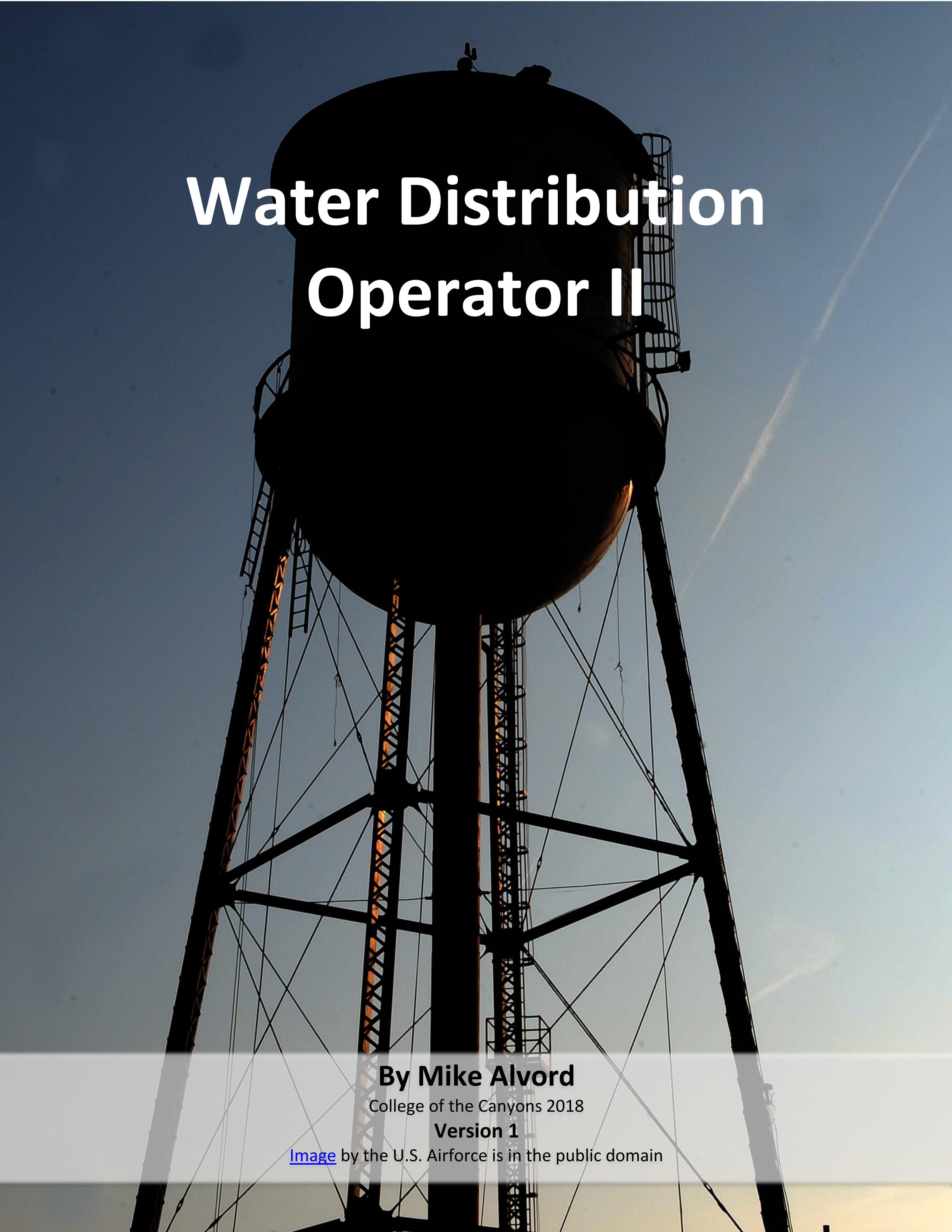


Water Distribution Operator II

By Mike Alvord

College of the Canyons 2018

Version 1

Acknowledgements

We'd like to extend appreciation to the following people and organizations for allowing this textbook to be created:

California Community Colleges Chancellor's Office
Chancellor Dianne G. Van Hook
Santa Clarita Community College District
College of the Canyons Distance Learning Office

Edited by Alexa Johnson

Table of Contents

CHAPTER 1 – WATERMAIN INSTALLATION

This chapter we will examine the details of water main installation

Student Learning Outcomes

After reading this chapter, you should be able to:

- Understand the basic practices of water main installation
- Evaluate the processes of backfilling and main testing
- List the steps of installing a water main and placing into service
- Analyze the use of maps and various types of drawings

In a previous chapter, we discussed the importance and purpose of selecting specific water mains. In some instances plastic pipe might be a better selection and other times ductile iron pipe might be useful. There are different uses for different types of pipe too. Regardless of the type of pipe selected, all pipe needs to be installed appropriately. The installation process will be discussed in this chapter.

Pipe Shipment

Water utilities need to order pipe from various manufacturers and sometimes the pipe needs to be shipped larger distances. The cost of shipping pipe is typically dependent on the distance the pipe is being transported, the size of the pipe, the weight of the pipe, and the quantity of the pipe being purchased. These variables will also dictate the method the pipe will be transported and will also contribute to the shipping costs. Ultimately, pipes are usually delivered to the water utility by truck. However, depending of the origin of the manufacturing of the pipe it may be transported by train or barge.

Image by Srahman is in the public domain

Pipe Handling

Once the pipe is delivered to a water utility, it should be properly **inspected** before it is unloaded from the truck. Even though manufacturers typically have a final inspection process prior to leaving their plant, damage can occur during transport. In addition, the wrong material or size may have been delivered by mistake. Therefore, it is important to inspect the following things prior to the pipe being unloaded:

- Size of pipe and fittings
- Class of pipe and fittings
- Quantity of pipe and fittings
- Condition of pipe and fittings

Any problems observed during unloading should be noted in writing. The driver, shipping company, and manufacturer should all be notified. The unloading process is usually accomplished using some type of equipment. Often times with smaller shipments, the pipe will be strapped to wooden pallets and they can be unloaded from the truck using a forklift. However, with larger shipments or larger size pipe, heavy equipment might be needed. It is important that the pipe not dropped or placed down roughly, Pipes should not be allowed to strike other pipes, the ground or other items. Some pipes are shipped with special coatings and it is important these coatings are in good condition and not damaged. Padded forks on forklifts, rubber hooks, or slings are ways to prevent such damage.

Pipe Storing

Once the pipe has been unloaded from the delivery truck, it must be properly stored to prevent damage and contamination. If pipe is stored at job sites or remote locations, protection from vandalism should also be considered. Stockpiles of pipe should be built on a flat base to prevent rolling. If possible, the pipe should be stored off the ground and grouped by size and class. If all different sizes and classes are stored together, it will make it more difficult to transport the pipe to the job site when it is time for construction. It is helpful to lay the pipe by alternating the bell and spigot ends. This allows the pipe to be stored evenly.

Polyvinyl chloride pipe should be stored out of direct sunlight as ultraviolet radiation can damage it. Any pipe that can crack or become damaged by hitting the ground, the height of the stacks of pipe should be limited to no more than three high. It is also prudent to cover the ends of the pipe during storage to prevent rodents or other animals from entering the pipe. Covering the ends also protects against contamination from dirt or other foreign objects. Sometimes covering the ends is not feasible and not critical since part of the installation process includes proper flushing and disinfecting of the pipe before being placed in service.

Image by PublicDomainPictures is licensed under CC0

Preparing the Pipe for Installation

Pipeline projects can be small jobs requiring only a few sticks of pipe. Or, they can be extensive jobs covering several miles or more. Regardless of the size of the job, it is important to properly plan. Preparing the pipe at the job site is an important aspect of job preparation.

The pipe should be placed as close to the trench as possible. This makes it easier for the pipe to be accessed and placed into the trench. String the pipe on the opposite side of the trench as the dirt (spoils) that is being excavated and should be located away from traffic and heavy equipment. The bells should be located in the direction of installation and only enough pipe should be laid out for a days work. It is also important that the pipe is protected from rolling into the trench or away from the job site.

Excavation

Trench excavation is the most expensive process of pipeline installation. It is important to know the location, depth, and width required for pipeline installation. A nonprofit organization called “Underground Service Alert” provides a means for anyone digging under ground the opportunity to identify any other utilities or conflicts, which may exist. A toll free number (811) should be called at least forty-eight (48) hours before any digging occurs. By calling this number, any utility in the area receives a notification that trenching will be occurring and they are then responsible to mark their utilities on the ground with an appropriately colored paint. Each different utility has a specific color as standardized by the American Public Works Association (APWA).

APWA Uniform Color Code	
White	Propose Excavation
Red	Electric Power Lines
Orange	Cable, Communication
Purple	Irrigation
Pink	Temporary Survey Marking
Yellow	Gas, Oil, Steam, Chemical
Green	Sewer, Storm Drain
Blue	Potable Water

The local soil conditions should also be considered before trenching begins. Is there local groundwater, which can fill the trench? Is there frost or freeze issues? Is the native soil in good condition or will “fill” material need to be brought in for backfilling? Sometimes in cold climates where adequate depths are not possible, special insulation might be needed to prevent the water in the pipes from freezing. In some areas (especially in warmer climates), minimum ground cover depths are required. Some common depths are thirty-six (36) inches for water mains and eighteen (18) inches for service laterals.

Whenever a pipe needs to be installed in an existing street, special consideration needs to be addressed to minimize inconveniences to the public. For example, some local cities may limit the times of construction activities. If the road is a main thoroughfare, construction may not be allowed during commute times in the mornings and evenings. Special permits for excavation may also be required. It is also very important to understand the existing and future road conditions, because these will dictate the road surface restoration requirements.

Once these and other considerations are reviewed, it is important to set an excavation plan. The construction crew should review the work zone. What heavy equipment will be needed, where will the spoils and materials be placed, where will traffic control be required, and where might there be public exposure to the work zone are just a few areas crews will need to understand prior to beginning work.

Since the excavation process is the most expensive part of pipeline installation, it is important to understand how much dirt is required to be removed. This is important because you don’t want to remove more dirt than is needed. Typically, the trench width should be one (1) to (2) feet greater than the outside diameter of the pipe.

Trenches can be very dangerous for workers from the potential of cave-ins. There are four (4) common danger signs workers should look for to help prevent trench wall failure. These are:

- Tension cracks in the ground surface parallel to the trench.
- Material crumbling off the walls of the trench.
- Settling or slumping of the ground surrounding the trench.
- Sudden changes in soil color, which indicates previous excavations.

In addition to these warning signs, certain precautions need to be in place to protect crews working in trenches. There are four (4) basic methods of preventing trench wall cave-ins.

- Sloping – If there is enough room in the construction work zone, sloping the trench walls is an adequate means of preventing cave-ins. This process involves excavating the walls at an angle. The **angle of repose** prevents the downward forces of the soil from exceeding the soils cohesive strength. Sloping a trench is dependent on the type of soil being excavated, the amount of moisture in the soil, the surrounding conditions, and the potential of soil vibration from heavy equipment. Various angles of repose are used depending on the type of soil. Below are some common examples.
    - Compacted crushed rock – for every foot of depth, the trench is cut one half of a foot wide.
    - Average soils – for every foot of depth, the trench is cut one foot wide.
    - Compacted sharp sand – for every foot of depth, the trench is cut one and one half foot wide.
    - Well-rounded loose sand – for every foot of depth, the trench is cut two feet wide.
- Shielding – This form of trench wall protection involves the use of a steel box, which is placed into the trench. It is open at the top, bottom, and on the ends, so workers can work inside of it. The protective box is pushed or towed along the trench to provide constant shield against cave-ins. It is important that the shield extends above the ground level in order to provide complete protection. These shielding boxes are also referred to as **trench shields**.
- Shoring – Shoring is a general term used when referring to trench wall projection. It is a framework system of wood, metal, or a combination of both. This support system maintains pressure against both trench walls preventing cave-ins. It is important to install shoring from the top of the trench to the bottom of the trench. Removal of the shoring should be done in the opposite manner. This will minimize worker’s exposure of unprotected trench walls. There are three (3) main components of a shoring system.
    - Uprights – These are the vertical boards placed in direct contact with the face of the trench wall. The spacing of the uprights is dependent upon

the soil stability. If the soil is sandy, then the uprights would be placed tightly together.
  - Stringers – These are the horizontal members of the shoring system to which the braces are attached. The stringers are commonly referred to as **whalers**.
  - Braces – The braces are the horizontal members, which run across the excavation to keep the uprights separated.

The trench bottom should be level so the pipe has support along the entire length. Sometimes a leveling board is needed to ensure the bedding is level. After the pipe is placed in the trench, the backfill material should be compacted beneath the pipe curvature. This process is known as "**haunching**." It is important to make sure the pipe has proper support on all sides under ground. The pipe should be set on flat firm ground. This proper bedding provides support and strength under the pipe. Bedding up to fifty (50) percent of the pipe diameter increases supporting strength by thirty-six (36) percent and proper bedding up to sixty (60) percent of the pipe diameter increases supporting strength by seventy-three (73) percent. By providing bedding over one hundred (100) percent of the pipe diameter and good compaction along the sides of the pipe increases the supporting strength by one hundred fifty (150) percent.

It is also important to protect potable water mains from non-potable pipes such as sewer and storm drain. Ideally, water mains should be installed above any non-potable pipes and a one (1) foot vertical distance is commonly required. In addition, a ten (10) foot horizontal separation from sewer pipes and four (4) foot from storm drains is common. Instances where these minimum offsets cannot be achieved, special provisions and health department regulatory approval might be required. Placing water mains in a larger diameter "sleeve" and concrete encasement are some alternative solutions.

Push-On Joint Installation Procedure

1. Prepare the pipe
   a. Thoroughly clean the bell socket and plain end
   b. Inspect the gasket for any damage
   c. Follow the manufacturer's recommendation on whether the socket should be lubricated
   d. Insert the gasket into the socket
   e. In cold weather, it may be necessary to warm the gasket to facilitate insertion
   f. Apply lubricant to the gasket and plain end
   g. Protect the lubricant from contamination

2. Connect the pipe

a. Be sure the plain end is properly beveled. Sharp edges can damage the gasket
b. Keep pipes in line when making up the joint. Deflection should take place only after the joint is assembled
c. Push the plain end into the socket.
d. When pushing pipe with a backhoe or jack, use a timber header across the end of the pipe to protect it

Mechanical Joint Installation Procedure

1. Prepare the pipe
    a. Clean the socket and plain the end
    b. Lubricate the gasket and plain end with soapy water of an approved lubricant
    c. Install the gland and rubber gasket

2. Connect the pipe
    a. Keep the pipes in line during joint assembly
    b. Insert the plain end into the socket
    c. Press the gasket evenly into the bell

3. Prepare the mechanical connection
    a. Push the gland toward the socket
    b. Insert the bolts and hand tighten the nuts

4. Tighten the bolts
    a. Alternately tighten the nuts on opposite sides to maintain the same distance between the gland and the flange
    b. Tighten the nuts to the correct torque

Sample Questions

1. What is the most common cause of joint failure?
    a. Having the joint too clean
    b. Using unapproved soap or lubricant
    c. Not having the joint completely clean
    d. None of the above

2. What types of things in the recesses of the bells of pipe can cause joints to leak?
    a. Sand
    b. Gravel
    c. Dust
    d. All of the above

3. What is the piece of pipe that is cut out during tapping called?
    a. Slug
    b. Coupon
    c. Cookie
    d. Only a and b
    e. All of the above

4. Large diameter pipe should be unloaded
    a. By hand
    b. With heavy equipment
    c. By rolling it off the truck
    d. Any of the above

5. What is the most expensive part of pipeline installation?
    a. The material
    b. The planning
    c. The excavation
    d. All of the above

6. What is a "story pole"?
    a. A pole which is used to track the progress of the days work
    b. A pole designed to improve efficiency during pipe installation
    c. A pole that marks how many feet of pipe are installed each day
    d. A pole with a string used to check the depth and grade of a trench

CHAPTER 2 – WATER STORAGE

This chapter we will discuss the importance of water storage within distribution systems.

Student Learning Outcomes

After reading this chapter, you should be able to:

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

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

Why Water Storage is Needed

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

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

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

Water Storage and Water Quality

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

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

What Type and Size of Storage is Needed?

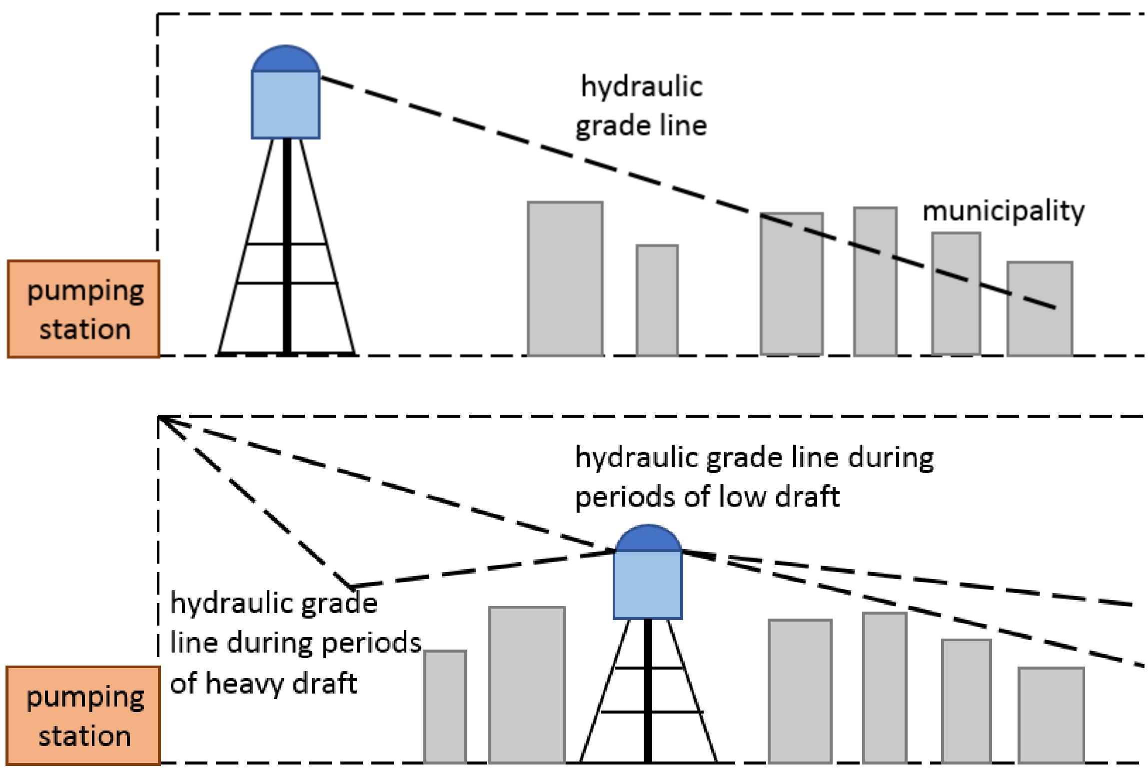
Water storage tanks come in various sizes and styles. Some of the factors to determine the type and capacity of storage in a distribution system depend on the size of the system, the topography of the distribution system, and how the distribution system is laid out (is the system spread out or concentrated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

Several terms related to water storage should be understood.

- Average Day Demand (ADD) – This is the total demand for water during a period of time divided by the number of days in that time period. This is also called the average daily demand.
- Maximum Day Demand (MDD) – This is the highest total demand over a 24 hour period within a given year.
- Peak Hour Demand (PHD) – This is the maximum demand over a one hour period within a given year.

- Float on the System – This is a method of operating a storage facility. Daily flow into the system is approximately equal to the average day demand. When customer demands are low, the storage facility will be filling and when demands are high the storage facility will be emptying.

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



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

Types of Water Storage Structures

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

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

Image by McGhiever is licensed under CC BY-SA 4.0

- Hydroneumatic Storage Tanks – These tanks are used in very small systems with in adequate pressure. They are kept partially full with compressed air to provide water in excess of the pump capacity when required. These types of systems will also provide water for a limited time if a pump fails.

- Standpipes – These tanks are constructed directly on the ground and have a height greater than the diameter. They are commonly used to equalize storage near a source of supply like a well field. They can also be used to provide additional fire protection.

Image by Necraig is licensed under CC BY-SA 3.0

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

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

Components of Elevated and Above Ground Storage Tanks

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

Inlet and Outlet Pipes

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

Overflow Pipe

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

Drain Connection

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

Monitoring Devices

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

Valves

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

Vents

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

Access Hatches

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

Ladders

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

Cathodic Protection

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

Tank Coatings

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

Operation and Maintenance

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

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

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

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

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

Sample Questions

1. An altitude valve is used to

   a. Prevent storage tanks from filling too fast
   b. Prevent storage tanks from overflowing
   c. Separate the inlet and out let flows
   d. None of the above

2. Water storage reservoirs should be completely inspected?

   a. Every year
   b. Every other year
   c. Every 3 to 5 years
   d. Every 5 to 10 years

3. Without storage, pumping capacity would be approximately

   a. Twice the average requirement
   b. Three times the average requirement
   c. Less than the average requirement
   d. None of the above

4. Fire demand may account for as much as

   a. 10% of storage
   b. 25% of storage
   c. 50% of storage
   d. 100% of storage

5. It is recommended that storage tanks have

   a. Separate inlet and outlet piping
   b. Common inlet and outlet piping
   c. Outlets twice as large as inlet piping
   d. There are no recommendations

CHAPTER 3 – DISINFECTION

This chapter we will examine the process of drinking water disinfection, the benefits it provides, and the effects on drinking water quality.

Student Learning Outcomes

After reading this chapter, you should be able to:

- List the various types of disinfectants
- Explain the disinfection process
- Describe the concepts of breakpoint chlorination and nitrification

Disinfection is often thought of as drinking water treatment. However, it is more of a conditioning and preventative process. The process of disinfection is design to inactivate pathogenic organisms in water with chemical oxidants or equivalent agents. This simply means the destruction (killing) of microorganisms, which pose a threat to public health. In contrast, drinking water treatment usually involves the removal of contaminants. Another term that sometimes is confused with disinfection is sterilization. Sterilization is the destruction of all organisms and not just pathogens. While sterilization may result in providing safe drinking water, it is not a necessary process and it would result in higher costs.

The following chemicals can be used for the chemical disinfection of water:

-
- Chlorine – Cl_2
- Chlorine dioxide – ClO_2
- Hypochlorites – OCl-
  - Sodium hypochlorite – NaClO
  - Calcium hypochlorite – $Ca(ClO_2)$
- Trichloroisocyanuric acid – $C_3Cl_3N_3O_3$
- Ozone – O_3
- Bromine – Br_2
- Iodene – I
- Various bases

There are other means of disinfection besides the use of chemicals. We will refer to these as physical disinfectants. The following list can be used as a physical mean to disinfect water:

- Ultraviolet light – The UV rays must come in contact with each organism in order to provide disinfection.
- Heat – Boiling water for about five (5) minutes is usually sufficient to destroy essentially all microorganisms in the water.

- Ultrasonic waves – Sonic waves destroy microorganisms by vibration.

Chemical Disinfectants other than Chlorine Based Compounds

Four (4) non-chlorine based disinfectants were listed above and while the can provide a means to disinfect and kill microorganisms in drinking water, there are drawbacks to each of them.

- **Iodine** – Using iodine as a disinfectant in drinking water can be effective, but it has a relatively high cost. In addition, iodine has potential serious physiological side effects especially to pregnant woman.
- **Bromine** – There are safety concerns and difficulties handling bromine. Direct contact with the skin can cause burns and residuals are hard to maintain. Bromine is commonly used is spas and swimming pools.
- **Ozone** – Ozone is commonly used at drinking water treatment plants and reduces bad tastes and odors. Ozone is not usually used in distribution systems is because of the lack of a residual, high costs, and maintenance requirements.
- **Bases** – Two of the more common bases include lime and sodium hydroxide. They leave a bitter taste and can also burn skin.

Chlorine and Chlorinated Disinfectants

Disinfection with chlorine and chlorinated compounds result in a disinfectant residual of free chlorine or total chlorine. **Free chlorine** is the amount of “free” and available chlorine to perform the disinfection process. As chlorine combines with nitrogen related compounds (as we will describe in more detail with chloramination) a combined chlorine residual occurs. This combined chlorine, along with any available free chlorine makes up a **total chlorine residual**.

Chlorine Gas

Chlorine is the most common disinfectant used in drinking water. It is in the form of a gas, provides a relatively long lasting residual, and tends to lower the pH of the water. Chlorine gas is greenish yellow in color and has a high coefficient of expansion. Therefore, chlorine cylinders should not be filled more than eighty-five (85) percent. Chlorine cylinders come in one hundred (100), one hundred fifty (150), and one (1) ton sizes. Only forty (40) pounds per day can be withdrawn from the smaller sized cylinders unless they are equipped with an evaporator. Cylinders are equipped with a fusible plug, which is designed to melt at temperatures between 158F and 156F to prevent the cylinder from combusting. One-ton cylinders have six (6) fusible plugs and two (2) valves to withdraw the chlorine. Chlorine gas is 2.5 times heavier than air and ventilation in chlorine rooms needs to close to the floor. Commonly vents are twelve (12) inches above the floor. Leaks can be detected by waving an ammonia soaked rag, which creates a white cloud. Chlorine gas has an immediately dangerous to life and health (IDLH) level of 10 ppm. Chlorine can combine with organics in drinking water created halogenated disinfection by-products.

Hypochlorites of Sodium and Calcium

Sodium hypochlorite comes in the form of a liquid and the chlorine concentration is commonly twelve and one half (12.5) percent. Calcium hypochlorite comes in the form of a solid as granules or tablets and is typically sixty-five (65) percent. Calcium hypochlorite is also known as high test hypochlorite (HTH). When dissolved in water hypochlorites tend to raise the pH. Hypochlorites can combine with organics in drinking water created halogenated disinfection by-products.

Chlorine Dioxide

Chlorine dioxide is highly effective in controlling waterborne pathogens while minimizing disinfection by-products. It is an effective means of controlling taste and odor issues. It can be expensive to use, especially in smaller quantities and can be difficult to handle.

Chloramine

Chloramine is a disinfection process using chlorine and ammonia together. This disinfection process is referred to as chloramination and it results in a combined or total chlorine residual. There are several reasons chloramination is used instead of chlorine alone. Chloramines are produced under three different processes; pre-ammoniation with post-chlorination, pre-chlorination with post-ammoniation, or concurrent addition of chlorine and ammonia. Concurrent addition produces the lowest disinfection by-products and pre-chlorination produces the highest disinfection by-product levels.

Physical Disinfection

While chemical disinfectants and chlorine specifically provides the majority of disinfection in drinking water systems, there are several other means of disinfecting water without using chemicals. These are referred to as physical means of disinfection and they include:

- Ultraviolet rays – Ultraviolet (UV) light rays and inactivate microorganisms. However, the light must come in direct contact with each organism in order to inactivate. Therefore, it is not a sufficient process in drinking water systems. UV systems are commonly used with fish aquariums.
- Heat – Boiling water is an efficient process to destroy microorganisms in water. “Boil Water” orders are often implemented whenever there is an issue with a drinking water system. Boiling water requires heat and time. Typically is takes approximately five (5) of boiling to destroy all microorganisms.

- Ultrasonic waves – Sound waves generate cavitation bubbles in liquids resulting in intense shear forces and high stress.

Factors Influencing Disinfection

Depending on the disinfection process, whether physical or chemical, there are things affecting the effectiveness. For example, UV light must come in direct contact with the organisms to work. We will look at six (6) variables influencing the disinfection process.

The **pH** of the water plays a pivotal role in the effectiveness of disinfection especially when using chlorine or chlorine related compounds. When using free chlorine with water, hypochlorus and hydrochloric acids are formed. In dilute solutions with a pH above 4, the formation of hypochlorus acid is most complete and leaves little chlorine in the solution. However, hypochlorus acid is a weak acid and poorly dissociated at pH levels below 6. The higher the pH, the greater percent of hypochlorite ion exists. Hypochlorus acid has a greater disinfection potential than hypochlorite ion. Therefore, pH plays an important role with disinfection. At a pH of approximately 7.2, 60% of dissolved chlorine exists as hypocholrus acid. At a pH of 8.5, approximately 90% of the dissolved chlorine exists as hypochlorite ions. Therefore, chlorine as a disinfectant is more efficient at pH levels around 7.

Temperature also influences disinfection. The higher the temperature the more efficiently water can be disinfected. At lower temperatures, longer contact times are required. Adding larger quantities of chlorine can speed up the disinfection process. One major disadvantage to warmer waters exposed to the atmosphere is the increased dissipation rate of chlorine into the atmosphere.
Excessive **turbidity** in water supplies will greatly reduce the efficiency of the disinfection process. Any suspended solids present in the water supply can shield microorganisms from the disinfectant. In addition, some types of suspended solids can create an increase in chlorine demand, this results in less available chlorine to react with pathogens.

If some of the turbidity or if other substances in the water are in the form of **organic** compounds, chlorine disinfectants are greatly reduced. In addition, unwanted by-products can be formed, including trihalomethanes and halo acetic acids. The overall affect is a reduction in the overall chemical available for disinfection.

Various other non-organic **reducing agents** can also impact the disinfection process. The demand for chlorine for all reducing agents must be satisfied before chlorine becomes available for disinfection. Inorganic reducing agents impacting chlorine disinfection include, but are not limited to hydrogen sulfide, ferrous ions, manganous ions, and nitrite ions.

Chloramination vs. Chlorination

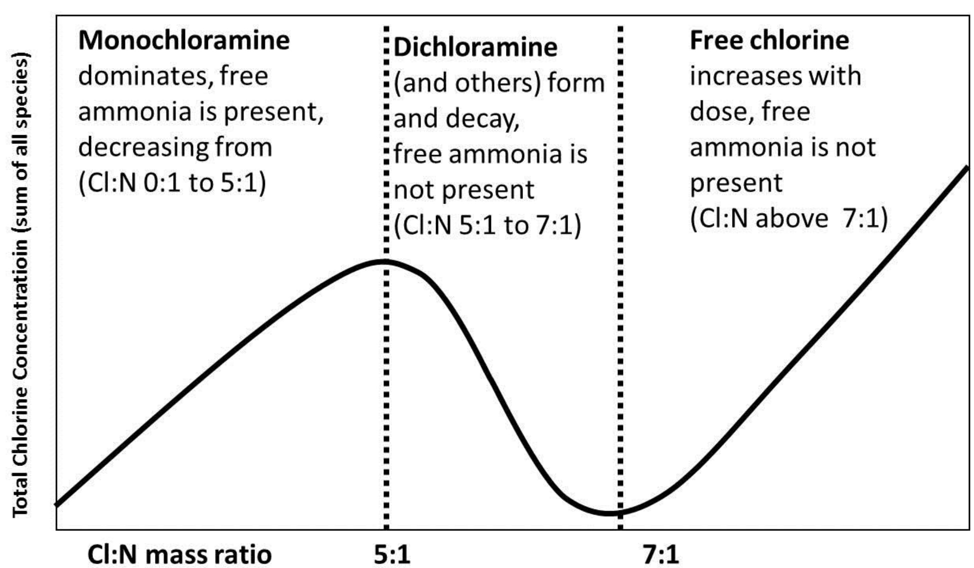
Both chemicals are widely used to disinfect drinking water. Each has their benefits and drawbacks. As previously described, Chloramination results in a total chlorine residual and chlorine creates a free chlorine residual.

Both free and total are efficient with inactivating/killing microorganisms, including heterotrophic plate count bacteria and pathogenic organisms. They both can penetrate biofilm and reduce coliform regrowth. While free chlorine is a stronger oxidizer, chloramines provide a longer lasting residual.

At the correct ratio between chlorine and ammonia, taste and odor problems can be controlled. If water contains organic compounds, free chlorine can combined with these compounds creating disinfection by-products, such as trihalomethane and halo acetic acid compounds. Chloramines reduce this disinfection by-product formation.

Breakpoint Chlorination

As chlorine is initially added to water, reducing compounds are destroyed. Both organic and inorganic reducing agents contribute to this first stage of disinfection. As a result, no chlorine residual is present. Understanding this is critical, but it is also counter intuitive. As you add chlorine no chlorine residual is detected. More chlorine must be continually added. The next stage of breakpoint chlorination is the formation of chloroganics and chloramines. At this point, a residual begins to be detected. As the chloroganics and chloramines start to be destroyed, the residual starts to decrease. Once all the chlororganics and chloramines are completely destroyed, **breakpoint** is hit and all the chlorine demand is satisfied. At this point, any chlorine added is directly proportional to the chlorine residual measured.



If disinfecting with chloramines, an ideal chlorine to ammonia ratio is 5:1. This means for every part of ammonia added, there should be five parts of chlorine. At this point, the highest total chlorine residual is realized and taste and odor issues are minimized. Lower chlorine to ammonia ratios result in free available ammonia. This creates a potential food source for microorganisms and results in a decreased disinfectant residual. This results in a condition referred to as **nitrification.** Therefore, it is important to monitor for nitrogen related components to control this condition. If the chlorine to ammonia ratio increases, the disinfectant residual also decreases and unwanted taste and odor compounds increase. If a free chlorine residual is desired and ammonia is not added along with chlorine, then chlorine needs to be continually added until breakpoint is reached.

Nitrification

Nitrification is an aerobic process in which bacteria reduce ammonia and organic nitrogen into nitrite and then nitrate. Nitrite rapidly reduces free chlorine and can also interfere with the measurement of a free chlorine residual. This results in a loss of total chlorine and ammonia and an increase in heterotrophic plate count bacteria. Higher temperatures and longer detention times in storage facilities increase the potential for nitrification. Water utilities using chloramination as a disinfection practice, usually have a nitrification monitoring plan. This plan would specify and describe steps the utility will take to monitor, prevent, and reduce the affects associated with nitrification. For example, the plan would specify when increased monitoring would be required. It would specify the constituents, which would need to be monitored. It would also describe maintenance activities within the distribution system such as a proactive flushing program to help distribute the chlorine residual and also remove stagnant water. Another example would be to properly cycle the water within storage tanks to prevent or reduce stratification, higher temperatures, and stagnant water. Constituents routinely monitored in systems using chloramines include ammonia, total and free chlorine, nitrite, and heterotrophic plate count bacteria. A reactive approach, which is commonly used by water utilities, is a process referred to as “batch” chlorination. Batch chlorination is the process of adding chlorine to water storage facilities when residuals become too low and/or when nitrification compounds are present.

Conclusion

There are a variety of methods and chemicals, which can be used to disinfect drinking water, with chlorine and chlorine related compounds being the most common. The disinfection process is critical in making sure drinking water is safe to drink by eliminating pathogenic microorganisms from the water supply. It is important to disinfect source water supplies and it is important to maintain detectable chlorine residuals within the distribution system. There are side effects related to the disinfection process including taste and odor issues and the potential formation of unwanted disinfection by-products. Therefore it is important to have adequate monitoring programs and to make sure the appropriate disinfectant is used.

Sample Questions

1. The IDLH of chlorine is?

    a. 5 ppm
    b. 10 ppm
    c. 20 ppm
    d. 100 ppm

2. A 1,000 ton gas chlorine cylinder has?

    a. 6 valves and 2 fusible plugs
    b. 2 valves and 6 fusible plugs
    c. 4 valves and 2 fusible plugs
    d. 4 fusible plugs and 2 valves

3. Gas chlorine

    a. Lowers the pH
    b. Raises the pH
    c. Keeps the pH neutral
    d. None of the above

4. HTH stands for

    a. High Tolerant Hypochlorite
    b. Hypochlorite Total Hypochlorate
    c. High Test Hypochlorite
    d. High Total Hypochlorite

5. After “breakpoint”

    a. All chlorine added is free
    b. All chlorine added is combined
    c. Chlorine is not detectable
    d. Chlorine is a weak disinfectant

6. Chloramines are

    a. A combination of Clorox and ammonia
    b. A combination of amino acids and chlorine
    c. A combination of chlorine and ammonia
    d. Bad because they create high levels of disinfection byproducts

7. Chlorine leaks are best detected with?

   a. A chlorine gas detector
   b. A rag soaked with DPD
   c. A rag soaked with ammonia
   d. Your nose

8. Fusible plugs are designed to melt between

   a. 155°F and 165°F
   b. 168°F and 175°F
   c. 158°F and 165°F
   d. <150°F

9. A 150 lb chlorine cylinder is designed to provide 40 ppd of chlorine unless it has a(n)

   a. Evaporator
   b. Chiller
   c. Extra fusible plug
   d. They can never deliver more than 40 ppd

10. Which of the following has no effect on the disinfection process?

    a. Turbidity
    b. Temperature
    c. pH
    d. They all effect disinfection

CHAPTER 4 – MOTORS

This chapter we will examine the principles of electric motors and their operation.

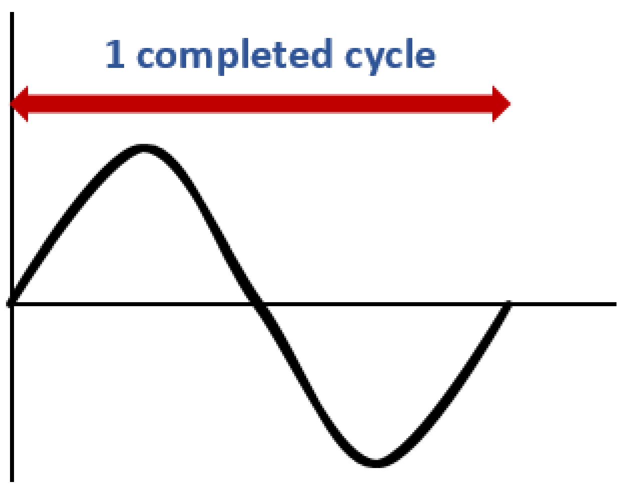
Student Learning Outcomes

After reading this chapter, you should be able to:

- List the various types of electric motors
- Describe the construction of electric motors
- Explain motor control equipment
- Identify the types of motor maintenance

Motors

In order to pump water throughout a distribution system, a motor is needed to run the pump. Motors and engines are an integral part of moving water from the source to the customer. Almost all electrical motors used by water utilities to operate pumps are powered by alternating current (AC). AC flows in one direction and then the other. The current strength rises from zero to a maximum, returns to zero, and then falls and rises in the opposite direction.



This sequence is called a cycle. The frequency of AC is the number of cycles that are completed in one second. For example, 60 hertz (Hz) is equivalent to 60 cycles per second. The number of peaks per cycle equals the phase power. Larger motors are usually powered by three-phase power.

Electric motors are available in a wide range of types, speeds, and power capabilities. Smooth power output and high starting torque is suited for direct connection to centrifugal pumps. While most motors used in the water industry, internal combustion engines are used and have their place of function. Internal combustion engines are primarily used for standby service during emergencies or when there are power outages.

Motor Definitions

As with most things, there are certain terms, phrases, and words associated with motors. Therefore, this section will handle several definitions, which will help in the overall understanding as we progress through this chapter.

- **Horsepower** (hp) is the unit of measure of power for electric motors. A Scottish engineer adopted the term by the name of James Watt. Watt compared the output of steam engines with the power of horses.

- **Watt** is the standard unit of measure of power. One watt is equivalent to one joule per second. It is used to quantify the rate of energy transfer. The conversion between watts and horsepower is shown below:

  0.746 watt = 1 hp

- **Volt** is a measurement of electrical pressure. It is similar to pounds per square inch of pressure in water. Common voltages are 110/120 and 220/240 volts for lighting and operation of small motors. Large motors require voltages of 440/480 or higher.

- **Ampere** is the unit used to measure the flow electrical current.

- **Ohm** – is a measure of electrical resistance or impedance. Electrical pressure drops due to resistance.

- **Stator** is the stationary part of a motor. It usually consists of a steel core with slots in which insulated coils of copper or aluminum winding are placed.

- **Rotor** is the rotating part of the motor. It consists of a steel core with copper or aluminum windings. The rotor is located on the motor shaft within the stator and is separated from it by only a small air gap.

There are other terms associated with motors, which will be discussed later in this chapter.

How a Motor Works

As previously mentioned, motors are found throughout the water utility industry. However, there are motors everywhere in our day to day lives. There are motors in computers, hair dryers use a motor, fans, appliances, toys and so many other things use motors. When an electrical current starts to move along a wire, it creates a magnetic field around it. This magnetic field can cause movement, which can propel a motor. The link between electricity, magnetism, and movement is the basic science behind an electric motor.

The attracting and repelling forces of a magnet within a motor are what create the rotational motion. One pole of the magnet is designated as north and the other south. Current passing through a wire wrapped around a wire rod is called electromagnet. A simple motor is formed when a rotating magnet is placed near an electromagnet. When AC power is connected, current is passed through the electromagnet (stator) creates a magnetic pole that attracts the unlike pole of the other magnet (rotor). Reversing the current changes the pole and the rotor spins and rotates the shaft. The magnetic field in the stator induces current in the rotor, which then rotates, turning the motor and pump shafts.

The speed at which the magnetic field rotates is called the motor's synchronous speed. This speed is expressed as revolutions per minute (rpm). A frequency of 60 Hz has a maximum synchronous speed of 3,600 rpm or 60 revolutions per second. Remember, in 60 Hz, there are 60 cycles per second. The 60 cycles multiplied by the 60 revolutions equals the 3,600 rpm. Motors can run at fractions of 3,600 rpm by increasing the number of poles in the stator. For example, a four-pole motor has a synchronous speed of 1,800 rpm and a six-pole has a synchronous speed of 1,200 rpm. Motors may also run at their synchronous speed or slightly lower.

More electrical current is needed to start motors than there is needed to keep the motor running. The motor starting current (locked-rotor current) is the current drawn by the motor the instant the motor is connected to the power supply system. The locked-rotor current is often five to ten times the normal full load current. The current starts out at its maximum value and then decreases to the motor's ordinary current draw as the motor reaches full speed.

Single Phase Motors

Single-phase motors operate in the same fashion as 3-Phase motors, except they are only run off of one phase. The instantaneous power of single-phase motors is not constant. This is because the system reaches a peak value twice in each cycle. Typically they are only used in fractional horsepower sizes, but they can be furnished up to 10 hp at 120 or 240 V. No power is required to bring these motors up to speed and they must be started by some outside device. A starting winding is usually built into the motor to provide initial high torque. As the motor comes to high speed a centrifugal switch changes connections to running winding.

There are three basic types of single-phase motors.

- **Split-phase** motors use a rotor with no windings. They have a comparatively low starting torque so a low starting current is needed.
- **Repulsion-induction** motors are more complex and expensive than split-phase motors and require a higher starting current.
- **Capacitor-phase** motors have a high starting torque and high starting current. They are used in applications where the load can be brought up to speed very quickly and infrequent starting is required.

Three-Phase Motors

Three-phase motors are used when more than ½ horsepower is needed. A three-phase motor has two main parts. A rotor is the turning component and the stator is the part that turns the rotor. The rotor is also referred to as a squirrel cage. The squirrel cage consists of a circular network of bars and rings, which look similar to a cage connected to an axle. The stator within a three-phase motor consists of a ring with three pairs of coils. The coils are evenly spaced around the rotor. Each pair of coils is attached to one phase power. Since each is out of phase with each other, a rotating magnetic field is created and spins around the stator at a continuous rate. Three phase motors are operated at 230, 460, 2,300, or 4,000 V. There are three main classes of three-phase motors.

- **Squirrel-Cage Induction** motors
- **Synchronous** motors
- **Wound-Rotor Induction** motors

Various motors are used to operate pumps in the water industry. The table below identifies the motor type, phase, application, and provides some additional comments.

Motor Type	Phase	Application	Comments
Induction (Squirrel cage rotor)	Single	Jet pumps, small centrifugal pumps	<1 hp, requires switch
Induction Squirrel Cage (split-phase)	Three	General centrifugal	Low maintenance, single speed
Phase-Wound	Three	Variable speed	Speed adjustable
Synchronous	Three	Used where power efficiency is critical	No slip, efficient
Vertical Hollow-Shaft	Three	Vertical Turbine	Mounted on pump discharge head
Submersible	Three	Submersible	Submersible

Principal Motor Components

There are several components, which make up a motor. This section discusses five (5) principal components.

- **Frame** – The frame of a motor provides protection. A frame is usually made of cast iron or steel. There are four (4) common frame types.
    - **Open drip-proof** – This frame type has openings that allow air to pass through and cool the motor. The openings are constructed so drops of liquid or solid particles will not normally interfere with motor operations. These frames are suitable for most indoor installation, but should not be used if water or chemicals will splash on the frame.
    - **Totally Enclosed Fan-Cooled** – In a totally enclosed frame, it is constructed so that outside air cannot enter the motor. Cooling is provided by a built in fan. These frames are suitable for outside use and in moisture laden atmospheres.
    - **Totally Enclosed Explosion-Proof** – This type of frame is constructed to withstand an explosion of gas or vapor within the motor. It also prevents ignition of gas or vapor surrounding the motor by sparks within the motor. This type of frame should be used whenever the motor is located near an explosive atmosphere such as chemical feeding areas.
    - **Submersible** – A submersible frame is designed to be totally submerged in water. It is equipped with special seals to keep the water out and retain the oil surrounding the motor.
- **Stator** – As previously explained, the stator is the stationary part of the motor. It usually consists of a steel core with slots that are insulated coils of copper or aluminum winding.
- **Rotor** – The rotating part of a motor is called the rotor. It is located on the motor shaft within the stator.
- **Bearings** – In order for the motor shaft to be held in position with minimal frictional resistance, bearings are used. The rotor is in turn supported by bearings, which allows the rotor to turn. The motor housing supports the bearings. Bearings are either lubricated with oil or grease to prevent metal surfaces from wearing.
- **Shaft** – The shaft is a rod that extends through the bearings and rotor. The rotor turns the shaft to deliver the mechanical power.
- **Windings** – The windings are wires laid in coils wrapped around a magnetic core. This forms magnetic poles when energized with electrical current.
- **End Bells** – Motor end bells or shields are the main support for the bearings.

Motors are designed for a wide range of loads, environmental conditions, and mounting configurations. Many motor configurations are standardized is sizes up to 200 hp. Larger motors are not usually standardized. As motors convert electrical energy into mechanical energy, heat is generated. Therefore, motors must be designed with some type of ventilation. In external temperatures greater than 104°F, the life of a motor can be shortened.

Motor Control Equipment

Smaller motors are usually started by directly connecting line voltage to the motor. However, in larger motors (greater than fractional horsepower) a motor started is needed. A typical motor starter includes a main disconnect switch, fuses or circuit breakers, temperature monitors, and a means for operating the motor remotely.

The functions of motor control fall into two main categories. Much of the functions of a motor control are for the protection of the motor and associated feeder cables. The other function determines when and how a motor operates.

There are full voltage and reduce voltage motor controllers. Full voltage controllers use the full line voltage from the electrical source to start the motor. The starting current is drawn directly from the power line. In a reduce voltage controller the starting current of the motor is too high and may damage the electrical system. The controller uses a reduced voltage and current to start the pump motor.

Motor control systems are either automatic of manual. Manual systems are usually less expensive and require employee labor to operate. These types of control systems are generally located in a central control room. Automatic controllers are commonly operated remotely and reduce the need of manual operation. Either type of control system should be included with high and low level alarms as an early warning system.

In order to prevent or reduce the likelihood of motor failure, motor protection equipment is often used. Thermal overload relays on starters prevent a motor from burning out if abnormal operating conditions increase the load beyond the design capacity. Fuses and circuit breakers are place in the main power wiring of a motor to protect against short circuits. The fuses or circuits fail and shut down the motor. Overcurrent or overload relays are used to sense current surges in the power supply. In the event of a power surge these relays disconnect the motor from the power supply. In areas where lightning may occur, lightning arresters are used to prevent damage from high voltage surges. Voltage relays are frequently used to detect a loss of power and to initiate a switchover to an alternate power source. There are a variety of other relays to protect against things such as reverse currents, phase reversals, and frequency changes. Sensors are also used to protect against over heating, increases in speed, and other operational variables, which are not considered normal.

Motor Maintenance

As with all mechanical equipment, a regularly scheduled maintenance program is prudent. General inspection and maintenance items include, good housekeeping in order to keep the area around the motor clean and free of things, which can contribute to premature failure. An inspection checklist to routinely examine things such as alignment and balance of the motor, proper lubrication, adequate insulation, phase imbalance, and connections of switches and circuitry should be followed.

Bearings need to be properly maintained as well. The bearing housing should be filled with oil. With new pumps, the oil should be completely replaced after the first month of operation. Then routine oil changes should occur every 6 to 12 months. In grease lubed bearings the temperature should be monitored closely, especially during the first month. Regreasing should be completed per manufacturer specifications.

Proper records should also be maintained. The make, model, capacity, type, serial number, and warranty information should be kept in order to replace or repair the same or compatible motor. The installation date and name of the company who installed the motor should also be kept with all the other records of the motor. Manufacturers provide suggested inspection and maintenance schedules. It is also important to maintain records of the names and addresses of the manufacturer and local repair representatives.

Results from any testing should also be kept on file. Depending on the size and type of motor, testing can vary. Some common testing parameters include, but are not limited to motor vibration and operating temperatures. Routine checking of cables and grounding is also recommended.

Sample Questions

1. Volt is a measurement of electrical?

   a. Resistance
   b. Pressure
   c. Power
   d. Current

2. Ampere is a measurement of electrical?

   a. Resistance
   b. Pressure
   c. Power
   d. Current

3. Ohm is a measurement of electrical?

   a. Resistance
   b. Pressure
   c. Power
   d. Current

4. Which of the following is not a three-phase motor?

   a. Repulsion induction
   b. Squirrel-cage induction
   c. Synchronous
   d. Wound-rotor induction

5. A four-pole motor has a synchronous speed of?

   a. 1,200 rpm
   b. 1,800 rpm
   c. 2,400 rpm
   d. 3,600 rpm

6. The speed at which the magnetic field rotates is called the motor's

    a. Run speed
    b. Rotation speed
    c. Synchronous speed
    d. Dynamic speed

7. Which of the following is a basic single-phase motor?

    a. Repulsion-induction
    b. Squirrel-cage induction
    c. Synchronous
    d. Wound-rotor induction

8. The stator is the _______ part of the motor.

    a. Rotating
    b. Stationary
    c. Insulating
    d. Not part of a motor

9. Motors are designed for an external temp

    a. less than 150F
    b. less than 125F
    c. less than 110F
    d. less than 104F

10. PLC stands for

    a. Programmable Logic Center
    b. Pump Local Control
    c. Programmable Logic Controller
    d. Pump Local Center

CHAPTER 5 – INSTRUMENTATION AND SCADA

This chapter we will discuss how instrumentation and Supervisory Control and Data Acquisition Systems are used by water utilities

Student Learning Outcomes

After reading this chapter, you should be able to:

- Explain the differences between primary and secondary instrumentation
- List the various ways water utilities use SCADA to operate a distribution system
- Define the term telemetry and how it relates to a SCADA system

There are many different processes that need to be monitored by water utility operators. These include, but are not limited to flow rates, meter totalizers, chemical dosages, pressures, levels, and various water quality parameters.

Primary Instrumentation

Primary instrumentation is an instrument used to measure process variables. Some of the more common process variables measured in a water distribution system include but are not limited to, flows, pressures, levels, chemical dosages, and temperatures. This sort of process flow measurement provides water utility operators information on the efficiency and overall operation of the system. Pump stations, groundwater wells, storage tanks and other facilities should be monitored to ensure they are operating correctly and to help maintain the quality and quantity of the drinking water supply.

Flow Sensors

Measure the flow of water is an important aspect for any distribution system. Flow measurements are used to monitor flows coming into a distribution system (wells, treatment plants, and purchased water sources), flows moving through a distribution system (pump stations), and flows delivered to customers (water service). Measuring flows is important for accounting for the amount of water being purchased, pumped, and sold. Flows can also be used to help track when a piece of equipment needs to be maintained and/or replaced. Meters for measuring flows are typically differential pressure and velocity. They either transmit a read directly to a register (similar to a car's odometer) or have a pulse or electronic output for monitoring at remote locations.

Pressure Sensors

Pressures on the inlet or suction side of a pump and pressures on the outlet or discharge side of a pump are important parameters to track. Too high or too low of pressure can cause problems with pumping equipment and within a distribution system. Pressure sensors can provide direct-read outputs or provide electronic pulses, which can transmit readings to remote locations. There are four common pressure sensors.

1. Strain gauge – This is the most widely used pressure gauge in modern instrumentation. It consists of a section of wire fastened to a diaphragm. The diaphragm moves changing the resistance of the wire. This changing resistance can be measured and transmitted by electrical circuits.
2. Bellows sensor – A bellows sensor uses flexible copper that can expand and contract with varying pressures. This is a direct reading pressure gauge.
3. Helical sensor – A spiral wound tubular element that coils and uncoils with changes in pressure is a helical sensor. This is a direct reading pressure gauge.
4. Bourdon tube – This is a semicircular tube with an elliptical cross section that tends to assume a circular cross sectional shape with changes in pressure. This is a direct reading pressure gauge.

Level Sensors

Water levels in groundwater wells and water storage tanks are commonly measured. The depth to groundwater is important to ensure the groundwater table is not drawn down too low and it also indicates when the water level drops below the bowls within a well. At this point a well should be shut off. Water levels in storage tanks are also important to measure. Water storage tanks provide millions of gallons of water to consumers and it is critical that storage tanks do not overflow or run empty.

1. Float mechanisms – A simple and inexpensive type of liquid level measuring device is a float that rides on the surface and drives a transducer through an arm or cable.
2. Diaphragm element – This type of level sensor operates on the principle that the confined air in a tube compresses in relation to the head of water above the diaphragm. The change in pressure sensed is then related to a change in the head of water.
3. Bubble tube – A bubble tube provides a constant flow of air in a tube, which is suspended in the water. The pressure required to discharge air from the tube is proportional to the head of water above the bottom of the tube. Bubbler tubes are not very common and are being replaced with newer electronic equipment.

Direct Electronic Sensors

Probes, variable resistance devices, and ultrasonic sensors are also being used to measure levels. A probe can be suspended in the water and has an electronic circuit that detects a change in capacitance between the probe and water. It then electronically converts this information into water depth. A wound resistor inside a semi-flexible envelope makes up a variable-resistance level sensor. As the water level rises, a portion of the resistor element temporarily shorts out and changes the resistance of the sensor. This resistance is converted to a level output signal. Transducers are common water level measuring devices, which translate the head of water over the unit into a signal (typically 4-20mA), which is then converted to feet of head or pressure.

Temperature Sensors

There are two main types of temperature measuring devices used in water, they are thermocouples and thermistors. A **thermocouple** uses two wires made of different materials, which are joined at two points. One wire is referred to as the sensing point and the other the reference junction. Temperature changes between the two points causes a voltage to be generated, which can then be read directly or transmitted. A **thermistor** uses a semi conductive material, such as cobalt oxide, which is compressed into a desired shape from the powder form and then it is heat treated to form crystals to which the wires are attached. Temperature changes are reflected with a corresponding change in resistance through the wires.

Primary instrumentation provide real-time measurements of the condition of various pieces of equipment. Some of this information can be used for planning and scheduling routine maintenance and also can be used to indicate when something is out of the norm. These instruments are composed of a sensor, which responds to a physical condition being measured and an indicator, which converts the signal into a display on an indicator. This

Equipment Sensors

Several parameters are monitored for different pieces of equipment in a distribution system. Electrical sensors are used to monitor voltage (volts), current (amps), resistance (ohms), and power (watts). A D'Arsonval meter is used to measure volts, amperes, and ohms on equipment. It is a current sensing device where an electromagnetic core is suspended between the poles of a permanent magnet.

While these types of sensors have been used over the years, digital sensors, which indicate values directly, are more commonly found in the industry nowadays.

The status of equipment is an important parameter to monitor. Common equipment status monitors include, but are not limited to vibration, position, speed, and torque sensors. Any time equipment turns on, off, or simply just runs, vibration occur. This is normal when the components within the equipment are in good condition and the flow of energy is smooth. However, as components age and begin to wear, vibration can increase. A vibration sensor, especially in locations where daily visual inspections are not possible, can be connected to the power circuit and shutdown the equipment if vibration exceeds a specified value.

Similar sensors measuring speed, torque, position, and various other parameters can also be used to monitor equipment and help protect against excessive damage by shutting down equipment at specified set points.

Process Analyzers

In addition to sensors used to monitor the status of equipment, various other processes are commonly monitored within the water utility industry. Measuring water quality is important and common. While measuring water quality parameters in drinking water treatment plants is routine, there are several water quality parameters monitored within distribution systems.

One of the most common water quality parameters measured in distribution systems is the disinfectant residual. Chlorine or chloramines are chemicals used to make sure the biological integrity of drinking water is maintained. Chlorine and chloramine residual analyzers are commonly used to measure the water quality on sources of supply such as groundwater wells and purchased water sources. The measurements can trigger alarms or can be automatically adjusted if the measured parameter falls outside predetermined set points.

Secondary Instrumentation

Secondary instrumentation converts signals from sensors and primary instrumentation. There are several ways instrumentation receives and transmits (indicates) parameters. There are a variety of ways including, but not limited to direct-reading indicators, which express values such as gallons per minute (gpm) for flows, volts from motors, and pressures expressed in pounds per square inch.

Some receivers and indicators collect and record data. Charts are sometimes used to express the values such as the strip chart shown below. Other recorders display total accumulated values or some combination of data collection and expression.

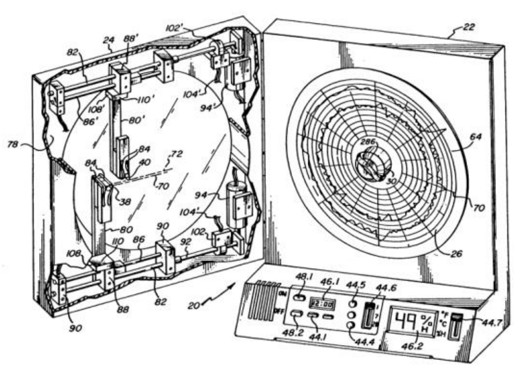


Image is in the public domain

On analog devices, the values will range smoothly from the minimum and maximum values. They are generally easier to read the relative position of the value being displayed throughout the entire range. If values fall between the scaled values on the display they can easily be estimated. On digital devices, the accuracy tends to be better than analog systems and they are very easy to read. The values are typically decimal numbers on mechanical or electronic displays. However, estimating the exact value when the reading falls between divisions on the display is difficult.

When sensors and the indicators are not located in the same area, some type of equipment is needed to send the signal from the sensor to the indicator. In these instances, telemetry is often used. Early telemetry systems used audio tones or electrical pulses. Digital systems are common and se a binary code to transmit signals. A sensor signal feeds into a transmitter, which then generates a series of on-off pulses. The number of on-off pulses represents a number. For example, the pulse sequence of off-on-off-on represents the number five (5). The transmitting device in a digital system is referred to as a remote terminal unit (RTU) and the receiver is called a control terminal unit (CTU).

Whenever multiple signals need to be sent from more than one sensor over the same transmission line is needed, there are several employable methods. **Tone-frequency** sends signals over one wire or radio signal by having tone-frequency generators in the transmitter. Each parameter is sent at a different frequency. There are filters within the receiver, which sort out the signals and send them to the proper indicator. An example of this is a single voice grade telephone line. As many as twenty-one (21) frequencies can be sent over these types of systems.

Scanning equipment is used to transmit the value of several parameters one at a time in a specified sequence. The receiver decodes the signals and displays each one in a specific turn. Scanning equipment can also be combined with tone-frequency to allow even more signals over a single transmission line. **Polling** is a system used where each instrument has its own unique address. A system controller sends out a message requesting a specific piece of equipment to transmit its data.

Duplexing is the last process of transmitting signals we will discuss. There are three (3) types of duplexing systems: full duplex, half duplex, and simplex.

- In **full duplex** systems, the signals can pass in both directions at the same time
- **Half duplex** systems only allow signals to pass one direction at a time.
- A **simplex** system only allows signals to pass in one direction.

Control Systems

The idea of instrumentation and control systems is to obtain the ability to make changes or corrections in the parameters being measured. Yes, it is very valuable to know what a chlorine residual is at a groundwater well, but if you need to visit the location to make actual changes based on the signals being received from a sensor then valuable time can be lost. Therefore, control systems are extremely useful. A control system allows for adjustments to be made based on the data being transmitted and received. Control systems can be broken down into four (4) main types of systems.

- **Direct Manual** – A direct manual system, is the simplest and least complicated control system. Components are controlled by an operator that must physically visit each location to make a change. For example, if a signal is transmitted that requires a system to be turned off, in a direct manual control system, an operator must drive out to the location and manually turn the component off. This type of system has a low initial cost and has little complicated equipment to maintain. However, it does require labor and operator expertise and judgment.
- **Remote Manual** – In a remote manual control system, an operator can make adjustments to systems and components from a remote location. This type of system still requires operator expertise and judgment, but it requires less physical labor. An example of this type of control system could be when a pump needs to be turned on or off. Instead of requiring an operator to physically visit a location to perform this task, it can be controlled remotely from a control room or some remote location.
- **Semiautomatic** – This type of control system combines manual control from a remote location (control room) with automatic control of specific pieces of equipment. An example of this could be a circuit breaker. A breaker will disconnect automatically in response to an overload, but then it must be reset manually. This "resetting" can be remotely or at the facility.
- **Automatic** – Full automatic control is when equipment can turn on and off or adjust their operation in response to signals from sensors and analytical instruments. There are two general modes of automatic controls: on-off differential and proportional.
    - **On-Off Differential** control systems turns equipment either full on or off in response to a signal. The rate of the equipment would need to be adjusted manually.
    - **Proportional** control systems adjust variables automatically. Proportional control systems can be broken down into three (3) main types.
        - **Feedforward proportional control** measures a variable such as chlorine dosage. The flow of water is being measured and the faster (or more) water flows through a meter, the chlorine feed system increases the amount of chlorine. This type of system is useful, but it cannot account for varying chlorine demand.
        - **Feedback proportional control** measures the output of a process and will then react to adjust the operation of the piece of equipment. This type of system is also referred to as a "closed-loop" control system because it continuously self corrects. These systems can be troublesome if there are wide variations in the water flow rate.

- **Combined control** systems adjust in response to changes in the flow rate, but an analyzer monitoring the chlorine dosage makes minor adjustments in the feed rate of the chemical to maintain the selected residual being measured in the finished water.

Supervisory Control and Data Acquisition

The processes discussed in this chapter are wrapped up together into a Supervisory Control and Data Acquisition (SCADA) system. SCADA a system used in a variety of industries including drinking water treatment and distribution systems. There are field devices (primary instrumentation) such as sensors, which read various parameters, sending signals, which are received and transmitted (secondary instrumentation) through telemetry, to a centralized computer system. This allows an operator a complete view of a distribution system to see how things are operating.

Image by U.S. Department of Agriculture is in the public domain

A variety of components and processes are monitored in a drinking water distribution system, including but not limited to storage tank levels, pump station flow rates, pressures, groundwater well depths, and chemical feed such as disinfection systems.

Here is a simple example of a how a SCADA system works in a water distribution system.

A groundwater well provides water to the distribution system. So, how does this well turn on and start pumping water? Years ago, an operator would drive out to the well, open the gate to the facility, insert a key to unlock the control panel, and then turn a switch to power it on. Water would enter the distribution system through a network of pipes. If a customer turns on a faucet, water would come out. What is no one was using water when the well was turned on? The water would then flow to a water storage tank. This tank would begin to fill. What would happen if the well was not shut off? Obviously enough, the storage tank would overflow. So, how would an operator know when to shut the well off? Without some sort of computer system, signal, or alarm, the operator would need to drive to the tank and visually look at the level of water. Then, the operator would drive back down to the well site and shut off the well. This is not very complicated, but it is labor intensive and time consuming. Fast forward to the age of computers. A sensor could be installed in the water storage tank to monitor the level. With the help of a SCADA system, specific level set points can be programmed to tell another set of sensors when to turn on and off something like a groundwater well. This is a very simplistic example of how a SCADA system works, but it adequately explains the process of a sensor sending a signal, a computer system reading this signal, and responding with a function.

A control room is typically equipped with a human-machine interface (HMI). This interface is a window into the SCADA system. It graphically displays all the facilities within a system. The tanks, pumps, sources of supply are all interconnected to make sure water is continually distributed throughout the system. The system is usually equipped with various alarms to remotely notify operators through pagers, text messaging, or some other type of remote notification. This allows the system to continually function without someone sitting at a computer twenty-four (24) hours a day, seven (7) days a week. An alarm is received by an operator and then the fully trained operator would either verify the alarm was cleared after the process returned to normal operation or inform the operator that additional tasks might be needed to fix the system.

Sample Questions

1. Which of the following is used to measure pressure?

    a. Volute
    b. Multi-jet
    c. Strain gauge
    d. All of the above

2. Which of the following is used to measure low pressure?

    e. Bellows sensor
    f. Helical sensor
    g. Bourdon tube
    h. All of the above

3. Bubble tubes must be installed

    a. At the top of the tank
    b. In the middle of the tank
    c. At the bottom of the tank
    d. Any where in the tank

4. Which of the following temperature measuring devices uses two wires?

    a. Thermometer
    b. Thermister
    c. Thermostat
    d. Thermocouple

5. Which of the following temperature measuring devices uses cobalt oxide as a semi conductive material?

    a. Thermometer
    b. Thermister
    c. Thermostat
    d. Thermocouple

6. Which type of control would not account for varying chlorine demand?

    a. Feedback proportional
    b. Feedforward proportional
    c. Combined
    d. All of the above

7. Which of the following is the smallest measurement of power?

    a. Voltage
    b. Amperes
    c. Ohms
    d. Watts

8. Amperes is a measurement of

    a. Current
    b. Resistance
    c. Power
    d. Voltage

9. SCADA stands for

    a. Self Contained Analog Digital Assembly
    b. Superior Computer And Data Acquisition
    c. Supervisory Computer And Digital Assembly
    d. Supervisory Control And Data Acquisition

10. Which of the following allows signals to only pass in one direction?

    a. Half duplex
    b. Full Duplex
    c. Simplex
    d. All of the above

CHAPTER 6 – SAFETY

This chapter we will discuss good safe practices and emergency preparedness related to the water utility industry.

Student Learning Outcomes

After reading this chapter, you should be able to:

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

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

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

Various Types of Safety

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

- **Organizational Safety** – This is the most universal type of safety businesses (organizations) are faced with. It is the overall prevention of injury to employees. This prevention of injury is for employees both on and off the job. You might ask why an employer should be concerned with an employee's personal safety when they are not working. The main reason organizations should instill the value of safety for employees both on and off the job is two fold. First, any injury can result in lost time. This means if an employee gets injured at home, they may not be able to report to work. This results in inefficiency in the workplace and sometimes results in a loss of revenue for the employer. The second reason and maybe more importantly is creating a culture where safety is a value within the organization. Valuing safe work practices both on and off the job will result in a safer work environment and less loss time and money for organizations.

- **Fleet Safety** – Water utility workers work within a community. They are required to operate equipment and drive vehicles. This can result in traffic accidents and equipment related accidents. Fleet safety is designed to help prevent these types of accidents.
- **Public Safety** – Put simply, public safety is the prevention of injury to the general public. Water utilities have facilities throughout a community and it is important these facilities do not pose a safety hazard to the general public. An example of this might be something simple like a meter box lid. If the lid is missing or broken, it could present a tripping hazard to someone walking along a sidewalk. Water utility workers also work in public streets. This not only presents a safety hazard to the employee, but blocking off portions of a street can lead to traffic accidents and exposes the public to potential safety hazards.

Organizing a Safety Program

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

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

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

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

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

The following is an example policy safety statement:

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

Safety Regulatory Requirements

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

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

Causes of Accidents

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

- Ignorance – It is not that employees are ignorant. It is when they lack the experience or training to do their job safely.
- Indifference – Some employees and in some instances employers are "indifferent" or do not care about safe work practices.
- Poor work habits – Many times employees develop bad habits if they don't understand how to perform task correctly in the first place.
- Laziness – Sometimes employees do not want to or are unable to provide the required effort.
- Haste – Working too fast can contribute to unsafe work conditions.
- Poor physical condition – Employees need to have proper rest and for some tasks must be physically fit.
- Temper – Impatience and anger can cloud judgment and result in accidents.

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

Safety Training Topics

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

Hazard Communication

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

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

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

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

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

Personal Protective Equipment

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

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

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

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

Slips Trips and Falls

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

Back Safety

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

Trench Safety

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

Confined Spaces

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

Permit Required Confined Spaces

- Contains or has the potential to contain a hazardous atmosphere
- Contains a material that has the potential for engulfing an entrant

- Has an internal configuration such that an entrant could be trapped or asphyxiated by inwardly converging walls or by a floor that slopes downward and tapers to a smaller cross-section
- Contains any other recognized serious safety or health hazard

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

Respiratory Safety

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

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

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

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

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

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

Traffic Control

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

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

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

Occupational Injuries

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

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

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

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

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

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

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

- Any work related fatality
- Any work related injury or illness that results in loss of consciousness, days away from work, restricted work, or transfer to another job

- Any work related injury or illness requiring medical treatment beyond first aid
- Any work related diagnosed case of cancer, chronic irreversible diseases, fractured or cracked bones or teeth, and punctured eardrums

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

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

Sample Questions

1. When symptoms develop rapidly within a person it is considered

    e. A chronic health effect
    f. An acute health effect
    g. A disease
    h. Both a and c

2. What is the primary responsibility of the safety officer?

    e. Should be a line function
    f. Should be a staff function
    g. Should provide all the training
    h. All of the above

3. Traffic control should be set up in the following order

    e. Buffer Zone, Transition Zone, Work Zone, Termination Zone, Advanced Warning
    f. Advanced Warning, Buffer Zone, Work Zone, Transition Zone, Termination Zone
    g. Advanced Warning, Transition Zone, Buffer Zone, Termination Zone, Work Zone
    h. Advanced Warning, Transition Zone, Buffer Zone, Work Zone, Termination Zone

4. Fusible plugs are designed to

    e. Melt, preventing combustion
    f. Melt between 158°F - 165°F
    g. Fuse the valve connection to the hose
    h. Only a and b

5. A 1-ton chlorine cylinder has

    e. 2 fusible plugs and 6 valves
    f. 2 valves and 6 fusible plugs
    g. 1 valve and 5 fusible plugs
    h. 5 valves and 1 fusible plug

6. The IDLH for chlorine gas is

    e. 5 ppm
    f. 10 ppm
    g. 20 ppm
    h. 100 ppm

7. All fatalities, serious injuries and illnesses must be reported to Cal/OSHA within

    e. 8 hours
    f. 16 hours
    g. 24 hours
    h. 48 hours

8. A chronic health effect is?

    e. An adverse effect developing rapidly
    f. An adverse effect resulting in cancer
    g. An adverse effect developing over a long period of time
    h. A disease with little or no symptoms

CHAPTER 7 – WATER RATES

This chapter we will discuss the various sources of supply available for water utilities.

Student Learning Outcomes

After reading this chapter, you should be able to:

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

Why Are There Water Rates?

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

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

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

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

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

Below is a list of some factors affecting revenues:

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

Below is a list of factors affecting revenue requirements:

- Number of customers served
- Customer water use
- Non-recurring sales
- Weather
- Conservation
- Use restrictions
- Inflation
- Interest rates on debt
- Capital financing needs
- Changes to tax laws
- Other changes in operating
- Economic conditions

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

Cash-Needs Approach

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

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

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

Utility Approach

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

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

Revenue Requirement Components

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

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

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

Operations and Maintenance

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

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

Debt Service

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

Reserves

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

Capital Expenditures

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

Coverage Ratio

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

Revenue

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

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

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

Customer Classes

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

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

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

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

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

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

Water Rates

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

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

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

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

Why would a utility have a two-part rate versus just charging water based on the actual usage of each customer?

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

Flat Rates

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

Variable Rates

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

Tiered Rates

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

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

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

http://www.latimes.com/local/orangecounty/la-me-water-law-20150227-story.html

It is extremely important a utility properly explains and notifies their customers before implanting water rates, especially tiered water rates.

Budget Based Rates

A budget based rate structure is similar to a tiered rate structure. The difference between the two is instead of charging water purely based on the quality of water used. In a water budget based rate structure, water charges are assigned based on customer usage both indoors and outdoors. While most utilities do not measure these (indoor/outdoor) uses separately, under a budget based water rate, a certain volume is often assigned for indoor water use. In addition, a specific amount is assigned for outdoor water use (irrigation). These assigned amounts are considered a customer's budget. The rate assigned to the budget is a standard volumetric water rate. If customer's stay within their budget, do not use more than the allocated amount, then the rate does not change. However, if a customer uses more water than their allocation, the cost of water increases similar to a tiered structure.

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

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

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

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

Sample Questions

1. Budget projections beyond 10 years tend to be

    i. Accurate
    j. Speculative
    k. Adequate
    l. Both a and c

2. The “Cash-Needs” approach is typically used by

    i. Private utilities
    j. Public utilities
    k. Agencies with multiple commodities
    l. All of the above

3. Which of the following is not included in O&M expenses?

    i. Salaries
    j. Purchased water
    k. Chemicals
    l. None of the above

4. Investor owned utilities are governed by

    i. An elected board of directors
    j. A City Council
    k. The California Public Utilities Commission
    l. A Mayor

5. A periodic stated charge for utility service not based on metered quantity of service defines

    a. Firm service
    b. Flat rate
    c. Rate blocks
    d. Standard rates

6. The annualized period for which costs are to be analyzed and rates established defines

a. Test year
b. Yearly projections
c. Annual analysis
d. None of the above

7. Connection fees are charged to

a. Create revenue for O&M expenses
b. New customers for costs of new facilities needed to apply water
c. Help establish service area boundaries
d. All of the above