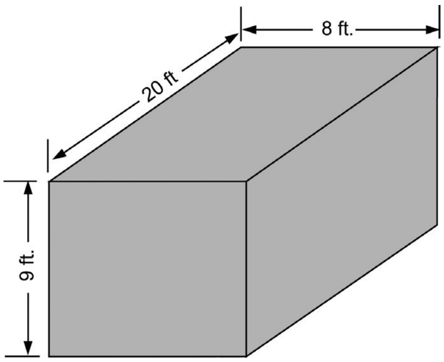
Cylinder

$V = H \times \pi r^2$ or $V = H \times .785 D^2$



Example – Volume

Find the volume in cubic feet of the sedimentation basin below:

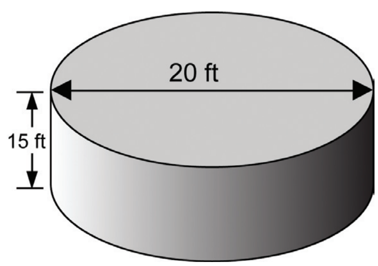


V = L x W x D
V = 20 ft x 8 ft x 9 ft
V = 1,440 ft^3

Example – Cylinder
Find the volume of a tank 20 feet in diameter and 15 feet tall.

Volume = H x πr^2 or Volume = H x .785 D^2

The radius of a circle is one-half the diameter. Since the diameter is 20 feet, the radius is 10 feet.



V = 15 ft x π (10 ft)^2
V = 15 ft x π x 100 ft^2
V = 4,712 ft^3

Or

V = 15 ft x .785 x 20^2
V = 15 ft x .785 x 20 x 20
V = 4,712 ft^3

Practice Problems – Volume

1. Find the volume of the following:
   A. A 3-inch pipe 200 feet long. (Hint, change the diameter of the pipe from inches to feet by dividing by 12.)
   B. A fuel tank 4 feet in diameter and 10 feet long.
   C. A chlorine barrel that is 20 inches in diameter and 42 inches tall.
   D. A trench 2.5 feet wide, 6 feet deep, and 60 feet long.

Working with Percent

Definition

Percent means parts of 100 parts. The symbol for percent is %. We use percent to describe portions of the whole. For instance, if a tank is 1/2 full, we say that it contains 50% of the original solution. We also use percent to describe the portion of a budget spent or a project completed. For example, "There is only 25% of the budgeted amount remaining." "The water line project is 80% complete."

How Expressed

Percentage is expressed as a whole number with a % sign after it, except when it is used in a calculation. In a calculation, percent is expressed as a decimal. The decimal is obtained by dividing the percent by 100. For instance, 11% is expressed as the decimal 0.11, since 11% is equal to 11/100. This decimal is obtained by dividing 11 by 100.

Finding Percentage

To determine what percentage a part is of the whole, divide the part by the whole.

Example 1 – Percent

There are 80 water meters to read, Jim has finished 24 of them. What percentage of the meters have been read?

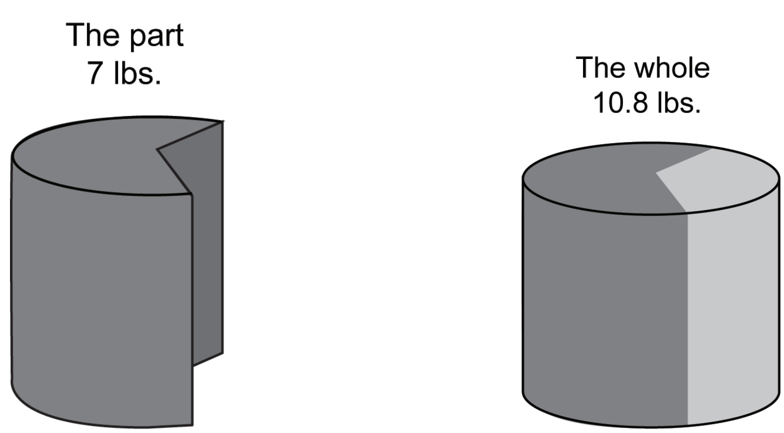
24 ÷ 80 = 0.30

The 0.30 is converted to percent by multiplying the answer by 100.
0.30 x 100 = 30%

Thus 30% of the 80 meters have been read.

Finding the Whole

To determine the whole when the part and its percentage is given, divide the part by the percentage.



Example 2 – Percent

How much 65% calcium hypochlorite is required to obtain 7 pounds of pure chlorine? The part is the 7 pounds, which is 65% of the whole.

1. Convert the percentage to a decimal by dividing by 100.

   65% ÷ 100 = 0.65

2. Divide the part by the decimal equivalent of the percentage.

   7lbs ÷ 0.65 = 10.769 – rounding 10.8 lbs.

Changing Decimals to Percent

To change the percent obtained above to the decimal equivalent, divide the percent by 100.

Example – Changing Decimals to Percent

Change 30% to a decimal.

30% ÷ 100 = 0.30 (0.30 is the decimal equivalent of 30%.)

Percentage of a Number

To find the percentage of a number, multiply the number by the decimal equivalent of the percentage given in the problem.

Example – Percentage

What is 28% of 286?

1. Change the 28% to a decimal equivalent.

   28% ÷ 100 = 0.28

2. Multiply 286 x 0.28 = 80

   28% of 286 is 80. 80 is 28% of 286.

Increase a Value by a Percent

To increase a value by a percent, add the decimal equivalent of the percent to "1," and multiply it times the number.

Example – Increasing a Value by a Percent

A filter bed will expand 25% during backwash. If the filter bed is 36 inches deep, how deep will it be during backwash?

1. Change the percent to a decimal.

   25% ÷100 = 0.25

2. Add the whole number 1 to this value.

   1 + 0.25 = 1.25

3. Multiply times the value.

   36 in x 1.25 = 45 inches

Percentage Concentrations

The concentration of chemicals, such as fluoride and hypochlorites, is commonly expressed as a percentage.

Example – Percentage Concentrations

A chlorine solution was made to have a 4% concentration. It is often desirable to determine this concentration in mg/L. This is relatively simple: the 4% is four percent of a million.

To find the concentration in mg/L when it is expressed in percent, do the following:

1. Change the percent to a decimal.

   4% ÷ 100 = 0.04

2. Multiply times a million.

   0.04 x 1,000,000 = 40,000 mg/L

We get the million because a liter of water weighs 1,000,000 mg. 1 mg in 1 liter is 1 part in a million parts (ppm). 1% = 10,000 mg/L.

Practice Problems – Percentage

A. 25% of the chlorine in a 30-gallon vat has been used. How many gallons are remaining in the vat?

B. The annual public works budget is $147,450. If 75% of the budget should be spent by the end of September, how many dollars are to be spent? How many dollars will be remaining?

C. A 75 pound container of calcium hypochlorite has a purity of 67%. What is the total weight of the calcium hypochlorite?

D. 3/4 is the same as what percentage?

E. A 2% chlorine solution is what concentration in mg/L?

F. A water plant produces 84,000 gallons per day. 7,560 gallons are used to backwash the filter. What percentage of water is used to backwash?

G. The average day winter **demand**[16] of a community is 14,500 gallons. If the summer demand is estimated to be 72% greater than the winter, what is the estimated summer demand?

[16] Demand – When related to use, the amount of water used in a period of time. The term is in reference to the "demand" put onto the system to meet the need of customers.

Pump Efficiency

Horsepower

There are three types of horsepower associated with a pumping installation:

- Electrical Horsepower (EHp) – The horsepower that is purchased from the power company.
- Brake Horsepower (BHp) – The horsepower that is the output of the electric motor. This is the input horsepower to the pump.
- Water Horsepower (WHp) – The horsepower that is the output of the pump.

Process – Pump or Motor

To determine the efficiency of a pump or motor, divide the output horsepower by the input horsepower. Then multiply the result by 100 to change the decimal into percent.

$$\frac{\text{Output Horsepower}}{\text{Input Horsepower}} \times 100 = \%\ \text{efficiency}$$

Process – When % is Given

If the efficiency of each unit is known and you wish to determine the efficiency of the entire pump station, then merely multiply the decimal equivalency of the two percentages together.

Efficiency of Motor x Efficiency of Pump = Station %

Example 1 – Pump Efficiency

It has been determined that the water horsepower of a pump is 5 Hp and the brake horsepower output of the motor is 7.2 Hp. What is the efficiency of the motor?

$$\frac{5 \text{ WHp}}{7.2 \text{ BHp}} \text{ x } 100 = 69.4\%$$

Example 2 – Pump Efficiency

If a motor is 90% efficient and the output is 7.5 BHp, what is the electrical horsepower requirement?

$$\frac{7.5 \text{ BHp}}{0.90} = 8.3 \text{ EHp}$$

Example 3 – Well Efficiency

If a pump is 70% efficient and the motor is 90% efficient, what is the efficiency of the well?

1. Change the efficiency into decimals by dividing each by 100.
   $$\frac{70\%}{100} = 0.70, \quad \frac{90\%}{100} = 0.90$$
2. Multiply the two values.
   0.70 x 0.90 = 0.63
3. Multiply the value by 100 to convert the decimal to a percentage.
   0.63 x 100 = 63%

Practice Problems – Efficiency

A. The water horsepower of a pump is 10 Hp, and the brake horsepower output of the motor is 15.4 Hp. What is the efficiency of the pump?

B. The water horsepower of a pump is 25 Hp, and the brake horsepower output of the motor is 48 Hp. What is the efficiency of the pump?

C. The efficiency of a well pump is determined to be 75%. The efficiency of the motor is estimated at 94%. What is the efficiency of the well?

D. If a motor is 85% efficient and the output of the motor is determined to be 10 BHp, what is the electrical horsepower requirement of the motor?

E. The water horsepower of a well with a submersible pump has been calculated at 8.2 WHp. The output of the electric motor is measured as 10.3 BHp. What is the efficiency of the pump?

Making Conversions

Use

Conversions are a process of changing the units of a number in order to make the number usable in a specific instance. Common conversions in water works include the following:

- gpm to cfs
- Million gallons to acre feet
- Cubic feet to acre feet
- Cubic feet of water to weight
- Cubic feet of water to gallons
- Gallons of water to weight
- gpm to **MGD**[17]
- psi to feet of **head**[18]

[17] MGD (Million gallons per day) – A unit of flow and a unit of volume.
[18] Head – The measure of the pressure of water expressed as height of water in feet: 1 psi = 2.31 feet of head.

Working with Formulas

To use a formula, you must change the units of the data given to meet the requirements of the formula.

Example – Formulas

The formula for finding **velocity**[19] in a pipe is V = Q ÷ A, where Q is the flow in cubic feet per second. We most often measure flow in gallons per minute. To use this formula, we must often convert the flow from gpm to cfs.

[19] Velocity – The speed at which water moves, expressed in feet per second.

What Is a Conversion?

A conversion is a number that is used to multiply or divide into another number in order to change the units of the number.

Known Conversions

In most instances, the conversion factor cannot be derived. It must be known. Therefore, tables such as the one below are used to find the common conversions.

Committing to Memory

Most operators memorize some standard conversions. This happens as a result of using the conversions, not as a result of attempting to memorize them.

Some Common Conversions	
Linear Measurements	Weight
1 inch = 2.54 cm 1 foot = 30.5 cm 1 meter = 100 cm = 3.281 feet = 39.4 inches 1 acre = 43,560 ft^2 1 yard = 3 feet	1 ft^3 of water = 62.4 lbs 1 gal = 8.34 lbs 1 lb = 453.6 grams 1 kg = 1000 g = 2.2 lbs 1 % = 10,000 mg/L 1 pound = 16 oz dry wt 1 ft^3 = 62.4 lbs
Volume	Pressure
1 gal = 3.78 liters 1 ft^3 = 7.48 gal 1 L = 1000 mL 1 gal = 16 cups	1 ft of head = 0.433 psi 1 psi = 2.31 ft of head
Flow	
1 cfs = 448 gpm 1gpm = 1440 gpd	

Selecting a Conversion

The key to selecting which conversion to use is to look at the units. If you wish to convert cubic feet of water to pounds, then you need a conversion that has both of these units (1 ft^3 of water = 62.4 lbs).

Complex Process

The process of converting units can be highly complex and require several steps. A working understanding of the processes used requires a basic understanding of algebra. Because this is outside of the scope of this material, a process that does not require the understanding of algebra is described below. This process works only if there is an existing conversion and only a single conversion is required.

Straight Line Conversion

The technique described below is for working with straight line conversions. A straight line conversion is one that is direct: gpm to cfs, gal to liters, gallons to pounds, etc.

Process

The best way to describe this process is with an example.

Example – Straight Line Conversion

Convert 865 gpm to cfs.

1. Place the known value on the paper with the units as a fraction and with 1 as the denominator to that fraction.
2. Place a multiplication sign (x) after the units.
3. Place a straight line after the x.
4. Follow the straight line with an equal sign (=).

$$865 \frac{\text{gpm}}{1} \text{ x}$$

5. Ask the following question, "What units do I want to get rid of?"

$$865 \frac{\text{gpm}}{1} \text{ x } \frac{?}{\text{gpm}} =$$

6. Place this unit under the straight line. In this case, we want to get rid of the gpm.
7. Ask yourself, "What units do we want when we get done?"
8. Place this unit above the straight line. The original question ask that we convert gpm to cfs. So cfs is what we want when we get done.
9. Find a conversion that goes between these two units. From the conversion table, we find the following conversion:
   1 cfs = 448 gpm
10. Place the conversion next to the proper units above or below the line. In our example, the conversion was 448 gpm, so the 448 goes below the line next to its proper units.

$$865 \frac{\text{gpm}}{1} \text{ x } \frac{1 \text{ cfs}}{448 \text{ gpm}} =$$

11. Solve the problem. The information above could be rewritten into a fraction.

$$\text{cfs} = \frac{865 \text{ gpm x } 1 \text{ cfs}}{1 \text{ x } 448 \text{ gpm}} = \frac{865 \text{ gpm x } 1 \text{ cfs}}{448 \text{ gpm}} = 1.92 \text{ cfs}$$

Practice Problems – Conversion

1. Convert the following:

   A. 750 ft^3 of water to gallons

   B. 50 gallons of water to pounds

   C. 560 gpm to cfs

   D. 4 lbs to ounces

E. 128 ft^3 of water to weight in pounds

F. 340 in^2 to ft^2

G. 3.4 cfs to gpm

H. H. 65 ft^3 to yd^3

I. 3,000 gallons to ft^3

J. 250,000 gallons to MG

K. 75 gpm to MGD

L. 8 inches to feet

M. 2.4 MGD to cfs

N. 2.4 MGD to gpm

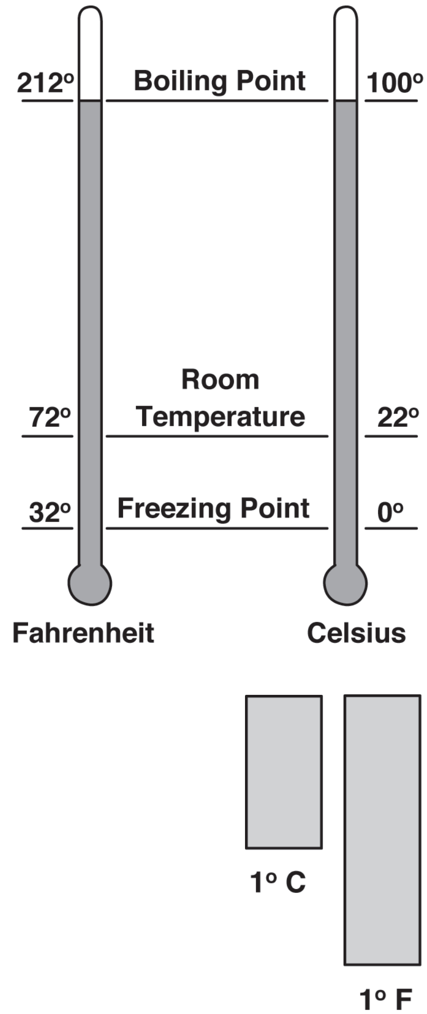
O. 65 pints to gallons

P. 2.5 ft^2 to square inches

Q. 7 yards to feet

R. 36,000 gpd to gpm

S. 125 gpm to gph



Temperature Conversion

Two Scales

There are two scales used to report temperature: the English scale of Fahrenheit and the metric scale of Celsius. There are two classic equations used to convert between these two scales:

$°C = 5/9\ (°F - 32°)$
$°F = (9/5 \times °C) + 32°$

Confusion

Typically, these two formulas provide more confusion than clarity. The following is our attempt to share a method that we find helpful in making these conversions.

The Scales

To understand how to make these conversions, start with comparing the two scales. With the Fahrenheit scale, water freezes at 32° and boils at 212°. On the Celsius scale, water freezes at 0° and boils at 100°.

Difference of 32°

We can see that if we want to go from Fahrenheit to Celsius we must start by subtracting 32°. To go from Celsius to Fahrenheit, we must add 32°.

Size of the Division

The difference between 32° and 212° is 180°. This is the difference between water freezing and boiling on the Fahrenheit scale. The difference between freezing and boiling on the Celsius scale is 100°. Therefore, we can see that each 1° change in the Celsius scale is the same as a 1.8° change in the Fahrenheit scale.

Changing Scales

As a result, to change from Celsius to Fahrenheit, we must multiply the result by 1.8. To change from Fahrenheit to Celsius we must divide by 1.8.

Final Confusion

The most confusing part is to determine if you should adjust for the 32° first or adjust for the size of the scale first. Here are the rules:

Rule 1 – To change °F to °C - subtract 32° then divide by 1.8.
Rule 2 – To change °C to °F - multiply by 1.8 and add 32°.

Conclusion

We now have two new formulas:

$$°C = \frac{°F - 32°}{1.8}$$

$$°F = °C \times 1.8 + 32°$$

A Third Choice

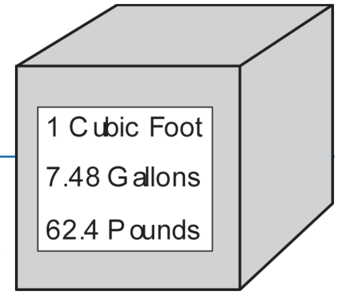
Several textbooks show a third method of making this conversion. This is a three-step method:

Step 1 – Add 40° to the existing value.
Step 2 – Multiply by 1.8 if going to °F and divide by 1.8 if going to °C.
Step 3 – Subtract 40°.

Example – Temperature Conversion

Change 212°F to °C.

1. 212°F + 40° = 252°F
2. 252°F ÷ 1.8 = 140 °
3. 140° - 40° = 100°C



Your Choice

It makes little difference which technique you use. Select the one that fits your style and proceed.

Practice Problems – Temperature Conversion

A. Change 70 °F to °C ____________

B. Change 140 °F to °C ____________

C. Change 20 °C to °F ____________

D. Change 85 °C to °F ____________

E. Change 4 °C to °F ____________

Calculating Pressure and Head

Definition

Pressure is the weight per unit area. Typical pressure units are pounds per square inch (lbs/in^2 – psi) and pounds per square foot (lbs/ft^2). The pressure on the bottom of a container is not related to the volume of the container or the size of the bottom. The pressure depends on the height of the fluid in the container. (For more information, see the Hydraulics section of Chapter 2.)

Pressure and Head

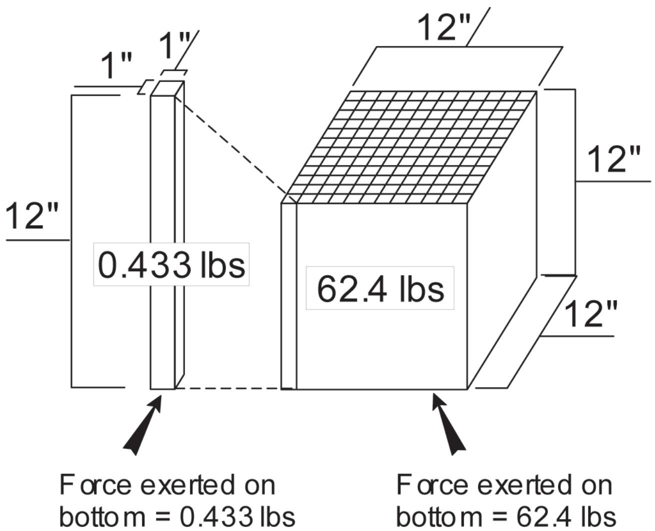
The height of the fluid in a container is referred to as head. Head is a direct measurement in feet and is directly related to pressure.

Relationship Between Feet and Head

Weight of Water

Water weighs 62.4 pounds per cubic foot.

The surface of any one side of the cube contains 144 square inches (12" x 12" = 144 in^2). Therefore, the cube contains 144 columns of water one foot tall and one inch square.



The weight of each of these pieces can be determined by dividing the weight of the water in the cube by the number of square inches.

$$\text{Weight} = \frac{62.4 \text{ lbs}}{144 \text{ in}^2} = 0.433 \text{ lbs/in}^2$$

or 0.433 psi

Since this is the weight of one column of water one foot tall, the true expression would be 0.433 pounds per square inch per foot of head or 0.433 psi/ft.
What formula do you want here?

Conversion

We now have a conversion between feet of head and psi.

1 foot of head = 0.433 psi

While it can be calculated from the relationship above, it is also desirable to know the relationship between pressure and feet of head. In other words, 1 psi represents how many feet of head. This is determined by dividing 1 by 0.433 psi.

$$\text{foot of head} = \frac{1 \text{ ft}}{0.433 \text{ psi}} = 2.31 \text{ ft/psi}$$

In other words, if a pressure gauge were reading 10 psi, we know that the height of the water necessary to represent this pressure would be 10 psi x 2.31 ft/psi = 23.1 ft.

Both Conversions

1 ft = 0.433 psi
1 psi = 2.31 feet

Which Conversion to Use

Many operators find having two conversions for the same thing is confusing. They agree that it is best to memorize one and stay with it. The most accurate conversion is the 1 ft = 0.433 psi. This is the conversion used in this text.

Example – Conversion

To convert 40 psi to feet of head, use the standard conversion technique described earlier.

$$40 \frac{\text{psi}}{1} \times \frac{\text{ft}}{0.433 \text{ psi}} = 92.4 \text{ feet}$$

Convert 40 feet to psi.

$$40 \frac{\text{ft}}{1} \times \frac{0.433 \text{ psi}}{1 \text{ ft}} = 17.3 \text{ psi}$$

Another Way

As you can see, if you are attempting to convert psi to feet, you divide by 0.433, and if you are attempting to convert feet to psi, you multiply by 0.433. It can become confusing about when to divide and when to multiply. The above process can be most helpful in making that determination. However, there is another way. Notice that the relationship between psi and feet is almost two to one. It takes slightly more than two feet to make one psi. Therefore, when looking at a problem where the data is in pressure and you want it in feet, we can see that the answer will be at least twice as large as the number we are starting with. For example, if the pressure were 20 psi, we know that the head is over 40 feet. Therefore, we must divide by 0.433 to obtain the correct answer.

Practice Problems – Pressure and Head

1. Make the following conversions:

   A. Convert a pressure of 45 psi to feet of head.

   B. Convert 12 psi to feet of head.

   C. Convert 85 psi to feet of head.

   D. It is 112 feet in elevation between the top of the reservoir and the watering point. What will the static pressure be at the watering point?

   E. A reservoir is 20 feet deep. What will the pressure be at the bottom of the reservoir?

Determining Flow

Units

Flow is expressed in the English system of measurements using many terms. The most common flow terms include the following:

- gpm – Gallons per minute
- cfs – Cubic feet per second
- gpd – Gallons per day
- MGD – Million gallons per day

Conversions

Flow rates can be converted to different units using the conversion process describe above. The most common flow conversions are 1 cfs = 448 gpm and 1 gpm = 1440 gpd.

Gallons per Day (gpd) to MGD

To convert gallons per day to MGD, divide the gpd by 1,000,000.

Example – Conversion of gdp to MGD

Convert 125,000 gallons to MGD.

$$\frac{125{,}000 \text{ gpd}}{1{,}000{,}000} = 0.125 \text{ MGD}$$

Convert 2,300,000 gpd to MGD.

$$\frac{2{,}300{,}000 \text{ gpd}}{1{,}000{,}000} = 0.2.3 \text{ MGD}$$

Conversion of MGD to gpm

There are many instances where the design or plant information is given in MGD, and we wish to have the flow in gpm. This conversion is accomplished in two steps:

1. Convert to gpd by multiplying by 1,000,000.
2. Convert to gpm by dividing by the number of minutes in a day (1440 min/day).

Example – Conversion of MGD to gpm

Convert 0.125 MGD to gpm.

1. Convert the flow in MGD to gpd.

   0.125 MGD x 1,000,000 = 125,000 gpd

2. Convert to gpm by dividing by the number of minutes in a day (24 hrs per day x 60 min per hour) 1440 min/day.

$$\frac{125{,}000 \text{ gpd}}{1{,}440 \text{ min/day}} = 86.6 \text{ or } 87 \text{ gpm}$$

Convert gpd to gpm

The process of converting gpd to gpm is shown in the example above. The process is to divide the flow in gpd by the number of minutes in a day (1440 min/day).

Conversion of gpm to cfs

The conversion from gpm to cfs is shown in the examples in the above section on conversions. The conversion is 1 cfs = 448 gpm.

Determining Flow Equation

Flow in a pipeline, channel, or stream is found using the equation:

Q = V x A
Where
Q = cubic feet per second (cfs)
V = velocity in feet per second (ft/sec)
A = area in square feet (ft^2)

Example – Determining Flow

Find the flow in cfs in a 6 -inch line, if the velocity is 2 feet per second.

1. Determine the cross-sectional area of the line in square feet. Start by converting the diameter of the pipe to inches.

   The diameter is 6 inches: therefore, the radius is 3 inches. 3 inches is 3/12 of a foot or 0.25 feet.

2. Now find the area in square feet.

$A = \pi \times r^2$		$A = 0.785 \times D^2$
$A = \pi \times (0.25 \text{ ft})^2$	Or	$A = 0.785 \times 0.5^2$
$A = \pi \times 0.0625 \text{ ft}^2$		$A = 0.785 \times .05 \times .05$
$A = 0.196 \text{ ft}^2$		$A = 0.196 \text{ ft}^2$

3. Now find the flow.

   Q = V x A
   Q = 2 ft/sec x 0.196 ft^2
   Q = 0.3927 cfs or 0.4 cfs

Practice Problems – Flow

A. Find the flow in MGD when the flow is 34,000 gpd.

B. Find the flow in gpm when the total flow for the day is 65,000 gpd.

C. Find the flow in gpm when the flow is 1.3 cfs.

D. Find the flow in gpm when the flow is 0.25 cfs.

E. Find the flow in a 4-inch pipe when the velocity is 1.5 feet per second.

Calculating Detention Time

Detention time is the amount of time that a fluid stays in a container.

Units

Detention time is expressed in units of time. The most common are seconds, minutes, hours, and days.

Calculations

The simplest way to calculate the detention time is to divide the volume of the container by the flow rate into the container. The theoretical detention time of a container is the same as the amount of time it would take to fill the container if it were empty.

Volume Units

The most common volume units used are gallons. However, on occasion cubic feet may also be used.

Time Units

The time units will be in whatever units are used to express the flow. For instance, if the flow is in gpm, then the detention time will be in minutes. If the flow is in gpd, then the detention time will be in days. If in the final result the detention time is in the wrong time units, then simply convert to the appropriate units.

Example – Detention Time

The reservoir for the village is 85,000 gallons. The well will produce 55 gpm. What is the detention time in the tank in hours?

$$DT = \frac{85{,}000 \text{ gal}}{55 \text{ gpm}} = 1{,}545 \text{ min or } \frac{1{,}545 \text{ min}}{60 \text{ min/hr}} = 25.8 \text{ hrs}$$

Practice Problems – Detention Time

A. How long will it take to fill a 50-gallon hypochlorite tank if the flow is 5 gpm?

B. Find the detention time in a 45,000 gallon reservoir if the flow rate is 85 gpm.

C. If the fuel consumption to the boiler is 35 gallons per day, how many days will the 500 gallon tank last?

D. The sedimentation basin of a water plant contains 5,775 gallons. What is the detention time if the flow is 175 gpm?

Ratio and Proportion

What is a Ratio?

A ratio is a relationship between two numbers. A ratio can be written using a colon (1:2, 5:9, 20:60) or a fraction (1/2, 5/9, or 20/60).

What Is a Proportion?

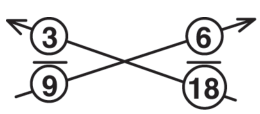
A proportion exists when the relationship between one ratio is the same as the relationship between a second ratio.

How Is This Determined?

To determine if two ratios are proportional, the two are cross-multiplied. If the answers are equal, then they are proportional.

Example 1 – Ratio and Proportion

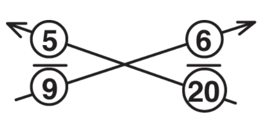
Determine if 3/9 is proportional to 6/18.



9 x 6 = 54 and 3 x 18 = 54; therefore, the two ratios are proportional.

Example 2 – Ratio and Proportion

Determine if 5/9 and 6/20 are proportional.



9 x 6 =54 and 5 x 20 = 100; therefore, the two are not proportional.

So Now What?

This process is an introduction into the practical use of ratios and proportions used to solve common problems. To use this process, we need to discuss one more major step and then provide some basic rules. The first step is what to do when one part of a ratio is unknown.

The Unknown

To solve for an unknown portion of a ratio, follow these steps:

Step 1 – Set up the ratios in a proportion format. Place an "X" in the ratio for the unknown value. Notice that we have set the two ratios up as a proportion with the colon (:) between them.

$$\frac{2}{15} : \frac{X}{50}$$

Step 2 – Cross-multiply keeping all numbers as numerators. (We are multiplying both sides of the equestion by the denominators over 1.)

$(15)\ (X) = (2)\ (50)$

Step 3 – To get the X on the left side of the equation, divide both sides by 15.

$$X = \frac{(2)\ (50)}{15}$$

Step 4 – Solve for X.

$X = 6.67$

Practical Application

Proportion problems deal with larger and smaller values of the same units. For instance, a common proportion problem might be the following:

If it takes 5 pounds of calcium hypochlorite to give the correct dosage in a 35 gallon tank, then how many pounds will it take to make 12 gallons?

Rule 1 – Set up the proportion with the same types of units on one side of the colon. Using our example above, pounds would go on one side and gallons on the other.

Rule 2 – The numerators must contain the same size of units (either larger or small units), and the denominator must contain the same size units (either larger or smaller). For instance:

$$\frac{\text{Smaller Value}}{\text{Larger Value}} : \frac{\text{Smaller Value}}{\text{Larger Value}}$$

or

$$\frac{\text{Larger Value}}{\text{Smaller Value}} : \frac{\text{Larger Value}}{\text{Smaller Value}}$$

Rule 3 – Place an "X" in the unknown value, and solve for "X."

Hint

Using our example above, you can set up a verbal relationship. For instance, 5 pounds is to 35 gallons as X pounds is to 12 gallons. To place these in the equation, start in the upper left with the 5 pounds. The "is to" represents the equal sign. For instance:

$$\frac{5 \text{ lbs}}{X} : \frac{35 \text{ gal}}{12 \text{ gal}}$$

(X) (35 gal) = (5 lbs) (12 gal)

$$X = \frac{(5 \text{ lbs})(12 \text{ gal})}{35 \text{ gal}} = 1.7 \text{ lbs}$$

Example 3 – Ratio and Proportion

If one chlorine cylinder is used in 20 days, how many will be used in 100 days?

Step 1 – Set up the proportion.

1 cylinder is to 20 days as X cylinders is to 100 days.

$$\frac{1 \text{ cylinder}}{X} : \frac{20 \text{ days}}{100 \text{ days}}$$

Step 2 – Cross-multiply.

(X cylinders) (20 days) = (1 cylinder) (100 days)

Step 3 – Rearrange the equation to get "X" on the left by its self; divide both sides by 20 days.

$$X \text{ cylinders} = \frac{(1 \text{ cylinder})(100 \text{ days})}{20 \text{ days}}$$

Step 4 – Solve for X cylinders.

X = 5 cylinders

Practice Problems – Ratio and Proportion

A. It takes 6 gallons of chlorine solution to obtain a proper residual when the flow is 45,000 gpd. How many gallons will it take when the flow is 62,000 gpd?

B. A motor is rated at 41 amps average draw per leg at 30Hp. What is the actual Hp when the draw is 36 amps?

C. If it takes 2 operators 4.5 days to clean an aeration basin, how long will it take three operators to do the same job?

D. If it takes 20 minutes to pump a wet well down with one pump pumping at 125 gpm, then how long will it take if a 200 gpm pump is used?

E. It takes 3 hours to clean 400 feet of collection system using a sewer ball. How long will it take to clean 250 feet?

F. It takes 14 cups of HTH to make a 12% solution, and each cup holds 300 grams. How many cups will it take to make a 5% solution?

Pounds Formula

Use

One of the most common formulas used by water and wastewater operators is the pounds formula. This formula is used to determine the loading on the plant and its various process units; the loading on the receiving water; and the amount of chemicals needed for a specific function, such as disinfection. The formula can also be used to determine the amount of mixed liquor in the aeration basin and the amount of sludge to be disposed of in the landfill.

Basic Assumption

The formula assumes that all of the material found in water (TSS, BOD, MLSS, Chlorine, etc.) weighs the same as water, that is, 8.34 pounds per gallon.

The Formula

The basic pounds formula is

Lbs = Flow, MG x 8.34 x Conc, mg/L

Where
Lbs = pounds
MG = Flow or volume in millions of gallons
Conc = concentration or dosage in mg/L

Process

The process of using the pounds formula to determine pounds of a substance in water is relatively simple. Just plug the values into the appropriate slots and multiply. However, there are two items that can cause some confusion: flows of less than one million gallons and concentrations in ppm.

Flow

Flow and volume are often expressed in gallons per day, gallons per minute and millions of gallons per day. Regardless of how they are expressed, they must be converted to MG in order for them to be placed in this formula. When the flow is in gallons or million gallons per day (MGD), the pounds must be expressed in lbs/day.

Flow or Volume in gpd

When a flow or volume is expressed in gallons, it must be converted to MGD by dividing it by 1,000,000. For instance, a flow of 120,000 gpd is 0.12 MGD, and a flow of 40,000 gpd is 0.04 MGD.

Flow or Volume in gpm

When a flow or volume is expressed in gpm, it must be first converted to gpd by multiplying by the number of minutes per day (1440) and then divided by 1,000,000 to get MGD.

Example 1 – Flow

The flow is 250 gpm. What is the flow in MGD?

250 gpm X 1440 min/day = 360,000 gpd

360,000 gpd ÷ 1,000,000 = 0.36 MGD

PPM

PPM or ppm is an abbreviation for parts per million. Parts per million is the same as mg/L (milligrams per liter). While they mean the same, mg/L is the preferred and more accepted unit.

Example 2 –Flow

A water treatment plant feeds alum at a dosage of 26 mg/L. The flow is 2.5 MGD. How many pounds of alum are used each day?

lbs/day = MGD x 8.34, lbs/gal x Conc, mg/L
lbs/day = 2.5 MGD x 8.34 lbs/gal x 26 mg/L
lbs/day = 542 pounds/day

Practice Problems – Pounds Formula

A. How many pounds of 100% gas chlorine are needed to disinfect a flow of 85,000 gpd at 12 mg/L?

B. The suspended solids in a stream are measured at 360 mg/L. The stream flow is estimated to be 3.2 MGD. How many pounds of solids are carried by the stream each day?

C. The backwash water of a treatment plant contains 320 mg/L of solids. 4,000 gallons of water are used for backwash. How many pounds of solids are deposited in the backwash lagoon with each backwash?

D. A 400,000-gallon storage tank is to be disinfected with 50 mg/L of chlorine. How many pounds of gas chlorine would it take to disinfect this tank?

E. How many pounds of calcium hypochlorite at 67% is needed to disinfect 125,000 gallon per day flow with a dosage of 8 mg/L?

Metric System (SI)

Description

The system of units and measures that is commonly called the metric system is more correctly titled the SI (or System International). This is the system that is used throughout most of the world, except the United States. The metric system is a base 10 system. This base makes it very easy to convert between various units. While the system has not gained widespread acceptance in the US, it is widely accepted in most of the world, and it is highly desirable that the operator be familiar with the basic components of the system.

Base Units

The following are the base units of this system.

Quantity	Unit	Symbol
Length	meter	m
Mass	gram	g
Time	second	s
Temperature	Kelvin	K
Volume	liter	L

Description of the Units

Length

The basic unit of measurement of length is the meter. A meter is approximately 3 feet in length (3.281 ft).

Mass

Mass in the metric system is used as a comparison with pounds in the English system. The base unit is the gram. There are approximately 454 grams in a pound.

Time

The time base of seconds in the metric system is the same as the time base in the English system.

Temperature

The basic unit of temperature in the metric system is the Kelvin unit. However, Celsius is the unit that is most commonly associated with this system. One degree Kelvin is the same size as one degree Celsius. The major difference is in the starting point (zero). In the Kelvin thermometer, 0°K is equal to -273.15 °C.

Metric Prefixes

English

When a number becomes too large to handle easily, we convert it by dividing it by a value and call it something else. For instance, when we have too many feet, we divide by 3 and call the result yards, or we divide by 5,280 and call the result miles. Seldom are the divisions even numbers, and they change with each set of units. Notice that yards are feet divided by 3, but miles are feet divided by 5,280. This makes it difficult to remember how to make the proper conversion.

Metric

In the metric system, there are standard prefixes to numbers that have been divided in order to reduce their size. In addition, the divisions are always in multiples of 10. The following is a listing of the basic metric prefixes:

Prefix	Symbol	Mathematical Value
giga	G	1,000,000,000
mega	M	1,000,000
kilo	k	1,000
hecto*	h	100
deka*	da	10
Base	none	1
deci*	d	0.1
centi*	c	0.01
milli	m	0.001
micro	µ	0.000,001
nano	n	0.000,000,0001

* Under normal circumstances these prefixes are seldom used and should, if possible, be avoided.

Metric Abbreviations

Limitations

The following is a listing of common abbreviations used in math problems in the water and wastewater field. With a few exceptions, this listing is limited to those abbreviations that are associated with the SI or metric system units of measurement. Abbreviations associated with the English system of measurements are found at the beginning of this lesson on metric units.

Unit	Symbol	Unit	Symbol
year	A	newton	N
gram	g	pascal	Pa
hour	h	second	s
hectare	ha	watt	w
joule	j	milliliter	mL
kilogram	kg	kilowatt	KW
kilometer	km		
liter	L		
meter	m		
milligram	mg		
minute	min		

Metric to English Conversions

Area

From	To	Multiply	by	to get
square feet	square meters	ft^2	0.0929	m^2
square inches	square meters	in^2	6.4516×10^{-4}	m^2
acre	hectare	ac	0.4047	ha
square meter	square feet	m^2	10.76	ft^2
hectare	acre	ha	2.471	ac

Energy - Work

From	To	Multiply	by	to get
kilowatt-hour	joules	kwh	3.6×10^6	j
horsepower-hour	joules	Hph	2.6845×10^6	j

Flow Rate

From	To	Multiply	by	to get
cubic feet per second	meters per second	cfs	0.028317	m^3/s
gallons per minute	liters per second	gpm	0.06309	L/s
liters/second	gallons per minute	L	15.85	gpm

Force

From	To	Multiply	by	to get
pounds	Newtons	lbs	4.4482	N

Length

From	To	Multiply	by	to get
inch	meters	in	0.0254	m
inch	centimeters	in	2.54	cm
foot	meters	ft	0.3048	m
mile	meters	mi	1609.3	m
mile	kilometers	mi	1609	km
meter	foot	m	3.281	ft
kilometer	mile	km	0.6214	mi

Mass

From	To	Multiply	by	to get
ounce	kilogram	oz	0.02835	kg
pound	kilogram	lb	0.45359	kg
pound	gram	lb	453.6	g
liter of water	kilogram	L	1	kg
kilogram	pounds	kg	2.205	lb

Metric to English Conversions

Power				
From	To	Multiply	by	to get
horsepower	watts	Hp	746	w
Joules/second	watts	J/s	1	w
Pressure				
From	To	Multiply	by	to get
pounds /square inch	pascal	psi	6895	Pa
pounds /square inch	kilopascal	psi	6.9	kPa
pounds /square inch	newtons /square meter	psi	6895	N/m^2
kilopascal	pounds/square inch	kPa	0.145	psi
Velocity				
From	To	Multiply	by	to get
foot/second	meter/second	ft/s	0.3048	m/s
miles/hour	meter/second	mph	0.44704	m/s
kilometers/hour	meter/second	km/hr	0.27778	m/s
Volume				
From	To	Multiply	by	to get
acre-foot	cubic meters	ac-ft	1233.5	m^3
cubic foot	cubic meters	ft^3	0.028317	m^3
gallon (U.S.)	cubic meters	gal	3.7854×10^{-3}	m^3
gallon (U.S.)	liters	gal	3.78	L
gallon (Imperial)	cubic meters	gal(I)	4.5459×10^{-3}	m^3
liter	cubic meters	L	1000	m^3
yard	cubic meters	yd	0.76455	m^3
cubic meters	gallons	m^3	264.2	gal
cubic meters	cubic feet	m^3	35.31	ft^3
cubic meters	yards	m^3	1.308	yd

Metric Conversions

Two Types

Like the English system, there are two types of conversions: reducing or enlarging a value within the same base and converting between bases.

Conversions in the Same Base

Prefix Is the Key

The key to making conversions within the same base lies in understanding the prefixes and their associated values. For instance, the prefix kilo indicates 1000; therefore, a kilogram is 1000 grams, and a kilometer is 1000 meters.

Linear Conversions

The base unit of linear measurement is the meter. The common divisions of the meter are the following:

Kilometer = 1000 meters
Centimeter = 1/100 of a meter or there are 100 centimeters in a meter.
Millimeter = 1/1000 of a meter or there are 1000 millimeters in a meter.

Example 1 – Conversion

Convert 4500 meters to kilometers.

Step 1 – Divide the number of meters by 1000 (kilo).

$$\frac{4{,}500 \text{ meters}}{1{,}000 \text{ meters/kilometers}} = 4.5 \text{ kilometers}$$

Example 2 – Conversion

Convert 4.6 meters to centimeters.

Step 1 – Multiply meters times 100 (centi).

4.6 meters x 100 cm = 460 cm

Volume Conversions

The most common volume conversion is from liters to milliliters. Since milli is the prefix for 0.001, liters can be converted to milliliters by multiplying times 1000. Likewise, milliliters can be converted to liters by dividing by 1000.

1L = 1000 mL

Example 3 – Conversion

Convert 2,400 mL to liters.

Step 1 – Divide the number of milliliters by 1000.

$$\frac{2{,}400 \text{ mL}}{1{,}000 \text{ mL/L}} = 2.4 \text{ L}$$

Example 4 – Conversion

Convert 0.35 L to milliliters.

Step 1 – Multiply the number of liters times 1000.

0.35 L X 1000 mL/L = 350 mL

Mass Conversion

The two most common mass conversions are between kilograms and grams and between milligrams and grams. Since kilo is 1000 grams, it can be converted to kilograms by dividing by 1000. Since milli is 1000, grams can be converted to milligrams by multiplying by 1000.

Example 5 – Conversion

Convert 2,600 mg to grams.

Step 1 – Divide the 2,600 mg by 1,000.

$$\frac{2{,}600 \text{ g}}{1{,}000 \text{ mg/g}} = 2.6 \text{ g}$$

Example 6 – Conversion

Convert 1,345,000 g to kilograms.

Step 1 – Divide 1,345,000 g by 1,000.

$$\frac{1{,}345{,}000 \text{ g}}{1{,}000 \text{ g/kg}} = 1345 \text{ kg}$$

Conversion to Another Base

Key

The common conversion made between basic units is between mass and volume. Volume in the metric system is expressed as liters, cubic meters, or cubic centimeters. The relationship between mass and volume is the following:

> 1g =1ml =1cc, (one gram is equal to 1 milliliter is equal to 1 cubic centimeter)

Other Relationships

1 cubic meter (m^3) = 1000 liters
1kg = 1 L

Cubic Measurements

It is common practice to convert liters to cubic meters when the volume exceeds 1000 liters.

Practice Problems - Answers

Example 7 – Conversion

Convert 500 kilograms of water to liters.

Since kilograms and liters are the same base, the conversion is a simple matter of changing the units. 500 kg = 500 L

Example 8 – Conversion

Convert 3,600 L to cubic meters.

Step 1 – Divide the liters by 1000.

$$\frac{3{,}600 \text{ L}}{1{,}000 \text{ L/m}^3} = 3.6 \text{ m}^3$$

Practice Problems – Metric Conversion

A. Convert 4.2 kg to g.

B. Convert 0.5 kg to g.

C. Convert 4600 g to kg.

D. Convert 3.4 km to m.

E. Convert 0.5 km to m.

F. Convert 10,000 m to km.

Practice Problem Answers – Fractions

1. Reduce the following to their simplest terms.

A.	1/2	Both were divided by 2
B.	2/3	Both were divided by 6
C.	3/4	Is in its simplest terms
D.	3/4	Both were divided by 2
E.	3/4	Both were divided by 8
F.	1/2	Both were divided by 9
G.	5/9	Both were divided by 3

Practice Problem Answers – Rounding

1. Round the following to the nearest hundredths:

A.	2.4568	= 2.46
B.	27.2534	= 27.25
C.	128.2111	= 128.21
D.	364.8762	= 364.88
E.	354.777777	= 354.78
F.	34.666666	= 34.67
G.	67. 33333	= 67.33

1. Round the following answers off to the most significant digit:

A.	26.34 x 124.34567 = 3,275.26495	= 3,275.26
B.	25.1 + 26.43 = 51.53	= 51.5
C.	128.456 – 121.4 = 7.056	= 7.1
D.	23.5 ft x 34.25 ft = 804.875 ft^2	= 804.9 ft^2
E.	12,457.92 x 3 = 37,373.76	= 37,374

Practice Problem Answer – Averages

1. The total is 2.4. There are 9 numbers in the set. Therefore 2.4 ÷ 9 = 0.2667, rounding to 0.3.

Practice Problem Answers – Formulas

1. Find the diameter of a settling basin that has a circumference of 126 feet.

$$C = \pi D$$

$$126 \text{ ft} = \pi D$$

$$D = \frac{126 \text{ ft}}{\pi} = 40 \text{ ft}$$

2. Find the diameter of a pipe that has a circumference of 12 9/16”.

12 9/16” = 12.56”

$C = \pi D$

$12.56 \text{ in} = \pi D$

$$D = \frac{12.56 \text{ in}}{\pi} = 4 \text{ in}$$

3. Find the diameter of a settling basin that has a surface area of 113 ft^2.

$A = \pi r^2$

$113 \text{ ft}^2 = \pi r^2$

$$r = \sqrt{\frac{113 ft^2}{\pi}} = 5.997 \text{ or } 6 \text{ ft}$$

6 ft x 2 = 12 ft diameter

4. Find the diameter of a storage tank that has a surface area of 314 ft^2.

$A = \pi r^2$

$314 \text{ ft}^2 = \pi r^2$

$$r = \sqrt{\frac{113 ft^2}{\pi}} = 9.997 \text{ or } 10 \text{ ft}$$

D = 10 ft x 2 = 20 ft

5. The detention time in a chlorine contact chamber is 42 minutes. If the chamber holds 3200 gallons, what is the flow rate in gpm?

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

$$42 \text{ min} = \frac{3200 \text{ gal}}{\text{flow, gpm}} = \text{flow, gpm} = \frac{3200 \text{ gal}}{42 \text{ min}}$$

flow = 76 gpm

6. A clearwell has a detention time of 2 hours. What is the flow rate in gpm if the clarifier holds 8000 gallons?

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

$$120 \text{ min} = \frac{8000 \text{ gal}}{\text{flow, gpm}} = \text{flow, gpm} = \frac{8000 \text{ gal}}{120 \text{ min}}$$

flow, gpm = 67 gpm

7. A rectangular settling basin has a weir length of 10 feet. What is the weir overflow rate when the flow is 80,000 gpd?

$$WO = \frac{\text{Flow rate in gpd}}{\text{Weir length in feet}}$$

$$WO = \frac{80{,}000 \text{ gpd}}{10 \text{ ft}} = 8{,}000 \text{ gpd/ft}$$

Practice Problem Answers – Perimeter/Circumference

1. Find the perimeter or circumference of the following items:

   A. $= \pi$ x 14 inches = 44 inches

   B. 6 ft + 9 ft + 6 ft + 9 ft = 30 ft

   C. 42 ft + 20 ft + 42 ft + 20 ft = 124 ft

   D. π x 28 feet = 88 feet

Practice Problem Answers – Area

1. Find the area of the following items:

   A. Diameter is 14 inches. Therefore, the radius, being 1/2 of the diameter, is 7 inches.
   $A = \pi \times (7 \text{ in})^2$
   $A = \pi \times 49 \text{ in}^2$
   $A = 154 \text{ in}^2$

   B. A = L x W
   $A = 9 \text{ ft} \times 6 \text{ ft} = 54 \text{ ft}^2$

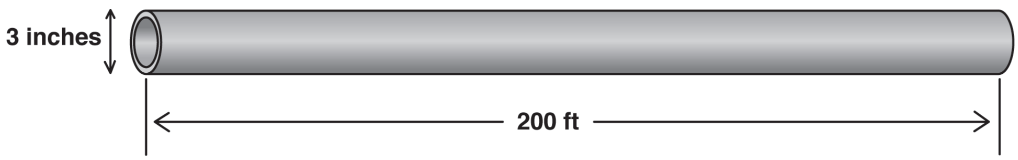
   C. A = L x W
   A = 42 ft x 20 ft
   $A = 840 \text{ ft}^2$

   D. The diameter is 28 feet. The radius is one-half of the diameter; therefore, the radius is 14 feet.
   $A = \pi \times r^2$
   $A = \pi \times (14 \text{ feet})^2$
   $A = \pi \times 196 \text{ ft}^2$
   $A = 616 \text{ ft}^2$

Practice Problem Answers – Volume

1. Find the volume of the following:

   A. 3-inch pipe 200 feet long



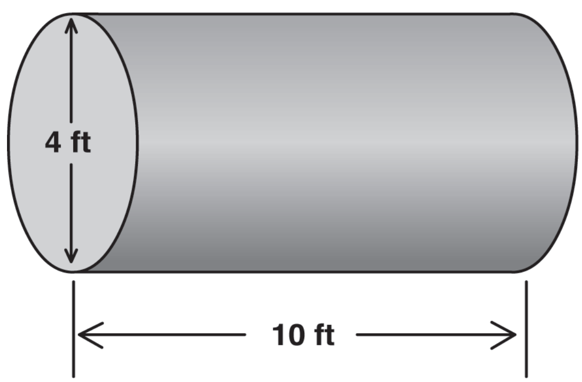
Hint: change the diameter of the pipe from inches to feet by dividing by 12.

1. Change diameter to feet 3 ÷ 12 = 0.25 ft.

2. Find the radius by dividing the diameter by 2.
   0.25 ft ÷ 2 = 0.125 ft

3. Find the volume.
   $V = L \times \pi r^2$
   $V = 200 \text{ ft} \times \pi (0.125\text{ft})^2$
   $V = 200 \text{ ft} \times \pi \times 0.01563 \text{ ft}^2$
   $V = 9.8 \text{ ft}^3$

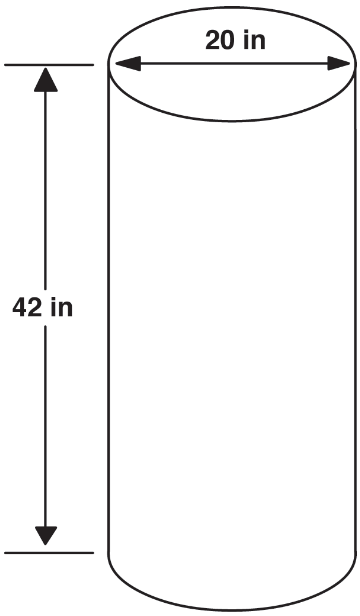
B. Find the volume of a fuel tank 4 feet in diameter and 10 feet long.



1. Find the radius of the tank. The radius is one-half of the diameter.
   4 ft ÷ 2 = 2 ft

2. Find the volume.
   $V = L \times \pi r^2$
   $V = 10 \text{ ft} \times \pi (2 \text{ ft})^2$
   $V = 10 \text{ ft} \times \pi \times 4 \text{ ft}^2$
   $V = 125.7 \text{ ft}^3$

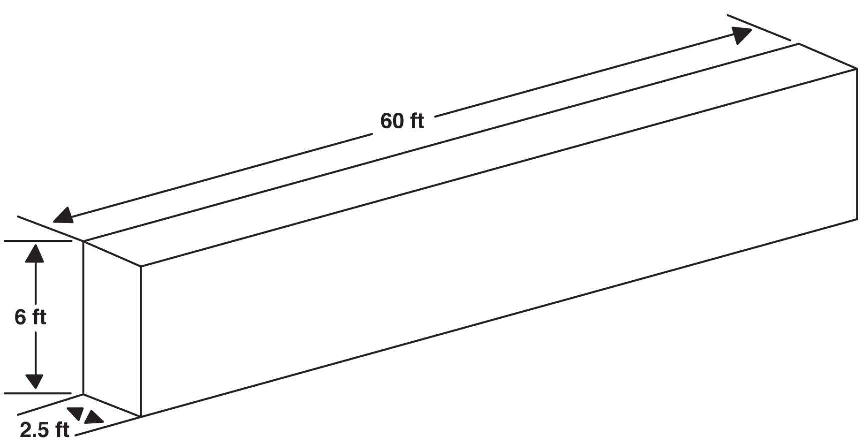
C. Find the volume of a chlorine barrel that is 20 inches in diameter and 42 inches tall.



1. Find the radius of the tank. The radius is one-half of the diameter.
   20 inches ÷ 2 = 10 inches

2. Find the volume.
   $V = H \times \pi r^2$
   $V = 42 \text{ in} \times \pi (10 \text{ in})^2$
   $V = 42 \text{ in} \times \pi \times 100 \text{ in}^2$
   $V = 13{,}195 \text{ in}^3$

D. Find the volume of a trench 2.5 feet wide, 6 feet deep, and 60 feet long.



$V = L \times W \times D$
$V = 60 \text{ ft} \times 2.5 \text{ ft} \times 6 \text{ ft}$
$V = 900 \text{ ft}^3$

Practice Problem Answers – Percentage

A. 25% of the chlorine in a 30 gallon vat has been used. How many gallons are remaining in the vat?

1. Find the percentage of chlorine remaining.
100% – 25% = 75%

2. Change the percent to a decimal.
75% ÷ 100 = 0.75

3. Multiply the percent as a decimal times the tank volume.
0.75 x 30 gal = 22.5 gal

B. The annual public works budget is $147,450.00. If 75% of the budget should be spent by the end of September, how many dollars are to be spent? How much is remaining?

1. Change the percentage to a decimal.
75% ÷ 100 = 0.75

2. Multiply the budget amount by the percent to be used.
$147,450.00 x 0.75 = $110,587.50 to be spent

3. Find what will be remaining.
$147,450.00 – 110,587.50 = $36,862.50

C. There are 50 pounds of pure chlorine in a container of 67% calcium hypochlorite. What is the total weight of the container?

1. Change the percent to a decimal.
67% ÷ 100 = 0.67

2. Divide the weight by the percentage.

$$\frac{50 \text{ lbs}}{0.67} = 74.6 \text{ lbs}$$

D. 3/4 is the same as what percentage?

1. Change the fraction into a decimal.

$$\frac{3}{4} = 0.75$$

2. Convert to a percentage.
0.75 x 100 = 75%

E. A 2% chlorine solution is what concentration in mg/L?

1. Change the percentage to a decimal.
2% ÷ 100 = 0.02

2. Multiply times one million.
0.02 x 1,000,000 = 20,000 mg/L

F. A water plant produces 84,000 gallons per day. 7,560 gallons are used to backwash the filter. What percentage of water is used to backwash?

1. Divide the part by the whole.

$$\frac{7{,}560 \text{ gal}}{84{,}000 \text{ gal}} = 0.09$$

2. Change the value to a percentage.

0.09 X 100 = 9%

G. The average day winter demand of a community is 14,500 gallons. If the summer demand is estimated to be 72% greater than the winter, what is the estimated summer demand?

1. Change the percent to a decimal.

72% ÷ 100 = 0.72

2. Add this value to 1.

1 + 0.72 = 1.72

3. Multiply the demand times this value.

14,500 gal x 1.72 = 24,940 gal

Practice Problem Answers – Efficiency

A. The water horsepower of a pump is 10 Hp and the brake horsepower output of the motor is 15.4 Hp. What is the efficiency of the motor?

$$\frac{10 \text{ BHp}}{15.4 \text{ EHp}} \times 100 = 64.94 \text{ or } 65\%$$

B. The water horsepower of a pump is 25 Hp and the brake horsepower output of the motor is 48 Hp. What is the efficiency of the motor?

$$\frac{25 \text{ BHp}}{48 \text{ EHp}} \times 100 = 52\%$$

C. The efficiency of a well pump is determined to be 75%. The efficiency of the motor is estimated at 94%. What is the efficiency of the well?

0.75 X 0.94 = 0.705 X 100 = 70.5%

D. If a motor is 85% efficient and the output of the motor is determined to be 10 BHp, what is the electrical horsepower requirement of the motor?

$$\frac{10 \text{ BHp}}{0.85} = 11.8 \text{ EHp}$$

E. The water horsepower of a well with a submersible pump has been calculated at 8.2 WHp. The Output of the electric motor is measured as 10.3 BHp. What is the efficiency of the pump?

$$\frac{82 \text{ WHp}}{10.3 \text{ BHp}} \text{ x } 100 = 79.6\%$$

Practice Problem Answers – Conversion

1. Convert the following:

A. 750 ft^3 of water to gallons

$$750 \frac{ft^3}{1} \text{ x } \frac{\qquad}{} \frac{?}{ft^3} =$$

$$750 \frac{ft^3}{1} \text{ x } \frac{\qquad}{} \frac{gal}{ft^3} =$$

$$750 \frac{ft^3}{1} \text{ x } \frac{7.48 \text{ gal}}{ft^3} = 5{,}610 \text{ gal}$$

B. 50 gallons to pounds

$$50 \frac{gal}{1} \text{ x } \frac{\qquad}{} \frac{?}{gal} =$$

$$50 \frac{gal}{1} \text{ x } \frac{\qquad}{} \frac{lbs}{gal} =$$

$$50 \frac{gal}{1} \text{ x } \frac{8.34 \text{ lbs}}{gal} = 417 \text{ lbs}$$

C. 560 gpm to cfs

$$560 \frac{gpm}{1} \text{ x } \frac{\qquad}{} \frac{?}{gpm} =$$

$$560 \frac{gpm}{1} \text{ x } \frac{\qquad}{} \frac{cfs}{gpm} =$$

$$560 \frac{gpm}{1} \text{ x } \frac{1 \text{ cfs}}{448 \text{ gpm}} = 1.25 \text{ cfs}$$

D. 4 lbs to ounces

$$4\ \frac{\text{lbs}}{1} \times \underline{\hspace{2cm}}\ \frac{?}{\text{lbs}} =$$

$$4\ \frac{\text{lbs}}{1} \times \underline{\hspace{2cm}}\ \frac{\text{oz}}{\text{lbs}} =$$

$$4\ \frac{\text{lbs}}{1} \times \frac{16\text{ oz}}{\text{lbs}} = 64\text{ oz}$$

E. 128 ft^3 of water to weight in pounds

$$128\ \frac{\text{ft}^3}{1} \times \underline{\hspace{2cm}}\ \frac{?}{\text{ft}^3} =$$

$$128\ \frac{\text{ft}^3}{1} \times \underline{\hspace{2cm}}\ \frac{\text{lbs}}{\text{ft}^3} =$$

$$128\ \frac{\text{ft}^3}{1} \times \frac{62.4\text{ lbs}}{\text{ft}^3} = 7{,}987\text{ lbs}$$

G. 3.4 cfs to gpm

$$340\ \frac{\text{cfs}}{1} \times \underline{\hspace{2cm}}\ \frac{?}{\text{cfs}} =$$

$$340\ \frac{\text{cfs}}{1} \times \underline{\hspace{2cm}}\ \frac{\text{gpm}}{\text{cfs}} =$$

$$340\ \frac{\text{cfs}}{1} \times \frac{448\text{ gpm}}{1\text{ cfs}} = 1{,}523\text{ gpm}$$

H. 65 ft^3 to yd^3

$$65\ \frac{\text{ft}^3}{1} \times \frac{1\text{ yd}^3}{27\text{ ft}^3} = 2.4\text{ yd}^3$$

I. 3,000 gallons to ft^3

$$3{,}000\ \frac{\text{gal}}{1} \times \frac{1\text{ ft}^3}{7.48\text{ gal}} = 401\text{ ft}^3$$

J. 250,000 gallons to MG

$$250{,}000\ \frac{\text{gal}}{1} \times \frac{1\text{ MG}}{1{,}000{,}000\text{ gal}} = 0.25\text{ MG}$$

K. 75 gpm to MGD

75 gpm x 1440 min/day = 108,000 gpd

$$108{,}000\ \frac{\text{gpd}}{1} \times \frac{1\text{ MGD}}{1{,}000{,}000\text{ gpd}} = 0.108\text{ MGD}$$

L. 8 inches to feet

$$8\ \frac{\text{in}}{1} \ \text{x}\ \frac{1\ \text{ft}}{12\ \text{in}} = 0.667\ \text{ft}$$

M. 2.4 MGD to cfs

$$2.4\ \frac{\text{MGD}}{1} \ \text{x}\ \frac{1{,}000{,}000\ \text{gpd}}{1\ \text{MGD}} = 2{,}400{,}000\ \text{gpd}$$

$$2{,}400{,}000\ \frac{\text{gal}}{\text{day}} \ \text{x}\ \frac{1\ \text{day}}{1{,}440\ \text{min}} = 1{,}667\ \text{gpm}$$

$$1{,}667\ \frac{\text{gpm}}{1} \ \text{x}\ \frac{1\text{cfs}}{448\ \text{gpm}} = 3.7\ \text{cfs}$$

N. 2.4 MGD to gpm

$$2.4\ \frac{\text{MGD}}{1} \ \text{x}\ \frac{694.5\ \text{gpm}}{1\ \text{MGD}} = 1{,}668.8\ \text{cfs}$$

O. 65 pints to gallons

$$65\ \frac{\text{pint}}{1} \ \text{x}\ \frac{1\ \text{gal}}{8\ \text{pint}} = 8.125\ \text{gal}$$

P. 2.5 ft^2 to square inches

$$2.5\ \frac{\text{ft}^2}{1} \ \text{x}\ \frac{144\ \text{in}^2}{1\ \text{ft}^2} = 360\ \text{in}^2$$

Q. 7 yards to feet

$$7\ \frac{\text{yd}}{1} \ \text{x}\ \frac{3\ \text{ft}}{1\ \text{yd}} = 21\ \text{ft}$$

R. 36,000 gpd to gpm

$$36{,}000\ \frac{\text{gpd}}{1} \ \text{x}\ \frac{\text{gpm}}{1{,}440\ \text{gpd}} = 25\ \text{gpm}$$

S. 125 gpm to gph

125 gpm x 60 min/hr = 7,500 gph

Practice Problem Answers – Temperature Conversion

A. Change 70° F to °C

$$°\text{C} = \frac{70°\ \text{F} - 32°}{1.8} = 21°\ \text{C}$$

B. Change 140° F to °C

$$°C = \frac{140° F - 32°}{1.8} = 60° C$$

C. Change 20°C to °F

°F = °C x 1.8 + 32°

°F = 20° C x 1.8 + 32°

°F = 68° F

D. Change 85 °C to °F

°F = °C x 1.8 + 32°

°F = 85° C x 1.8 + 32°

°F = 185° F

E. Change 4 °C to °F

°F = °C x 1.8 + 32°

°F = 4° C x 1.8 + 32°

°F = 39°F

Practice Problem Answers – Pressure and Head

1. Make the following conversions:

A. Convert a pressure of 45 psi to feet of head.

$$45 \frac{psi}{1} \times \frac{ft}{0.433\ psi} = 103.9\ feet$$

B. Convert 12 psi to feet.

$$12 \frac{psi}{1} \times \frac{ft}{0.433\ psi} = 27.7\ feet$$

C. Convert 85 psi to feet.

$$85 \frac{psi}{1} \times \frac{ft}{0.433\ psi} = 196.3\ feet$$

D. It is 112 feet in elevation between the top of the reservoir and the watering point. What will the static pressure be at the watering point?

$$112 \frac{ft}{1} \times \frac{0.433\ psi}{1\ ft} = 48.5\ feet$$

E. A reservoir is 20 feet deep. What will the pressure be at the bottom of the reservoir?

$$20\ \frac{\text{ft}}{1} \times \frac{0.433\ \text{psi}}{1\ \text{ft}} = 8.7\ \text{feet}$$

Practice Problem Answers – Flow

A. Find the flow in MGD when the flow is 34,000 gpd.

$$\frac{34{,}000\ \text{gpd}}{1{,}000{,}000} = 0.034\ \text{MGD}$$

B. Find the flow in gpm when the total flow for the day is 65,000 gpd.

$$\frac{65{,}000\ \text{gpd}}{1{,}440\ \text{min/day}} = 45\ \text{gpm}$$

C. Find the flow in gpm when the flow is 1.3 cfs.

$$1.3\ \frac{\text{cfs}}{1} \times \frac{448\ \text{gpm}}{1\ \text{cfs}} = 582\ \text{gpm}$$

D. Find the flow in gpm when the flow is 0.25 cfs.

$$0.25\ \frac{\text{cfs}}{1} \times \frac{448\ \text{gpm}}{1\ \text{cfs}} = 112\ \text{gpm}$$

E. Find the flow in a 4-inch pipe when the velocity is 1.5 feet per second.

The diameter of the pipe is 4 inches. Therefore, the radius is 2 inches. Convert the 2 inches to feet.

$$\frac{2}{12} = 0.6667\ \text{ft}$$

$A = \pi \times r^2$
$A = \pi \times (0.167\ \text{ft})^2$
$A = \pi \times 0.028\ \text{ft}^2$
$A = 0.09\ \text{ft}^2$

$Q = V \times A$
$Q = 1.5\ \text{ft/sec} \times 0.09\ \text{ft}^2$
$Q = 0.14\ \text{ft}^3\text{/sec (cfs)}$

Practice Problem Answers – Detention Time

A. How long will it take to fill a 50 gallon hypochlorite tank if the flow is 5 gpm?

$$\frac{50 \text{ gal}}{5 \text{ gal/min}} = 10 \text{ min}$$

B. Find the detention time in a 45,000 gallon reservoir if the flow rate is 85 gpm.

$$DT = \frac{45{,}000 \text{ gal}}{85 \text{ gal/min}} = 529 \text{ min} \quad \text{or} \quad \frac{529 \text{ min}}{60 \text{ min/hr}} = 8.8 \text{ hrs}$$

C. If the fuel consumption to the boiler is 35 gallons per day. How many days will the 500 gallon tank last.

$$\text{Days} = \frac{500 \text{ gal}}{35 \text{ gal/day}} = 14.3 \text{ days}$$

D. The sedimentation basin on a water plant contains 5,775 gallons. What is the detention time if the flow is 175 gpm.

$$DT = \frac{5{,}775 \text{ gal}}{175 \text{ gal/min}} = 33 \text{ min}$$

Practice Problem Answers – Ratio and Proportion

A. It takes 6 gallons of chlorine solution to obtain a proper residual when the flow is 45,000 gpd. How many gallons will it take when the flow is 62,000 gpd?

$$\frac{6 \text{ gallons}}{X \text{ gallons}} : \frac{45{,}000 \text{ gpd}}{62{,}000 \text{ gpd}}$$

$$(X \text{ gallons})\ (45{,}000 \text{ gpd}) = (6 \text{ gallons})\ (62{,}000 \text{ gpd})$$

$$X \text{ gal} = \frac{(6 \text{ gal})\ (62{,}000 \text{ gpd})}{45{,}000 \text{ gpd}} = 8.3 \text{ gal}$$

B. A motor is rated at 41 amps average draw per leg at 30 Hp. What is the actual Hp when the draw is 36 amps?

$$\frac{41 \text{ amps}}{36 \text{ amps}} : \frac{30 \text{ Hp}}{X \text{ Hp}}$$

$$(41 \text{ amps})\ (X \text{ Hp}) = (36 \text{ amps})\ (30 \text{ Hp})$$

$$X \text{ Hp} = \frac{(36 \text{ amps})\ (30 \text{ Hp})}{41 \text{ amps}} = 26.3 \text{ Hp}$$

C. It it takes 2 operators 4.5 days to clean an aeration basin, how long will it take three operators to do the same job?

$$\frac{2 \text{ operators}}{3 \text{ operators}} : \frac{\text{X days}}{\text{4.5 days}}$$

(2 operators) (X days) = (3 operators) (4.5 days)

$$\text{X days} = \frac{(2 \text{ operators})\ (4.5 \text{ days})}{3 \text{ operators}} = 3 \text{ days}$$

D. If it takes 20 minutes to pump a wet well down with one pump pumping at 125 gpm, then how long will it take if a 200 gpm pump is used?

$$\frac{20 \text{ min}}{\text{X min}} : \frac{200 \text{ gpm}}{125 \text{ gpm}}$$

(X min) (200 gpm) = (20 min) (125 gpm)

$$\text{X min} = \frac{(20 \text{ min})\ (125 \text{ gpm})}{200 \text{ gpm}} = 12.5 \text{ min}$$

E. It takes 3 hours to clean 400 feet of collection system using a sewer ball. How long will it take to clean 250 feet?

$$\frac{3 \text{ hrs}}{\text{X hrs}} : \frac{400 \text{ ft}}{250 \text{ ft}}$$

(X hrs) (400 ft) = (3 hrs) (250 ft)

$$\text{X hrs} = \frac{(3 \text{ hrs})\ (250 \text{ ft})}{400 \text{ ft}} = 1.9 \text{ hrs}$$

F. It takes 14 cups of HTH to make a 12% solution. Each cup holds 300 grams, how many cups will it take to make a 5% solution?

$$\frac{14 \text{ cups}}{\text{X cups}} : \frac{12\%}{5\%}$$

(X cups) (12%) = (14 cups) (5%)

$$\text{X cups} = \frac{(14 \text{ cups})\ (5\%)}{12\%} = 5.8 \text{ cups}$$

Practice Problem Answers – Pounds Formula

A. How many pounds of 100% gas chlorine are needed to disinfect a flow of 85,000 gpd at 12 mg/L?

lbs = 0.085 MGD x 8.34 lbs/gal x 12 mg/L

lbs = 8.5 pounds

B. The suspended solids in a stream are measured at 360 mg/L. The stream flow is estimated to be 3.2 MGD. How many pounds of solids are carried by the stream each day?

lbs = 3.2 MGD x 8.34 lbs/gal x 360 mg/L

lbs = 9,607 pounds

C. The backwash water of a treatment plant contains 320 mg/L. 4,000 gals of water are used for backwash. How many pounds of solids are deposited in the backwash lagoon with each backwash?

lbs = 0.004 MGD x 8.34 lbs/gal x 320 mg/L

lbs = 10.7 pounds

D. A 400,000 gallon storage tank is to be disinfected with 50 mg/L of chlorine. How many pounds of gas chlorine would it take to disinfect this tank?

lbs = 0.4 MG x 8.34 lbs/gal x 50 mg/L

lbs = 166.8 pounds

E. How many pounds of calcium hypochlorite at 67% is needed to disinfect 125,000 gallon per day flow with a dosage of 8 mg/L?

Abbreviations and Common Conversions

For 100% chlorine

lbs = 0.125 MGD x 8.34 lbs/gal x 8 mg/L

lbs = 8.34 pounds of 100%

This is the part of the whole.

$$\text{Percent} = \frac{\text{Part}}{\text{Whole}} \text{ X } 100$$

$$67\% = \frac{8.34 \text{ lbs}}{\text{Whole}} \text{ X } 100$$

$$\text{Whole} = \frac{8.34 \text{ lbs}}{67\%} \text{ X } 100 = 12.45 \text{ pounds}$$

Practice Problem Answers – Metric Conversion

A. Convert 4.2 Kg to g

4.2 kg x 1000 g/Kg = 4,200 g

B. Convert 0.5 Kg to g

0.5 Kg x 1000 g/Kg = 500 g

C. Convert 4600 g to Kg

$$\frac{4600 \text{ g}}{1000 \text{ g/Kg}} = 4.6 \text{ kg}$$

D. Convert 3.4 Km to m

3.4 Km x 1000 m/Km = 3,400 m

E. Convert 0.5 Km to m

0.5 Km x 1000 m/Km = 500 m

F. Convert 10,000 m to Km

$$\frac{10{,}000 \text{ m}}{1000 \text{ m/Km}} = 10 \text{ Km}$$

Limitations

The following is a listing of common abbreviations used in math problems in the water/wastewater field. With a few exceptions, this listing is limited to those abbreviations associated with the English units of measurement. Abbreviations associated with the SI (metric) system of measurements are found in the section of this lesson on metric units.

Abbreviations			
Ac	acre	hr	hour
ac-ft	acre-feet	Hp	horsepower
Af	acre-feet	in	inch
amp	ampere	in^2	square inches
BHp	Brake horsepower	in^3	cubic inches
°C	degrees Celsius	kw	Kilowatt
cfm	cubic feet per minute	kwh	Kilowatt-hour
cfs	cubic feet per second	lb	pound
cu-ft	cubic feet (ft^3)	M	Million
cu-in	cubic inch	MGD	million gallons per day
EHp	electrical horsepower	mg/L	milligrams per liter
°F	degrees Fahrenheit	min	minute
ft	feet or foot	psi	pounds per square inch
ft^2	square feet	ppm	parts per million
ft-lb/min	foot pounds per minute	sq ft	square feet (ft^2)
gal	gallon	W	watt
gpd	gallons per day	WHp	Water horsepower
gpcpd	gallons per capita per day	yd^3	cubic yard
gpm	gallons per minute		

Some Common Conversions

Area	Weight
1 acre = 43,560 ft^2 1 ft^2 = 144 in^2	1 ft^3 of water = 62.4 lbs 1 gal = 8.34 lbs 1 lb = 453.6 grams kg = 1000 g = 2.2 lbs 1% = 10,000 mg/L

Linear Measurements
1" = 2.54 cm 1' = 30.5 cm 1 yard = 3 feet 1 meter = 100 cm = 3.281 feet = 3.94 inches

Pressure	Flow
1 ft of head = 0.433 psi 1 psi = 2.31 ft of head	1 cfs = 448 gpm 1 cfs = 0.6463 MGD 1 MGD = 694.5 gpm

Volume
1 gal = 3.78 liters 1 ft^3 = 7.48 gal 1 ft^3 = 62.4 lbs 1 gal = 8.34 lbs 1 Liter = 1000 mL 1 acre foot = 43,560 cubic feet 1 gal = 8 pint 1 gal = 16 cups 1 pint = 2 cups 1 pound = 16 oz dry wt 1 yd^3= 27 ft^3 1 gpm = 1440 gpd

Waterworks Math Quiz

1. What is the average of the following set of numbers: 0.5, 0.3, 0.6, 0.2, 0.3, 0.4, 0.5, 0.4?
   A. 0.3
   B. 0.4
   C. 0.5
   D. 0.6

2. A clearwell has a detention time of 4 hours. What is the flow rate in gpm if the clearwell holds 6000 gallons?
   A. 25 gpm
   B. 20 gpm
   C. 50 gpm
   D. 1500 gpm

3. A chlorine barrel is 26 inches in diameter and 40 inches tall. What is the volume of the tank?
   A. 5.9 ft3
   B. 14.7 ft3
   C. 187 ft3
   D. 12.3 ft3

4. A water plant produces 96,000 per day, of which 7,200 are used to backwash the filter. What percentage of water is used to backwash?
   A. 8.5 %
   B. 8.3 %
   C. 7.5 %
   D. 8.0 %

5. The water horsepower of a pump is 20 Hp, and the brake horsepower output of the motor is 45 Hp. What is the efficiency of the pump?
   A. 40 %
   B. 44 %
   C. 53 %
   D. 38 %

6. How many cfs is 600 gpm?
   A. 1.3 cfs
   B. 1.1 cfs
   C. 1.0 cfs
   D. 0.9 cfs

7. How many pounds does 100 gallons of water weigh?
   A. 628 lbs
   B. 525 lbs
   C. 748 lbs
   D. 834 lbs

8. How many degrees Fahrenheit is 23 degrees Celsius?
   A. 71 °F
   B. 73 °F
   C. 68 °F
   D. 67 °F

9. How many feet of head are necessary for a pressure gauge to read 75 psi?
   A. 173 ft
   B. 32 ft
   C. 45 ft
   D. 150 ft

10. The sedimentation basin of a water plant contains 6,000 gallons. What is the deten tion time if the flow is 150 gpm?
    A. 60 minutes
    B. 50 minutes
    C. 45 minutes
    D. 40 minutes

11. If it takes 20 minutes to pump a wet well down with one pump at a rate of 125 gpm, how long will it take if the pump operates at a rate of 175 gpm?
    A. 35 minutes
    B. 32 minutes
    C. 28 minutes
    D. 15 minutes

12. How many pounds per day of 100% gas chlorine are needed to disinfect a flow of 75,000 gpd at 15 mg/L?
    A. 9.4 lbs
    B. 8.4 lbs
    C. 10.3 lbs
    D. 7.0 lbs

13. A 500,000 gallon storage tank is to be disinfected with 50 mg/L chlorine. How many pounds of gas chlorine will it take to disinfect this tank?
    A. 187 lbs
    B. 209 lbs
    C. 198 lbs
    D. 202 lbs

14. A pipe has a circumference of 11 ¾ inches. What is the diameter of this pipe?
    A. 5.1 inches
    B. 4.2 inches
    C. 2.8 inches
    D. 3.7 inches

15. How many square inches are in 3.0 ft2?
    A. 432 in2
    B. 36 in2
    C. 144 in2
    D. 88 in2

Environmental Protection Agency (EPA)

Ground Water and Drinking Water:

http:// water.epa.gov/drink

Compliance Guidance under the Safe Drinking Water Act:

http://water.epa.gov/lawsregs/guidance/sdwa/index.cfm

State of Alaska

Alaska Department of Environmental Conservation (ADEC)

Drinking Water Program

http://dec.alaska.gov/eh/dw/index.htm
Anchorage: (907) 269-7656
Fairbanks: (907) 451-2108
Juneau: (907) 465-5350
Soldotna: (907) 262-5210
Wasilla: (907) 376-1850
Drinking Water Watch: http://dec.alaska.gov:8080/DWW/

Operator Training and Certification Program

http://dec.alaska.gov/water/opcert/index.htm
Juneau: (907) 465-1139
Email: dec.opcert@alaska.gov

Alaska Department of Commerce Community and Economic Development (DCCED)

Rural Utility Business Advisor (RUBA) Program

http://commerce.alaska.gov/dnn/dcra/ruralutilitybusinessadvisorprogramruba.aspx
Anchorage: (907) 269-4556

Training and Technical Assistance Providers

Alaska Rural Water Association (ARWA)

http://arwa.org/
(907) 357-1155

Alaska Water Wastewater Management Association (AWWMA)

http://www.awwma.org/
(907) 561-9777

American Water Works Association (AWWA)
http://www.awwa.org/

Association of Boards of Certification (ABC)
http://www.abccert.org/

California State University, Sacramento (CSUS), Office of Water Programs
http://www.owp.csus.edu/
(916) 278-6142

Linn-Benton Community College
Water, Environment, and Technology Program
http://www.linnbenton.edu/wet
(541)917-4636

National Environmental Services Center
http://nesc.wvu.edu/drinkingwater.cfm

University of Alaska, Southeast (UAS) Sitka Campus
Water and Wastewater Operator Training
http://www.uas.alaska.edu/sitka/programs/all/wwo.html
(907) 747-7762
(800) 478-6653, ext. 7762

Water Environment Federation (WEF)
http://wef.org/

A

AC (Alternating Current) – An electric current of constantly changing value that reverses direction of flow at regular intervals.

Acute – A rapid onset with low levels of exposure.

Adjacent – As used with trench protection systems, the area within a horizontal distance from the edge of the trench equal to the depth of the trench.

Adsorption – The gathering of a gas or dissolved substance onto the surface of a solid.

Aeration – A treatment process bringing air and water into close contact in order to remove or modify constituents in the water.

Aerobic – A condition in which "free" or dissolved oxygen is present in the aquatic environment.

Aesthetics – Concerning an appreciation of the beauty. With water, the term means pleasant in appearance, odor, and taste.

Agglomerate – Gathered into a mass.

Aggressive – Aggressive waters are those that are high in dissolved oxygen, are neutral to low pH, and have low (below 80 mg/L) alkalinity. These conditions allow water to easily dissolve metals such as iron, copper, and lead.

Air Gap – A positive means of preventing a cross-connection. An air gap should be twice the diameter of the discharge pipe or a minimum of 1 inch above the rim of the tank.

Air Scour – The agitation of filter media by the injection of compressed air.

Alkalinity – The buffering capacity of water to retard the change in pH by an acid. Alkalinity is composed of bicarbonates, carbonate, and hydroxide.

Alternative Filtration – A filtration technology other than diatomaceous earth filtration, conventional or direct filtration, or slow sand filtration that is used to meet the requirements of the Surface Water Treatment Rule.

Altitude Valve – A valve that automatically opens and closes to maintain the level of water in a reservoir. Most commonly a wide body globe valve.

Alum – Trade name for the common coagulant aluminum sulfate. $Al_2(SO_4)_3 \cdot 18H_20$.

Ambient – The surrounding atmosphere.

Amperage – The measurement of electron flow.

Anaerobic – A condition in which "free" or dissolved oxygen is not present in the environment.

Anion – A negatively charged ion.

Anionic – An ion or group of ions with a negative charge.

Appurtenances – Portions of a main structure necessary to allow it to operate as intended, but not considered part of the main structure: hydrants, valves, tees, elbows, etc.

Aquatic – Pertaining to water.

Aquatic Life – All forms of plant and animal life that live in water.

Aquifer – A porous, water-bearing geologic formation from which surface water is obtained.

Area – The extent of a surface, measured by the number of squares of equal size it contains.

Arsenite – Arsenic (III), the dissolved form of arsenic.

Arsenate – Arsenic (V), the oxidized form of arsenic.

Atmosphere – The gases that surround the earth.

Atom – The smallest part of an element that still retains the properties of that element.

Average – An arithmetic mean. The value is arrived at by adding the quantities in a series and dividing the total by the number in the series.

AWWA (American Water Works Association) – An association of waterworks personnel, equipment manufacturers, suppliers, and engineers.

Axial Flow Pumps – A type of vertical turbine that uses a propeller instead of an impeller. In axial flow pumps, the energy is transferred into the water so that the direction of the flow is directly up the shaft.

B

Backflow – A reverse flow condition, created by a difference in water pressures, which causes nonpotable water to flow into a potable water system.

Backsiphonage – A form of backflow caused by a negative or below-atmospheric pressure within the water system.

Backwash – The reversal of flow through a filter in order to clean the filter by removing material trapped by the media in the filtration process.

Bacteria – Living organisms, microscopic in size, that consist of a single cell. Most bacteria use organic matter for their food and produce waste products as the result of their life processes.

Bacterial Spores – A resistant, viable structure regarded as the resting stage of an organism.

Bag Filter – A membrane filter shaped like a bag.

Baseline Data – The water quality data, precipitation data, and stream flow data accumulated from a drainage basin or groundwater supply when there is little or no activity in the area.

Biofilms – A colony of tiny microorganisms.

Brake Horsepower – The output horsepower of an electric motor. The representation of the amount of work that the motor can perform. Providing work of 33,000 foot pounds per minute is equivalent to one horsepower.

Breakpoint Chlorination – The point at which near-complete oxidation of nitrogen compounds is reached. Any residual beyond breakpoint is mostly free chlorine.

Butterfly Valve – A valve whose movable closure rotates 90° around a shaft that is set through the center of the closure and the center of the flow path.

C

"C" Factor – The factor used in the Hazen and Williams equation for determining headloss. The "C" Factor is a representation of the hydraulic roughness of the pipe. The larger the number, the smoother the pipe is hydraulically.

Caisson – Large pipe placed in a vertical position.

Calcium Carbonate – The principle compound of hardness. The term used as an equivalent for hardness and alkalinity. Symbolically represented as $CaCO_3$.

Can Turbine Pumps – A type of line shaft turbine. The pump assembly is mounted inside of a sealed can. The inlet is mounted opposite the outlet on the discharge head. The can must always be under pressure.

Cartridge Filter – A membrane filter in the form of a cartridge.

Cation – A positively charged ion.

Cationic – An ion or group of ions with a positive charge.

Cave-in – (1)The separation of a mass of soil or rock material from the side of an excavation or (2) the loss of soil from under a trench shield or support system and its sudden movement into the excavation, either by falling or sliding, in sufficient quantity so that it could entrap, bury, or otherwise injure or immobilize a person.

Celsius – Relating to a metric system thermometer scale with the boiling point at 100 degrees and the freezing point at 0 degrees.

Centrifugal Force – The force that when a ball is whirled on a string, pulls the ball outward. On a centrifugal pump, it is the force that throws water from the spinning impeller.

Centrifugal Pump – A pump consisting of an impeller fixed on a rotating shaft and enclosed in a casing, and having an inlet and discharge connection. The rotating impeller creates pressure in the liquid by the velocity derived from centrifugal force.

cfs (Cubic Feet per Second) – A measurement of flow. One cfs is equal to 448 gpm.

Chemistry – The study of substances and the changes they undergo.

Chloramines – (1) Compounds of organic or inorganic nitrogen and chlorine. (2) Nitrogen compound changed to form monochloramines, dichloramines and trichloramines. Compounds produced when chlorine and ammonia react. A weak oxidant or disinfectant.

Chronic – A slow onset with repeated exposure over long periods of time.

Circumference – The perimeter of a circle.

Close-coupled Pumps – End suction centrifugal pumps in which the pump shaft and motor shaft are the same. The pump bearings and motor bearings are also the same. The impeller is attached directly onto the end of the motor shaft.

Coagulation – In water treatment, the destabilization and initial aggregation of colloidal and finely divided suspended matter by the addition of a floc-forming chemical; the clumping together of fine particles by the neutralization of electrical charges.

Coliform Bacteria – The coliform group of bacteria is a bacterial indicator of contamination. This group has the intestinal tract of human beings as one of its primary habitats. Coliforms may also be found in the intestinal tract of warm-blooded animals and in plants, soil, air, and the aquatic environment.

Colloidal – Any substance in a certain state of fine division in which the particles are less than one micron in diameter: 1.0 to 0.005 micron.

Colloidal Solids – Suspended solids so small they will not settle even if allowed to sit quietly for days or weeks. They are not dissolved, but even though they are extremely tiny, they often make the water cloudy.

Color – Primarily organic colloidal particles in water.

Combined Chlorine Residual – The amount of chlorine available as a combination of chlorine and nitrogen.

Competent Person – One who is capable of identifying existing and predictable hazards in the surroundings or working conditions which are unsanitary, hazardous, or dangerous to employees and who has authorization to take prompt corrective measures to eliminate them.

Complexed – A bound form of two or more substances.

Compression Hydrant – A fire hydrant where the main valve moves reciprocally on a vertical axis is against a seat located in the hydrant base. The valve moves against the seat to close and away from the seat to open.

Concentric Reducer – A device used to connect a large pipe to a smaller pipe so that the center lines of both pipes are aligned.

Conductor – A substance, body, device, or wire that readily conducts or carries electrical current.

Cone of Depression – The depression, roughly conical in shape, produced in a water table or other piezometer surface by the extraction of water from a well at a given rate.

Confined Aquifer – An aquifer surrounded by formations of less permeable or impermeable material.

Confined Space – As defined by NIOSH, a space that by design has limited openings for entry and exit; has unfavorable natural ventilation that could contain or produce dangerous air contaminants; and that is not intended for continuous employee occupancy.

Contact Time – The amount of time in minutes that the disinfectant, measured as a free residual, is in contact with the water before the water is delivered to the first customer.

Contamination – The introduction into water of toxic materials, bacteria, or other deleterious agents that make the water unfit for its intended use.

Conventional Treatment – A standard treatment process involving coagulation, flocculation, sedimentation, filtration, and disinfection.

Coprecipitation – Simultaneous precipitation of more than one substance containing impurities within its mass.

Covalent Bond – A form of chemical bonding that is characterized by the sharing of pairs of electrons between atoms.

Cross-connection – Any physical arrangement whereby a public water supply is connected, directly or indirectly, with a non-potable or unapproved water supply or system.

Cross-sectional Area – The area at right angles to the length of a pipe or basin.

Cryptosporidium – A pathogenic microorganism excreted by some animals that is 4-6 micrometers in size.

Cubic Feet – A measurement of volume in the number of cubes that are one foot on a side.

Cylinder – A solid or hollow figure, traced out when a rectangle rotates using one of its sides as the axis of the rotation.

D

DC (Direct Current) – A flow of electrons in a single direction at a constant rate so that the value remains stable.

Demand – When related to chlorine, the amount of chlorine utilized by iron, manganese, algae, and microorganisms in a specified period of time. When related to use, the amount of water used in a period of time. The term is in reference to the “demand” put onto the system to meet the need of customers.

Density – The weight per unit volume of a substance.

Detention Time – The theoretical time required to displace the contents of a tank or unit at a given rate of discharge or flow.

Diameter – The distance across a circle. A straight line passing through the center of a circle.

Diatomaceous Earth Filter – A pressure filter utilizing a media made from diatoms.

Differential Pressure – The difference in water pressure between two points.

Direct Filtration – A gravity or pressure filter system involving coagulation, flocculation, filtration, and disinfection.

Disinfection – The process used to control pathogenic organisms.

Disinfection Byproduct – A chemical compound formed by the reaction of a disinfectant with contaminants in water.

Displacement Pumps – Pumps in which the energy is added to the water periodically and the water is contained in a set volume.

Dissolved Solids – The material in water that will pass through a glass fiber filter and remain in an evaporating dish after the water has evaporated.

Dosage – When related to chlorine, the amount of chlorine added to the system.

Double Check Valve Assembly – An assembly of two independently acting check valves with shut-off valves on each side of the check valves and test ports for checking the water tightness of each check valve.

Drainage Basin – An area from which surface runoff or groundwater recharge is carried into a single drainage system, also called a catchment area, watershed, or drainage area.

Drawdown – The distance between the static level and the pumping level.

Dynamic Pumps – Pumps in which the energy is added to the water continuously and the water is not contained in a set volume.

E

Eccentric Reducer – A device used to connect a large pipe to a smaller pipe so that one edge of both pipes is aligned.

Effective Size – The diameter of particles for which 10 percent of the total grains are smaller and 90 percent are larger.

Electromagnetism – (1) The magnetic force produced by an electric current or (2) the science that studies the interrelation of electricity and magnetism.

Electron – A negatively charged particle that travels around the nucleus of an atom.

Element – One of 106 fundamental substances that consist of atoms of only one kind and that singly or in combination constitute all matter.

EMF (Electromotive Force) – The electrical pressure (voltage) that forces an electric current through a conductor.

End Suction Centrifugal Pumps – The most common style of centrifugal pump. The center of the suction line is centered on the impeller eye. End suction centrifugal pumps are further classified as either frame-mounted or close-coupled.

Energy – The ability to do work. Energy can exist in several different forms, such as heat, light, mechanical, electrical, or chemical. Energy can neither be created nor destroyed, but can be transferred from one form to another. Energy exists in one of two states: potential or kinetic.

Evaporate – The process of conversion of liquid water to water vapor.

Evapotranspiration – The combined vaporization of water from water surfaces and plants.

Excavation – Any man-made cavity or depression in the earth's surface, including its sides, walls, or faces, formed by earth removal and producing unsupported earth conditions by reason of the excavation.

F

Facultative – Microorganisms that can switch from aerobic to anaerobic growth or can grow in an anaerobic or aerobic environment.

Fahrenheit – Relating to an English thermometer scale with the boiling point at 212 degrees and the freezing point at 32 degrees.

Fecal Coliform – The Fecal coliform group of bacteria is a bacterial indicator of contamination. This group has as one of its primary habitats the intestinal tract of human beings. Coliforms also may be found in the intestinal tract of other warm-blooded animals. Also called E. Coli or Escherichia Coli.

Filtration – The process of passing liquid through a filtering medium –which may consist of granular material such as sand, magnetite, or diatomaceous earth, finely woven cloth, unglazed porcelain, or specially prepared paper–to remove suspended colloidal matter.

Floc – Small gelatinous masses formed in a liquid by the reaction of a coagulant added thereto.

Flocculation – The agglomeration of colloidal and finely divided suspended matter after coagulation by gentle stirring by either mechanical or hydraulic means.

Flow – To be in constant movement, typically in a single direction. In regards to water, this term typically relates to a volume per unit of time, gallons per minute, cubic feet per second, etc.

Flume – An open conduit made of wood, masonry, or metal and constructed on grade that is used to transport water or measure flow.

Foot Valve – A one-way valve placed at the entrance of a suction line that is opened by the flow of water. The purpose of the valve is to prevent reverse flow.

Force – Influence (as a push or pull) that causes motion. Physics - The mass of an object times its acceleration: F = ma.

Frame-mounted Pumps – End suction centrifugal pumps designed so that the pump bearings and pump shaft are independent of the motor. This type of pump requires a coupling between the pump and the motor in order to transfer energy from the motor to the pump.

Free Chlorine Residual – The amount of chlorine available as dissolved gas, hypochlorous acid, or hypochlorite ion that is not combined with an ammonia or other organic compounds. It is 25 times more powerful than the combined chlorine residual.

Fungi – Non-chlorophyll-bearing plants that lack roots, stem, or leaves, that occur in water, sewage or sewage effluents, and that grow best in the absence of light.

G

Gases – Of neither definite volume nor shape, they completely fill any container in which they are placed.

Giardia – A pathogenic microorganism excreted by some animals that is 6-18 micrometers in size.

Glycol – Common name for propylene glycol, a colorless, thick, sweet liquid used as antifreeze.

Greensand – Naturally occurring silicates of sodium and aluminum that respond as a natural ion exchange medium. Commonly used as the primary filter medium in a potassium permanganate, greensand, iron, and manganese removal process.

Groundwater – Subsurface water occupying a saturated geological formation from which wells and springs are fed.

H

HAA5 – Five Haloacetic Acids including monochloroacetic acid, dichloroacetic acid, trochloroacetic acid, monobromoacetic acid, and dibromoacetic acid. Compounds formed when natural organic substances from decaying vegetation and soil (such as humic and fulvic acids) react with chlorine.

Hardness – A characteristic of water caused primarily by calcium and magnesium ions. Hardness causes deposits and scale to form on pipes and fixtures.

HDPE – High-density polyethylene is a polyethylene thermoplastic made from petroleum. The material is used for water service lines and main lines.

Head – The measure of the pressure of water expressed as height of water in feet: 1 psi = 2.31 feet of head.

Headloss – As it applies to a water filter, the difference between the pressure or head between two points.

Health-related – Capable of influencing health.

Heater – A device designed for overload protection of electric motors. The device is heat-sensitive and placed in the power circuit with an electrical connection to the control circuit.

Hertz – The frequency at which a cycle repeats within one second. For instance, a repeat of a cycle at a rate of 60 times per second is called 60 Hertz.

Horsepower – A measurement of work, 33,000 foot pounds per minute of work is 1 horsepower.

Humidity – The amount of water vapor in the air.

Hydrant Bury – The distance from the invert of the hydrant lead to a point 4 inches below the flange between the upper and lower barrels of a hydrant.

Hydraulic Loading – The flow rate per surface or cross-sectional area.

Hydraulic Shear – The shear force of water flowing past an object.

Hydrogen Sulfide Gas – A gas that results from bacterial anaerobic decay. It produces a strong rotten egg odor that can be detected at levels as low as 0.1 µg/L.

Hydrologic Cycle – Nature's method of continuously recycling the earth's renewable water supply, between the earth and atmosphere, makes it possible to use this water over and over again.

Hydrology – The applied science pertaining to properties, distribution, and behavior of water.

Hydrophilic – Water-loving. In water, hydrophilic refers to organic colloidal particles that contribute to color.

Hydrophobic – Water-fearing. In water, hydrophobic refers to inorganic colloidal particles that contribute to turbidity.

Hydrosphere – All of the water on the earth.

Hypochlorite Ion – An ion that results from the reaction of chlorine gas and water. Hypochlorite ion (OCl^-), along with hypochlorous acid, are called free chlorine residual. However, the hypochlorite ion is not as powerful a disinfectant as hypochlorous acid.

Hypochlorites – Compounds containing chlorine that are used for disinfection. They are available as liquids or solids and in barrels, drums, and cans.

Hypochlorous Acid – An usable strongly oxidizing but weak acid (HOCl) obtained in solution along with hydrochloric acid by reaction of chlorine with water.

I

Impeller – A rotating set of vanes designed to impart rotation to a mass of fluid.

Impermeable – Not allowing, or allowing only with great difficulty, the movement of water.

Infiltration – The initial movement of water from the earth surface into the soil.

Inorganic – Chemical substances of mineral origin, not usually containing carbon.

Insulator – A substance, body, or device that prevents the flow of electrical current.

Invert – The bottom inside surface of a pipe.

Ion – An atom or group of atoms that carries a positive or negative electric charge as a result of having lost or gained one or more electrons.

Ion Exchange – A reversible chemical reaction between an insoluble solid and a solution during which ions may be interchanged.

Ionization – The formation of ions by splitting molecules or electrolytes in solution.

L

Launder – Sedimentation tank effluent troughs.

Lineshaft Turbine Pumps – A type of vertical turbine. In this type of vertical turbine, the motor is mounted above the ground, and the pump unit is mounted below the water surface. A column extends from the pump to a discharge head found just below the motor. A shaft extends on a straight line from the center of the motor to the pump. The pump may be mounted a few feet to several hundred feet away from the motor.

Liquid – A definite volume, but not shape, that will fill containers to certain levels and form free-level surfaces.

Lithosphere – The solid crust of the earth. It consists of the thin, loose layer known as soil and the mass of hard rock, several miles in thickness, upon which soil lies.

Lockout/Tagout – A process of physically locking and tagging hazardous energy sources to prevent energy during maintenance.

Log Inactivation – A mathematical relationship relating percent inactivation to logarithmic inactivation. Common inactivations are three log or 99.9 percent and four log or 99.99 percent.

M

Magnetic Breaker – An electrically operated mechanical device used for over current protection.

Magnetic Starter – An electrically operated mechanical switch used to connect power to an electric motor.

Matter – Anything that has weight and occupies space.

MCLGs (Maximum Contaminant Level Goals) – The maximum level of a contaminant that is associated with no adverse health effects from drinking water containing that contaminant over a lifetime.

MCLs (maximum contaminant levels) – The maximum level of certain contaminants permitted in drinking water supplied by a public water system as set by the EPA under the federal Safe Drinking Water Act.

Mechanical Joint – A joint used on cast iron valves, fittings, fire hydrants, and cast iron pipe. The joint consists of a rubber gasket and follower ring held to a flange by a row of bolts. The gasket is compressed between the follower ring and the flange seat.

Mechanical Seal – A mechanical device used to control leakage from the stuffing box of a pump and usually made of two flat surfaces, one of which rotates on the shaft. The two flat surfaces are of such close tolerances as to prevent the passage of water between them.

Membrane Cartridge Filtration – Bag or cartridge filters capable of removing giardia and cryptosporidium.

mg/L (milligrams per Liter) – A unit of the concentration of a constituent in water. It is 0.001g of the constituent in 1,000 ml of water. mg/L has replaced the PPM (parts per million) in reporting results in water.

MGD (Million gallons per day) – A unit of flow and a unit of volume.

Microfiltration – Membrane filters capable of removing pathogenic organisms larger than 0.1 micrometers in size.

Microorganisms – Minute organisms, either plant or animal, invisible or barely visible to the naked eye.

Mixed Numbers – A fraction combined with a whole number is called a mixed number.

Molecule – The smallest division that a substance can be broken down to without separating its individual atoms.

MSDS (Material Safety Data Sheet) – Written material produced by the chemical manufacturer describing properties and safe-handling procedures.

MVO (Main Valve Opening) – The inside diameter of the bronze main valve seat of a fire hydrant.

N

Nanofiltration – Membrane filters capable of removing pathogenic organisms and dissolved organic contaminants larger than 0.001 micrometers in size.

Neutron – A neutrally charged particle in the nucleus of an atom. This particle has the same weight as a proton, an atomic weight of 1.

Nonionic – An ion or group of ions with no charge.

NFR – National Fire Rating System This system provides the users of chemicals with a four diamond placard that indicates the health concern, flammability, and reactivity levels of the chemical.

NSF – National Sanitation Foundation.

ntu – The units of measure of turbidity, Nephelometric Turbidity Units, the measurement as made with a nephelometric turbidimeter.

O

Odor – A quality that affects the sense of smell.

Organic – Chemical substances of animal or vegetable origin, made basically of carbon structure.

Organic Carbon – A carbon substance that comes from plant or animal sources.

OSHA – Occupational Safety and Health Act.

Overland Flow – The movement of water on and just under the earth's surface.

Oxidation – The addition of oxygen, removal of hydrogen, or removal of electrons.

P

Packing – Material made of woven animal, plant, mineral, or metal fiber and some type of lubricant, placed in rings around the shaft of a pump and used to control the leakage from the stuffing box.

Palatable – In relation to drinking water, it is water that does not give off an unpleasant taste and odors, is cool in temperature, has low color and low turbidity, and is pleasant to drink.

Parshall Flume – A device used to measure flow in an open channel. The flume narrows to a throat of fixed dimension and then expands again. The flow is determined by measuring the difference between the head before and at the throat.

Pathogenic Microorganisms – Minute organisms, either plant or animal that are invisible or barely visible to the naked eye and capable of causing disease.

Pathogenic Organisms – Bacteria, virus, and protozoa that can cause disease.

Peak Demand – The maximum momentary flow required of a water treatment plant, pumping station, or distribution system. This demand is usually the maximum average flow in one hour or less.

Percolation – Movement of water into and through the ground.

Permeability – The property of a material that permits appreciable movement of water through it when it is saturated and the movement is actuated by hydrostatic pressure of the magnitude normally encountered in natural subsurface water.

Permit-required Confined Space – A confined space that contains or has the potential to contain a hazardous atmosphere, that contains a material that has the potential for engulfing an entrant, that has an internal configuration such that an entrant could be trapped, or that contains any other recognized serious safety hazard.

pH – An expression of the intensity of the basic or acidic strength of water. pH may range from 0 to 14, where 0 is most acid, 14 most alkaline, and 7 neutral. Natural waters usually have a pH between 6.5 and 8.5.

pi – Greek letter (π) used as a symbol denoting the ratio of the circumference of a circle to its diameter.

Polluted Water – Water than contains sewage, industrial wastewater, or other harmful or objectionable substances.

Polymer – High-molecular-weight synthetic organic compound that forms ions when dissolved in water. Also called polyelectrolytes.

Polymeric – A material constructed of small molecules.

Porosity – The ratio of pore space to total volume. That portion of a cubic foot of soil that is air space and therefore can contain moisture.

Potable Water – Water satisfactorily safe for drinking purposes from the standpoint of its chemical, physical, and biological characteristics.

Precipitate – A solid substance that can be dissolved but is separated from solution as a result of a chemical reaction or change in conditions, such as pH or temperature. The material that results from precipitation – A phenomenon that occurs when a substance held in solution in a liquid passes out of solution into a solid form.

Precipitation – The process by which atmospheric moisture is discharged onto the earth's crust. Precipitation takes the form of rain, snow, hail, and sleet.

Pressure – The force exerted on a unit area. Pressure = Weight x Height. In water, it is usually measured in psi (pounds per square inch). One foot of water exerts a pressure of 0.433 pounds per square inch.

Primacy – The primary responsibility for administering and enforcing regulations.

Proton – A positively charged particle in the nucleus of an atom. This particle has an atomic weight of 1 and an atomic charge of plus 1.

Protozoa – A small, one-celled animal including, but not limited to, amoebae, ciliates, and flagellates.

Public Water System – Any source of water, intake works, collection system, treatment works, storage facility, or distribution system, including vehicle or vessel used to distribute water, from which water is available for human consumption.

Pump Bowl – The case that functions as a volute case on a mixed flow vertical turbine.

Purveyor – An agency or person that supplies potable water.

PVC (Poly Vinyl Chloride) – A plastic pipe made by forcing heated plastic through a die.

Q

QA/QC - Quality Assurance/Quality Control - The formal process of assuring the laboratory is performing testing in the most accurate and precise manner possible in order to comply with specified regulations.

R

Radius – A line from the center of a circle or sphere to the circumference of the circle or surface of the sphere.

Raw Water – Water that has not been treated and is to be used, after treatment, for drinking water.

Recharge Area – One from which precipitation flows into the underground water sources.

Rectangle – A four-sided figure with four right angles.

Reservoir – A tank used to hold water.

Residual – What is remaining in the water after a set period of time.

Resistance – The opposition offered to the flow of electrical current. Usually measured as Ohms.

Restraining Joint – A mechanical joint with some type of restraining device designed to withstand thrust and pressure due to movement of water within the pipe.

Reverse Osmosis – Membrane filters capable of removing pathogenic organisms, dissolved organic, and salts contaminants larger than 0.0001 micrometers in size.

Riprap – Broken stones or boulders placed compactly or irregularly on dams, levees, dikes, etc. for the protection of earth surfaces against the action of the water.

RPZ (Reduced Pressure Zone Backflow Prevention Assembly) – A backflow prevention assembly containing two check valves, a differential relief valve located between the two check valves, shut-off valves on each end of the assembly, and test ports for checking the water tightness of the check valves and the operation of the relief valve.

S

Sample Siting Plan – A plan that specifies where in the distribution system routine samples will be drawn in order to ensure that they are "representative" of the water supplied to every customer.

Saturated Solution – The physical state in which a solution will no longer dissolve more of the dissolving substance (solute).

Schmutzdecke – A thin organic mat that grows on a sand filter.

Seal Water – The water supplied to the stuffing box to lubricate and flush the packing or the mechanical seal.

Sedimentation – The removal of solid particles from water by settling induced by gravity.

Septum – Filter media on which diatoms are collected during filtration with a diatomaceous earth filter. Usually made of nylon, plastic, stainless steel, or brass.

Sequestering Agent – A chemical compound or polymer that chemically ties up (sequesters) other compounds or ions so that they cannot be involved in chemical reactions.

Shroud – The front and/or back of an impeller.

Sine Wave – The wave traced by the sine of an angle as the angle is rotated through 360°. Alternating current values follow a sine wave with respect to time.

Single Phase Power – A circuit or generator in which only one alternating current is produced.

Slide Gate Hydrant – A fire hydrant where the main valve moves vertically by means of a threaded stem. When the stem is rotated, the internally threaded gate moves. The gate is forced against the valve seat by a wedging mechanism.

Slow Sand Filtration – A method of filtration that uses a layer of microorganisms and sand media to remove contaminants.

Soda Ash – A common name for commercial sodium carbonate. A salt used in water treatment to increase the alkalinity of pH value of water or to neutralize acidity.

Softening – The process of control or destruction of hardness.

Solids – Pertaining to water, suspended and dissolved material in water. Substances that maintain definite size and shape.

Soluble – A substance that is easily dissolved.

Solute – The component of a solution that is dissolved by the solvent.

Solvent – The component of a solution that does the dissolving.

Split Case Pumps – A centrifugal pump designed so that the volute case is split horizontally. The case divides on a plane that cuts though the eye of the impeller.

Spores – A resistant, viable structure regarded as the resting stage of an organism.

Spring – A surface feature where, without the help of man, water issues from rock or soil onto the land or into a body of water, the place of issuance being relatively restricted in size.

Static Water Level – The water level in a well when the pump is not running.

Sterilization – The process of destroying all living organisms.

Static – A non-moving condition.

Stratify – To place into layers.

Stratum – A layer of the earth's crust.

Stuffing Box – That portion of the pump that houses the packing or mechanical seal. Usually referred to as the dry portion of the pump. The stuffing box is located in back of the impeller and around the shaft.

Submersible Turbine Pumps – A style of vertical turbine pump in which the entire pump assembly and motor are submersed in the water. The motor is commonly mounted below the pump.

Suction Head – A pumping condition where the eye of the impeller of the pump is below the surface of the water from which the pump is pumping.

Suction Lift – A pumping condition where the eye of the impeller of the pump is above the surface of the water from which the pump is pumping.

Surface Runoff – The amount of rainfall that passes over the surface of the earth.

Surface Water – Water on the earth's surface as distinguished from water underground (groundwater).

Suspended Solids – The quantity of material deposited when a quantity of water, sewage, or other liquid is filtered through a glass fiber filter.

T

Three Phase Power – A circuit or generator in which three power sources 120° out of phase with each other are produced.

Thrust Block – A concrete wedge placed between a fitting and the trench wall, used to transfer the force from the fitting to the trench wall, and thus prevent the fitting from being pushed away from the pipe.

Toggle Hydrant – A fire hydrant where the main valve moves reciprocally on a horizontal axis against or away from a vertical seat located in the base of the hydrant. The main valve is moved by means of a vertical stem. Rotation of the stem causes the arms of the toggle mechanism to move the main valve.

Total Chlorine Residual – The sum of the combined and free chlorine residuals.

Total Dynamic Head (TDH) – The total energy needed to move water from the center line of a pump (eye of the first impeller of a lineshaft turbine) to some given elevation or to develop some given pressure. This includes the static head, velocity head and the headloss due to friction.

Total Solids – The solids in water, sewage, or other liquids; it includes the suspended solids (those largely removable by a filter) arid filterable solids (those that are able to pass through a filter).

Transpiration – The process by which water vapor is lost to the atmosphere from living plants.

Trench – A narrow excavation made below the surface of the ground. In general, the depth is greater than the width, but the width of a trench should not be greater than 15 feet.

TTHMs (Trihalomethanes, also referred to as TTHMs or Total Trihalomethanes) – (1) Regulations – The sum of the concentrations of bromodichloromethane, dibromochloromethane, tribromomethane, and trichloromethane. (2) Compounds formed when natural organic substances from decaying vegetation and soil (such as humic and fulvic acids) react with chlorine.

Turbidity – A condition in water caused by the presence of suspended matter, resulting in the scattering and adsorption of light rays.

Turbidity Breakthrough – A rapid rise of turbidity in the effluent from a filter.

U

Ultrafiltration – Membrane filters capable of removing pathogenic organisms larger than 0.005 micrometers in size.

Unconfined Aquifer – An aquifer that sits on an impervious layer but is open on the top to local infiltration. The recharge for an unconfined aquifer is local and is called a water table aquifer.

V

Vacuum Breaker – A mechanical device that prevents backflow due to siphoning action created by a partial vacuum that allows air into the piping system, breaking the vacuum.

Velocity – The speed at which water moves, expressed in feet per second.

Velocity Head – The amount of energy required to bring a fluid from standstill to its velocity. For a given quantity of flow, the velocity head will vary indirectly with the pipe diameter.

Vertical Turbine Pumps – A classification of centrifugal pumps that are primarily mounted with a vertical shaft; the motor is commonly mounted above the pump. Vertical turbine pumps are either mixed or axial flow devices.

Virus – A submicroscopic organism that passes through filters capable of removing bacteria. A very small microorganism that is possible pathogenic.

Voltage – The measurement of EMF between two points.

Volume – The amount of space occupied by or contained in an object. Measured by the number of cubes, each with an edge 1 unit long that can be contained in the object.

Volute – The spiral-shaped casing surrounding a pump impeller that collects the liquid discharged by the impeller.

W

Water Hammer – The result of the conversion of velocity head to pressure head. The pressure spike created by suddenly stopping the flow of water.

Water Rights – The rights, acquired under the law, to use the water accruing in surface or groundwater, for a specified purpose in a given manner and usually within the limits of a given time period.

Water Table – The average depth or elevation of the groundwater over a selected area. The upper surface of the zone of saturation, except where that surface is formed by an impermeable body.

Waterborne Disease – A disease caused by organisms or toxic substances that are carried by water. The most common waterborne diseases are typhoid fever, cholera, dysentery, giardiasis, and other intestinal disturbances.

Waterborne Pathogens – Bacteria, virus, and protozoa that cause disease and are carried by water.

Watershed – A drainage basin from which surface water is obtained.

Weir – A vertical obstruction, such as a wall or plate, placed in an open channel and calibrated in order that a depth of flow over the weir (head) can easily be measured and converted into flow in cfs, gpm, or MGD.

Z

Zeolite – Natural or man-made minerals that collect from a solution certain ions (sodium or $KMnO_4$) and either exchange these ions, in the case of water softening, or use the ions to oxidize a substance, as in the case of iron or manganese removal.