WTRM 201 INTRODUCTION TO WATER, WASTEWATER TECHNOLOGY



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WTRM 201 Introduction to Water, Wastewater Technology

by

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Remixed for Gavilan College

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Page 1.1: Introduction to Water Systems Technology

Water Systems Technology is a program designed to provide the student with enough information to build a successful and lasting career in the water and wastewater industries. It is a program that has been developed by professionals within the industry and within academia. Upon successful completion of the program and after completing any required general education course work, the student can earn an Associate of Science degree in Water Systems Technology. In addition, each course provides supplemental course work hours required for renewal of existing certifications in the water and wastewater industries and many provide specialized training coursework to qualify students to take state certification exams. The program has several general topic course options, includes coursework related to waterworks mathematics, and has specialized courses covering water distribution, water treatment, and wastewater.

Introduction to Water Systems Technology (Water 020) is a general overview course of the entire Water Systems Technology program. Topics covered include the requirements to obtain a career in the water and wastewater industries, and an overview of specific disciplines covered throughout the program. The various courses will provide the student a broad understanding of both the drinking water and wastewater industries, as well as specific technical background. This course and the accompanying text will provide the student with enough information to determine if “water” is the type of career for them.

Water is a vital resource to sustain both animal and plant life. It is a resource that many take for granted. As long water flows out of the faucets within a home, many people don’t think much more about it. However, if the flow of water stops, people take notice. Think for a moment about all the things we use water for: washing, bathing, drinking, cooking, cleaning, restrooms, brushing teeth, the list goes on and on. And this is only some of the indoor water usage. Most of the water used by residential consumers is outdoors. Whether it is landscaping, swimming pools, washing cars, or growing crops, outdoor water use can account for up to 70% of a customer’s water usage. In addition, commercial and industrial businesses use water for a variety of different processes. Some industries might use millions of gallons of water a year while others might only use a few thousand gallons. Take for example an insurance office with 10 employees. More than likely the office will have a restroom and perhaps a small kitchen area. The water use at this type of business would probably be rather low. Maybe a couple hundred gallons of water flushed down the toilet and a couple pots of coffee a day might be all. Now, take the example of chemical manufacturing plant with 100 employees. In addition to restrooms and possibly a kitchen, this type of business might have boilers, water treatment and conditioner systems, and may also use a lot of water in the production of chemicals. You can see how water use can vary from business to business. Lastly, and the biggest user of water, is the agricultural industry. In California, growing crops throughout the state can account for up to 80% of the total water use. Water is not only a health and safety need of millions of people, it is a vital resource for keeping the economic system flourishing. Some of these topics and a discussion of the various uses of water will be covered throughout this course.

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Page 1.2: Operator Certification and Regulations

There are numerous regulations that pertain to the water industry as a whole. In addition to general business and accounting regulatory requirements, health and safety requirements, environmental requirements, labor requirements, etc, there is a set of regulations that specifically govern water utilities. These regulations are referred to as the Safe Drinking Water Act. The Environmental Protection Agency promulgated these regulations in the early 1970s and required states to adopt them or create similar regulations that meet the minimum requirements. The practical application of the California Safe Drinking Water Act (SDWA) encompasses the federal act and in some instances has added additional requirements that have made some of the water quality regulatory standards more stringent. California's SDWA can be found in California Code of Regulations Title 22, Division 4 Environmental Health. Much of the SDWA deals with water quality regulations, which will be discussed in a later chapter. However, there are other operational requirements that are specified as well. In 1996, the SDWA was amended for the second time. Some of the changes included provisions for "Operator Certification" requirements. Treatment Operator certification requirements were part of the original SDWA regulations establishing the level at which water treatment facilities should be manned, the minimum qualifications for testing at five (5) different grade levels, and criteria for the renewal and revocation of certificates. The recent amendments now include the certification and recertification requirements for distribution operators at five (5) different grade levels.

Operator Certification refers to requirements for both treatment and distribution operators in order for them to perform certain work. Both treatment and distribution operators are classified by five (5) different certification grade levels. Treatment Operators are listed as T1, T2, T3, T4, and T5 and Distribution Operators as D1, D2, D3, D4, and D5. T1 and D1 are the lowest certification levels and T5 and D5 are the highest. Generally entry level positions require lower level certifications such as D1, D2, T1, or T2. These positions are primarily labor related jobs and require little contact and or control of the water supply. Supervisors and managers sometimes require higher certification levels depending on their job descriptions. However, there are specific regulations that spell out minimum certification requirements for certain job related tasks.

The Operator Certification regulations provide very specific requirements for becoming certified and who actually needs to be certified. In addition, there are a number of definitions. Among them are definitions for what is referred to in the regulations as "Shift" and "Chief" Operators.

- **Shift Operator** - "Shift Operator" means a person in direct charge of the operation of a water treatment or distribution system for a specified period of the day.
- **Chief Operator** - "Chief Operator" means the person who has overall responsibility for the day-to-day, hands-on, operation of a water treatment facility or the person who has the responsibility for the day-to-day, hands-on, operation of a distribution system.

Although these definitions may seem specific, they do have some ambiguity. What if you have a distribution operator who is in charge of a certain operation for the day, but he has been told to call a supervisor before making any decisions or changes in the system. Is this person a "shift operator" per the definition above? Can a manager that is responsible for a treatment facility, but doesn't actually work on the treatment facility be a "chief operator"? As you can see, there needs to be some clarification to these and other definitions in the regulations.

The regulations do offer some clarification. For example, they specify that water systems shall utilize only certified operators to make decisions addressing the following operational activities:

1. Install, tap, re-line, disinfect, test and connect water mains and appurtenances
2. Shutdown, repair, disinfect and test broken water mains
3. Oversee the flushing, cleaning, and digging of existing water mains
4. Pull, reset, rehabilitate, disinfect and test domestic water wells
5. Stand-by emergency response duties for afterhours distribution system operational emergencies
6. Drain, clean, disinfect, and maintain distribution reservoirs (tanks)
7. Operate pumps and related flow and pressure control and storage facilities manually or by using a system control and data acquisition (SCADA) system
8. Maintain and/or adjust

What determines the level of certification needed? Each treatment facility and distribution system is classified at a certain level. Meaning a treatment facility and distribution system are either classified as a T1 - T5 facility or D1 - D5 system respectively. The facility and system classification is based on a number of different parameters and in California is specified by the Division of Drinking Water (DDW), a branch within the State Water Resources Control Board of California (SWRCB.) In general, classifications are based on a point system. Treatment Facility Classification is primarily based on the type and quality of water being treated and the treatment/disinfection processes used. Distribution System Classification is based on population served. If the population served is five (5) million or less then a point system is used based on number of pressure zones, disinfectants used, size of pumping equipment, and number of storage tanks. If the point based system total exceeds 20 points then the classification is upgraded by one (1) level. Once the facility and system have been classified, the regulations then stipulate the minimum certification requirements needed by the staff. The following table specifies the minimum certification requirements for each treatment facility and distribution system classification.

Treatment Facility and Distribution System Classification	Minimum Certification of Chief Operator	Minimum Certification of Shift Operator
T1 / D1	T1 / D1	T1 / D1
T2 / D2	T2 / D2	T1 / D1
T3 / D3	T3 / D3	T2 / D2
T4 / T4	T4 / D4	T3 / D3
T5 / D5	T5 / D5	T3 / D3

How does someone become certified? There are certain requirements and prerequisites to becoming a certified operator. As previously mentioned, the first certification level (T1, D1) is the lowest level and has the least amount of requirements to become certified. Similarly, T5 and D5 are the highest certification levels and have the most requirements to reach these levels. There are two requirements for each level, one for being able to take the certification exam and the other to receive the actual certification. Let's take a look at the requirements for each certification level. Since the requirements are similar for both treatment and distribution, they will be referred to as 1 - 5 in this discussion.

Level 1 - The only requirement to take a level 1 exam is a high school diploma or equivalent. A General Education Diploma (GED) is an example of something that is equivalent to a high school diploma. Even though there is no "water" related requirement to take a level 1 exam, most people would have difficulty passing the exam without having any experience or knowledge of water systems. For example, do you know the difference between a butterfly valve and a gate valve? Or, the difference between flocculation and coagulation?

In order to receive the level 1 certification, the only requirement is the passing of the exam with a score of seventy percent (70%) or better.

Level 2 - Level 1 is the only certification level that can be skipped. If you meet the minimum requirements of a Level 2 exam, you can skip Level 1. In order to take a Level 2 certification exam you must also have a high school diploma or equivalent. In addition, you must complete thirty six (36) hours of instruction in a water related field. A three (3) unit course meets the thirty six (36) hour requirement. The course must meet certain minimum specifications in either water supply, distribution, treatment, or similar topics. Any of these classes would provide you with the information needed to pass both a Level 1 and Level 2 exam. Therefore, it is very common for people to skip Level 1, take the required course work and then take Level 2. However, some people are curious as to the format and type of questions that are asked on these exams and take a Level 1 exam while they are also completing courses in a water related field.

The requirements for receiving a level 2 certification are the same as level 1, you must pass the level 2 exam with a score of seventy percent (70%) or better.

Level 3 - The requirements for taking exams and becoming certified for Level 3 and higher are a little more restrictive. In order to be able to take a Level 3 exam, you must complete two (2) thirty six (36) hour courses. One course must meet the same requirements as described for a Level 2 and the other can be a supplemental water related course. A supplemental course can be a

less specific water related course such as, waterworks mathematics, water quality, or some other course that don't specifically focus on distribution or treatment. Once you successfully complete and pass the required coursework, you can take a Level 3 exam.

Once you have successfully passed a Level 3 exam with a score of seventy percent (70%) or better you are not automatically eligible for a Level 3 certification. In addition to completing and passing the required two (2) courses, you must also be a certified Level 2 Operator for at least one (1) year. Therefore, you cannot skip Level 2 and become a Level 3.

Level 4 - The requirements for Level 4 certifications are similar to Level 3. In addition to the two (2) classes required as Level 3, an additional supplemental course is required. Therefore, a total of three (3) thirty six (36) hour (or 3 unit) courses are required to be able to take a Level 4 exam.

After successfully passing a Level 4 exam with a score of seventy percent (70%) or better and you have been a Level 3 certified operator for one (1) or more years you can obtain a Level 4 certificate.

Level 5 - Four (4) thirty six (36) hour (3 unit) courses are required to qualify for taking a Level 5 exam. One (1) class must be specialized training and the other three (3) can be a supplemental course.

After passing a Level 5 exam and meeting a minimum of one (1) year experience as a certified Level 4 operator a Level 5 certificate can be obtained.

Division of Drinking Water Certification Exams

The DDW website provides recommended reading material and an expected range of knowledge section to help prepare for the exams:

www.waterboards.ca.gov/drinking_water/certlic/occupations/DWopcert.shtml

In addition, this website provides all the required material to apply and prepare you to become a Certified Operator. Exams for Treatment and Distribution are each offered two times a year approximately six (6) months apart. The Treatment Exams are offered in May and November of each year with their respective filing dates March 1st and September 1st of each year. The Distribution Exams are offered in March and September of each year with their respective filing dates January 2nd and July 1st of each year. Although these are the exam schedules at the time this text was being written, the DDW website should always be visited for any updates.

Treatment Exams

The Treatment exams consist of multiple choice questions covering topics of Source Water, Water Treatment Processes, Operation and Maintenance of Treatment Facilities, Laboratory Procedures, Safety, Regulations, and Administrative Duties. Below is a summary breakdown of each category:

Source Water

- Wells and Groundwater
- Surface Water and Reservoirs
- Raw Water Storage
- Clear Well Storage

Water Treatment Processes

- Coagulation
- Flocculation
- Sedimentation
- Filtration
- Disinfection
- Demineralization
- Corrosion Control
- Iron and Manganese
- Fluoridation
- Water Softening

- Best Available Technology

Operation and Maintenance

- Chemical Feeders
- Pumps and Motors
- Blowers and Compressors
- Water Meters
- Pressure Gauges
- Electrical Generators

Laboratory Procedures

- Sampling
- General Laboratory Practices
- Disinfectant Analysis
- Alkalinity Analysis
- pH
- Specific Conductance
- Hardness
- Fluoride
- Color Analysis
- Taste and Odor
- Dissolved Oxygen
- Algae Count
- Bacteriological Analysis
- Safety
- Administrative Duties
- Regulations

In addition to all the above knowledge you must have, there are always a series of math related questions on each exam. There are typically fifteen math related questions and are usually worth two (2) points each compared to one (1) point for the general knowledge questions. The math questions range from a variety of topics and include some simple addition type computations on the lower grade exams to complex algebraic and geometric computations. Below is a brief outline of what one can expect on an exam.

Math Related Computations

- Areas
- Volumes
- Pressure
- Flow
- Chemical Dosage
- Filtration
- Horsepower
- Milliamps

This list is not complete and there are various topics within each of the above but it does provide you an insight into some areas of waterworks mathematics.

Distribution Exams

The Distribution exams consist of multiple choice questions covering topics of Disinfection, Distribution System Design, Hydraulics, Equipment Operation, Maintenance, Inspections, Drinking Water Regulations, Management, Safety, Water Mains, Piping, Water Quality, and Sources of Supply. Similarly to the Treatment Exams, there are a series of math related questions as

well. In addition, there is some overlap between the information on both the Treatment and Distribution exams. Below is a summary breakdown of each category covered on the Distribution exams:

Disinfection

- Water Main, Well, Storage Reservoir Disinfection
- Disinfection By-Products
- Chloramination and Various Types of Disinfectants
- Chlorine Curve Chemistry

Distribution System Design and Hydraulics

- System Layout
- Storage Facilities
- Cross Connection Control and Backflow Devices
- Service Connections
- System Maps
- Flow Rates and Velocity
- Pressure and Head Loss
- Water Hammer

Drinking Water Regulations

- Disinfection By-Products (DBP) and Lead and Copper Rules
- Maximum Contaminant Level (MCL)
- Monitoring and Sampling
- Total Coliform Rule (TCR)
- Safe Drinking Water Act (SDWA)
- Compliance
- Budgets
- Emergency Response
- Conservation Planning
- Water Rates

Equipment Operation, Maintenance, and Inspections

- Valves
- Meters
- Hydrants
- Chemical Feed
- Corrosion
- Sensors
- SCADA
- Pumps
- Horsepower
- Water Mains
- Repair and Installation
- Wells

Water Mains and Piping

- Excavation
- Installation
- Joints and Fittings
- Leak Detection
- Repair

- Material Selection

Water Quality and Sources of Supply

- Coliform Group
- Heterotrophic Bacteria
- Organic and Inorganic Compounds
- pH
- Hardness
- Turbidity
- Flushing
- Disease
- Groundwater
- Surface Water
- Sanitary Surveys

This is not a complete list of all the topics covered on the Distribution Certification Exams but it is a good overview of the topics and areas that are covered. In addition, the mathematical computations you are expected to know are similar to the math questions found on the Treatment exams.

Drinking Water Distribution and Treatment were both governed by California Department of Public Health (CDPH). However, in 2014 the Division of Drinking Water Programs within CDPH was moved under the State Water Resources Control Board (SWRCB) and is now referred to as Division of Drinking Water (DDW.) SWRCB also governs wastewater and the certification program for wastewater operators. In addition, the California Water Environment Association has a wastewater certification program that SWRCB recognizes. Certified Wastewater Operators can apply for an examination waiver with SWRCB if they meet certain requirements.

Wastewater Exams

The following information is a review of the areas of expertise and topics covered on Wastewater Certification exams:

- **Collection System Maintenance** – This vocation deals with sewer maintenance and repair. The collection system is the from the customer's property to the treatment plant.
- **Laboratory Analyst** – Wastewater needs to be analyzed in a laboratory. The Laboratory Analyst has the responsibility of testing the water in the laboratory.
- **Environmental Compliance Inspector** – Wastewater treatment facilities have a number of regulations that they must follow. The Environmental Compliance Inspector is in charge of inspecting and monitoring the wastewater that empties into the sewer system. This is also known as "Source Control," "Industrial Pretreatment Inspection," "IPP," and "Industrial Waste Inspection."
- **Plant Maintenance** – This vocation deals with the maintenance and repair of wastewater treatment plants. Electrical/Instrumentation (EIT) and Mechanical Technology (MT) are the two specialties within this career. The EIT deals with the maintenance and repair of wastewater treatment plant electrical and instrumentation systems while the MT focuses on mechanical systems such as pumps and motors.
- **Industrial Waste Treatment Plant Operator** – This type of operator works at wastewater treatment plants in private industrial facilities.
- **Biosolids Land Application Management** – Biosolids are the inert biological materials (sludge) resulting from the wastewater treatment process. This vocation focuses on the management of these wastes.

Most of the careers within the water and wastewater industries will require some type of certification. However, there are other specialty areas such as engineering and accounting that may require a specific degree. Throughout this course and program you will be exposed to a variety of career choices. Find the one(s) that you are interested in and pursue that discipline.

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Page 1.3: Career Opportunities In the Water Industry

Finding a job is dependent on a number of factors. Timing, current economic conditions, work skills, and more all play a part in trying to land a job. However, with a little bit of discipline and effort, finding a job is not too difficult. Although finding a "job" might not be too difficult, finding a career can be. What is the difference between a "job" and a "career"? A "job" for discussion purposes in this chapter is a place of employment that may or may not be full-time and will probably not lead to multiple years of employment in the same industry. That is not to say that someone cannot turn a "job" into a successful long lasting place of employment. It is just to distinguish between some place to work and a career in a specific industry. In this chapter, a career refers to a place of employment in a similar industry for many years—a career in the "water" industry.

There are some industries that will flourish at times and then feel the downward effects of a slowing economy. For example, a career in the aerospace industry usually reaps the benefits from defense contracts but can also see a significant hit when the government decides to implement cuts in the defense budget. Although the "Tech" industry saw tremendous financial gains during the "dot com" boom of the late 1990s, there was a hit to that industry after the turn of the century. In addition, when the housing market crashed in 2008, many home builders and the construction industry saw profits plummet along with high levels of unemployment. All of these examples can be profitable and long lasting careers but they are also susceptible to economic uncertainty.

Water and wastewater industries are a little different. This is not to say there are never layoffs or periods of economic challenges in these industries. However, people will always need a safe and reliable supply of drinking water and people will always create wastewater. Therefore, water utilities in general are very sustainable and recession proof industries. The water and wastewater industries will be referred to collectively as "water industry" throughout the text. Within each industry, there are multiple layers of careers from office functions to field construction workers. Some of these positions require specific job training and expertise while others might only require a high school diploma. The careers discussed in this text will fall under water distribution, water treatment, and wastewater treatment. Within each of these industries, distribution and treatment operators will be the main focus.

A general understanding of distribution and treatment should be explained first. Water that is delivered to millions of people throughout the United States is transported through an array of aqueducts, storage reservoirs, large and small diameter pipes, treatment plants, pumps, valves, meters, and various appurtenances before it arrives at the customer's faucet. In California, most of the water treated for domestic use moves through the State Water Project, Los Angeles Aqueduct, or the Colorado River Aqueduct. These large water conveyance systems are owned and operated by a variety of state and local agencies. For example, the State Water Project (SWP) is managed by the California Department of Water Resources (DWR). DWR manages the movement of water from an area just north of Sacramento down into Southern California. They employ hundreds of people who have the responsibility of delivering water to SWP contractors. There are twenty-seven member agencies including the local Santa Clarita Valley Water Agency and Metropolitan Water District. Much of the water we use for domestic purposes requires some type of treatment. There are dozens of treatment plants throughout the state and thousands throughout the country. These treatment plants rely on a network of sophisticated treatment process to provide safe and reliable drinking water to millions of people. Operating these treatment plants require highly trained and certified treatment operators, engineers, maintenance workers, managers, and office staff to keep the treatment process running effectively and efficiently. Once treated water leaves a treatment plant, it must move through a network of pipes, pumps, storage structures, and appurtenances before it reaches each customer. This is where water distribution systems step in. Water distributors are typically referred to as water purveyors or water retailers. A water purveyor might have as few as a couple employees or as many as hundreds to thousands. Field distribution operators are trained professionals and are required to be certified. Once the water has been used by customers, it ends up in either a storm drain, which predominately is left untreated as it makes its way to the ocean, or it ends up in a sanitary sewer system and is treated through a Water Reclamation Plant (WRP), Publically Owned Treatment Works (POTW), or a Wastewater Treatment Plant (WTP). WTP will be used in this text to collectively refer to all wastewater (sewer) treatment facilities. For all practical purposes, these are all similar facilities where wastewater (sewer water) is treated before being discharged. In addition, WTPs will have a network of piping leaving home and businesses to the WTP.

Water Industry Careers

Water industry employees are responsible to provide customers with safe and reliable drinking water and to safely treat wastewater to further protect human life and the environment. Safe water means it must comply with both state and federal drinking water regulations (discussed later in this text). Reliable water means that when a customer turns on their faucet water flows out. People tend to take things like electricity and water for granted. We flip a switch and the light goes on. We turn a faucet and water comes out. It is not until these resources are interrupted people get concerned and sometimes upset.

There are hundreds of drinking water treatment plants throughout the U.S. These treatment plants have the responsibility to treat surface water to certain standards making it safe for human consumption. There are a variety of highly skilled positions within a treatment plant and staff responsibilities can range from operator to laboratory technician, from administrative assistant to water resource engineer.

The distribution of water is an unseen necessity by millions of people throughout the world. There are over 18 billion miles of distribution piping throughout the U.S and over 50,000 community water systems. All of these drinking water systems require people to operate and run them. There are thousands of employment opportunities available throughout the U.S. However, operating a distribution system is a complex operation requiring trained personnel in a variety of job functions. Water purveyors can have different sources of supply including surface water, purchased water, groundwater, and recycled water. They can have few customers or thousands, a handful of employees or hundreds, but all of them will have similar functions.

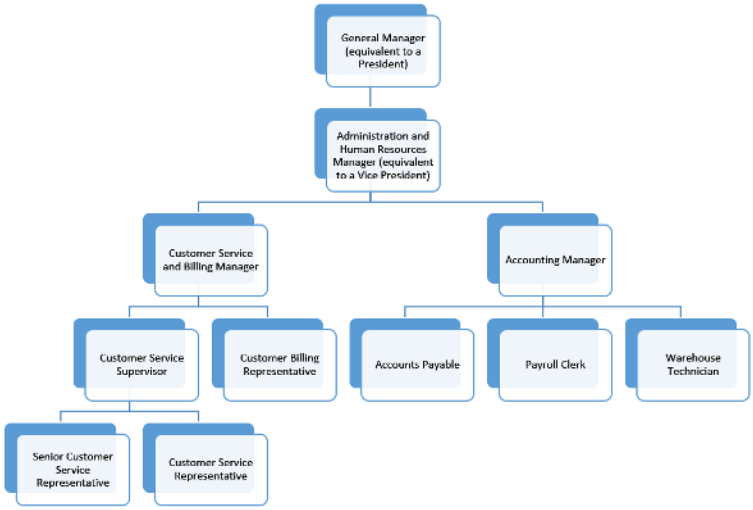
Making sure wastewater is properly treated is important for human and animal safety as well as for protecting the environment. WTP operators are responsible for making sure sewer flows coming into the plant are adequate for treatment purposes and must respond to any and all releases should they occur. Solids that are removed during the wastewater treatment process must also be properly handled and disposed.

Although there are many unique and specialized job functions within a utility that require certification, there are also a number of “common” job opportunities as well. Most utilities will have staff positions that are similar to many other industries such as customer service, office management, accounting, etc. While some of the terminology might be different, many of these jobs will not require specific water related training.

The previous paragraphs briefly introduced the areas of drinking water distribution and treatment and wastewater treatment. The remaining pages of this chapter will look at specific career opportunities in the water industry and how someone should go about applying for these jobs.

The Office Staff

Most offices are staffed with accounting, financial, human resource, billing, and customer service departments. Depending on the size of the organization these departments can be interrelated while other times there can be a number of employees staffing each department. Los Angeles Department of Water and Power (LADWP) for example staffs over 8,500 employees serving a total population of greater than one million. Approximately half of this staff is responsible for the water side while the other half is responsible for the electric side of the utility. Although there might be some overlap between the human resource and administration functions, there will still be staff that provide office and field related services to their respective areas. Typically, in larger organizations there will be multiple employees in each department providing specific support needs and functions. While in smaller organizations, certain functions might be covered by the same staff person. For example, sometimes billing and customer service functions might fall under a Customer Service Department and financial, accounting, and human resources might be under an umbrella such as an Administration Department. Regardless of department titles, all utilities must provide similar services, such as creating and mailing water bills, collecting money from customers, answering phone calls, responding to customer questions and complaints, ordering supplies, paying bills, providing salaries and services to employees as well as other vital job tasks. Although some operational staff spend much of their time in the office, we will consider them “operational” employees and list them under “Field Staff.” For the purpose of this text let’s look at a smaller sized utility as an example. Below is an organizational chart for the office staff of fictitious XYZ Water Department:



The above chart represents a medium sized water utility with eleven (11) office employees. Remember, this is just an example and may not reflect what an agency looks like exactly. Some utilities are very large and have hundreds of employees and are usually separated into multiple departments, while other utilities can be quite small and one employee might perform multiple jobs/tasks. Let's analyze the above example and discuss what some of the general functions might look like for each position and department. The next several paragraphs are some typical examples of what each job might entail. Remember, these are just examples to get you familiar with the industry as a whole and may not represent a specific job that you can apply for in the future.

- **General Manager** – The General Manager (GM) is typically the position at the top of a water utility organization. However, in a privately (investor) owned utility, the title of the person at the top of the organizational chart would be referred to as the President. Regardless of the exact title, a President and General Manager have similar job functions. The GM oversees the daily operations of the entire organization. This oversight is not usually direct, which means that the GM does not typically discuss day-to-day operations with the staff on a daily basis. They might get updates through meetings or from managers. Although they may not be involved in the day-to-day operations, they are ultimately **responsible** for all aspects of the utility. In public agencies, they usually report to a governing board of directors, city council, water commission or some other entity that is either elected or appointed. In private (investor owned) water utilities, they would report to shareholders, which would be equivalent to a board of directors. The primary responsibility of a General Manager is to manage upper level staff, sources of water supply, budgeting, provide support to staff, and create meaningful and efficient policies for the governing body to review and adopt. General Managers are usually contracted employees and are hired by the governing boards whereas Presidents are typically hired employees and do not have any guaranteed contract. Education and background for people seeking a GM type of position would be in the areas of engineering, science, and public administration. Sometimes a General Manager will also serve as the "Chief Engineer" of an agency. They may also have an advanced degree in a science-related field. Regardless of their background and education, this position would have similar responsibilities in all three (3) types of water related industries
- **Administration, Finance, and Human Resource Manager** - This position can have various titles, but the function is to manage and oversee the day-to-day operations within the office. In a private utility, this position is typically referred to as a Vice President. They usually have multiple direct reports and in smaller utilities it might be one (1) person handling all human resource related tasks as well as administration and financial related responsibilities. Typical functions include preparing documents such as policy, safety, emergency response, and employee manuals. These types of managers keep the office organized and running efficiently. In larger organizations there may be separate positions for Administration, Finance, and Human Resource responsibilities with a staff reporting to each manager. These types of positions typically require a degree in business and or public administration.
- **Customer Service Managers and Departments** - Customer Service staffs are the "face" of the organization. They deal directly with the public on a daily basis. They make sure that water meter reads are accurate and input correctly into the billing system. They issue water bills, accept payments, send reminders to late paying customers, and handle any issue a customer has when they call or come into the office. Many interactions with customers are related to complaints of incorrect billings, high usage, and other customer account related inquiries. However, other times customers will call to complain about operational

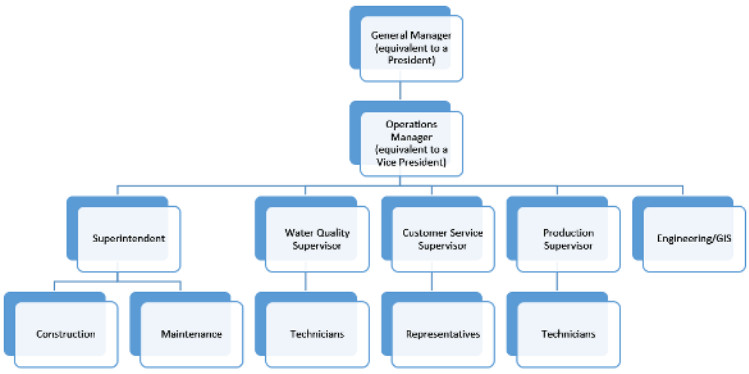
problems such as leaks, low pressure, no water, poor quality, etc. Sometimes, customer service staff can resolve these types of complaints by asking a few questions and responding the customer's concern. Other times, work orders are generated and forwarded on to the appropriate operations department. As with most managerial positions, a degree is usually required. However, sometimes organizations will promote long time employees that have shown a dedication to the agency and a willingness and ability to learn on the job.

- **Accounting Managers and Departments** - The flow of money moves through accounting departments. The primary revenue source for most water utilities is through water usage payments. However, some utilities collect taxes, rents, and various other sources of revenue. Just as money comes into a utility it goes out as well. Salaries, benefits, insurance are some of the more costly expenses that utilities must balance. In addition, office supplies are purchased and an inventory of parts and materials are maintained so operational staff can make repairs and replacements as they present themselves. Consulting is also a large part of a utilities expense. Engineering consultants, attorneys, and specialized contractors are all a part of a utilities operation. Every utility has a **warehouse** to store and maintain a variety of inventory items. Although operational staffs are using the material in inventory, it is the responsibility of the accounting department to reconcile the "ins and outs" of each item and the associated costs. Typically accounting managers will be Certified Public Accounts (CPA) and have a business-related degree.

Typically, all of the above mentioned managers and departments will have support staff. The support staff will process paperwork, deal directly with customers, and provide a variety of support related responsibilities. These employees will need to be proficient with computers and be able to write memos, input data into spreadsheets, and use specialized software to handle billing, inventory, purchasing orders, and other various tasks. Many of these positions are entry level and will not require a degree.

The Field Staff

Every utility has a staff that predominately works in the office and a staff that occupies most of their time outside (or in the "field"). As explained earlier in this text some of the operational managers and supervisors spend most of their time in the office, but will be discussed as "field staff" in this text. Field staff and operational duties range from reading meters, fixing leaks, collecting water samples, installing services and pipelines to responding to complaints, maintaining facilities and appurtenances. Many utilities are separated into several departments such as Maintenance, Construction, Water Quality, and Customer Service while others might divide departments even further. For instance there might be a department for valve operators, leak repairs, electricians, etc. Regardless of the structure of a utilities operation, they all have the same basic functions of getting water from the source to the customer in a reliable and safe manner. Below is a generic organizational chart for a medium sized utility:



In this example, there would be crews under each Supervisor/Superintendent. Sometimes the Superintendent is a step up and oversees the various departments. Crews can be large or small. For instance, construction and maintenance crews tend to be larger than water quality technicians, primarily because there are more construction and maintenance related activities compared to collecting water quality samples. Let's take a look at common tasks and responsibilities of the various operation positions.

- **General Manager** - As previously mentioned, the GM (and President) is responsible for the entire organization. In addition to the various administrative and personnel related functions, a GM quite often gets involved in planning and design of the vast array of different facilities. Many times a GM will have an engineering degree, water quality experience, or some science and business related background.

- **Operations Manager** - This position is responsible for the overall day-to-day operations of a utility. Although Operations Managers spend most of their time in an office, they meet regularly with the various operations supervisor getting updated and briefed on daily activities. An operation manager will typically be responsible for the operations budget and tracks expenses incurred for various construction and maintenance related projects. Many times an operations manager and GM work closely together to strategically plan system improvement projects and future development. This type of position is typically the equivalent to the Vice President position of a private utility. Most Operations Managers will have some type of four (4) year degree in engineering, science, or sometimes business.
- **Superintendent** - Superintendents are usually the eyes and ears of all field activities. They are typically field-based employees that spend some of their time in an office behind a desk. They coordinate and communicate most of the day-to-day activities and assist the various departments including, but not limited to construction, maintenance, water quality, and field customer service. Typically the Superintendent has many years of experience in the field as an operator or some other field position and works their way up to this position. Usually this position would not require a four (4) year college degree. However, there would be certification requirements and more than likely a D5 certification would be required.
- **Construction** – Not every utility will have a construction crew(s). Sometimes this type of work is contracted out to independent private construction companies. Either way, construction can be a large part of the responsibilities for water utilities. Construction activities range from the installation of water mains and services to the repair of leaks. Crews may build facilities such as pump stations and they may provide services for new infrastructure installation and capital improvement replacements. A supervisor or foreman typically leads this group and there usually is at least one heavy equipment operator. There are also certification requirements for positions within construction departments, including the required Division of Drinking Water (DDW) certifications and Class A licenses for heavy equipment operators. Typically very little experience is required for entry level construction jobs. However, positions within construction departments can be the most demanding physically and can often require employees to work nights and weekends.
- **Maintenance** – In addition to the installation and repair of facilities and appurtenances, maintenance of the systems is an important part of every utility. Pumps and motors need routine inspection and adjustments. Valves need to be routinely operated. Fire hydrants need to be flushed and painted periodically. There are also many different types of routine maintenance of buildings and the property facilities are built on. Just as you might maintain a car or a home, water facilities and structures need to be maintained. Typically there is a supervisor for maintenance crews. The supervisor would be the person in charge of scheduling and assigning the maintenance work. There might be various types of schedules with varying frequency. For example, valves might be on an annual schedule and motors and pumps might be on a semi-annual schedule. Regardless of the schedule, all maintenance activities should be well documented and tracked.
- **Water Quality** – All water utilities will have some type of water quality department. In small organizations it might be one person who handles these responsibilities. In larger utilities, there might be a department with multiple crews. There are minimum sampling, monitoring, and reporting requirements all utilities must abide by. A water quality specialist or technician is usually responsible for these duties. Sometimes agencies will have field technicians and an office water quality position. While other times field and office duties will be the responsibility of the same person or group of people. For example, a technician might be the person collecting the samples and a specialist might be the person preparing the sample bottles, interpreting the sample results, and preparing the reports. Regardless who is responsible for what task, a water quality professional will need to be a certified operator and sometimes will need a science-related degree.
- **Engineering and Geographic Information Systems (GIS)** - There are many engineers in the water industry. Treatment plants, pumping facilities, storage tanks, and many other types of facilities need to be designed and constructed. On-staff engineers or hired engineering consultants are the ones responsible for designing and mapping the systems. After a facility, piping infrastructure, or some part of a system is designed and constructed there are “mark-up” plans that come back to the engineering departments. These plans are called “as-built” drawings. They are drawings “as they were built”. Sometimes the construction crew will make field modifications for various reasons. They will then create as-built drawings so the engineers can update their plans and provide the staff will accurate complete drawings. Many utilities employ GIS personnel. GIS is another mapping function and includes facility data and information in a geographic database. For example, pipelines have information associated with them such as, diameter, length, material, installation date, etc. This data can be geographically coded with the pipe and retrieved at the click of a button. Often times field operators will have “paper” maps with minimal information written

on them. Sometimes they will need to return to the office or contact someone to retrieve detailed information. Technology is now allowing field crews to carry tablets or laptops in the field enabling them to access GIS data immediately. Engineering and GIS employees will almost always require a four (4) year degree and quite often advanced degrees and special licenses and certifications.

These examples are by no means an exhaustive list of career paths and job opportunities in the water industry. Utilities are unique in size and in their hiring processes. As mentioned above, each department can have few or many employees. For example, there might be a Water Quality Manager with three (3) Water Quality Supervisors each having several Water Quality Technicians reporting to them. In very small utilities one person might make up the entire department. The size of the utility will have an effect on the hiring process and the employment opportunity potential. Large public utilities can have hundreds of people applying for one position and typically have a test that all the applicants must complete. This “test” is used to screen out individuals and quite often only the top few scores are called back for an interview. Sometimes you will be interviewing in front of a panel of people, while in small private agencies it might be a one-on-one interview. Regardless of the process a worthy applicant needs to be well prepared. Taking water related coursework, becoming certified operators, and gaining experience will all help to increase the opportunity for gaining employment. Stay focused, work hard, and don’t become discouraged. Landing a job that turns into a career in the water industry is a real possibility and very rewarding.

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Page 1.4: Career Opportunities

Cover Letters, Resumes, and Applications

Looking for a job can be a very stressful task. No one likes rejection and many times rejection is part of the job-seeking process. The best time to look for a job is when you are currently employed. This way a rejection letter from a prospective employer may not "sting" as much since you are currently working. However, most of us are not that fortunate to be able to search for a new job while we are currently employed. Many times we are forced into a situation where we are looking for work because we have been laid-off, or the business has closed, or perhaps we are looking for a career change. No matter what the reasons are requiring us to search for new employment, a cover letter, resume, and interview will play an important role in helping us land that ideal job. Taking time to prepare a thoughtful cover letter and a complete resume are extremely valuable tools in presenting your skills and experience to employers. With the help of the Internet, there is really no reason to not have a well-written cover letter and resume. Below are just a couple of the resources you can find online to assist you with the development of cover letter and resume.

- **About.com Job Searching**

http://jobsearch.about.com/od/coverletters/a/aa030401a.htm

- **Yale Undergraduate Career Service**

http://ucs.yalecollege.yale.edu/content/cover-letters

Cover Letter

What is a Cover Letter and why is it so important? Is a cover letter needed when submitting a resume and applying for a job? What constitutes a good cover letter? Is there a difference between a "good" cover letter and a "great" cover letter?

Many times people overlook the importance of a cover letter. Much time is spent on crafting and developing a complete resume; oftentimes, the cover letter is an afterthought. According to www.careerbuilder.com, neglecting a cover letter is a "big mistake." A cover letter is your first shot at introducing yourself to a prospective employer and making a good or even great first impression can be the difference between landing an interview and receiving the dreaded, "thank you for your interest, but we have selected another candidate." Cover letters provide you the opportunity to cover everything that cannot be expressed in a resume and begin the "selling" process of your abilities. They also provide the opportunity to address a specific person within an organization making your application for a job more personable. It is advised to find the name of the person you are sending your cover letter and resume to and address it to them specifically. Doing a little research in the organization you are applying with can go a long way. To the person reviewing and filtering applicants it looks better to see their name on the cover letter as opposed to "To whom it may concern." What makes a cover letter? In general, cover letter should be well written, concise, to the point, and specific to the job you are seeking.

- **Well written** – No one likes to read a cover letter filled with spelling and grammar mistakes. Sometimes simple words like "form" and "from" can be accidentally used because they are both spelled correctly and are just out of context. Long run-on sentences, too many paragraphs, and improperly used punctuation can make a cover letter a struggle to read and can be the difference between landing an interview or having your resume passed over. Make sure you proofread it multiple times. Sometimes reading out loud can help identify mistakes. It also doesn't hurt to have a friend, co-worker, or family member review it for you. Sometimes a second or third set of eyes can pick up things that you might miss.
- **Concise** – Being concise means writing clearly and efficiently. Do not add a bunch of words just to fill space. Identify what you want to say and draft an outline of the key points. Many times you will be applying for a job with dozens of other candidates and the person receiving and reading cover letters may not have the time to read through paragraphs of writing. Typically a well-written cover letter should contain:
  - An introduction of who you are and why you are writing the company. A few sentences identifying yourself and why you are applying for this specific job.
  - A paragraph summarizing your qualifications and experience, without rewriting your resume in the cover letter. Sometimes a few bullet points listing your strong points works or a short paragraph of your highest level abilities and experiences.

- A concluding paragraph of why you would be a good fit for the organization. Do some research on the organization and try and figure out the culture of the company. Each business has a unique culture. Being able to identify the culture and describing how you will fit in this culture can go a long way. Finishing off with a sentence such as, "I look forward to speaking with you in person to discuss my qualifications and experience" is a nice closing.

There is a fine line between being concise and not providing enough information to peek the interest of the organization. There are plenty of sample cover letters on the Internet. Be sure to do your research on crafting and writing a cover letter and also on the company you are applying with.

- **Specific to the job you are applying for** – A generic cover letter and resume indicate a sign of laziness. Much of your cover letter can be "generic." It can have the same heading and components of the introduction and closing can be similar. However, tailoring your cover letter to the specific job you are applying for shows the organization that you have at least put some thought into this application process. Here is an example of a cover letter introduction:

Please accept this cover letter and resume as serious interest in the position available with your company. I think I will be a good fit.

Or

Please accept this cover letter and resume as serious interest in the position of Water Quality Specialist with XYZ Water District. I believe my qualifications and education will set me apart from others applying for this position.

Identifying the position and the agency shows that you have taken time to write the cover letter.

Lastly we will look at formatting. Organizing and formatting your cover letter is also very important. Take your time writing contact information on the top of your cover letter and resume. It should include your name, address, phone number, and email address. It shouldn't be too fancy but it should also stand out so that it is recognizable at a glance. Here is an example:

John Doe

1234 Water Way, Spring Town, USA

111-222-3333 jdoe@yahoo.com

It doesn't have to be fancy, it just needs to stand out and be easy for the agency to identify whose resume and cover letter they are looking at. You should provide a phone number that you typically answer or check regularly. You should also use an appropriate email address. Many times people have what they consider to be funny or clever email addresses. If you are one of these people, then create an email account specifically for looking for a job. A prospective employer is not interested in contacting "hotdogjimmy@coolemail.com" or "sexysusie@awesomeemail.com" for an interview. A simple first initial, last name or first name, last initial is an appropriate email address to list on all your contact information when searching for employment. Lastly regarding format, make your cover letter look clean and professional and be sure to personally sign it. If you are submitting your information through email or online, print the document, sign it, scan it, and then submit it.

Resume

Your resume should contain a summary of your work and education experiences. It should list each employer that you have worked for and the position you held with that organization. It should list your educational background and any related research work you may have participated in. There are various types of resumes and there is a ton of reference information that can be found online. Do your research and find the type of resume that fits best and enables you to express your experiences and education. In this section we will focus on three main resume types: Chronological, Functional, and Targeted (www.jobsearch.about.com).

Don't worry if you do not have any work experience. Everyone has to have a "first" job. In situations where you do not have any work experience state this in your cover letter. Write a couple short sentences as to why you do not have any work experience and something like, "I am eager to start a career and gain on the job experiences."

Sometimes applicants have work experience, but not directly related to the job they are applying. Perhaps you have experience in aerospace or computers or something completely different. In these instances, be creative.

There are a couple of general rules regarding resume content. Typically you should include the following information:

- **Objective** – a one to two sentence statement about your goal. What is it that you seek to accomplish? “I am seeking a career in the water industry to further my knowledge in water technology and to increase my commitment to serving the public by helping to provide a vital resource.”
- **Summary of Qualifications** – a summary of qualifications is not always necessary in a resume, especially if you provide this type of summary in your cover letter. However, if you have some specific skills that are required by the job you are applying for, it can’t hurt.
- **Work Experience** – listing your prior work experience is very important. It shows your prospective employer that you are employable and that you have a track record of good standing.

Chronological Resume

This type of resume shows your work experience and educational experience in chronological order, starting with your most recent experience. This is probably the most common type of resume and is often preferred by employers. It is an easy way for an employer to see what you have done and the various times you have done it. This type of resume can be problematic if you have large gaps in employment. Large gaps in employment can be a red flag for employers. Sometimes there are perfectly acceptable reasons for gaps in employment but you don’t want to alarm a prospective employer before you have the chance to explain. If you do have gaps in employment and you have specific reasons for the gaps, it might be a good idea to discuss those briefly in your cover letter. For example, if you decided to stop working to go back to school or maybe you stopped working to have children. These are understandable reasons for having some gaps in employment. Regardless of the reason, you want to be able to explain it during an interview and you do not want your resume to be passed over without having the ability to explain yourself. There are various thoughts on what you should list first, your work experiences or your educational experiences. The best answer is probably to lead with whatever is stronger. For example, you might be a recent college graduate with very little work experience. In this situation, you may want to list your education first.

Functional Resume

This type of resume focuses on skills and experience. When there are be gaps in your employment history, it is sometimes better to focus on the specific skills and experiences you might have for the job you are applying for. This type of resume is very common for people who are changing careers. For example, you may have been an auto mechanic for 15 years and decided to change career paths. You took some time off to study the industry of water systems technology. Several years have passed without any employment history and you are now applying for a maintenance mechanic position with a water agency. Instead of listing your employment history with a gap while you were in school, focus on your experiences as a mechanic and relate those to the position of maintenance mechanic. During the interview, if you are asked about the gap in employment you can explain that at the time it was your desire to change careers and go back to school.

Combination Resume

As the name implies, a combination resume includes both experience and employment history. You can focus on the specific skills and experiences related to the job you are applying for and list the employment history as a reference for the employer. This is a very common approach when applicants have a combination of experience and work history but neither one is strong enough on its own merit.

There are many examples of the various types of resumes online. It is strongly recommended that you research the type and style that would fit best.

Applications

It may seem fairly straight forward how and why you should complete an application but many times the application is the crucial document that will either bring you to the next level or result in the dreaded, “Thank you for your interest in employment with ABC Water Company but you have not met the minimum requirements for the position.” Quite often, especially when there are hundreds of applicants, there is an application screening process and the simplest of errors on the application can result in being disqualified. Or, sometimes in smaller agencies, your application can be put on the bottom of the list based on sloppiness, misspellings, missing information, etc. Completeness and neatness are two key elements to a successful application.

Many job descriptions will state minimum requirements to help filter out what can at times be hundreds of applicants. Maybe a certain certification level is required or perhaps a specific degree? Depending on the agency you are applying for employment with,

you may not need ALL the minimum requirements at the time of applying. While others will disqualify your application if you do not meet everything stated in the description. Below are a couple job description requirements and what is recommended for an acceptable application submission:

Meter Reader - Minimum Requirements

Associate of Science Degree from a two-year college is required. One year general work experience and Water Distribution Operator Grade D1 certificate from Division of Drinking Water preferred.

Let's say that you will receive your AS in one month and you meet the minimum "general work experience" requirement. Remember, the D1 is not a requirement. Some agencies may look at your application and accept the fact that your official graduation date is in one month and allow your application to be processed for an interview. Other agencies may disqualify you because you will not be in possession of the degree at the time the application is due.

While looking at this job requirement scenario, the questions below may have come to mind:

What if you don't have an AS degree but you have a D1 certificate?

What if you have both an AS degree and a D1 certificate?

They are excellent questions and cannot be fully answered because each water utility will have different requirements and standards for their application review process. However, your chances of progressing through the application process are probably better if you meet the minimum and preferred requirements.

Water Quality Specialist - Minimum Requirements

This position requires a 2-year degree in Biology, Chemistry or related field and 2 years experience in a water laboratory environment. A Water Treatment Operator T2 certificate is required.

The requirements for this job are a little more stringent and most agencies would probably disqualify you if you did not meet them. However, if you have completed and passed the T2 exam and you are just waiting for your certificate, you might be allowed to progress through the application process.

Regardless of your skills, experience, education, and background, you should not be discouraged from applying for jobs even if you think you are not qualified. Each agency is different and there are variety of circumstances. Just make sure you are well prepared and provide neat and complete cover letters, resumes, and applications before you apply. Something not discussed in this chapter or text is the interviewing process. Interviewing is as much a skill as an art. The following are simple tips to help you prepare for an interview. However, the best preparation is practice. Try video recording yourself or practice in a mirror. You can also ask a friend or family member to ask you specific questions in a mock interview.

Interview Tips

1. Dress for Success but don't over dress for the job. First impressions mean a lot. If you walk into an interview wearing jeans and a t-shirt, the first impression might disqualify you before you even say a word. Likewise, if you are applying for a construction related position, it might not make sense to show up at the interview in a suit. Nice slacks and a button down shirt or blouse should be acceptable for most field related water positions. You can add a jacket or blazer if you wish. It is important to not seem too overdressed for a field position but you don't want to seem underdressed either. Slacks and a button down shirt or blouse is a good compromise for a field position. And, of course, your clothes should be clean and unwrinkled.
2. Improve you interview technique. Practice is the best way to improve. Getting caught off guard with a certain question might be the difference between you and the next person. However, you should also not be afraid to say you don't know or ask if they could repeat the question. Try to be relaxed and take time to think before answering.
3. Take time to say thank you. Always be polite and thank the interviewers. It is also recommended to write a thank you letter after the interview.
4. Networking is always helpful. Knowing someone in the organization or if you know common acquaintances can always help your chances to separate you from the next person.
5. Research the company. Researching the company is not only helpful with preparation of your cover letter and resume, it also helps during the interview process.

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Page 1.5: Water Quality

One of the most important responsibilities of a water utility is to provide SAFE drinking water. “Safe” can be a confusing word for water utility customers. At times the safety of drinking water is confused with its aesthetic qualities such as taste, odor, and color. Sure, no one wants to drink water that is discolored, has an odor, or tastes bad. However, most of the time the water is safe to drink regardless of how it looks, tastes, and smells. Now, this doesn’t mean that water utilities are supplying customers with aesthetically unpleasing water. It simply means that often the safety of the water has little to do with its aesthetic quality. This is why there are both PRIMARY and SECONDARY drinking water regulations. Primary standards deal with health-related issues while secondary standards focus on aesthetic qualities of the water supply. Although water utilities strive to supply the best water possible, there are times when the water might be unpleasant from aesthetic characteristics. This chapter will discuss both primary and secondary water quality regulations, providing examples of both, as well as a discussion of various job opportunities within this discipline of the water utility industry.

Almost everyone is concerned with the quality of their water. It is typically the top complaint from customers, with the exception of high water bills. Since tap water is usually colorless, odorless, and, for the most part, tasteless, as soon as something changes, customers want to know why. Water quality is also a top concern of water professionals. Water quality professionals are responsible for the treatment, disinfection, testing, and compliance of the water served to their customers. Every year water utilities collect thousands of water samples and have them analyzed by laboratories to ensure compliance with water quality regulations. In addition to collecting samples, water utility operators conduct preventive maintenance, routinely inspect facilities, and respond to customer complaints to prevent and/or correct any water quality problems.

Water Quality Regulations

Current drinking water regulations are very complex and include many different requirements. This following text is a brief historical overview. President Gerald Ford signed the Safe Drinking Water Act (SDWA) in 1974 under growing pressure from newspaper articles, documentaries, and the general public’s skepticism that drinking water might not be safe. The Environmental Protection Agency (EPA) conducted a national reconnaissance study to assess the concentrations, sources, and potential danger of certain contaminants in municipal drinking water supplies. In 1977, the national safe drinking water standards went into effect across the country. These standards included microbiological contaminants, ten (10) inorganic chemicals, six (6) organic pesticides, turbidity (or cloudiness), and radiological contamination. Among other things, the regulations also included a provision for the States to assume primary enforcement responsibility.

Since the enactment of the Federal Safe Drinking Water Act, there have been two (2) amendments. In 1986, the first amendment was passed. Some of the new requirements with this amendment increased the number of regulated contaminants, required certain filtration processes for surface water supplies, added disinfection requirements for some groundwater systems, and prohibited the use of lead solders, flux, and pipes in public water systems. Ten (10) years later the 1996 amendment was passed. This added a provision in the SDWA referred to as the Unregulated Contaminant Monitoring Rule (UCMR). The UCMR requires the EPA to provide a list of potential contaminants every five (5) years to water utilities so that their drinking water supplies can be analyzed. The EPA will then use this data to prepare future water quality standards. The amendment also created distribution and treatment operator certification requirements and a funding system for states needing financial help to comply with drinking water quality regulations. This funding is referred to as the Safe Drinking Water Revolving Loan Fund.

It is important to note that although there are federal drinking water regulations, many states have their own drinking water standards. In California, the regulatory agency is the Division of Drinking Water (DDW) under the State Water Resources Control Board (SWRCB). The DDW is responsible for enforcing the California Safe Drinking Water Act (CSDWA). Many states create their own regulatory agencies to help enforce the Safe Drinking Water Act.

Drinking water quality standards can be broken into two main categories: Primary Drinking Water Standards and Secondary Drinking Water Standards. Each set of standards has a list of contaminants that must be monitored by municipal water utilities and they must be below levels considered safe. These safe levels are referred to in the regulations as Maximum Contaminant Levels (MCL). Each constituent has a separate MCL that cannot be exceeded in the water supply or else some action must be taken. An action can be as stringent as taking the source of supply (i.e., groundwater well) immediately out of service. Or it may increase the

amount of sampling requirements for a particular constituent. Exceeding an MCL may also require some type of notification to customers. The goal is to protect the public from unsafe levels of potential contaminants in water supplies.

Drinking water quality regulations are not the only water quality regulations water utilities must comply with. There are many water quality regulations protecting the environment. These regulations are part of the Clean Water Act (CWA). The CWA regulates and permits the sampling and monitoring of discharges to “navigable waters of the United States.” Navigable waters are defined by the US Army Corps of Engineers as waters that are subjected to the ebb and flow of tide, and those inland waters that are presently used, or have been used in the past or may be susceptible to use in interstate or foreign commerce. This definition can be interpreted by water utility operators as any body of water wet or dry that discharges can flow into. Common water utility discharges include, but are not limited to flows from:

- Fire hydrant and dead-end flushing
- Water main flushing
- Meter testing
- Water leaks
- Storage tank overflows
- Water sample collection

Although water utilities are required to discharge water for a number of these activities, they must still comply with the CWA and the various State and Local regulatory agencies responsible for implementing the requirements set forth in the CWA. Much of the requirements involve preventing chlorinated water from entering a water body or preventing debris from gutters and storm drains being washed into a water body.

Primary Drinking Water Standards

Primary Drinking Water Standards are for contaminants that pose a health threat when detected in water supplies above an MCL. In order to establish an MCL, the EPA will take into consideration several different factors. They will examine the prevalence and exposure of the contaminant in the environment and in water specifically. A contaminant that isn’t found in water supplies often would find a place low on the EPA priority list. However, a contaminant that is widespread would be at the top of the list. The EPA also looks at health effects. If it is wide spread contaminant but has little to no known health effects to humans then an MCL would not be very probable. However, if the contaminant is toxic or a known carcinogen then an MCL would be very likely. Another consideration is in regards to the analytical methodology. There has to be a statistically reproducible laboratory analytical method in order for the EPA to consider an MCL. If a laboratory cannot detect the contaminant readily and statistically accurate, then having an MCL would be very difficult. Lastly, an economic evaluation is completed. Typically the cost benefit analysis looks at all the previously reviewed material.

Millions of dollars a year are spent by water utilities in efforts to comply with Primary Drinking Water Standards. It is one of the most important responsibilities of water professionals. There are a host of treatment technologies that are used to inactivate or remove contaminants from water. Thousands of samples are collected and analyzed to determine the level of each contaminant. Reports are prepared and filed with public health agencies to demonstrate compliance with the regulations.

Primary Drinking Water Standards are commonly broken up into four (4) main categories:

1. Bacteriological
2. Inorganic Chemical
3. Organic Chemical
4. Radiological Compounds

There are multiple constituents within each broad category and it is the utility’s responsibility (with the assistance from the regulatory agencies) to understand the requirements for complying with these contaminants. Below is a brief description of each category, the predominant health effect associated with each, and various treatment methods.

Bacteriological

This group consists of not only bacteriological contamination, but also viruses, protozoa and various other microorganisms that pose a health threat. Most of the health effects associated with microbiological contamination in water are gastrointestinal.

Symptoms include vomiting, diarrhea, headache, fever, etc. Many of the symptoms are similar to influenza. However, to various sub-populations, for example the very young or old or people with compromised immune systems, the health effects can be deadly.

Because of the vast number of microorganisms and the difficulty and cost of trying to analyze all of them, an indicator organism group is used for analysis. This group is known as the total coliform group. Coliforms are a group of bacteria that indicate the presence or absence of disease causing microorganisms. The Total Coliform Rule (TCR) is a set of regulations that cover this wide range of contaminants.

Although there are various treatment techniques for the removal and inactivation of microbiological contamination, disinfection is the most common method. Drinking water treatment facilities and distribution systems both use disinfectant chemicals (primarily chlorine) for maintaining the health and safety of drinking water from microorganisms.

Inorganic Chemicals

There are many different chemicals found in drinking water supplies that fall under this broad category. Fortunately most of them are naturally occurring and are considered safe. For example, minerals such as calcium and magnesium are commonly found in drinking water supplies. Although these may pose aesthetic problems for consumers (discussed later in this chapter), they pose no health effects. However, contaminants such as nitrate, arsenic, and chromium can also be found as naturally occurring elements in drinking water and these can pose health problems if ingested at levels above the MCL. In addition to being found naturally in the environment, these and many others are the result of some type of contamination.

- **Nitrate** – The primary source of nitrate contamination is from some type of fecal contamination. Agricultural farms and leaking septic systems both contribute to nitrate contamination. The main health effect is related to infants six (6) months and younger. If nitrate is ingested at levels above the MCL by this sub-population, a condition known as metheglobinemia (Blue Baby Syndrome) can occur. This results in suffocation when nitrogen displaces oxygen in the bloodstream.
- **Arsenic** – Arsenic has been used as a wood preservative resulting in contamination and is also naturally occurring. The primary health effect associated with drinking water containing arsenic at levels above the MCL are cancer-related.
- **Chromium** – This chemical got its spotlight from the movie Erin Brockovich. An oxidized form of chromium known as “Chrome6” or hexavalent chromium was brought to everyone’s attention when Pacific Gas and Electronic was accused of contaminating the groundwater supply in Hinkley, California. This contaminant also causes cancer-related health effects.

Inorganic chemicals are not commonly found in drinking water supplies above their respective MCL. However, if they are, there are several treatment techniques that can remove these and many other contaminants from the water supply, ion exchange being one of the most common.

Organic Chemicals

The most commonly found organic chemicals found in drinking water supplies fall under the category of VOCs. VOC stands for volatile organic compound and are present in drinking water typically from the result of some type of contamination. Some of the more common VOCs found in drinking water include:

- Trichloroethylene (TCE)
- Tetrachloroethylene (PCE)
- Methyl Tertiary Butyl Ether (MTBE)

These chemicals come from various sources including degreasing agents, dry cleaners, and fuel additives respectively. These are considered “volatile” because of their propensity to evaporate or sublimate from the liquid or solid form of the compound and enter the surrounding atmosphere. Therefore, one of the more common treatment techniques to remove VOCs from drinking water is granular activated carbon in combination with packed air towers. The primary health effect from drinking water containing VOCs at levels above the MCL is cancer.

Radiological Compounds

The primary source of radiological compounds in drinking water is from naturally occurring sources. Geologic formations can contain uranium, radium, strontium and other radiological compounds. In rare cases, radiological contamination can result from a nuclear facility accident. However, this is not very common. As with many drinking water contaminants the primary health effect is cancer-related. Common treatment for radionuclides is ion exchange.

In addition to the treatment techniques previously mentioned, blending is a type of “treatment” technique that DDW may approve. However, blending is typically only approved for contaminants that do not pose an acute (immediate) health risk. The previous examples are not a complete list of potential contaminants in drinking water, nor is the information provided an exhaustive explanation. It is a glimpse into drinking water quality providing the reader a background overview.

Secondary Drinking Water Standards

Although Primary Drinking Water Standards are the most important regulations for water professionals, aesthetic quality is still a significant challenge and focus of drinking water providers. Making sure water is safe to drink is critical but if customers do not like the taste, odor, or color of the water they are likely to think that the water is unsafe and not fit for cooking and drinking. Therefore, it is important for water utilities to respond and take seriously all customer complaints, have a good preventive maintenance program, collect samples routinely and comply with all regulatory requirements. However, even the most diligent utilities can experience aesthetic water quality problems. Some aesthetic quality problems can be addressed by routine flushing and preventive maintenance programs, but some are the result of certain naturally occurring conditions and can only be removed through treatment and/or blending.

With varying sources of supply, comes varying water quality. Aquifer formations made up of limestone would tend to have higher levels of calcium, while other geologic formations might contribute other minerals such as magnesium, sodium, and potassium to name a few. Therefore, the quality of water in Los Angeles can be completely different than the water quality in Phoenix. However, in the United States all water must meet the minimum federal and state drinking water standards.

Common Aesthetic Issues with Drinking Water

Although the United States has some of the safest drinking water supplies in the world, sometimes little effort is focused on the aesthetic qualities. A crystal clear glass of water may not be safe to drink because it can have harmful tasteless and colorless contaminants in it. At the same time, discolored water with a bad smell and taste can be perfectly safe to drink. Everyone wants safe water to drink but it is usually the aesthetic qualities that determine if we will drink the water. Many times when people are asked why they drink bottled water instead of tap water, their answer is usually “because it tastes” better.

So why does some water look, taste, and smell bad? There are various things that can cause aesthetic issues with drinking water. The following scenarios provide just a few common issues facing water utilities. Please note that each scenario only reflects typical responses to common problems. They are meant as examples only.

- **Scenario 1** - A customer calls their local utility complaining of a slight yellow color to the water. What can cause this discoloration? What should the utility tell the customer? As mentioned previously, all water quality complaints should be treated with concern and taken seriously. A common first response from a water quality professional might be, “Is the discoloration coming from all the faucets in the home?” This simple question will help determine if the problem is coming from the customer’s internal plumbing system or if it is coming from the water being served by the utility. If the discoloration is coming from all faucets, then the next step would be to check the water coming into the home. Sometimes the utility will send someone out to investigate, while other times the homeowner can be asked to flow the water at the front hose bib to check for discoloration. Usually the answer from the customer is the discoloration is only coming from a certain faucet or area in the home. A common source of the discoloration is from older galvanized internal plumbing systems. Sometimes a bathtub or sink is not used very often and iron from the internal plumbing system can leach out and cause a brown/yellow discoloration. A common suggestion to the homeowner would be to run the faucet for a while until the discoloration clears up.
- **Scenario 2** - A customer calls complaining of cloudy water. Cloudiness or “milky” looking tap water is commonly entrapped air in the water. A test that water quality professionals ask the customer to try is to fill up a clear glass and set it on the counter. If it is air then the cloudiness will begin to clear from the bottom of the glass up. This is because the air bubbles will rise into the atmosphere.
- **Scenario 3** - Sometimes customers will call and complain about odors. Customers will often call saying their water smells like a “pool.” Chances are something has changed in the distribution system or with the disinfection process. Drinking water is commonly disinfected with chlorine or chloramines. The switch from one to the other can cause “pool” chlorine type of orders. Or if water usage demands in the system have changed these same odors can be present for a short period of time.

No matter what the customer complaint is, all water professionals need to be honest, provide specific detail and help, and if they are ever uncertain of the solution to the customer's concern, tell them they will need to investigate the issue and will provide them with a response as soon as possible.

As you can see, drinking water quality regulatory compliance is a complex and detailed area of the drinking water industry. However, regulations are readily available and government regulators are typically very helpful and responsive to questions from utilities. Water professionals and regulators alike should have the same goal of providing the public with a safe and reliable supply of drinking water.

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Page 1.6: Water Distribution Systems and Operations

Drinking water comes from a variety of different sources. As water makes its way through the hydrologic cycle, it comes back to land in the form of precipitation (rain, sleet, snow, etc.). Some of it is captured in lakes and rivers, while some of it percolates into the earth's surface and becomes groundwater. Groundwater can be pumped back up through groundwater wells and surface water can be treated and delivered to customers. In order for water to continue to flow out of the faucet when it is turned on by customers, it requires a network of pipes, pumps, storage, and other components which make up a distribution system. The water distribution system is the focus of this chapter. We will identify how water enters, travels through, and leaves a distribution system. Some of the focal points for discussion are storage, pipes, pumps, and various appurtenances. Appurtenance is a general term used to describe things such as valves, fire hydrants, meters, among other things. There are various names which refer to a company which distributes water to customers. Some examples include, water retailer, water utility, water district, water agency, water purveyor, and water supplier. These terms may be used throughout this text with the understanding they all virtually mean the same thing.

Sources of Supply

Water 032 Water Supply is a full semester course covering the details of sources of water supply. For this course, we will touch on some of the general aspects of water supply. As mentioned in the introduction to this chapter, most water supplies come from either surface water sources or groundwater sources. All surface water must go through treatment before it can be used for domestic purposes. A water supplier operating a distribution system must either operate their own drinking water treatment plant or purchase water from a drinking water treatment plant if they intend to use surface water as a source of supply. Let's look at a couple of local Southern California examples. The Los Angeles Department of Water and Power (LADWP) is one of the largest water suppliers in the country. They are an example of a utility which owns and operates a drinking water treatment plant as well as distributes water to its customers. In contrast, Las Virgenes Municipal Water District purchases all of its water from a water wholesaler. This wholesaler is the Metropolitan Water District (MWD) of Southern California. MWD owns and operates drinking water treatment plants but is referred to as a wholesaler because they do not serve domestic customers directly. They sell water to water suppliers who then sell directly to the end user customer. Surface water is carried through pipelines, aqueducts, and canals to the treatment plants for processing before being delivered to customers.

The other primary source of drinking water supply comes from underground aquifers. An aquifer is an underground layer of water-bearing permeable rock or unconsolidated materials from which groundwater can be extracted. Groundwater is extracted using wells. Wells can also be owned and operated by a water supplier or they can be owned and operated by a wholesaler who sells the water to a supplier.

Distribution Systems

Once the source brings the water to the water supplier, it must make its way through a network of pipes, facilities, and various appurtenances in order for water to get to the customer. Below is a breakdown of the primary components of each of these.

Pipelines

1. Transmission Mains
2. Distribution Mains
3. Service Laterals

Facilities

1. Storage Structures
2. Pump Stations
3. Pressure Reducing Stations

Appurtenances

1. Valves
2. Angle Joints
3. Fire Hydrants
4. Meters

This list is by no means exhaustive, but it provides a basic overview of a distribution system.

Pipelines

Pipelines are arteries and veins of a water distribution system. They are in a variety of lengths and sizes and deliver water throughout a wide range of areas. They are commonly referred to as transmission, distribution, and service mains/pipes.

Transmission Mains

As water is brought from a surface water treatment plant to a water supplier, or as water is pumped from the ground, it must be connected to piping to begin the distribution process. Many times a surface water treatment plant and sometimes drinking water wells are located outside of the area where customers are being served. If this is the case, then transmission mains play an important role in bringing water to the distribution system. Transmission mains are large diameter pipes, which travel long distances carrying large volumes of water. Some transmission mains can exceed diameters of 10 feet (120 inches) or more. Not all water suppliers have transmission mains of this size and some may not travel long distances. Smaller water suppliers might have transmission mains around 24 inches in diameter and only travel a mile or less. Typically there are no service connections to customers off transmission mains unless they are smaller in size and are located within a distribution system.

Transmission mains are commonly welded steel and ductile iron pipe.



Figure ***Page*1.6.1**: - Four, 36-inch cast-iron pipes.

Distribution Mains

As water makes its way into a distribution system the pipe sizes become smaller. Distribution mains typically range in size from 6 inches up to 24 inches in diameter. This is not to say there are never distribution mains larger than 24 inches in diameter, it is merely a general description. Unlike transmission mains, distribution mains have customer services connected to them. There are three common network structures distribution mains are laid out in: arterial, grid, and tree. The “tree” network is typically the least desirable since they result in multiple dead ends. A dead end is a pipeline, which ends without any connections on the end of it. For example, most cul-de-sacs are dead ends. A grid network is usually the most desirable because all the pipelines within the grid are interconnected. Distribution mains are most commonly ductile iron pipe. However, polyvinyl chloride (PVC) is also extensively used. Asbestos cement pipe is often found in older water systems and is not typically installed any more. These network layouts and pipelines in general will be discussed in more detail in Water 040 and 041.

Service Laterals

In order for water to get to each customer individually, pipes need to be connected to a distribution main and brought to the customers parcel. Service laterals are these pipes. They are typically made of copper or plastic and connect to a distribution main and run to the customer’s parcel, connecting to a water meter. The picture below refers to the “distribution main” as a water main and the “service lateral” as a service line.

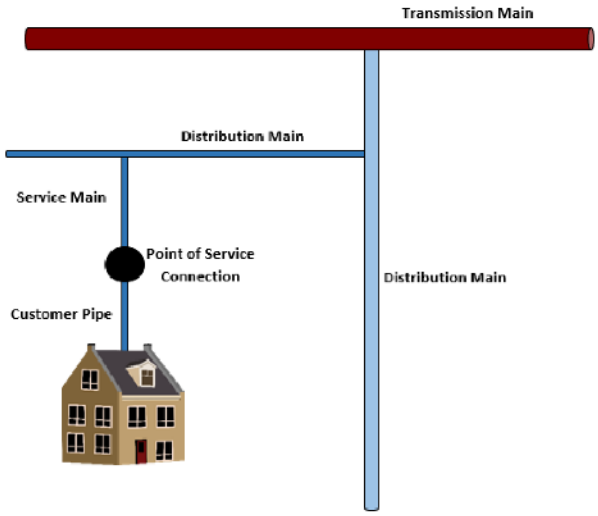


Figure *Page*1.6.2: – Service laterals.

It is also important to point out in this particular picture there is no water meter or valves connecting the pipes. However, it is a nice reference for illustration purposes.

Facilities

A water supplier has a variety of facilities to store and move water through the distribution system. The information below is not a complete list of facilities but it is a basic overview of common facilities within a distribution system. Storage structures, pumps, and pressure control valves are common among most water distribution systems.

Storage Structures

Storage is an important requirement for distribution systems. Storage provides pressure and water demand for daily operations, maximum day demands, and enough flows for putting out fires. In order for water to flow through pipes there needs to be pressure. If pumps are not running, then something else needs to provide the pressure. This is where storage structures come into play. Next time you drive around the Santa Clarita or San Fernando Valleys look up on the surrounding hills and you will see tanks scattered around. These cylindrical shaped tanks are above ground water storage tanks. Above ground storage tanks are not the only type of distribution storage, but they are the most common in California. Depending on the topography of the area, the tanks might be placed at various heights throughout the system. Some might be at lower elevations and others at higher elevations. These varying elevation differences are referred to as “pressure zones.”

Pump Stations

A pump station is used to pump water from lower elevations to higher elevations. In order for water to get to these storage structures, pumps are needed to do the lifting. If a community were completely flat there might not be a need for pump stations. Groundwater wells could possibly provide enough pressure to lift water to elevated storage tanks. In areas where there are varying elevation differences, pumps are needed to lift water to the different pressure zones. This is not to say pumps are only providing water to storage tanks. However, the level of water in a tank is commonly used to determine when a pump needs to be turned on and off. Look at the example below. Imagine homes scattered around the line between the pump and tank too. When the level in the storage tank gets low, the pump would need to be turned on to refill the tank. While the tank is filling, customers might be connected to the pipe leading to the tank and use some of the water while it makes its way to the tank. Once the tank is full the pump would then be turned off.

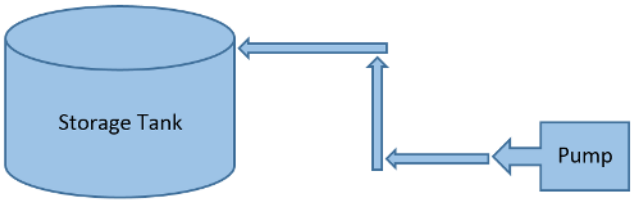


Figure *Page*1.6.3: – Pump Station.

Pressure Reducing Stations

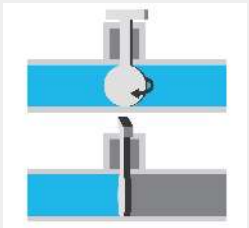
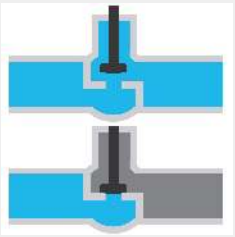
Sometimes, the distance between the storage tank and a customer can be so great that the pressure the customer receives is too high for normal plumbing systems. In this case a pressure reducing station can be installed to reduce the pressure down to acceptable levels. Acceptable pressure values vary from water supplier to water supplier but a general range of 40 pounds per square inch (psi) to 140 psi is very common. These pressure reducing stations are very similar to a "pressure regulator" you might have at your home. Generally speaking, the maximum acceptable pressure inside a home is around 80 psi. Therefore, since water suppliers can have pressures up to 140 psi or more, it is common for customers to also have pressure regulating devices. Water supplier pressure reducing stations can also be designed to allow water to flow from higher pressure areas to lower pressure areas if pressures in the lower pressure area drop below a previously determined set point.

Appurtenances

Appurtenance is a generic term and commonly used for miscellaneous components throughout a distribution system. They are the "joints" and parts used to hold the distribution system together, monitor flows, allow to flow, and to stop water from flowing. In this section we will briefly discuss valves, angle joints, fire hydrants, and meters.

Valves

The primary purpose of a valve is to stop the flow of water. These are installed throughout water distribution systems to stop the flow of water especially when there is a break in a pipe. As with pipelines, valves come in various sizes. For example, if a water main is 12" in diameter, then the valve is usually 12" in diameter. There are valves on transmission mains, distribution mains, and service laterals. There are also shut off valves connected to most customer meters. When a repair needs to be made or some modification to an existing system needs to be performed the flow of water needs to be stopped. Therefore, valves are a critical component to a water distribution system. Valves connecting a distribution main to a service lateral are commonly referred to as corporation stops (corp stop). Valves located at meter connections are typically referred to as angle, curb, and meter stops. Below are a couple examples of valves.

Valves		
		
Figure 6.4	Figure 6.5	Figure 6.6

Angle Joints

An angle joint is very similar to a joint in your body. Its use is to allow a pipe to change directions. If a pipe is installed in a street and the street turns to the right, the pipe needs to turn to the right too. If the turn is a 90 degree turn, then the angle joint would be referred to as a 90° elbow. There are a variety of different angle joints. The more common ones are at the following angles: 90°,

45°, and 22 ½°. If pipes coming from different directions need to be connected, then a “tee” or a “cross” would be used. See the examples below.



Figure ***Page*1.6.7**: – Angle joint.

Fire Hydrants

Fire hydrants are critical appurtenances in a distribution for putting out fires and keeping insurance costs lower. Fire hydrants allow water to flow at high volumes in order to help fight fires. Fire hydrants are also used to flow water for cleaning out sewers, provide water to trucks for dust control, and as a means to “flush” a distribution system for water quality purposes. Water sitting in pipelines for long periods of times without being used can become stagnant and discolored. Therefore, from time to time fire hydrants can be used to “flush” out a system. If a fire hydrant is broken or for some other reason “out of service”, it is important that it is identified as not working. Therefore, if the fire department needs to put a fire out they are not wasting any time connecting to a not functioning hydrant.

Fire Hydrants	
	
Figure 6.9 – Fire hydrant.	Figure 6.10 – Flushing a fire hydrant.

Meters

The last appurtenance we will discuss in this text is a water meter. Meters are very important for tracking the amount of water traveling in, out or through a distribution system. Meters are commonly placed on pump stations and wells to track the water being pumped into a distribution system. Or, if the pump station is boosting water to a different zone, it is important to track the amount of water entering a particular zone. The most common location for water meters is at the customer service connection. Especially in areas where water is scarce, it is extremely important to be able to track the amount of water a customer uses in order to accurately

charge them for the cost of water. Meters also come in various sizes and types depending on the amount of flow needed for the respective service connection.

Water Meters	
	
Figure 6.11 – Meter.	Figure 6.12 – Meter.

The information provided in this chapter (as with all chapters in this text) is a snapshot look into distribution systems. In Water 040 and 041 of the Water Systems Technology program you will take a more in depth look at this and more water distribution information.

Careers in Drinking Water Distribution

There are a variety of career opportunities working for a water distribution supplier and depending on the size of the organization, there can be multiple levels of each position with multiple departments. A large organization such as Los Angeles Department of Water and Power (LADWP) has over 4,000 employees. They have multiple departments with very specific tasks and responsibilities. For example, they might have a meter reading crew that only reads meters. Whereas in a smaller water utility, a meter reader might also be responsible for leak inspections at the meter service, hanging shut-off notices for non-paying customers, and other functions. In even smaller agencies, an employee might read meters one day, fix a leak the next day, and conduct well and pump maintenance on another day. Below is list of some of the more common job opportunities and a brief description of some of the responsibilities.

Meter Reader

Responsible for reading water meters for customer billing persons. Typically requires walking from service to service, bending down to lift a meter lid, and making note of the meter read.

Customer Service Representative

Responsible for assisting with sending out water bills, answering customer calls, processing customer payments, and creating work orders based on customer complaints.

Water Quality Technician

Responsible for the collection of water quality samples, reading and interpreting water quality results, writing reports, and ensuring the water being served to customers is in compliance with drinking water quality regulations.

Well and Pump Maintenance

Performs daily visits to well and pump sites to ensure proper operation. Collects meter reads, changes oil, monitors and maintains disinfection systems, keeps sites clean, and various other maintenance responsibilities.

Managers and Supervisors

There are various department managers and supervisors for both field and office staff. Their responsibilities range from organizing and assigning work tasks, creating and monitoring budgets, report writing, and other specific tasks related to their department.

This is only a small snap shot of possible opportunities within a water distribution utility. There are many more areas of specific focus such as engineering, human resources, administration, accounting, and construction, just to name a few. However, it is a good list to give a person some perspective on the operations of a distribution system.

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Page 1.7: Water Treatment Facilities and Operations

Water treatment is one of the most critical steps in the drinking water process. It is critical to remove unwanted particles, inactivate harmful organisms, and treat to a level that complies with the Safe Drinking Water Act (SDWA). Most water treated within drinking water treatment plants comes from surface supply sources. As snow melts and rainfall moves along the ground surface into rivers, streams, and lakes, particles are picked up along the way. Therefore, ALL surface water to be used for domestic drinking water purposes must be treated. Surface water is also more susceptible to contamination because much of this contamination comes from "runoff". Every time it rains or as snow melts, water is washed down from mountains, hillsides, roads, and other areas, picking up anything along the way. For example, imagine a farm next to a stream that feeds a local lake used as a drinking water storage reservoir. There is a potential for animal waste among other things making its way to the storage reservoir. Just the sediment from a lake's hillside and the natural organic matter in a lake makes the water not suitable for drinking. Therefore, there are regulations within the Safe Drinking Water Act called Surface Water Treatment Rule (SWTR), which specifically addresses surface water treatment requirements. There have been several iterations of this rule to improve the quality of drinking water. The SWTR is crafted to prevent waterborne diseases caused by microorganisms. The rule requires water systems to filter and disinfect water from surface water sources to reduce the occurrence of unsafe levels of disease causing microbes.

One of the primary constituents the SWTR requires treatment and monitoring for is turbidity. Turbidity is the cloudiness or haziness seen in water samples and prevents the performance of filtration systems. Low turbidity requirements are used to protect against certain microbial contaminants, in particularly *Cryptosporidium*. *Cryptosporidium* is a protozoan that can cause gastrointestinal illness in humans, which is similar to many disease causing microorganisms. The lower the turbidity levels, the less likely there will be disease causing microorganisms. The SWTR also requires disinfection to protect against these pathogens. Disinfection chemicals, such as chlorine, are used to inactivate (kill) pathogens during the treatment process through a required residual present in the water throughout the distribution system.

Surface waters also have to be treated for aesthetic qualities. An aesthetic quality doesn't typically have an effect on public health. These types of qualities are usually related to the appearance and palatability of the water. Does the water taste good, look good, and smell good? Taste, odor, and color are three qualities surface water quality is treated to improve.

Particles in Water

Particles in water can be broken into three (3) general categories: suspended solids, colloidal compounds, and dissolved solids. Microorganisms fall under the colloidal compound category. One of the main goals of a surface water treatment plant is to prevent the outbreak of disease from microorganisms. These disease-causing agents are referred to as pathogens. The three main pathogen categories are distinguished as bacteria, virus, and protozoa. In drinking water quality, these organisms are not specifically analyzed in samples. Specific organisms, viruses, and protozoa can be very costly and require extensive sampling techniques. Some of the more common pathogens, which can be found in water, are:

- Bacteria – *Escherichia coli (E. coli)* and *Vibrio cholera*
- Viruses – *Enterovirus* and *Coronavirus*
- Protozoa – *Cryptosporidium parvum* and *Giardia lamblia*

Instead of analyzing for these organisms specifically, a class of organisms called *total coliforms* (TC) is used analyzed instead. TC is referred to collectively as indicator organisms. The *presence* or *absence* of TC bacteria indicates the presence or absence of pathogens. The analytical test is easy, inexpensive, and very effective. Microorganisms are one class of "particles" removed or inactivated from water. Microorganisms are difficult to remove from water, therefore they are usually destroyed or inactivated through the treatment process.

In contrast to colloidal compounds, suspended solids are more easily removed. Much of the suspended material found in surface water supplies is referred to as turbidity. This turbidity comes from decaying plant material and soil as water runs across land and makes its way to streams and lakes. While suspended solids are not typically associated with disease, they can shield microorganisms from treatment processes and provide an overall poor quality to the water supply.

Dissolved compounds are the most difficult to remove because they are dissolved in the water. Think about sugar or salt mixed in a glass of water. Once it dissolves and mixes in the water a treatment process is needed to remove it from the water. These treatment

processes are more complex than the standard drinking water treatment plant. There are a variety of processes including things such as ion exchange, membrane filtration, chemical absorption, and others. If the dissolved compounds do not pose a health threat or if they are below their corresponding Maximum Contaminant Level (MCL), they are not typically treated for in the drinking water treatment process.

Pre-Storage

Prior to entering a drinking water treatment plant, water is typically held in large storage reservoirs. These “reservoirs” (lakes) provide an area for large amounts of water to collect so the treatment plant has a constant source of supply. These reservoirs can also allow for some settling of solids and many double as a recreation space for fishing, boating, and water-skiing, etc.

Entering the Treatment Plant

As discussed in earlier chapters, surface water used for drinking is commonly stored in above ground lakes. These storage reservoirs are sometimes used for recreation such as fishing, boating, and water skiing. This recreational use is an important part of the economy and public use. However, they can add additional water quality problems for the water treatment plant. Water leaving these storage reservoirs needs to be free of large debris such as plants fish, trash, wood, etc. In order to take water from the storage reservoir and leave the larger debris behind there are “intake” structures. A surface water intake structure is a screened structure to let water through and keep larger items from entering the treatment plant. The screen size can vary depending on the use of the storage reservoir and the quality of the raw water. Raw water is the term used to identify water before treatment. The picture below shows an example.

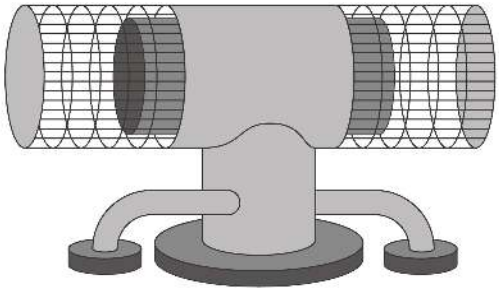


Figure ***Page*1.7.1**: – Surface water intake structure.

The water entering the intake structure can either be pumped or can flow by gravity to the treatment plant depending on the location of the plant compared to the storage reservoir. Valves can be used to adjust the flow into the plant and the water is sometimes kept in an onsite storage tank leading into the plant.

Inside a Water Treatment Plant

Pre-Disinfection

Once raw water enters a treatment plant there may be a pre-disinfection process. Some plants use a disinfectant to kill pathogens and other microorganisms prior to the water going through the treatment process. This can be done to prevent certain organisms from entering the plant and having an effect on the various treatment processes. Or it can be done to remove precursors, such as total organic carbon, to prevent disinfection by-products from forming. Newer treatment plants will use ozone as the disinfectant primarily because it is an effective oxidizer and it does not leave a residual in the water throughout the treatment process.

Ozone is a trivalent form of oxygen. Simply put it is a compound of three (3) oxygen molecules (O3). If you have ever smelled an electrical spark or a lightning strike, chances are it is ozone that you smelled. It must be used at the point of generation. Unlike chlorine, which can be processed at a chemical plant (for example), a treatment plant using ozone must generate it on site. Ozone has a number of benefits over chlorine.

Ozone Compared to Chlorine

1. Stronger disinfectant
2. Does not contribute to disinfection by-products
3. Kills a wider range of organisms

4. Achieves removal of unwanted tastes and odors
5. Reactions are more rapid

However, as mentioned previously, ozone does not leave a disinfectant residual in the water. This might be a good thing for a treatment plant, but ozone is not used in distribution systems because a residual is needed.

Conventional Treatment vs. Direct Filtration

There are two main types of drinking water treatment plants. There are conventional treatment plants and direct filtration plants. Each has benefits and drawbacks. All of which will be discussed in this text. It is important to remember that this text is an introductory text for a very general overview of the waterworks industry. Therefore, details of each treatment process discussed may be omitted and are provided in more specialized courses. The basic difference between a conventional water treatment plant and a direct filtration water treatment plant is a sedimentation basin. A conventional drinking water treatment plant has a sedimentation basin and a direct filtration plant does not. So, why would one be used over another? Below is an example of some of the “pros” and “cons” of a sedimentation basin.

Sedimentation Basin Pros

- Allows solids to settle out of the water prior to entering the filtration process
- Reduces the amount and duration of backwashing filters

Sedimentation Basin Cons

- Sedimentation basins are large and require a bigger treatment plant
- The sludge at the bottom of a sedimentation basin needs to be removed from time to time.

We will now look at the other processes typically found in a conventional and direct filtration drinking water treatment plants. The photos provided in this section are courtesy of the Michigan Department of Environmental Quality.

Coagulation

Coagulation is the process of chemical addition such as “Alum” to the water supply in order for small suspended particles to “stick” together forming floc. The chemicals added produce positive charges to neutralize the negative charges on the particles. The particles stick together becoming larger and larger during this process.

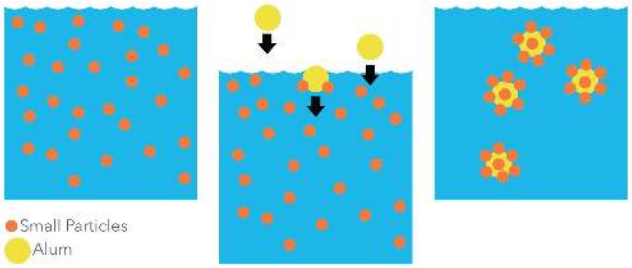


Figure ***Page*1.7.2**: – Coagulation.

Flocculation

As the particles begin to stick together, the water is then sent through a series of tanks with “paddles.” These paddles are designed to slowly mix the water, bringing the particles together to form larger and larger particles called “floc.” The mixing process must be gentle enough to not break apart the floc back into smaller particles.

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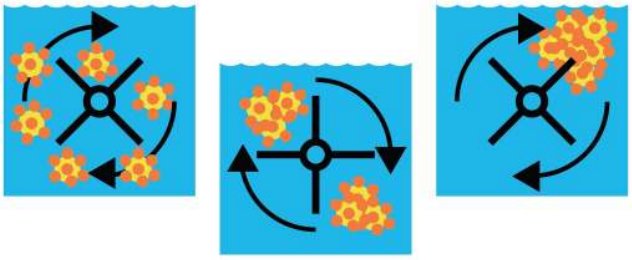


Figure ***Page*1.7.3**: – Flocculation.

Sedimentation

In conventional drinking water treatment plants the sedimentation process allows for the forces of gravity to allow the floc to "settle" to the bottom of the basin. Not all the floc will settle. As you might expect, the large particles settle more rapidly than small particles. Also, the slower the water moves through the basin the more particles will settle out. Water in a direct filtration plant moves straight from the flocculation tanks to the next step…filtration.

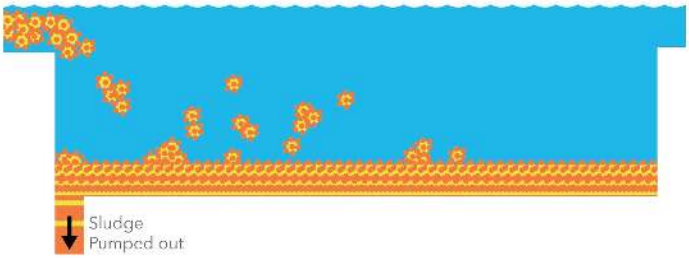


Figure ***Page*1.7.4**: – Sedimentation.

Filtration

The filtration process is one of the most critical steps. Filters are commonly constructed in concrete boxes and contain sand and gravel. Sometimes other filter media is used, but many times sand is sufficient enough to remove the remaining suspended particles. The purpose of the gravel is to support the sand and prevent it from leaving the filter. Under the gravel is a structure called an "underdrain." The purpose of the underdrain is to allow clear filtered water out of the filter while supporting the gravel and sand filter media. The process of backwashing will be discussed later.

Post-Disinfection

Prior to the water entering the distribution system, it is usually disinfected with a chlorine based disinfectant. Chlorine gas was and still is commonly used to provide a "free" chlorine residual throughout the distribution system. However, because of the water quality risk of disinfection byproducts, many water treatment plants are using a "total" chlorine residual by mixing chlorine and ammonia together. This disinfection process is referred to as chloramination.

How much disinfectant is required before water can be provided to customers for domestic use?

There are two "standards" when it comes to disinfection. There is a maximum residual disinfectant level (MRDL) and a minimum disinfectant level, which should be provided to the furthest areas within a distribution system. The MRDL is 4.0 mg/L and this level should not be exceeded in the water entering a distribution system. Typical free (chlorine) and total chlorine (chloramination) levels in water leaving a treatment plant can vary, but are commonly between 2.5 and 3.5 mg/L. The minimum residual level, which should be maintained in the furthest areas of a distribution system is 0.2 mg/L. Since microorganisms have the ability to multiply, a "residual" helps prevent regrowth and keeps the water free of pathogens. The previously mentioned dosage values typically provide enough disinfectant to kill/inactivate (disinfectant demand) remaining microorganisms and allow for a constant and minimal residual within the distribution system. The previous sentence used three (3) common terms associated with disinfection; dosage, demand, and residual.

1. **Dosage** – is the amount of a disinfectant added.

2. **Demand** – is the amount of disinfectant "used up" by the disinfection reducing agents in the water (microorganisms, organic matter, etc.)
3. **Residual** – is the amount of disinfectant left in the water supply.

Therefore, the following formula is commonly used.

Dosage = Demand + Residual

The amount of disinfectant added to a water supply (dosage) minus the amount "used up" (demand) equals the amount remaining, which is referred to as the residual.

Storage

In order for treatment plants to provide large quantities of water to distribution systems, a large amount of storage is commonly required and provided at the treatment plant. This "post" storage can and often times be in the millions to tens of millions of gallons. Therefore, treatment plants require large areas of land for the entire treatment process and storage.

Additional Treatment Processes

If the influent quality of water coming into a treatment plant or if the water supply a distribution system is producing, (often times from groundwater wells), is contaminated and not within drinking water standards, the water will require additional treatment. Some of these processes include but are not limited to, ion exchange, membrane filtration, and air stripping. Ion exchange, for example, is the process of removing ions using water with opposite charged ions. In Water 050 and 052, you will take a more in depth look at each process and analyze the benefits and challenges a water treatment operator might encounter.

Careers in Drinking Water Treatment

Because many drinking water treatment plants are wholesale water providers, meaning they sell water to various water agencies, the extent of career opportunities and paths can be quite extensive. They can have careers ranging from field technicians, maintenance workers, treatment plant operators, engineers, water resource professionals, as well as a variety of office and policy related opportunities. For example, Metropolitan Water District (MWD) of California deliveries is one of the largest wholesaler water suppliers in the country. MWD provides approximately 1.7 billion gallons of water per day and is the largest contractor of the State Water Project. In addition to the responsibilities associated with operating a water treatment plant, MWD has an extensive distribution system. They also have the important task of securing sources of supply to ensure there is always enough water for the water retailers who purchase water from them. They have additional responsibilities in the areas of water conservation, legal matters, public relations, human resources, finance, administration…the list goes on and on. They employ almost 2,000 people with jobs ranging from laborers to scientists, to engineers and more. As you can imagine, trying to list and discuss the vast amount of opportunities for an organization like this would be a lengthy process. For an introductory course like this one it would be impractical. Therefore, we will just look at a smaller example of a drinking water treatment plant and focus on career opportunities available for students such as you.

Treatment Plant Operator

Water Treatment Plant Operators (WTPO) typically work various assigned shifts. It is not usually a typical "8 to 5" type of job. After all, treated, safe drinking water needs to be available to customers 24 hours a day, 7 days a week. Therefore, WTPO need to work around the clock to make sure the treatment process is functioning efficiently. Below is a list of some of the more common tasks and responsibilities of a WTPO.

- Ensure the treatment plant is operating
- Perform biological, chemical, and physical laboratory tests on water
- Interpret test results
- Monitor and read gauges, meters, charts, and other treatment performance indicators
- Monitor and inspect treatment process equipment and instrumentation
- Make adjustments and take corrective action on treatment process equipment
- Maintain operational and water quality records
- Prepare reports
- Participate in training programs

In addition, other responsibilities may include cleaning and disinfecting storage tanks, flushing pipelines, and conducting public tours of the treatment plant. Often, plants will have a variety of automated processes and the WTPO will monitor these processes on a computer screen making adjustments through a Supervisory Control and Data Acquisition System (SCADA).

Experience and educational qualifications will also depend on the size of the facility, but many entry level positions will require a minimum of a Grade 3 Treatment Operator certification (T3) or a Grade 2 Treatment Operator certification with the ability to obtain a T3 within a year of employment. Since treatment plants may also have an associated distribution system to get water to the utilities purchasing water from them, a Distribution Operator certification may also be required. The more education and experience you can obtain will always help your chances in landing a job. An associate's or bachelor's degree is sometimes listed as a "desirable" qualification.

Water Treatment Plant Maintenance Worker

Just as a distribution system needs maintaining, a water treatment plant also requires maintenance. Pumps and motors can malfunction. Pipes can leak. System process and equipment can breakdown requiring repairs or replacement. Therefore, most treatment plants will have a maintenance crew as part of the staff.

Water Quality and Laboratory Staff

Many water treatment plants will have their own drinking water laboratory to analyze samples throughout the treatment process ensuring proper function and for adjusting chemical doses. The staff might be in charge of collecting samples and running analytical instrumentation in the lab. They might also be responsible for writing reports and keeping track of water quality data for regulatory compliance.

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Page 1.8: Water Supply

We have already discussed our water supply in several chapters. Remember, the two main sources of supply for use are surface water supplies and groundwater supplies. And, as you will see in Chapter 10 there are other sources of water used to supplement these two main sources. If you recall, surface water receives its supply from precipitation in the form of rain, sleet, snow, etc. Moist warm air rises and condenses on upward slopes. On the west coast, rain falls mostly on the westward facing mountains and as dry air drops a rain shadow effect occurs on the east facing slopes. Much of this precipitation runs off into streams, rivers, and lakes. Evaporation occurs condensing water back into the atmosphere. Some of it percolates into the ground and becomes groundwater. Plant roots also take up some water and transpiration occurs. The process of water transpiring and evaporating back into the atmosphere is referred to as evapotranspiration. When precipitation occurs the entire cycle is continued. This cycle is known as the hydrologic cycle.

Most of the water on earth is salt water. In fact 97% of the earth's water is seawater and only 3% is fresh water. This means of all the water on the planet, we get our fresh water from 3% of it. The story continues. Approximately 69% of all fresh water is in the form of glaciers and icecaps. Groundwater is approximately 30% and surface water is less than 1%. This is fairly startling considering much of the water we use every day comes from a fraction of the fresh water on earth. The vast majority of this small fraction is found in lakes. Some of these lakes are natural and some are manmade storage reservoirs behind dams. Much of the water that supplies California sits in these "manmade" storage reservoirs as the water moves through several aqueduct systems.

California Surface Water

California's diverse climate and geography presents an interesting situation when it comes to water supply. Approximately 2/3 of the state's rainfall occurs in the upper 1/3 of the state, while 2/3 of the usage occurs in the lower 1/3 of the state. In other words, water is used more in areas where it doesn't naturally fall from the sky. Therefore, surface water supplies are plumbed thousands of miles across California. There are 6 main aqueduct systems providing surface water throughout the state. They include:

- State Water Project
- L.A. Aqueduct
- Colorado River Project
- Hetch Hetchy Aqueduct
- Mokelumne Aqueduct

These aqueduct systems originate in the central to northern portion of the state and are operated by a variety of agencies.

State Water Project

The California State Water Project (SWP) originates from the tributaries of Lake Oroville, north of Sacramento. It runs a distance of approximately 600 miles and includes twenty-nine (29) dams/storage reservoirs, eighteen (18) pumping plants and five (5) hydroelectric power plants. It passes through the California Bay Delta. The Bay Delta is one of the nation's largest and most complex water delivery system and is known for its agricultural productivity, ecological diversity, and complexity. The SWP also includes the world's largest water lift. The Edmonston Pumping Plant at the base of the Tehachapi Mountains pumps (lifts) water 2,000 feet over this mountain range. More than 2/3 of Californians receive water through the SWP. The California Department of Water Resources (DWR) operates the State Water Project.

Los Angeles Aqueduct

In contrast, the Los Angeles Aqueduct is owned and operated by the Los Angeles Department of Water and Power. In the early 1900s, William Mulholland and Fred Eaton traveled north to find additional sources of supply for Los Angeles. What they discovered was the Owen's Valley, which had more water than the area knew what to do with. They built an aqueduct approximately 223 miles from the Valley diverting water down to Los Angeles. The unique thing about this aqueduct system is it flows entirely by gravity. The book and movie titled *Cadillac Desert* documents the vast undertaking by William Mulholland.

Colorado River Aqueduct

The Colorado River Aqueduct begins at Parker Dam along the Colorado River and travels approximately 242 miles west into California. There are two (2) storage reservoirs along the way and five (5) pumping stations to traverse the desert. The

Metropolitan Water District of Southern California holds the priority water rights on the Colorado River Aqueduct.

Groundwater

Underground aquifers hold a vast amount of water. Pores in the soil and fractures in rock formations hold millions of gallons of water beneath the earth's surface. As rain falls and snow melts, rivers fill with water and recharge these underground storage basins. There are three (3) main types of aquifers, each with unique geological characteristics. An unconfined aquifer can be very shallow, around 20 feet below the earth's surface to several hundred feet deep. These aquifers are commonly made of alluvium deposits consisting of porous, water-bearing materials of sand and gravel. These aquifers are capable of yielding large amounts of water and relying on annual recharge to keep them full of water. Beneath unconfined aquifers are confined aquifers. These aquifers are separated by an impermeable layer of soil (commonly clay) with porous sand and gravel beneath the clay. This impermeable layer acts as a barrier between the soil sediments above acting as a protective shield. Confined aquifers are less susceptible to surface contamination because of this impermeable layer. Fractured rock aquifers are not very common, but they can exist in mountain regions where there are cracks or fissures in the underlying rock. Water from precipitation can then make its way into the cracks and can be withdrawn by wells. Most wells require a pump and motor to get the water from below the ground to the surface. However, where recharge zones are higher than the elevation, the water can flow out without any help. These types of aquifers are referred to as artesian.

Groundwater banking or aquifer storage and recovery (ASR) is becoming increasingly popular, especially in areas prone to experience drought. Water can be pumped into an aquifer through injection wells or spread across acres of land allowing the water to percolate into the aquifer. This type of water storage is often done using surface supplies when water is plentiful. Instead of allowing the surface water to flow to the ocean, it can be diverted into an underground storage "bank".

What is Water?

When discussing water, sometimes we often overlook the very unique qualities of this vital resource. Water is composed of three (3) atoms. There are two (2) hydrogen atoms attached to one (1) oxygen atom. The bonding of these atoms to form a water molecule is what truly gives water its amazing characteristics. A water molecule is a polar compound, meaning it has the hydrogen ion bonds angled away from the oxygen atom. The oxygen atom has an affinity for positively charged ions while the hydrogen atoms attract negatively charged ions. This polarity allows water to bond with a variety of compounds making water a "universal" solvent. Water is found in three different phases; liquid, solid, and gas.

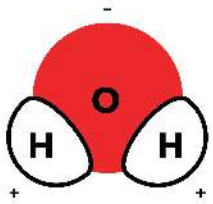


Figure ***Page*1.8.1**: –Water molecule.

The ability of water to attract other water molecules is called cohesion. This characteristic creates surface tension of water. A simple experiment to see surface tension in action is to float a paper clip on water. Fill a glass and gently place a paper clip on the water. The surface tension among the water molecule bonds allows the paper clip to float. Adhesion is ability of water to attract other molecules. This attraction to other molecules can be seen by the meniscus in a cylinder. Water attaches to the sides of the cylinder causing it to "creep" up the sides. Some substances are not attracted to water molecules preventing them from dissolving in water. For instance, fats and oils are considered hydrophobic because they do not dissolve in water. Conversely, hydrophilic substances such as salts and sugars dissolve quite easily in water.

Water Rights

Does everyone have a right to water? Well, on the surface this seems like an easy answer. Everyone should have the right to a safe, clean, and affordable water. However, this isn't always the case. Water rights laws are very complex and simply stating everyone has the right to access drinking isn't always enough. Typically, in highly populated cities, the "right" to water isn't a big issue. However, accessing a safe, clean, and reliable supply in rural areas isn't always possible, let alone feasible. In 2012, California

enacted Assembly Bill 685 establishing a state policy that every Californian has a human right to safe, clean, affordable, and accessible drinking water. This sounds great, but making this a reality is very difficult to accomplish, especially in very rural areas where the infrastructure doesn't exist to provide the water. Who actually "owns" the water we use every day?

Water rights are held by a variety of different private and public entities. Individual farmers can own water rights as well as large municipalities. Water rights are commonly land-based rights. Rights can be allocated based on land ownership or possession. Another type of water right is termed "riparian" rights. This type of land-based right gives the owner of land adjacent to the bank of a water body the right to the water flowing next to their property. Water rights can be also based on use. Use-based rights grant the user certain rights based on the amount of water previously used. Use is given for certain beneficial uses. This can also be for municipalities serving a certain population. Most water rights are associated with surface water supplies. Groundwater is often left to the people owning groundwater wells and pumping water out of the underlying aquifer system. At times this can be contentious if one entity is considered to be pumping more water than others deem is appropriate for the area and or use. This type of contention can result in something called adjudication. Adjudication is a legal process to determine who has a valid right to the water and how much of it can be used by each entity.

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Page 1.9: Water Use

It is amazing what water is used for and how much is used on a daily basis. We tend to not think about all the daily activities we do which requires the use of water. We turn on the faucet in the morning without giving it much thought. We flush the toilet, make coffee, and shower without the consideration of where or how the water comes out of our tap. If we think about the simple and obvious water uses, we might list washing our face and hands, taking showers or baths, brushing our teeth, making coffee, boiling pasta, washing dishes and clothes, flushing toilets. However, the list of water use goes on and on. In addition to the obvious uses (i.e., drinking, bath, irrigation, etc.) millions of gallons are used in the manufacturing and processing of everything from semiconductors to beer and everything in between. Water is a vital resource for public health and safety and plays a significant role in our economy. One of the largest water uses in California is the agriculture industry. According to the Pacific Institute's 2009 report titled *Sustaining California Agriculture in an Uncertain Future*, approximately 17.2 million acre-feet of water is used for agriculture annually. In addition, a large portion of the state's water supply is undeveloped and used for environmental purposes.

Water use can be broken down into several different categories: geographic, socioeconomic, availability, reliability, and quality. Geographically where water is plentiful very little is used for outdoor irrigation and sometimes use isn't even tracked. In contrast, in areas of the world where precipitation is low and water is scarce, it is treated differently and very little is used for outdoor irrigation. In poorer areas of the globe, water is a vital resource for survival. Approximately one (1) billion people lack safe and adequate water. In these regions people are not concerned with keeping a lawn green with water. They are worried about surviving. Availability, reliability, and the quality of water also play an important role in usage patterns. Industrialized countries tend to have water readily available, with reliable infrastructure, and of high quality. However, as we have seen in recent years, in certain areas, such as Australia and California, long droughts can occur, jeopardizing water availability, reliability, and quality. The point of this introduction is not to memorize facts and figures; it is to illustrate the vast amount of water uses and variability of supplies throughout the world. The remainder of this chapter will focus on common water uses primarily in California. As mentioned above, water plays an important role in the manufacturing of items. The following table is an example of how much water is needed to prepare certain items.

ITEM	GALLONS OF WATER
Pair of Jeans	1,800
Cotton T-Shirt	400
Barrel of Beer (32 gallons)	1,500
Single Board of Lumber	5.4
Gallon of Paint	13
Individual Plastic Bottle of Water	1.85

Units of Water

Whenever we discuss water we talk in volumes. However, there are various units to measure volumes of water. Each unit has its own purpose and are commonly interchanged with each other. Below is a partial list of units and the common use for reporting.

USE	UNIT
Meter Reads	Cubic feet (cf) Hundred cubic feet (HCF / CCF)
Groundwater Well Flow	Gallons per minute (gpm)
Daily Production	Million gallons per day (MGD)
Annual Production	Acre-feet per year (AFY)
Per Person	Gallons per capita per day (GPCD)

Understanding the terminology and units used in any industry is very important. The water industry uses a variety of different units and has a lot of terms not used in any other industry. As you start taking more classes in this field and begin your career in water you will become acquainted with the “language” of the industry.

As shown in the above table, the common unit of measure to track water use on a per person basis is “gpcd”, which is gallons per capita (per person) per day. This is the amount of water used by one person per day. It is typically calculated by taking the total water demand (use) for the year and dividing it by the total population served. This will give you the amount of water each person uses for one year. Dividing it by 365 (the number of days in a year) will yield the gpcd, the gallons per person (per capita) per day. This number and unit were not used very often in the industry prior to 2009. In 2009, the governor of California passed legislation for conserving water and one of the parameters used to measure the required amount of conservation required by water suppliers is gpcd. Senate Bill X7-7 requires water suppliers to conserve at least 20% of their water demand by the year 2020. Hence, the bill is commonly referred to as 20x2020 (20 by 2020).

In order to conserve water it is important to identify water use. Where is the water being used? This may seem like an obvious statement, but being able to identify where the most water is being used can help in targeting specific areas for conservation. For example, gpcd includes both indoor and outdoor water use from residential customers. As previously stated, it is simply the total amount of water used divided by the total population. However, it doesn’t distinguish between indoor or outdoor water uses. It also doesn’t discern between other uses such as business or industry (these will be discussed later in the text.) In the next section we will analyze and assume the entire population of the first few examples is a residential community. Therefore, the gpcd would be for all residential water use both inside and outside the home.

GPCD

Water usage varies from person to person, city to city, state to state, and more importantly climate to climate. Geography and socioeconomic status also plays an important role with water use. Little irrigation water is needed in areas with high amounts of precipitation. However, sometimes in areas with very little precipitation, little is used for outdoor irrigation too. For example, the gpcd for someone living in an area where there is a lot of annual precipitation will more than likely have a lower gpcd than compared to someone living in a warmer climate. Socioeconomic status will also have an effect on water use and gpcd. A single person living alone in a small apartment will probably have a lower gpcd than someone living in a Beverly Hills mansion with a large yard. Someone with high efficiency appliances, low flow toilets and faucets would tend to have a lower gpcd than someone with access to these types of things. Below is an example of the differences between geographic regions and the respective gpcd values.

Average Daily Per Capita Water Use in Several Major U.S. Cities

Metropolitan Area	GPCD
Phoenix, AZ	115
New York, NY	78
Seattle, WA	52
Sacramento, CA	280
San Diego, CA	143

Before even looking at the actual gpcd values in the above table, you could probably guess which city would have the lower and which would have the higher average gpcd values. The only city which may have tricked a few people could possibly be Phoenix, Arizona. Phoenix is a very hot and arid city and one might expect a very high gpcd. However, the gpcd value is considerably lower to a similarly hot and arid Sacramento community. Why is this? If you have ever traveled to Phoenix and Sacramento, the difference between most of the homes in Sacramento compared to Phoenix is the type of landscaping at an average sized single family home. In Phoenix, many homes have “native” or natural landscaping such as rocks and cactus. In contrast, many Sacramento homes have grass (turf) for landscaping. There are other reasons why Sacramento has a higher gpcd than Phoenix, but this is one of the more obvious reasons. Water use is dependent on availability, reliability, and quality.

Let's now take a look at a hypothetical gallon per capita per day (gpcd) calculation to

work with as an example to identify water use. Typically when a gpcd is calculated it is not done based on individual water usage. It is commonly calculated based on total annual consumption divided by the total population served. Assume a population of 5,000 people uses 1,120 acre-feet of water in one year. What would be the gpcd for this hypothetical community? Using the formula "total gallons divided by total population", converts to a gpcd of approximately 200 (see below).

1 AF = 325,829 gallons

1,120 AFY x 325,829 gallons = 364,928,480 gallons per year

364,928,480 gallons / 5,000 people = 72,986 gallons per person per year

72,986 gallons per person per year / 365 days = 200 gpcd

This type of calculation will be discussed in more detail in the Water 031 Advanced Waterworks Mathematics course. Therefore, you will not be required to perform this type of calculation in this course. It is used as an example and to help explain how water use is calculated and identified. Now that we have an example gpcd, let's break down the actual usage.

California

Among all the countries in the world, the United States has the highest average daily water use per person. In fact, on average, the U.S. uses approximately 410 billion gallons of water per day. The majority of this water use comes from surface supplies; about 80% and the remaining 20% comes from groundwater. Thermoelectric power is responsible for approximately half of all U.S. water demand. Irrigation (agriculture) and public water supply makes up just about all the remaining.

California water use is strongly dependent on the Mediterranean climate throughout much of the state. However, California also has some very tall mountain ranges with subarctic conditions. The lower flatland areas of California consist of long dry summers, cool evenings, and mild rainy winters. This is why so many people flock to areas in Southern California. A summer day in Santa Monica or San Diego is almost the perfect climate condition; warm (not hot) days and cool evenings. Many of the mountain areas throughout the state experience a more traditional four-season year with snow lasting from November to April. However, because California is a coastal state, the climate is also dependent on the conditions of the Pacific Ocean. This means, there can be times of significant drought and also high amounts of rainfall during weather conditions such as El Nino.

Because of California's unique size and location, there are four (4) main climate regions; Central Coast, Mountain, Central Valley, and Imperial Valley. These four (4) regions have very diverse climate conditions. The Central Coast has more mild than hot summers and more mild than cold winters. Think of San Francisco as an example. The summers in San Francisco are not typically too hot and the winters are not extremely cold. The mountainous regions of California also have typically mild summers. However, in contrast the winters can be very cold with high amounts of rain and snow. The Central Valleys usually experience very hot summers and cool winters. The San Joaquin Valley for example can have summer temperatures, which exceed 100F and also see some snow in the winter. The Imperial Valley (e.g. Palm Springs) is very hot and dry in the summer and the winters are typically very mild with little to no rainfall.

Most of the rain and snow occurs in the eastern and northern portions of California. While most of the people live along the coast and southern portions of the state. This presents a unique distribution challenge for water professionals. Bringing water from where it is to where most of the people are is something California does quite well. However, during years of drought the ability to distribute water throughout the state can be costly and difficult. Most of the time there are ample supplies of water in California for all of the various uses. During extremely wet years, there is sometimes too much water and not enough storage and a lot of the supply ends up in the Pacific Ocean.

Indoor Water Use

In this section we will analyze some potential indoor residential water use and compare it to the 200 gpcd we calculated in the previous section. If indoor and outdoor uses are not metered separately, certain assumptions will have to be made to distinguish between the two main areas of use. A lot of research and study has gone on and continues regarding water use. In January 2010, the California Homebuilding Foundation published a document titled *"Water Use in the California Residential Home"*. Many of the

estimates used in this section were collected from this document. However, it is important to note this is a “fluid” topic (pun intended) and regulations and policies are constantly changing when it comes to water use and conservation.

Now that we have established a 200 gpcd for this example community, we know how much water each person uses on an average per day. There are a number of variables affecting the actual use per individual, but this is the actual average gpcd for this example. Once the average gpcd is calculated you can break down the usage. First, let’s identify typical indoor uses. There are a number of different indoor water uses. For example, flushing toilets, brushing your teeth, bathing, washing your hands, cooking, cleaning dishes, and cleaning clothes. In addition to these common uses a certain amount of water can be lost through leaks in the plumbing system. There are obvious leaks such as a broken pipe or fixture. However, some leaks can go undetected for days or possibly longer. Toilets are probably some of the more common areas where leaks occur. The slightest little crease or crack in the rubber seal in the toilet tank can cause water to slowly drip into the bowl without being noticed. This is just one example of leaks which can account for a high percentage of water use both indoors and outdoors. The list of indoor water use can be larger, but this is a good start. Look at the table below for some estimated amounts and volumes of indoor water use.

USE	**AMOUNT (%)**	**Volume per Use**	**Time/Quantity of Use**	**TOTAL based on 200 gpcd**
Bathing	8%	2.5 gpm	8 min	16 gal
Toilets	3%	1.6 gpf	4	6.4 gal
Faucets (cooking/washing)	6%	2.2 gpm	5.5 min	12.1 gal
Clothes Washer	2%	1 load per week	25.5 per load	3.6 gal
Other/Leaks	8%			16 gal
Total Gallons per Day				**54.1 gpd**

Based on the information in the above table, the indoor usage would account for approximately 27% of a person’s usage with a 200 gpcd. This is to say 54.1 gallons of indoor water use divided by a total water use of 200 gpcd equates to about 27%. If 27% is identified as indoor water use, then the outdoor (or irrigation) usage would account for approximately 73% or 145.9 gallons per day.

In the space below, make a list of your various indoor uses and estimate how much water you use per day in your home.

Use Time or Frequency Volume

Outdoor Water Use

Sticking with the same 200 gpcd example, the average outdoor water use equates to approximately 73% or 146 gpcd. In California, the average outdoor residential water use ranges from approximately 60 - 75%. Most of this water is used to keep lawns green. Drive around any single family residential community in California and you’ll see acres and acres of turf. This green lush landscaping requires significant amounts of water to keep it green, especially in some of the dry semi-arid inland communities across the state. However, in 2015, the State Water Resources Control Board (SWRCB) adopted water conservation regulations mandating urban water suppliers to reduce water consumption on average of 25%. In addition, new home building standards are becoming stricter making it almost impossible to install grass as the normal focal point in front and backyards throughout California. As usage patterns change, there are still millions of homes with front and backyards covered in grass. So, how much water is used to irrigate a lawn. New efficient drip, micro-spray, and irrigation systems are coming out every day, but many outdoor irrigation systems use standard “sprinkler heads.” The amount of water sprayed out of a sprinkler head varies, but the average nozzle produces approximately four (4) gallons of water per minute. Let’s look at a hypothetical example.

Assumptions:

- 1 sprinkler head produces four (4) gallons per minute
- 7 sprinkler heads per irrigation station
- 5 irrigation stations

- Each station operates for 10 minutes per day

Based on the assumptions above, let's calculate how much water this irrigation system produces in one day.

7 sprinkler heads x 4 gallons per minute per head = 28 gallons per minute

28 gallons per minute x 10 minutes = 280 gallons per station

280 gallons per station x 5 stations = 1,400 gallons per day

You can see by this example, the amount of water used for outdoor irrigation can add up in a hurry. In fact, based on the 200 gpcd example we used in the above example this would equate to a much higher gpcd. One other thing needs to be mentioned regarding the 200 gpcd. Remember, this is for one person. Someone with the irrigation system used in the above example may be from a family's home. So, let's assume the irrigation system is from a family of four (4) and they are not watering daily. Let's assume they are watering three (3) days per week. How does this look in terms of a gpcd?

First, take the 200 gpcd and multiply it by a family of four (4).

200 gpcd x 4 = 800 gpcd for this home

Next, take the 1,400 gallons per day, multiply it by three (3) days a week and then divide it by seven (7) days a week to get the per day amount.

1,400 gpd x 3 days = 4,200 gallons per week

4,200 gpw / 7 days in a week = 600 gallons per day

The 600 gallons of outdoor water use is for the entire family of four. As a percentage, this equates to approximately 75%, which is consistent to the example given above.

Now, divide this by four (4) for the family.

600 gallons per day / 4 people = 150 gallons per person per day

Therefore, in this example, one (1) person uses 200 gallons per day with 150 coming from outdoor uses and 50 from indoor uses. If you remember the indoor usage calculated in the earlier example it was 54.1 gallons, similar to the results in this exercise. Please note that this is just one example in a very complex and diverse world, but it should illustrate the point of how indoor and outdoor uses can be estimated.

Other Water Uses

This section will focus on other uses in California. The California Department of Water

Resources (DWR) breaks down California's total water use into three (3) main broad categories: Urban, Agricultural, and Environmental uses. Urban use includes domestic residential use as previously described. In addition, urban water use includes commercial, industrial, and institutional uses. These three (3) categories make up a component of water use in California and throughout the world. In California, these use categories are defined by the DWR.

- **Commercial:** Water users that provide or distribute a service.
- **Industrial:** Any water users that are primarily manufacturers or processors of materials as defined by the Standard Industrial Classifications (SIC) Code.
- **Institutional:** Any water using establishments dedicated to public service. This includes schools, courts, churches, hospitals, and government facilities.

As you can imagine, the use percent for these three (3) categories can vary widely based on the area. For example, the amount of commercial, industrial, and institutional water use in a small "bedroom" community would be quite low. However, in a city such as San Pedro, California, where there are a variety of industries this component of usage can be quite high. In California, these categories only account for a small percentage of all urban water use.

Agricultural and Environmental Water Use

In California, it is estimated that the agriculture industry accounts for approximately four (4) times as much water use as all urban water uses. This is not surprising since California's unique geography and Mediterranean climate have allowed the State to become

one of the most productive agricultural regions in the world. California produces over 250 different crops and leads the nation in production of 75 commodities. California agriculture irrigates approximately 9.6 million acres of land. Environmental uses are identified as coming from developed and undeveloped water supplies. A developed water supply is one controlled and operated by someone. For example, the State Water Project is a developed water supply controlled and operated by DWR. It comes from natural runoff from precipitation and snow melt runoff, but it has been developed into a supply for specific uses. In contrast, an undeveloped supply would be a “free” flowing stream or river which is not used for specific uses. Both of these supplies are used for and by the environment. Among other things, developed flows are needed to keep salinity levels lower in the Sacramento Bay-Delta area and to help keep cold, clean water needed for salmon migration and spawning. According to DWR, roughly 52 percent is used for agriculture, 14 percent for urban, and 33 percent for environmental uses.

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Page 1.10: Recycled Water, Reuse, and Conservation

Water is one of our most precious and vital resources on earth. Without it, life would not exist. However, at times we all take water for granted. Every time we turn on the faucet at home water comes flowing out. We have learned throughout this text where water comes from, how it is treated, and how it is distributed. We also learned about the hydrologic cycle and how water is transformed from one phase to another. But, what if part of this hydrologic cycle is interrupted? What if it doesn't rain? What if there is no snow in the mountains? In 2011 – 2015, California was faced with one of the worst droughts in the state's history. California has seen record low snow pack in the Sierra Nevada Mountains and historically low rainfall throughout the state. In January 2015, San Francisco recorded no rain for the first time in the city's history. The Governor and the State Water Resources Control Board handed down mandatory conservation regulations in 2015. Some water suppliers were asked to conserve as much as 36%. What if droughts continue for long periods of time? Will conserving water be enough?

Conservation is always a prudent approach to saving water, but sometimes it will not be enough to offset the potential loss of water during times of serious drought. Reuse is a term used often in the water industry to identify reusable sources of supply. Recycled (reclaimed) water is one of the most common reuses of water.

Recycled Water

"Recycled Water" can be classified as any water which is reused and has not been processed for drinking purposes. For example, if you have a rain barrel and you collect rain water and use it to irrigate your yard; this can be thought of as a type of recycled water. Storm water runoff can also be looked at as a type of "recycled water." As it rains and storm water is captured and reintroduced into a groundwater basin to recharge, an aquifer can be considered a form of recycled water. Greywater systems are also a form of recycled water. Grey water is the water collected after uses such as dish and laundry washing machines and reused as irrigation water. Although these previous examples can be thought of as "recycled water", most people think of recycled water as treated wastewater. Wastewater is solid and liquid discharges from all sources dumping into a municipal sewer system. Sometimes, storm water can enter a sewer system through manholes in a street. However, most storm water makes its way through a storm drain system and eventually flows to the ocean. This water is typically untreated. In contrast, wastewater goes through a series of treatment processes to remove solids, harmful pathogens, and other things to make it acceptable to be discharged back into the environment. The various wastewater treatment stages are referred to as primary, secondary, tertiary, and advanced treatment. Most wastewater used for recycled water purposes goes through at least tertiary treatment. Below is a brief description of each wastewater treatment process. These processes are covered in more detail in the Water 060 and 061 courses.

- **Preliminary Wastewater Treatment** - The removal of large, entrained, suspended or floating objects. The treatment process usually consists of large screens and cutting devices.
- **Primary Wastewater Treatment** - The separation of solids and greases through settling tanks and clarifiers.
- **Secondary Wastewater Treatment** - This step involves the removal of organic matter primarily through biological treatment.
- **Tertiary Wastewater Treatment** - Disinfection chemicals such as chlorine and ultra-violet light are used to remove pathogens (disease causing organisms) from the wastewater.
- **Advanced Wastewater Treatment** - If additional contaminants need to be removed sometimes advanced treatment is employed with the use of membrane filtration and/or additional chemical treatment processes.

When discussing recycled water the main purpose is to reduce the burden on fresh water supplies by reusing water such as treated wastewater. Recycled water is commonly discussed in unison with water conservation. The idea is to **R**educe the amount of water used, **R**euse water supplies for various purposes, and **R**ecycling treated wastewater. The remaining sections of this chapter will discuss these "conservation" related topics and how the three "R"s are incorporated.

Groundwater Recharge

Groundwater recharge is the process of water from the surface re-entering the ground becoming groundwater. Typically groundwater aquifers are recharged through precipitation. Rain and melted snow makes its way to an aquifer recharge zone and percolates deep into the soil becoming groundwater. However, there are other sources of water which can makes its way to a recharge zone can become groundwater. For example, if a fire hydrant gets hit and water flows into a storm drain which discharges

to a dry riverbed with an underlying aquifer can percolate into the soil becoming groundwater. Another example is the treated effluent from a wastewater treatment plant. These types of examples are referred to as “incidental” recharge.

Direct Potable Reuse

Direct potable reuse is using a source of recycled wastewater directly as potable water. At the time this text was written, this is not an approved source of potable water. There are too many health concerns and unknowns regarding the quality

Indirect Potable Reuse

Indirect potable reuse is the process of reusing treated wastewater to recharge groundwater basins and aquifers and to augment various surface water supplies. This type of reuse can be something which is termed “incidental” or it can be a planned and constructed use. Anywhere wastewater is treated and discharged back into the environment has the potential to recharge an aquifer. For example, if a wastewater treatment plant is discharging into a dry river bed and this dry river bed has an underlying groundwater aquifer, this would be considered incidental recharge. If there are groundwater wells downstream of this discharge location, this “incidental” recharge would be a potential supply for these wells. Conversely, in Orange County, CA there is the Groundwater Replenishment District which takes highly treated wastewater and pipes it back up into the groundwater basin for recharge. They process enough water to serve approximately 600,000 people.

There are however, several challenges when presenting these wastewater reuse strategies. Professionals within the water and wastewater industries have a good understanding of the various treatment and distribution processes of water making it safe and reliable for human use and for the environment. The general public typically has less of an understanding, especially when it comes to reusing wastewater. This lack of understanding usually results in a reluctance of the public. When terms as “toilet to tap” are floated around the media, the public becomes skeptical. In addition to perception, there is a significant cost which goes along with all reuse options. A significant amount of infrastructure is needed to bring water from wastewater treatment plants to the various customers. Many times miles of pipeline is needed as well as pumps and storage. The infrastructure costs can often times be cost prohibitive. However, in new developing communities, the infrastructure costs can be greatly reduce by charging connection fees to developers and because it is much cheaper to install pipe lines in dirt than existing streets in asphalt.

There are multiple reasons why recycled water should be used. Since water can be a limited resource in many parts of the world, recycled water can be used for many different non-potable uses where potable drinking water is typically used. For example, an office building can be “dual-plumbed” so the restroom water for toilets is recycled water and the sink water is potable drinking water. By far, the most common use of recycled water is for irrigation. By using recycled water we reduce the reliance of fresh water from sensitive ecosystems, reduce the dependence on importing water, and there is the potential for energy savings by reusing a local resource. These are just a few examples of recycled water uses and benefits from reusing treated wastewater. In addition to the public and costs issues with using recycled water, there are various permitting hurdles with Los Angeles Regional Water Quality Control Board (LARWQCB) and Division of Drinking Water (DDW). The LARWQCB is responsible for promulgating the federal Clean Water Act. As part of this act, it gives the authority of maintaining clean water in what is called “navigable waters of the U.S.” Locally, a navigable water of the U.S. would mean the Los Angeles River and the Santa Clara River. All water discharged into these and other water bodies must meet certain water quality standards known as Basin Objectives. Each watershed can have different water quality objectives depending on the beneficial use of the water in the watershed. Since DDW is responsible for drinking water systems in California, they oversee recycled water use and water used for groundwater recharge. Their requirements involve the quality of the water and how long the water being discharged and subsequently pumped out through groundwater wells for domestic use. In addition, the agency responsible for treating wastewater may also have specific regulatory requirements. In Los Angeles, this would be the Los Angeles County Sanitation District. LA County Sanitation District has permits with the Regional Water Quality Control Boards for discharges and they have also set up specific requirements to use their treated wastewater as recycled water. These and other rules and regulations are not limited requirements, but they do require time for research, analysis, and permitting before recycled water can be used. Below is a list of some of the approved recycled water uses.

- **Groundwater Recharge** – certain LARWQCB and DDW rules and regulations apply. For example, the quality of the water used must meet certain LARWQCB Basin Water Quality Objectives and the quality and distance before the water is pumped out of the ground for domestic use must adhere to certain DDW regulations.
- **Lavatory Facilities** – if the plumbing system of a building is “dual-plumbed”, meaning there are pipes specific for different uses, recycled water can be used for toilets, drainpipe priming, etc. There are specific DDW rules and regulations that apply.

Currently (2015) dual-plumbed systems are not allowed in residential homes.

- **Industrial and Commercial** – certain business processes can use recycled water for non-potable purposes. Various regulations apply.

In addition to the regulatory requirements mentioned above, some of the specific requirements imposed on water suppliers before they can began using recycled water are the following:

- Users must have a Site Supervisor. The water supplier is required to coordinate with the user training and assignment of an onsite supervisor.
- Annual visual inspections must be conducted. The Site Supervisor and the water supplier must coordinate these inspections.
- Pressure test inspections are also required every four (4) years. In addition to the Site Supervisor and water supplier, a State or County Health Department usually provides an inspector.

Locally in the greater Los Angeles area Valencia Water Company, Burbank Water and Power, and Los Angeles Water and Power serve recycled water.

Conservation

Why should we conserve water? There are a number of reasons why someone would conserve water. During times of drought there may be regulatory requirements for water conservation. Some people may think it is just the right thing to do since water can be a limited resource in certain parts of the world. Or, maybe you just want to try and save a little money. Water rates are always getting higher and higher and the less you use, means the less you will pay. Reusing water, whether it is recycled water for irrigation or recycled water used to recharge groundwater aquifers, is a prudent approach when it comes to water resources. However, water conservation or reducing the amount of water used is also an important tool when it comes to water supply resources. Reducing the amount of water we use will help ensure the availability of water in the future. As the cost of water continues to rise, it is also economically prudent to reduce the amount of water used.

In 2009, the governor of California signed into law Senate Bill x7-7. This bill is also known as 20x2020 and requires all water suppliers to reduce their water demand by 20% by the year 2020. The 20% reduction is calculated using the water suppliers average customers daily use or gallons per capita per day (gpcd). Gpcd is calculated by taking the total water production and dividing it by the total population.

Daily Production = 9,600,000 gallons

Total Population = 40,000

9,600,000 gallons / 40,000 people = 240 gpcd

A 20% reduction for this example would equate to a 192 gpcd. In this example, you might be thinking that this is a lot of water for one person to use in one day. However, if you recall from the Water Use chapter, the amount of water used can add up quickly. Regardless of the reasons you decide to conserve water, the bottom line is you will save money.

Let’s go back to the 20% savings example above. A 20% daily savings of 48 gpcd for a family of four (4) will equate to over 70,000 gallons a year. Let’s take a look.

48 gpcd x 4 people = 192 gallons per day.

192 gallons per day x 365 days = 70,080 gallons per year

Most utilities bill in hundred cubic feet (HCF or CCF) billing units

1 CCF = 748 gallons 70,080 gallons / 748 = 94 CCF

Now, we need to make an assumption how much a water supplier would charge for a CCF. Water rates vary, but averages in the southern California area range between $1.60 - $3.50 per CCF. Therefore, using the low and high of this range, this family of four (4) would save

94 CCF x $1.60 = $150.40 per year 94 CCF x $3.50 = $329 per year

I don’t think anyone would turn down $150 a year let alone $329! So, regardless of the reason you might decide to conserve, there is the potential to save a lot of money.

How Do Water Suppliers Get Customers To Conserve?

Sometimes people are not aware of how much water they use. They might look at their monthly water and if it looks similar to the month before they do not think twice before paying their bill. Communication is the number one tool water suppliers have at their disposal to promote water conservation. Bill inserts, flyers, social media, and all good ways to communicate to the public about conservation. Some water suppliers may also use billboards and radio and television advertisements. Getting the word out is the first step. Many water suppliers offer a variety of incentive rebates to help people conserve water. Low flow toilets, efficient appliances, drip irrigation nozzles, and "turf" buyback programs are just a few rebate programs water suppliers use.

Sometimes water suppliers need to take a more aggressive approach, especially if there is a drought and regulations require conservation. If the public does not respond to outreach programs or rebates, utilities will often resort to increasing water rates and/or issue fines. This is not the most popular approach among customers, but sometimes it is a necessary tool to force customers to conserve water. It is also important to note that sometimes water suppliers will have to increase water rates because of conservation. The less water used means the amount of revenue a utility collects will decline. This is probably one of the most difficult things to communicate to customers. Water suppliers tell customers to use less water and then the water rates are increased anyway.

One of the last things a water supplier will use to get customers to use less water is to shut off their water service. This is not usually advisable, because a minimal amount of water is needed to maintain health and safety, but at times, people might have their water service discontinued for a certain period of time until they decide to use less water.

Water Rates

There are various different rates structures water suppliers use. They include; flat rates, uniform single quantity rates, tiered rates, and water budgets. The type of water rate a utility will use is dependent on a number of factors and vary for area to area.

Flat Rate

Flat rates are the simplest rate design. The rate is the same or flat for every customer regardless of water use. This type of water rate is common in areas where use is relatively the same for everyone. For example, an area where outdoor irrigation is not needed because of ample amounts of precipitation and indoor use is the predominant use a flat rate might be used. However, some people might deem this type of rate unfair because a large family would essentially pay the same amount as a single person living in a home. This is a very easy rate structure for utilities. No meters are needed and the revenue amount every year is relatively constant.

Uniform Single Quality Rate

This type of rate structure is considered a more fair way to charge for water and the services associated with treatment and delivery. There is a single rate price for one unit of water. Therefore, if you use one unit (CCF) you only pay for one unit of water. Whereas if you use 100 CCF of water you pay for the 100 CCF you used. It is probably the most common rate structure. Each utility with this rate structure must make sure they review the income revenue often since a large reduction in use will translate to a large reduction in revenue. The amount of money a utility needs to operate is referred to as revenue requirements. This will be reviewed later in this chapter.

Tiered Rate

Tiered rates are becoming more common, especially in areas where use patterns can fluctuate, such as areas affected by drought. This type of rate structure can be used to encourage conservation. The cost of a unit of water increases the more you use. There can be as few as two tiers and some agencies have up to five tiers. A tier rate structure might look something like this;

Tier 1 = $1.50 per CCF up to 10 CCF (1 – 10 CCF)

Tier 2 = $2.00 per CCF for each unit over 10 CCF up to a certain amount (11 – 20 CCF)

Tier 3 = $3.00 per CCF for anything used over 20 CCF (21 and up)

Let's see how this type of rate structure works. The following example is based on a monthly water usage of 30 CCF. The first 10 CCF of the monthly 30 CCF usage would be billed at the $1.50 per CCF rate. Therefore, you would multiply 10 CCF by $1.50.

10 CCF x $1.50/CCF = $15

The remaining CCF would be 20 (30 CCF - 10 CCF). The next 10 CCF of water used (11, 12, 13…20 CCF) would be billed at the second tier rate of $2.00 per CCF.

10 CCF (11 - 20 CCF) x $2.00/CCF = $20

The remaining usage up to 30 CCF is another 10 CCF. These remaining 10 CCF (21, 22, 23…30 CCF) would be billed at the third tier rate of $3.00 per CCF.

10 CCF (21 – 30 CCF) x $3.00/CCF = $30

All three total charges would be added together for a total monthly bill amount of $65.

$15 + $20 + $30 = $65

This is a very simplistic look at a tiered rate structure, but it should illustrate how the cost of water increases based on the amount used. You can see how this type of rate structure might encourage conservation.

Water Budgets

The last rate structure we will look at in this text is called water budgets. It is a similar structure to tiered rates. However, unlike tiered rates, water budgets provide a more fair and equitable way of charging for water use. In a straight tiered rate structure many people complain because of the subsidization issue. Large use customers pay much more and in some instances subsidize smaller users. This is because a traditional tiered rate structure is blind to parcel size. Water budgets are different. A water budget is an individualized rate structure based on each customer's specific parcel. For example, a customer with a large yard and multiple people living in their home will have a larger budget than a single person living in an apartment with no outdoor landscaping. Both customers would have a monthly allocation specific to their needs. Water budgets usually classify an indoor allocation of 50 - 60 gpcd and then specify an outdoor allocation based on actual landscape measurements or perhaps a percentage of the parcel size. All this information gets input into a formula to calculate the monthly budget. The formula typically includes a monthly evapotranspiration rate (ETo) and a coefficient for the specific type of landscape material. The evapotranspiration rate is the amount of water needed to sustain plants based on the current weather. For example, the ETo rate is higher in summer months than during the winter. Although this is a more equitable rate structure, it does require additional work by the water supplier and can sometimes be confusing for customers to understand.

Regardless of the rate structure, the utility must demonstrate that their rates are truly the cost of providing service. There have been lawsuits in the past and will continue in the future, challenging various rates structures and the amount being charged. Utilities must adequately identify why their rate structure is the needed amount for their specific revenue requirements.

Service Charge

One last rate component should also be discussed. A service charge is a monthly (or bi-monthly) charge placed on each customer regardless of the amount of water used. This charge is a flat rate and covers some specified percentage of the water supplier's revenue requirement. It is sometimes referred to as a "readiness to serve" charge. It guarantee's a certain amount of revenue every billing period allowing the utility to continue basic business functions without worrying about usage fluctuations.

Revenue Requirements

This term has been mentioned several times in the preceding sections. A revenue requirement is nothing more than the amount of money (revenue) a utility must collect to maintain their basic day-to-day service. Water rates and service charges are the primary source of revenue water suppliers receive. Well, what is a "revenue requirement"? A water supplier has certain expenses, which cannot be avoided. For example, water treatment is required in order to provide a safe drinking water supply to customers. For each gallon of water served it requires a certain cost for treatment. Likewise, there are electrical costs for pumping water, maintenance costs, salaries and benefits for employees, and costs for replacements and improvements to infrastructure. There a many expenses to operate a water utility, but this doesn't mean there is no room to reduce costs to keep rates low. Each water supplier must determine what is necessary and what can be reduced or cut in order to maintain an efficient operation.

Water is a vital resource and the availability of fresh water varies throughout the world and is dependent on weather patterns. An El Niño weather pattern can bring much needed rain to parts of the world while creating devastating droughts in other parts. Understanding the use and need of water will help us all use it a little more wisely and will help professionals manage this

important resource. There will always be a need for water professionals as long as clean, safe, and reliable drinking water is needed.

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SECTION OVERVIEW

Page 2.1: Water All Around Us

In Part One of this text, we'll explore the basics of water supply and demand. We'll review the water cycle, explore basic concepts in water management, introduce surface water and groundwater rights, and then introduce the ideas of stakeholders in water projects. Part One is divided into these four sections:

- The Water Cycle
- Water Management Concepts
- Water Rights
- Stakeholder Concepts

For many of you, the Water Cycle will not be a new concept. But now you will need to frame it differently. Rather than considering it as a scientific concept, you'll have to see the interface between science and society and between supply and demand.

Water management concepts will take the water cycle further as you learn how different sources of groundwater and surface water supplies are identified and used both separately and together. There are benefits and drawbacks to each type of source of water.

Water rights are important to all aspects of the water supply. While we can't make you an attorney, you'll understand the basic types of water rights in California by the end of this section.

And lastly, in Part One, you'll finish with an examination of typical stakeholders in different water issues. Stakeholders aren't just a concept from business theory. They are critical to how we get things done in the water industry. You'll look at a few real-life examples of the consequences of working with (or neglecting) stakeholders in the water industry.



Figure ***Page*2.1.1**: Hydraulic Gold Mining by Carlton Wakins is in the public domain - *Hydraulic mining in the 1880s in Nevada City, California*

Page 2.1.1: Water Cycle

Page 2.1.2: Water Management Concepts

Page 2.1.3: Water Rights

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Page 2.1.1: Water Cycle

Learning Objectives

After reading this section, you should be able to:

- Identify processes in the water cycle that influence the water supply
- Analyze situations in terms of precipitation, condensation, evaporation, and transpiration
- Evaluate yearly data for evapotranspiration

You've probably heard on the news the statewide water supply in California described in terms of snowpack and rainfall. These are critical measures of how much water is available for human use. Water managers in California follow both snowpack measurements and rainfall measurements closely. In the diagram above from the United States Geological Survey (USGS), you can see that precipitation is shown as rainfall and snow.

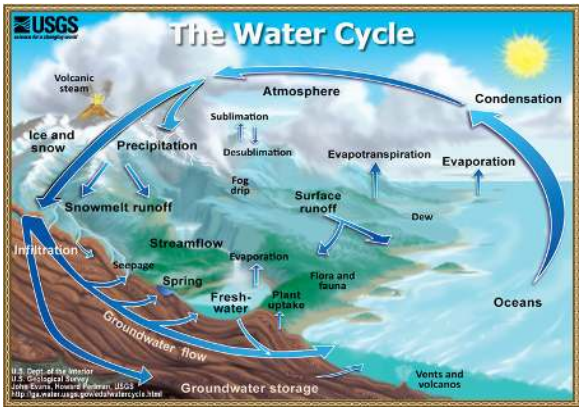


Figure ***Page*2.1.1.1**: The Water Cycle by John Evans and Howard Perlman is in the public domain

Precipitation also includes something you don't see too often in California: hail and sleet. All forms of water that fall from the sky, including rain, snow, hail and sleet, are forms of precipitation. Rainfall can provide much needed water in the ground by the process of infiltration, the process by which water seeps into the ground and eventually recharges our groundwater, water stored in the ground. Using the diagram above, you can also trace the flow of groundwater in some cases to both rivers, lakes, and even to the ocean.

Above ground, rainfall can also be stored on earth's surface in lakes. Precipitation in California also provides snow for snowpack, which can be our largest area of storage of water in the winter. In fact, it is common for water managers to view the snowpack in the Sierra as a reservoir; it is simply a seasonal reservoir that melts in the spring. Snowmelt runoff from the snowpack can fill streams and lakes. Runoff from rainfall is also captured in streams and lakes and can serve to recharge aquifers through percolation and infiltration.

The diagram also shows the key process of evaporation, or the process through which liquid water turns into a gas. Evaporation occurs over bodies of water like the ocean or lakes, but also over the land. If you own a home with a pool, you have probably noticed that if you leave the pool without a cover in the summer, you have to add water more often in the summer than in the winter. This is because the rate of evaporation is higher in the summer than the winter, often dramatically so.

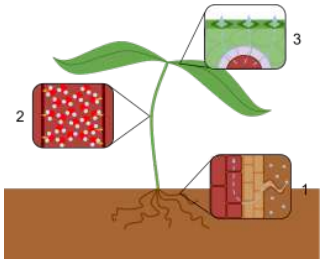


Figure ***Page*2.1.1.2**: Transpiration Overview by Laurel Jules is licensed under CC BY-SA 3.0

Transpiration is the process through which plants lose water. This may seem like an inconsequential process, but it is the entire process that drives irrigation. In the diagram below you can follow the transpiration process. In Step 1, plants bring in moisture from the soil with their roots. Then, in Step 2, water travels up through the plant. In Step 3, water leaves through their pores or stomates (plural of stomata) and enters the atmosphere again.

The combination of water loss from liquid water in the ground evaporating and water in plants losing water is called evapotranspiration (ET). Evapotranspiration is frequently used by scientists as a measurement of the plant water needs. If a location has a high ET, then the plant needs are greater than a location with a low ET.

Most locations in the state of California are close to a weather station that is part of the California Irrigation Management Information System (CIMIS) network. A CIMIS station measures a variety of variables in order to calculate the ET including: temperature, solar radiation, humidity, wind speed, and wind direction. With a complicated formula, the CIMIS station will calculate the ET for a specific geographic location. This information is frequently used to make a water budget, an estimate of how much water a location should use, including outdoor watering based on the amount of landscaping, the type of landscaping and the evapotranspiration.



Figure ***Page*2.1.1.3**: CIMIS Station #204 (Photo used with permission of Castaic Lake Water Agency)

The monthly inches of ET data in the table for Santa Clarita reflects the water needs in terms of inches of water that grass would need to receive per month. You can see that the highest needs are in summer, primarily July and August, with needs decreasing rapidly in September through December. Even though September is typically almost as hot as August, the days are shorter and the sun is less intense so the evapotranspiration is less in September than August. This means the plant needs for irrigation are significantly less.

CIMIS Station #204 Santa Clarita - 2016 Evapotranspiration Data

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly ET (in)	1.97	4.80	4.51	5.24	5.77	7.77	8.99	8.13	6.30	4.68	3.40	2.69

Knowledge of evapotranspiration has a practical application - in Southern California, many people find they can turn off their irrigation systems for grass in normal years from November through February and that their plants' water needs will be met with rainfall alone.

The opposite process of evaporation is condensation, the process through which water as a gas turns into liquid water again. Condensation is the process through which clouds form. This is also the process through which water beads on the outside of a glass of iced tea on a humid day or on a mirror in a steamy bathroom. In terms of the water supply picture, condensation is the key process that can lead to precipitation, so clouds are carefully monitored by scientists.

What makes the water cycle work? In short, gravity and the sun. Notice that there is always groundwater flow and streamflow from a higher altitude to a lower altitude. Gravity drives this flow of water in the water cycle, and is also a key force in most water distribution systems. If you're not using gravity, you're going to need a pump to go from a lower elevation to a higher elevation. Systems are generally designed to avoid pumps if possible and use the force of gravity. The sun drives the water cycle in a different

way, by heating the water and causing it to evaporate. It also melts the snowpack in the mountains while gravity causes the water to flow into streams, rivers and lakes.

In Section 1.1, you've learned the basic processes in the water cycle: precipitation, infiltration, evaporation, transpiration, and condensation. Next, you'll see how these processes create surface and groundwater supplies and how these supplies are used for water management.

Try It!

Describe a process at work in each scenario and how the process works:

1. Analyze the effect on the water cycle if California had no precipitation for a year.
2. You hang a wet swimsuit out on the balcony to dry overnight. What process is at work? How is water changing states?
3. Using the CIMIS web site (www.cimis.water.ca.gov/), register for an account (free). Then under the Data tab, find the nearest CIMIS station to your home create a monthly web report for 12 consecutive months, which should include ET. When should you water the most? When should you water the least?

Key Terms

Condensation—The process through which water as a gas turns into liquid water again; opposite of evaporation

Evaporation—The process through which liquid water turns into a gas; opposite of condensation

Evapotranspiration—The combination of water loss from liquid water in the ground evaporating and water in plants losing water

Groundwater—Water stored in the ground

Infiltration—The process through which water seeps into the ground

Precipitation—All forms of water that fall from the sky, including rain, snow, hail, and sleet

Transpiration—The process through which plants lose water

Water budget—An estimate of how much water a location should use, including outdoor watering based on the amount of landscaping, the type of landscaping and the evapotranspiration

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Page 2.1.2: Water Management Concepts

Let's engage in a little thought experiment.

If a zombie apocalypse happened right now and you ran for the hills, you would have to find water to survive. How would you go about doing this? In this section, you'll identify sources of water supply. This section is critical to an understanding of water management, both personally as well as regionally and statewide.

Learning Objectives

- After reading this section, you should be able to:
- Describe various sources of surface and groundwater supply
- Give examples of water storage
- Evaluate a situation in terms of conjunctive use

Now back to the zombie apocalypse. If you had to find water, you would probably:

- Try to find a stream or lake
- Start digging a well

Notice that you didn't start with the ocean. This is important because most of us intuitively understand the amount of energy it takes to make ocean water drinkable. Although most of the water on earth is in the oceans, bays, and seas, it's not drinkable without expensive treatment. Who would have time for that level of treatment in the zombie apocalypse? And you also didn't start with the ice caps (too far and too many zombies in the way). What you have intuitively chosen is the right solution—surface water and groundwater. And your strategy reveals another challenge for water managers—most of the water on earth is not accessible or easily potable (drinkable).

Most of the water on earth is in the ocean (97%). For the 3% that remains as freshwater, most of it is trapped in glaciers and ice caps (68.7%). That leaves only groundwater and surface water making up less than 1% of the water on earth. You can see why people refer to water as precious! In fact, 20% of all freshwater on earth is in one enormous lake in Russia, Lake Baikal, which is inaccessible to most of us on earth.

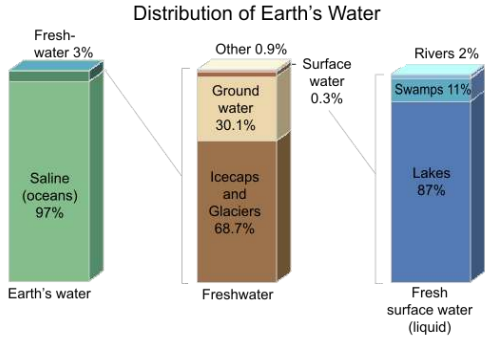


Figure ***Page*2.1.2.1**: Distribution of Earth's Water by the U.S. Geological Survey is in the public domain

Surface water can be broken into different types, but it is easiest to think of surface water as either bodies of water and flowing water. Surface water can occur as a lake or pond, both bodies of water at low places in the land where water has accumulated. Most lakes have both inflow and outflow. Some lakes lack inflow and/or outflow and they become salty over time (e.g., Great Salt Lake, Dead Sea, Salton Sea). A reservoir is a lake that is manmade by making a dam across a river.

Surface water can be flowing water, such as a creek, stream, or river. It can also be water stored in a lake or reservoir. People tend to use the terms creek, stream or river interchangeably. Rivers (or streams or creeks) form when water moves from higher ground to lower ground. You'll remember that in the water cycle, gravity is a driving force—all water flows downhill. When water falls from the sky as rain in the water cycle, it may infiltrate into the ground, but it also may run off and form creeks and streams. Eventually, creeks, streams and rivers flow to the ocean.

As a source of water, surface water has both benefits and drawbacks.

Benefits of Surface Water	Drawbacks of Surface Water
Easy to access	Water is lost to evaporation
Lakes and reservoirs can provide flood control in addition to a water supply	Lakes and reservoirs may experience a build-up of sediment, especially after fires
	Distribution requires a network of pipes and/or canals

Well, nothing is perfect in the study of water supply. If surface water isn't the perfect supply, perhaps groundwater is better. In the diagram below, you can see both surface water and groundwater. The water table is the line at which soil becomes saturated with water. The soil above the water table is unsaturated and the water below the water table is saturated. Groundwater is stored in aquifers, which are areas underground of soil or rock that can hold and transmit water beneath the water table.

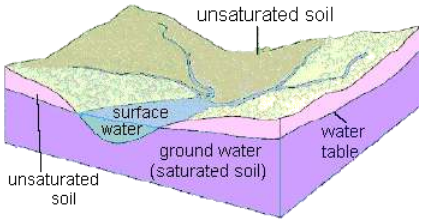


Figure ***Page*2.1.2.2**

> *Misconception Alert!*
>
> *Frequently, people will describe an aquifer as an underground swimming pool. While this does illustrate the idea that water is stored underground, it is really misleading. A swimming pool contains water entirely. An aquifer is mostly sediment or rock with water in the pores between grains of rock or sediment.*

Sediment and rock vary in terms of how much water it can store. The ability for rock to transmit media is often referred to as permeability. Sometimes gravel has large pores and rock has large connected fractures that enable water to move through them. Other times, the pores in gravel and the fractures in rock are impermeable.

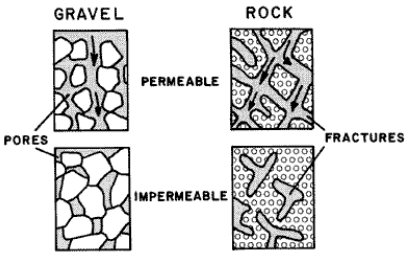


Figure ***Page*2.1.2.3**

In order to get water from the aquifer to the surface, you need either the water to come up from the ground naturally because of pressure in the layers confining the aquifer or you need to drill a well, which is much more common. In the diagram below, you can see the difference between a deep well and a shallow well. When the water table is at a normal level, both the shallow and deep well can produce water. However, when it is a drought, only the deep well can reach below the water table. The shallow well would end up being dry.

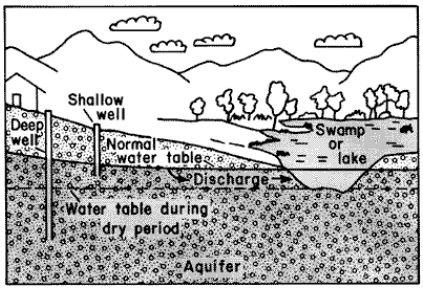


Figure ***Page*2.1.2.4**: Rock layers image by the U.S. Geological Survey is in the public domain

Groundwater as a water supply also has benefits and drawbacks that communities consider when they build their water supply portfolios.

Groundwater Benefits	Groundwater Drawbacks
Difficult to pollute	Difficult to clean up
Useful in times of drought when surface supplies are low	Replenishment is slow
Generally, cheaper	Hard to manage as levels dwindle
No need for an expensive network of pipes and canals to transport long distances	Visual inspection is difficult

Some communities use both surface water and groundwater as a supply. In years of heavy snowfall and deep snowpack, there may be abundant surface water available. In this case, surface water would be used for water supply while groundwater supplies could be allowed to replenish naturally through the infiltration of rainfall. In addition, surface water could be stored in groundwater basins to aid in replenishment. In the reverse situation, in years of light rainfall and little snowpack, groundwater would be relied on as a primary source because surface water was not a sufficient supply. The practice of alternating water supplies to meet the needs in a community is called conjunctive use.

Both surface water and groundwater can provide adequate yearly sources of water, but it is best to have water stored for use in dry years or for emergencies. Water can be stored above ground in reservoirs and below ground in banks. Storing water in reservoirs makes it readily accessible in times of drought or emergency, such as fires or if part of a distribution system goes out of service. Storing water in the ground can be done in water banks, such as the banks in Kern County.

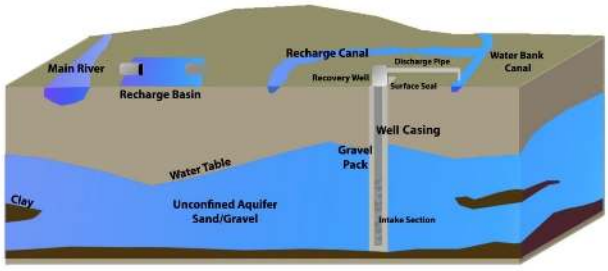


Figure ***Page*2.1.2.5**: Water Bank Diagram by Natalie Miller is licensed under CC BY 4.0

In these banks, water is injected or infiltrates directly into an aquifer. It can be retrieved later for a fee during times when groundwater and surface water are not sufficient. Many water districts find that storing water in various water banks can diversify their water supply portfolio, giving them more flexibility in providing water in dry years.

How can you make your water supply more reliable? Think of the last drought. You probably noticed lower levels in surface water at lakes and reservoirs and even in streams. In the photo comparison, you can see the difference in just over a month's time in 2014 in the visible shoreline. In this example, more water has been taken from the reservoir to treatment facilities during the late spring in 2014 with a very visible effect on the appearance of the lake!



Figure *Page*2.1.2.6: Images of Castaic Lake (Photo used with permission of Castaic Lake Water Agency)

In California, typically, it is only through a combination of water supplies that you can have a reliable water supply. The best scenario is that you have a water supply that consists of multiple sources of groundwater and surface water. That way, when one source is dry or less reliable due to a drought or unusable due to a water quality issue, you have a backup. The ultimate scenario for water supply reliability also includes a supply of water in storage.

In Santa Clarita, there are multiple sources of water supply for the water retail companies. Sources of supply include relatively shallow groundwater wells into the alluvium, clay, silt, and gravel, as well as deeper groundwater wells into the Saugus formation. While the shallower alluvial wells provide a source of relatively inexpensive supply, they also tend to be more sensitive to droughts. Imported water from the State Water Project makes up roughly 50% of the water supply in a normal year though the amount in this supply relies entirely on the snowpack in the Sierra Nevada Mountains.

During the last drought in Santa Clarita when water deliveries from the State Water Project were at a minimum, groundwater pumping was increased above normal year levels. When deliveries from the State Water Project returned to pre-drought levels in 2017, groundwater wells were pumped less in order to let the well levels recover. This is a classic example of conjunctive use that brings together what you've learned about groundwater and surface water because of the alternation of supplies in order to achieve greater reliability.

Now that you understand the concepts used to manage groundwater and surface water, let's take a look at water rights in California.

Try It!

1. Identify at least three potential sources of water that you could use during the zombie apocalypse.
2. Describe the drawbacks of surface water and groundwater.
3. Many communities in California rely on groundwater and surface water. Explain how conjunctive use might apply.

Key Terms

Alluvium—Clay, silt, or gravel left from old rivers

Aquifers—Areas underground of soil or rock that can hold and transmit water

Conjunctive use—Use of alternating water supplies to meet the water demands

Permeability—The ability to transmit water

Potable—Drinkable water

Reservoir—A lake that is manmade by making a dam across a river

Surface water—Flowing water, such as a creek, stream, or river; also still river stored in a lake or reservoir

Water table—The line at which soil becomes saturated with water

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Page 2.1.3: Water Rights

In order to understand the types of water rights that you'll find in California, you'll have to take a bit of a trip back in time, not just in California history, but in British history as well. You will be able to apply what you have learned about surface and groundwater.

Learning Objectives

After reading this section, you should be able to:

- Distinguish between surface water and groundwater rights
- Describe types of water rights found in California
- Analyze a situation involving water rights to determine which rights should prevail

You probably recall that California was not always a state within the United States. For many years, it was a settlement of the Spanish government, and later, the Mexican government. Settlements of the Spanish and Mexican governments have pueblo rights to both the surface and groundwater within the settlement limits. These rights are considered to have the highest priority compared to all other right types and cannot be lost.

The City of Los Angeles has exercised pueblo rights several times in its history, illustrating interesting features of pueblo rights:

1. A pueblo water right can increase in quantity as the population increases. As the population of Los Angeles has increased, the pueblo water right to flows of the Los Angeles River as well as to groundwater have increased in terms of quantity;
2. A pueblo water right can be extended to newly annexed areas of the original pueblo, such as when the City of Los Angeles annexed the San Fernando Valley

You can see how pueblo water rights are extremely encompassing and useful.

Pueblo Rights	Riparian Rights
Exist because of historical affiliation with Spain and Mexico	Exist because of streamside location
Can increase in quantity based on population or area annexed	Not quantified
	Only beneficial and reasonable use (not wasteful)

Shifting continents for a moment, we will explore the idea of riparian rights. In English common law, a riparian right (riparian means "streamside") is the right to use surface water because you own property that is adjacent to it. This means that if you bought a home that was adjacent to a stream, you would have the right to use the water from it. You could only use the water that was naturally flowing from the stream, not water from upstream or downstream that you channeled into your land. If you lived one street further away and didn't own any property adjacent to the stream, you would have no riparian rights. Riparian rights are not quantified, so if you owned that house on the stream, you may only use as much water to make reasonable and beneficial use of it.

Now taking what you've learned about pueblo water rights and riparian rights, let's shift back to California to the mid-1800s when gold mining was thriving. An appropriative right stems from mining practices in which miners worked on public land using the water to dislodge soil to expose gold. Often, water had to be channeled a distance from its origin to where it was used. This was considered an appropriation of water. Miners literally posted a notice about their diversion of water to stake a claim to that water. Whereas riparian rights are not quantitative, an appropriative right is a specific amount of water for a specific purpose in a specific place. If there is not enough water for all appropriators, the ones with the older appropriations get their water first.



Figure *Page*2.1.3.1: Hydraulic Gold Mining by Carlton Wakins is in the public domain - *Hydraulic mining in the 1880s in Nevada City, California*

The most famous legal case involving surface water rights is Lux v. Haggin (1886), which established the existence of both riparian rights and appropriative rights and the relationship between the types of rights. In this case, Haggin owned the upstream Kern Valley Land and Water Company, which diverted water for irrigation. Because Haggin did not own land that was adjacent to the water, he was exercising appropriative rights and not riparian rights. Miller-Lux owned downstream land that was adjacent to the Kern River and exercised riparian rights. During a drought, Haggin continued to use upstream water and cattle owned by Miller-Lux died due to lack of available water. Miller-Lux sued Haggin. The primary question, in this case, was whether an upstream appropriator could divert water in a way that hurt a downstream holder of riparian rights. In a surprising outcome, the California Supreme Court ruled that appropriators (Haggin) could have senior rights if the rights were established prior to downstream riparian use.

In Herminghaus v. Southern California Edison (1926), riparian and appropriative rights faced off again. Herminghaus was using riparian rights to irrigate by letting water from the San Joaquin River flood his crops. Southern California Edison wanted to build an upstream power plant using appropriative rights. The California Supreme Court ruled that downstream riparian use had the right to the entire flow of the San Joaquin River for flood irrigation. In other words, the California Supreme Court ruled that the downstream riparian right trumped the appropriative right, which meant Southern California Edison received no water rights.

Currently, appropriative rights are governed by a “first in time, first in right” philosophy and regulated by the State Water Resources Control Board. A “first in time, first in right” philosophy means that if you are using the water first, you have seniority in terms of water use. In times of water shortage, you will get your water first. Much like you saw in the previous court cases, you do not need to own the land in order to have an appropriative right to water. However, you do need to use the water in a reasonable and beneficial way with an appropriative right.

While surface water rights have hundreds of years of history, groundwater rights are relatively recent and currently changing in California. Currently, in California, the Sustainable Groundwater Management Act is driving the management of groundwater in a much more deliberate fashion. Basins in California have been ranked according to their priority for the development of a groundwater management plan into high, medium, and low priority. Basins with high ranking are currently developing plans for agency formation.

Groundwater rights can be overlying or appropriative. Remember your streamside house? It had riparian rights to use water from the stream. You would also own overlying rights and the rights to drill a well and pump water to use water on your own land. If your neighbor behind you wanted to pump water to take the water off of the land, he would be using appropriative rights. Appropriative rights in groundwater are similar to rights in surface water. “First in time, first in right” means that groundwater appropriators are evaluated in terms of when they started using the water.

Although groundwater and surface water rights have some of the same names, it is important to note that they are managed as if they are not related. For surface water rights, you can have pueblo water rights if the land was originally a Spanish or a Mexican settlement, riparian rights if you are using the water streamside and appropriative rights if you are using the water away from the source. For groundwater rights, you can have overlying rights or appropriative rights. From studying the water cycle, you already understand that surface water and groundwater are related. It would make sense if their rights were connected rather than treated as separate entities.

Try It!

1. You own a home and would like to dig a well in the backyard. What type of water rights would be involved?
2. You would like to run a pipe from your neighbor's creek to your home to engage in flood irrigation. What types of rights are involved? What issues might come up?
3. When might you have a surge in water rights disputes?

Key Terms

Appropriative right—Right to move water from its source; quantities for a specific purpose in a specific location; often called "first in time, first in right" rights

Overlying rights—Groundwater rights for water underneath the land

Pueblo rights—Rights that pueblos and settlements of the Spanish and Mexican government have for surface and groundwater rights; pueblo water rights can increase in quantity as population increases and can be extended to newly annexed areas

Riparian right—Streamside right to surface water

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Page 2.1.4: Stakeholder Concepts

Who are stakeholders in your water supply?

While you might immediately think of your water utility, city or county agencies, you are also a stakeholder in the water supply. You are a resident and you use the water in some fashion (e.g., drinking, cooking, cleaning yourself and clothes, irrigating, and swimming).

How much interest do you have in the water supply? And how much power do you wield in critical discussions about water?

Learning Objectives

After reading this section, you should be able to:

- Identify and classify stakeholders
- Differentiate among stakeholders according to the level of interest and the level of power

Stakeholders are people with a “stake” in an idea or project. These could be people who are financially related to the idea or project, interested in the environmental impacts, or just plain curious. In many nationwide issues, like the presidential election, health insurance, or gasoline prices, all residents of the United States have a “stake.” Some issues are much more regional, such as water supply issues or air pollution issues, in which residents in a smaller geographic area have a stake while some issues, such as health care, are nationwide issues

Stakeholders are typically classified as internal or external. An internal stakeholder is a person within an organization, such as a staff person or board member, while an external stakeholder is outside an organization. For example, suppose that staff at a water agency was considering changing the rules for a turf grass removal program, commonly called "Cash for Grass," in order to stop rebating artificial turf. Here is a table of the internal and external stakeholders who have a “stake” in this proposal to remove artificial turf from the Cash for Grass program:

Internal Stakeholders	External Stakeholders
Staff at the water agency	Residents in the area
Management at the water agency	Landscapers (who install plant material)
Board members at the water agency	Contractors (who install artificial turf)

Why is it important to identify stakeholders and categorize them? As you work in the water industry, you will find that reaching out, listening to, and working with stakeholder groups is critical to your success. In the example above, what would happen if staff didn't reach out to contractors who install artificial turf? It's possible that they would become very angry because a potential source of income (installation of artificial turf for rebates) has been taken away from them. They might make phone calls to managers and board members. They might attend board meetings to speak and protest during public comment. Their anger might have been moderated if staff had reached out ahead of time to explain the reason for the rule change and offer some alternative strategies to move ahead.

Let's take another example from the water industry. Let's say the customer service manager decided to implement a new software program that sent work orders to field representatives. The customer service manager bought the software with her own manager's approval, but chose not to introduce customer service and field staff to the new product. Instead, the customer service manager rolled out the product at a meeting after the software was purchased. How do you think the staff felt? They may have had valid concerns about the software, but the entire purchase was presented to them like a done deal. The customer service manager should have identified her stakeholders, including internal stakeholders like customer service and field staff, ahead of time.

Stakeholders are people very specifically interested in an idea or concept whether it's artificial turf or work order software. Stakeholders are specific to the locale as well as the concept. For example, the City of Beverly Hills developed a cultural plan, which included an extensive list of stakeholder groups: residents, businesses, chamber of commerce, entertainment industry, faith-based communities, fashion community, financial sector, gay community, homeowners associations, Iranian community, lawyers

associations, media, private galleries, restaurants, senior community, service clubs, and the tourist industry, including hotels and visitors.

A cultural plan for a different city would have different stakeholder groups and, a stakeholder list for a different issue in the same city would have different stakeholders. Let's look at what would happen if we looked at a different issue, like water supply reliability, and identify internal and external stakeholders in Beverly Hills. Stakeholders who were added to the list are in blue text. Many of the stakeholder groups that were interested in a cultural plan do not appear below because they may not be interested in water supply reliability.

Internal Stakeholders for Water Supply Plan	External Stakeholders for Water Supply Plan
City of Beverly Hills staff	Residents
City of Beverly Hills management	Businesses
Beverly Hills City Manager	Chamber of Commerce
Beverly Hills City Council	Environmental Groups
Metropolitan Water District (wholesale supplier of water)	Homeowners' Associations (HOAs)
	Large Residential Users (A Top 100 List)
	Media
	Restaurants
	Tourism & Hotel Industry
	Visitors

The list is by no means all-inclusive, but shows that there are some groups that will be constant in an area because they are powerful (HOAs, tourism & hotel industry, and restaurants) and some groups that are specific to an issue (e.g., Environmental Groups and Top 100 water users). This list is shorter and more focused on where the water is used.

Once you have identified your stakeholders, you can arrange them according to their level of interest and power.

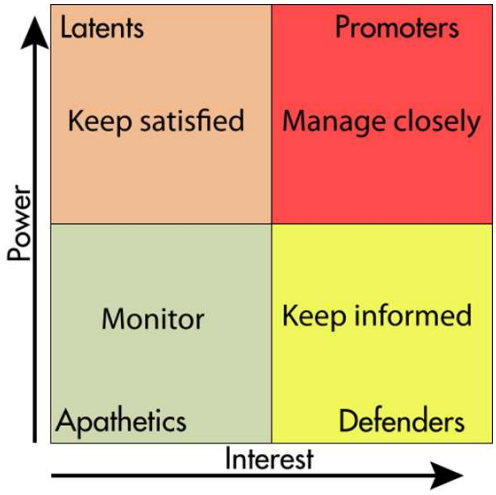


Figure ***Page*2.1.4.1**: Stakeholders Matrix by Zirguezi is licensed under CC0 1.0 - *Power vs. Interest Chart*

In terms of water issues, most of the public, most of the time, unfortunately, has a relatively low level of interest and low level of power, which would classify them as Apathetics. But come drought time? You will have a much higher level of interest for most people and they will shift from the Apathetics to the Defenders. They may not have a high level of power, but their interest in water supply reliability is much higher.

Not everyone who is powerful is interested in all issues. For water supply, there are frequently groups that simply do not perceive water supply to be an issue, and choose to focus their energy elsewhere. They would be considered Latents (“latent” means that the interest is lying dormant, but could be expressed with the right circumstances). A Latent stakeholder might become more interested in water supply reliability if he/she were involved in a development that needed water, if there was a drought, or if there were mandatory watering schedules or penalties that affected his/her interests.

One of the most important issues in water supply management in the state of California is the challenge of the Sacramento-San Joaquin Bay Delta. Formed by the confluence of the Sacramento and the San Joaquin Rivers, the Bay Delta, south of Sacramento is the source of continual stakeholder challenges. Who are the stakeholders in the Bay Delta? At first, it seems obvious: there are residents and farmers who live and work in the Delta. While they are the most visible stakeholders, the water supply for much of Southern California flows through the Delta so Central Valley farmers and Southern Californians are also stakeholders (most Southern Californians would be Latents though until a crisis arises). Likewise, Northern Californians are stakeholders, because this is water that is leaving their area. Frequently discussions about the Bay Delta are framed around the strong interest and immense amounts of power that Southern California wields and the high interest, but low amounts of power that the farmers in the Bay Delta hold. We will discuss more about the Bay Delta in the section on the State Water Project.

You've learned about the importance of involving stakeholders and that stakeholders can be classified as internal or external and in terms of power and influence as well as interest. In Part Two of this text, you'll look at four major surface water development projects in terms of stakeholders.

Try It!

1. Identify a water-related issue in your area. Try typing into Google "water issues" and the name of the community. Who are the stakeholders? Classify them as internal or external. Classify each stakeholder on a grid in terms of their interest and power.
2. In the water-related issue you chose above, what are ways (other than the drought) to increase the level of interest of stakeholders in the issue?
3. Add the stakeholders in the conservation program rule change scenario to a chart in terms of interest and power. Who has both a lot of interest and a lot of power? Who has neither interest nor power?

Key Terms

Stakeholders—People or organizations with a “stake” in an idea or concept

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SECTION OVERVIEW

Page 2.2: Supply-Side Management

In Part Two of this text, we'll explore supply-side management. A supply-side management approach to water concentrates on securing more water supplies through engineering feats. Supply-side management was frequently done by building massive engineering projects to move water hundreds of miles. While they were impressive projects at the time, today, there are more significant regulatory hurdles to building supply-side projects, including environmental regulations. The difficulty of building major infrastructure projects has led to more work being done with exploring alternative supplies and reducing demand.

For a long time, human beings have related to nature as if nature was something to be conquered. In the United States, until the 1960s, the natural environment was viewed as mostly inconsequential to expansion and development. The environmental movement, beginning with the publication of Rachel Carson's *Silent Spring* in 1962 and continuing with the Cuyahoga River catching on fire due to pollution in 1969, began to change the way we related to nature. Perhaps nature wasn't something to be vanquished as an enemy. Perhaps nature isn't limitless. As you examine four large public works projects in California, it is important to keep the shifting mentality of these times in mind. Each project was a feat to build at the time, and in some cases seen as a battle of man against nature. With current regulatory requirements, these projects would be just about impossible to build today.

In Part Two, we will cover these topics:

- Water Development Projects
  - Los Angeles Aqueduct
  - Colorado Aqueduct
  - Central Valley Project
  - State Water Project
- Alternative Water Sources
  - Recycled water
  - Gray water
  - Stormwater
  - Desalination

Water Development Projects

The primary challenge in water supply planning in California is usually framed as spatial. Most of the water is in the northern part of the state and most of the people live in the southern part of the state. In other words, the supply does not exist where the demand is. However, there is an additional challenge as well. Much of California receives water during the winter and early spring when the demands are the least, and not during the summer and fall when the demands are the greatest. This creates a temporal (time) challenge because the supply has to be stored until it is needed.

The map below shows the population centers in the Bay Area and Los Angeles Area as well as the volume of storage at various reservoirs throughout California. Notice how storage is concentrated in central and Northern California away from Southern California. This frames many of the water development projects.

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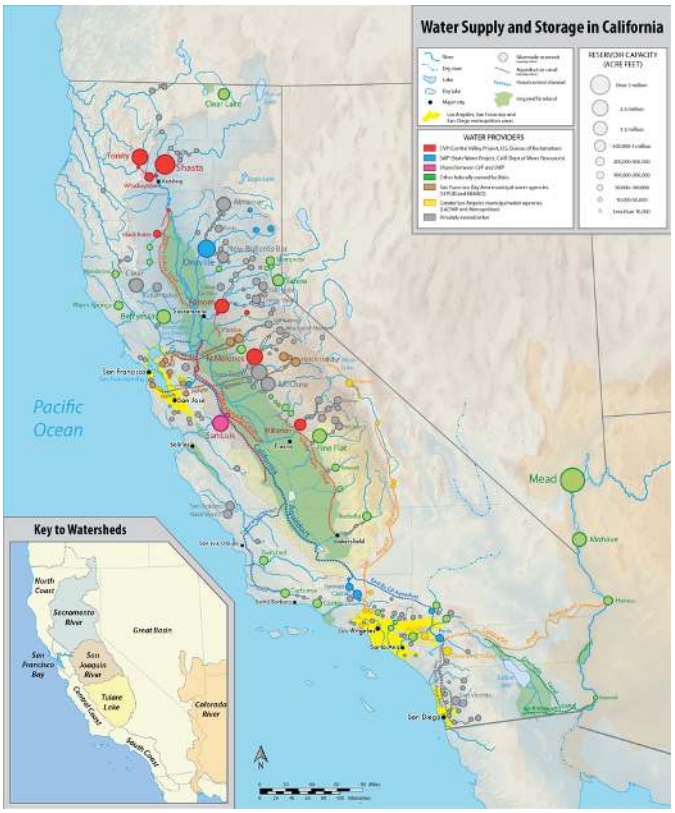


Figure ***Page*2.2.1**

Page 2.2.1: Los Angeles Aqueduct

Page 2.2.2: Central Valley Project

Page 2.2.3: Colorado River Aqueduct

Page 2.2.4: State Water Project

Page 2.2.5: Alternative Water Supplies

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Page 2.2.1: Los Angeles Aqueduct

Learning Objectives

After reading this section, you should be able to:

- Identify driving factors in the construction of the Los Angeles Aqueduct
- Classify stakeholders in the construction of the Los Angeles Aqueduct
- Evaluate the impacts of Decision 1631

Year	Population
1850	1,610
1860	4,385
1870	5,728
1880	11,183
1890	50,395
1900	102,479

To understand current day Los Angeles, you need to understand the population explosion in the last two hundred years in the Los Angeles basin. Los Angeles was initially a Spanish pueblo when founded in 1781 and it had a small population. A combination of surface water from the Los Angeles River and groundwater from artesian springs remained sufficient supply for a long time. As you know, Los Angeles was entitled to these supplies of surface water and groundwater because of pueblo water rights. While the supplies were sufficient for the existing population, the introduction of cattle ranching and citrus cultivation in the 1880s coupled with a drought resulted in strained water supplies.

Now, imagine you are the superintendent of this water system within California, which has been reliable under current conditions, but is strained by more and more people.

Ack! Look at those numbers! You're going to run out of water!

In 50 years, the population increased from just over fifteen hundred to over one hundred thousand people. This is the fix William Mulholland found himself in as superintendent of the water system: a burgeoning population and a dwindling water supply. His friend and colleague, former mayor of Los Angeles, Fred Eaton, suggested the Owens River as a potential supply. The Owens River relied on snowmelt from the Sierras. In order to obtain the rights for the water, the land surrounding the river was purchased to obtain water rights.



Figure ***Page*2.2.1.1**: Photographic portrait of William Mulholland with a surveyor's scope on a tripod by University of Southern California Libraries and California Historical Society is licensed under CC BY 3.0

Both Eaton and Mulholland were engineers. They were intrigued by the idea that the water could be conveyed entirely by gravity with a slight slope in the aqueduct from more than 3800 feet above sea level to 1400 feet above sea level. The energy from the water was even enough to generate electricity at a number of power plants that were built along the way. In many ways, their

fascination with the engineering aspects of the project may have kept them from fully considering other ethical concerns as they orchestrated purchases of land in the Owens Valley.

Year	Population
1910	319,198
1920	576,673
1930	1,238,048
1940	1,504,277
1950	1,970,358
1960	2,479,015
1970	2,811,801
1980	2,968,579
1990	3,485,398
2000	3,694,742
2010	3,792,621

Eaton and Mulholland certainly seemed to disregard stakeholders in this potential project. For example, the residents of the Owens Valley, including farmers, ranchers and the indigenous Paiute people, were certainly going to be impacted by directing the water to Southern California. These stakeholders, whose lives were dependent on the water, had very little power to mount a protest at the time. And, in fact, they generally were not asked for permission. The purchases of land in the Owens Valley were conducted in ways that seemed underhanded and non-transparent, including agents for the City of Los Angeles representing themselves as from the Bureau of Reclamation. At the point when actual stakeholders in Southern California were brought in to fund and approve the project, the land was already purchased. This is a classic example of stakeholders not being consulted until the project is almost a *fait accompli*.

Even though Mulholland had found enough water for the existing population in Los Angeles, the population continued to grow. By 1923, Mulholland had explored the possibility of bringing water from the Colorado River as well as the second portion of the Los Angeles Aqueduct to Mono Lake. Both projects moved ahead because it was clear that the original Los Angeles Aqueduct was not enough.

And, in the end, even the second addition to the Los Angeles Aqueduct was not enough. The Los Angeles Aqueduct was completed in three parts:

- Part One: 1913 - Los Angeles voted 10 to 1 to authorize $23 million for the first Los Angeles Aqueduct and it is subsequently built.
- Part Two: 1940 - Los Angeles votes to extend the Los Angeles Aqueduct to the Mono Lake watershed for $40 million and the extension is built.
- Part Three: 1963 - Los Angeles begins the construction of the second Los Angeles Aqueduct project



Figure ***Page*2.2.1.2**: Los Angeles Aqueduct used with permission of Los Angeles Department of Water and Power

In sum, using only gravity, the Los Angeles Aqueduct encompasses canals from the Mono Lake watershed to Los Angeles stretching over 340 miles in three separate projects.

While the Los Angeles Aqueduct provided a great benefit to the residents in Southern California, it left the Owens Valley a dust bowl, including carcinogenic dust containing cadmium and nickel. After numerous years of protest and litigation, the State Water Resources Control Board in Decision 1631 drastically reduced the amount of water that could be removed from the Owens Valley from 90,000 acre-feet per year (AFY) to 16,000 AFY. How did this happen? This decision applied the public trust doctrine in a new way. The public trust doctrine addresses rights to things that are owned collectively for public use by the government, such as water and air. This interpretation allowed the water in the Owens Valley to be seen as a public resource and not something that could solely benefit Los Angeles.

As a water supply, the Los Angeles Aqueduct provides water that is dependent on local hydrology within Owens Valley. Because of the variability and Decision 1631, Los Angeles has been forced to focus on demand reduction, rely more on alternate sources of water, such as those from Metropolitan Water District of Southern California, and remediation of existing groundwater supplies in the San Fernando Groundwater Basin.

> *Misconception Alert!*
> *Many people think that all of the water supply in Los Angeles comes from the Owens Valley. As you saw in this section, only 16,000 AFY currently come through the Los Angeles Aqueduct. The rest of the supply is a matter of other imported water, including the Colorado River, as well as groundwater in the San Fernando Groundwater Basin.*

Try It!

1. What were some of the drawbacks of removing water from the Owens Valley?
2. What were the effects of Decision 1631?

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3. What stakeholders were not consulted in the development of the Los Angeles Aqueduct?

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Page 2.2.2: Central Valley Project



Figure *Page*2.2.2.1: Central Valley Project by Shannon1 is licensed under CC BY-SA 4.0

California's Central Valley is known as one of the most productive agricultural regions on earth, but it was not always this way. For a long time, the Central Valley was ranching country. And then it was farming country, but was farmed "dry," meaning without supplemental irrigation. It wasn't until the population influx in the 1850s with the gold miners and the development of a pump that there was a drive to make the Central Valley intensively agricultural.

After decades of pumping water for irrigation in the Central Valley and a drought from 1928-1934, the Central Valley Project was conceived as a plan to ensure water supply reliability and protect it from floods.

Learning Objectives

After reading this section, you should be able to:

- Identify and critique the purposes of the Central Valley Project
- Anticipate the future crises for the Central Valley Project

The Central Valley typifies the challenge of California's water supply. Most of the rainfall occurs in five months, from December to April. There is enough rain to regularly produce flooding in these months. But when the needs of the plants are the greatest for food production (spring and summer), there is little natural rainfall. Pumping supplemental water made the groundwater levels drop significantly in the Central Valley causing subsidence. Diverting river flows for irrigation brought in the salt waters to the Sacramento-San Joaquin Bay Delta, which meant saltier water, sometimes unfit for irrigation, came inland.

The state of California authorized the California Central Valley Project Act of 1933 to sell bonds to fund the project. However, due to the Great Depression, the bonds didn't sell. The federal government took control of the project with the Rivers and Harbors Act of 1935 and the project was finally approved in 1935 for construction by the federal Bureau of Reclamation, which eventually took over operation.

The Central Valley Project was authorized with three key elements in its mission: flood control, water for irrigation and power generation. Water quality was added later to the mission as well as recreation and fish and wildlife enhancement.

Although the Central Valley Project is the largest of the federal water reclamation projects and includes reservoirs capable of storing 11 million acre-feet of water, it has a fairly simple structure. Water is stored in Shasta Reservoir and Shasta Dam acts as flood control for the Sacramento River. The Trinity River supplements the Sacramento River. The San Joaquin River supplies areas south of the Delta.

The Central Valley Project shares some facilities including San Luis Reservoir with the State Water Project. The photo below shows Shasta Dam, which is exclusively used by the Central Valley Project.



Figure ***Page*2.2.2.2**

> *Misconception Alert!*
>
> *Many people believe that Shasta Lake is part of the State Water Project. As you learned in this section, this is part of the Central Valley Project. The State Water Project has another larger reservoir that stores water in Northern California, Lake Oroville. These reservoirs are typically confused by many people.*

The Central Valley Project Improvement Act in 1992 allocated water for fishery restoration. This is similar to Decision 1631 in that a water development project was re-evaluated with current environmental norms. The allocation for fishery restoration is 800,00 AFY, which is perceived as enormous by some. This was a considerable change in the mission of the Central Valley Project from water supply reliability, irrigation, and power generation to fish and wildlife enhancement.

Try It!

1. Compare and contrast the Los Angeles Aqueduct and Central Valley Project.
2. Investigate potential challenges to the Central Valley Project in the future.

Key Terms

California Central Valley Project Act of 1933—Authorized by the state of California to sell bonds to fund the Central Valley Project. However, due to the Great Depression, the bonds didn't sell.

Central Valley Project Improvement Act in 1992—Allocated water for fishery restoration in the Central Valley Project

Rivers and Harbors Act of 1935—Authorized by the federal government to fund the Central Valley Project in 1935 for construction by the federal Bureau of Reclamation

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Page 2.2.3: Colorado River Aqueduct

Metropolitan Water District was formed in 1928 with the explicit purpose of picking up on where the City of Los Angeles left off with the planning for the use of the Colorado River. The Colorado River Aqueduct was funded by voters three years later in 1931, begun in 1933 and completed in 1935. Water first began to flow in 1939. Even though this time frame is relatively short, the Colorado River Aqueduct was the result of a series of lengthy and heated negotiations, which we will now explore. Collectively the agreements that govern the Colorado River are known as The Law of the River.

Learning Objectives

After reading this section, you should be able to:

- Differentiate among key agreements that are part of The Law of the River
- Conjecture as to possible sources of future disagreement



Figure ***Page*2.2.3.1**

The primary tension with all Law of the River negotiations is similar to the tension in California: spatial. The water doesn't exist where the population centers are. But the geography of the Western United States is much more vast than just California. There are seven states considered to be within the Colorado River Basin: Wyoming, Colorado, Utah, New Mexico, Arizona, Nevada, and California. These are all primary stakeholders in the use of the Colorado River. The upper basin states include Wyoming, Colorado, Utah, and New Mexico. Upper basin states were especially sparse in population and anticipated that they might need the Colorado River water at some point as their populations increased or industries like natural gas extraction grew, but they didn't have an immediate need for the water. The lower basin states included California, Arizona, and Nevada, most of whom had burgeoning populations. The upper basin states were originally concerned that if the lower basin states constructed dams, including Hoover Dam, and began to use the Colorado River that under the doctrine of prior appropriation, the upper basin states would not be able to use the Colorado River's water again.

The first important agreement in The Law of the River is the Colorado River Compact of 1922, which divided the basin in half. Each basin had the right to use 7.5 MAF of water based on an average flow of the Colorado River of 18 million acre-feet per year, plus a small allocation to Mexico. While most states ratified this agreement, it took Arizona 22 years to ratify it, which is a window into the contentiousness. Arizona was greatly concerned about not receiving enough water eventually and of California taking water that Arizona was entitled to.

The second important agreement in The Law of the River was the Boulder Canyon Project Act of 1928. Negotiations for this agreement lasted seven years, and including four bills being introduced and a filibuster. In this agreement, the lower basin was apportioned among the states:

- Arizona - 2.8 MAF
- California - 4.4 MAF
- Nevada - 0.3 MAF

The Secretary of the Interior was directed to function as the authority for water use in the lower basin, including the ability to commission studies on feasibility for dams and storage. It is interesting to note how small the apportionment for Nevada is.

As a slightly less important agreement in the Law of the River, the California Seven Party Agreement of 1931 is an agreement for division of water among seven entities. The parties included Palo Verde Irrigation District, Yuma Project, Imperial Irrigation District, Coachella Valley Irrigation District, Metropolitan Water District, and the City and County of San Diego. This agreement temporarily settled longstanding disagreements between agricultural and urban users.

The third important act in The Law of The River is an international treaty. In the Mexican Water Treaty of 1944, 1.5 MAF of the Colorado River flow were committed to be received in Mexico. While the amount was agreed upon, the quality of the water remained undetermined. Due to agricultural and urban use, the quality of the Colorado River becomes worse the further south the river flows. A desalting plant for removing salt was eventually built in Yuma, Arizona to increase the quality of the water released to Mexico.

In the fourth important agreement in The Law of the River, the Upper Colorado River Basin Act of 1948, the upper Colorado River Commission was created and the Upper Basin was apportioned:

- Colorado - 51.75%
- New Mexico - 11.25%
- Utah - 23%
- Wyoming - 14%

During the negotiations, it was noted that the originally agreed upon amount of 18 million acre-feet of normal flow for the Colorado River might be an overestimation and that agreements would be better done by percent rather than flat allocations of water.

The Law of the River is a complicated set of agreements, and the previous pages only covered the major agreements. It should be clear that there will be issues of allocations, water rights, and urban v. agricultural differences for many years to come. Several recent modifications to the Law of the River were made because of droughts. In 2007, interim guidelines for allocating the Colorado River during water shortages through 2026 were signed by the Secretary of the Interior. Water shortages were determined based on the surface elevation of Lake Mead. In 2012, the United States and Mexico signed Minute 319 that addressed how Mexico's allocation of 1.5 MAF would change in drought conditions also based on the surface elevation of Lake Mead.

Try It!

1. What is the difference between the Upper Colorado Basin Act and the Boulder Canyon Project Act?
2. What is a likely source of disagreement in the future?

Key Terms

Boulder Canyon Project Act of 1928—Apportioned the lower Colorado River basin among three states:

- Arizona - 2.8 MAF
- California - 4.4 MAF
- Nevada - 0.3 MAF

Colorado River Compact of 1922—Which divided the basin in half; each basin had the right to use 7.5 MAF of water based on an average flow of the Colorado River of 18 million acre-feet per year, plus a small allocation to Mexico

The Law of the River—Collectively the laws and regulations that govern the Colorado River

Mexican Water Treaty of 1944—Committed 1.5 MAF of the Colorado River flow to Mexico; did not describe the quality of water, just quantity

Minute 319—An international agreement between the United States and Mexico regarding the Colorado River that addressed how Mexico's allocation of 1.5 MAF would change in drought conditions also based on the surface elevation of Lake Mead

Upper Colorado River Basin Act of 1948—Apportioned the Upper Colorado River Basin by percent:

- Colorado - 51.75%
- New Mexico - 11.25%
- Utah - 23%

- Wyoming - 14%

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Page 2.2.4: State Water Project

The last major water infrastructure project undertaken for water supply in California was the State Water Project (SWP) and it still isn't quite finished! The SWP major features were outlined in 1957 in the California Water Plan and it was funded by the Burns-Porter Act in 1960 in $1.75 Billion in general obligation bonds.

Learning Objectives

After reading this section, you should be able to:

- Identify the major stakeholder groups and their needs
- Analyze major threats to the Sacramento-San Joaquin Delta in terms of water supply
- Project future impacts to the State Water Project

The State Water Project is a massive infrastructure project that involves several major stakeholder groups throughout the state of California, all of which have been stakeholders in other water development projects that you've learned about:

- Northern California communities that wanted flood control protection (as a result of devastating floods on the Feather River in 1955)
- San Joaquin-Sacramento River Delta communities that wanted flood protection, but also access to high-quality water for farming
- San Joaquin farmers who wanted access to water for expansion of agriculture, but also because of groundwater overdraft issues
- Southern California residents who wanted water for future growth and for water supply reliability

The State Water Project brought together these stakeholder groups with a combined mission of providing water supply to the San Joaquin Valley farmers as well as Southern California.

The State Water Contract was among 32 public water agencies all over the state, including some agencies that formed specifically to contract for SWP water supplies. The terms of the contract were 75 years minimum or until the bonds were repaid. The State of California was obligated to make reasonable efforts to complete the project. The Contractors were obligated to pay even if the water supplies were reduced or the project was not complete. As you might guess, these aren't great contract terms (paying for a project that is incomplete or reduced in some way).

The State Water Project had several purposes: flood control (specifically at Lake Oroville), recreation (e.g., Pyramid Lake, Castaic Lake) and water supply (including primary reservoirs at Oroville and San Luis and terminal reservoirs at Pyramid and Castaic Lake, Lake Perris and Lake De Val). Facilities to convey water through the Delta and for additional storage were not completed.

The Delta

The Sacramento-San Joaquin Delta (sometimes referred to only as "the Bay-Delta" or "the Delta") is one of the most interesting places in California to study in terms of stakeholders, science, and water supply.

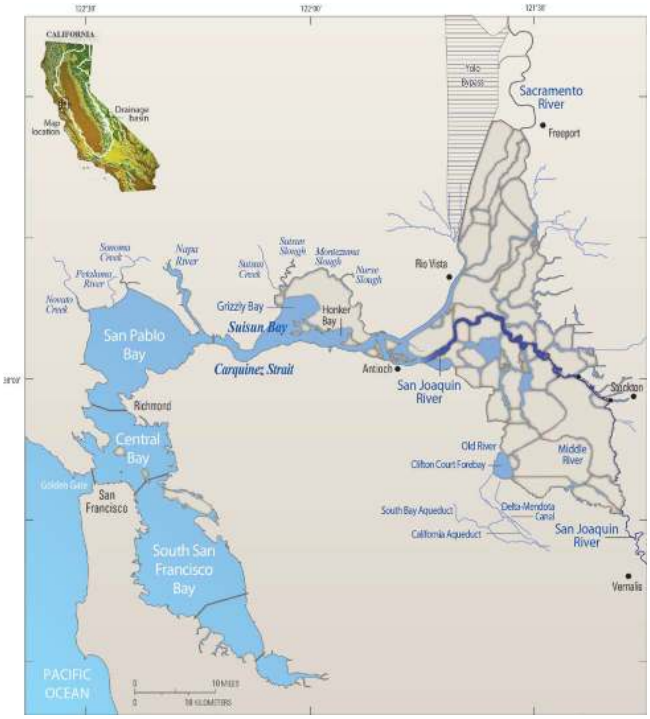


Figure ***Page*2.2.4.1**: Image of the Sacramento-San Joaquin Bay-Delta by the U.S. Geological Survey is in the public domain

In terms of stakeholders, the Delta is home to historic towns and family farms. Many farms are under sea level with manmade levees their only protection. The Delta is also fully used for recreation—boating, fishing, sightseeing, bird watching (and duck hunting). There are also millions of stakeholders south of the Delta that rely on the water supply that passes through the Delta. So combine various stakeholders with a location that is literally described as the "heart" of the water supply and you can see how there might be inherent conflicts.

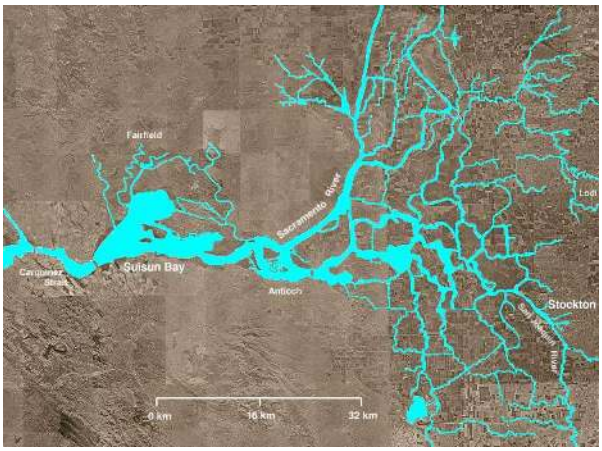


Figure ***Page*2.2.4.2**: Sacramento Delta by Matthew Trump is licensed under CC BY-SA 3.0

The Delta has been altered by farmers over the past 150 years and it has also been altered by the operation of the State Water Project and Central Valley Project. It is currently threatened by three primary issues:

Seismic—A large earthquake could break down the manmade levee system, allowing seawater into the Delta, and essentially making the water supply undrinkable for anyone south of the Delta

Subsidence—Land within the Delta is made of peat soil, which is excellent for farming, but compacts and subsides over time, leading to levees sinking and needing to be repaired and strengthened

Sea Level Rise—Sea level rise also threatens the Delta as there is often only a few feet between the top of the water and the top of the levee

The most likely path forward is two twin tunnels under the Delta. This is known as the California Water Fix (formerly known as the Bay Delta Conservation Plan).

Try It!

1. Identify three purposes of the State Water Project.
2. Write a letter advocating a plan to fix the Delta.

Key Terms

Burns-Porter Act—Funded the State Water Project in 1.75 billion in general obligation bonds in 1960

This table summarizes the four major infrastructure projects covered.

	Los Angeles Aqueduct	Central Valley Project	Colorado River Aqueduct	State Water Project
Purpose	Water supply reliability	Flood control Water for irrigation Power	Water supply	Water supply Flood control Irrigation for farms
Stakeholders	Southern California residents Owens Valley ranchers, farmers, Paiute tribe	San Joaquin Valley farmers	Wyoming, Colorado, Utah, New Mexico, Nevada, Arizona, California	Southern California residents San Joaquin Valley farmers Northern California communities with flood protection needs
Legislation		California Central Valley Project Act of 1933 Rivers and Harbors Act of 1935 Central Valley Project Improvement Act in 1992	All under The Law of The River: Colorado River compact of 1922 Boulder Canyon Project Act of 1948 Mexican Water Treaty of 1944 Upper Colorado River Basin Act of 1948 Minute 319	California Water Plan Burns-Porter Act
Major Features	Owens Lake Mono Lake	Lake Shasta San Luis Reservoir	Lake Powell Lake Mead	Lake Oroville San Luis Reservoir

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Page 2.2.5: Alternative Water Supplies

Alternative Water Supplies are supplies other than groundwater and surface water. Frequently, they are “reused” supplies, meaning they were potable water supplies that were captured for use individually or system-wide after being used once.

Here are a few quick definitions to begin:

Recycled Water	Gray water	Storm water	Desalinated Water
Heavily treated wastewater that is used for irrigation, groundwater replenishment and as a subsurface barrier against seawater intrusion; typically in California, recycled water is used for irrigation	Household wastewater, including water from the washing machine, shower, bathroom sinks, that is captured and reused, but excluding blackwater, which is water from toilets and kitchen sinks; commonly referred to as "lightly used" water	Runoff from precipitation (rain or snowmelt) that flows overland; may mobilize pollutants and is better to capture on site to replenish groundwater	Ocean or brackish water that has had the salt removed to make it potable; two primary methods are used worldwide, but in the United States, reverse osmosis is most frequently used

Learning Objectives

After reading this section, you should be able to:

- Analyze the water supply portfolio for several geographic locales in terms of the likelihood of adding an alternative water supply
- Differentiate among types of alternative supplies and their appropriateness, given different situations

Recycled Water

You may hear “recycled water” used in a variety of ways in the United States and abroad. In California, specifically, there is some confusion in terminology. Changes to a variety of codes occurred in 1995 when “recycled water” became the term of choice rather than “reclaimed water.” These are essentially the same thing. Regulations for the level of treatment for various uses are in Title 22 of the California Code of Regulations.

What happens to wastewater when it leaves your house? It travels through a series of larger and larger pipes to a wastewater treatment facility. Alternatively, if you live rurally, your wastewater may be held and separated in a septic tank on your own property. Wastewater that has undergone primary treatment has had the solids removed. Wastewater that has undergone secondary treatment has had organic materials removed through biological processes. Secondary treated wastewater can be used for groundwater recharge and irrigation. Water that has undergone tertiary treatment has undergone sedimentation, chemical flocculation, and filtration. As you might imagine, water that has undergone tertiary treatment has a range of uses, even those involving body contact, such as recreational use in lakes, as well as irrigation.

Recycled water has only system-wide applications in that individual homes are not creating and using recycled water. You may be familiar with recycled water for irrigation of golf courses, medians, but it also can be used for groundwater recharge, including to act as a seawater intrusion barrier. Orange County Water District treats recycled water in a three-step process of microfiltration, reverse osmosis, and ultraviolet treatment. The treated water is then injected into the groundwater basin. The water serves as a barrier against the intrusion of ocean water into the aquifer.

Recycled water seems like an important source to add to a water supply portfolio. After all, what community in California wouldn't want a reliable source of water for irrigation of landscapes? And what coastal community wouldn't want water to inject into the ground as a barrier of seawater intrusion. Overall, recycled water can decrease the demand for potable water by providing an addition to a water supply portfolio. But recycled water is expensive. Next to desalination, it is one of the most expensive options out there (think of the treatment costs!). Like many aspects of infrastructure, recycled water is politically appealing to residents, but the added costs are not.

Gray water

Certainly, the water that you drink, wash your clothes in, and use to bathe needs to be potable. But what about the water that you flush your toilets with? What about the water that you irrigate with? The premise of gray water use is that not all water that we use on a daily basis needs to be potable. Keeping this in mind, you then have to consider what can be reused in your indoor water use.

Wastewater from toilets and wastewater from the kitchen sink both contain bacteria from feces or meats. But wastewater from a washing machine can be reused without many concerns, assuming diapers are not washed or clothes are not highly soiled, greasy or contaminated.

The easiest gray water system to construct is called “Laundry to Landscape.” Wastewater from the washing machine is directed to a drip irrigation system outside the house. Water isn’t stored in any fashion - when you run a load of clothes in the wash, you are irrigating with the wastewater directly afterwards. You can see that you would need to time your laundry - washing everything on Sunday would lead to too much water for irrigation. Doing a load of wash every other day might be enough water for irrigation in the summer.

What do you need in order to have a simple Laundry to Landscape system?

- Your washing machine should be located close to an exterior wall in order to run a pipe to the outside of the house
- Your house should be slightly above the area that you are irrigating so you can use gravity to direct the water to the drip system and the plants without a pump (though pumps that remove water from washing machines can be powerful and enough to move water some distance);
- You need to have plants that can be irrigated with drip irrigation (shrubs or trees); and
- You need to install a diverter valve at the washing machine that would allow especially dirty loads of laundry to drain toward the sewer or septic tank and not into your irrigation system.

There are more complicated gray water systems that involve storing gray water in tanks and using pumps and filters, but most gray water practitioners agree that simple is best.



Figure ***Page*2.2.5.1**

Here are some best practices in residential gray water systems:

- Don’t store gray water
- Minimize body contact with gray water
- Allow gray water to infiltrate the soil with drip irrigation, not pool on the surface
- Simple is better. Avoid pumps and filters.
- Install a diverter valve
- Match needs of plants

Please note that these are best practices, but not necessarily rules and regulations. Rules and regulations vary by city and county.

In a recent study of graywater systems in the Bay Area, it was noted that the most common problem in gray water systems was clogs, but this wasn't much of a surprise because most people reported performing no maintenance on the system. Plants were generally just as healthy as with a standard irrigation system and some were overwatered and some were under watered. Overall, people saw an average reduction in water use of 26%. There was at least one unintended consequence - with an abundance of water to irrigate, some people planted more plants and their irrigated area increased in size.

There are a number of institutional hurdles to expanding gray water use. The primary hurdle is one related to the construction of homes: homes are plumbed with intermingled graywater and blackwater. This means that the wastewater from the entire home is treated as blackwater and sent to the sewer or septic tank. Additionally, if you check the city, county and state code related to graywater, they are frequently contradictory. California code, Title 24, Part 6, Chapter 16 a, Part 1 establishes minimum requirements for gray water regulations. Additionally, AB 849 (Gatto) prohibits local jurisdictions from banning gray water. However, a city or county may impose additional regulations so that it becomes too complicated to establish gray water in the home. Furthermore, as you can imagine, setting up a gray water system relies on a knowledge base of basic plumbing and wastewater. It is probably not an overstatement to say that most customers try not to think about this.

> *Misconception Alert!*
>
> *Many people use "graywater" to refer to all sorts of alternative supplies, including recycled water and stormwater. This is simply incorrect, but a common misuse of language. Graywater must be water from indoor use that can be reused, typically for irrigation. It is not wastewater or stormwater.*

Stormwater

Picture the last rain storm that you remember in Southern California. Was there gentle rain for a long time? Or was there a short burst of rainfall? When there is an entire day (or even just an afternoon) of gentle rain, the rain is usually able to infiltrate into the ground, and eventually recharge the aquifers beneath the surface. But much of the rainfall that we receive in California is in bursts with heavy downpours and then days, weeks, and even years of nothing. This type of heavy rain results in a lot of run off. Stormwater is run off that can be captured.

Stormwater becomes a problem when it encounters a lot of impervious surfaces, such as asphalt and concrete. These surfaces may hold visible pollutants (e.g., trash, dog poop) and invisible residues (e.g., pesticides, herbicides). When stormwater encounters impervious surfaces and pollutants, it turns can drain pollutants into storm drains and eventually the ocean.

What slows down stormwater? Vegetation and pervious surfaces. These sorts of textured surfaces allow water to infiltrate the soil. Parkways, the area in between the sidewalk and the street, can slow water from running off properties and into the street. Planter beds near downspouts can let water percolate rather than run into the street. Plants, whether shrubs, or groundcover, or even trees, can slow water down on slopes and hillsides.

What about rain barrels? Aren't they a good way to capture stormwater? Rain barrels are typically used on a residential site to capture water that comes off the roof through the rain gutters. In many parts of the country, rain barrels work well because the water needs of the plant correspond to the times when there are heavy rains. In much of California, the rainfall occurs in the cooler times of the year when the plant water needs are minimal. This means that water in a rain barrel must be stored for lengthy periods of time. And this is where we run into issues with creating the perfect habitat to breed mosquitoes - it's still water available for irrigation, but it may be there for more than 4-7 days, which is all mosquitoes need to breed.

There are other (and better) ways to capture rainfall. On a small scale keeping vegetation on hillsides and parkways, directing downspouts to planter beds, and keeping lots of green plants will decrease stormwater run-off. On a larger scale, stormwater can be captured within a neighborhood. Several neighborhoods within Los Angeles are tackling this. Elmer Avenue in Los Angeles has a stormwater capture area. Catch basins with soft bottoms allow water to percolate into the groundwater rather than re-enter the stormwater system and get flushed into the ocean. There are also bioswales in the yards near the catch basin to slow the water and allow it to infiltrate rather than run off.

Desalination

You may hear desalination or "desal" frequently touted as the solution to all water supply problems. You may wonder why there are not more desalination plants around if it is such the perfect solution. Good question—read on.

There are two primary methods of desalination: thermal and membrane. In thermal desalination, water is heated in a boiling chamber, it then condenses in a dome, and collects in a chamber leaving all the salt behind. In membrane desalination, seawater is screened, filtered, and pushed through a reverse osmosis membrane under high pressure, and then the distilled water is treated to

drinking water standards. These methodologies aren't that complicated, but they do tend to use large amounts of energy, leading to a high cost.

For both methods of desalination, there are similar hurdles:

Seawater intake—Seawater needs to be removed from the ocean very carefully so as not to hurt plant and animal life. Typically, a speed slower than the ocean current is best.

Power consumption—Typically, the reverse osmosis process uses the most energy, which contributes to the highest costs

Brine—While brine can be returned to the ocean, most plants and animals thrive in a small range of salinities. There may be environmental consequences associated with creating areas of higher than normal salinity.

Santa Barbara, California, provides an interesting case study in desalination work. As a result of the drought in the 1980s, the City of Santa Barbara along with Montecito and Goleta constructed a desalination facility with a capacity of 7,500 acre-feet per year (AFY) with expansion to 10,000 AFY. Construction costs of $34 million were shared based on proportions of water provided for the City of Santa Barbara of 3,181 AFY, Montecito of 1,250 AFY and Goleta of 3,069 AFY.

By the time the desalination facility was built, the drought had ended and a period of heavy rainfall had begun. The plant operated for March, April, May and June of 1992 during and after a time of heavy rainfall. Then the desalination plant was put on standby. After it was paid off over 5 years, Goleta and Montecito decided not to renew the contract and subtracted desalination from their water supply portfolio.

Santa Barbara has recently decided to re-activate the desalination plant as the sole funder of this enterprise. The facility will produce 3,125 acre-feet per year or roughly 30% of Santa Barbara's water supply in a year. In terms of hurdles, the intake is 2,500 feet off shore with openings of 1 millimeter and takes in water at a rate of 0.5 feet per second, which is slower than the existing current. Additionally, the power consumption for reverse osmosis has decreased by 40% since the facility was designed. The brine has twice the salinity of seawater and will be discharged at an outfall shared with the wastewater treatment facility. A study was recently completed with Scripps Institute of Oceanography, which suggested the city can comply with discharge requirements.

It probably goes without saying, but let's say it anyway: desalination is more appropriate for coastal communities, such as Santa Barbara, San Diego or Santa Cruz. For an inland community to fund desalination, the inland community would also be evaluating

an expensive pipeline to transport water or negotiating a water exchange with a coastal community in order to avoid building the pipeline. Proximity to the source is everything in desalination.

Alternative Supply	What is it?	What are the benefits?	What are the drawbacks?	System-wide Opportunities?
Desalinated water	Potable water that was ocean or brackish water that has the salt removed to make it potable	A drought-proof supply	Generally, the most expensive source of supply. Disposal of the brine can be problematic. High energy use.	Yes
Gray water	Non-potable household wastewater, including water from the washing machine, shower, bathroom sinks, that is held and reused; excludes blackwater, which is water from toilets and kitchen sinks	Cost-effective method for residential irrigation	Supply and demand must be balanced. Easy to end up with too much supply Water can contain pathogens.	No
Recycled water	Non-potable water that is treated wastewater that is used for irrigation, groundwater replenishment and as a barrier against seawater intrusion	Non-potable use of water; can recharge groundwater	Expensive; requires separate plumbing system of purple pipes	Yes
Stormwater	Non-potable water that is runoff from precipitation (rain or snowmelt) that flows overland; may mobilize pollutants	Can recharge groundwater	Must be captured, retained and allowed to percolate	Yes

Try It!

1. A coastal community in Southern California is considering diversifying its water supply with an alternative water supply. Which type of water supply is considered “drought-proof”? Why?
2. An inland community is looking for an alternative supply to use for recharge. Which type of supplies make sense to use for recharge? Why?

Key Terms

Desalinated water—Potable water that was ocean or brackish water that has the salt removed to make it potable; considered a drought-proof supply

Gray water—Non-potable household wastewater, including water from the washing machine, shower, bathroom sinks, that is held and reused; excludes blackwater, which is water from toilets and kitchen sinks

Recycled—Non-potable water that is treated wastewater that is used for irrigation, groundwater replenishment and as a barrier against seawater intrusion

Stormwater—Non-potable water that is runoff from precipitation (rain or snowmelt) that flows overland; may mobilize pollutants

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SECTION OVERVIEW

Page 2.3: Demand-Side Management

In Part Three, you will shift from supply-side to demand-side management. When we manage the water demand, which is to say the water “need” or water “consumption” you tend to lessen the need for supply-side management. That is to say, if you can get people to need less water, you do not need to go out and find more water for them to use. In Part Three, we will cover:

- Regulations that affect conservation in California
- Water loss
- Water rates
- Indoor water use and conservation
- Outside water use and conservation
- CII water use and conservation
- Social marketing campaigns

Everything listed above addresses ways of decreasing demand for water, whether it is a regulation that mandates watering schedules, an aggressive leak detection program run by a water district, higher water rates for higher consumption, or toilet rebates.

There are many ways to control the demand for water. One of the most effective ways is with regulation. This frequently isn’t what people expect to or want to hear, but between statewide legislation, statewide mandates from the Water Resources Control Board, and California Building Code requirements, demand was substantially regulated during the drought in California. In this section, you will:

- Analyze potential outcomes of the requirements of SBX7-7
- Identify the prohibited measures by the State Water Resources Control Board
- Interpret requirements of building codes in California for water conservation

Page 2.3.1: Regulations

Page 2.3.2: Water Loss

Page 2.3.3: Water Rates

Page 2.3.4: Indoor Water Use

Page 2.3.5: Outdoor Water Use

Page 2.3.6: CII Water Use

Page 2.3.7: Social Marketing Campaigns

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Page 2.3.1: Regulations

SBX7-7

For many years, water agencies conducted water conservation programs as public outreach. They often set goals of fairly minimal savings over long periods of time—in other words, goals that were easy to achieve. Rebates were intended to help people save water, but also make them feel good and appreciate the water agency at the same time. Meanwhile, water agencies often had their own revenues in mind. They did not want people to be wasteful with water, but they also calculated a certain demand in order to set rates. They did not want too much conservation without planning for a reduction in revenue.

SBX7-7 changed everything. In 2009, Governor Schwarzenegger signed into law SBX7-7, the Water Conservation Act of 2009, which required retail water suppliers to determine their baseline per capita water use and reduce water use by 20% of their baseline by 2020.

What happens if a retail water supplier misses its target? Compliance with SBX7-7 determines eligibility for state water grants and loans. Failure to meet the target establishes a violation of law for administrative or judicial proceedings. This means a supplier wouldn't be eligible for many grants and loans that suppliers rely on to fund infrastructure, and could have legal actions taken against it.

No doubt in 2020 some water suppliers will not meet SBX7-7 goals either intentionally or unintentionally. What will actually happen to them? Sometimes it is worth making a distinction between agencies that are making an effort and those that are deliberately ignoring the law. Some may be penalized with proceedings and some may not be because they made a good faith effort. This will be interesting to see.

State Water Resources Control Board Mandatory Measures

While SBX7-7 set a long-term goal of 20% by 2020, in July of 2014, mandatory measures from the State Water Resources Control Board (SWRCB) were enacted to combat the severity of the drought. The table below walks you through the executive and regulatory decisions about the drought.

January 2014	Governor Brown declared a drought state of emergency.
April 2014	Governor Brown signed an Executive Order (April 2014 Proclamation), which asked for reductions of 20% by all Californians with an emphasis on outdoor conservation. The order prohibited HOAs from punishing homeowners who limit their watering,
July 2014	State Water Resource Control Board (SWRCB) asked for mandatory reductions with an emphasis on outdoor reductions.
March 2015	SWRCB adopted an expanded mandatory emergency conservation regulation, which prohibited: • Non-recirculating fountains • Hosing sidewalks and driveways to clean • Washing a car without a shut-off nozzle • Run-off from over-irrigating Water suppliers are tasked with enforcement and ordered to report data monthly to the SWRCB.
April 2015	Governor Brown directed the SWRCB to implement mandatory water reductions in urban areas to reduce urban use overall by 25% compared to 2013. Instructions to the SWRCB included considering relative per capita water usage of each supplier's service area and requiring areas with higher use to cut consumption more.
May 2015	SWRCB adopted an emergency conservation regulation with residential gallons per capita per day (R-GPCD targets).
January 2016	Mandatory measures are extended through October 2016 with adjustments to R-GPCD possible for suppliers for climate and growth.
May 2016	Prohibited measures described above become permanent. Water suppliers are allowed to "self-certify" their conservation targets by analyzing their water demand (average of 2013 and 2014) and their water supply and using a target for any shortfall.

So while SBX7-7 concentrated on long-term conservation goals compared to a baseline of total water production, the SWRCB mandatory measures concentrated on short-term conservation goals, particularly in the residential sector and particularly outdoors.

The goals (or targets) were widely criticized for not being fair. This is usually referred to as having "equity issues." While the SWRCB separated out commercial, industrial and institutional water use and concentrated strictly on a residential water reduction, it tended to penalize the water suppliers with higher per capita consumption with larger goals. Water suppliers with higher per capita consumption tended to be inland areas with higher water demand—meaning it was simply hotter inland and the plant water needs were much greater.

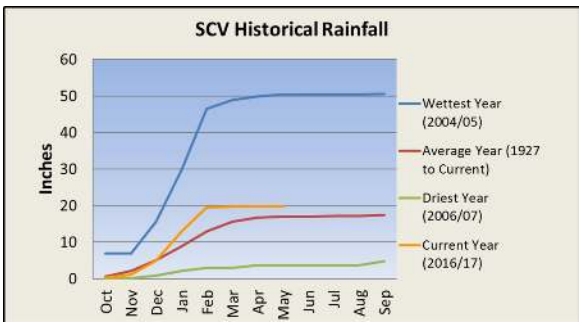


Figure *Page*2.3.1.1

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And then the winter of 2017 was wet. In Northern California, it was unbelievably wet breaking records. In Southern California, it was slightly wetter than average. In the Santa Clarita Valley, while it "felt" like a break from the drought, you can see that Water Year 16/17 (October 2016 – September 2017) was only slightly wetter than average with around 20 inches of rain for the entire year.

Is the drought over? Certainly, if you rely on imported water from the State Water Project, there was plenty of water in 2017. But most Southern California communities that used groundwater still found their groundwater supplies below average. For some parts of Southern California, including Ventura and Santa Barbara Counties, the drought was definitely not over. Looking at the graph above, would you say the drought was over in the Santa Clarita Valley?

As of this writing, the State Water Resources Control Board is implementing targets by service area to include an indoor component, a landscape component, a water loss requirement, and separate measures for commercial, industrial, and institutional users.

Building Codes

What type of regulations govern the building of a home? In terms of water use, how does a developer decide what type of toilet to use? Or aerators to install? Or landscaping to put in? These sorts of choices are governed by layers of codes, including city, county, state, and federal. In most instances, when there are overlapping standards, the most stringent apply.

Cal Green Building Code (2014 update)

Indoors	Water Use
Toilets	1.28 gallons per flush
Showerheads	2.0 gallons per minute at 80 psi
Bathroom faucets	1.2 gallons at 60 psi
Kitchen faucets	1.8 gallons at 60 psi
Outdoor	
Controllers	All controllers shall be weather-based or soil-moisture-based and shall have a rain shut off

All of the indoor devices listed above have a specific flow or flush rate. This is the rate from the manufacturer and may not be the rate in real life. Toilets, for example, leak over time and may use more than 1.28 gallons per flush. Similarly, faucets have a rating at 60 pounds per square inch, but it is entirely possible to have more pressure inside a house and use more water because of it.

Building codes are very useful in driving long-term demand downwards, primarily inside the home. In California; if there was a change to the code that forbid turf grass from being installed in new homes, demand could be driven down further outside rather than simply relying on controllers.

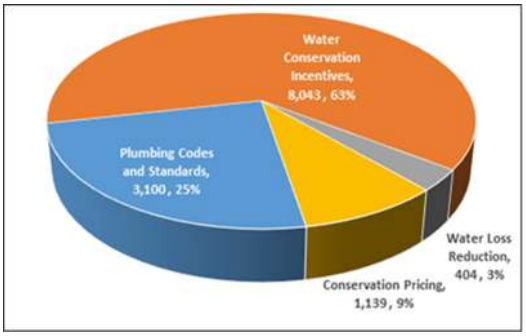


Figure ***Page*2.3.1.2**: of Castaic Lake Water Agency

The graph above shows the savings in 2020 in the Santa Clarita Valley as a result of various measures, including incentives (rebates), plumbing code and standards, pricing and water loss reduction. Note that 9% of the savings are from conservation pricing

and 25% of the savings are from plumbing codes and standards. These are powerful ways to drive demand down.

Try It!

Conduct a quick inventory of a bathroom at home. What can you tell about the flow rate of these devices?

Toilets	_____ gallons per flush
Showerheads	_____ gallons per minute at 80 psi
Bathroom faucets	_____ gallons at 60 psi

1. Which type of regulation (SBX7-7, SWRCB restrictions, or Building Code) do you think will result in the most savings over time?
2. Which measure prohibited by the SWRCB would be the most difficult for customers to prevent?

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Page 2.3.2: Water Loss

Learning Objectives

After reading this section, you will

- Differentiate among real losses
- Differentiate among apparent losses
- Prioritize leak fixing

If you were asked to picture water loss, you would probably think of a leak. Water is definitely lost through leaks. In this section, you will learn about types of leaks, but there are other ways systems lose water as well. As a general rule, you can estimate the amount of loss in a system by subtracting total consumption from total production.

Real losses include leaking pipes, joints, fittings; leaks from reservoirs and tanks; reservoir overflows, and improperly open drains and system blow-offs. Real losses are typically used (in terms of a percent of total production) to show how efficient a water retailer is in managing its assets. You can think of real losses as three primary types:

Reported leaks - These are the most dramatic leaks that end up in the local newspaper. These have high flow rates, but a relatively short run time because they are reported. They can be disruptive to staff (Stop everything and fix this!) as well as the customer (Why don't I have any water?)



Figure *Page*2.3.2.1: Photo used with permission of Laura Miller Ginsberg (taken April 4, 2016)

Unreported leaks—These are hidden underground. They may have low to moderate flow rates, and often very long run times. How would a utility find these leaks? They would need an active leak detection program of some sort or the leak would need to increase in flow to become noticed on the surface.

Background leakage—All systems have weeps and seeps. The flow rates are generally too small to be detected and not cost-effective to be fixed (until the leak escalates).

Keep in mind that as much as customers like to have water under relatively high pressure delivered to their homes, and high pressure is necessary to make it up to the top of hills in your service area, high-pressure systems are much more likely to leak than lower pressure systems.

Leaks are wasted water and money, but there are other consequences too. Wet areas may be liabilities for a water supplier and create a slippery surface or even a sink hole where people may get hurt.

> *Misconception Alert!*
>
> *Many people think of real losses as the only type of loss. But there are losses that occur in all sorts of ways, which you'll learn about below. Imagine what has to happen from the meter read to the actual delivery of the bill. Inaccuracies can be introduced in any number of ways.*

Real losses are not the only source of leaks; they are just the most obvious ones. Water can be lost because of under-recording customer meters or theft. These are considered apparent losses. With an apparent loss, water may not be actually lost from the system. You can think of apparent losses as stemming from these sources:

- Customer metering inaccuracies—It is considered a best practice for all connections to be metered (though in some communities this is certainly not the case). Metering allows customers to make a connection between the volume of water used and the cost of water. It also provides information for water resource planners in terms of consumption trends. As meters age, they slow down. Without a meter replacement program, a water utility could easily be under billing based on customer metering inaccuracies.
- Customer billing system errors and data handling errors—Think of the process to get information from the customer meter to the customer water bill—there are a number of steps, including the actual read of the meter and transfer of information into the customer information system to billing. At any point in data transfer, an error can occur, but data errors can also be introduced in the analysis if estimates are used or accounts are closed or not transferred between customers.
- Unauthorized consumption—You would be surprised how much water is stolen! Yes, intentionally stolen! This could be an illegal opening of a fire hydrant, illegal connection, or tampering with a meter. Some customers will reactivate their own service connection after the service connection has been terminated for non-payment.

As you can see, there are a half dozen ways a water utility can lose water. The biggest reason for recovering water that was lost through real and apparent losses is revenue. This is literally money that is lost, whether it is by a medium-sized leak underground, a broken main above ground, theft, or meter reading errors. Other than weeps and seeps, all of these losses can be fixed, and usually cost-effectively.

Try It!

1. If a water agency tracks the difference between consumption (the sum of all meter reads) and production (the sum of all water pumped from the ground or imported), would the difference between consumption and production be real or apparent losses?
2. What is the relationship between pressure and leaks?
3. What might be an argument to implement a leak detection program?

Glossary

- Apparent losses—Losses from customer metering inaccuracies, customer billing system errors and inaccuracies, and unauthorized consumption (theft)
- Background leakage—Weeps and seeps that have small flow rates and are not cost-effective to fix
- Real losses—Leaking pipes, joints, fittings; leaks from reservoirs and tanks; reservoir overflows and improperly open drains and system blow offs
- Reported leaks—Leaks that are reported with high flow rates, but short run times
- Unreported leaks—Leaks that are most likely hidden underground with moderate flow rates and long run times

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Page 2.3.3: Water Rates

Learning Objectives

- In this section, you will:
- Differentiate among types of water rates
- Classify rates according to whether they encourage conservation

You can look at the ways that water suppliers can organize a volumetric rate structure:

Type of Rate	Description	Benefits	Drawbacks
Uniform Rate	a constant unit price for all volumetric water sales	Simple and perceived as equitable; easy to implement (not a lot of math!); some revenue stability	Not much of a conservation signal
Declining Block Rates	the unit price for each block of water use is charged at a lower unit rate than the previous block	High-water users benefit from lower rates than in other structures	Perceptions of inequity, does not encourage conservation; complicated to design
Increasing Block Rates	the unit price for each block of water use is charged at a higher unit rate than the previous block	Encourages conservation	Perceptions of inequity; complicated to design
Seasonal Rates	the unit price varies by time period (generally a higher price during peak demand months)	Encourages conservation	Complicated to design and administer

The common wisdom is to encourage conservation, you need to make people aware of how much water they use, and increase the price as they use more. In this way, customers get a price signal to be conscious of their water use and are intentional about their water use and conserving.

You can see in the chart above, two rate types (uniform and declining block rates) do not encourage conservation. They actually could encourage an increase in demand. Why do these rate types exist? A uniform rate exists for one reason: equity (or perceptions of equity). A uniform rate treats the smallest customer and the largest customer exactly the same with the same volumetric rate. A declining block rate exists when the agency wants to increase water use, presumably by commercial and industrial users who would benefit.

Why not increase rates across the board to increase conservation? Rates are considered governed by Proposition 218 and have to go through a public process that ties the rates to actual costs from the water retailer. In general, Proposition 218 is intended to make sure that additional taxes are brought to the public for a vote. In short, a water retailer cannot charge more than proportional costs of the water per parcel served. This means that the water retailer can't charge high fees just because it wants to decrease consumption overall.

In the case of Capistrano Taxpayers Association v. City of San Juan Capistrano, the trial court decided that the City of San Juan Capistrano had not provided enough justification for their costs for the higher tiers. This has been interpreted by some as making tiered rates illegal, but this isn't really the case. Rate calculations need to be able to be justified by the cost of service. If it is costing a significant amount more to purchase an additional source of expensive supply because of high water users, these costs can be passed on to the high water users. But you can't simply charge high water users more because you want to decrease their consumption.

> *Misconception Alert!*

> *Many people disregard the fixed charge on their bills and focus on the volumetric charges. While the volumetric charges are a measure of how much water is used, they may not actually be the bulk of the cost. Much of the cost may be in the fixed charge. There is just very little you can do about the fixed charge.*

Try It!

1. Check out your water bill. How are you billed? Is there a fixed and volumetric rate? What type of rate is the volumetric rate?
2. What types of rates will encourage conservation? Why?

Glossary

- Declining block rates—The unit price for each block of water is charged at a lower unit rate than the previous block
- Increasing block rates—The unit price for each block for water use is charged at a higher unit rate than the previous block
- Proposition 218—The legislation that governs the public process for rate setting. In general, Proposition 218 is intended to make sure that additional taxes are brought to the public for a vote.
- Seasonal rates—The unit price varies by time period, generally with a higher price during peak demand months
- Uniform rates—A constant unit price for all volumetric water sales

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Page 2.3.4: Indoor Water Use

Learning Objectives

In this section, you will:

- Analyze indoor water consumption
- Audit and track your own indoor water use

When you start to talk to people about conservation, they generally want to discuss ways of reducing their indoor water consumption, particularly bathing less. This is a problem - most of the water in the residential sector in California is used outside! And, frankly, no one in conservation wants to decrease basic hygiene of the general public. Still, indoor water use and conservation is not a bad place to start because it is a place people are very familiar with.

In the graph below, based on real data from residential homes, you can see that toilets are the biggest users of water in the home, followed by showers and faucets, and then clothes washers. Surprisingly, 14% of all water metered to the home is also lost to leaks. That puts an interesting spin letting a leaky faucet drip. It's using only a little less water than your faucets!

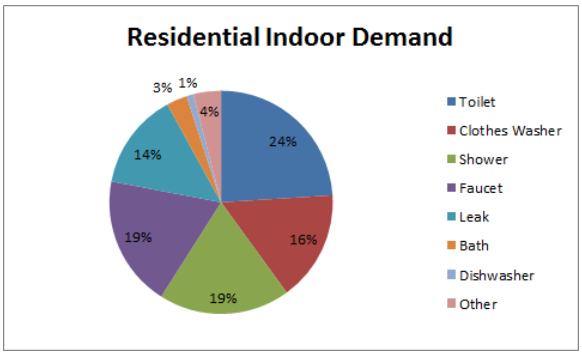


Figure ***Page*2.3.4.1**: Residential Indoor Demand by the EPA is in the public domain

Let's return to our inventory of your bathroom fixtures. What did you discover when you inventoried your bathroom?

Toilets	_____ gallons per flush
Showerheads	_____ gallons per minute at 80 psi
Bathroom faucets	_____ gallons at 60 psi

Toilets

How many gallons does your toilet use?

Sometimes it is difficult to tell how many gallons per flush a toilet has by observation. But if you remove the tank lid, often the number of gallons per flush is stamped somewhere on the inside of the tank at the top. In some toilets, you can also find the gallons per flush on the flat surface behind the seat lid. And, of course, in a store, the gallons per flush is written on the box. If you are browsing in a store, a toilet with the WaterSense label guarantees that the product is 1.28 gallons per flush.



Figure ***Page*2.3.4.2**

In the United States (as of 2017), you can purchase 1.6 gallon per flush toilets in most states, which is the federal standard, but in California, you can only purchase 1.28 gallon per flush toilets. This is 20% less water used per flush. (1.28 compared to 1.6). Yuck!

you may say. That's not enough water. Actually, it's plenty. Some of us remember the early 1990s, which was the time "low-flush" (a.k.a. low-flow) toilets came on the market in California. These were the first toilets that used 1.6 gallons per flush. Unfortunately, most of them were not re-engineered from the 3.5 gallon per flush toilets of the previous generation. A 1.6 gallon per flush toilet was pretty much a 3.5 gallon per flush toilet with less water. And these did not work well. Water agencies up and down the state of California had to deal with angry customers who felt that the water agency rebate had "recommended" a toilet with poor performance. No one wants a repeat of this. The current 1.28 gallon and 1.6 gallon per flush toilets work well. To check the performance rating of your toilet, see map-testing.com for an entire database of toilet rankings.

Toilet-Related Conservation

Toilet rebates are a "classic" conservation program and a favorite of many in conservation. Why? The toilet stays in place for a long time. The savings are essentially "hard-wired" into the home. In this type of rebate program, a customer buys an approved product from a list, and the water agency gives a check or a credit on the bill after the purchase of the toilet. In order to receive the credit or check, the customer must present the receipt and purchase from the list. The approved list is important. It is a best practice to only rebate fixtures that are more efficient than what is standard in the market. Otherwise, you are essentially rebating for people to replace something with a fixture they would have purchased anyway. So if a high-efficiency toilet (1.28 gallons per flush) is on the market, customers shouldn't be rebated for purchasing it because you are not incentivizing an increase in efficiency. They should be rebated for purchasing an ultra-high-efficiency toilet (1.0 gallon per flush or less).

Sometimes retail water suppliers will run a one-day toilet giveaway program. In this conservation program, people come to a central location, such as a big park, and pick up a new toilet after providing a driver's license for identification purposes and a water bill (with a matching name). They are allowed to take the toilet home, but they must return two weeks later to drop off the old toilet to the park (in a giant dumpster) or they will be charged for the new toilet on their bill. This guarantees (almost!) that the new toilet is installed at the home in the service area. This is one model for success but involves a lot of coordination and disposal of old toilets.

> *Misconception Alert!*
>
> *You have probably heard, "If it's yellow, let it mellow. If it's brown, flush it down." Do not do this. Please keep flushing your toilets. This is advice from the 1980s when toilets used 3.5 gallons per flush or more. It wasn't bad advice then (though still sort of gross), but it's terrible advice now. Upgrade your old toilet with a 1.28 gallon per flush toilet and keep flushing. We don't want to keep waste in our homes, and if you have kids, it's a hard-to-break habit if they learn not to flush. Keep flushing!*

Showerheads

It may be hard to tell how many gallons per minute a showerhead uses just by looking at it. Many showerheads are labeled with this information, but calcium and magnesium in hard water build up to obscure the numbers. In the United States, you can buy showerheads with up to a 2.5 gallons per minute rating, but in California, the only showerhead you can buy is 2.0 gallons per minute or less. To earn a WaterSense label, a showerhead would also need to use 2.0 gallons per minute or less.

Shower-Related Conservation

Many water agencies have giveaway programs with showerheads. One of the challenges with a giveaway program is that the water agency typically does not know that the product is installed properly (or installed at all). So the water agency may "count" on the savings from purchasing and distributing showerheads, but not necessarily receive the savings as a decrease in overall consumption.



Figure ***Page*2.3.4.3**: Shower Better image by the EPA is in the public domain

Additionally, and equally problematic to conservation program design, showers are seen as “sacred” by many people. It’s their “me” time and they do not want you to mess with their shower, including affecting the quality with a sub-par showerhead and length of shower.

Washing Machines

A traditional style washing machine uses 40-50 gallons per load of laundry. That’s a lot! A high-efficiency washing machine uses about half of that (20-25 gallons). That’s a significant savings. But, of course, high-efficiency washing machines cost more - typically $200 more than a traditional machine (as of 2016). A high-efficiency machine typically soaks the clothes longer to remove stains and dirt rather than using a central agitator. The loads of wash may take longer in a high-efficiency machine.

Washing-Machine-related Conservation

Many water agencies operate washing machine rebates, which offer a rebate of $100-300 to make the purchase more cost-effective for consumers. Washing machines rebates have mostly replaced toilet rebates in popularity in California. While it’s possible that a customer may receive the rebate and move out of the water agency’s service area, it’s also equally possible that a customer may move in with a high-efficiency machine already.

Faucets



Figure ***Page*2.3.4.4**

A standard faucet purchased in the United States uses 2.2 gallons per minute. A WaterSense approved faucet will use 1.5 gallons per minute. Aerators can be added to standard faucets to inject air into the water flow and make the flow seem fuller with less water.

Faucet-related Conservation

Aerators are typically available at water agencies for free and are given away at events. As with showerheads, aerators are difficult to track and impossible to make sure they are installed properly. They can also present problems in giveaway programs in that customers may need a male or female threaded aerator, but take one of each to hedge their bets.

Audits

Do you remember the table where you quantified your measurements of indoor fixtures? An “audit” is really an extension of that exercise. You make a list of all the water-using fixtures in the house, quantify their use, decide on a number of times per day, and come up with a total. Completing the table below will help you audit your own home.

Try It!

Complete the table below to audit your own home (indoor water use).

Bathrooms	Amount of Water Used per Use	Times Used per Day	Total Water Used per Day by Device
Toilet #1	_____ gallons per flush		
Toilet #2	_____ gallons per flush		
Toilet #3	_____ gallons per flush		
Showerhead #1	_____ gallons per minute		
Showerhead #2	_____ gallons per minute		
Showerhead #3	_____ gallons per minute		
Bathroom faucet #1	_____ gallons per minute		
Bathroom faucet #2	_____ gallons per minute		
Bathroom faucet #3	_____ gallons per minute		
Kitchen			
Kitchen faucet	_____ gallons per minute		
Dishwasher	_____ gallons per use		
Other Water Using Devices			
Total Water Used Per Day			_____

In what category is the most water used per day?

What could you do to save the most water in your home?

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Page 2.3.5: Outdoor Water Use

How much water is used outdoors? Most estimates for outdoor water use in the United States suggest that it is more than 50% of all water used for residential use. In general, the hotter the locale, the more water is used for landscaping.

Learning Objectives

In this section, you will:

- Identify the benefits and needs of landscape
- Differentiate among types of irrigation
- Classify plants according to their watering needs
- Design a landscape with best practices in mind

Why don’t we get rid of all the landscape, cover the ground with cement, and save all that water? Landscape serves a variety of purposes, and is considered a beneficial use of water. After all, plants make oxygen, and we humans love oxygen. Plants also lower the air temperature. An entirely paved landscape would be a hot one - check out the center of a parking lot in the summer. And soil acts as a giant sponge, absorbing and filtering water, which eventually allows for aquifers to replenish. So, keeping landscape is a given, and acknowledging that live plants in the landscapes need water is important. However, choosing a waterwise landscape and giving it just the water it needs is essential.

Couldn’t all of our irrigation problems be solved if we saved the rainwater that falls from the sky? Doesn't that just go to waste if it runs into the ocean? We do save it in both surface reservoirs and in groundwater aquifers. Water isn’t wasted if it infiltrates. And even when it runs into the ocean, it is still part of the water cycle.

Sometimes, rain barrels are presented as the perfect solution to irrigating landscape. However, rain barrels bring with them a host (no pun intended) of other problems, including providing the perfect breeding ground for mosquitoes. We are poised on having a worldwide explosion of babies with microcephaly, caused by the Zika virus, which is spread by mosquitoes.

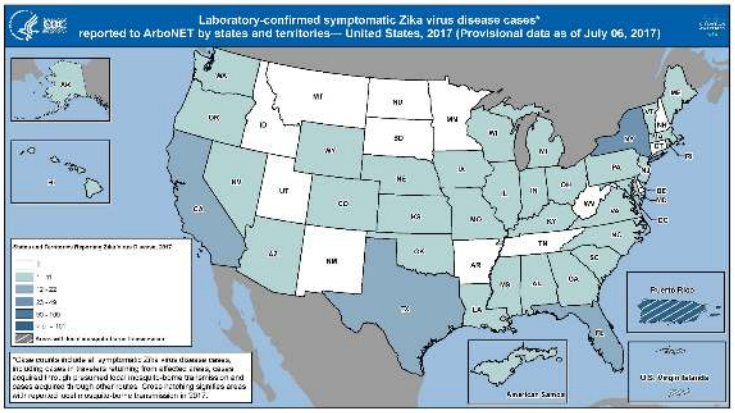


Figure ***Page*2.3.5.1**

Additionally, mosquitoes spread the West Nile Virus, and a number of locations in Southern California, including Santa Clarita, are “hot spots” for the disease. It is almost impossible to mosquito-proof a rain barrel—mosquitoes will enter that smallest opening to lay eggs in water. This makes rain barrels perfect for breeding mosquitoes, and not for saving water.

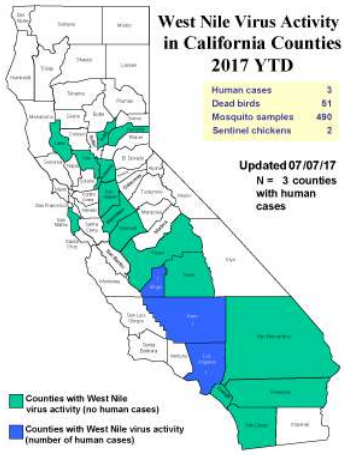


Figure ***Page*2.3.5.2**: West Nile Virus Activity map by the California Department of Public Health is in the public domain

Setting mosquitoes aside, why wouldn't rain barrels help save water? In Southern California, most of the rainfall occurs when the plant water needs are the least. Rain barrels may be a good solution in places like Arizona and New Mexico, which get summer monsoonal storms when the water needs for plants are the greatest. In California, our storm season generally lasts from November through February when the plant water needs are the least.

Best Practices in Landscapes

It is a much better idea to look beyond rain barrels and beyond eliminating landscape entirely to principles that would help landscape use water more efficiently. These are practices that are a compromise between what is called "all or nothing" thinking. You will hear a lot of this sort of thinking as you hear people talk about their landscape. This is the sort of thinking that says, "If I can't have my grass in the front and backyard, then I'm going to pave over everything" or "If I can only water twice a week, I'm just going to give up and let everything die." In the next part, you will learn a few of the principles that landscape professionals use to create and maintain drought-tolerant landscapes. There is a middle ground between paving everything and having no landscape and having turf grass everywhere.

Maintain the irrigation system—This means conducting a regular review of the system while it is running to look for common problems (overspray, clogged nozzles, blocked heads). Much like we learned in the section on alternative water supplies, including gray water, frequently maintenance is a hurdle that homeowners do not want to overcome. If something needs maintenance, such as a gray water system or an irrigation system, it may simply be avoided and neglected. There is water-saving potential in conducting maintenance.

Mulch the exposed soil—Any surface that is not covered by a plant (or a six inch space around a plant) should be covered with three to five inches of mulch. Mulch has a ton of benefits including keeping the soil temperature more moderate (warmer in the winter and cooler in the summer), preventing weeds from sprouting in soil and decreasing the evaporation. Mulch does need to be raked periodically and re-applied year to year, but it makes a great improvement in the aesthetics and health of a planted surface.

Hydrozone—The highest water use plants used in California landscapes are types of turf, including cool season turf, which has slender blades of darker green color, and warm season turf, which has wider blades of medium-green color. You can see in the table below how the water needs, measured in evapotranspiration in inches per day, vary tremendously among types of turf grasses. Typically, when someone admires a lawn, the lawn is Kentucky blue grass or another cool season turf grass. There are low water using options, such as Buffalo grass, which can easily use half as much water. But grass overall is still a very water thirsty plant.

Relative Ranking	ET in inches/day	Cool Season	Warm Season
Very low	< 0.24		Buffalo grass
Low	0.24-0.28		Bermuda grass Zoysia grass
Medium	0.28-0.33	Red fescue St. Augustine	
High	0.33-0.39	Perrential Rye grass Kikuyu grass	
Very high	> 0.39	Annual bluegrass Kentucky blue grass Annual rye grass	

Hydrozoning, or separating your plants by their water needs, helps you water the right amount in each zone. In the table below, you can see how you might group plants according to their high, moderate, low and very low water needs. Each plant is compared to a cool season turf grass of 4-7 inches tall that is not stressed. This is the plant with the highest water need. Trees and shrubs should be in their own zone. Anything drought-tolerant typically has a low water need and should be in a separate zone. And anything with a very low water need typically does not need irrigation. Note that a plant with moderate water needs only needs 40-60% of the water of a cool season turf grass. That means that typically anything other than turf grass will need half as much water - this is truly astounding.

Water Needs	Percent of Reference ET	Types of Plants
High	70-90% ET	Most turf grasses
Moderate	40-60% ET	Most trees and shrubs
Low	10-30% ET	Drought-tolerant plants, like salvia (sages)
Very Low	<10% ET	Cacti

Irrigate deeply and water infrequently—Daily watering isn't necessary for most plants, including turf grass, even during the summer. Irrigation depends on a number of factors, including:

Soil type—Both clay and sandy soil in your yard mean you must irrigate in short bursts and allow water to sink in in between bursts. This is typically called cycle and soak because you allow the controller to cycle on once and then let the water soak in before cycling on again.

Depth of roots—If you water grass multiple times a day, you train the grass to have short roots, which mean the roots cannot reach other available water deeper in the soil. Try to water less frequently to encourage deeper roots to grow.

Seasonal variation—Plants have greater water needs in the summer than the spring, fall or winter. This is intuitive, but many people water the same amount of time all year round.

Types of plant material—Would you water your lawn and a cactus the same amount? Of course not. But many people water everything in their yard the same amount, which usually results in over-irrigation of most non-grass plants. This is why separating your yard into hydrozones is so important.

Irrigation system type—Spray heads put out water much faster than rotating heads or than drip irrigation - you need to understand this when you program your system. Spray heads and rotating heads can be high-efficiency, meaning they apply water at a slower rate. Spray and rotating nozzles are appropriate for grass, but drip irrigation is a more appropriate choice for shrubs and trees. The table below summarizes the four major types of irrigation, including their water pattern, ideal use, and precipitation (precip) rate, which is the amount of water that the irrigation type puts out.

Irrigation Type	Water Pattern	Ideal for...	Precipitation Rate	How to irrigate well with it?
Spray	fan	turf grass	Faster than soil can absorb	Cycle and soak
Rotating	stream	turf grass	Faster than soil can absorb	Cycle and soak
Bubbler	gush	trees with wells	Faster than soil can absorb	One run time to fill the wells
Drip	drip	shrubs and trees	Same rate soil can absorb	One long run time (45 minutes +)

Irrigation Controllers

In California, any new homes will come with a weather-based or soil-moisture-based irrigation controller. This means that some of the guess work will be taken out of irrigation decisions. Typically people have no idea how much to water and end up over-irrigating everything. Irrigation controllers can be programmed by the days to water, the time of days to water (called the start time), the length of time to water (called the run time). A weather-based irrigation controller or a soil-moisture based irrigation controller needs to be guided on what days to water and what times to start, but can determine how long to water based on weather or on soil moisture.

When do you think you might see savings from using a weather-based irrigation controller? Typically, people set their controller at the summer levels for irrigation and keep the controller at that level all year. This means they are watering both more frequently than needed and longer than needed for most of the year. The savings when upgrading to a weather-based irrigation controller come in the spring, fall and winter, when the person was over-irrigating.

Grass and Artificial Turf

When is grass appropriate? Are people playing on the surface? If so, grass is the perfect plant - no other plant will take being trampled and literally bounce back. If kids or adults are using the grass to play on, keep it. It's the right plant in the right place at the right time. But the way grass is used in many communities is as a default plant. Grass is easy and inexpensive to install and has been installed in all sorts of places that are hard to irrigate without run-off, like parkways, hills and slopes or medians.

What about **artificial turf**? While artificial turf does not change the landscape aesthetic in a community, it has both benefits and drawbacks, which are detailed in the table below.

Benefits of Artificial Turf	Drawbacks of Artificial Turf
It's green	It can become hot in the sun (and contribute to a heat island effect on your property)
It saves water	Many installers recommend hosing down artificial turf for dust control and to clean pet waste
No mowing is necessary	It can photodegrade in the sun (10-year lifespan)
No fertilizers are necessary	It will smell of pet waste if not cleaned effectively
Costs incurred are most likely one time charges (until time for replacement in around 10 years)	Typically, artificial turf is $10-15 a square foot

There are other types of outdoor water use, but they are negligible in the greater scheme of things when compared to landscaping. For example, leaks may occur outdoors in the irrigation system. Water can also be used for cleaning hardscape (pavement, sidewalks, driveways), washing vehicles, filling fountains and swimming pools.

Try It!

1. Propose a strategy for landscaping an area that you see frequently, such as your home, a local park, or your school. This could be your front or backyard, a common area, or an area at work. Consider the types of plants that you might install, an arrangement for them, the irrigation system you should use, and what obstacles you might encounter along the way. Identify the best practices you have used.
2. A friend wants to install artificial turf in his front and backyard. Give an overview of the benefits and drawbacks of artificial turf.

Key Terms

Cycle and soak—Irrigating in short bursts and allow water to sink in between bursts

Hydrozoning—Separating your plants by their water needs, which helps you water the right amount in each zone

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Page 2.3.6: CII Water Use

What do a car mechanic and an aerospace engineer have in common? They both work in the Commercial, Industrial, and Institutional (CII) section, which is very diverse in terms of water use. Using water for cleaning as a car mechanic or water for manufacture of aerospace parts are very different uses. As we study CII customers, you'll be able to bring together what you've learned about indoor and outdoor conservation and apply it to the workplace.

Learning Objectives

In this section, you will:

- Classify customers according to type
- Identify challenges in the CII sector
- Analyze the consumption history of CII customers

For CII customers considering conservation, financial incentives are typically a useful conservation tool as well as providing information on the return on investment (ROI). One particular challenge in the CII sector is that a master meter typically provides water for both indoor and outdoor use. Sometimes an entire strip mall of diverse businesses (e.g., nail salon, microlender, lawn mower repair) will be behind the same meter. This makes it very difficult to account for individual commercial water use and to offer appropriate rebates and incentives. With the challenges in the CII sector understood, we will spend some time looking at each type of business within the CII sector.

Commercial, Industrial and Institutional Customers

Within the commercial, industrial and institutional (CII) sector, water use varies by type of customer. The EPA provides this bar graph of typical water use within different types of commercial and institutional organizations:

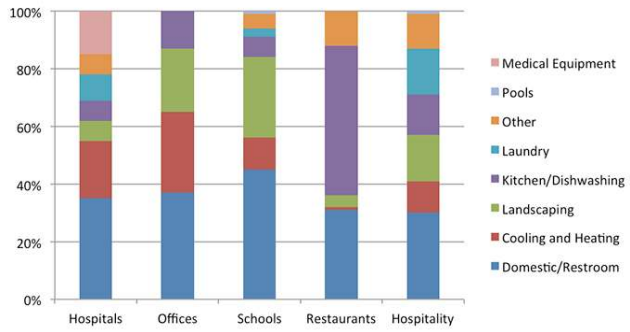


Figure *Page*2.3.6.1

There are a few key observations you can make, most of which are intuitive:

Most customers have a sizable proportion of domestic or restroom water use. This suggests that a program that rebates toilets, urinals, and aerators might be useful to many types of customers.

- Schools, offices and hospitality (hotels) use a significant amount of water for landscaping. This suggests that a rebate program for smart irrigation controllers, sprinkler nozzles, landscape audits or checkups or for turf grass removal might be useful.
- Some types of customers, such as hospitals or offices, have sizable amounts of water used for heating and cooling (including cooling towers, which can recirculate water).
- Kitchens and hotels (hospitality) use a significant amount of water in the kitchen.

Commercial Customers

Restaurant water use is typically about 50% used in the kitchen, primarily for dishwashing. This suggests that a dishwasher rebate for a water-efficient dishwasher might be in order. And, of course, there is typically a third of total water used for restrooms, which suggests a toilet and urinal rebate program might be well received and needed.

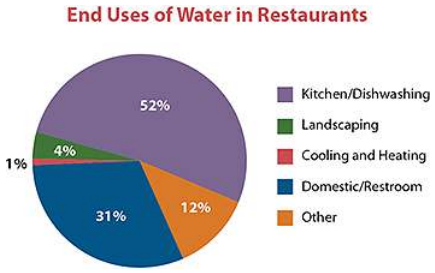


Figure *Page*2.3.6.2

Restaurants have other uses of water in the kitchen, including woks and dipper wells, both of which may have continuous flows of water. The next time you are in an Asian restaurant, if the restaurant has an open kitchen, check out the wok. Many restaurants have a continuous flow of water in a faucet behind the wok to use while cooking and to cool the wok. Similarly, dipper wells in ice cream parlors may also have a continuous flow of water to keep the ice cream scoop clean. For kitchen clean-up, pre-rinse spray valves, which are used to pre-clean dishes before going in the dishwasher, can also be upgraded to less gallons per minute, and are a common rebate program.

The EPA features a case study in conservation in a restaurant in Chicago, Illinois. The restaurant is called Uncommon Grounds and it conducted three stages of upgrades:

1. Aerators on prep sinks, more efficient pre-rinse spray valves and water only served on request
2. Dishwasher and ice machine upgrades to ENERGY STAR qualified models
3. Rooftop garden with a drip irrigation system that uses a rainwater collection system

This case study illustrates that there are a wealth of possibilities for upgrades, but that for restaurants focusing on the kitchen first often makes the most sense.

Hotels are another common customer type in the commercial sector. Their water use often encompasses a restaurant, but also restrooms, landscape, and laundry uses.

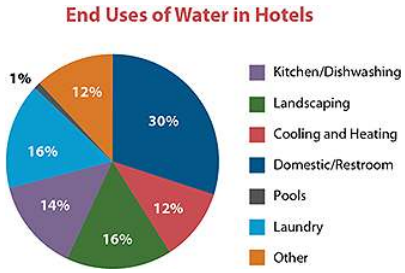


Figure *Page*2.3.6.3

Hotels may have more flexibility for implementing changes for water conservation if they are small and privately-owned or if they have sustainability as part of their mission, such as Kimpton Hotels. Small behavioral changes may be successful for hotels, such as instituting linens/towels re-use options for customers, particularly if customers have to “opt-in” for fresh daily towels or linens.

The EPA has a case study in water conservation in a hotel in a Holiday Inn in San Antonio Texas. The water utility spent $100,000 in a retrofit of guest bathrooms upgrading as shown below:

Fixture	Original Efficiency	Retrofit Efficient	Number of Units
Toilets	3.5 gpf	1.1 gpf	297
Toilets	5.0 gpf	1.1 gpf	100
Aerators	2.2 gpf	1.5 gpm	397
Showerheads	2.5 gpm	1.75 gpm	397

The hotel achieved an average of 35% savings per upgraded room and $68,000 in water and sewer costs per year.

Industrial Customers

The Mid-Continent Ecology Division Laboratory (MED) of the Environmental Protection Agency (EPA) can also be studied as a case study for water conservation. Located in Duluth, Minnesota, the MED is 50 labs, administrative offices, a library, and 7 constant temperature rooms. As with many scientific laboratories, there was a good deal of water used for cooling of scientific instruments. In particular, single-pass cooling occurred not only in the cooling system for the building but for many elements of the research equipment. Because the facility is adjacent to Lake Superior, the facility was able to use waters from the lake for cooling rather than potable water, which reduced its total potable use by 90 percent. Additionally, the water can be returned to Lake Superior after it is used to cool the building or equipment.

This use of lake water for cooling is innovative. In California, lakes are much more sporadically occurring than in Minnesota and this would be more of a challenge both in finding a lake to use and in not having detrimental environmental effects. Also, aquatic species tend to like water within a temperature range so any water that is returned to the lake would need to be similar in temperature to the lake water.

Institutional Customers

Although decreasing water use by 90% in the case of the MED or 35% for the Holiday Inn seems extreme, the types of processes and analyses that occurred at the MED are the sorts of processes that would need to occur are typical of ways to save with other industrial customers as well as institutional customers. Institutional customers are typically schools and universities, hospitals, houses of worship, and city and county agencies. These are typically the sorts of customers who may have many people visiting their facilities for a short period of time. They may also have a variety of different types of use in one building, such as a church that also has a school during the weekdays and group counseling or AA meetings in the weekday evenings.

Stanford University is useful as a case study because of the wide-ranging uses of the facility ranging from scientific research to residential housing. At Stanford University, conservation staff met with each department to attempt to quantify water use and potential reductions. Important to this effort was the involvement of stakeholders in the process, which include professors and research staff, but also building and grounds staff who understand how the buildings function, particularly the cooling systems.

In the end, a variety of conservation measures were chosen from removal of unnecessary turf grass and installation of weather-based irrigation controllers as outdoor measures to upgrading most bathrooms on campus and replacing one-pass sterilizing equipment, to real-time metering to provide feedback on water use, and especially on leaks.

In the same vein as Stanford University, a case study from the EPA found a wide range of possible upgrades for a hospital in Olympia, Washington, to decrease water use. These water conservation measures concentrated on:

- Upgrading sterilizer equipment
- Recovering condensate from the sterilizer for re-use (non-potable use)
- Upgrading water-using equipment with non-water using equipment

This process resulted in a savings of 5.9 million gallons once the retrofits were completed and a cost savings of $140,000 per year. So while it may seem like the CII sector is technical, case studies such as this one illustrate that by identifying the high-water using appliances and equipment and researching upgrades, there is a significant potential for water savings.

Try It!

1. Where is most water used in a restaurant? Where is most water used in a school?
2. College of the Canyons is considered an “institutional customer.” Where might the greatest water savings lie?

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Page 2.3.7: Social Marketing Campaigns

How do you get people to change? It's a good question and one with which numerous governmental agencies struggle, particularly those in the health and healthcare fields, where there are the most social marketing campaigns of any field.

As you have seen, there are major water infrastructure projects that can be relied on to a certain extent to bring water to the thirsty parts of California. But how can you decrease the amount of water that is needed in the first place? This is called managing demand. You've learned a variety of tools from regulation to restrict water use or limit waste, to building codes that require more efficient devices to water loss detection to conservation programs. Decreasing demand is both an art and a science. One additional way to reduce demand is to engage in a social marketing campaign with residents.

Learning Objectives

In this section, you will:

- Differentiate between awareness campaigns and social marketing campaigns
- Identify behaviors that most water utilities target
- Design a social marketing campaign

Typically, public outreach campaigns in the water industry have focused on awareness. That is to say, the campaign wants you to be aware of the importance of water or the amount of water that you use. In the Santa Clarita Valley, a campaign in 2010 focused on residents knowing their "water number," the amount of water that they used in one day. This campaign relied on the jarring realization that the amount of water that people used was much more than they expected.

An awareness campaign might also focus on a rebate program by promoting toilet or washing machine rebates. The goal of an awareness campaign is to make more people aware of something, but it isn't necessarily to make people change their behavior. There isn't a clear call to action.



Figure *Page*2.3.7.1: of Castaic Lake Water Agency

In the image above, the viewer is made aware that funds are still available for a Cash for Grass Program (called Lawn Replacement). This ad assumes that most people do not know that there is still money available, and is attempting to raise awareness of this. In Southern California, water agencies, such as Castaic Lake Water Agency, frequently have challenges with messaging that contradicts the messaging from Metropolitan Water District of Southern California, which is a much larger wholesale agency. In this case, Castaic Lake Water Agency has funds available for a cash for grass program, while Metropolitan Water District has run out of funds. Customers who do not know who their water wholesaler was were confused about the availability of funds.

Success or failure of the campaign could be measured in a change of awareness in rebates with a phone or email survey of a representative sample of residents. Awareness of the rebate could be measured before the campaign launches to establish a baseline (e.g., 20% of residents surveyed in the Santa Clarita Valley are aware there are funds available for the Lawn Replacement Program) and then a follow-up phone survey after the campaign runs for 3-12 months to see if there is any increase in awareness (e.g., 3 months later, 30% of residents surveyed in the Santa Clarita Valley are aware there are funds available for the Lawn Replacement Program).

Another awareness campaign that you may have seen is a drought awareness campaign. Most water agencies had to launch some sort of drought awareness campaign that combined with efforts from the State of California to make people aware of the severity of the drought. San Diego County Water Authority has an effective ad to make people aware of state-mandated conservation. Using a modified image from the Drought Monitor of the state of California, the campaign make some suggestions for conservation, but is mostly focused on awareness of the drought and restrictions in place.



Figure ***Page*2.3.7.2**: of San Diego County Water Authority

A similar awareness campaign from the Family of Water Suppliers in Santa Clarita, including Castaic Lake Water Agency, focuses slightly differently on a common misconception: when it rains, the drought is over. This awareness campaign reminds people that just because it rains, the drought is not over.



Figure ***Page*2.3.7.3**: of Castaic Lake Water Agency

A social marketing campaign differs from an awareness campaign significantly. A social marketing campaign is a campaign that tries to change behavior. By presenting images that motivate people to do the “right” thing (or that poke fun of people doing the “wrong” thing), public agencies can gently move people to better practices that are good for the residents and good for the public agency. However, most of the time, you can’t just tell people to do the right thing. It generally doesn't work. People have too much going on in their lives to listen, unless you make it extremely relevant. You need to have a campaign that refines your message.

These are the sorts of questions that are used in campaign planning:

- Who are we targeting?
- What is our message?
- What partnerships will help with our message?
- What are the barriers to being understood (or listened to)?

During the last drought, many water agencies in California had to tackle how to let people know it was okay to let their lawn get less water and go dormant (yellow). Because green lawns are one way that people tend to rate their status (i.e., I have a green lawn, so I must be financially secure), this is a particularly challenging task. San Diego County Water Authority has a social marketing campaign that tackles this in a unique way.



Figure ***Page*2.3.7.4**: of San Diego County Water Authority

In the image from San Diego County Water Authority, the Authority has chosen to reframe brown grass as “tan” grass, most likely hoping that this will make it seem more appealing. This is a variation of “Brown is the new green,” a phrase made popular by Governor Brown in the same drought, but working with language that may be more appealing (i.e., tan rather than brown).

Castaic Lake Water Agency has a similar goal of reducing water use for turf grass, but has taken a different tactic by focusing on the appealing aspects of replacing a lawn (more color, more fun, more time):



Figure ***Page*2.3.7.5**: Images used with permission of Castaic Lake Water Agency

Many social marketing campaigns have concentrated on the behavior that was prohibited initially during the drought in California, including stopping irrigation run-off, but also refraining from watering sidewalks or washing cars without shut-off nozzles, or using even non-recirculating fountains. While raising awareness of the drought is important, these were all behaviors that were targeted by many water companies in social marketing efforts to behavior change.

Try It!

1. Do a quick scan through a newspaper or click through a few websites starting with an online newspaper. Give an example of an awareness campaign and an example of a social marketing campaign. Examples do not need to be from the water industry.
2. Design a social marketing campaign and present your results. Answer these questions:
    1. Who are you trying to target?
    2. What is the message?
    3. What are the hurdles?

Key Terms

Awareness campaign—A campaign to make more people aware of something, but it isn't necessarily to make people change their behavior

Social marketing campaign—A campaign that tries to change behavior

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Page 3.1: Introduction To The Operator Certification

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

Student Learning Outcomes

After reading this chapter, you should be able to:

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

Introduction to Water Distribution

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

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

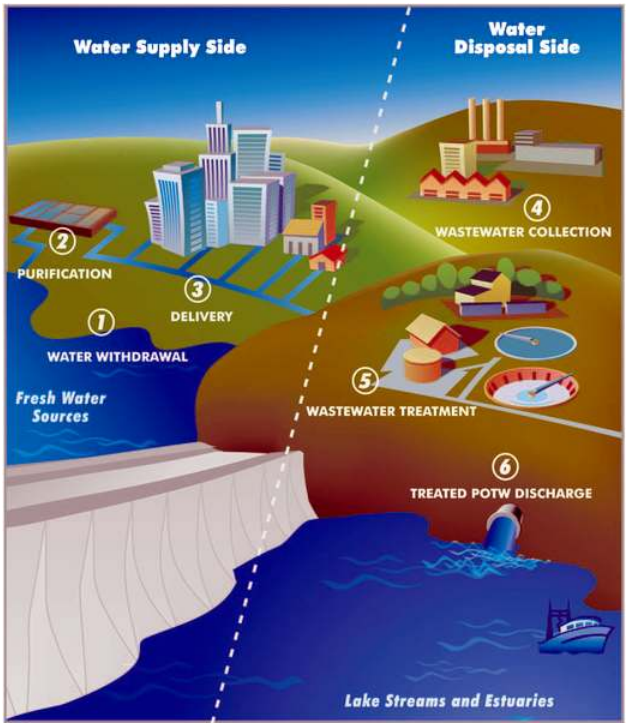


Figure ***Page*3.1.1**: Image from the *Primer for Municipal Wastewater Treatment Systems* by the EPA is in the public domain

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

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

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

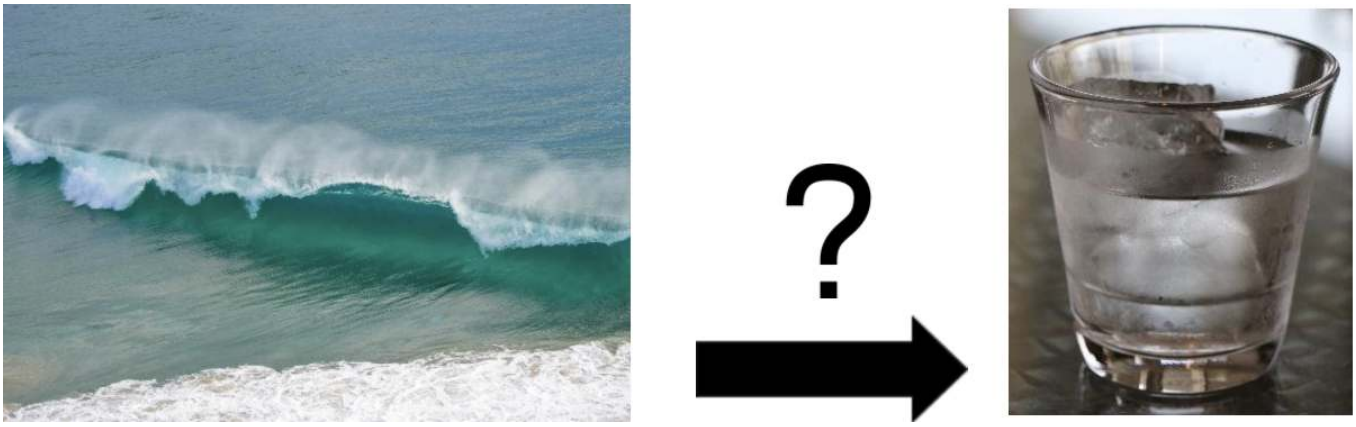


Figure ***Page*3.1.2**: Photo by Marianne Heino on Unsplash; Photo by insightzaoya is licensed under CC0

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

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

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

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

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

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

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

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

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

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

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




Figure ***Page*3.1.3**: Image by kim traynor is licensed under CC BY-SA 2.0; Image by caitriana is licensed under CC BY-SA 2.0

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



Figure ***Page*3.1.4**: EPA Seal is in the public domain

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



Figure ***Page*3.1.5**: Photo of Mill Creek Sewer is in the public domain

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



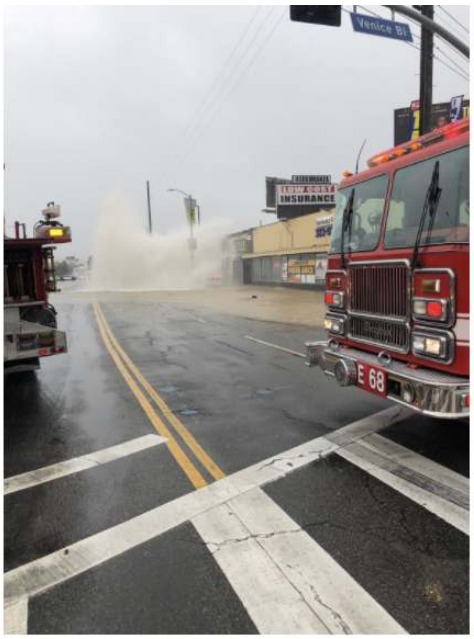


Figure *Page*3.1.6: Image by Los Angeles Fire Department is licensed under CC BY-ND 2.0; Image by Los Angeles Fire Department is licensed under CC BY-ND 2.0

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

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

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

State Water Resources Control Board

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

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

Field Operations Branches

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

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

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

Program Management Branch

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

Operator Certification

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

Distribution

D1, D2, D3, D4, D5

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

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

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

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

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

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

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

Examination Certification Eligibility Criteria

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

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

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

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

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

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

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

Operator Certification Examination Content

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

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

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

Drinking Water Distribution & Treatment System Operators

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

Sample Questions

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

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Page 3.2: Sources and Characteristics of Water

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

Student Learning Outcomes

After reading this chapter, you should be able to:

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

Hydrologic Water Cycle

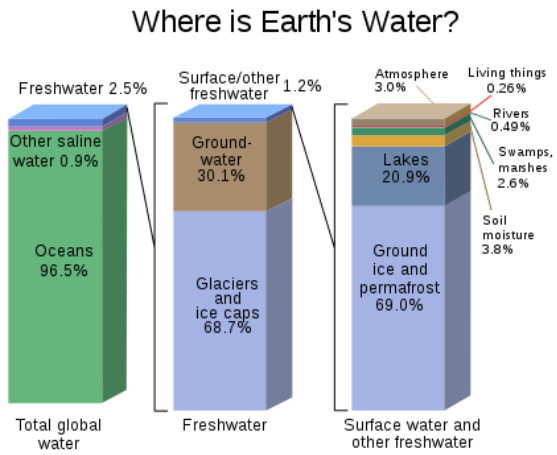


Figure ***Page*3.2.1**: Image by the USGS is in the public domain

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

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

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

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

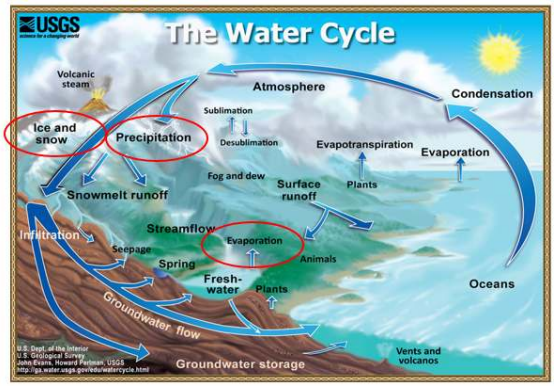


Figure *Page*3.2.2: Image by the USGS is in the public domain

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

Water Sources

Surface Water

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

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

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

Groundwater

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

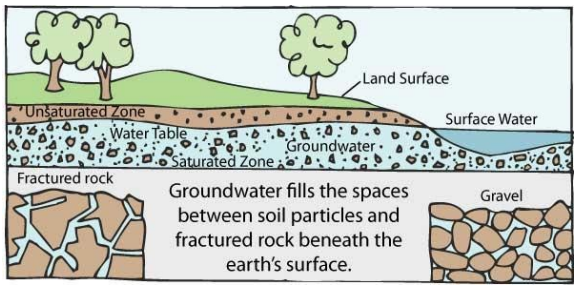


Figure ***Page*3.2.3**: This material was reproduced from groundwater.org with the permission of The Groundwater Foundation. © The Groundwater Foundation. All Rights Reserved.

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

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

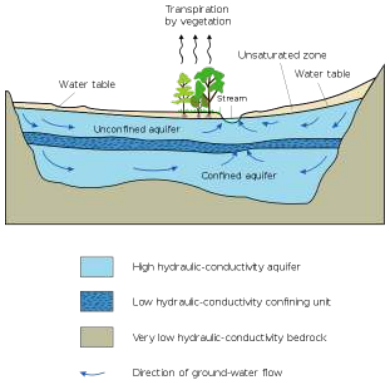


Figure ***Page*3.2.4**: Image by Hans Hillewaert is licensed under CC BY-SA 3.0

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

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

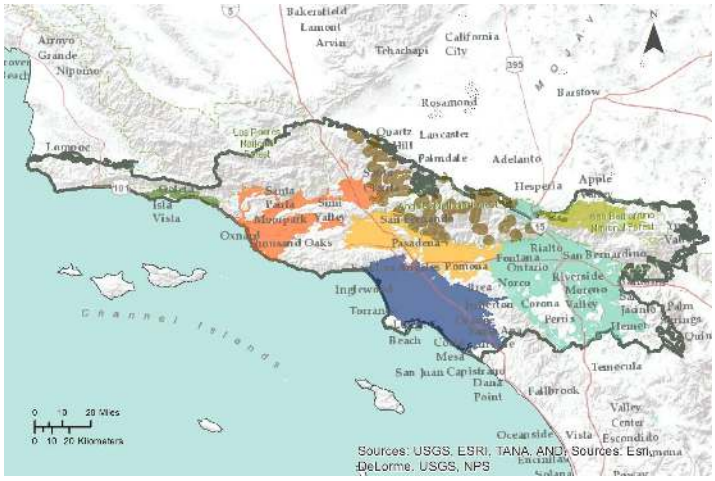


Figure ***Page*3.2.5.1**: Map by the USGS is in the public domain

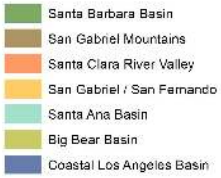


Figure ***Page*3.2.5.2**: The Transverse Ranges and Selected Peninsular Ranges Province consists of the following Study Units

Recycled Water

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

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

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

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

Water Characteristics

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

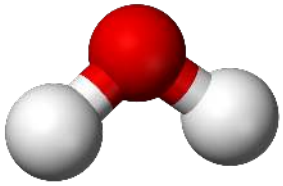


Figure ***Page*3.2.6**: Water-3D-balls by Benjah-bmm27 is in the public domain

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



Figure ***Page*3.2.7**: Gerris by webrunner is licensed under CC BY-SA 3.0

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

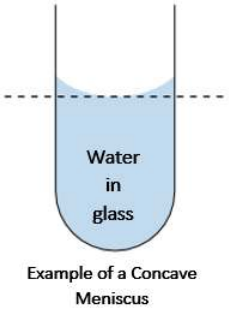


Figure ***Page*3.2.8**: Image by Jleedev is licensed under CC BY-SA 3.0 (image modified by COC OER)

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

Physical Characteristics

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

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

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

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

Sample Questions

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

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Page 3.3: Regulations

Student Learning Outcomes

After reading this chapter, you should be able to:

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

Is My Water Safe to Drink?

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

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

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

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

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

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

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

Sources of Contamination

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

Physical Contamination

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

Biological Contamination

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

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

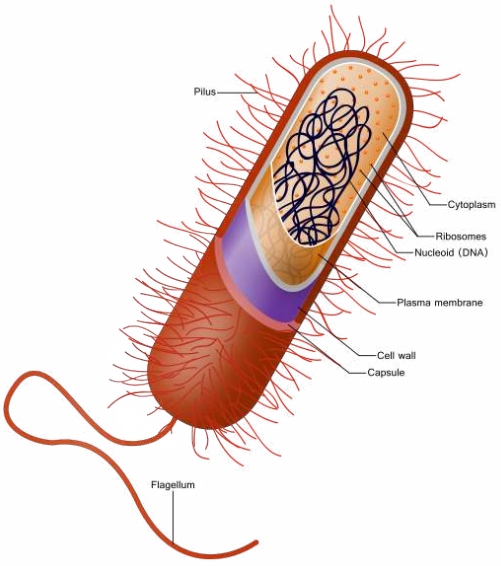


Figure ***Page*3.3.1**: Image by Ali Zifan is licensed under CC BY-SA 3.0

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

Revised Total Coliform Rule

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

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

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

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

The main changes to the RTCR include the following:

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

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

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

Chemical Contamination

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

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

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

Drinking Water Standards

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

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

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

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

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

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

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

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

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

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

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

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

Nitrate

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



Figure ***Page*3.3.2**: Image by OpenStax is licensed under CC BY 4.0 (image modified by COC OER)

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

Arsenic

Arsenic – MCL = 10 ug/L

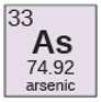


Figure ***Page*3.3.3**: Image by OpenStax is licensed under CC BY 4.0 (image modified by COC OER)

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

Radiological Compounds

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

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

Lead and Copper

Lead and Copper – AL = 15 ug/L for Lead (Pb) and 1,300 ug/L for Copper (Cu) – Lead and copper contamination does not typically occur in the source water or even in the distribution system of drinking water systems. The primary source of lead and

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

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

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

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

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

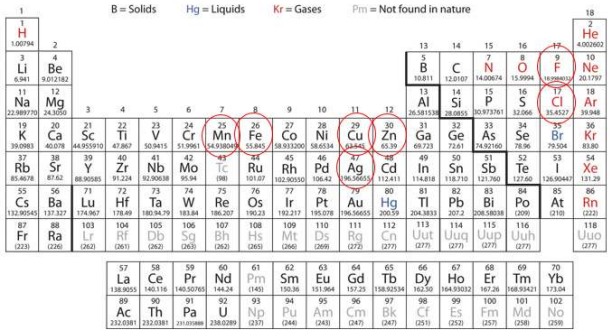


Figure ***Page*3.3.4**: Image by Saylor Academy is licensed under CC BY-NC-SA 3.0 (image modified by COC OER)

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

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

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

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

Disinfection

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

Physical Disinfectants

While not common, microorganisms can be inactivated in water supplies through physical means. These include, but are not limited to ultraviolent rays, heat, and ultra-sonic waves. While all of these are physical means of inactivating harmful organisms,

they lack something chlorine and chlorine related compounds provide. These processes are good at the time of use but provide no long term protection from regrowth.

Non-chlorine Disinfectants

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

Chlorine and Chlorine Related Compounds

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

Distribution System Water Quality

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

Distribution Sampling

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

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

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

As part of the TCR, water utilities prepare sample siting plans. These plans identify the number of customers the utility serves, which in turn determines how many samples must be collected for total coliform bacteria. The sample locations and sampling frequency are also identified in these plans. Larger utilities can be required to sample dozens of locations on a weekly basis for total coliform bacteria as part of the TCR, while smaller utilities may just have to sample a few locations a month. At each location the disinfectant residual is also analyzed. This data can help determine if there is the potential for a problem within the distribution

system. Let's take a look at a hypothetical example. Suppose ten (10) locations per week are being sampled for total coliform bacteria and a chlorine disinfectant residual. Over three weeks, all the total coliform results come back negative (absent of total coliform bacteria), but the sampler has noticed a downward trend in the chlorine residual level at one of the sample locations. This sort of information can indicate a potential problem and maybe the next total coliform sample at this site will come back positive. This scenario doesn't necessarily mean something is wrong, but the sampler at least has data, which can be presented to other operators and may trigger some type of maintenance.

Distribution System Maintenance

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



Figure ***Page*3.3.5**: Image by Daniel Case is licensed under CC BY-SA 3.0

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



Figure ***Page*3.3.6**: Image by Barksdale Air Force Base is in the public domain

Water Quality Violations

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

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

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

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

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

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



Figure ***Page*3.3.7**: Image by Shaw Air Force Base is in the public domain

Nitrate Sampling Requirements

The SDWA states that nitrate must be sampled annually at each source entering the distribution system. If the result is more than half the MCL (>22.5 mg/L as NO3 or >5 mg/L as N) then quarterly sampling is required. Quarterly must continue until four (4) consecutive quarters yield results less than half the MCL.

Consumer Confidence Report (CCR)

The CCR is an annual report sent to all customers receiving water from a utility. This report provides information on the sources of supply, updates on new or emerging water quality regulations, health effects from contaminants found in their drinking water, levels for all contaminants found in the drinking water supply, and any violations which may have occurred. This CCR is very helpful in communicating to the public the safety of their water supply. The information within the report is from the prior calendar

year and must be sent to all customers by July 1 of the following year. The report also must be provided in each language spoken within the utility service area if the population speaking that language is greater than ten (10%) percent of the total population.



Figure ***Page*3.3.8**: Sample CCR – Photo by Tim Marshall on Unsplash (modified by COC OER)



Figure ***Page*3.3.9**: Sample CCR – Photo by rawpixel on Unsplash (modified by COC OER)

Sample Questions

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

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Page 3.4: System Design

Student Learning Outcomes

After reading this chapter, you should be able to:

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

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

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

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

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

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

Water Availability

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

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

Water Reliability

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

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

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

Water Quality

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

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

Location

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

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

Local, State, and Federal Requirements

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

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

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

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

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

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

Distribution System Layout

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

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

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

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

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

Distribution Design Configurations

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

Arterial Loop System

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

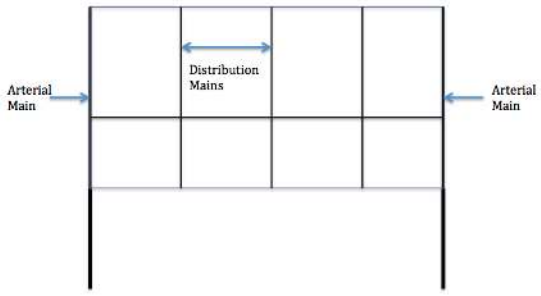


Figure ***Page*3.4.1**: Arterial Loop Distribution System by Mike Alvord is licensed under CC BY 4.0

Grid System

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

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

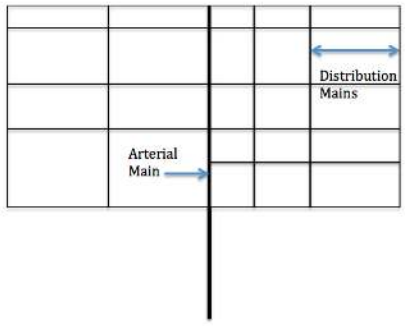


Figure *Page*3.4.2: Grid System by Mike Alvord is licensed under CC BY 4.0

Tree System

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

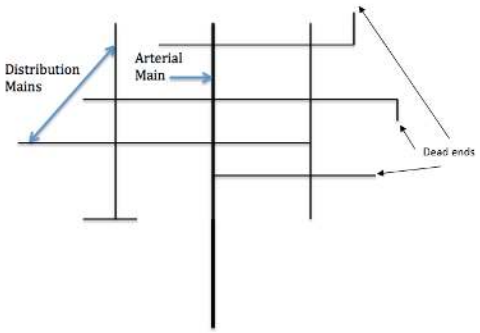


Figure *Page*3.4.3: Tree System by Mike Alvord is licensed under CC BY 4.0

Appurtenances

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

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

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

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



Figure *Page*3.4.4: Image by the Anderson Air Force Base is in the public domain

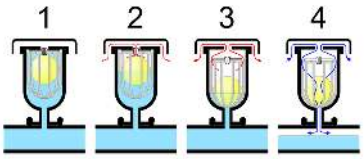


Figure *Page*3.4.5: Image by Shigeru23 is licensed under CC BY-SA 3.0



Figure *Page*3.4.6: Elbow pipe fitting – Image by Cschirp is licensed under CC BY-SA 3.0



Figure *Page*3.4.7: Downtown Charlottesville Fire Hydrant by Ben Schumin is licensed under CC BY-SA 2.5

Water System Demands

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

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

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

Fire Flow Demands

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

Network Analysis

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

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

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

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

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

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

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

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



Figure ***Page*3.4.8**: Image by Los Angeles Fire Department is licensed under CC BY-ND 2.0



Figure *Page*3.4.9: Image by Mike Alvord is licensed under CC BY 4.0

Mapping (Plans)

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

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

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

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

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

Sample Questions

1. Which of the following is the most desirable system configuration?
    1. Arterial loop
    2. Tree
    3. Grid
    4. Depends on the system
2. Dead-ends cause _____.
    1. Restricted flow
    2. Stagnant water
    3. Water outages during breaks
    4. All of the above
3. Blow offs should be installed _____.
    1. At high points
    2. Low points
    3. Regular intervals
    4. Only on large main lines
4. Air and vacuum valves should be installed _____.
    1. At high points
    2. Low points
    3. Regular intervals
    4. Only on large main lines
5. ISO stands for _____.
    1. Insurance Services Organization
    2. Insurance Services Office
    3. Insurance Standards Organization
    4. Insurance Standards Office

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Page 3.5: Pipelines

Student Learning Outcomes

After reading this chapter, you should be able to:

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

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

- Transmission Piping
- Distribution Piping
- Service Piping

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

Transmission Piping

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



Figure ***Page*3.5.1**: Image by James T M Towill is licensed under CC BY-SA 2.0

Distribution Piping

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

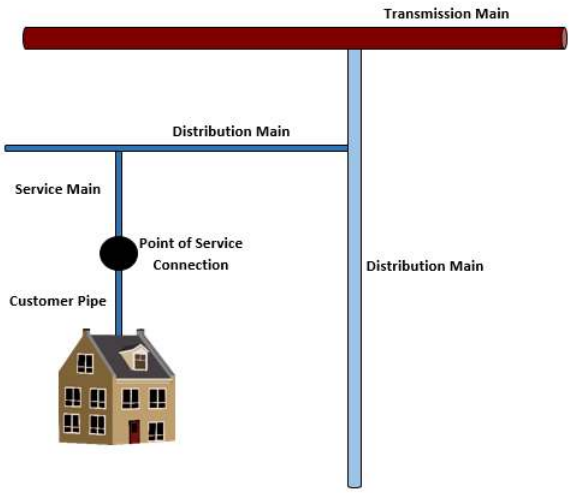


Figure *Page*3.5.2: Image of house by rdevries is licensed under CC0 1.0 (modified by COC OER)

Service Main

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

Pipe Selection

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

Pipeline Materials

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



Figure *Page*3.5.3: Image by John Newcomb is licensed under CC BY 3.0

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

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



Figure ***Page*3.5.4**: Image by Andrew Curtis is licensed under CC BY-SA 2.0

Ductile Iron Pipe

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



Figure ***Page*3.5.5**: Image by Yeti Hunter is licensed under CC BY-SA 4.0



Figure ***Page*3.5.6**: Image by Frankemann is licensed under CC BY-SA 4.0

Steel Pipe

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



Figure *Page*3.5.7: Image by Mike Alvord is licensed under CC BY 4.0

Asbestos-Cement Pipe

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



Figure *Page*3.5.8: Image by DDanielsson and Wayne Eddy is licensed under CC BY-SA 3.0

Polyvinyl Chloride Pipe

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



Figure *Page*3.5.9: Image by Pam Broviak is licensed under CC BY-SA 2.0

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

Pipeline Connections

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



Figure ***Page*3.5.10**: Image is in the public domain



Figure ***Page*3.5.11**: Image by Dwight Burdette is licensed under CC BY 3.0

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

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

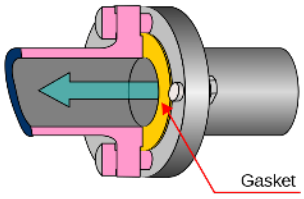


Figure ***Page*3.5.12**: Image by Mysid is in the public domain



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Figure ***Page*3.5.14**: Image by Brandonrush is licensed under CC BY-SA 4.0



Figure ***Page*3.5.15**: Image by Markus Schweiss is licensed under CC BY-SA 3.0

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

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Figure *Page*3.5.16: Image by Tech. Sgt. Michael Boquette of the U.S. Air Force is in the public domain

Sample Questions

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

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Page 3.6: Valves

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

Student Learning Outcomes

After reading this chapter, you should be able to:

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

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

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

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

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

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

Types of Valves

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

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

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

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

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

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

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

What Differentiates the Various Types of Valves?

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

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

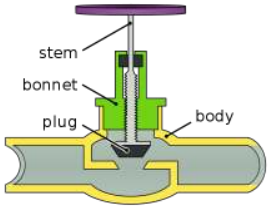


Figure ***Page*3.6.1**: Image by Petteri Aimonen is in the public domain

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

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

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

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



Figure ***Page*3.6.2**: Image by HerbstrittM is licensed under CC BY-SA 3.0

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

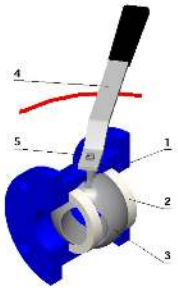


Figure ***Page*3.6.3**: 1) Body 2) Head 3) Ball 4) Lever handle 5) Stem - Image by Ruben Castelnuovo licensed under CC BY-SA 3.0

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

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

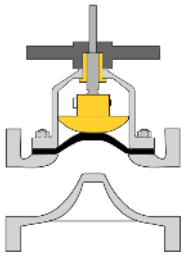


Figure ***Page*3.6.4**: Image by Muskid is licensed under CC BY-SA 3.0

Gate Valves

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



Figure ***Page*3.6.5**: Image by COC Water Systems Technology Faculty is licensed under CC BY 4.0



Figure ***Page*3.6.6**: Image by Heather Smith is licensed under CC BY 3.0

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

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



Figure ***Page*3.6.7**: Image by Mike Alvord is licensed under CC BY 4.0

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



Figure ***Page*3.6.8**: Image by Mike Alvord is licensed under CC BY 4.0

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



Figure ***Page*3.6.9**: Image by Rainier5 is licensed under CC BY-SA 3.0

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

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

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

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

Other Valves

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

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

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



Figure ***Page*3.6.10**: Image by Heather Smith is licensed under CC BY 3.0

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

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

Relieving and Controlling Pressure

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

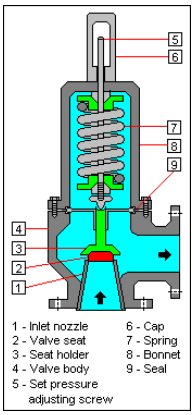


Figure ***Page*3.6.11**: Image by Mbeychok is licensed under CC BY-SA 3.0

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

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



Figure ***Page*3.6.12**: Image by Markus Schweiss is licensed under CC BY-SA 3.0

Backflow Prevention

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

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

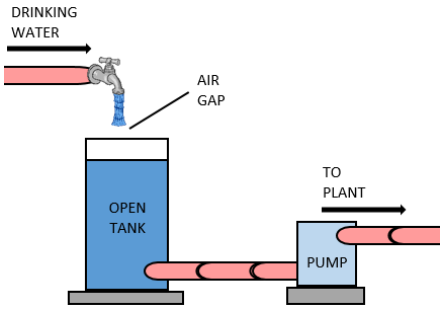


Figure ***Page*3.6.13**: Faucet image by frankes is licensed under CC0 1.0 (modified by COC OER)



Figure ***Page*3.6.14**: Images by the Ohio EPA

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

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

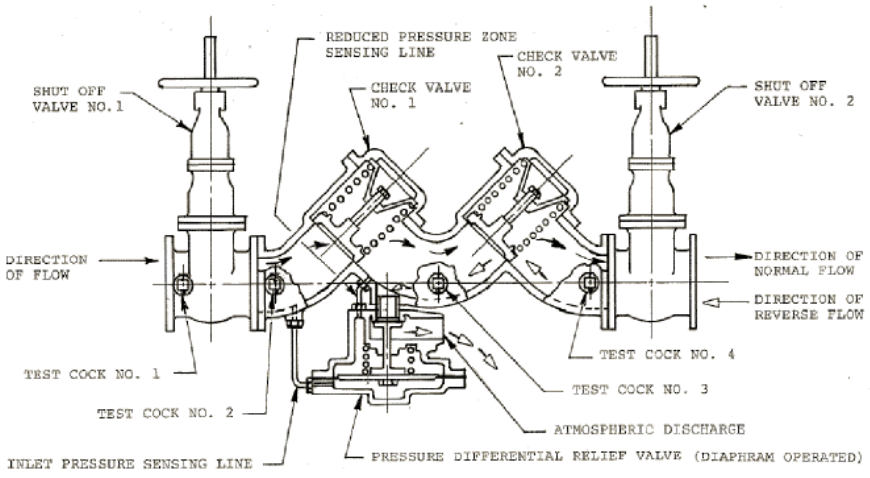


Figure ***Page*3.6.15**: Image by the Ohio EPA



Figure ***Page*3.6.16**: Image by the Ohio EPA

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

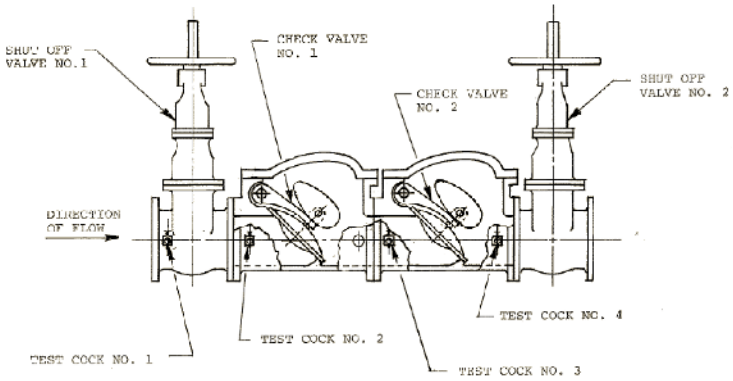


Figure ***Page*3.6.17**: Image by the Ohio EPA



Figure *Page*3.6.18: Image by the Ohio EPA

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

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

Valve Maintenance

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

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

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

Sample Questions

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

1. Butterfly
2. Gate
3. Ball
4. All are compatible

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

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Page 3.7: Hydrants

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

Student Learning Outcomes

After reading this chapter, you should be able to:

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

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



Figure ***Page*3.7.1**: Photo by Ashim D'Silva on Unsplash

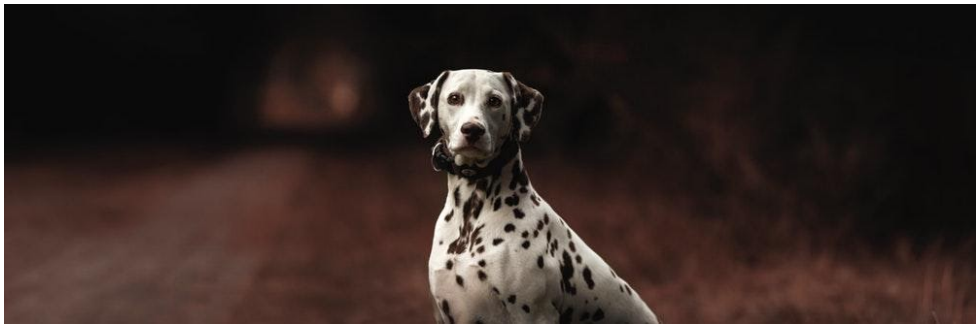


Figure ***Page*3.7.2**: Photo by Tim Zänkert on Unsplash

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



Figure ***Page*3.7.3**: Image by Matt Gregory is licensed under CC BY-ND 2.0

Fire Hydrant Uses

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

Flushing Water Pipelines, Storm Drains, and Sewers

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

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

Street Sweeping and Landscape Watering

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



Figure *Page3.7.4*: Image by Ildar Sagdejev is licensed under CC BY-SA 4.0

Construction

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

Is Water From Fire Hydrants Free?

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

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



Figure ***Page*3.7.5**: Image by the U.S. Air Force is in the public domain

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

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

Parts of a Fire Hydrant

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



Figure ***Page*3.7.6**: Image by Ben Schumin is licensed under CC BY-SA 2.5 (modified by COC OER)



Figure ***Page*3.7.7**: Image by the U.S. Air Force is in the public domain

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



Figure *Page*3.7.8: Image by FEMA is in the public domain

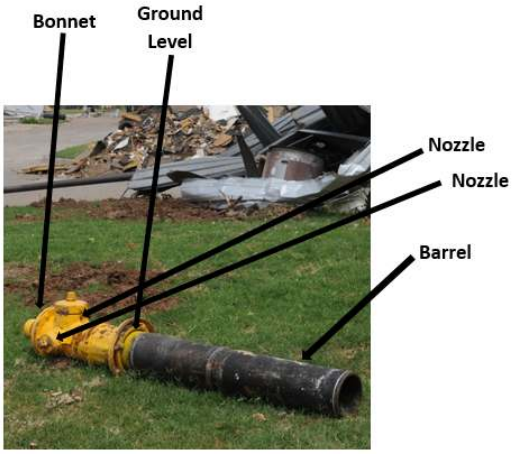


Figure *Page*3.7.9: Image by FEMA is in the public domain

Types of Fire Hydrants

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

Dry Barrel Hydrants

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

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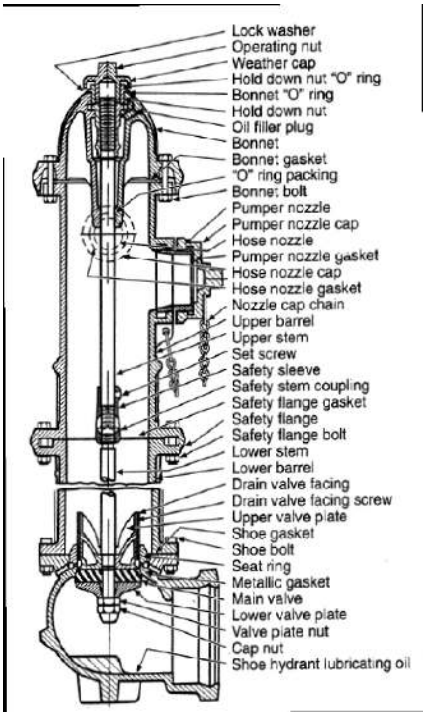


Figure ***Page*3.7.10**: Dry Barrel Fire Hydrant - Image by the U.S. Fire Administration is in the public domain

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

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

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

Wet Barrel Hydrants

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

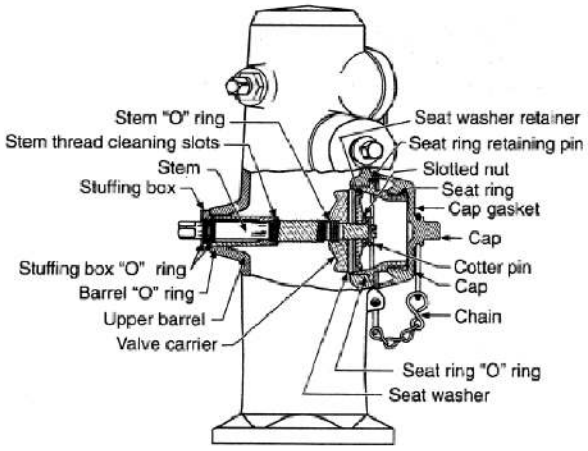


Figure ***Page*3.7.11**: Wet Barrel Fire Hydrant - Image by the U.S. Fire Administration is in the public domain

Locating Fire Hydrants

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

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

Potential Problems

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

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

Sample Questions

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

1. Bonnet
2. Cap
3. Nozzle
4. Bury-El

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

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Page 3.8: Meter Services

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

Student Learning Outcomes

After reading this chapter, you should be able to:

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

Why Water Meters?

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

Purpose of a Water Meter

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

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

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

Types of Water Meters

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

Positive Displacement Meters

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

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

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

Velocity Meters

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

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

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

Venturi and Orifice Meters

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

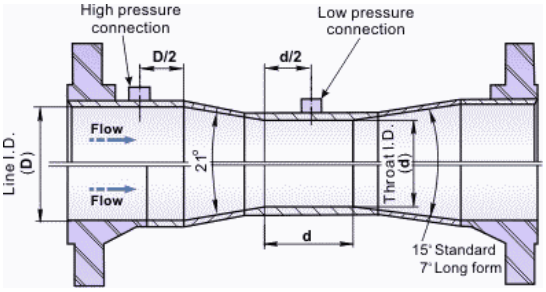


Figure ***Page*3.8.1**: Image by Aadilnashit is licensed under CC BY-SA 4.0

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

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Magnetic and Ultrasonic Meters

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



Figure ***Page*3.8.2**: Image by Mike Alvord is licensed under CC BY 4.0

Weirs and Flumes

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



Figure ***Page*3.8.3**: Image by Risker is licensed under CC BY-SA 3.0



Figure *Page*3.8.4: Image by A. Balet is licensed under CC BY 3.0

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

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



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



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Compound Meters

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



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Meter Selecting and Installation

As previously mentioned, meters are often selected based on the volume of water needing to be measured. Meters are commonly one size smaller than the diameter of size of the service lateral. For example, if the service lateral is 1” in diameter serving a residential home, the meter might be ¾” in size. In a typical residential housing track, it is common to have 1” service laterals and ¾” meters. However, in commercial areas, the service lateral might be sized for greater usage compared to residential units, but still might have smaller meters. For example, a 2” service lateral might be installed for a bookstore where the only usage might be a single restroom and a ¾” meter might be installed. However, if this bookstore changes the use to a restaurant and higher flows are required, the service lateral is already sized appropriately and only the meter would need to be replaced with a larger one. Therefore, it is important to size services for future potential uses.

Residential meters are typically 5/8” or ¾” in size depending on water demand. However, in some communities, residential homes might require internal fire sprinkler systems, in which case the meter size might need to be larger. There are various plumbing codes for sizing meter services and can also be dependent on the number of internal plumbing fixtures. Commercial businesses and multi-family residential homes commonly have meter sizes of 1”, 1 ½”, and 2”. If accuracy at low rates is not important and if typical flow rates between 5 % and 35% of the maximum rated capacity then a positive displacement style of meter is adequate. If accuracy of low flows is required, as well as being able to accurately measure higher flows then a compound meter should be used. Installations requiring large capacity and low flow accuracy, and flows at 10% to 15% maximum rating then a turbine meter should be selected.



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



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Figure ***Page*3.8.10**: Flanged Water Meter - Image by COC Water Systems Technology Faculty is licensed under CC BY 4.0

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



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

Meter Reading

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



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

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

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

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

Meter Testing

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

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

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

Sample Questions

1. Which of the following meters would be most likely to over-register?
    1. Turbine
    2. Positive displacement
    3. Multi-jet
    4. All of the above
2. A compound meter is used when _____.
    1. Low flow accuracy is required
    2. High flow accuracy is required

3. Constant high velocities at low flows are required
4. Both 1 and 2

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

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Page 3.9: Pumps

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

Learning Outcomes

After reading this chapter, you should be able to:

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

Purpose of a Pump

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

Positive Displacement Pumps

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

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

Variable Displacement Pumps

Variable displacement pumps deliver the same volume or flow of water against any head pressure within the operating capacity. Typical types are piston (reciprocating) pumps and screw or squeeze displacement (diaphragm) pumps. There are various types of variable displacement pumps and include; jet, turbine, and centrifugal. The most common in the water industry are turbine and centrifugal.

Centrifugal Pumps

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

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

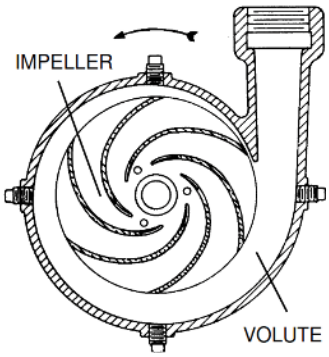


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The impeller of a centrifugal pump is either open, semi-open, or closed design. Open impellers are generally used to pump raw water. This is because raw water may carry with it some solids, which would damage the other impeller designs. Semi-open impellers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

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

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

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

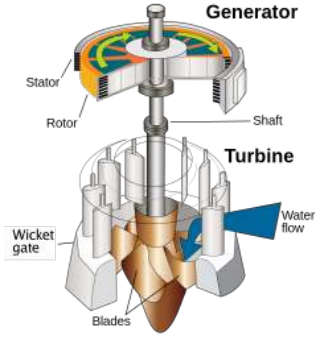


Figure *Page*3.9.2: Image by the U.S. Army Corps of Engineers is in the public domain

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

Pump Components

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

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

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

Casing

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

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

Single-Suction and Double Suction Pumps

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

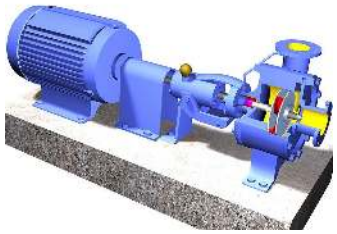


Figure ***Page*3.9.3**: Single-Suction Pump - Image by Kaze0010 is licensed under CC BY-SA 3.0

Impeller

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

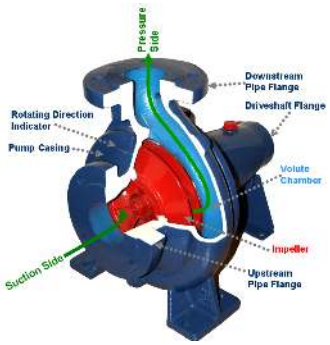


Figure ***Page*3.9.4**: Image by Fantagu is in the public domain

Wear Rings

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

Shaft and Shaft Sleeves

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

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

Packing Rings and Stuffing Box vs Mechanical Seals

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

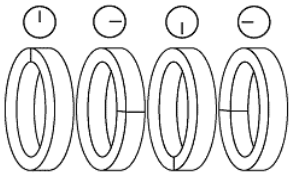


Figure ***Page*3.9.5**

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

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

Bearings

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

Couplings

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

Pump Operation

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

Cavitation

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

Avoiding Cavitation

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

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

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

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

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

Sample Questions

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

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Page 3.10: Wells

Student Learning Outcomes

After reading this chapter, you should be able to:

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

Groundwater Sources of Supply

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

Aquifers

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

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

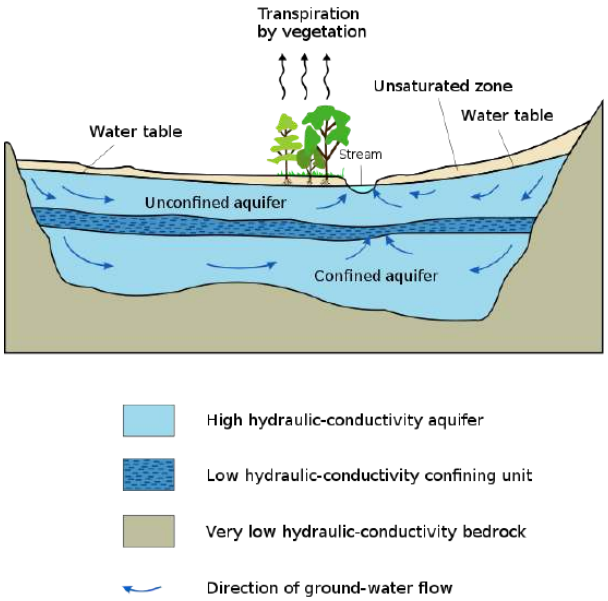


Figure ***Page*3.10.1**: Image by the USGS is in the public domain

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

Wells

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



Figure ***Page*3.10.2**: Image by Didiervberghe is in the public domain



Figure ***Page*3.10.3**: Image by SuSanA Secretariat is licensed under CC BY 2.0

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

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

Well Components

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

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

Well Casing Vent

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

Gravel Tube

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

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

Sounding Tube

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

Pump Pedestal

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

Pump Motor Base

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

Sampling Taps

Drain Line (Discharge to waste)

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

Casing

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

Conductor casing

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

Annular seal

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

Intake section

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

- Non clogging slots/screen
- Resistant to corrosion

- Sufficient collapse strength
- Resistant to encrusting
- Low head loss
- Prevent sand from entering

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

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

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

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

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

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

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

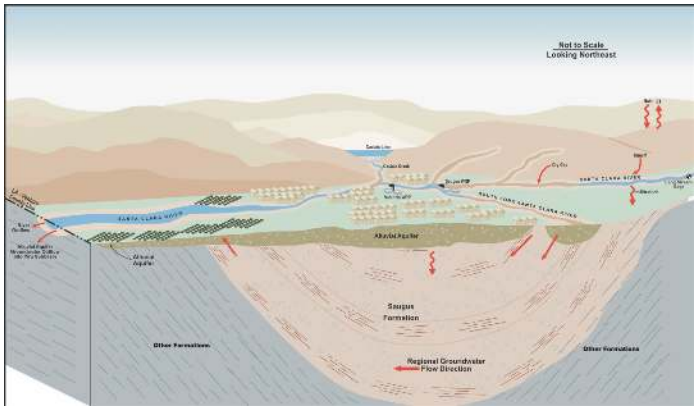


Figure *Page*3.10.4: Source: Adapted by LACSD from the Task 2A - Conceptual Model Development East and Piru Subbasins Final Report by CH2M HILL 2006

Well Drilling

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

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

Cable Tool Method

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

California Stovepipe

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

Direct Rotary

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

Reverse Circulation Rotary

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

Air Rotary

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

Shallow Wells

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

Here is an animation of a well being constructed.

Well Pumps

A few terms should be defined before discussing the classification and types of pumps used for wells. These terms are general terms relating to the inlet and outlet side of all pumps. Pressure is the concept of a continuous force being exerted on or against an

object, while “head” is commonly used because it evaluates a pump’s capacity to do a job. For this discussion, both pressure and head will be considered interchangeable. Pressure is expressed as pounds per square inch (psi) and head expressed in feet.

Suction Head, Suction Lift, and Discharge Head

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

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

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

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

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

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

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

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

- 1 psi = 2.31 feet (head)

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

- 100 psi12.31 feet1 psi=231 feet

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

Measuring Groundwater Levels

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

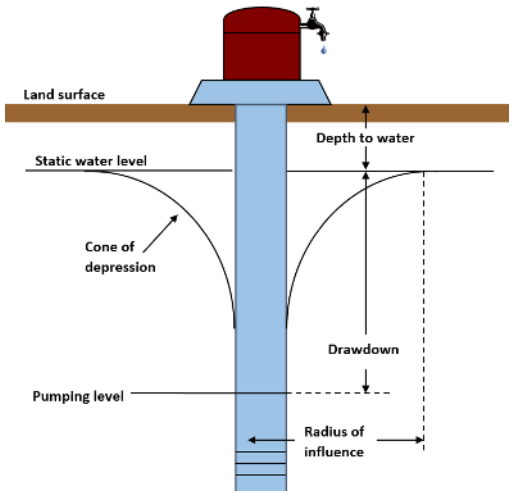


Figure *Page*3.10.5: Image by COC OER is licensed under CC BY 4.0

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

Sample Questions

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

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

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Learning Objectives

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

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

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

The Hydrologic Cycle

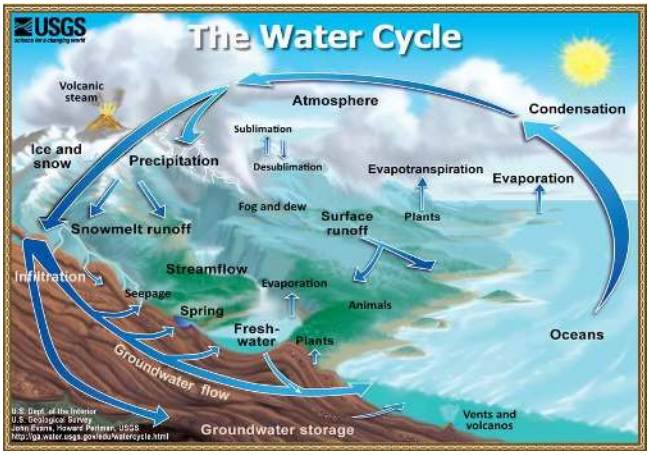


Figure ***Page*4.1.1**: The Water Cycle by the USGS is in the public domain

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

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

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

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

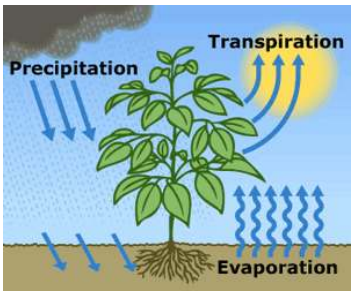


Figure ***Page*4.1.2**: Image by the USGS is in the public domain - Evapotranspiration is the sum of evaporation from the land surface plus transpiration from plants. Precipitation is the source of all water

Groundwater

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

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

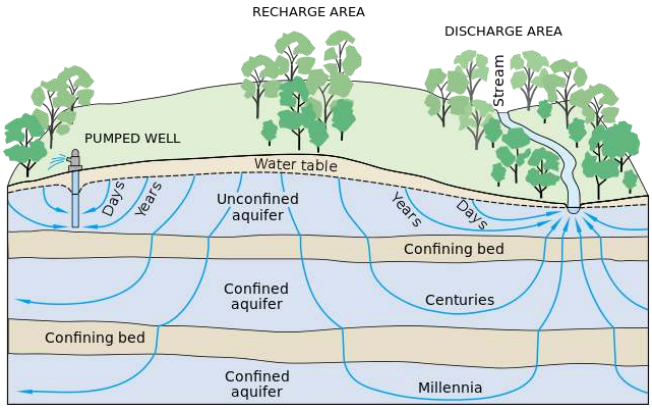


Figure ***Page*4.1.3**: Image by the USGS is in the public domain

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

Wells

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

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

Specific Capacity Calculation

$$\text{Specific capacity} = \text{Flow (GPM)} \div \text{Drawdown (ft)} \qquad \text{(Page 4.1.1)}$$

Example *Page*4.1.1

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

Solution

This is a direct application of Equation Page 4.1.1

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

Surface Water

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

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

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

Natural Watercourses

Key Terms

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

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

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



Figure ***Page*4.1.4**: Image of the Colorado River by Paul Hermans is licensed under CC BY-SA 3.0



Figure ***Page*4.1.5**: Santa Clara River Map by Shannon1 is in the public domain

Lakes

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

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

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



Figure *Page*4.1.6: Image of Castaic Lake by Rehman is in the public domain

Introduction to Water Math

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

Table 1.1: Units and Conversion Factors

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

Working with Fractions

NumeratorDenominator

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

Rounding

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

Unit Dimensional Analysis

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

Example 1

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

48 inches11 foot12 inches=4 ft1

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

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

Example 2

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

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

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

Example 3

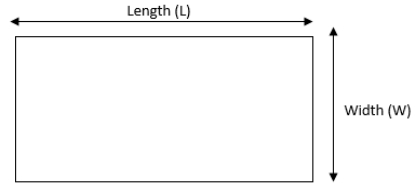
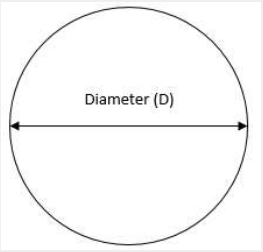
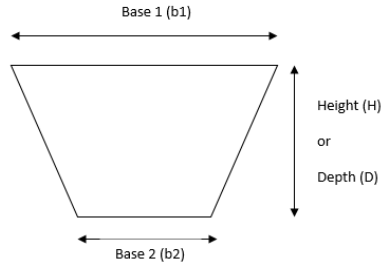
How many gallons are there in a tank which holds 300ft^3 of water?

300ft317.48 gal1ft3=2,244 gallons

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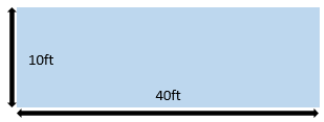
Area

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

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

Example 1

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

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

Example 2

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

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

Area = 3.14 x 50 x 50

Area = 7,850 ft^2

Equation #2 Area= .785 x d^2

Area = .785 x 100 x 100

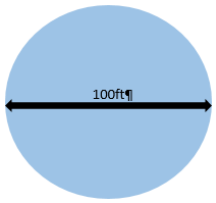
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Area = 7,850 ft^2

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

Example 3

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



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

Chapter Review

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

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

Math Questions

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

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

3. 45 Bags
4. 48 Bags

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Page 4.2: Water Chemistry and Standards

Learning Objectives

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

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

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

Matter, Elements, and Compounds

Matter

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

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

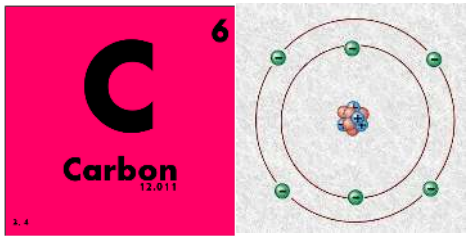


Figure ***Page*4.2.1**: (left) Carbon by Science Activism is licensed under CC BY 2.0. Figure ***Page*4.2.2**: (right) Carbon atom by Alejandro Porto is licensed under CC BY-SA 3.0

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

Most common elements in the water treatment profession:

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

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

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

Drinking Water Standards

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

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

Public Water Systems

There are three different categories of public water systems:

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

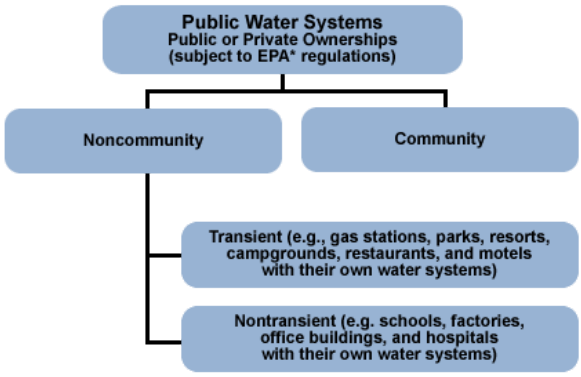


Figure ***Page*4.2.2**: Image by the CDC is in the public domain

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

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

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

Table 2.1: Recommended Levels for Contaminants and Characteristics

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

Source: Graph by the EPA is in the public domain

Public Notification

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

Violations

Tier I

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

Tier II

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

Tier III

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

Water Quality monitoring

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

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

Record Keeping

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

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

Variances and Exemptions

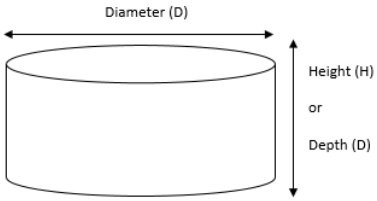
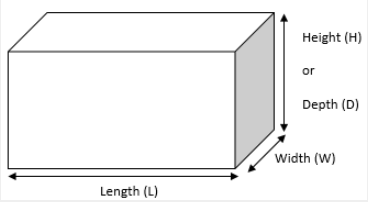
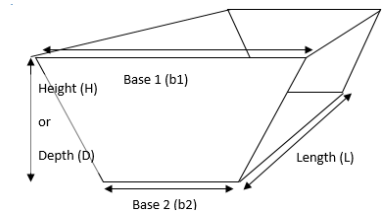
In the event a water system is unable to meet a MCL because of the source water, a primacy agency can grant a variance or exemption. The variance is only given when the agency has incorporated the best available technology and there is zero risk to public health. In the case of Flint Michigan, the new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

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

Volume

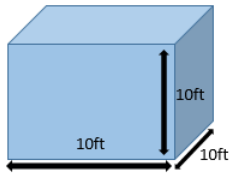
Volume calculations will become very common for water treatment operators. Operators use volume calculations to solve math questions with circles, triangles, and rectangles. If you look around a water treatment facility, it is full of geometric shapes. Tanks

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

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

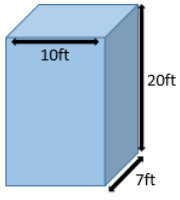
Example *Page*4.2.1

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

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

Example *Page*4.2.1

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

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

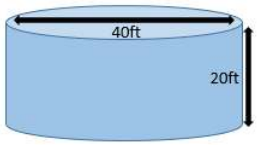
There are two different ways to solve cylindrical math problems. The easiest formula to use is volume= .785 d^2 H. This formula is easiest because in water math we are generally looking at the diameter of a cylindrical shape and not the radius. The

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radius of a circle is half the diameter. It is a straight line measured from the center of the circle to the edge of the circle. The diameter is a straight line that passes through the center of the circle with endpoints on the circle.

Example *Page*4.2.2

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



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

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

Example *Page*4.2.3

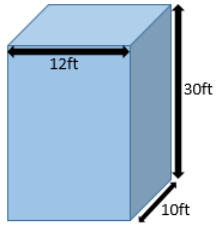
Convert the answer from Example ***Page*4.2.3** into gallons.

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

Answer: 187,898 gallons

Example *Page*4.2.4

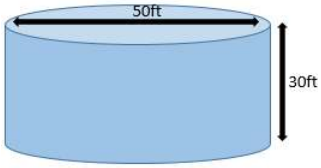
A rectangular water tank is full. The dimensions are 30ft high 12ft wide and a length of 10 ft. Convert to gallons.



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

Example *Page*4.2.5

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



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

Chapter Review

1. The smallest part of an element is known as _____.
    1. Proton
    2. Neutron
    3. Atom
    4. Nucleus

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

1. 0.5 mg/L
2. Zero
3. Public health goal
4. Detection Level for reporting

12. Primary Standards are based on _____

1. Color and Taste
2. Aesthetic quality
3. Public Health
4. Odor

13. A circular clearwell is 150 feet in diameter and 40 feet tall. The Clearwell has an overflow at 35 feet. What is the maximum amount of water the clearwell can hold in Million gallons rounded to the nearest hundredth?

1. MG
2. 4.62 MG
3. 18.50 MG
4. 7.50 MG

14. A sedimentation basin is 400 feet length, 50 feet in width, and 15 feet deep. What is the volume expressed in cubic feet?

1. 100,000 ft^3
2. 200,000 ft^3
3. 300,000 ft^3
4. 400,000 ft^3

15. A clearwell holds 314,000 ft^3 of water. It is 100 ft in diameter. What is the height of the clearwell?

1. 25 ft
2. 30 ft
3. 35 ft
4. 40 ft

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Page 4.3: Microorganisms

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

Surface Water Treatment Rule

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

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

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

Table 3.1: Waterborne Pathogens

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

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

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

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

Case Study: Milwaukee April 1993

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

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

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

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

Total Coliform Rule

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

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

Long-Term 1 Enhanced Surface Water Treatment Rule

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

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

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

Long-Term 2 Enhanced Surface Water Treatment Rule

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

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

Filter Back Wash Recycling Rule

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

Lead and Copper Rule

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

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

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



Figure ***Page*4.3.1**: Image of lead pipes by Borsi112 is licensed under CC BY-SA 3.0

Stage 1 and 2 Disinfectant Bi-Product Rule

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

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

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

*Maximum residual disinfectant level

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

*ppb- parts per billion ppm- parts per million

Consumer Confidence Reports

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

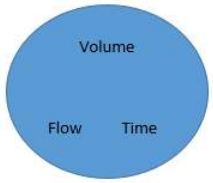
- System information including contact info
- Different sources of water (i.e. lakes, wells, rivers)
- Definitions non-water personnel can understand including MCL's, MCLG's and treatment techniques
- Any detected contaminants in the system along with a listing of the possible health effects if limits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

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

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

Flow Rate Calculation

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

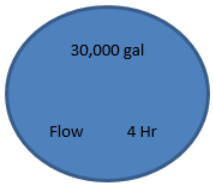


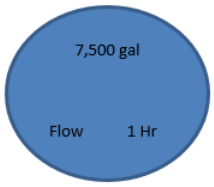
Flow Rate Equation
Flow Rate = Volume ÷ Time
The algebraic "Wheel" is a very effective way to solve many water math problems. Those students with more "mechanical" minds may find this way of solving math problems easier. Below is an example of how to solve a flow rate equation with both methods.

Example 1

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

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





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

Example 2 - Solve for Time

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

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

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

Example 3 - Solve for Volume

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

Volume = 3,000 GPM x 90 min

Volume = 270,000 gallons

Example 4

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

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

Flow Rate = 250,000 gallons/8 hours

Flow Rate = 31,250 gallons/1 hour

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

Chapter Review

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

4. No DBP formation

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

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Page 4.4: Coagulation and Flocculation

Learning Objectives

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

- Coagulant types
- Coagulation chemistry
- Mixing systems for both coagulation and flocculation
- Flocculation process theory
- Pounds formula

One of the most important steps in the water treatment process is the removal of suspended solids. The two-part process in water treatment involves chemical deactivation and physical removal of pathogenic organisms. The physical removal of pathogens is accomplished in several steps. The first two steps include the processes of **coagulation** and **flocculation**. In this process, colloidal particles are destabilized to gather all the suspended material together. They can also be referred to as **nonstable solids**. This process increases particle sizes which assists in removal during the filter process. The larger floc particles will be removed during the sedimentation and filtration process. Coagulation occurs very quickly in the rapid mix or flash mix process. The flash mix process only lasts several seconds as the coagulant rapidly mixes and reacts with the raw untreated water. The floc will gain in size during the second step of flocculation. Filtration cannot occur without proper coagulation and flocculation.

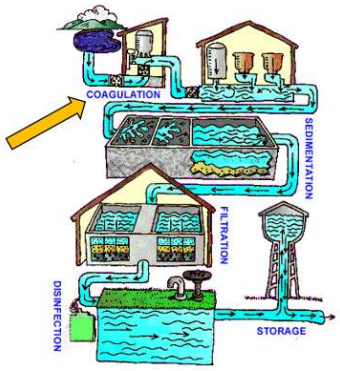


Figure ***Page*4.4.1**: Image of water treatment by the EPA is in the public domain

Coagulant Types

In general, two types of coagulants are used during coagulation. A **primary coagulant** and a **coagulant aid** will be used during the rapid mix process. The colloidal surfaces are negative thus positively charged metal salts are used as primary coagulants. The coagulant dissolves in water and ionizes. To ionize is when a molecule loses or gains an electron to form an ion. The three most common coagulants used in water treatment are Aluminum Sulfate (Alum), Ferric Sulfate, and Ferric Chloride. The most commonly used primary coagulant in water treatment is Alum because of its wide availability and affordability.

Synthetic polymers are often used as a coagulant and filter aid but have also been used as a primary coagulant. Operators use different charged groups of polymers known as cationic (positive), anionic (negative), and nonionic (without ionizable groups). Coagulation aids assist in the building of settable floc.

Important things to consider when choosing a polymer:

- Overdosing a polymer can decrease the efficiency of the coagulation process and cause filter binding and increased headloss in filters
- Not all supply water is created equal. Every single water source has a different chemistry and jar tests must be performed to see what polymer works best with the specific source water.
- There is no widespread standard for choosing a polymer. Different states have chemical approval standards that must be met.
- The addition of chlorine can effect polymer effectiveness
- As with any chemical, there is a dosage limit

Chemistry

Like many processes in water treatment, the theory of coagulation is very complex. As an operator, you should have a basic understanding of the chemistry involved in each process. The coagulant added to the water will react with the alkalinity in the water to form insoluble floc. Insoluble is something that will not dissolve. If the floc is not formed properly, then operators cannot effectively remove pathogens from the treated water. Alkalinity is not the same as pH. This gets very confusing as “alkaline water” has become a more widely popularized marketing term. Alkalinity is the water’s ability to neutralize an acid based on its makeup of carbonate, bicarbonate, or hydroxide. The measure of alkalinity is the amount of acid that would have to be added to water to lower the pH to 4.5 and there is where the confusion arises.

Coagulation is most effective in the pH range of 5-7 because of the waters ability to react with alkalinity. In this range, the water tends to buffer or stay in the same pH range and will allow the complete mixing of coagulant chemicals. If the raw water has a low pH, agents such as soda ash can be added to increase the pH.

Proper water quality tests must be performed by operators to promote the proper addition of coagulant chemicals. Underdosing coagulants will cause problems with floc formation while overdosing coagulants can cause clogging during the filter process. Clogged filters lead to head loss problems in the filters and increased filter washing.

Mixing

As noted earlier the coagulation process is completed within a matter of seconds. Mixing can be achieved by utilizing hydraulic mixers, mechanical mixing, diffusers, or pumped blenders. Hydraulic mixers use flow to achieve mixing. This kind of mixing requires enough flow to create a disturbance in the water to achieve proper mixing. Mechanical mixers require the greatest amount of energy because they require an electrical source to achieve mixing. Diffusers apply uniform flow during the coagulation process but may require many adjustments after flow changes. Finally, pumps can be used to push coagulant into water flow. Mixing can occur in a basin, channel, or pipeline.

Flocculation

Flocculation is the slow mixing process that causes smaller particles to merge into larger particles that settle more easily. The particles are then more easily removed in the sedimentation and filtration process. The process of flocculation is achieved by controlling the rate of impacts between particles as they gain size. Floc size can range between 0.1 mm-3 mm. The size of the floc produced depends on which type of treatment process is utilized at a specific plant. It is important that floc has good size but also density so the floc will not shear during the sedimentation and filtration process. This process is much longer than coagulation lasting roughly 15-45 minutes.

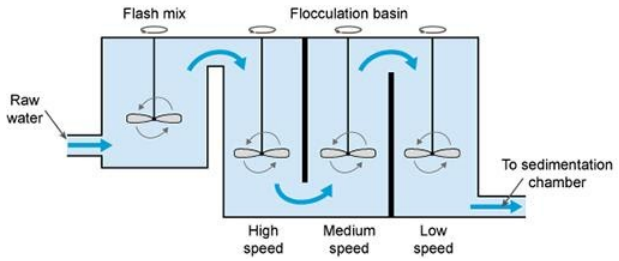


Figure ***Page*4.4.2**: The coagulation–flocculation process by The Open University and partners is licensed under CC BY-NC-SA 4.0

Shown Above: The flash mix portion is also known as coagulation. The chemicals are added together and the process occurs within seconds. After flash mix, the water heads to the flocculation basins to allow floc particles to gather in size.

Mechanical flocculators can be installed both horizontally and vertically. The horizontal type utilizes paddle-style mixers while the vertical style mixers can include paddle, turbine, and propeller style mixers. The shape and size of a flocculation basin is determined by the type of mixing used and the adjacent structures such as the sedimentation basins. Flocculation basins are usually split into 3 compartments. The speed of the mixing is decreased in each compartment to prevent the particles from breaking apart as they become larger. If the particles break apart during flocculation, the particles will place a heavier burden on the filters during the filtration process causing lower filter run times. This phenomenon will be discussed in further detail in Chapter 6.

Monitoring and Process Control

The coagulation and flocculation process requires a great amount of attention to detail along the way. An operator cannot just set a dose and "hope" everything works out. Water quality can change frequently and operators must ensure they are on top of changing conditions. One way an operator can achieve this is through jar testing. This is a laboratory procedure that finds the best coagulant dose based on water quality conditions.



Figure ***Page*4.4.3**: Image of a jar test by Jigchen L. Norbu is licensed under CC BY-SA 4.0

The efficiency of water treatment plants is determined by the combined effluent turbidity reading. Individual filter efficiency is also closely monitored. This will be discussed at length in the filtration chapter of the text, but it's important to have a basic grasp of that concept at this point in the treatment process. Water treatment is a lengthy process. What's occurring right now can have grave impacts down the line in the treatment process. Because of this consideration, jar testing and plant monitoring is all the more critical. Jar testing and laboratory grab sampling ensure the water which is theoretically being treated now, will be safe when entering the distribution system hours from now.

During abnormal conditions, it is important for operators to take notes and inform senior operators and/or a supervisor. Record keeping is important because operators can go back to notes used from previous experiences. For example, a large rain event has changed the influent turbidity entering the treatment plant. A similar event happened three years prior and the influent turbidity is very similar to the ones operators are seeing currently. Wouldn't it be nice to have a record of what the operators did three years ago? Hopefully, the operations staff from three years ago noted changes in coagulant dose, mixing speeds, chlorine demand, and other significant plant changes.

Enhanced Coagulation

The **enhanced coagulation** process is used to remove natural organic matter by adjusting the pH and coagulant dose to remove the greatest amount of suspended matter during the treatment process. The addition of acid is used to achieve the proper pH unlike sweep treatment were the operator overdoses the coagulant to achieve the correct pH range. Enhanced coagulation occurs at a lower pH. and accordingly will see improvements in treatment such as:

- Humic and fulvic molecules separate better with lower pH. Humic and fulvic acids are organic acids commonly found in raw water sources
- Less coagulant is required for treatment
- Flocculation improves at a lower pH
- Sulfuric Acid addition before coagulant is added preconditions organic matter

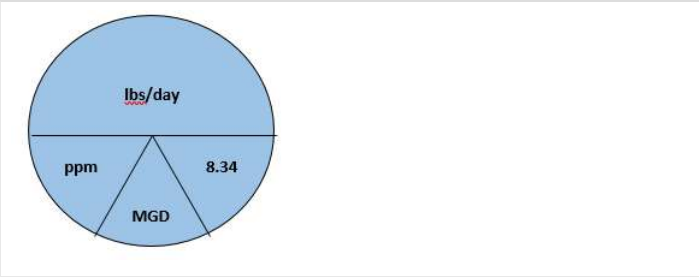
The Pounds Formula (Chemical Dosage Problems)

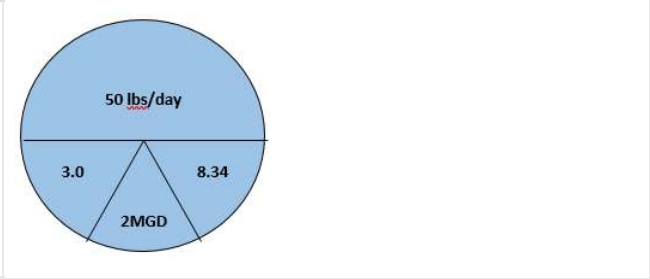
One of the most important calculations an operator will use is the "Pounds Formula." The pounds formula can be used to solve water math problems including milligrams per liter to pounds per day, feed rate, chlorine dosage, percent strength, and dilution calculations. The formula for the pounds calculations is:

$$\text{Feed Rate (lbs/day)} = \text{dosage (parts per million)} \times \text{Flow Rate (million gallons per day)} \times 8.34 \text{ lbs/gal}$$

Below is the pounds formula expressed in a mechanical wheel. The mechanical wheel can be used to solve a chemical dosage problem by plugging in the given information and then multiplying or dividing as indicated to determine the solution. For example,

a treatment plant will produce 2 MG a day. The chlorine dose is 3.0 mg/L. How many pounds of chlorine will the operator use?





$$\text{Feed Rate} = 3.0 \times 2 \times 8.34$$

$$\text{Feed Rate} = 50 \text{ lbs/day}$$

It is important to note that when using the pounds formula, the water production is always expressed in MGD. For example, a problem may ask what the chlorine production is for a water treatment plant that produces 1,000,000 gallons a day. This is the easiest expression because 1,000,000 ÷ 1,000,000 = 1.

EX: A water treatment operator must super chlorinate a 650,000-gallon tank at 50 ppm. How much chlorine must the operator add?

$$50 \times .65 \times 8.34 = 271 \text{ pounds}$$

* You must divide 650,000 by one million to get .65 to solve the equation. Round to the nearest tenth or hundredth place to get the most accurate answer. Remember you must show all work during exams to get credit but the format is still multiple choice so be careful when rounding.

Practice Pounds Formula Problems

Example *Page*4.4.1

The dry alum dosage rate is 15 mg/L. The daily flow rate of a treatment plant is 5 MG. How many pounds of dry alum per day is required?

Solution

$$\text{Feed Rate} = 15 \text{ mg/L} \times 5 \text{ MGD} \times 8.34 \text{ lbs/gal}$$

Feed Rate = 625.5 lbs/Day

* This sample problem is pretty simple. Plug the numbers into the equation and multiply to get your answer.

Example *Page*4.4.2

A treatment plant uses 300 lbs of alum a day. The plant output is 2,500,000 gallons a day. What is the dose?

Solution

Step 1: 2,500,000 ÷ 1,000,000 = 2.5 MGD

Dose = 300 lbs/day/(2.5 × 8.34)

Dose = 250/20.85

Dose = 12 mg/L

Example *Page*4.4.3

How many pounds of 65% available chlorine must an operator add to a treatment plant with a dose of 3.0 mg/L and a plant output of 5 MGD?

Solution

https://workforce.libretexts.org/@go/page/51245

* Start the equation as you normally would. Since you are adding a solution of chlorine that is not 100 percent an extra step is needed to solve the problem. Remember, if the chlorine solution is not 100 percent available chlorine you are going to need more to dose properly!

Feed Rate = 3.0 × 5 × 8.34 = 125 lbs/day

Next, you will need to make an adjustment based on chlorine strength.

(.65)(x lbs/day) = 125 lbs/day

x = 125.65

x = 192 lbs/Day

Note: If the number is smaller than the original number, you multiplied instead of dividing. You will always need more chemical if it's not 100% strength.

Example *Page*4.4.4

A water tank that is 30 ft high and 100 f in diameter must be dosed at 50 ppm for disinfection. How many pounds of 65% calcium hypochlorite must be added to dose the tank?

Solution

$$0.785 \times 100\text{ft} \times 100\text{ft} \times 30\text{ft} \times 7.48\ \text{Gal/ft}^3 = 1{,}761{,}540\ \text{gallons}$$

1,761,540 gallons/1,000,000 = 1.76MGD

Feed Rate = 50 × 1.76 × 8.34 = 733.92 pounds/day

(.65)(x) = 734

x = 734/.65

x = 1129 lbs

Chapter Review

1. The optimal coagulant dose is determined by a _____.
    1. Chlorine test
    2. Flocculation test
    3. Jar test
    4. Coagulation test
2. The most common primary coagulant is _____.
    1. Alum
    2. Cationic polymer
    3. Fluoride
    4. Anionic polymer
3. Bacteria and viruses belong to a particle size known as _____.
    1. Suspended
    2. Dissolved
    3. Strained
    4. Colloidal
4. The purpose of coagulation is to _____.
    1. Increase filter run times
    2. Increase sludge
    3. Increase particle size
    4. Destabilize colloidal particles

https://workforce.libretexts.org/@go/page/51245

5. The purpose of flocculation is to _____.
    1. Destabilize colloidal particles
    2. Increase particle size
    3. Decrease sludge
    4. Decrease filter run times
6. Primary coagulant aids used in the treatment process are _____.
    1. Poly-aluminum chloride
    2. Aluminum sulfate
    3. Ferric chloride
    4. All of the above
7. Flocculation is used to enhance _____.
    1. Number of particle collisions to increase floc
    2. Charge neutralization
    3. Dispersion of chemicals in water
    4. Settling speed of floc
8. If there is a problem with floc formation, what would you consider changing?
    1. Adjust coagulant dose
    2. Stay the course
    3. Adjust mixing intensity
    4. Both 1 and 3
9. Which step in the treatment process is the shortest?
    1. Filtration
    2. Sedimentation
    3. Flocculation
    4. Coagulation
10. To lower the pH for enhanced coagulation the operator will add _____.
    1. Chlorine
    2. Sulfuric acid
    3. Lime
    4. Caustic soda
11. The flocculation process lasts how long?
    1. Seconds
    2. 5-10 minutes
    3. 15-45 minutes
    4. Over an hour
12. The function of a flocculation basin is to _____.
    1. Settle colloidal particles
    2. Destabilize colloidal particles
    3. Mix chemicals
    4. Allow suspended particles to grow
13. A treatment plant has a maximum output of 30 MGD and doses ferric chloride at 75 mg/L. How many pounds of Ferric Chloride does the plant use in a day?
    1. 18,765
    2. 17,765
    3. 19,765
    4. 16,765

https://workforce.libretexts.org/@go/page/51245

14. A treatment plant uses 750 pounds of alum a day as it treats 15 MGD. What was the dose rate?
    1. 4 mg/L
    2. 5 mg/L
    3. 6 mg/L
    4. 7 mg/L
15. A treatment plant operates at 1,500 gallons a minute and uses 500 pounds of alum a day. What is the alum dose?
    1. 18 mg/L
    2. 28 mg/L
    3. 8 mg/L
    4. 38 mg/L

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Page 4.5: Sedimentation

Learning Objectives

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

- Sedimentation process
- Zones of sedimentation basin
- Types of sedimentation basins
- Velocity math problems
- Detention time

Sedimentation is the 3rd step in a conventional treatment process. It occurs after coagulation and flocculation and before filtration. Sedimentation removes suspended solids with the use of gravity by slowing the flow of water down to allow material to settle. The settleable solids fall to the bottom of the sedimentation basin reducing the load on the filtration process. A sedimentation basin acts like a lake in the sense that it allows particles to settle naturally. Deeper lakes have much higher quality water entering the treatment plant because the water is able to "settle" for a longer period of time. Treatment plants that use imported water from higher turbidity water sources may be required to use conventional treatment with sedimentation for efficient treatment.

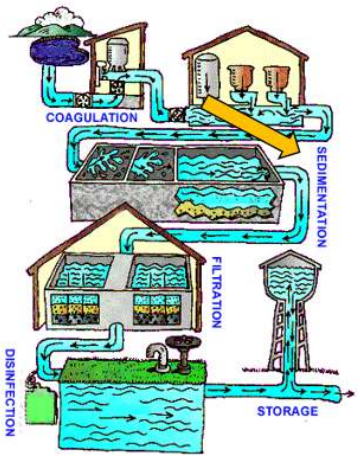


Figure ***Page*4.5.1**: Image of water treatment by the EPA is in the public domain

Factors affecting Sedimentation

Several factors can affect the sedimentation process including physical and environmental conditions. Increased pretreatment may be necessary when adverse conditions are present. Factors that affect the sedimentation process include the shape and size of particles, the density of particles, water temperature, particle charge, dissolved substances in the water, environmental effects, and characteristics of the basin.

As discussed in the previous chapter, smaller particles do not settle out easily and their size must be increased with coagulation and flocculation. The larger, denser particles created are called floc. Particles greater than .01 millimeters will settle in the sedimentation process. The shape of particles is also a consideration. Smoother particles with less jagged edges settle out quicker and easier.

Temperature decreases will cause the settling rate to decrease. The settling rate or velocity decreases when the water temperature is colder. Chemical dosage rates need to be adjusted during colder periods of the year or lower flows are necessary in the flocculation basins.

There are three types of currents, surface, density, and eddy, found in a sedimentation basin. Surface currents are caused by wind while density currents are caused by temperature differences and the concentration of solids. Eddy currents are caused by the influent and effluent flow of water in the sedimentation basin. Currents can be beneficial as they can help to promote the building of floc, but they can also cause uneven disbursements of solids throughout a sedimentation basin reducing the efficiency.

Sedimentation Zones

The four zones of a Sedimentation basin include:

- Inlet Zone: Where the water enters seamlessly from the flocculation basin. Water is distributed evenly throughout the sedimentation basin to prevent short-circuiting. Short-circuiting occurs when water entering a treatment process tank or basin quickly moves from influent to effluent reducing the waters detention time in a given process.
- Settling Zone: Is the largest part of a sedimentation basin. The water will stay here undisturbed for three or more hours while particles settle to the bottom.
- Sludge Zone: Located at the bottom of the settling zone. It is where settled particles collect in the form of sludge. Velocities at the bottom of the sludge zone should be minimized to prevent solids from re-suspending.
- Outlet Zone: The location where water seamlessly enters a channel or conduit. Launders also known as effluent troughs are used to collect the clarified or settled water.

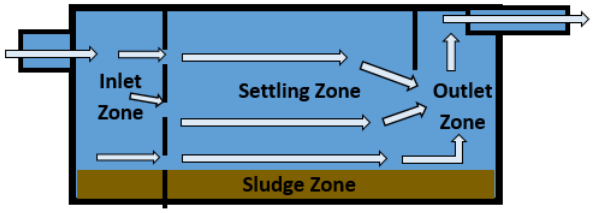


Figure *Page*4.5.2: Image by COC OER is licensed under CC BY

Types of Sedimentation Basins

There are several different types of basin designs available for engineers and planners when building a water treatment facility. Rectangular basins are typically found at large scale water facilities because of their predictable treatment and high tolerance to turbidity, color, and algae. They are cost-efficient, require lower maintenance, and have less short-circuiting issues. The figure above representing the different zones of a sedimentation basin is an example of a rectangular sedimentation basin.

Circular and square basins are used in areas where space is limited. They are sometimes called clarifiers and are subject to short-circuiting in the corners. The circular variety can also include up-flow clarifiers or solids contact clarifiers. In these types of clarifiers, the coagulation, flocculation, and sedimentation process all occur in the same basin or clarifier.

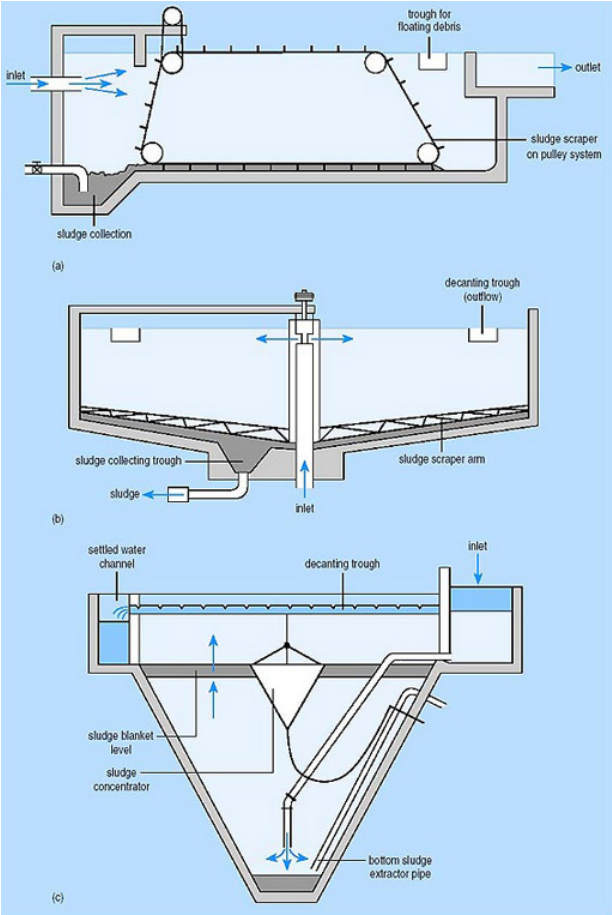


Figure ***Page*4.5.3**: Typical sedimentation tanks: (a) rectangular horizontal flow tank; (b) circular, radial-flow tank; (c) hopper-bottomed, upward flow tank – Image by The Open University is licensed under CC BY-NC-SA

Detention Time

Detention time is the amount of time it takes water to travel through a tank or sedimentation basin. It is also referred to as retention time. You will hear some operators use the terms CT and contact time interchangeably but it is incorrect. The term CT will be discussed in greater detail in Chapter 7. Detention time can be used to solve equations for time and flow. Formulas for both types of equations are listed below:

Detention Time (Hours) = Volume gal((24Hours/day))/Flow gal/day

Flow, gal/day = Volume((24Hours/day))/Detention Time, Hours

Reminder: Circular volume calculation (.785)(D ft)^2(Depth ft)

Rectangular Volume calculation: (L ft)(W ft)(D ft)

Answers will be in cubic feet so it will be multiplied by 7.48 gal/ft^3 to convert to gallons.

Example *Page*4.5.1

A rectangular sedimentation basin is 80 ft long by 25 ft wide and is 25 ft deep. The flow per day is 2.0 MGD. What is the detention time in hours?

Solution

Step One: calculate the volume of the basin (80 ft)(25 ft)(25 ft)(7.48 gal/cubic ft.) = 374,000 gallons

Step two: DT = (374,000 gal x 24 Hours)/2,000,000 gal day

Step Three: Detention Time = 4.5 hours

*Note: more complicated problems will have you solve for hours and minutes. Keep this in mind for future math equations that ask for more information.

.5 hours/1 x 60 min/1 Hour = 30 min

Example *Page*4.5.2

A circular basin is 100 ft in diameter. The basin is 25 ft deep and has a detention time of 4 hours. What is the flow per day?

Solution

Step one: Calculate volume .785(100 ft)^2(25 ft)(7.48 gal/cubic ft.) = 1,467,950 gal

Step Two: Flow = (1,467,950 gal x 24 Hours)/4 hours

Step three: Answer is 8,807,700 divide by 1,000,000 to get 8.807 or 8.8 MGD

Sludge Handling and Removal

Sludge that collects at the bottom of a sedimentation basin must be removed from time to time for several reasons. As discussed earlier in the chapter, sludge can become re-suspended after settling creating greater load on the downstream filter. Next, sludge buildup can cause the water source to become septic. In this scenario, microbiological growth occurs when oxygen supplies are depleted. Septic conditions can cause taste and odor problems in treated water and also require more chlorine during the disinfection process. Finally, the more sludge that builds up leads to decreased detention time because there is less area for the water to travel and for solids to settle out.

Larger plants will have to remove sludge at a greater rate and with the assistance of sludge removal equipment. Smaller plants may be able to remove sludge manually with portable sanitary pumps and squeegees and hoses to complete cleanup. The amount of time between cleanups can vary with the quality of the water source and the amount of water being treated. Consequently, shutdowns for sludge clean-up will vary dramatically from treatment plant to treatment plant.

Sludge removal equipment includes mechanical rakes, drag-chain and flights, and traveling bridges. The chain and flight system is used in rectangular basins. A chain with scrappers attached moves across the bottom of the basin collecting sludge and moving it to a sump. This system works well but has several moving parts. Additionally, the basin must be dewatered to perform maintenance. The traveling bridge system is also used in a rectangular basin. It travels the entire length of the basin. A pump is attached to the bottom of the system and sludge is pumped to a trough just below the top of the sedimentation basin. The bridge system is easier to perform maintenance on because the parts can be removed from the basin; therefore, dewatering the entire basin isn't required. Finally, mechanical rakes are used in rectangular or circular basins. A rake spans the entire length of the basin while spinning around the basin. Sludge is moved into a trough that can be pumped out or moved by gravity to a sludge collection tank.

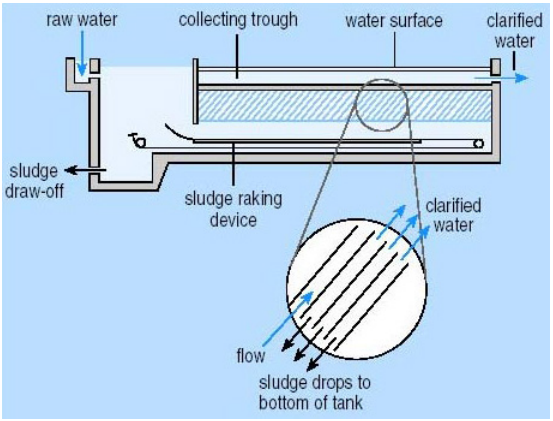


Figure *Page*4.5.4: Image by The Open University is licensed under CC BY-NC-SA

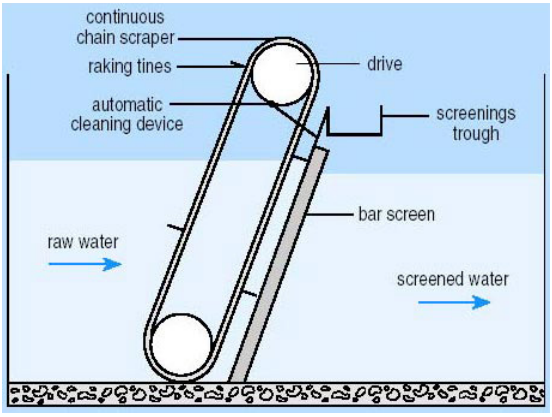


Figure *Page*4.5.5: Image by The Open University is licensed under CC BY-NC-SA

Review and Daily Operations of Sedimentation Basins

In review, the purpose of sedimentation is to allow suspended solids to settle through the physical process of gravity. The flow of water is slowed down to allow settling to occur. During the process, sedimentation can remove 95% or more of the total solid material operators remove during the entire water treatment process.

Water treatment plants with low turbidity or fewer than 10 turbidity units may find direct filtration or clarification to be a more cost-effective process. A reoccurring theme that should be noted throughout the text is the fact that all treatment facilities are different and the factor that dictates plant processes including facility building and day to day operation is the source water.

The settling characteristics of suspended material dictates how well sedimentation performs. Flow rate through the sedimentation basin drives performance as well as the control of sludge. High flow rates cause solids to carry over, and could also impact the sludge at the bottom of the sedimentation basin. Operators must perform regular jar testing and laboratory testing as well as operate sedimentation basins based on the designed capacity of the basin to ensure optimal performance. Improper operation of sedimentation basins will lead to increased load on downstream filters resulting in early filter washes, increased disinfectant use, and possibly tier violations.

Velocity Math

The movement of water is obviously an important thing to know if you are a water treatment operator. You will need Algebra to solve the next set of water math problems which will have two known values and one unknown value. Flow rates can be used to determine dosage rates, to identify daily averages, to dewater pipelines, to fill pipelines, and for future planning of distribution and treatment equipment.

To solve a flow problem, you need the diameter of the pipe and the velocity of the water (or liquid) in the pipe. Flow rate is expressed as Volume over Time. The equation will be:

$$Q(Flow) = A(area) \times V(velocity). \quad \textbf{(Page 4.5.1)}$$

A velocity problem occurs when the known value is the pipe diameter and flow rate of pipe.

$$V(Velocity) = Q(Flow) \div A(Area). \quad \textbf{(Page 4.5.2)}$$

Finally, pipe size is used when known value is pipe flow rate and velocity.

$$A(Area) = Q(Flow) \div V(Velocity). \quad \textbf{(Page 4.5.3)}$$

Proper use of dimensional analysis is critical when attempting to solve velocity equations. These types of problems often take multiple steps because answers need to be converted to the appropriate units based on the situation.

Example *Page*4.5.3

A pipeline is 18” in diameter and flowing at a velocity of 125 ft per minute. What is the flow in gallons per minute?

Solution

Step one: Convert pipeline diameter to feet: 18 inches/(12 inches/foot) = 1.5 ft

Step Two: Q(Flow) = (.785)(1.5ft.)2(125 ft./min)

Step Three: 221 ft^3 per minute × 7.48 gal/ft^3 = 1651 gpm

Example *Page*4.5.4

The flow of a pipe is 2,000 gallons per minute. The diameter of pipe is 24". What is the velocity of the pipe in ft. per minute?

Solution

Step one: Convert units 2,000 gpm ÷ 7.48 gal./ft^3 = 267 ft^3/min. 24 inches ÷ 12 inches/ft = 2 feet

Step two: V(velocity) = 267 ft^3/min ÷ .785(2 ft.)^2

Step three: V = 85 feet per minute

Example *Page*4.5.5

The velocity in a pipeline is 2 ft./sec. and the flow is 3,000 gpm. What is the diameter of the pipe in inches?

Solution

Step One: Convert flow to match units of measurement of velocity: 3,000 gal/min x 1 min/60 sec x 1 ft^3/7.48 gal = 6.68 ft^3/sec

Step two: Area= 6.68 ft^3/sec ÷ 2 ft/sec= 3.3 feet

Step three: Convert feet to inches: 3.3 ft/1 × 12 inches/1 ft = 40 inches

Chapter Review

1. The treatment process that involves coagulation, flocculation, sedimentation, and filtration is known as _____.
    1. Direct filtration
    2. Slow sand filtration
    3. Conventional treatment
    4. Pressure filtration
2. Sedimentation produces waste known as _____.
    1. Backwash water
    2. Sludge
    3. Wastewater
    4. Mud
3. What kind of process is the sedimentation step?
    1. Physical
    2. Chemical
    3. Biological
    4. Direct
4. The weirs at the effluent of a sedimentation basin are also called _____.
    1. Effluent weirs
    2. Baffling
    3. Launders
    4. Spokes
5. Sedimentation is used in water treatment plants to _____.
    1. Settle pathogenic material
    2. Destabilize particles
    3. Disinfect water

4. Reduce loading on filters

6. Scouring is a term that describes conditions in a sedimentation tank which _____.
    1. Could impact the rest of the treatment process
    2. Higher flow rates in the sludge zone
    3. Re-suspends settle sludge
    4. All of the above
7. The four zones in a Sedimentation basin include _____.
    1. Inlet, sedimentation, sludge, outlet
    2. Inlet, filter, waste, outlet
    3. Inlet, top, bottom, outlet
    4. Surface, sedimentation, sludge, outlet
8. Short-circuiting in a sedimentation basin could be caused by _____.
    1. Surface wind
    2. Ineffective weir placement, or weirs covered in algae
    3. Poor baffling in sedimentation inlet zone
    4. All of the above
9. How much solids should be removed during sedimentation?
    1. 95% or more
    2. 80-95%
    3. 70-80%
    4. 60-70%
10. The type of basin that includes coagulation and flocculation is _____.
    1. Rectangular
    2. Triangular
    3. Up-flow
    4. None of the above

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Page 4.6: Filtration

Learning Objectives

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

- Treatment technologies
- Filter media configurations and types
- Filter operation and backwashing
- Filtration math

Filtration is the final and most important removal requirement required by the Surface Water Treatment Rule (SWTR). Water passes through material such as sand, gravel, and anthracite coal to remove floc and disease-causing microorganisms from the finished water. Physical removal of colloids is also achieved during sedimentation but this filtration is the final step. This is the process where suspended colloidal particles are removed from the water. Along with removing possible pathogenic material in the water, removal of turbidity is also achieved which could hide pathogenic organisms and add color to the finished water.

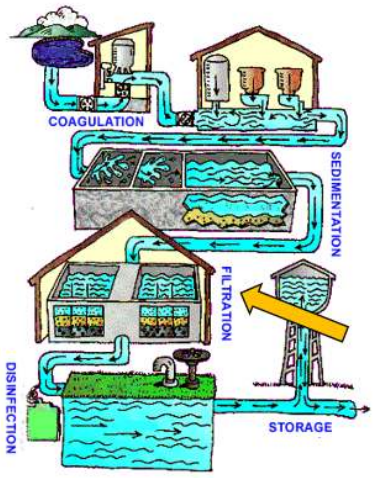


Figure ***Page*4.6.1**: Image of water treatment by the EPA is in the public domain

The SWTR sets forth guidelines for all public water agencies that use surface water as a source. Surface water was covered in chapter #1 and is any water open to atmosphere that is susceptible to runoff. The minimum requirements for treatment is disinfection, but most water sources do not meet these very stringent guidelines.

The effectiveness of filtration is based on several important factors. Proper filtration occurs based on incoming source water quality. For example a storm event near the source water could case higher incoming turbidity than the treatment plant is used to handling. Operational changes such as washing filters may be required. The physical and chemical characteristics of suspended material also come into play during treatment. Too much or too little chemical can lead to ineffective filtration. To follow the storm event example an operator may need to make changes to coagulant and polymer doses to account for increased turbidity and particulate entering the treatment plant. Finally the type of filtration used by a treatment facility is also very important. This decision is mostly out of operators hands as engineers and water quality experts will decide what the most effective treatment process is for the source water before building a treatment facility.

Pictured below is a filter in normal operation.

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Figure ***Page*4.6.2**

Treatment Technologies

There are four approved treatment technologies in the United States. The most widely used treatment technologies include conventional treatment, direct filtration, diatomaceous earth treatment, and slow sand filtration. Below are the descriptions:

Slow sand filtration facilities are becoming less common because of the large amount of time it takes to treat water and the large amount of space the facilities require. The filtration rates for slow sand filtration are .05 to .10 GPM/sq ft. Particles are adsorbed in a chemical layer known as a schmutzdeke. After an amount of time the biological layer must be manually removed by an operator or maintenance staff. The slow time and intensive labor make this treatment method the least ideal especially in areas with larger populations.

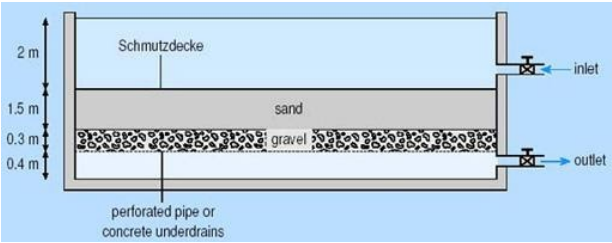


Figure ***Page*4.6.3**: Image by The Open University is licensed under CC BY-NC-SA

Diatomaceous Earth filtration is accomplished through pressure filtration. It can also be referred to as precoat filtration. The filter media in this case is added as slurry to the treatment vessel. Within the vessel lays a pipe known as a septum. The slurry attaches itself to the septum and water is run through the vessel where pathogenic and suspended material is captured and strained out of the finished water. This kind of treatment process is very common for swimming pool treatment and beverage companies. This type of treatment method is generally not used by larger municipalities because of the large amount of disposal of sludge and the continuous purchasing of filter media.

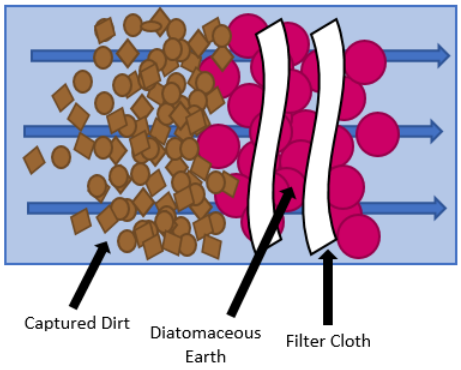


Figure ***Page*4.6.4**: Image by COC OER is licensed under CC BY

Gravity filtration is comprised of the final two approved Water Treatment technologies. Direct Filtration and conventional treatment are the most widely used treatment technologies in the United States. It is described as gravity filtration because the head pressure of the water forces the water to travel through filtered media in order to remove impurities from the drinking water. Direct Filtration differs from conventional treatment because the sedimentation process is skipped. Areas with source water higher in quality may opt for direct filtration to reduce costs and the amount of land space for sedimentation basins can be substantial. The average filtration rate for gravity filtration beds is 3.0 GPM/Sq. ft.- 6.0 GPM/ sq. ft.

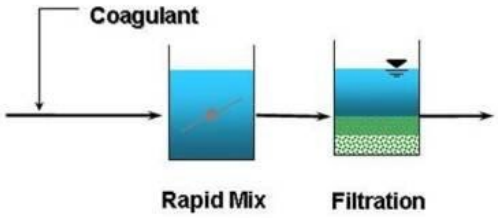


Figure ***Page*4.6.5**: Direct Filtration - Image by the EPA is in the public domain

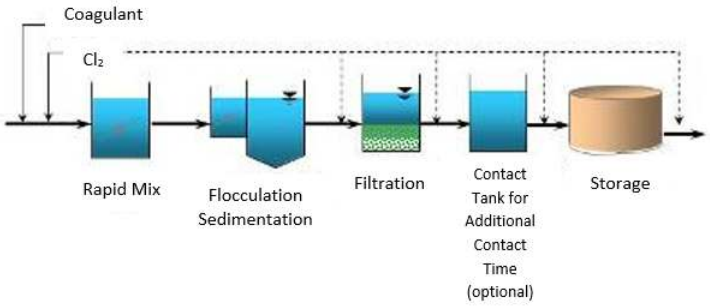


Figure ***Page*4.6.6**: Conventional Treatment - Image by the EPA is in the public domain

Alternative treatment plant methods can be approved on a case by case basis. Newer technologies such as membrane filtration and reverse osmosis have been utilized as the technology has improved and the costs associated with running these particular operations have decreased. Santa Clarita Valley (SCV) Water utilizes an alternative technology known as Upflow Clarification. SCV Water is able to use this technology because of the very low turbidity levels in the water provided by Castaic Lake. It is a more condensed version of conventional treatment and requires much less space due to the lack of sedimentation basins.

Filter Media

The type of media used in gravity filters is sand, anthracite coal and garnet. Garnet is a reddish colored mineral sand comprised of silicates (calcium, iron, manganese, and magnesium) and its density is greater than sand. Gravel is also used as a filter under layer below the filter media being used. It has to be heavier than the filter media so it is able to settle back under media after a completed filter wash cycle.

When choosing filter media it is important to select media that has good hydraulic characteristics, is durable, has no impurities, is insoluble in water, will not dissolve, and does not react with constituents in the water supply. Media is classified by four parameters including its effective size, uniform efficiency, specific gravity, and the hardness of the media. The effective size is the sieve opening in the media that allows water to pass through while collecting the impurities in water. 90 percent of the particles must be bigger than the opening to filter out particles.

When deciding what kind of media to choose for the filer it is important to consider the amount of time it takes for filter turbidity to break through. For example, you operate a treatment plant that requires individual filters say below 0.3 NTU (or Nephelometric Turbidity Units). Once an individual filter goes above this limit it must be washed. Secondly, head loss must be a consideration. Head loss occurs after material builds up over time during the filtration process. The head loss will cause longer filtration times and cause the filter level to rise. Once a filter reaches terminal head loss it must be back washed. The media is not always the cause of head loss and turbidity breakthrough. As discussed earlier, operators must ensure they are dosing chemicals properly as improper dosage can cause the aforementioned head loss and breakthrough.

The uniform coefficient is the ratio between the different sizes of media comprised in the filter bed. The lower the uniform coefficient means the media is closer to the same size than if it were higher. The lower the efficiency number adds to the cost of the media.

Filter production is the amount of water that a given filter can produce in a day. This flow is usually accounted for in Million Gallons per Day (MGD). Individual filtration rates are calculated by dividing the flow rate of the filter in gallons per minute by the surface area of a filter. The filtration rate for gravity filters can be between 2gpm-10gpm/ square foot. This topic will be discussed in more detail during the math portion of this chapter.

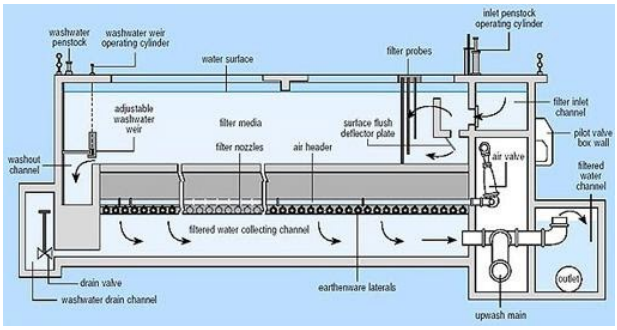


Figure ***Page*4.6.7**: Rapid gravity sand filter - Image by The Open University is licensed under CC BY-NC-SA

Filter Media Types			
			
Gravel Image by Martin Olsson is licensed under CC BY-SA 3.0	Sand Image by Yug is in the public domain	Garnet Image by Siim is licensed under CC BY-SA 4.0	Anthracite Image is in the public domain

There are several different types of media configurations. Filtration plants can utilize monomedia, duel media, and multimedia configurations. A monomedia plant has only one type of media which could be coarse sand or anthracite coal. Single media filters may have to be washed more frequently as they tend to be smaller and have more frequent head loss issues. Dual media filters consist of a lower sand level and an upper anthracite layer with larger diameter pores that allow deeper solids penetration. Finally, multimedia filters are used in pressure vessel treatment applications. Multimedia filters have sand, anthracite, and an upper garnet layer. The drawback to pressure vessels is the inability to view filter media within the pressure vessel.

Filter Operation and Backwashing Filters

Throughout the chapter, the subject of “washing” has come up. Filter run times are dependent on three factors but first it is important to know how filter efficiency is measured. The efficiency of a filter is measured by the filter effluent turbidity. And the overall plant efficiency measures the combined effluent turbidity of all the filters. Improper coagulation and filtration could lead to turbidity spikes and in the worst-case scenario could lead to a public health crisis.

Pictured below is a photo of a typical filter deck at a water treatment plant.



Figure ***Page*4.6.8**

The first factor that an operator uses to determine whether a filter wash is necessary is the individual filter turbidity. Each treatment plant will have its own operating conditions and permits to follow. If an individual filter fails to meet the turbidity goals or limits, the filter must be put in a backwash cycle. Filters that continue to have decreased run times may need a filter profile ran to figure out why the filters are not meeting standards.

High head loss is the second factor that will lead to a filter wash. After the filter is used for a certain period of time it becomes clogged with the solids the filter is removing. This condition will also lead to increased turbidity as the solids that should be getting captured “breakthrough” the effluent into the treated water supply. Finally, a filter wash will be performed after a certain period of time no matter what the operating conditions are. This is the ideal scenario for washing a filter.

The backwash procedure is the reverse flow of water through the filter. This process removes solids from the filter after breakthrough or the filter run time is hit. Operators must operate the backwash rates at an optimal range because inadequate rates will not properly remove the solids from the filter and excessive rates can cause mud balls and mounds to form within the filter.

Washed water is able to be recycled by sending the waste stream to collection basins. The water can then be returned to the head works of the plant and be mixed with raw water to be treated again. The filter backwash rule limits the amount of water that can be returned into the head works of the plant at a given time. Returning too much recycled water could increase the chances of allowing microorganisms such as *Cryptosporidium* into the treatment plant.



Figure ***Page*4.6.9**

The Filter to the left is in the process of a filter back wash. The water is moving in the opposite direction and overflowing over the weir and heads to the waste basin where it is collected and eventually returned into the head works of the plant to be treated again. Operator Actions

As a Water Treatment operator, you will be expected to have knowledge of how to properly use equipment related to filtration. While running a treatment plant you will routinely:

- Monitor filter performance
- Check turbidity levels with online analyzers and grab samples
- Adjust chemical flow rates
- Backwash filters
- Visually inspect filters

Filters run differently under changing water conditions. The plant will not always run the same as temperature differences and storm events will make operators examine important operational considerations from time to time. It is important to look at the weather and understand how it might affect the treatment plant. A severe rainstorm near your source water could increase turbidity levels coming into the plant. Under these conditions, operators may have to wash filters more frequently and make adjustments to chemical doses.

There are other abnormal conditions to consider when monitoring filter performance. Monitor filter washes to look for mud balls, excessive boiling in certain spots, and media being displaced and sent to waste basins. These conditions would indicate that the backwash flow is too high. Also identify shorter filter run times, filters that may not be coming clean, and algae growth. These factors may be due to improper chemical dosing and a backwash flow that is too low.

Filtration Math

Filtration Rate

Calculating the filtration rate of the filters in your plant is an important function. Operating plans and permits limit the amount of water a filter can produce so it is important to have an understanding of filter rates also known as loading rates. Filtration rates will also give an operator a basic understanding of the treatment plants daily average production.

The filtration rate formula is a velocity equation. These formulas are easily confused with flow problems so make sure you pay attention to the units you add into the formula and pay attention to what the problem is asking. The formula for filtration rate is:

Filtration Rate = Flow Rate ÷ Area

Filtration rate equations will use GPM and the area of a given filter. The area of the filter is length x width. A problem may give you the depth of a filter to confuse you. Pay very close attention to the wording in the problem.

Example 1

What is the filtration rate of a treatment plant that has 3 filters that are 20 ft. wide and 20 ft. in length in a plant that produces 1 MGD?

Filtration Rate = (20 ft x 20 ft x 3) ÷ 1 MGD

1,000,000 gal/1 Day x 1 Day/24 hours x 24 hours/60 min = 694 GPM1

**Note: Quick shortcut for future equations, there are 1,440 minutes in a day.*

Filtration Rate = 1,200 ft^2 ÷ 694 GPM

Filtration Rate = 1.73 gpm/ft^2

Backwash Rate

As discussed in the chapter, after a filter reaches its capacity due to head loss, turbidity break through, or maximum amount of hours run, the filter must be washed. The filter wash cycle water velocity will be much greater than the amount of water that flows through the filter during normal operation. Many math equations will have the operator solve for rate of rise which is expressed as in/min. The backwash is the flow of water in the opposite direction where water is moving up instead of down.

Example 2

The maximum backwash rate for a filter is 5,000 GPM. The filter is 20 ft. wide and 20 ft in length. What is the rate of rise in the filter?

Rise Rate = Flow Rate ÷ Area

Rise Rate = 5,000 GPM ÷ 400 ft^2

Rise Rate = 12.5 GPM/ sq./ft

12.5 gal/min(ft)/1 x 12 inches/1 ft x 1 ft^3/7.48 gal = 20 inches rise/min

Percent Back Wash

Water treatment plants are very efficient at recycling waste stream water. The water sent to waste basins and lagoons is able to be recycled but only a certain amount at a time. The percent backwash math problems compare the total plant production with the amount of finished water used to backwash a filter.

Example 3

A treatment plant treats 2 MGD. It has 2 filters that are washed each day and each uses 10,000 gallons during the wash. What is the percent backwash water?

2 filters x 10,000 gallons = 20,000 gallons

20,000 gal/2,000,000 gal = 0.01

100 × 0.01 = 1%

1% of the water the plant uses is for backwash water.

Chapter Review

1. Solids removed from a filter are most commonly removed by what method?
    1. Adsorption
    2. Straining
    3. Deactivation
    4. Flocculation
2. What is a typical filtration rate for slow sand filters?
    1. 2.0-6.0 GPM/sq. ft
    2. 6.0-10.0 GPM/sq. ft

3. 1.0-2.0 GPM/sq. ft
4. 0.5-0.10 GPM/sq. ft

3. In a typical conventional treatment plant, the finished water turbidity for an individual filter should be less than _____.
    1. 1.0 NTUs
    2. 0.3 NTUs
    3. 5.0 NTUs
    4. 3.0 NTUs
4. A filter running under normal conditions will see head loss in a filter _____.
    1. Remain constant
    2. Increase slowly
    3. Rapidly increase
    4. Decrease slowly
5. A filter must be washed if this condition is met:
    1. Head loss
    2. Turbidity breakthrough
    3. Maximum filter run time
    4. All of the above
6. Filter performance is measured by the removal of _____.
    1. Oxygen
    2. Head loss
    3. Turbidity
    4. Chlorine
7. What is the biologically active layer of a slow sand filter called?
    1. Mixed media
    2. Duel media
    3. Sludge layer
    4. Schmutzdecke
8. The pressure drop in a filter is called _____.
    1. Turbidity breakthrough
    2. Head Loss
    3. Filtration
    4. Backwash
9. What is the most common reason for putting a filter into the wash cycle?
    1. Head loss
    2. Filter run time
    3. Turbidity breakthrough
    4. Water level decrease
10. Formation of mud balls and excessive boiling during a wash is an indicator of _____.
    1. Proper backwash rate
    2. Too low backwash rate
    3. Excessive backwash rate
    4. Improper chemical dose
11. Important processes which occur during filtration are _____.
    1. Sedimentation
    2. Adsorption
    3. Straining
    4. All of the above

12. Typical filtration rates for a conventional treatment plant are _____.
    1. 0.2-0.6 GPM/sq.ft
    2. 2.0-10.0 GPM/sq.ft
    3. 10.0-20.0 GPM/sq.ft
    4. 200-400 GPM/sq.ft
13. There are four filters at a water treatment plant. The filters measure 20 feet wide by 30 feet in length. What is the filtration rate if the plant processes 8.0 MGD?
    1. 1.51 GPM/sq.ft
    2. 2.31 GPM/sq.ft
    3. 2.61 GPM/sq.ft
    4. 2.91 GPM/sq.ft
14. A water treatment plant treats 6.0 MGD with four filters. The filters use 60,000 gallons per wash. What is the percent backwash at the plant?
    1. 10%
    2. 8%
    3. 6%
    4. 4%
15. A treatment plant filter washes at a rate of 10,000 GPM. The filter measures 18ft. wide by 24ft. long. What is the rate of rise expressed in inches per minute?
    1. 17 inch/min
    2. 27 inch/min
    3. 37 inch/min
    4. 47 inch/min

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Page 4.7: Disinfection

Learning Objectives

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

- Disinfection terminology
- Regulations
- Types of disinfectants used during water treatment

The final step in the water treatment process before finished or treated water enters a clearwell for storage is the disinfection process. Disinfection is the process where chemical agents are added to a water source to kill or inactivate pathogenic microorganisms. Pathogenic microorganisms are disease-causing and must be eliminated from treated water. As population sizes increase and freshwater sources become scarcer, the ability to remove and deactivate microorganisms becomes increasingly important. Another factor to consider, especially in California, is stricter regulations due to advancements in technology and water quality testing.

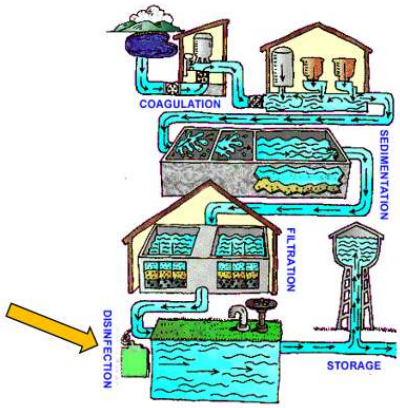


Figure ***Page*4.7.1**: Image of water treatment by the EPA is in the public domain

Disinfection Basics

Treatment plant operators use the two-part process of removal and deactivation of microbiological constituents in water. Most of the pathogens water treatment professionals remove and deactivate from drinking water have adapted to living in the bodies of warm-blooded animals. Pathogens thrive and survive in those environments. Outside those environments, these pathogens can stay dormant until they are consumed. Even more frightening, some of the illnesses can cause death. In the United States, our water is generally safe to drink and we often take for granted that turning on a tap will produce a flow of potable water.

Because of limitations in testing, it is difficult to indicate the presence of specific waterborne illnesses caused by virus, bacteria, and *Giardia*. Water professionals use tests such as the total coliform test to look for the likely presence of waterborne disease. The Surface Water Treatment Rule sets specific guidelines for removal and treatment to ensure the removal and inactivation of pathogenic organisms.

Strict regulations set forth by the Safe Drinking Water Act were created to ensure the public's drinking water was safe to consume. To ensure drinking water is safe for human consumption, 3 log removal and deactivation or 99.9% of *Giardia* lamblia is required. For viruses, 4 log or 99.99% removal and deactivation is required. Bacteria fall in the middle of viruses and *Giardia* so the government determined it was not necessary to have regulations specifically regulating their inactivation and removal.

Below is a list of waterborne diseases and illnesses.

Table 7.1: Waterborne Diseases and Illnesses

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Bacteria	Internal Parasite from Protozoa	Virus caused
• Anthrax • Dysentery • Cholera • Gastroenteritis (Stomach Flu) • Leptospirosis • Paratyphoid • Salmonella • Shigellosis (Shigella) • Typhoid fever	• Dysentery • Ascariasis (round worm) • Cryptosporidiosis from *Cryptosporidium* • Giardiasis from *Giardia*	• Gastroenteritis • Heart anomalies • Hepatitis A • Meningitis • Poliomyelitis

Purpose of Disinfection

Operators disinfect water to destroy the harmful organisms listed in the above chart. Filtration is used to remove the organisms while disinfection kills them or deactivates them. Operators do not sterilize water because sterilization would kill everything in the water. The process of disinfection relies heavily on everything that occurs downstream in the treatment process. As water enters the treatment plant in the form of raw water, the chemistry of that water affects how well the specific disinfectant will work at each stage of the treatment process.

What Affects Disinfection?

There are several characteristics of water that can affect treatment. Water is more easily disinfected with higher temperatures. In lower temperatures, longer contact times may be required and larger amounts of chemical must be used. Higher turbidity rates will decrease disinfection as well. The chapters before have covered how critical it is to remove suspended material early and efficiently. Excess turbidity will require greater amounts of chemical to properly disinfect the water supply. Chemicals such as chlorine can interact with organic and inorganic matter. Chlorine's ability to interact with these constituents may reduce or eliminate the effectiveness of the disinfectants.

Types of Disinfectants Physical

Physical disinfection is not widely used to treat potable water at this time. Ultraviolet rays are starting to be used more consistently but chemical means of disinfection must still be used as ultraviolet disinfection does not carry a disinfectant residual. The process is very expensive and thus is not used by large scale treatment operations in the United States. Other means of physical disinfection include boiling and ultrasonic wave production. Agencies will call for boil water notifications during emergencies and when there is a waterborne illness outbreak but it is not used as a primary means to disinfect drinking water.

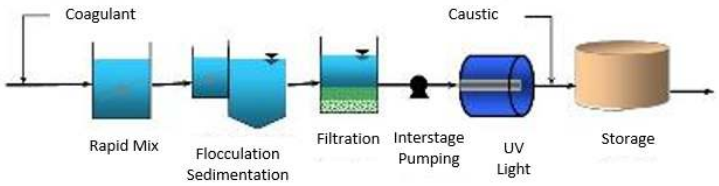


Figure ***Page*4.7.2**: Image by the EPA is in the public domain

Types of Disinfectants Chemical

There are several chemical disinfectants available in drinking water applications. The most commonly used in the United States is Chlorine. The topic of Chlorine will be discussed in greater detail in the following chapter. The basics will be covered below as well as a background on the other chemicals available. The chemicals will be broken down into subcategories based on their practical usage in the United States.

Rare

- Iodine—It is commonly used for emergency treatment in the form of droplets or tablets. It is not used by the water treatment industry because of its cost and the potential health hazards to pregnant women and possible thyroid issues, which can develop

with frequent use.

- Bromine—It is not used by water treatment facilities as it is very corrosive and can cause severe skin burns. It is used more commonly as a disinfectant in swimming pools. When it reacts with choline (a common nutrient from plants and animals) in water, it can create disinfectant byproducts. It was used by the United States Navy for a time, but most systems have been removed because of bromine's corrosiveness.
- Sodium Hydroxide and Lime—More frequently used to sterilize pipes. They are not used as an everyday disinfectant because of the bitter taste that is left behind after application. Sodium hydroxide and lime are more often used to increase the ph of the water in the distribution system after treatment with gas chlorine.

More Common

- Chlorine Dioxide—Used as a water treatment disinfectant and oxidizer. It does not react with ammonia which is an issue with chlorine. Chlorine dioxide is used as a disinfectant but is also very effective at removing iron, manganese, taste, odor, and color from treated water. *Cryptosporidium* is resistant to chlorine but is not resistant to chlorine dioxide. Up to 70 percent of chlorine dioxide is converted to chlorite, which is a regulated disinfectant by-product so the dosage rates when using it as a disinfectant must be lower than 1.4 mg/L. Chlorine dioxide must also be made on site which necessitates higher operational and maintenance costs.
- Ozone—Ozone was first used in Europe in the early 1900's. It is a strong disinfectant that also reduces taste and odor issues. The drawback of ozone is that it is very expensive to produce, has high electrical costs, has limited solubility, and does not leave a residual in the treated water because it is so reactive. If bromide is present in the water, ozone can react with it to form bromate, an undesirable DBP (this is an issue for SCV Water). Ozone is very efficient at disinfecting *Cryptosporidium* so it is generally used as a secondary disinfectant along with chlorine or chloramines.

Most Common

- Chlorine—The most widely used disinfectant in the United States is free chlorine. Chlorine can be added as a gas in the form of chlorine gas, as a solid in the form of calcium hypochlorite, or as a liquid in the form of sodium hypochlorite. Most likely, you have a bottle of sodium hypochlorite in your house. We call it bleach. The use of free available chlorine has declined over the years because of the discovery of disinfectant by-products (DBPs). This topic will be discussed in further detail in the next chapter.
- Chloramines—The use of chloramines has become more common in recent years in order to reduce DBPs mainly trihalomethane (THM). Chloramines are also referred to as combined chlorine as it is the combination of chlorine and ammonia. Chloramines are also effective at eliminating taste and odor problems and the residual lasts longer in the distribution system. However, chloramine disinfection is not as strong as chlorine and the improper addition of ammonia can lead to excessive amounts of ammonia in the treated water which results in nitrification.



Figure ***Page*4.7.3**: Image by olegschedrin0 is licensed under CC0

Regulations

The Safe Drinking Water Act (SDWA) is the basis of all drinking water regulations in the United States. It is the umbrella in which all new regulations and rules have subsequently been created and enacted. The SDWA regulates drinking water standards in the United States along with its territories. We take for granted all of the research and technology we have available that allows us to

never really be concerned about the quality of our drinking water. The SDWA was passed in 1974 and set fourth standards to regulate public water sources. It was amended in 1986 to include some basic principle definitions:

- Defined regulated contaminants and approved treatment techniques
- Defined criteria for filtration of drinking water
- Defined criteria for disinfecting surface and groundwater
- Outlawed the use of lead material in drinking water facilities

After a large public health crisis in Milwaukee, Wisconsin, provisions were made to support drinking water programs through operator training and certification programs. All entities serving water to the public were required to meet program standards with regards to training and certification. In 1999, the government allowed states to hold primacy over drinking water certification programs as long as federal minimums were met. States such as California often have stricter standards than the federal standards.

Surface Water Treatment Rule

The Surface Water Treatment Rule (SWTR) was enacted in 1990 and sought to prevent waterborne illness from surface water sources. Water systems with supplies from surface sources which are susceptible to carrying viruses, legionella, and *Giardia lamblia*, have to follow new requirements with regards to filtration and disinfection known as the multiple barrier approach. The rule also required that systems that used groundwater as a source for drinking water had to adhere to SWTR standards if their water source could come into contact with surface water sources.

Water treatment plants would have to achieve removal and deactivation requirements through the combined efforts of filtration and disinfection. The removal and deactivation of 99.9% of *Giardia* or 3 Logs and the removal and deactivation of 99.99% of viruses or 4 Logs was the new standard set forth. This requirement is measured by monitoring combined effluent turbidities in the combined filters and meeting disinfection requirements through the CT calculation. The CT calculation will be covered in greater detail in the following chapter.

Groundwater Rule

The Groundwater Rule (GWR) was established in 2009 in response to the frequency of groundwater contamination from surface water runoff sources. The rule requires monitoring for systems that do not disinfect to make sure microbiological contamination is not occurring. If a groundwater supplier did use disinfection, they are to meet 99.99% virus inactivation much like groundwater sources.

Total Coliform Rule

The final rule which indirectly relates to water disinfection is the **Total Coliform Rule** (TCR) which was established in 1990. As stated several times within the text, it is nearly impossible and certainly too costly to test for every type of microbiological contaminant that could lead to a public health risk. Instead, the TCR uses a risk based process which tests for the “worst case scenario”. Coliforms grow in warm blooded animals just like viruses, bacteria, and *Cryptosporidium*. They pose no health risk to humans and they grow more abundantly than forms of microbiological agents that will do us harm. If coliforms are present in the water supply, there is a chance for a public health concern.

In the event of a positive coliform test, the downstream and upstream sampling sites as well as the site where the positive sampling occurred will be retested. System maps and sampling plans are a requirement of the TCR. The amount of samples the water supplier takes is based on the population served. Systems which collect less than 40 samples a month can only have one positive sample before notifying the public of a Maximum Contaminant Level (MCL) violation. Systems that collect more than 40 samples a month must not have positives in more than 5% of their coliform samples. If you work at a water supplier that takes 50 samples a month and had 3 positive samples are you in compliance with the TCR?

$$47 \div 50 = 0.94 \times 100$$
$$= 94\%$$

So 6% of the samples were positive so you would not be in compliance) or...

$$\frac{3}{50} = 0.06 \times 100$$
$$= 6\%$$

Therefore, 3 positives are 6% of the total samples.

Disinfectant By-Product Rule

The disinfectant by-product rule (DBPR) was put in place to protect the public from cancer causing risks associated with disinfectants reacting with organic and inorganic matter in treated drinking water. Disinfectant by-products such as trihalomethanes are classified as volatile organic compounds. The Stage 1 DBPR established maximum contaminant levels for several DBPs including:

- Trihalomethane (TTHMs) - 80 ug/L or 80 ppb
- Haloacitic Acid (HAA5) - 60 ug/L or 60 ppb
- Bromate - 10 ug/L or 10 ppb
- Chlorite - 1.0 ppm

While it is all together possible to remove DBPs from treated water with activated carbon, it is a very expensive treatment process and not cost effective for large treatment operations. Other forms of disinfection are possible but will also cause DBP formation. Chlorite formation is associated with chlorine dioxide treatment, while bromate is associated with ozone treatment. The issue of DBP formation becomes even more problematic as chlorite and bromate are often found naturally in source water.

The stage II DBP Rule enhanced regulations on DBP formation by targeting water sources that are more vulnerable to DBP formation and the rule also requires monitoring for HAA5s and THMs. The number of samples taken and the number of sampling sites is based on the size of the population served by the water agency. The use of chloraminated water is being used more commonly to combat DBP formation but using chloramines instead of other disinfectants has other risks associated with its use which will be covered in greater detail in the next chapter.

This is the link to the quick reference guide from the EPA with information on the Stage I and Stage II DBP rule.

Chapter Review

1. What is residual chlorine?
    1. Chlorine used to disinfect
    2. The amount of chlorine after the demand has been satisfied
    3. The amount of chlorine added before disinfection
    4. Film left on DPD kit to measure residual
2. When Chlorine reacts with natural organic matter in water it can create _____.
    1. Disinfectant by-products
    2. Coliform bacteria
    3. Chloroform
    4. Calcium
3. What are trihalomenthanes classified as?
    1. Salts
    2. Inorganic compounds
    3. Volatile organic compounds
    4. Radio
4. What disinfectant is used for emergency purposes and not utilized in the water treatment industry?
    1. Chlorine
    2. Iodine
    3. Ozone
    4. Chlorine dioxide
5. What is the disinfectant with the least killing power but that has the longest lasting residual?
    1. Chlorine
    2. Ozone
    3. Chlorine dioxide

4. Chloramines

6. The active ingredient in household bleach is _____.
    1. Calcium hypochlorite
    2. Calcium hydroxide
    3. Sodium hypochlorite
    4. Sodium hydroxide
7. *Cryptosporidium* is not resistant to this chemical:
    1. Ozone
    2. Chlorine dioxide
    3. Chlorine
    4. Both 1 and 2
8. The Removal and inactivation requirement for *Giardia* is?
    1. 99.9%
    2. 99.99%
    3. 99.00%
    4. 90%
9. If a coliform test is positive, how many repeat samples are required at a minimum?
    1. None
    2. 1
    3. 3
    4. Depends on the severity of the positive sample
10. Your water system takes 75 coliform tests per month. This month there were 6 positive samples. What is the percentage of samples which tested positive? Did your system violate regulations?
    1. 3% Yes
    2. 5 % No
    3. 8 % Yes
    4. 10 % No

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Page 4.8: Chlorine

Learning Objectives

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

- Chlorine terminology
- Chlorine chemistry
- Chlorine safety
- Advanced chlorine calculations

As discussed in previous chapters, chlorine is the chemical most frequently used in the water treatment industry for disinfection purposes to meet the standards of the surface water treatment rule. Chlorine is used in several different forms and can be fed into the system in a variety of different methods. It is a very dangerous chemical, so proper safety and handling procedures must always be followed. In addition to being used as a disinfectant, Chlorine may also be used as a controlling agent for the removal of algae, for taste, and for odor. Other beneficial applications of Chlorine include disinfecting new water facility infrastructure such as pipes and tanks and the oxidation of iron, manganese, and hydrogen sulfide.

Chlorine Terminology

Chlorine is available in three forms: gaseous, solid, and liquid.

- Gaseous(chlorine)—Cl_2
- Solid (Calcium hypochlorite)—$Ca(OCl)_2$
- Liquid (Sodium Hypochlorite)—$NaOCl$

It is not explicitly known how chlorine disinfection works. One explanation is that chlorine attacks a bacterial cell and destroys it. The other theory suggests that chlorine deactivates enzymes within the cell enabling the microorganisms to use their food supply. Adding chlorine to a water supply causes chemical reactions to take place between the water and the organic and inorganic molecules within the water. After chlorine is done combing with organic and inorganic material in the water, the demand has been satisfied.

The dose of chlorine minus the demand is the residual. The reason chlorine is used in the United States over other disinfecting chemicals is Chlorine's ability to leave a lasting residual within the framework of the water distribution system. This residual continues to fight potential disease-causing microorganisms after treatment has concluded.

Assume that you are working as an operator at a water treatment plant. Your chief operator would like to maintain a residual of 2.0 mg/L of chlorine residual in the distribution system. The demand is 1.5 mg/L. What is the dose you must add to achieve a residual of 2.0 mg/L?

$$\begin{aligned}\text{Dose} &= \text{Demand} + \text{Residual} \\ &= 2.0\,\text{mg/L} + 1.5\,\text{mg/L} \\ &= 3.5\,\text{mg/L}\end{aligned}$$

Therefore, you would need to maintain an average of a 3.5 mg/L dose of Chlorine to achieve the residual requested by your chief operator.

Other Chlorine terminology includes Free Chlorine, Combined Chlorine, and Total Chlorine. It is important to understand these terms before taking a deeper dive into the chemistry of chloramination. The term Free or Available Chlorine refers to the amount of Chlorine that is "free" or "available" in the system to kill or deactivate pathogenic organisms. Combined Chlorine is chlorine that has combined with other molecules and Total Chlorine is the combination of Free or Available Chlorine and Combined Chlorine. Although Combined Chlorine lasts longer in the distribution system, it is a far less effective disinfectant. It is also important to note, not all Chlorine has the same strength. This will be covered more thoroughly later in the chemistry and math portion of the chapter.

Chlorine Content

As mentioned earlier in the chapter, Chlorine is available in different states of matter. The amount of chlorine used to dose water in a treatment plant is determined by the compound used. Below is a chart illustrating the different compounds of chlorine. The percent column indicates the percentage of Chlorine in the compound. For example, Chlorine Gas is pure Chlorine and yields the highest available percentage at 100%.

Table 8.1: Chlorine Content in Different Chlorine Compounds

Chlorine Compound	Percent	Amount needed to attain 1lb
Chlorine Gas	100	1 lb
Calcium Hypochlorite	65	1.54 lbs
Sodium Hypochlorite	15	.8 gallons
Sodium Hypochlorite	12.5 (most common)	1.0 gallons
Sodium Hypochlorite	5 (household bleach)	2.4 gallons

In the math section of this chapter, the impact of the Chlorine percentage will become evident. It is important to read the question and understand what concentration of chlorine is being added to the treatment plant. The third column in the table provides the lb or gallon needed of the specific compound to provide 1 lb of chlorine. For example, if your plant requires a weight or quantity of 100 lbs of chlorine and you use gas chlorine, then you will be adding 100 lbs. of Chlorine Gas. If you are using calcium hypochlorite, you will need to calculate the number of pounds required. From the table, Calcium Hypochlorite is 65% Chlorine. To determine the total number of pounds of Calcium Hypochlorite needed to provide 1 lb of Chlorine, divide the dose required by the percent chlorine.

$$100 \div 0.65 = 153.8\,lbs \qquad \text{(Page 4.8.1)}$$

Therefore, you will need to use 153.8 lbs of Calcium Hypochlorite to obtain a 100 lbs dose of chlorine.

Factors of Chlorine Success

Several factors during the water treatment process will impact the effectiveness of the Chlorine. The five factors that affect chlorine treatment are:

- The concentration of chlorine, more specifically the dose
- The amount of time chlorine is in contact with the water
- The temperature of the source water
- The pH of the source water
- The constituents in the source water

The amount of time the chlorine is in contact with the water determines the effectiveness of the chlorine disinfection. The CT (Concentration multiplied by Contact Time) formula is used to calculate the time chlorine is in contact with the water. C is the concentration of chlorine residual, therefore CT is expressed as (mg/L-min). If water is leaving a drinking water storage tank, also referred to as a clearwell, at a rapid rate, then the chlorine concentration will have to be increased. If the concentration of chlorine is decreased, then the water will have to stay in contact with the disinfectant for a longer period of time. Combined Chlorine treatment associated with monochloramine disinfection will require longer holding periods due to its decreased effectiveness.

Temperature affects chlorine treatment in a variety of ways. Chlorine is more effective at killing pathogens at higher temperatures but at lower temperatures, the chlorine residual will last longer. Practically speaking, chlorine disinfection works better in warmer temperatures as more credit is given with the CT calculation. The pH level of the water is also a significant factor when treating with chlorine. The ratio of HOCl to OCl- is affected based on the pH. HOCl will remain the dominant disinfectant in water with a lower pH while OCl- will remain in higher quantities in water with a higher pH.

In the disinfection process, chlorine not only reacts with organisms that are to be killed, but it also reacts with the turbidity in the water and other substances such as ammonia. Reducing turbidity in treated water through coagulation, sedimentation, and filtration

ensures disinfection will be more effective. The maximum and minimum chlorine residual in the distribution system is 4.0 mg/L and 0.2 mg/L respectively. However, corrective measures must be taken when you see the residual in the distribution system dramatically decreasing. You would never want to see the minimum chlorine residual of 0.2 in the distribution system.

Chlorine Chemistry

Below is the reaction that occurs between water and free available chlorine:

$$\mathrm{Cl_2\ (Chlorine) + H_2O\ (Water) \longrightarrow HOCl\ (hypochlorous\ acid) + HCl\ (hydrochloric\ acid)} \quad \text{(Page 4.8.2)}$$

Hypochlorous acid is more effective of the two forms of available chlorine. First, it is important to understand how chlorine demand works. We can do this by examining the effects of adding free available chlorine to distilled water. If we were to dose distilled water with 1.0 mg/L of free available chlorine, the residual would be 1.0 mg/L chlorine because there is nothing in distilled water that will react with the chlorine other than the water itself. Distilled water lacks impurities.

It is clear that the raw source water is filled with impurities. Chlorine will have many constituents to react with during the treatment process. When the Chlorine reacts with the water and the impurities, five different types of chlorine residuals result. The following chart illustrates the effectiveness of each type of residual. The most effective is hypochlorous acid (HOCl) so the effectiveness of the remaining four types of residuals are in comparison to HOCl.

Table 8.2: Effectiveness of Different Residuals

Residual	Abbreviation	Effectiveness
Hypochlorous Acid	HOCl	1
Hypochlorite Ion	OCl-	1%
Trichloramine	NCl_3	More info later in the chapter
Dichloramine	$NHCl_2$	1.25 %
Monochloramine	NH_2Cl	.667%

As the chart shows, dichloramines are a “more effective” disinfectant than monochloramines but their use may cause taste and odor problems. The effectiveness of trichloramines has not been extensively researched and as with dichloramines, a pungent taste and odor problem occurs with its use. Thus the water industry only uses monochloramines as a disinfectant. Below are the chemical formulas which illustrate when hypochlorous acid disassociates and becomes a weaker disinfectant.

$$\mathrm{HOCl\ (Hypochlorous\ acid) \longrightarrow H^+\ (Hydrogen\ ion) + OCl^-\ (Hypochlorite\ ion)} \quad \text{(Page 4.8.3)}$$

$$\mathrm{HCl\ (Hypochloric\ acid) \longrightarrow H^+\ (Hydrogen\ ion) + Cl^-\ (Chlorine\ ion)} \quad \text{(Page 4.8.4)}$$

Chlorine Handling and Safety

As a Treatment operator, you will come in contact with many dangerous chemicals used to treat water. One chemical that is widely used in the water treatment industry is chlorine. As discussed earlier in the chapter chlorine comes in three different states: gas, powder, and liquid. All three types of chlorine have risks associated with the handling and storage of the chemical. It is important that proper safety procedures are followed at all times.

Chlorine Gas

Chlorine gas is 2.5 times heavier than air. The odor is pungent and the color is greenish-yellow. Gas chlorine is only visible in very high concentrations and you don’t ever want to see it. Chlorine gas is irritating to eyes, nasal passages, and the respiratory system. It is a very dangerous substance and concentrations as low as 100 parts per million can kill a person.

Chlorine gas is available in three different types of containers: 150-pound containers, 1-ton containers, and, for very large plant operations, in railroad containers. A majority of treatment operations will use chlorine tanks. The amount of chlorine used in a

given day will determine which type of chlorine container your plant will use.

When delivered to a treatment plant, the “150-pound” chlorine gas cylinder container weighs roughly 250-280 pounds. A chlorine cylinder consists of the cylinder body, neck ring, valve, and protective hood.

Cylinders are transported around the facility with the use of a dolly or hand truck. The use of a safety chain or strap is mandatory at all times. Cylinders should never be rolled because it could lead to employee injury or the shearing off of the valve. The maximum daily withdrawal rate for a chlorine cylinder is 40 pounds.

Chlorine “ton” containers hold 2000 pounds of chlorine and usually weigh around 3700 pounds when filled with chlorine. The Containers are shipped and stored horizontally. The edge of the chlorine container has a ring, which enables cranes and hoists to move them from the truck to the storage or withdrawal area. Containers are stored on trunnions that allow operators to rotate containers with the use of a special tool. Each container has two valves, one at the top and one at the bottom. The top valve allows the chlorine to be withdrawn as a gas while the bottom valve allows chlorine to be withdrawn as a liquid. When putting containers in storage, they should placed such that the liquid chlorine is allowed to settle in the bottom of the container. The maximum daily withdrawal rate for a 1-ton tank is 400 pounds.

Gas chlorine cylinders and 1-ton containers use similar methods to feed chlorine into the water. Feeding systems include a scale, valves and piping, a chlorinator, and an injector or diffuser. The weighing scales are used to keep track of how much chlorine has been used or is left in the cylinder or tank. Record keeping is critical for all chemical use. Monitoring and reviewing the recorded data can help identify problems with the chlorine system and manage costs by reducing chemical waste.



Figure *Page*4.8.1

Pictured above is a standard chlorine scale and trunnion system. The trunnion acts as a form of storage while also keeping an accurate measure of the amount of chemical left in the tanks. In California, the tanks must also be secured with straps due to earthquakes.

Valves and piping are just as important in the chlorine system as they are in the water system. Each chlorine tank or cylinder is equipped with valves which allow or prohibit the flow of the chlorine during the transfer and storage of the product. In an emergency, the valves can also be used to quickly shutoff the flow of chlorine. Large scale systems will include piping manifolds that allow for the transfer of chlorine from multiple tanks. The associated feed system will include valves and piping to provide chlorine to different feed points in the system.

The chlorinator is the piece of equipment that feeds the chlorine directly into the system. Chlorine is dispersed evenly into the system based on a dosage set point using vacuum and pressure regulators. For safety, a vacuum must be maintained in the line. The vacuum ensures that the chlorine is always being pulled into the chlorine feed system. Most modern systems have emergency shutoff valves which prevent the flow of chlorine if a leak is detected. Chlorine systems will also include alarms, leak detectors, and repair kits.

Other safety measures are also required when working around chlorine gas. For example, when switching tanks, the operator should be wearing a self-contained breathing apparatus (SCBA). As noted earlier, a 0.1 part per million dose of chlorine gas can be immediately fatal.

Hypochlorination

Gaseous chlorine is the strongest and least expensive form of chlorine even with the required use of bases such as caustic soda to increase the pH of the finished water. However, due to safety concerns associated with the use and transportation of gaseous

chlorine, Hypochlorination is becoming more common in water treatment. When building or redesigning a treatment plant, an analysis of the costs and benefits of each type of chlorine will determine which type the facility will use.

The two types of hypochlorite used are calcium and sodium. Calcium hypochlorite is a whiteish-yellow dry chemical. It contains 65% available chlorine. Since it is highly reactive with organic compounds, special requirements must be used when storing it. Additionally, it is flammable if enough heat and oxygen are added. Calcium hypochlorite should always be added to water and not the opposite. Generally, Calcium hypochlorite is primarily used for disinfecting new and repaired water mains and storage tanks. It is not used for the day-to-day treatment of finished water.

Sodium hypochlorite is a clear to yellowish liquid available in a variety of different concentrations. Household sodium hypochlorite, known as bleach, is available in a 5% solution. Treatment plant operations will use an industrial-strength concentration of 12.5% available chlorine. Sodium hypochlorite does not have special storage requirements, but it is a strong base at 9-11 on the pH scale so it is highly corrosive. Additionally, the chemical loses its effectiveness over time in storage. Stored for a month, the chemical can lose 2% to 4% of its chlorine content. Direct exposure to sun and/or heat will further the loss of available chlorine. Therefore, it is recommended that sodium hypochlorite be stored no more than two weeks (in the event the treatment plant is offline) in a temperature-controlled room to prevent excessive strength loss.

Cylinder Tank Safety and Connecting

When attaching a chlorine regulator to a tank to go into service, safety precautions must be used. Any time you are dealing with gas chlorine the operator must wear a respirator, but a SCBA is recommended. The SCBA has a 30-60 minute supply of oxygen. SCBA's operate under positive pressure, so in the event of a leak, no chlorine gas will be able to enter your mask, assuming a proper seal of the mask has been established. Along with a respirator or SCBA the operator should wear gloves and a long sleeve shirt when changing cylinders or tanks.

A new lead washer should be used every time a new tank is put into service. Inspect the lead washer for any deformities, cracks, or bends. Washers must be thrown out after one use. When the chlorine tank valve is first opened, rapidly open and close the valve. Use an ammonia solution near the valve and tubing to check for leaks. The ammonia solution used is commercial Be ammonia. If chlorine is present, you will see a white cloud. In the event of a white cloud, a leak is present. The operator will have to remove the regulator from the valve and use a new lead washer.

Lastly, be vigilant. Changing chlorine cylinders will become routine as it is something you will have to do often if your facility uses chlorine gas. Chlorine gas is a highly dangerous chemical that must be respected. Forgetting how dangerous it is, could lead to serious harm or death for you or your co-workers.

Chapter Review

1. The form of Chlorine which is 100% available chlorine is?
    1. Sodium hypochlorite
    2. Calcium hypochlorite
    3. Calcium hydroxide
    4. Gaseous chlorine
2. What is the minimum amount of chlorine residual required in the distribution system?
    1. There is no minimum
    2. mg/L
    3. 0.2 mg/L
    4. mg/L
3. What is the approximate pH range of sodium hypochlorite?
    1. 4-5
    2. 6-7
    3. 9-11
    4. 12-14
4. What is the typical concentration of sodium hypochlorite utilized by water treatment professionals?

1. 5%
2. 65%
3. 100%
4. 12.5%

5. Chlorine demand refers to _____.
    1. Chlorine in the system for a given time
    2. The difference between chlorine applied and chlorine residual—usually caused by inorganics, organics, bacteria, algae, ammonia, etc.
    3. Chlorine needed to produce a higher pH
    4. None of the above
6. What is the most effective chlorine disinfectant?
    1. Dichloramine
    2. Trichloramine
    3. Hypochlorite ion
    4. Hypochlorous acid
7. What can form when chlorine reacts with natural organic matter in source water?
    1. Disinfectant by-products
    2. Sulfur
    3. Algae
    4. Coliform bacteria
8. What is the maximum withdrawal rate per day for a 150-pound chlorine cylinder?
    1. There is no maximum
    2. 20 pounds
    3. 40 pounds
    4. 50 pounds
9. What kind of solution is used to check for a gas chlorine leak?
    1. Sodium hydroxide
    2. Ozone
    3. Ammonia
    4. Calcium hypochlorite
10. Chlorine is _____.
    1. Heavier than air
    2. Lighter than air
    3. Brown in color
    4. Not harmful to your health
11. Chlorine demand may vary due to _____.
    1. Chlorine demand always stays the same
    2. Temperature
    3. pH
    4. Both 2 and 3
12. What effect does high turbidity have on disinfection?
    1. It can increase chlorine demand
    2. It has no effect
    3. It gives the water a milky appearance that will clear out after some time
    4. You must increase the temperature of the water

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Page 4.9: Chloramination and Nitrification

Learning Objectives

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

- Why chloramine treatment has been employed, (hint) DBP formation
- The use of ammonia in water treatment
- Breakpoint chlorination
- Nitrification

The water treatment profession is constantly evolving and continuously in motion. Advancements in science and lab procedures help water professionals find constituents in drinking water that can be harmful to human beings. We take for granted the fact that clean drinking water will flow when we turn on the tap.

Currently, chlorine is the best disinfectant available. However, the use of chlorine causes any number of disinfectant by-products (DBPs). Many of the DBPs have not been researched and are not regularly monitored. As screening methods improve, it is likely that more of the possible DBPs will be regulated in the future. Trihalomethanes (THMs) are a DBP of chlorine disinfection and are classified as volatile organic chemicals. Rising THM levels in raw water are increasing the use of chloramine as the preferred disinfectant. In this chapter, we will discuss chloramine disinfection and the associated challenges that come with its implementation. Nothing is easy in water treatment.

Why Use Chloramines?

As discussed, chlorine has been used with great effectiveness in water treatment for many years in the United States. However recently, many water agencies have been switching to Chloramine treatment. Now here is the twist; they have done it because they must, not because they necessarily want to. When natural organic matter reacts with chlorine, it can result in the formation of DBPs, specifically trihalomethanes (THM) and haloacetic acids (HAA5). It is believed that long term exposure to these DBPs should be avoided as it may lead to cancer.

Because of the implementation of the Stage 2 DBP Rule in 2012, many water agencies could no longer meet the regulatory limits established, if they continued using chlorine as a primary disinfectant. To continue using chlorine alone, enhanced coagulation would have to be used but its effectiveness is limited. Carbon or GAC absorption is also a solution but it is very expensive, and thus not employed by larger water treatment facilities. The other option is to limit contact with the water and chlorine, but this is limited by the chlorine demand. The last and most effective option is to use chloramines.

Chloramine treatment is also effective in limiting taste and odor problems in finished water. When free chlorine reacts with phenol it can cause taste and odor issues. Chloramine disinfection is not as strong a disinfectant as free chlorine, chlorine dioxide, or ozone, but it does leave the longest-lasting residual in finished water. Because of chloramines weaker disinfecting power, it is often added just before the treated water enters the clearwell for storage. If implementing this method, the operator must ensure the THM levels are low enough as not to violate any regulations. Determining the most effective way to treat drinking water while remaining in compliance is a complex and difficult task.

Chloramine Chemistry

Chlorine reacts with a number of substances in water including dissolved organic matter, particulate organic matter, iron, nitrite, sulfide, and ammonia. It reacts by taking away an electron from them. Ammonia in the water supply is undesirable as it strips away the Chlorine residual which then requires the need to use more Chlorine. What makes chloramine treatment so effective is chlorine's quick formation with ammonia (NH_3). (Ammonia is a compound of Nitrogen and Hydrogen.)

$$Cl_2 + NH_3 \longrightarrow NH_2Cl + HCl \qquad \text{(Page 4.9.1)}$$

Note that monochloramine is expressed as NH_2Cl.

The unit weight of Chlorine is 70 and the unit weight of Nitrogen is 14. When chloramine treatment is employed, the ratio of chlorine to ammonia will always be 5:1 because 5 mg/L of chlorine will always combine with 1.0 mg/L of ammonia. (70 ÷ 14 = 5)

You will often hear monochloramines referred to as combined chlorine due to this reaction.

Below is a list of terms dealing with Chloramine disinfection:

- Free Chlorine: Cl_2 (Free chlorine can refer to gaseous, sodium hypochlorite, or calcium hypochlorite.) If using hypochlorite, remember you must dose the water to achieve 100 percent free chlorine.
- Monochloramine: NH_2Cl or combined chlorine. Chloramine with the least taste and odor problems.
- Free Ammonia: NH_3 Ammonia is measured as nitrogen
- Chlorine: Ammonia ratio: Total chlorine to total ammonia nitrogen. You will always target a 5:1 ratio to avoid excess free chlorine or free nitrogen in the water supply.

Breakpoint Chlorination

The breakpoint chlorination curve is the visual representation of chlorine's ability to react with a variety of compounds to form a combined chlorine residual or to completely react with compounds to form a free chlorine residual. When using free available chlorine as a disinfectant we want to stay out of the combined curve. Some water agencies buy imported water that has a combined residual. To treat the water more effectively or eliminate the possibility of nitrification, some of these agencies add chlorine to "break" over to a free chlorine residual. We will discuss Nitrification in greater detail later in this chapter.

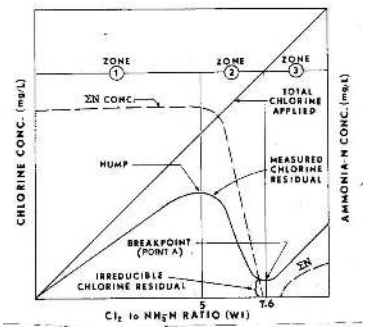


Figure ***Page*4.9.1**: The breakpoint chlorination curve. This curve represents chlorine's ability to have either a combined residual or a free residual. Image by the NSW Department of Premier and Cabinet is licensed under CC BY 4.0

A common problem that operators run into when using combined chlorine is "breaking over" to free chlorine by misdiagnosing problems on the treatment plant. For example, an operator is looking at a Supervisory Control And Data Acquisition (SCADA) screen. (SCADA is the computer system that monitors and controls the plant.) For the sake of ease, we will call this operator #1. He or she notices the chlorine effluent residual is beginning to drop. Operator #1 was not aware that the previous operator (Operator #2) had raised the chlorine dose a few hours before. With the added chlorine dose, the chlorine residual was "lowering" as it got closer to breaking over. If operator #1 panics and raises the chlorine dose again the combined chlorine residual will lower even further.

The important thing to remember is there are many things to look at if your chlorine dose is lowering. It may very well be an issue with your chlorine feed, but there are many other options to consider. If you check your chlorine feed system and everything is functioning normally, you may have an issue with the ammonia feed system. Many modern water treatment facilities have calculations built into the SCADA system that make chloramine dosing easier. Make sure to go to the screen with the chlorine: ammonia: ratio to make sure that it is set up correctly.

Lastly, free chlorine is always the preferred disinfectant as it is 25 times stronger a disinfectant than chloramines. However, chloramines last much longer in the distribution system. There are several factors that may lead to a lowered chlorine residual. An increase in biological growth is possible, but you should see other signs such as an increase in turbidity. The most common problem in chloramine treatment with a decreasing chlorine residual is operator error or an issue with the water treatment process.

Nitrification

Nitrification is a process in which bacteria reduces ammonia and organic nitrogen in treated water into nitrate and then nitrite. This condition usually occurs during the summer months when water temperatures are higher. It can also occur during the improper

turnover of reservoirs, when there are high levels of ammonia, and in dark environments, a typical condition for most water reservoirs.

This condition is one of the drawbacks of chloramine treatment. Nitrate and Nitrite are inorganic chemicals regulated by primary drinking water standards. The MCL (Maximum Contaminate Level) for Nitrate is 10 ppm and the MCL for Nitrite is 1 ppm. High nitrate and nitrite levels in drinking water can lead to methemoglobinemia also known as “blue baby syndrome.” This condition affects infants under six months old that consume water contaminated with nitrates and nitrites. The infant's blood is not able to carry enough oxygen to blood cells and tissue within their body.

The condition of Nitrification is a reoccurring cycle that can lead to the total loss of chloramine residual in the distribution system and in water storage tanks. If this was to occur, all the water in the system would have to be dumped and it would be a total loss. As an operator, this is something that you never want to happen. Not only would it be a loss of money for your company, but it could lead to an outbreak of methemoglobinemia. The cycle is below:

Chloramine decay → Release of ammonia→ oxidation of ammonia to nitrite from oxidizing bacteria → Biomass increase → (back to chloramine decay until there is a possibility of total loss of residual)

Some early indicators of nitrification:

- Lowering chloramine residual
- Increase in bacterial heterotrophic plate counts
- Excess ammonia in the treated water
- Total coliform positive samples

In summation, nitrification can cause a variety of problems and violations within the water system. What can we as operators do to minimize any chance of nitrification from occurring? There are a few steps every operator can take to avoid nitrification. First, you want to minimize free ammonia in treated water. Sampling and equipment around the treatment plant will help operators determine if there is too much free ammonia in the treated water.

Second, operators should always maintain a good chlorine residual. Isn’t that the name of the game? Sure, but it is easier said than done in some cases. Many water treatment companies will lower their target chlorine residual in the summer to save on costs because the disinfectant works more efficiently during the summer months. It is a good practice in theory, but not necessarily the best practice if you are working with chloramines and trying to combat nitrification.

Reducing water age is the third step operators can use to combat nitrification. This can be done by cycling reservoirs during the summer months and taking reservoirs out of service during the winter when water demands are lower. Distribution operators are continually balancing maintaining a good amount of water for fire flow and demand, but also cycling reservoirs to fight nitrification. A good practice is to take all the reservoirs in the distribution system and divide it into thirds. At any given point during the day 1/3 of the reservoirs are full, 1/3 are in the middle range, and 1/3 are in the lower range. This allows operators to cycle water while also keeping water in the system.

The last step is to keep the water system clean. This can be accomplished by flushing dead ends to prevent lower chlorine residuals at the end of the distribution system. Boosting chlorine by adding it directly to a reservoir is also an option but not always the best practice. The problem with this method is it could lead to short circuiting. Chlorine must mix adequately to be effective. Mixing can be accomplished by adding mechanical mixers in the reservoir to keep water moving and prevent short circuiting. Chlorine can also be added to the inlet of the reservoir so the water pressure acts as a mixer.

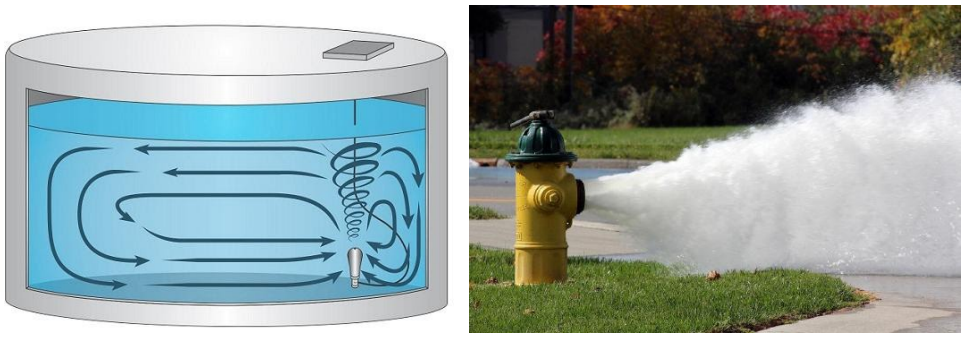


Figure *Page*4.9.2: (left) an example of a water reservoir mixer used to cycle water and prevent short-circuiting. (right) Hydrant flushing (CC0)

Hydrant flushing is a method that can be used to get rid of stagnant water at the ends of a distribution system. Stagnant water can lead to lower chlorine residuals and possible nitrification.

In summary, the use of chloramines as a disinfectant is being employed by many water agencies in the United States to prevent DBP formation. It is not the most ideal disinfectant available, but it does have some advantages. Chloramine disinfection limits DBP formation and has a longer-lasting disinfectant residual. This can be useful for larger systems where water must travel great distances to get to storage.

The drawbacks include the difficulty in effectively managing the breakpoint chlorination curve and managing nitrification. Because of advancements in water quality testing and more stringent regulations with DBPs, chloramine treatment is and will continue to be a more popular option in water treatment.

Chapter Review

1. What is the target chlorine to ammonia ratio?
    1. 2:1
    2. 3:1
    3. 4:1
    4. 5:1
2. What is the MCL for nitrates?
    1. 1 ppm
    2. 10 ppm
    3. 5 ppm
    4. None of the above
3. What is the atomic weight of chlorine?
    1. 70
    2. 14
    3. 65
    4. 20
4. What disinfectant has the longest-lasting residual?
    1. Ozone
    2. Chlorine
    3. Chloramine
    4. Chlorine dioxide
5. What are some of the early indicators of nitrification?
    1. Lowering chlorine residual
    2. Excess ammonia in treated water
    3. Raise in bacterial heterotrophic plate counts
    4. All of the above

6. What are THMs classified as?
    1. Turbidity
    2. Radiological
    3. Volatile organic chemicals
    4. Salts
7. What method can operators employ to combat nitrification?
    1. Lower residual chlorine target
    2. Keep reservoir levels static
    3. Minimize free ammonia in treated water
    4. Increase water age
8. How many times stronger is Chlorine compared to monochloramine?
    1. 25 times
    2. 20 times
    3. 15 times
    4. 5 times

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Page 4.10: Laboratory

Learning Objectives

- After reading this chapter you should be able to identify and explain the following topics related to treatment plant laboratories:
- Equipment in the laboratory
- Laboratory safety
- Water quality testing
- Contaminants tested in the laboratory and throughout the treatment plant

Working in a laboratory is probably something you never thought about when deciding to explore the career of water treatment. However, working in a laboratory is one of the more critical aspects of the profession. Many larger agencies have a dedicated staff of laboratory personnel that handles a lot of the day to day water quality analysis, but operators still play a key role. After all, the operator is the person in charge of running the plant, monitoring chemical feeds, and performing routine plant checks to ensure the system is running smoothly. A laboratory scientist can run all the tests in the world, but since they are not the ones running the plant, a lower chlorine residual may not stand out to them. The responsibility falls squarely on the shoulders of the operator. State regulations require operators to take grab samples throughout the day to ensure monitoring equipment throughout the plant is running correctly.

This topic is discussed at length in the water quality course. This is meant to be a brief overview if you have not taken that course yet.

Laboratory Instruments and Equipment

Throughout the lab, you will find a variety of beakers, flasks, dilution bottles, and graduated cylinders. A lot of these instruments look the same or similar but they all have a unique job and purpose. Beakers range in size from 25 to 4000 mL. They are used to mix samples during chemical analysis. A burette is a long skinny tube-like glass receptacle used to measure and disperse liquid. Flasks have a narrow neck and are round at the bottom. Each kind of flask serves a different purpose, but they all look very similar.

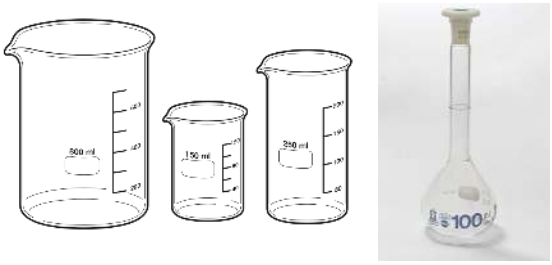


Figure ***Page*4.10.1**: (left) Beakers – Image by Xavax is in the public domain. (right) Volumetric flask – image by Lucasbosch is licensed under CC BY-SA 3.0

Graduated cylinders are tall and cylindrical and range in size from 10 mL-4000 mL. They are used to measure liquid, but not with accuracy. For example, they can be used during a chlorine test to gather a general volume of water. If you need an exact amount, it should be measured with a pipette or other similar and accurate liquid measuring device. The pipette measures a liquid with 100 percent accuracy.



Figure ***Page*4.10.2**: Sample Bottle – Image by Σ64 is licensed under CC BY-SA 3.0

You will find sample bottles in any laboratory. The bottles can be made of plastic or glass. They are used to store water for future lab tests and not used for measuring liquid. Sample bottles are used to collect bacteriological samples and for organic chemical analysis. The bacteriological bottle is one of the most important sample bottles you find in a lab. They are made of plastic and are 100 mL. Water treatment operators must take bacteriological samples per the Total Coliform Rule. These tests will be performed daily in the lab and throughout the distribution system based on your coliform sampling plan.

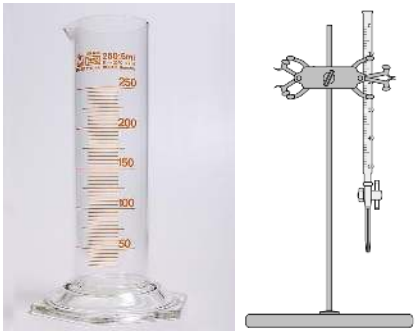


Figure ***Page*4.10.3**: (left) Graduated Cylinder – Image by Lilly_M is licensed under CC BY-SA 3.0. (right) Burette – Image by Roland1952 is licensed under CC BY-SA 3.0.

Other Items Found In the Laboratory

Incubators will be found in every lab at a water treatment plant. They are used to hold a temperature for bacteriological cultures. There are two types of incubators used, dry heat and water baths. Common uses for incubators include coliform testing, multiple tube testing, and heterotrophic plate counts. Ovens are other pieces of equipment found in the lab. Autoclaves, for example, are used to sterilize glassware items but can also be used to sterilize material that has been contaminated from perhaps a positive coliform test. Refrigerators are used to store samples for future testing and to store chemicals used for water quality testing. These refrigerators are for work use only and should not be used to store food and beverages.

Laboratory Safety

Operators should always be aware of safety regardless of where they are at the treatment plant. The laboratory should be treated no differently than if an operator was changing chlorine cylinders. There are chemicals that are combustible and others that can cause severe burns if they are exposed to skin. Some common safety equipment found in water treatment plant laboratories:

- Eye protection—Eye protection should include safety goggles, safety glasses, or face shields. It is not recommended to wear contact lenses if working with dangerous chemicals. Prescription safety eyewear is available. You only have one set of eyes, so it is important to protect them. Water laboratories have liquids and solids that can easily penetrate your eyes if you are not wearing the proper PPE (personal protective equipment).
- Safety Showers/Eyewash Bottles—In the event that something gets in your eyes, every lab is equipped with a safety shower. The shower should have a pull lever and an eyewash sink.
- Fire Extinguisher—Fire extinguishers are located throughout any building in the United States. Most water treatment companies will provide formal training on proper use of a fire extinguisher. In the event that you cannot put a lab fire out with the use of an extinguisher, exit the room right away and call the fire department. Fire extinguishers are meant to put out very small fires very quickly.



Figure ***Page*4.10.4**: Emergency eyewash and shower – Image by Korn966 is licensed under CC BY-SA 4.0

Meters

Laboratories use a variety of meters for water quality testing. Although meters are located throughout the treatment plant, the meters in the lab are used to verify that equipment throughout the treatment plant is functioning correctly. The most common meters used by water treatment operators are pocket colorimeters for chlorine testing in the field, turbidity meters, and pH meters. Pocket colorimeters are great to be used in the field, but the results are not reportable. For compliance purposes, you must use an electric colorimeter or photometer.

pH meters and turbidimeters are used to verify equipment is working throughout the plant. At a minimum, an operator will run labs on turbidity, chlorine residual, water temperature, and pH. All of these parameters are required for CT compliance and verification. These measurements are important in ensuring the treatment plant is operating in compliance with the surface water treatment rule.

Microbiological Testing

Microbiological testing is probably the most important testing done by water treatment professionals. As discussed at length in this text, treatment water operators aim to remove and deactivate pathogenic organisms from drinking water through filtration and disinfection. Water regulations require 3Log removal and deactivation of *Giardia* and 4 log removal and deactivation of viruses. Bacteria fall in the middle of *Giardia* and viruses. Therefore, it is safely assumed bacteria will be removed and deactivated along the same process.

Water professionals test for microbiological agents by testing for the indicator organism coliform. Coliform bacteria cause no harm to humans but are generally present when pathogens are present in the water. The reason coliforms have been used to identify contaminated water for over 100 years is because they are always present in contaminated water. Even if there is no fecal contamination, they are still present. They survive longer in water than pathogens and they are easy to identify with proper testing. When a positive sample is identified, we assume the water is contaminated until it can be proven otherwise.

Water treatment facilities use four different tests for coliform monitoring. The easiest, least expensive, and the most common method for coliform testing is the presence absence test (P-A). Both the P-A and multiple tube fermentation (MTF) tests work based on the fact that coliform produces gas from the fermentation of lactose within 24-48 hours. The MTF method uses three steps for the test. It includes the presumptive, confirmed, and completed test cycle. The presumptive test is accomplished in 24 hours. Samples are incubated at 35 degrees Celsius for 24 hours and then checked to see if a gas bubble has formed or if the sample is cloudy. You want to see no bubble or gas. The samples are then incubated for another 24 hours. If gas does not form, the test is over and the sample is absent. If there is a gas bubble, you move on to the confirmed test.

The confirmed test verifies the sample is positive from coliform and not another type of bacteria. Brilliant Green Lactose Vile is added to the sample and then incubated for another 48 hours. The same method is used. The lab technician or operator checks to see if gas is produced during the incubation period. The minimum requirement for water treatment operations is the presumptive and confirmed test. The completed tests are rarely used except for quality control by laboratory personnel. In the event of a positive confirmed test, coliform bacteria violation protocol will go into effect.

The P-A method is the most common method for treatment operators and field sampling staff. The bottles are easily transferred in an ice chest and the set-up is very simple. This method is commonly referred to as the Colilert method. The test uses a 100 mL plastic sample bottle. A nutrient is added to the sample, which is then incubated for a period of 24 hours at 35 degrees Celsius. The nutrient will cause the water to turn yellow if coliforms are present. In the event of a positive test, the bottle can be placed behind a fluorescent light that will turn a blue color which indicates fecal E. coli contamination.

The other two bacteriological tests include MMO-MUG and the membrane filter method. The MMO-MUG tests come with the testing agent already in the vials. A 10 mL sample is simply added to the vial. As with the P-A test, samples positive for coliform will turn yellow and for fecal contamination will turn blue. The membrane process begins with filtering 100 mL of water through a membrane filter. Then the sample is added to a petri dish and incubated for a 24-hour period. Coliform positive samples turn a red-pink color. Confirmative tests require incubation of a broth for another 24 hours.

Physical Water Quality

Operators test the water for both physical properties and contaminants that will cause harm to humans. There are secondary standards related to many of the physical tests operators perform. Acidity is the ability to neutralize a base. Alkalinity is the ability of water to neutralize acid. The reason operators are concerned with the acidity and alkalinity of drinking water is different pH scales have different effects on water treatment. When acids are added to water, they lower the pH of the water. A strong base may need to be added to boost the pH. Operators want a small amount of calcium carbonate present in the water to deposit around the pipes of the distribution system. This helps combat corrosion.

When we think of water drinkability, we might think of color, taste, odor, and temperature. The physical aesthetic of the water matters and impacts our desire to drink the water. The color of the drinking water may indicate water with higher levels of organic compounds and water with THMs.

Taste and odor issues in treated drinking water are hard to test. Many customers complain of a strong chlorine smell in their drinking water. Taste and odor problems can come from organic matter, chlorine, dissolved gases, and even industrial wastes. The threshold odor test is measured on the TON scale. (Water sample of 100 mL + dilution divided by 100 = TON.) Water registering as a 3 will most likely draw complaints from customers.

Water temperature plays a key role in water treatment because disinfectants work better at higher temperatures. However, nitrification occurs during the warmer months of the year so the water temperature has to be carefully managed. Water agencies in colder regions of the country must deal with freezing conditions within their treatment and distribution system. During the winter even in warmer regions, lake turnover can cause vast changes in water quality.

Turbidity is the suspension of particles in water. High levels of turbidity can signify major issues within the treatment plant. Therefore, turbidity is used to verify how efficiently the treatment plant is operating. High turbidity values may indicate higher levels of organic and inorganic matter. Pathogenic organisms can hide behind turbidity and render disinfection ineffective. Turbidity is measured in the lab with a nephelometric counter. A light source is added and, in the presence of turbidity, the light scatters, producing higher numbers with greater amounts of turbidity.

The final two water quality testing procedures most commonly performed by water treatment operators are chlorine and pH. The chlorine or chloramine feed system is one of the most critical components of a water treatment plant that operators monitor through online testing and grab samples.

The measurement of the hydrogen ion concentration in water is pH. The pH scale ranges from 1- 14 with 1 being the most acidic and 14 the most basic. The higher ends of both ranges produce the most corrosiveness. 7 is considered neutral. Do not confuse pH with acidity or alkalinity. It is important to monitor pH because the pH is used to control many chemical reactions in the treatment plant including coagulation, disinfection, corrosion control, and the removal of ammonia. pH also plays a key role in the CT calculation.

Chapter Review

1. An organism used to indicate the possible presence of E. coli contamination is _____.
    1. *Cryptosporidium*
    2. *Giardia*

3. Coliform
4. Brilliant green vile

2. The presence-absence (P-A) test used for microbiological testing is also commonly referred to as _____.
    1. Multiple tube fermentation
    2. Membrane filtration
    3. Confirmed test
    4. Colilert
3. When testing for coliform bacteria with the multiple tube fermentation (MFT) method what is the best indicator for a positive test?
    1. Color change
    2. Gas bubble formation
    3. Formation of a cyst
    4. Formation of turbidity
4. Coliform bacteria share many characteristics with pathogenic organisms. Which of the following is not true?
    1. They survive longer in water
    2. They grow in the intestines
    3. There are less coliform than pathogenic organisms
    4. They are still present in water without fecal contamination
5. What is the second step in the multiple tube fermentation test?
    1. Presumptive test
    2. Negative test
    3. Completed
    4. Confirmed
6. What is the removal and deactivation requirement for *Giardia*?
    1. 2 Log
    2. 3 Log
    3. 4 Log
    4. There is no requirement
7. The multiple barrier approach to water treatment includes removal through which method?
    1. Filtration
    2. Coagulation
    3. Disinfection
    4. Both 1 and 3
8. A pH reading of 7 is considered _____.
    1. Slightly acidic
    2. Acidic
    3. Basic
    4. Neutral
9. A higher than normal turbidity reading could signify _____.
    1. A change in water quality
    2. Nothing. Keep operating as normal
    3. Microbiological contamination
    4. Both 1 and 3
10. What is the ingredient used during the second multiple tube fermentation test?
    1. Colilert
    2. MMO/MUG
    3. Brilliant green vile

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4. Chlorine

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Page 5.1: Basic Overview/Introduction To Wastewater Treatment

Learning Outcomes

- Understand the importance of proper wastewater treatment
- Describe and construct the urban water cycle
- Analyze wastewater origins and how it is conveyed
- Differentiate between residential and industrial/commercial wastewater
- Evaluate the typical job function of a wastewater treatment operator
- Explain the certified wastewater treatment operator licensing requirements

Introduction

Proper wastewater treatment and disposal is essential for the vitality of a functioning society. Without it, a community's environment can be severely polluted and the health of the public is at great risk. To better understand the relationship between wastewater treatment and water treatment and distribution, examine the urban water cycle. Like the typical hydrologic cycle, which shows the natural movement of water in the environment, the urban water cycle shows how water is moved in an urban environment.

In some cases, wastewater that has been treated by a wastewater treatment plant will be discharged back into a natural water body. Water from that water body will then be used by downstream communities as source water for their water treatment plants. If either of these two treatment facilities are not operating to current regulations and standards, public health is at risk. In addition, if the wastewater treatment facility is not operating properly there can also be additional environmental damage to the water body.

Currently, there is a paradigm shift in water treatment and the line between water, wastewater, and stormwater is becoming thinner and thinner. For example, the use of reclaimed water from wastewater treatment plants can be used for various beneficial uses instead of being discharged into a water body. The term "One Water" is being used more frequently to encompass the idea that all of these water sources are beneficial and more innovation is needed to use these sources more efficiently. However, the focus of this textbook will be on the inner workings of a conventional wastewater treatment plant. The goal is to give you the vocabulary and knowledge needed to understand how wastewater treatment operators can take a contaminated water source and treat it to a level of quality that will not endanger the environment or public health.

The term wastewater has become the common term to describe sewage. In fact, when we talk about conventional wastewater treatment plants we are talking about facilities that take the used water from residences and businesses of a community and clean it up. Wastewater is anything and everything that goes down the drains of these households and businesses. All the water from sinks, garbage disposals, toilets, dishwashers, bathroom drains, and washing machines are considered residential wastewater. There is also commercial or industrial wastewater. Many manufacturing processes that use water, typically for washing or cooling purposes, need to properly dispose of this water. In some cases, this wastewater may be treated onsite before it is discharged into the wastewater collection system. Some municipalities will require the manufacturer to obtain an industrial waste permit that regulates what they are allowed to discharge.

Wastewater Treatment Plant Operators

A wastewater treatment plant operator's main responsibility is to ensure the wastewater treatment facility is being operated and maintained so the wastewater leaving the facility meets the limits of their National Pollutant Discharge Elimination System (NPDES) permit. We will learn the specifics of exactly what an NPDES is in later chapters. Throughout the rest of this book, we will look at the main roles and functions that wastewater treatment plant operators do every day.

Licensing Requirements

The State Water Resources Control Board (SWRCB) is the regulatory authority in California for many aspects of water laws and regulations. They are also responsible for overseeing the Operator Certification Program. In California, it is mandatory to be certified by the SWRCB if you are employed in the operation of a water distribution system, water treatment facility, or wastewater treatment plant.

To become certified there are three things that must be accomplished by the individual seeking certification. First, is to obtain the required amount of education for the level of certification. Each vocation has five levels of certification, with grade five being the highest. As the level of certification increases, more education is needed. The second requirement is experience. Just like education, higher certifications require more experience. However, these two requirements work together. The more education one has, the less amount of experience needed. Likewise, if one doesn't have a significant amount of education, they can still obtain higher certifications by gaining more work experience. The education and experience requirements for the Wastewater Treatment Operator certifications can be found here. The final thing is to pass the certification exams which are offered twice a year, in the spring and fall.

Becoming certified as a Wastewater Treatment Operator Grade 1 requires that the applicant has gained one year of work experience. This one year of work experience is one of the hardest hurdles for many people to overcome. Many employers want to hire people that already have certifications, but you can't get certified if you don't have experience. Many wastewater treatment facilities understand this predicament and offer what is called an Operator-In-Training (OIT) position. To obtain a Grade 1 OIT certificate you must have a high school diploma or GED, have six educational points by taking a college-level math or science course, and be employed by a wastewater treatment facility. These positions are becoming more competitive and often employers require additional related work experience or additional education. Successfully passing the certification examination can help set you apart from other applicants.

Type of Work

The type of work a wastewater treatment operator is involved in will be varied and depends on a lot of different factors. A common job description will include something along the lines of "to ensure the operation of the treatment facility and ancillary equipment in order to meet effluent requirements". The effluent of a wastewater treatment plant is the water that leaves the facility once it has been treated. To ensure the effluent requirements are met, an operator's typical job will include monitoring and logging critical information such as pump pressures and flow rates, tank levels, and water quality parameters such as turbidity and chlorine residual. There is also preventative maintenance that is required. Some tasks could include taking portions of the treatment system offline for cleaning and/or repairs.

Throughout the treatment system water samples will need to be taken and tested for various constituents, either for regulatory compliance or process control. Depending on the facility, the sampling may be done by operators or by laboratory technicians. However, it will almost always be the certified operators that will review the laboratory results and determine if any adjustments to the treatment process are needed.

It's important to note that wastewater treatment plants are industrial facilities and some of the work can be very dangerous. Operators can be working with heavy machinery such as forklifts, large pumps, and cranes. There is also high voltage electrical equipment that the operator will interact with on a daily basis. There can be situations where there are high-pressure lines and even the possibility to be exposed to harmful chemicals. This book will have a whole section dedicated to covering these safety topics and more.

Jobs

There are many different types of work available in the wastewater treatment industry as a whole. While this textbook will focus on the specifics of the job duties of a wastewater treatment operator (WTO), there are many other supporting jobs in both the public and private sectors. Most of the WTO positions are available through the public sector. For example, a city will be the owner and operator of a municipal wastewater treatment facility. That city will then employ as many WTOs as necessary to operate the plant. However, there will be many other jobs required to keep the facility running aside from the operators. Depending on the size of the plant, there can also be workers skilled in the maintenance of pumps and machinery, electricians, and instrumentation technicians. These jobs can also have their own trade certifications that may be required by the employer. In addition, there may be laboratory staff, administration personnel, engineers, managers, and financial experts. All of these positions will work together to keep the plant running. But it's important to remember that at the end of the day, it's the certified Wastewater Treatment Operators that can be legally responsible for the quality of water leaving the facility and compliance with the NPDES permit.

There are also many job opportunities in the private sector. There are many "package plants" that smaller private industries will operate to treat residual waste from a large scale manufacturing process. A brewery, for example, may need to treat their brewing

process wastewater before the water can be disposed of in the municipal sewer system. As of 2013, these privately run wastewater treatment plants require workers that are involved in the operation of the plant to meet the same licensing requirements as publicly operated wastewater treatment plants.

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Page 5.2: Wastewater Quality

Learning Outcomes

- Understand the purpose of NPDES permits
- Explain how TMDLs are obtained and how they improve water quality
- Assess the difference between chemical and physical water quality contaminants
- Describe how different contaminants can affect water bodies

National Pollutant Discharge Elimination System (NPDES) Permits

Wastewater treatment plants typically discharge their treated water into a water body that is nearby. Since 1972, with the passage of the Clean Water Act, it is illegal to discharge water from a point source into waters of the United States unless an NPDES permit is obtained. Since wastewater treatment facilities have all of their discharge leaving the plant from a single discharge pipe, it is considered a point source. This differs from nonpoint sources that have large areas of discharge like runoff from agricultural fields. An NPDES permit allows discharging the treated wastewater into a water body as long as it meets the requirements of the permit. These requirements can include limits on what can be discharged, how frequently samples must be taken, and other reporting requirements. There may also be other requirements specific to the discharger to assure that the water being discharged does not harm public health or the environment.

Total Maximum Daily Loads (TMDL)

The total maximum daily load (TMDL) is a calculated value of the maximum amount of a specific pollutant that a waterbody can receive without negatively impacting that water body. For example, 10,000lbs of pollutant X naturally occurs within a stream that has a TMDL of 50,000lbs for pollutant X and contains three point source discharges. Therefore, an additional 40,000lbs of pollutant X may be discharged into the stream without exceeding the TMDL. It's the job of permit writers to use the TMDLs of a water body and the total number of point source discharges to determine the waste load allocation (WLA) for each discharge and incorporate that into the NPDES permit as a limit. To continue with the example, a permit writer could determine that with three point source discharges each one would be allowed to discharge 10,000lbs of pollutant X. This would leave a margin of safety of 10,000lbs. So in theory, the discharge of pollutant X would not negatively impact the water body because the sum of all the discharges and naturally occurring contamination is below the TMDL of the water body.

Wastewater Solids

The solids found in wastewater are comprised of many different constituents including organic and inorganic material. A variety of laboratory tests can be performed to determine the total amount of solids. The total suspended solids (TSS) test will determine the total amount of solids that are suspended and that are easily settleable. This test is done by filtering a specific volume of the wastewater through a filter pad. The water and dissolved solids will pass through the filter; and the settleable solids and suspended solids will remain on top of the filter. The difference in weight of the filter before and after filtration is used to calculate the amount of TSS.

While all the solids remaining on the filter after the TSS test are suspended, not all of the solids are settleable. Settleable solids can be determined by using an Imhoff cone. Again, a specific volume, typically 1,000 mL, is poured into the Imhoff cone and allowed to settle. The settleable solids will collect on the bottom of the Imhoff cone. After an hour, the amount of solids that settled can be determined by the graduations on the Imhoff cone as seen in the figure below.

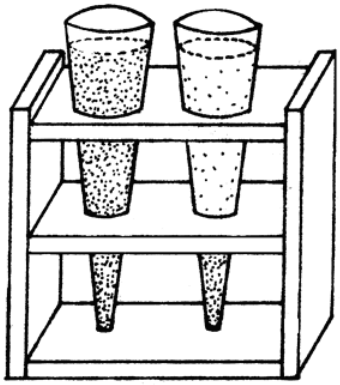


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The water that filtered through the filter pad during the TSS test still contains solids of contaminants that are dissolved into the water. Collectively this can be determined by completing a Total Dissolved Solids (TDS) test. This test takes the water left over from the TSS test and pours it into a pre-weighed dish. The water is then evaporated from the dish and weighed again. The difference in weight is then used to calculate the TDS.

Whether the solids are settleable, suspended, or dissolved, wastewater is generally made up of less than 1% solids. The other 99% is just water. The focus of the remainder of this text will be on treating the 1% of solids in wastewater. The difference in the type of solids will determine what type of treatment process is used. Settleable solids will easily settle during the primary sedimentation process. Suspended solids will require a secondary treatment process. TDS can only be removed by advanced treatment methods like membrane filtration or reverse osmosis. TDS will not be removed by conventional wastewater treatment methods.

Biochemical Oxygen Demand

Biochemical oxygen demand (BOD) is a measure of how much organic material is in the wastewater. When wastewater with high amounts of BOD is released to a water body, the organic material will consume the dissolved oxygen in the water body. If the BOD exceeds the TMDL of the water body, then the oxygen levels can be completely depleted. Without the dissolved oxygen, fish and other aquatic life will not be able to survive.

The BOD5 test is completed in a laboratory by taking a sample of wastewater and measuring the dissolved oxygen concentration. The sample is kept in an airtight container in a refrigerator set to a temperature of 25□C. After 5 days, yes, that's why there is a subscript 5 in BOD5, the dissolved oxygen concentration is measured again. The difference in oxygen concentrations is how much oxygen was consumed by the organic material in the wastewater. The more organic material there is, the higher the BOD5 will be.

The BOD5 test is the standard test that is used to measure the organic contamination in wastewater. It is one of the main regulatory components in an NPDES. However, it has one big drawback which is that it takes five days to get results. Another test that gives similar results is the chemical oxygen demand (COD). COD will measure the amount of oxygen needed to decompose organic material as well as inorganic chemicals. The difference between COD and BOD5 is that COD will also measure other chemicals that can be oxidized besides ones that are biological. COD laboratory results can be determined in approximately 6 hours. If a wastewater treatment facility is only treating wastes from a community that is mainly residential and does not have many industrial discharges, then the COD and BOD5 can be correlated after a significant number of samples are analyzed side by side. BOD5 is routinely done to meet regulatory requirements while COD results are used for process control to make sure the treatment plant is operating efficiently.

Microbiological Contaminants and Pathogens

There are many different types of microorganisms that can be found in wastewater. Some of these microbes are pathogenic. A pathogen is a microorganism that is capable of causing disease. Some common pathogens that can be found in untreated wastewater are Cholera, Giardia, Streptococcus, E. Coli, Cryptosporidium, and Salmonella. However, not all microorganisms are pathogenic and some non-pathogenic bacteria will actually be utilized as a treatment aide to reduce the amount of BOD5 in the wastewater.

One classification of microorganisms is a protozoa. A protozoa is a single-celled organism and is essential to the biological treatment processes. Amoebae, flagellates, and ciliates are some examples of protozoa commonly found in wastewater samples. Metazoa are multi-celled organisms that can also be found in wastewater treatment facilities. Some examples of metazoa are rotifers, nematodes, tardigrade (water bears). When we discuss the various biological treatment methods later in this textbook, we will learn that a microscopic examination of wastewater samples can show the health of the treatment system by comparing the quantities of protozoa and metazoa organisms.

Viruses can also be detected in wastewater samples. Viruses must have a host organism in order to live and reproduce. Unfortunately, they can remain dormant in water until they find such a host. Hepatitis A and polio are examples of viruses that can be found in wastewater samples. Viruses can be difficult to identify in the laboratory and are not routinely tested for in wastewater samples.

Coliform bacteria is the most common laboratory test done to determine the potential of the presence of pathogenic organisms. Coliform bacteria are abundant in the natural environment and can be found in water and soils. Coliform bacteria are not pathogenic but their presence can determine if pathogenic organisms may also be present. For example, if a tested wastewater sample has large amounts of coliform bacteria, then we can say that there is a high chance that pathogenic organisms are also in that sample. If we find that there are very low amounts of coliform bacteria, then we can say that there is a very small chance that pathogenic bacteria are also present. Because of this, coliform bacteria are often called an indicator organism. The laboratory test results can be used to indicate whether the sample has the potential for containing pathogens. Since there are so many pathogenic organisms, it would be extremely cumbersome to test for each one individually. It is much more economical to complete the coliform test instead. Now if the coliform test does indicate that there are coliforms present, further testing can be done to determine if pathogenic bacteria are also there. Typically, the test to determine if *E. coli* is present.

Eutrophication Effects of Nitrogen and Phosphorus

Algae typically is not present in wastewater but wastewater can contain nutrients such as nitrogen and phosphorus which will promote algae growth in waterbodies. In pond treatment systems, algae will actually be used to aide the treatment process by supplying oxygen to beneficial bacteria that will reduce BOD5.

When treated wastewater is discharged into a waterway, the amount of nitrogen and phosphorus must be closely examined. If there is too much nitrogen and phosphorus in the waterbody, it can lead to an overabundance of algae. When there is too much algae growth, the algae will consume more oxygen from the waterbody. With large amounts of algae consuming the oxygen, there is not enough oxygen for other aquatic organisms to sustain life. This excess growth of algae resulting from the increased nutrient loading on a waterbody is called **eutrophication**.

Other Chemical Contaminants

In addition to nitrogen and phosphorus, there are other chemical contaminants that can be found in wastewater. Almost every element that can be found on the periodic table will molecularly combine with water under the right conditions. Collectively these will be determined when completing the TDS analysis. There are some elements that we are particularly concerned about and these concentrations are measured independently.

Chlorides can be introduced into wastewater from road salts, food waste, water softeners, and naturally occurring surface water contamination. Chlorides can be found in water as sodium chloride, potassium chloride, calcium chloride, and magnesium chloride. When there are excess levels of chlorides in a waterbody, it can have adverse effects on aquatic organisms. Excessive chlorides can interfere with the biological processes going on inside the bodies of freshwater aquatic organisms.

Heavy metals found in wastewater typically come from industrial discharges. Metal finishing, electroplating processing, mineral extraction operations, and textile industries can contribute to heavy metals in wastewater. Lead, copper, zinc, mercury, arsenic, nickel, and silver are some common heavy metals that can be found in wastewater samples. Although, any metal on the periodic table can find their way into the sewer system. Heavy metals are a concern due to their toxicity in aquatic systems and adverse effects on plants and animals.

The pH of wastewater is very important and can influence the treatability of wastewater. If the pH is not between 6.5 and 8.5, chemicals may need to be added to bring the pH into that range. Alkalinity is another important characteristic of wastewater.

Alkalinity is the ability of the wastewater to buffer against changes in pH. Alkalinity is measured by determining the amount of acid-neutralizing basics. It is commonly measured in mg of $CaCO_3$ equivalents per liter. Alkalinity is critical to the physical, chemical, and biological treatment processes we will discuss throughout this book. These processes do not operate well under acidic conditions. Sufficient alkalinity is needed to ensure the pH stays within the 6.5 to 8.5 range.

Other Physical Contaminants

Odor, color, turbidity, and temperature are all physical characteristics of wastewater. Unlike the biological and chemical characteristics discussed previously, physical contaminants can be observed by the human senses. We can see what the color is, we can smell if the odor is foul, and we can feel if the sample is warm or cold. Although laboratory equipment can be used to obtain more quantitative data.

As you can imagine, untreated wastewater can give off a foul odor. However, odor can give an operator great insight. If the wastewater smells like rotten eggs, this is a sign that there can be high amounts of hydrogen sulfide in the wastewater. In densely populated areas where the wastewater treatment plant is in close proximity to residents, odors may be captured and sent to an air treatment unit to reduce the objectionable odors from the facility.

Color can also provide insight into what's happening in the wastewater or where it's coming from. An unusual color in the wastewater can indicate an industrial discharge such as dye from a manufacturing process. If the wastewater is dark or black, then it has most likely undergone septic or anaerobic conditions. Fresh wastewater typically has a murky yellowish/brown color.

Turbidity can be physically seen in wastewater samples and is often described as the cloudiness in the water. In the laboratory, a nephelometer is used to obtain a quantitative result measured in **Nephelometric Turbidity Units** (NTU). A nephelometer works by shining a light through the sample of wastewater. If the water has high amounts of turbidity the light will scatter and not make it to the detector on the other side of the sample. High amounts of turbidity can impact the effectiveness of disinfection. The small particles that cause turbidity can shield microorganisms from coming in contact with the disinfectant.

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Page 5.3: Wastewater Collection

Learning Outcomes

- Examine how wastewater is conveyed from the source to a wastewater treatment facility
- Assess the impacts and causes of odor in a collection system and explain how to mitigate the negative impacts for a community
- Analyze how gravity sewer design is used to maintain sufficient velocity
- Evaluate system conditions to determine when a sewer pump station is needed
- Differentiate between the various methods to maintain and clean sewer systems

Gravity Sewers

The main purpose of a wastewater collection system is to convey the wastewater from the source to a treatment facility. Recall from Chapter 1 that the source of wastewater contains anything and everything that goes down the drain. There are residential sources such as homes, apartments, and office buildings. And, there are industrial sources like restaurants and manufacturing processes. These sources will have laterals that are connected to a main sewer line. Laterals are usually privately owned and the maintenance on them is the responsibility of the property owner. The lateral is a direct connection from the source to the main sewer line. The main sewer line is typically owned, operated, and maintained by a public utility. The main line is several sizes larger than the laterals as it will be required to have enough capacity to accommodate all of the laterals that are being discharged into it. In larger cities, there may also be interceptors or trunk lines. These larger trunk lines collect all of the main lines through the city and send the wastewater to the wastewater treatment facility.

Whenever possible the collection system will utilize gravity to send the wastewater from a higher point to a lower point. To achieve gravity flow, the main sewer lines are designed and constructed on a slope. The amount the line is sloped is dependent on the size of the pipe and the expected quantity of wastewater. The collection system must have a minimum wastewater flow velocity of 2 ft/second (fps). At this velocity, solids will be kept in suspension. Slower velocities will allow settling in the piping collection system. If solids settle in the collection system, these depositions will accumulate over time and can cause a blockage. If the blockage becomes too severe, then wastewater will not be able to flow freely. If the blockage is large enough, it can cause the wastewater to back up and overflow onto the streets.

Pressure or Force Mains

Gravity sewer lines cannot be used in every situation. Areas that are very flat or communities that are located in a valley will require a lift or pump station. A lift station uses pumps to lift the wastewater from a lower elevation to a higher elevation. The section of pipe from the discharge to the gravity sewer connection is known as a force main. Unlike a gravity sewer, a force main is completely full and under pressure. The pressure comes from the energy of the pump which is needed to lift the wastewater to a higher elevation.

Different Types of Sewers

There are three different types of sewer systems; sanitary, stormwater, and combined. Sanitary sewer systems only convey wastewater that was derived from sanitary sources. As discussed in Chapter 1, this is wastewater from household toilets, showers, and dishwashers, as well as industrial sources of wastewater from manufacturing processes. Sanitary sewers differ from stormwater sewers in that they contain fecal matter from human waste. It's paramount that these wastes are conveyed to a wastewater treatment facility so they can be removed and stabilized to protect public health and the environment.

Stormwater sewers are a network of pipes that collect only stormwater runoff and directs the flow to a nearby waterbody or the ocean. While stormwater does have a direct connection to human or animal waste, it is considered less harmful and can be discharged without treatment. However, it's important to understand that stormwater is by no means "fresh water". Stormwater can have large amounts of trash, plant material, silt gravel, oil & grease. There are even fairly high amounts of harmful bacteria from animal wastes. The theory is that during storm events there is a significant amount of water flowing through these systems that these contaminants become diluted and are not as concentrated. This theory is constantly being challenged and stormwater is now being seen as another water source that can be treated and even beneficially reused.

A combined sewer is a network of pipes that conveys both sanitary wastes as well as stormwater. This can be beneficial during dry weather flows where there is minimal stormwater. The stormwater that does exist is sent to a wastewater treatment facility where harmful contaminants are removed prior to discharge to a waterbody. However, combined sewer systems can be overwhelmed during storm events. Systems that have older infrastructure which has not been upgraded to deal with larger populations and storm events are especially vulnerable. When this happens, instead of only diluted stormwater being sent to a waterbody, sewage containing high amounts of fecal matter from the sanitary sewer is also discharged. This can cause increased pollution to the waterbody.

Infiltration and Inflow

Collectively referred to as I & I, infiltration and inflow is wastewater that has entered into the collection system unregulated. An inflow is when water other than sanitary wastewater enters the collection system through an illicit connection such as rain gutters, basement drains, or foundation drains. Infiltration is water such as groundwater and stormwater that finds its way into the sewer piping from manhole covers and cracks in the piping.

Odor Control

Sewage can have an extremely foul odor. As the organic material starts to break down in the sewer system, it will generate foul odors. Often, this breakdown of organic material and the biological reduction of sulfates in the wastewater will create hydrogen sulfide (H2S). H2S has a very distinctive rotten egg smell and can cause several problems in a wastewater collection system. H2S is extremely toxic and workers working near or inside a wastewater collection system must continuously monitor the atmospheric conditions and properly ventilate the workspace to ensure that the environment is free of H2S and other hazardous atmospheric conditions. H2S will also breakdown in the collection system forming sulfuric acid which can corrode pipes, manholes, and other parts of the system. Although H2S is heavier than air, it is still able to escape the collection system and cause nuisance odor conditions to the surrounding community.

These sewer gases can be mitigated in several different ways. One way is to add chemicals to the collection system that will prohibit the formation of H2S. For example, iron salts such as ferric chloride will react with the sulfides in the wastewater and do not allow the molecules to form H2S. Another way to remove H2S is to let it form in the sewer system and then have a fan that will pull the foul sewer gases from the sewer and convey the odors to a treatment site. Typically, the air treatment is achieved by carbon adsorption or bio-filtration. Carbon in this filter form is extremely porous when examined under a microscope. When the foul sewer gases are forced through a media of carbon particles, the gasses will adhere to these microscopic pores and be removed from the airflow. In a bio-filtration setup, the sewer gases are conveyed to a large tank where bacteria will metabolize the H2S and thus remove it from the airflow.

Collection System Maintenance

Collection systems, while underground and out of sight from the general public, still require a significant amount of maintenance to ensure that the wastewater flowing through the system stays underground. If the wastewater cannot flow through the network of pipes, it will begin to back up and overflow out of the manhole covers in the streets. When this happens, it is called either a **Sanitary Sewer Overflow** (SSO) or a **Combined Sewer Overflow** (CSO) depending on which type of wastewater collection system is used within the community. To prevent this from happening, wastewater professionals have several tools available to them.

Bucketing, rodding, flushing, jetting, and closed-circuit television are the primary means used to maintain a wastewater collection system. **Flushing** is a hydraulic process that is great for light cleaning of wastewater lines. Flushing moves a high volume of water with low pressure through the wastewater line that needs to be cleaned. Adding this extra water increases the velocity in the line. At high velocities, the flushing water scours the sediments and debris in the line and pushes everything downstream.

Rodding and **bucketing** are both mechanical mechanisms that use machinery to physically remove any obstructions and debris from the wastewater pipeline. This is typically used when flushing is insufficient to remove the debris. Rodding occurs when a cable with a special attachment at the end of it is sent down the wastewater pipe that needs to be cleaned. The rod is then rotated and the tool can break through the obstruction in the line.

Jetting combines both hydraulic and mechanical tools. Jetting is similar to rodding except a heavy-duty hose that can handle high pressures is used instead of a rod. At the end of the hose, there is a nozzle specifically designed to send concentrated streams of water at high pressures against the interior wall of the pipe to remove any debris or obstructions.

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Page 5.4: Preliminary Treatment

Learning Outcomes

- Understand why preliminary treatment is necessary
- Compare and contrast the different types of preliminary treatment methods
- Evaluate the benefits of different treatment methods

Nuisance Substances

Preliminary treatment is the first step in treating raw wastewater. When the wastewater first enters the wastewater treatment facility there are a lot of **nuisance materials** that have found their way into the collection system. Items such as large rags, bottles, tree branches, and numerous other nuisance items can be found in the influent to the treatment facility. These large items can cause damage to downstream pumps, take up valuable space in settling tanks, and can be hazardous to other mechanical equipment needed in the treatment process. So the first, or preliminary step is to remove these large items.

Screening

One method to remove large debris items is by using a **bar screen**. Bar screens are capable of removing items that are larger than the spacing between the bars. For example, a ¾" bar screen will hold back any debris that is larger than ¾" and anything smaller will pass through it. Common items that are removed in this preliminary treatment step are rags, roots, large rocks and aggregate, bottles, cans, and numerous other large objects that can make their way into the wastewater collection system.

Over time, the debris collected behind the bar screen will need to be removed. This is done either manually or automatically. Manual bar screens typically have large spacing, 2" to 4" is common, between the bars. To manually clean a bar screen an operator will use a rake and pull out all of the debris stuck behind the bar screen. This can be extremely laborious and dangerous as the operator is lifting heavy objects over an open trench. Ideally, a wastewater treatment plant will have two or more channels with bar screens. This way one channel can be isolated and the debris can be removed without having wastewater flowing through it. Although this is safer, it is still laborious.

Newer bar screens are raked automatically. On more sophisticated systems, the channel where the bar screen is installed will have an upstream and downstream level sensor. When the debris is blocked by the bar screen it will also inhibit the flow of wastewater through the screen. This will cause the upstream water level to rise. When the difference between the upstream and downstream levels reaches a predetermined setpoint, the motorized rake will swing down and automatically pull the debris out of the channel and into a hopper. Other systems will automatically initiate the raking sequence based on a timer or will just run continuously.

Most automatic bar screens will have a washer/compactor that receives the removed debris. The washer/compactor will wash the debris removing any of the organic matter and then compact it. Washing is important because in this preliminary step we are only trying to remove the large inorganic items. We want to keep the organic material in the wastewater stream as it will be utilized in subsequent treatment processes. Compacting the debris is critical as it removes most of the water and makes it easier to transport for disposal.

Since automatic bar screens can run autonomously, the bar spacing can be smaller. Most models are around ⅝" to ¾" but newer models can be ½" or less. While automatic bar screens are capable of removing more debris with less manual labor, there is still a skill set required to properly operate this machinery. Operators will check the equipment multiple times during a day. Checks can include monitoring the rake arm and motor for proper function, removing compacted debris to a larger disposal truck, checking motor amps are within range, and calibrating level sensors.

Comminution and Barminution

An alternative to screen these large debris items is to shred or grind them. A **comminutor** is a device that sits inside the channel where wastewater is flowing into the treatment facility. The comminutor will grind the large debris items, turning them into smaller items. Communitors are designed to produce a solid size of a certain diameter. By breaking up the debris into smaller diameters, the downstream pumps and equipment will not be as impacted. It's important to note that comminutors do not remove the debris from

the flow of wastewater. The debris is just broken down into more manageable sizes. The debris will still need to be removed in the subsequent treatment process.

Barminutors combine a bar screen with a comminutor. There is a bar screen set inside of a channel where the wastewater flows. The debris is trapped behind the bars and then a device travels up and down the bars which breaks up the large solids into smaller pieces. The ground-up solids stay within the flow of wastewater and move onto the treatment process.

Grit Removal

Once the large items are managed, the next step in the treatment process is to remove the smaller inorganic solids, such as coffee grounds, eggshells, sand, silt, and gravel. These small diameter solids are collectively called **grit**. Grit must be removed because it will cause excessive wear on plant equipment such as the impeller of a pump. Also, this inorganic material can settle in the subsequent treatment process and take up valuable space in tanks which decreases plant efficiency and can inhibit further treatment. While most gritty materials are inorganic, large organic solids such as corn kernels and other food waste may also be removed.

There are several methods that can be used to remove grit but all of the methods rely on the fact the gritty material is relatively heavy. Compared to the organic solids, grit is much heavier and will settle faster. Grit can be removed by controlling the velocity of wastewater through a tank, adding air to the tank to aide in settling, or by using centrifugal force.

The basic concept of removing grit is to reduce the velocity of the wastewater flowing through a tank to less than 2 fps. Recall that in the collection system we want to achieve a velocity of 2 fps. The higher velocity in the collection system will keep all of the solids in suspension so they make their way to the treatment plant. But now that we are trying to remove these solids, we want to get the velocity between 0.7 and 1.4 fps. At this lower velocity, the heavy inorganic solids will settle to the bottom of the tank.

Detention time is a critical factor in designing the tank dimension for grit removal. The detention time needs to be long enough to allow the gritty material to settle to the bottom. The typical detention time of grit chambers is around 2 to 5 minutes. However, if the detention time is too great, then smaller organic solids will also settle out. These items are better dealt with in the next step of primary treatment.

Aerated grit chambers are set up in a similar manner except there will be air piped to diffusers at the bottom of the tank. The addition of air in the tank creates a rolling action of solids which helps keep the lighter organic solids in suspension while the heavier grit material is directed to the bottom of the tank. In aerated grit chambers, the amount of air sent to the chamber is a critical operating parameter. If too much air is supplied, then the grit material will stay in suspension and not be removed. If not enough air is supplied, then the lighter organic material can settle out.

Cyclone separators are another method of removing grit. These separators use centrifugal force to push the gritty solids to the edge of a circular chamber where they are then directed to the bottom of the tank. To create the centrifugal force, cyclone separators will require a higher velocity of wastewater moving through the unit. Typically a velocity of 2 fps to 3 fps will be sufficient.

Any of the grit removal methods described will result in an accumulation of material at the bottom of the unit. If these solids are not removed periodically, they will accumulate to the point where the unit will be ineffective. The tanks are designed to direct the gritty material toward the bottom of the tank which is sloped towards one end. This allows the settled grit to be removed from the tank for further treatment. The mixture of grit and wastewater is pumped and sent to a grit washer. Grit washers will wash out the organic material and send it back into the flow of wastewater as it moves onto the next treatment process. This allows only the inorganic abrasive solids to be collected for ultimate disposal. Once the gritty material is washed and collected it is sent to a landfill.

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Page 5.5: Primary Treatment

Learning Outcomes

- Describe different methods to measure wastewater flow
- Examine the purpose of primary treatment
- Compare and contrast conventional primary treatment with chemically enhanced primary treatment
- Assess how specific gravity and density relates to the removal of solids able to settle

Flow measurement

After preliminary treatment, and all of the large debris and inorganic solids are removed, it's vital to measure the amount of wastewater flowing into the treatment facility. This flow rate will be an important number for process control. Many wastewater treatment plants have a typical diurnal flow pattern as flow into the wastewater treatment plant is not constant. Over a 24 hour period, the flow can fluctuate significantly. There are usually two peaks during the day, typically in the late morning and evening. In the morning, the population that the treatment facility serves is waking up, taking showers, making coffee, cooking breakfast, and using the restroom. The flow tends to lessen in the late afternoon and then increases again in the evening. In the evening, a majority of the population is cooking dinner, washing dishes, doing laundry, and taking showers. In the middle of the night, most people are sleeping and not sending water down the drain.

There are several ways that flow can be measured. A simple way to measure flow is by using a weir. Weirs can either be square or V-notched, but the principle behind them is the same. As the flow of wastewater travels through a channel, the weir is placed in its path. The wastewater is then forced to move over the crest of the weir. Based on the dimension of the square or v-notched section in the weir, the flow can be determined by the height of the wastewater over the weir crest. If there is a significant amount of flow, then the height of wastewater will also be large. When the flow decreases, the height of wastewater over the weir will be lessened.

A Parshall Flume is another way to determine the flow rate entering or leaving the treatment facility. It works similarly to a weir in that the water is forced through a restriction in the channel and the height of water before and after the restriction is used to calculate a flow rate. All Parshall Flumes have a similar shape. There is a converging section, a throat section, and a diverging section. The converging section is where the flow is channeled and forced through a narrow section. The throat section is where the wastewater flow is restricted by traveling through a slimmer channel. This restriction will increase the velocity of the wastewater as it passes through the throat section and cause the level to rise in the converging section. Just like in a weir, higher flow rates will cause the wastewater level to increase and lower flow rates will show a decrease in the wastewater level. Many treatment plants have markings in the converging section to indicate the wastewater level. Modern treatment plants will have ultrasonic level transmitters that will record the level precisely. This data can be automatically transferred to a computer system where the flow rate is instantly calculated and recorded. A benefit of using the Parshall Flume instead of a weir is that the restriction in the channel will not cause any solids to settle out. In a weir, as water builds up behind it, the velocity is reduced and solids can settle out. Those solids will have to be removed periodically or odors can become problematic.

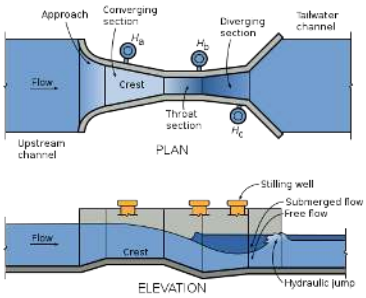


Figure ***Page*5.5.1**: Diagram of a Parshall Flume by Inductiveload is in the public domain

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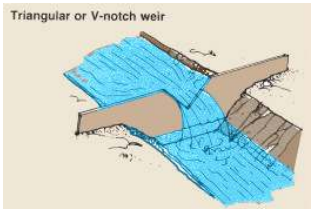


Figure ***Page*5.5.2**: Image of a v-notch weir by the FAO is licensed under CC BY-NC-SA 3.0 IGO

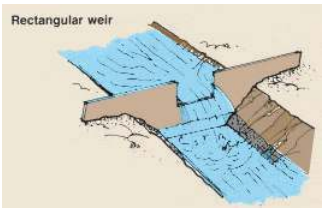


Figure ***Page*5.5.3**: Image of a rectangular weir by the FAO is licensed under CC BY-NC-SA 3.0 IGO

The most modern method of monitoring flow throughout a treatment facility is a magnetic flow meter, or “mag meter” for short. Mag meters work by having the wastewater flow through a pipe. The mag meter is connected to the pipe either by strapping the device to the outside of the pipe or more permanently, by bolting it between two sections of pipe. The device creates a magnetic field inside the pipe and as the water moves through, it creates a disturbance that is measured by the meter. Higher flow rates cause more of a disturbance. The meter can very accurately measure the flow of wastewater moving through the pipe. The benefit to mag meters is that there are no moving parts inside the pipe. So influent wastewater with lots of solids and organics will not interfere with the flow measurement. Mag meters are also very reliable and require little maintenance.



Figure ***Page*5.5.4**: Magnetic Flow Meter by Mtaylor848 is licensed under CC BY-SA 3.0

Some treatment facilities may have flow equalization. Recall that the incoming wastewater has an inconsistent flow rate that fluctuates drastically throughout a 24-hour period. This change in flow will also result in changing detention times which many of the treatment processes are dependent on. A treatment plant that utilizes flow equalization will attempt to even out the flow so it is consistent throughout the treatment plant all the time. By looking at historical data the plant operators will have a good idea of what the average flow rate for the plant is. This average flow rate is the target of the flow equalization. When the incoming wastewater is greater than the average flow, the excess amount will be directed towards a holding basin. When the flow is less than the average, typically in the middle of the night, the wastewater is pumped from the holding tank into the treatment facility. This can also reduce energy cost as day time pumping will be reduced. Energy costs are usually higher during peak periods. Some treatment facilities have flow equalization at the end of the treatment process. They may have restrictions in their discharge permit which may limit the flow rate leaving the facility. Other treatment plants don't have any flow equalization.

Sedimentation

After the incoming flow rate is measured the next step in the treatment process is primary sedimentation. The primary goal of sedimentation is to remove the settleable solids. A well-operated primary sedimentation tank can remove around 90% - 95% of settleable solids. There will also be a reduction in total suspended solids and a slight reduction in BOD5. Recall that settleable solids are the large solids in the wastewater and are measured by an Imhoff cone in the laboratory. The sedimentation process works because these solids are heavier, relative to the wastewater, and will, therefore, settle to the bottom of the tank. These tanks

are referred to as Primary Clarifiers or Primary Sedimentation Basins. A clarifier is a tank or basin where the sedimentation process will occur. The rate at which the solids will settle is determined by Stokes Law, which takes into account the size of the solid particle, the specific gravity of the particle, and the specific gravity of the liquid. Specific gravity is a unitless number and is a measure of density relative to a reference liquid. For this book when talking about specific gravity, we will assume water is the reference liquid and it has a specific gravity of 1. When determining how quickly solids will settle in the sedimentation tank, the specific gravity of the solids will be a significant factor. If the solids have a specific gravity less than 1, they will not settle at all, in fact, they will float on the water. If the specific gravity is only slightly greater than one, the solids will settle but at a much slower rate than another particle with a larger specific gravity. This is fairly intuitive. Clearly the heavier the solids the quicker they will settle.

Another phenomenon that occurs in the sedimentation process is that as the solids collect at the bottom of the tank, the weight of the solids begin to compact and compress. This causes the solids to be thickened and have slightly less water content. Detention time, or how long the wastewater takes to travel through the tank, is a critical design parameter of primary sedimentation tanks. There needs to be enough time to allow the solids to settle but not so much time that the solids start to decompose. Decomposition will cause gas bubbles to form which can hinder solids settling and create foul odors.

Primary sedimentation tanks can either be circular or rectangular. Regardless of the configuration, the tanks will have similar components. At the inlet structure where the wastewater enters the tank, the velocity is typically high in order to prevent solids settling in the piping network as the wastewater comes from the preliminary unit process to the primary tank. Once in the primary tank, the velocity must be slowed. To accomplish this there will be some type of diffuser at the inlet end that will redirect flow and prevent short-circuiting. The dimensions of the primary sedimentation tank must be able to accommodate the flow of wastewater but must also reduce the velocity.

Flotation

As discussed earlier, the specific gravity of the material in the wastewater will determine how it interacts with the wastewater in the sedimentation tank. In addition to settling solids, primary tanks will also remove floatables. Typically, these floatables are classified as fats, oils, and grease (FOG). The specific gravity of these materials is less than 1 so they will rise to the top of the sedimentation tank and be removed. A rectangular primary tank will have flights that span the width of the tank. They are connected by a chain that is motor driven to slowly move with the flow of wastewater. The flights provide several functions. They prevent short-circuiting of material on the surface, they convey the FOG on the surface to a collection trough at the end of the tank, and they convey the settled solids to a hopper at the beginning of the tank. Circular tanks have a similar mechanism called a swing arm that provides the same functions.

Sludge Removal

Once the solids have settled to the bottom of the tank, they are conveyed to a hopper in the tank. Circular tanks are typically coned at the bottom so the solids build up in the center. Rectangular tanks have a hopper at the front of the tank and the flights convey the solids there. The solids must be removed from the tank periodically so they do not cause adverse conditions. There is organic matter in the solids and if it starts to decompose, it will create foul odors and gas bubbles that will hinder other solids from settling. Typically incoming wastewater is around 1% solids. Due to the sedimentation process, the percent solids concentration increases to around 4% to 8%. Due to the high amounts of solids, a standard pump cannot be used. Instead, special pumps including a progressive cavity type pump or a stator/rotor pump are commonly used.

The stator/rotor pump has a stationary part, the stator, and a rotating element, the rotor. Both have a corkscrew type shape and the rotor moves within the stator. As it rotates, it is passing the mixture of solids and water progressively through the pump. These pumps are designed to be able to handle the abrasive nature of the solids and not clog up. The solids are sent to an anaerobic digester where they are further treated and stabilized. Eventually, they will be dewatered and sent to a landfill for disposal.

Chemical Addition

To further enhance the sedimentation process, chemicals can be added. These chemicals will adhere to the solids and increase their specific gravity. With a higher specific gravity, the solids will settle more quickly. This can either be done to increase the amounts of solids and BOD5 or can be used to achieve average results in a smaller footprint. This process is referred to as chemically

enhanced primary treatment (CEPT). Typically, ferrous or ferric chloride is used as the chemical aide. Other chemicals such as polymers may also be used. Polymers make the solids clump together which subsequently results in quicker settling in the sedimentation tank.

This process is not used as often anymore due to increasing regulatory requirements. Early in the wastewater industry, a treatment plant could have removed enough solids and BOD5 using the CEPT process. But as regulations became more stringent, many utilities upgraded to secondary treatment systems. This secondary biological treatment process is dependent on the BOD5. If too much is removed in the primary process, it will adversely affect treatment.

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Page 5.6: Biological Treatment Overview

Learning Outcomes

- Describe different methods to biologically treat wastewater
- Examine what target contaminants are being removed by the different biological processes
- Compare and contrast different biological processes and the type of bacteria and environmental conditions needed

Aerobic, Anaerobic, and Facultative Organisms

Aerobic bacteria require an environment that has free dissolved oxygen. The bacteria use that oxygen for respiration to live. They feed on the organic matter and other nutrients in the wastewater. As the bacteria consume these materials, they are removed from the wastewater, making it less contaminated. The byproduct of the aerobic decomposition of organic matter is carbon dioxide (CO_2).

Anaerobic bacteria require an environment that has no free or combined oxygen. Free oxygen is when there is excess oxygen dissolved in the water and is available as O2. Combined oxygen is when the oxygen molecule is bound to another element. Common examples of combined oxygen in wastewater is nitrate (NO3). In anaerobic conditions, there is absolutely no oxygen available to the bacteria for respiration. Anaerobic bacteria have more sophisticated means of respiration by using other chemical reactions instead of using oxygen directly. However, similar to aerobic bacteria, when anaerobic bacteria breakdown the chemicals in wastewater for respiration and feed off other organics, they subsequently remove the contaminants from the wastewater. The byproduct of anaerobic decomposition is methane gas.

Facultative bacteria have the ability to thrive in either aerobic or anaerobic conditions. While they prefer aerobic conditions, they have the ability to adapt when no oxygen is available and survive in anaerobic conditions.

Stabilization Ponds

Stabilization ponds are a simple way to reduce the amount of organic material in wastewater and require low maintenance. However, they require a lot of land and are mainly used for smaller rural communities. The concept of ponds is pretty simple. You have a large pond filled with wastewater. The size of the pond allows for a very long detention time. The pond creates an ecosystem for bacteria to thrive and those bacteria breakdown the organic matter. Since the detention time is very long, typically 45 days or longer, solids will also settle to the bottom and be removed from the effluent. Eventually, the solids will have to be removed but a well-operated pond can go a few decades before that is needed to be done.

As discussed earlier there are several different types of ponds depending on what type of bacteria are expected to be prevalent. Aerobic ponds utilize aerobic bacteria and require oxygen. These ponds are typically more shallow, around 2ft to 5ft, since the oxygen is provided by the atmosphere and algae that is produced on the surface of the pond. Ponds have a complex relationship between how much dissolved oxygen is available to the bacteria. This is driven by sunlight over a 24-hour period and photosynthesis. Photosynthesis is where plants such as algae use sunlight and carbon dioxide (CO2) to thrive. During the day when there is plenty of sunlight, the algae will utilize the CO2 in the water and produce oxygen. This will cause the pH in the pond to decrease and the dissolved oxygen concentration to increase. This is a good thing because, in an aerobic pond, the bacteria need oxygen to live and breakdown the organic waste. During the night when the sun goes down, the reverse happens. Without sunlight, photosynthesis is reduced and the algae will utilize the oxygen and produce CO2. This causes the pH to increase and the dissolved oxygen will decrease. Because sunlight is an important factor in pond performance, there will also be seasonal variations in addition to daily fluctuations. During the winter when the sun isn't as prevalent, the amount of oxygen produced via algae and photosynthesis will be reduced. If more oxygen is required than what can be produced naturally, it can be provided by mechanical means. Surface aerators and a mixing system can be installed. However, the mechanical systems in these aerated ponds will require more maintenance. They will also require more electricity to run the aeration equipment.

Anaerobic ponds utilize anaerobic bacteria which require no oxygen. To create this environment in a pond system, the depth is increased. Typically depths can range from 6 ft to 16 ft. At these increased depths, oxygen from the atmosphere is unable to penetrate the water, and a no oxygen environment, ideal for the anaerobic bacteria to thrive, is created. In these types of ponds, the bacteria are breaking down the more complex solids and organics that are found in the wastewater. It can provide sufficient

removal of nitrogen, phosphorus, and BOD5. The solids are further stabilized, broken down, and collected as sludge at the bottom of the pond. Like the aerobic ponds, these solids will eventually need to be removed.

Facultative ponds are a mix of aerobic and anaerobic ponds. Their depth is on the order of 3ft to 8ft. Recall, that facultative bacteria can switch from living in anaerobic conditions to aerobic conditions. This can be useful during seasonal variations where little oxygen is available. The facultative bacteria can then focus on breaking down organics by anaerobic decomposition. When sufficient oxygen is available they will switch mechanisms and break down the organic matter by aerobic decomposition.

Pond Performance

To improve pond performance, it is very common to have multiple types of ponds in series. Anaerobic ponds can handle higher influent BOD5 loading, so they would be the first pond. Then a facultative pond would follow, where further BOD5 reduction is achieved. Lastly would be an aerobic pond that would reduce organic wastes and remove pathogenic organisms.

Pond performance is going to be dependent on the loading of organic wastes and detention time. Typically a max of 30lbs of BOD5/day/acre is the desired loading rate. However, ponds are able to handle fluctuations if loading rates are exceeded for short periods of time. The wastewater must remain in the pond long enough so the bacteria can come in contact with the organic matter and consume it. Anaerobic ponds will maintain a detention time of 1 to 7 days. Facultative ponds have a detention time of 5 to 30 days and aerobic ponds are usually 30 days or greater.

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Page 5.7: Biological Treatment Methods

Learning Outcomes

- Describe different methods to biologically treat wastewater
- Compare and contrast fixed film treatment methods with other biological treatment methods
- Understand the operation of a trickling filter and how to control it

Fixed Film Processes

A fixed film treatment process is still a biological treatment method and utilizes the same type of bacteria as discussed in Chapter 6. The difference is that instead of the bacteria floating near the bottom of a pond, they are fixed to some type of medium. The media can either be natural stone, synthetic plastics, or large rotating disks.

Rotating Biological Contactors

Rotating biological contactors (RBCs) utilize aerobic bacteria to decompose the incoming BOD5. They are composed of a series of closely spaced circular disks. The disks are connected to a shaft that is coupled to a motor. The set of disks lay horizontally in a tank and rotate at a slow speed. The incoming wastewater enters the tank and submerges approximately 40% of the disks. The water moves through the tank and comes in contact with the aerobic bacteria that are growing on the disks. When the disks are submerged in the wastewater, the bacteria have access to the BOD5 and will consume it. As the disks rotate out of the liquid in the tank, they are exposed to the atmosphere where the bacteria can utilize oxygen for the aerobic decomposition of the BOD5.

The disks are typically 12 feet in diameter and multiple disks are combined together to make a long cylinder. Common lengths are 25 feet. The motor spins the disks at approximately 1.5 rpm. It's not uncommon to see multiple RBCs being used in both parallel and series configurations. As the bacteria thrive in this environment, eventually they will build up on the disks and start to slough off. The effluent of the RBC is sent to a finishing pond or clarifier to further treat these solids.

Each of the RBCs is covered for several reasons. Disks are commonly made out of plastic so covers will protect the disks from becoming brittle due to sun damage. Foul odors from the wastewater and H2S gasses will be present in the RBCs. Covering them will reduce these odors and prevent nuisance complaints from the community. Lastly, covers will protect the bacteria from being washed off the disks during rain events. Fiberglass covers are commonly used and are more cost-effective than building the RBCs in a building. The humidity and wastewater gases can be corrosive to cement, metals, and other building materials.

Trickling Filters

Trickling filters are another form of fixed film biological treatment. They are comprised of circular tanks filled with stone, lava rock, ceramic, or synthetic material all of which are referred to as media. Standard media is approximately 1 inch to 4 inches in diameter. The bacteria will become fixed to this media and aerobic decomposition will occur as the incoming wastewater comes in contact with the bacteria. While trickling filters can be relatively deep, around 3 to 8 feet, there is ample airflow in the voids of the media to allow for aerobic bacteria to thrive. Trickling filters often have ventilation ports near the bottom to ensure there is sufficient airflow to the bacteria. The wastewater enters the trickling filter at the top of the filter. Then gravity takes over and the wastewater trickles down through the media to the bottom of the tank where it is captured in an underdrain system.

The wastewater is conveyed from the primary sedimentation tanks to the trickling filters. This is either done by gravity or by using a pump. Either way, a trickling filter uses this pressure in the water to evenly distribute the wastewater to the trickling filter. There is a distributor arm that expands the diameter of the circular tank. The wastewater is forced out through small outlets on the distributor arm that will cause the arm to rotate.

The wastewater trickles through the media and comes in contact with the bacteria fixed to media. The bacteria are now in a sufficient environment where aerobic decomposition will occur and reduce the BOD5 of the wastewater. Over time the bacteria will build up on the media and eventually will fall or slough off. These solids will be captured in the underdrain system and sent to the secondary clarifier. In the clarifier, sedimentation will occur and the solids will settle to the bottom of the clarifier and be removed.

Recirculation

Recirculation of the clarified effluent is a key operational component of a trickling filter. Water from the secondary clarifiers has already gone through the biological treatment process of the trickling filter and has a lower amount of BOD5. By recirculating this treated water with the incoming wastewater, it will dilute the incoming BOD5. Recirculation will also be able to control the dissolved oxygen level in the trickling filters. Increasing the recirculation rate will cause the dissolved oxygen to increase and lowering the recirculation rate will cause it to decrease. An optimal concentration of dissolved oxygen in the trickling filter is 1.5 mg/L to 2.0 mg/L.

Organic Loading

Trickling filters can be further classified by how much BOD5 is being sent to the treatment unit. Low rate trickling filters receive up to 25 lbs of BOD5/1000 cubic feet/day. At this lower organic load, an operator can expect to achieve 80% - 90% BOD5 removal. Intermediate filters can handle up to 40 lbs of BOD5/1000 cubic feet/day but will see lower removal efficiencies of BOD5. High rate and roughing filters will have BOD5 loading in excess of 50 lbs of BOD5/1000 cubic feet/day. At these higher loadings, BOD5 removal significantly drops and will not meet current regulatory requirements. High rate and roughing filters are often used as a preliminary step and are combined with other forms of treatment to ensure regulatory compliance is achieved.

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Page 5.8: Activated Sludge

Learning Outcomes

- Compare and contrast the difference between fixed film and suspended growth biological treatment systems
- Describe how the activated sludge process can more efficiently reduce organic wastes
- Understand how different process control strategies work in an activated sludge system
- Examine how a secondary clarifier is utilized in an activated sludge system

Suspended Growth Processes

Unlike the fixed film biological systems discussed in Chapter 7, activated sludge uses a suspended growth process. This means that there is no media for the bacteria to become fixed to. The microorganisms are suspended in the tanks either by a mixer or air diffusers and are then mixed in with the incoming wastewater. This mixture of wastewater and microorganisms is referred to as the Mixed Liquor Suspended Solids (MLSS). A sample can be taken from the activated sludge system and analyzed in a laboratory to determine how many mg/L there are of MLSS in the system. This laboratory result will be a critical design and operational parameter that will need to be continually monitored to ensure effective treatment.

Activated Sludge Treatment

The activated sludge process was developed by two scientists, Edward Arden and William Lockett, in England in 1914. Their experiments showed that by taking the microorganisms that were already established from aerobic decomposition and introducing them to fresh wastewater, it would speed up the decomposition of the new organic wastes. Instead of relying on the 30 to 45 days that it would normally take to breakdown these organic wastes, the activated sludge process can achieve the same level of treatment in less than one day. This means that an activated sludge wastewater treatment system will be able to handle higher flow rates and higher organic loading than pond treatment or fixed film systems.

To achieve this on a large scale, conventional activated sludge systems are comprised of an aeration tank followed by a secondary clarifier. In the secondary clarifier, the microorganisms will separate from the now treated wastewater. A majority of those microorganisms will be returned back to the reactor and are now activated to treat more of the incoming wastewater. In the aeration tanks, the bacteria are in an environment with dissolved oxygen readily available and organic matter to consume. Like the other biological processes, this is how the reduction of BOD5 occurs, through aerobic decomposition. What makes activated sludge unique is that in the secondary clarifier, the bacteria become stressed because their food source has been drastically decreased and there is no more dissolved oxygen. They begin to go through endogenous respiration. The bacteria basically become so starved that they begin to breakdown their own cellular structure. Before the bacteria completely cannibalize themselves, they are sent back to the aeration tank where they are re-introduced to readily available dissolved oxygen and organic matter. The starved bacteria are then able to rapidly re-start aerobic decomposition and quickly reduce the BOD5 in the wastewater.

Food to Microorganism Ratio

A key parameter to determine the effectiveness of activated sludge systems is the food to microorganism ratio, or F/M. The food is determined by the amount of BOD5 in the incoming wastewater and the amount of microorganisms available to consume that food is determined by the amount of MLSS in the aeration tanks. Since it's a ratio, the units of these two laboratory results must be the same. The mg/L concentration of the laboratory results is converted into a mass with the units of lbs. While each treatment plant will determine which level of F/M has historically given effective treatment, a common range is around 0.2 to 0.5.

Return Activated Sludge

The return activated sludge, or RAS, are the bacteria that have settled in the secondary clarifier and are being sent back to the aeration tank. The rate of speed at which the microorganisms are returned is something that the operator can control.

Waste Activated Sludge (WAS)

Like the other biological process discussed, the bacteria, overtime will grow and their population will increase. To control the amount of bacteria in the system, a portion of the RAS will not be returned to the aeration tank but instead is directed to a separate

solids handling treatment unit. Typically, these solids are combined with the settled solids from the primary sedimentation tanks and sent to an anaerobic digester. After anaerobic digestions, the solids will be dewatered and ultimately sent to a landfill for disposal.

How much bacteria remains in the system and how much is wasted can be determined by the mean cell residence time or MCRT. The MCRT is a theoretical calculation of the average time a single bacteria will stay within the activated sludge system before being wasted. To calculate the MCRT an operator would determine how many pounds of MLSS there is in the system and divide that by how many pounds were removed from the system.

Process Control

The F/M ratio, MCRT, RAS, WAS, and dissolved oxygen concentrations can all be manipulated by the operators of a wastewater treatment facility to optimize the effectiveness of treatment. In fact, those parameters are the only things that can be easily controlled. The amount of incoming wastewater is going to be what it is and it will fluctuate throughout a 24 hour period as well as vary by season. The incoming BOD5 loading is what it's going to be and the operators can't control it.

If the F/M is too low, it means that there are more bacteria than what is needed to consume the available food. This is inefficient because supplying oxygen to the bacteria requires a significant amount of energy. If there is too much bacteria in the system and not enough food, the bacteria will still be consuming oxygen but the BOD5 won't be further reduced. To increase the F/M ratio operators can only control the "M" portion of the equation. By increasing the wasting rate, the MLSS will be reduced causing the F/M ratio to increase.

If the F/M ratio is high, then there is not enough bacteria to consume the large amounts of incoming BOD5. This will lead to poor treatment and the effluent will have a high BOD5 concentration. Operators cannot decrease the amount of BOD5 coming into the plant so they will have to increase the amount of MLSS in the system. They can do this by decreasing or stopping the wasting rate. Decreasing the wasting rate will cause the MLSS to increase and the F/M ratio will be reduced.

The MCRT is another process control tool that is used to determine the wasting rate by manipulating the equation to calculate the MCRT. Often the desired MCRT rate is determined by the design of the treatment facility or from historical data. By taking the pounds of MLSS in the system and dividing it by the desired MCRT, you will determine what the wasting rate needs to be to achieve that MCRT. However, the MCRT and F/M methods for determining the wasting rate can often conflict with each other. Operators need to look at the changes in MCRT and F/M over time and make minor adjustments to the process so the bacteria aren't "shocked".

Alternative Process Configurations

There are many different types of process configurations of activated sludge systems that differ by how the wastewater enters the aeration tanks. A plug flow reactor has all of the wastewater and RAS entering at the beginning of the tank. This will have a large organic loading at the beginning of the tank and as the wastewater moves through the tank, the load will lessen. Often, tapered aeration will be used in plug flow reactors. Tapered aeration will have lots of air diffusers at the beginning of the tank so more oxygen is available to the bacteria to handle the increased organic loading. As the wastewater flows through and the BOD5 is reduced, the air diffusers are also reduced.

An alternative is a step feed reactor where the incoming wastewater is split and sent to different portions of the tank. For example, 25% of the flow is sent to the first ¼ of the tank, another 25% to the second ¼ of the tank, and so on. This allows for a more even distribution of the organic loading as well as a more uniform demand for the air diffusers. Typically, a steep feed system will use less air overall than a plug flow reactor.

Secondary Clarification

A secondary clarifier is a key component of the activated sludge system. Not only does it separate out the microorganisms from the now treated wastewater, but it will also concentrate them through the sedimentation process. A secondary clarifier works exactly as discussed previously in primary sedimentation. The only difference is that in a primary sedimentation tank the main goal is to remove unwanted solids. In a secondary sedimentation (or clarifier) tank, the goal is to concentrate the MLSS so it can be returned to the aeration tanks.

How the biomass is settling in the clarifier can be difficult to see in real-time as the tanks are typically below-grade and made of concrete. A “sludge judge” is used to determine how many feet of MLSS are settled on the bottom and how much clear water there is on top. The tool is simply a clear PVC pipe with a ball check valve at the bottom. As the pipe is inserted into the water, the ball check valve opens, letting liquid in. When the stick hits the bottom, the operator will pull the PVC pipe out of the water forcing the ball check to close producing a cross-sectional sample of MLSS on the bottom and clear water on top. There are markings on the PVC pipe for every foot. So as the operator pulls it out of the clarifier, they can see where the clear water stops and where the MLSS is settling. Typically a sludge blanket of 1 to 3 feet on the bottom of the clarifier is optimal.

The settleability of the MLSS can also be seen in the laboratory by taking a sample of the MLSS and putting it into a 1000 mL beaker. After 30-minutes have gone by, the graduations of where the MLSS has settled will be recorded. Dividing the settled sludge volume in mLl/L, dividing by the MLSS in mg/L, and multiplying by 1,000 mg/g will yield the Sludge Volume Index (SVI) in mL/g. The SVI is utilized to gauge how well the MLSS will settle in the clarifier and will also shed light on how the activated sludge plant is operating.

Typical SVI is around 100 to 200 mL/g. Less than 100 mL/g will often show rapid settling of the sludge in the clarifier. When the MLSS settles too quickly, smaller “pin floc” particles will remain suspended in the middle of the clarifier. This will also be seen in the sludge judge test where there is clear water on top of the sludge judge, murky water in the middle, and darker solids on the bottom. This is usually caused by having a higher MCRT. An SVI greater than 200 mL/g will have sludge settling very slowly in the clarifier. This can be caused by having a low MCRT.

The water leaving the secondary clarifier has now gone through all of the previous treatment steps from preliminary screening, to primary sedimentation, and activated sludge treatment. In some areas with less stringent regulations, this water is clean enough to be discharged to the ocean or a nearby waterbody. However, some additional treatment like filtration and disinfection may be needed to meet regulatory compliance. Also, the solids that were removed from the primary and secondary process will still need to be treated and disposed of.

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00: Front Matter

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SECTION OVERVIEW

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Page 6.1.1: Understanding Fractions

Fractions are portions of whole numbers consisting of a numerator (or the top number of the fraction) and the denominator (or the bottom number of the fraction.) They are numbers that represent parts of a whole.

$$\frac{\text{Numerator}}{\text{Denominator}}$$

Figure ***Page*6.1.1.1**: Fraction

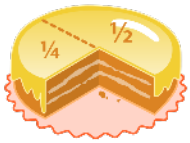


Figure ***Page*6.1.1.2**: Cake Fractions by Acdx is in the public domain

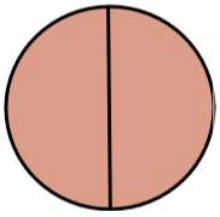


Figure ***Page*6.1.1.3**: Circle with Proportions by COC OER is licensed under CC BY 4.0

Fractions are broken down into three classifications:

- Proper - $\frac{3}{4}$ - Where the numerator is smaller than the denominator
- Improper - $\frac{5}{2}$ - Where the numerator is larger than the denominator
- Mixed - $1\frac{6}{7}$ - Where a whole number precedes the fraction

Exercise 1.1

Identify the following as a proper fraction, improper fraction, or mixed number. Identify the correct word.

1.	$\frac{1}{2}$	Proper	Improper	Mixed
2.	$\frac{10}{12}$	Proper	Improper	Mixed
3.	$10\frac{1}{2}$	Proper	Improper	Mixed
4.	$\frac{11}{3}$	Proper	Improper	Mixed
5.	$\frac{101}{13}$	Proper	Improper	Mixed
6.	$130\frac{10}{13}$	Proper	Improper	Mixed
7.	$\frac{1,000}{1,111}$	Proper	Improper	Mixed
8.	$\frac{12}{7}$	Proper	Improper	Mixed
9.	$\frac{1}{7}$	Proper	Improper	Mixed
10.	$13\frac{1}{7}$	Proper	Improper	Mixed

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Page 6.1.2: Reducing Fractions

Fractions can be reduced (expressed) in their lowest terms. This simply means that the fractions can no longer be divided by any other number.

In proper fractions, if the numerator and denominator can be divided by the same number, the fraction can be reduced.

Example: $\frac{2}{4} = \frac{1}{2}$

In the example above, this is accomplished by dividing the numerator and denominator by the number 2. Two fourths and one half represent the same number. They are just expressed differently. One half is a reduced form of two fourths.

Example: $\frac{2}{4} \div \frac{2}{2} = \frac{1}{2}$

At times a fraction can be divided multiple times in order to reduce it.

Example: $\frac{8}{12} \div \frac{2}{2} = \frac{4}{6} \div \frac{2}{2} = \frac{2}{3}$

This can also be performed in one step as follows. Both solutions provide the same answer.

Example: $\frac{8}{12} \div \frac{4}{4} = \frac{2}{3}$

In reducing improper fractions the denominator is divided into the numerator to create a mixed number. The remainder is written as a fraction.

Example:

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

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

Example:

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

Exercise 1.2

Reduce the following fractions to their lowest terms.

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

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

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Page 6.1.3: Why Fractions

Fractions are very common in waterworks mathematics. You may not see them in their “typical” form, for example:

$$\frac{3}{4} \quad \frac{2}{3} \quad \frac{1}{5}$$

You may see them as percentages:

$$75\% \quad 66\% \quad 20\%$$

Or you may see them as words:

Three quarters two thirds one fifth

However, these examples can also be expressed as fractions. We will discuss these later in the text. By understanding fractions, you can also understand how units are used to express things in terms of fractions. For example, if you drive a car at a velocity of 55 miles per hour, this is a form of a fraction.

$$\frac{55 \text{ miles}}{\text{hour}}$$

Fifty-five miles per hour is in fact a fraction. It is just expressed in a “per unit” example. It can be read as 55 miles per one unit of hour. What if you had an example of 110 miles per 2 hours? This could be written as:

$$\frac{110 \text{ miles}}{2 \text{ hours}}$$

Similar to reducing fractions such as:

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

The previous example of “55 miles per 2 hours” can be reduced as below:

$$\frac{110 \text{ miles}}{2 \text{ hours}} = \frac{55 \text{ miles}}{1 \text{ hour}} \text{ or } \frac{55 \text{ miles}}{hr}$$

The concept of “units” will be discussed in more detail later in this text, but understanding the concept is important to learn the process of solving waterworks mathematics problems. Since “adding” and “subtracting” fractions is not a common process in water-related math problems we will skip directly to multiplication and division of fractions.

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Page 6.1.4: Multiplying Fractions

Multiplying and dividing fractions is a common practice when solving water related math problems. However, the process may not appear to be the multiplication and division of fractions and is commonly referred to as “unit conversion” or unit dimensional analysis. The example below demonstrates this process and will be discussed in more detail later in this text.

$$\frac{2\text{sqft}}{1} \times \frac{3\text{ft}}{1\text{sec}} = \frac{6\text{cf}}{\text{sec}}$$

For now, ignore the “units” and focus on solving the math. “Unit Dimensional Analysis” is a section we will spend a significant amount of time covering. Just look at the above problem as a fraction multiplication problem. Yes, both 2 over 1 and 3 over 1 are simply 2 and 3, but it helps to illustrate the process by looking at them as fractions.

$$\frac{2}{1} \times \frac{3}{1} = \frac{6}{1}$$

When multiplying fractions the numerators are multiplied by each other and the denominators are multiplied by each other. In other words, the numbers are multiplied straight across. So, in the example above, 2 x 3 = 6 and 1 x 1 = 1. The resulting answer is 6 over 1 or more simply put 6. However, when “units” are introduced, you can’t just say the answer is “6”. Always remember to reduce as necessary. Look at a couple other examples below:

Example *Page*6.1.4.1

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

Example *Page*6.1.4.2

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

In the first Example ***Page*6.1.4.1**, if you multiply the numbers across as before, you would multiply 1 times 1 and then 2 x 2. The resulting answer would be 1 over 4 or one forth. In the next Example ***Page*6.1.4.2** you can do the same thing. Multiply the 2 and 4 to get 8 and then multiply the 3 and 6 to get 18. The resulting answer is 8 over 18 or eight eighteenths. However, remember to always reduce if necessary. In order to reduce you need to find a number, which will go into both 8 and 18. Since 2 will go into both of these numbers, you can reduce the answer to 4 over 9 or four ninths.

Cross canceling is also something you can do. Cross canceling is nothing more than reducing before you multiply. Look for any number that goes into both a numerator and a denominator. In the example below, 2 goes into both the 2 in the first fraction and the 6 in the second fraction.

Example *Page*6.1.4.3

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

In the Example ***Page*6.1.4.3**, when you cross cancel, you reduce the two-thirds times four sixths to one third times four thirds. Then you multiply the 1 and 4 (numerators) and the 3 times 3 (denominators) to get an answer of four ninths.

When multiplying whole numbers and fractions you must first convert the whole number into an improper fraction and then, multiply. Be sure to cross cancel if possible and reduce if necessary. Placing a whole number over a 1 is an important step not only in solving these types of fraction problems, but will also be a helpful tool later in this text.

Example *Page*6.1.4.4

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

The same rules apply when multiplying mixed numbers. Convert to improper fractions and multiply. In order to convert mixed numbers into improper fractions you must multiply the denominator by the whole number. Then add the numerator to the product and put that number over the denominator. Be sure to cross cancel if possible and reduce if necessary. **Note: Never leave an answer as an improper fraction.**

Example *Page*6.1.4.5

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

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

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

$\frac{3}{2} \times \frac{11}{4} = \frac{33}{8} \rightarrow 8\overline{)\,33}\,\begin{matrix}4\\ -32\\ \hline 1\end{matrix} = 4\frac{1}{8}$

Exercise 1.4

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

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

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Page 6.1.5: Dividing Fractions

When dividing fractions you invert (flip upside down) the fraction on the right side of the equation (the dividend). Then it becomes a multiplication problem. Invert and multiply!

Example *Page*6.1.5.1

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

Example *Page*6.1.5.2

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

This example reads $\frac{4}{9}$ divided by $\frac{8}{9}$.

However, after you "invert and multiply," it becomes:

$$\frac{4}{9} \times \frac{9}{8} \rightarrow \frac{1}{1} \times \frac{1}{2} = \frac{1}{2}$$

After inverting the fraction, the same rules apply as previously mentioned when multiplying fractions. You need to change mixed numbers into improper fractions; you can cross cancel, and always remember to reduce if necessary.

Example *Page*6.1.5.3

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

In the Example ***Page*6.1.5.3** above the 3 divided into itself once and into the 12 four times. Similarly, 2 divided into 6, three times and into 8, four times. Can you see a different way to cross cancel?

If the dividend is a whole number write it as a fraction before inverting. Always remember to cross cancel and reduce if necessary.

Example *Page*6.1.5.4

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

Exercise 1.5

Divide the following and reduce if necessary.

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

11. $2\frac{9}{20} \div 5\frac{2}{5}$
12. $3\frac{1}{2} \div 9\frac{1}{2}$
13. $5 \div 25$
14. $\frac{10}{3} \div \frac{1}{6}$
15. $\frac{13}{33} \div \frac{39}{3}$
16. $100\frac{1}{2} \div 10\frac{5}{6}$

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Page 6.2.2: Multiplying and Dividing Decimals

Page 6.2.3: Rounding

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Page 6.2.1: Understanding Decimals

Numbers written with decimals is another way of expressing fractions. However, decimals have a distinct differentiation with fractions in that decimals are based on 10. In that, one decimal place to the right of the whole number indicates *tenths*, two decimal places to the right of the whole number indicates *hundredths*, three decimal places to the right of the whole number indicates *thousandths*, etc.

Example *Page*6.2.1.1

0.1 = tenths place

1.01 = hundredths place

0.001 = thousandths place

1.01 = ten thousandths place

1.

Decimals can easily be written as fractions by using the number to the right of the decimal point as the numerator and then using a 10, 100, 1,000, 10,000, etc. as the denominator. Determining which “base-ten” number to use as the denominator is determined by the number of digits there are to the right of the decimal point.

Example *Page*6.2.1.2

$0.1 \rightarrow \frac{1}{10}$ **1 tenth**

$0.01 \rightarrow \frac{1}{100}$ **1 hundredth**

$0.001 \rightarrow \frac{1}{1,000}$ **1 thousandth**

$0.0001 \rightarrow \frac{1}{10,000}$ **1 ten-thousandth**

Exercise 2.1

Write the following decimals as fractions and reduce if necessary.

1. 0.2 =
2. 0.103 =
3. 0.13 =
4. 0.02 =
5. 0.1234 =
6. 0.0023 =
7. 0.0101 =
8. 0.1010 =
9. 0.020 =
10. 0.0202 =
11. 0.1000 =
12. 0.4500 =

Exercise 2.1.1

Write the following expressions as decimals and fractions.

		Decimal	Fraction
1.	7 tenths		
2.	1,000 ten-thousandths		
3.	475 thousandths		
4.	32 hundredths		
5.	12 thousandths		
6.	2,345 ten-thousandths		
7.	3 hundredths		
8.	10 thousandths		
9.	132 ten-thousandths		
10.	4,002 ten-thousandths		

Digits to the left of the decimal indicate a whole number. Whenever there is a whole number with a decimal fraction the expression is pronounced using “and.”

Example:

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

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

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

Exercise 2.1.2

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

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

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Page 6.2.2: Multiplying and Dividing Decimals

Multiplying and dividing decimals is simple enough if you use a calculator. When multiplying decimals, there is no certain order you need to type the numbers in your calculator.

Example *Page*6.2.2.1

0.255 × 0.23 = 0.05865

25 × 35 = 875

100.5 × 12.75 = 1,281.375

Exercise 2.2

Multiply the following problems

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

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

Example *Page*6.2.2.2

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

Exercise 2.2.1

Divide the following problems.

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

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

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Page 6.2.3: Rounding

Rounding is another important process to understand and properly use mathematics. As we discussed in Section 2.1, decimal places can be carried out to the ten-thousandths place and further if needed. However, there is a practical rule to follow and in waterworks mathematics we seldom carry decimal places much further than the hundredths place, unless we are working in the area of water quality. The rule to follow is to "round" the decimal to the furthest decimal place in the question. Look at the examples below.

Example *Page*6.2.3.1

2 × 2 = 4	Since both numbers you are multiplying are whole numbers, then you would leave the answer as a whole number.
2.0 × 2.0 = 4.0	Now, upon first glance, the answers may look like they are the same. After all, doesn't 4 and 4.0 equal the same number? The short answer is yes. However, 4.0 is actually more accurate than 4. Why? Because 4.0 is rounded to the tenths place and is saying the value is no more than 4 and 0 tenths. When we "round" the first answer "4" can be 4.1, 4.2, 4.3, or 4.4. We don't know, since the whole numbers are expressed as whole numbers and not round to the nearest tenth. Since both numbers being multiplied are rounded to the nearest tenth, then we round the answer to the nearest tenth.
2.0 × 2 = 4.0	This answer is also rounded to the nearest tenth since one of the numbers being multiplied is rounded to the nearest tenth. However, the second example is still the most accurate.

Why?

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

Example *Page*6.2.3.2

Round to the nearest whole number

1.2 = 1

1.24 = 1

1.25 = 1

Since we are rounding to the whole number, we look at the tenths place or the number to the right of the place we are rounding to. In these examples the number is 2, which is </= 4.

Round to the nearest tenths place

1.2 = 1.2

1.24 = 1.2

1.27 = 1.3

We now need to look at the hundredths place or the number to the right of the tenths place. Since there is no hundredths place in the first example, the number stays at 1.2. In the second example you would round down since the preceding number is </= 4 and in the third example, you would round up since the preceding number is >/= 5.

Exercise 2.3

Round the following numbers

Round to the nearest whole number.

1. 29.05
2. 135.9
3. 0.4

Round to the nearest tenth place.

4. 20.045
5. 0.98
6. 200.03

Round to the nearest hundredth place.

7. 1.234
8. 0.976
9. 345.095

Round to the nearest thousandth place.

10. 3
11. 1,367.0982
12. 0.9855

Did any of the questions above give you difficulty? Let's look at number 5. The question said to round to the nearest tenth place. Therefore, we need to look at the preceding number or the hundredths place. The number was 0.98, so we need to look at the 8. Since 8 is >/= 5 we must round the number in the tenths place up. However, in this case the number to be rounded up is a 9. Look at the example below:

0.98 the 9 becomes 10, but since it is a 0.9, it becomes 1.0

What about number 10? In this question, you need to round a whole number (3) to the thousandth place. Therefore, you need to add zeros until you get to the thousandths place. See below:

3 = 3.000

In this text we will typically round to the nearest whole number, tenths, or hundredths places.

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SECTION OVERVIEW

Page 6.3: Percentages

Page 6.3.1: Expressing Numbers as Percentages

Page 6.3.2: Word Problems

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Page 6.3.1: Expressing Numbers as Percentages

Percentages and decimals are commonly used in waterworks mathematics. Whether you are working with financial budgets, chemical percent concentrations, or water quality results, decimals and percentages are used often. Therefore, knowing how to convert to percentages from decimals is important and vice versa.

When expressing numbers as a percent they need to be whole numbers or decimals. Therefore, fractions must be converted first. Percent (%) simply means per hundred. Understanding that percent means per hundred indicates that 2 decimal places are involved.

When a number needs to be converted to a percent you multiply the number by 100 and put a percent sign (%) at the end.

Example *Page*6.3.1.1

The number 1 written as a percent is

$1 \times 100 = 100\%$

The number 5 written as a percent is

$5 \times 100 = 500\%$

When a decimal is written as a percent do the same thing.

$1.4 \times 100 = 40\%$

Note that the decimal moves two places to the right.

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

Example *Page*6.3.1.2

If 100% is to be written as a number, divide by 100.

$$100\% \div 100 = 1$$

$$8.25\% \div 100 = 0.0825$$

$$2,500\% \div 100 = 25$$

Exercise 3.1

Convert the following numbers to percentages and percentages to numbers (round all numbers to the nearest hundredth place.

1. 1 =
2. 30 =
3. 0.5 =
4. 0.75 =
5. 1.02 =
6. 35.5 =
7. 0.004 =
8. 5.005 =
9. 102% =
10. 2.3% =
11. 0.45% =
12. 1,570% =
13. 8% =
14. 0.9% =
15. 65% =

16. 12.5% =

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Page 6.3.2: Word Problems

Word problems tend to give people some difficulty. Especially in problems where there is a lot of information that is not needed to solve the actual problem. However, most of the problems we deal with involve words.

> How much money did I pay in taxes last year?
>
> How many pounds of chemical do I need to add to this water supply?
>
> How many gallons of water were sold last month?
>
> What is the flow rate of water through that pipeline?
>
> What is the area of the filter bed?

Yes, the questions posed above do not have any information to be able to solve for the answer, but these are some very common questions water operators are asked to solve. In word problems, there is always an underlying question that must be answered. Narrowing down the problem to the question you are trying to solve is an important step. Another important step is being able to pull out the information (numbers) in the question to help you solve for the answer.

In word problems with percentages, there are a couple of things you should take note of. The word “is” should be treated as an equal (=) sign and the word “of” as a multiplication (x) sign. You must also remember to convert the percent to a decimal prior to solving.

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SECTION OVERVIEW

Page 6.4: Equations and Word Problems

Page 6.4.1: Solving Equations

Page 6.4.2: Ratios and Proportions

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Page 6.4.1: Solving Equations

Equations are a vital component to solve many mathematical questions. In fact most of all water related mathematical questions would require the use of one if not several equations. An equation is a mathematical statement that both sides of an “equal sign” are in fact equal.

Example *Page*6.4.1.1

$3+1=4$ or $5-3=4-2$

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

Example *Page*6.4.1.2

$3+X=4$

What number must X be in order to make this equation correct?

Obviously, the answer is 1.

Now, this is a very simple example, but it will allow you to begin the process for solving more complex equations.

How did you solve the example above? Did you simply look at the equation and intuitively know that the answer was 1? Or did you use some mathematical process to solve for the variable? Let’s break it down.

Steps to solving equations;

1. Get the unknown or unknowns on one side of the equation.
2. Get the numbers on the other side of the equation.
3. Try and follow these helpful tips.
    a. If the problem is an addition problem, you will need to subtract
    b. If the problem is a subtraction problem, you will need to add
    c. If the problem is a multiplication problem, you will need to divide
    d. If the problem is a division problem, you will need to multiply

Depending on the type of problem, this will involve adding, subtracting, multiplying, or dividing. Perhaps several steps will need to be done to solve for the variable.

Since we will not be adding or subtracting in this course, we will focus on multiplication and division problems.

If the variable is next to a fraction or directly next to a number, solving for the variable will require either multiplying or dividing.

These next two examples are using multiplication and division to get the variable by itself. In order to prevent confusion, the variable of choice will be something other than an “X.”

Example *Page*6.4.1.3

$2N=10$	What multiplied by 2 equals 10? In order to solve for “N” you will need to divide both sides of the equation by 2.
$\frac{2N}{2}=10$	By dividing the left side of the equation by 2, you isolate the variable. However, since you divided one side of the equation by a number you must do the same to the other side of the equation.
$N=\frac{10}{2}$	
$N=5$	

In this next example, a fraction of a variable will equal a number.

Example *Page*6.4.1.4

$\frac{2}{3}N = 14$	In order to isolate the variable in this type of problem, you will need to multiply and divided. First, divide both sides of the equation by 2 and then multiply both sides of the equation by 3.
$\frac{2}{(2)3}N = \frac{14}{2}$	The two cancels out on the left side of the equation leaving N over 3 and 14 divided by 2 becomes 7.
$\frac{N}{3} = 7$	Now, multiply both sides of the equation by 3.
$\frac{(3)N}{3} = 7 \times 3$	Here, the 3 cancels out on the left and the right side of the equation becomes 21, which is the answer.
$N = 21$	

How can you prove (or show) that 21 is the correct answer in the above example.

Exercise 4.1

1. $2X = 10$
2. $3N = 15$
3. $\frac{3}{4}G = 9$
4. $4H + 2 = 10$
5. $\frac{1}{5}J + 4 = 5$
6. $13 = \frac{3}{6}K - 1$
7. $3B - 5 = 2B + 8$
8. $10C - 7 = 3C + 14$
9. $\frac{4}{3}S - 3 = 5$
10. $14 = 2F + 2$
11. $7X + 2 = 9X - 10$
12. $15 = 5 + \frac{2}{5}P$

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Page 6.4.2: Ratios and Proportions

Solving ratios and proportions is similar to the previous two exercises. It is simply just looking at the question a little differently. Instead of looking at it as numbers we will assign UNITS (or items) to the numbers, for example, 3 valves to 6 valves or 3 hours to 5 hours. However, the real comparisons of interest will be discussed in the next section when we compare different UNITS to each other, for example, 40 hours to 1 week, or 12 inches to 1 foot.

Example *Page*6.4.2.1

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

You can read this as, 2 is to 3 as F is to 9.

In order to solve the above ratio or proportion is by cross multiplying.

$$9 \times 2 = 3 \times F$$

This would equate to

$$18 = 3F$$

Then using the method as previously used in the Equation Section, you would divide both sides of the equation by 3. Three would then cancel on the right side of the equation isolating the variable and 18 divided by 3 would give you 6. Therefore, F equals 6.

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

Exercise 4.2

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

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

Example *Page*6.4.2.2

It takes 3 employees to flush 8 hydrants in 6 hours. How long would it take 5 employees to do the same job?

Solution

If you attempt to solve this problem as if it were directly proportional it would look like.

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

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

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

3 employees × 6 hours = 5 employees x W hours

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

Exercise 4.2.1

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

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

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

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

Example *Page*6.4.2.3

10% of 100 is

10% × 100 =

0.10 × 100 = 10

Exercise 4.2.2

Solve the following percent problems.

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

Word problems give people fits! However, most of the problems that present themselves in practical situations are in fact word problems, we just don’t always think of them that way. For example, if you are buying something from the store and you want to

figure out how much the tax will be on a certain item, you probably just multiply the cost of the item by the sales tax. You can though look at this problem as a word problem.

Exercise 4.2.3

Solve the following word problems.

1. A water utility executive earned $85,000 last year and received a 22% bonus. How much was her bonus?
2. A worker can paint a fire hydrant in ½ hour. How many hydrants can she paint in 4 hours?
3. A 5 gallon jug of bottled water is labeled 60% spring water. How many gallons in the jug is spring water?
4. On a state certification treatment exam you must score at least 70% to pass. If there are 65 questions on the test how many must you get correct to pass?

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SECTION OVERVIEW

Page 6.5: Unit Dimensional Analysis

Page 6.5.1: Units

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Page 6.5.1: Units

"Units" are the single most important component of many mathematical problems especially in the waterworks industry. If you are reporting a flow rate of 1,000, what does this mean? 1,000 gallons per minute? 1,000 cubic feet per second? Or, 1,000 acre feet per year? It is strongly recommended that you get in the habit of writing down the units for all the problems you are solving. Most of the problem solving in waterworks mathematics requires the conversion of units.

Cfs gpm MGD AFY

Therefore, Unit Dimensional Analysis (UDA) is the key to solving a majority of water related mathematical problems. UDA is the process of converting units of one type (e.g. gallons) to another similar type (e.g. cubic feet). Setting up your UDA problem is the most important step conversion problems. By "stacking" your units you create a visual representation of the problem where units can be canceled. This cancellation of units is very similar to cross canceling or reducing of fractions.

Example *Page*6.5.1.1

Convert seconds to days using UDA

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

Solution

If we break the problem up into segments you can see how the canceling of units occurs.

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

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

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

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

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

Example *Page*6.5.1.2

Convert cfs to gpm.

$$\frac{\text{cf}}{\text{sec}} \rightarrow \frac{\text{gal}}{\text{min}}$$

Solution

An important thing to note is that you will be converting "like" units. This means that you will be converting **cubic feet** to **gallons** which are both a measurement of volume and converting **seconds** to **minutes** which are both a measurement of time.

There are two conversion factors that need to be used to perform this conversion. You need to ask yourself…How many seconds are in a minute? How many gallons are in a cubic foot?

There are 60 seconds in every minute.

There are 7.48 gallons in every cubic foot.

$$\frac{\text{lcf}}{\text{sec}} \times \frac{60\text{sec}}{\text{min}}$$

The expression 60 sec per minute is a conversion factor that is an equality. The conversion factor is deliberately written with the 60 sec on top of the equality because it needs to cancel the unit sec from the 1 cfs.

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

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

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

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

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

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

Exercise 5.1

Solve the following problems using UDA

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

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SECTION OVERVIEW

Page 6.6: Geometric Shapes

In the waterworks industry geometric shapes are prevalent. For example, a pipe is a cylinder with the opening of a circle, a sedimentation basin can be a rectangle, and an aqueduct might be a trapezoid. These are a few of the shapes that we will cover in this text. It is important to understand how to work with these shapes to be able to calculate areas, volumes, perimeters, and circumferences.

We will first look at geometric shapes and how to calculate the corresponding area of these shapes. The answer when determining the area of a geometric shape should always be given in square feet (sqft or ft^2). Other units can be used such as, square meters or square inches, but these are not typically used in the waterworks industry. Remember though that the units you are given in a question (or in "real life" for that matter, may not be the units you need to calculate square feet. Therefore, you should always convert the "given units" to feet before calculating the area. The first shape we will look at is the CIRCLE. Pipes are the backbone to water distribution systems and can also be found in treatment plants. Pipe lines carry raw water to the treatment plant, transmission lines can carry water from treatment plants to storage tanks, and distribution pipe lines delivery water to customers.

Page 6.6.1: Areas

Page 6.6.2: Volumes

Page 6.6.3: Circumference

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Page 6.6.1: Areas

Circle

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

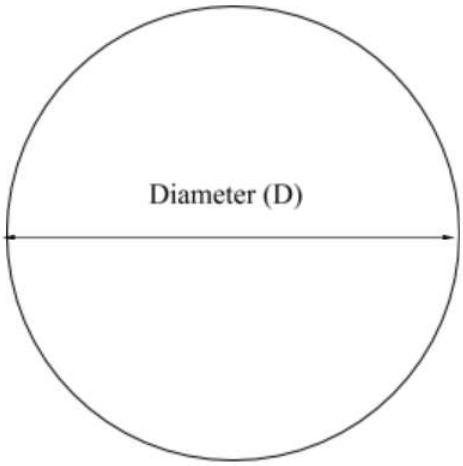


Figure *Page*6.6.1.1: Area of a circle = $0.785 \times D^2$

Typically, you will know the diameter of a circle, for example the diameter of a pipe or a storage tank. You may have learned the following formula ($\pi \times r^2$) for calculating the area of a circle. However, in this text we will only use the previous formula. Both formulas work, but in the water industry diameters are most commonly used.

Much of the time you will be asked to calculate the area of the opening of a pipe. However, the unit given to you will typically be given in inches. There are two ways to go about solving this type of problem.

Example *Page*6.6.1.1

What is the area of a 12” diameter pipe?

Solution

If you were to plug 12” into the formula (0.785 \times D^2\) you would end up with square inches and then you would most likely need to then convert to square feet.

So, the easiest way to solve all area problems where “feet” are not given is to convert to feet first and then plug the numbers into the formula.

A 12” diameter pipe equals a 1 foot diameter pipe.

$$\frac{12 \text{ / inches}}{1} \times \frac{1 \text{ foot}}{12 \text{ / inches}} = 1 \text{ foot}$$

By converting to feet before starting the problem you will avoid getting into units you are not familiar with.

Rectangles

Area of a rectangle = $L \times W$

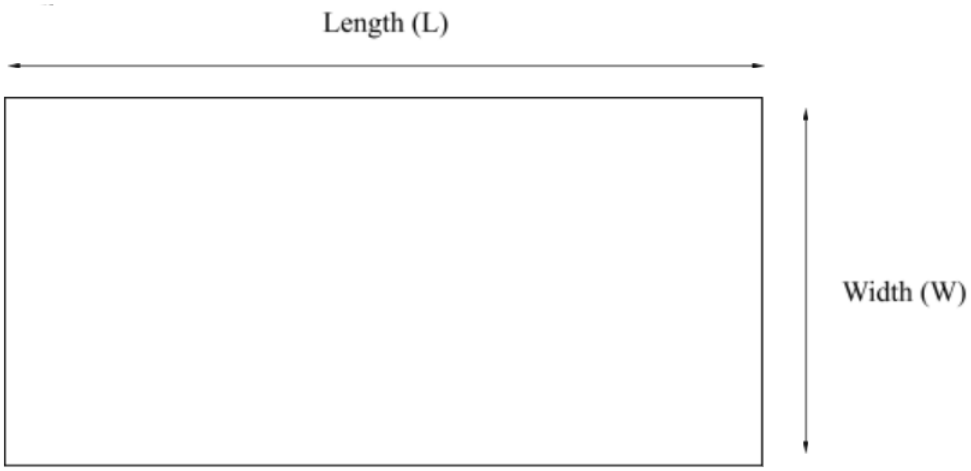


Figure *Page*6.6.1.2: Area of a rectangle = $L \times W$

Rectangles are common shapes of storage reservoirs, sedimentation basins, and even room in an office. Calculating the area for these types of structures is simple if you know how the length and width of the structure. Remember, the area of a square is calculated the same way. These types of dimensions are typically given in feet.

Trapezoid

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

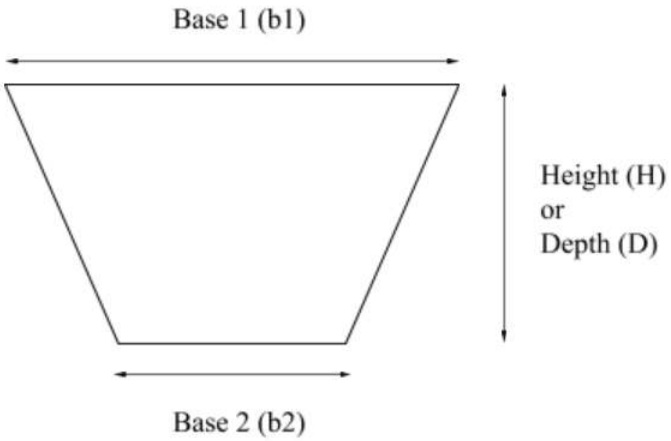


Figure *Page*6.6.1.3: Area of a trapezoid = $\frac{b1 + b2}{2} \times H$

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

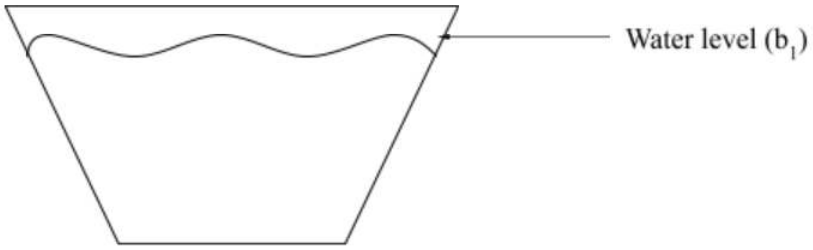


Figure *Page*6.6.1.3: Example of the base 1

Once you know the distance across the trapezoid at the water level, then add it to the distance across the bottom of the trapezoid and divide that number by 2. Doing this finds the average distance across the trapezoid. Multiply this number by the height of the water level and you know have the area of the trapezoid.

Exercise 6.1

Calculate the following areas.

1. What is the area of a circle with a 2 foot diameter?
2. What is the area of a 36” diameter pipe?
3. What is the area of a sedimentation basin that is 30 feet wide and 10 feet deep?
4. What is the area of an aqueduct that is 5 feet across the bottom, 10 feet across the top and 7 feet deep?
5. The roof on an above ground storage tank has a 130 foot diameter. What is the area?
6. A filter is 25 feet long and 20 feet wide. What is the area?
7. A water aqueduct is 10 feet wide at the bottom and 20 feet wide at the top. If it is 20 feet deep what is the area?

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Page 6.6.2: Volumes

Cylinder

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

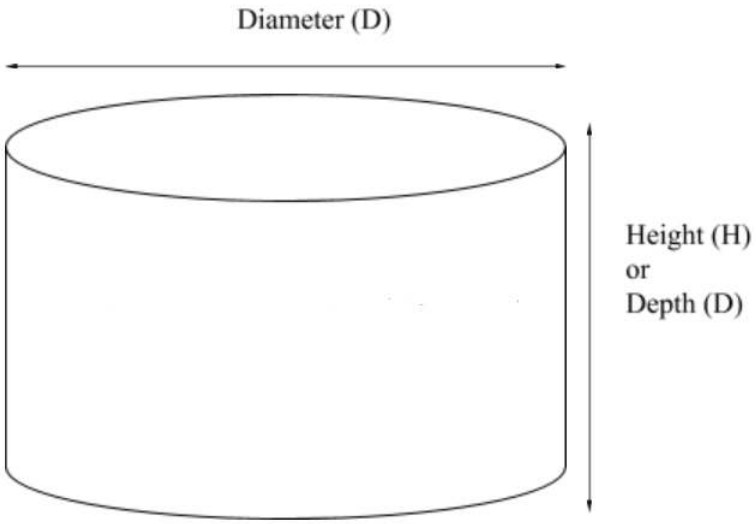


Figure ***Page*6.6.2.1**: Volume of a cylinder = $0.785 \times D^2 \times H$

The volume of a cylinder uses the area formula of a circle with the addition of a third dimension. Notice that a cylinder can have either a depth or a height. They are one and the same. It all depends on your perspective. In fact all 3 dimensional structures can have a depth or a height.

Rectangle

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

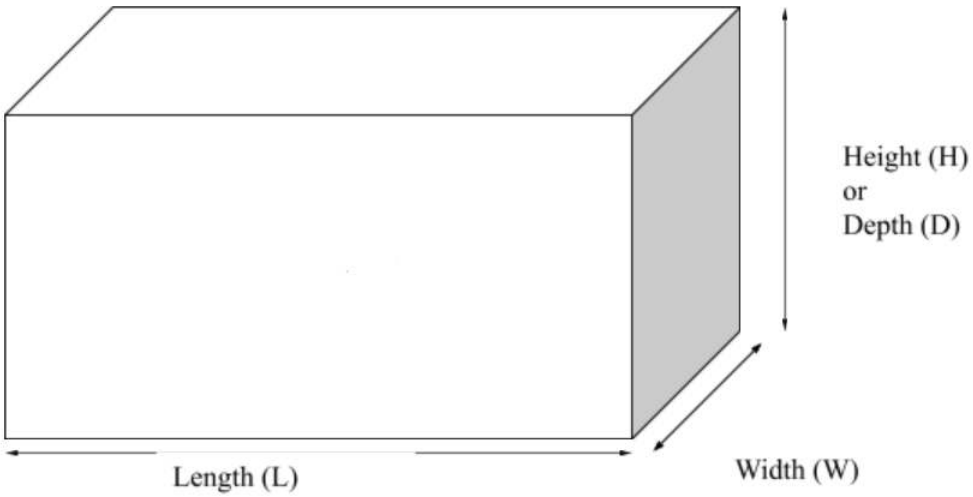


Figure ***Page*6.6.2.2**: Volume of a rectangle = $L \times W \times H$

Trapezoid

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

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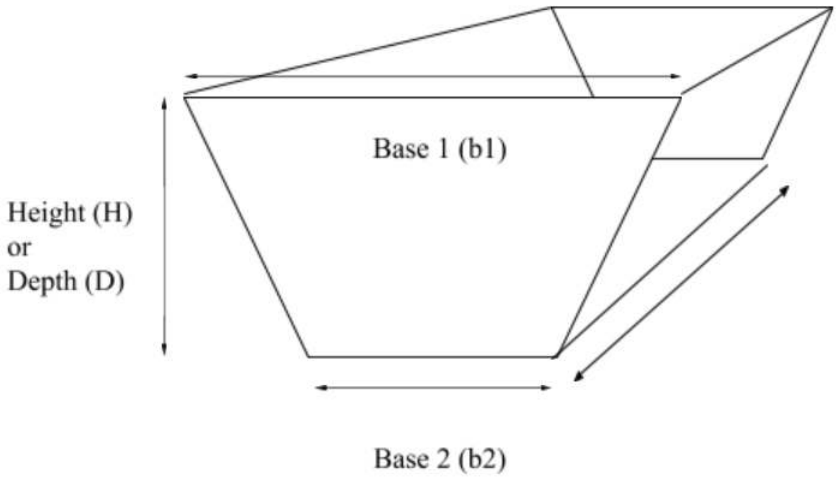


Figure ***Page*6.6.2.3**: Volume of a trapezoid = $\frac{b1 + b2}{2} \times H \times L$

There is something to keep in mind when calculating volumes. Most units in waterworks are given in “feet.” The length of pipe, the height of water tanks, the depths of aqueducts are all typically measured in feet. Therefore, calculating the volume for these geometric shapes result in cubic feet as the unit of measure. However, sometimes measurements are given in “inches” and will need to be converted to feet before solving a problem.

Exercise 6.2

Solve the following

1. What is the area of a circle with a 10 foot diameter?
2. What is the area of a circle with a 10 inch diameter?
3. What is the area of a rectangle with a depth of 10 feet and a width of 20 feet?
4. What is the area of a trapezoid that has a distance across the base of 5 feet and a distance across the top of the water level of 7 feet. The water depth is 4 feet.
5. Calculate the volume of a pipe that has a 12” diameter and is 10 feet long.
6. How many gallons of water can fit in a storage tank that is 40 feet tall and has a 90 foot diameter? (Remember one cubic foot equals 7.48 gallons)
7. A rectangular basin is 100 feet long, 40 feet wide and has a depth of 25 feet. If the water level is 3 feet from the top, how much water is in the basin?
8. A one mile long water aqueduct is 10 feet deep and is half full. The width across the water level is 7 feet and the width at the base is 5 feet. How much water is in the aqueduct? (Remember that one mile equals 5,280 feet)
9. A 75 foot tall water tank is ¾ full and has a 30 foot diameter. How many gallons of water are in it?
10. What is the capacity of a water basin that is 200 feet long, 40 feet wide, and 30 feet deep?
11. A water tank is being emptied at a rate of 1 foot per hour. If the tank has a diameter of 100 feet, how many gallons will be emptied in 4 hours?
12. A reservoir with the following dimensions (75 feet long, 20 feet wide, 10 feet deep) is 35% empty. How many gallons of water are in the reservoir?

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Page 6.6.3: Circumference

The last geometric shape formula we will look at is the circumference of a cylinder. The circumference is the distance around a closed curve. It is the distance around the length around a circle. The importance of this formula in waterworks mathematics displays itself in questions regarding the painting or coating of a cylinder. The picture below illustrates the circumference.

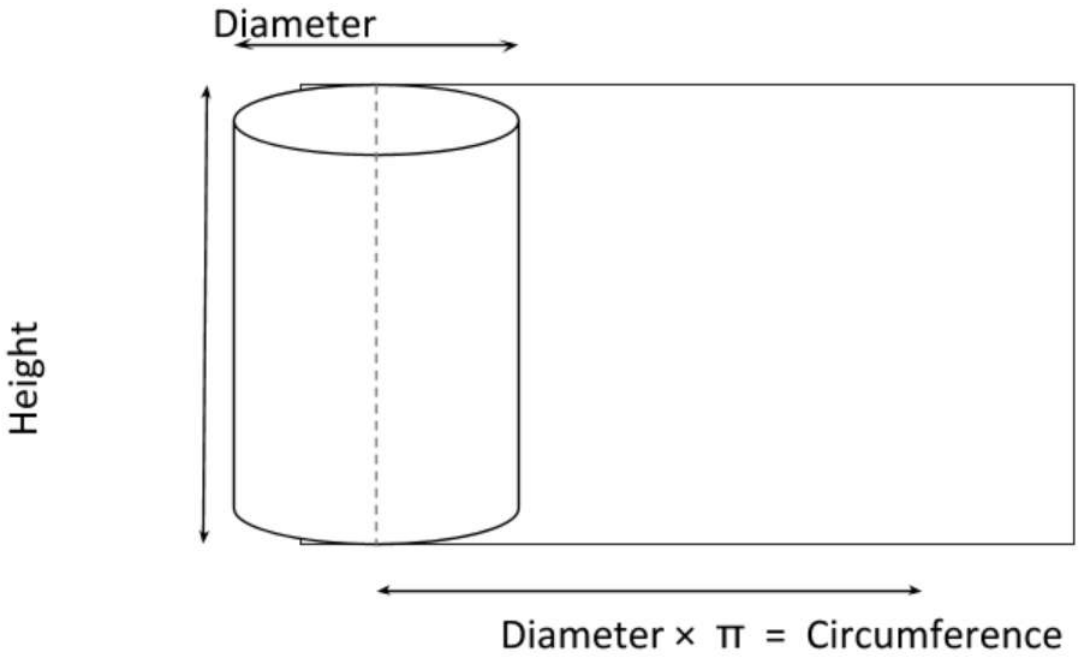


Figure *Page*6.6.3.1: Circumference of a cylinder

If you "slice" open a cylinder and unravel it, it becomes a rectangle. The length of this rectangle is the circumference of the cylinder. In order to calculate the surface area of a cylinder, use the following formula.

$$\text{Area of a cylinder} = H \times (\text{Diameter} \times \pi)$$

Where ($\text{Diameter} \times \pi$) is the length around the cylinder.

Exercises 6.3

Solve the following

1. What is the area of the wall of a 20 ft tall tank with a 30 ft diameter?
2. What is the area of the walls of a 1,000 ft section of 24" diameter pipe?
3. You have been asked to calculate how many gallons of paint would be needed to paint a 30 ft tall tank with a 100 ft diameter. You need to paint the inside roof, floor, and walls. One gallon of paint covers approximately 200 ft2. How many gallons of paint are needed?

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SECTION OVERVIEW

Page 6.7: Water Hydraulics

Hydraulics is a fundamental theory in waterworks mathematics. Hydraulics involves the mechanical properties of liquids. In this text we look at two different hydraulic principles, pressure and flow.

Page 6.7.1: Pressure

Page 6.7.2: Force

Page 6.7.3: Flow Rate

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Page 6.7.1: Pressure

Pressure is related to the vertical distance from the surface of water to a reference point somewhere below the water surface typically expressed in feet. For example, a water storage tank has a certain water level inside of it. The reference point below could be a water faucet a certain distance in feet below the water level. This distance in feet is the head pressure (in feet). The other common unit for pressure is POUNDS PER SQUARE INCH, (psi). You can convert back and forth between feet and pounds per square inch using one of the following conversion factors.

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

To stay consistent with UDA, view the following conversion factors as

$$\frac{1 \text{ foot}}{0.433 \text{ psi}} \quad \text{or} \quad \frac{1 \text{ psi}}{2.31 \text{ feet}}$$

Remember, as with all conversion factors, these can be written as the inverse.

$$\frac{0.433\text{psi}}{1\text{foot}} \quad \text{or} \quad \frac{2.31 \text{ feet}}{1\text{psi}}$$

Example *Page*6.7.1.1

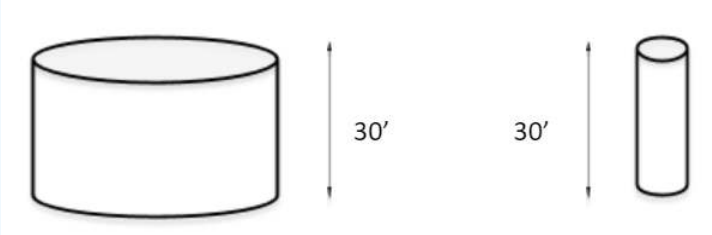


Figure ***Page*6.7.1.1**

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

Solution

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

Exercise 7.1

Calculate the following pressure problems

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

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Page 6.7.2: Force

Pressure is the force applied over a specific area. It is the weight of water expressed as pounds divided by the area expressed as inches squared (in^2). Therefore, the resulting unit is pounds per square inch (psi). However, in the previous section we looked at pressure based on the height or elevation of a column of water and compared it against a conversion factor.

Recall the following conversion factors:

0.433 psi = 1 foot and 1 psi = 2.31 feet

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

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

A pressure of 100 psi exerts how much force against an area of 1 in^2?

In this example, there is

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

This would equate to 100 lbs of force because the in^2 would cancel.

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

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

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

This volume can now be converted to pounds.

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

This is the force exerted.

Exercise 7.2

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

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Page 6.7.3: Flow Rate

Flow is the path that a certain liquid (water) takes for a specific time. It is commonly referred to as Flow Rate. A garden hose, a water main, an aqueduct, a gutter, have flow rates. You must know the area of the vessel or container that is flowing the liquid and you must also know the velocity that the liquid is moving. Flow Rate is simply expressed as volume over time.

$$\frac{\text{Volume}}{\text{Time}}$$

The volume can be gallons, million gallons, cubic feet or any other volume unit. The time can be any time such as, seconds, minutes, hours, etc. However, when solving Flow Rate ALWAYS use the UNTIS – CUBIC FEET PER SECOND, where Q represents Flow Rate.

Expressed as

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

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

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

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

And

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

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

Therefore, the equation should look like this

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

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

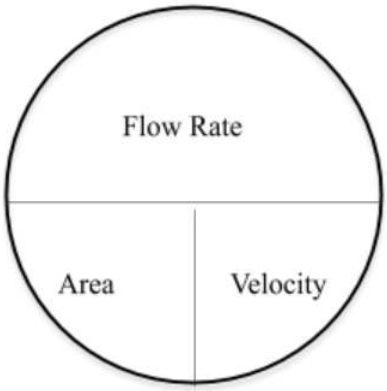


Figure ***Page*6.7.3.1**: Pie Wheel

Exercise 7.3

1. What is the pressure in pounds per square inch at the bottom of a 45 foot tall water storage tank?
2. An 80 foot tall standpipe is ¾ full. What is the pressure in psi at the bottom?
3. A 30 foot water tank has a pressure gauge installed 2 feet from the bottom of the tank. If the pressure gauge reads 11 psi, what is the level in the tank?
4. A 12” pipeline is flowing water at a velocity of 3.5 fps. What is the corresponding flow rate?

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

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SECTION OVERVIEW

Page 6.8: Chemical Dosage Analysis and Waste Water Treatment

One of the most common and useful formulas in waterworks mathematics is one in which you use to calculate the amount of chemical needed to add to water. It is commonly known as the Pound Formula. The “pound” formula, because it is a calculation for the weight of a chemical that is being added to water. Typically this chemical is chorine or a chlorine related compound. However, it can be also used to calculate alum, ferric chloride, or any other type of chemical dosage.

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

Page 6.8.1: The “Pound Formula”

Page 6.8.2: Food to Microorganism Ratio

Page 6.8.3: Mean Cell Residence Time (MCRT)

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Page 6.8.1: The “Pound Formula”

When solving the “Pound” formula the following two formulas are used.

The first formula is used when you are calculating chemical dosage on a volume of water, for example a tank, reservoir, or pipeline.

$$\frac{\text{MG}}{1} \times \frac{8.34\text{lbs}}{\text{gal}} \times \frac{\text{parts}}{\text{millionparts}} = \frac{\text{lbs}}{1}$$

The second formula is used when you are calculating chemical dosage on a flow rate, for example through a pipeline, in a channel, or through a treatment facility.

$$\frac{\text{MG}}{\text{D}} \times \frac{8.34\text{lbs}}{\text{gal}} \times \frac{\text{parts}}{\text{millionparts}} = \frac{\text{lbs}}{\text{day}}$$

Note that the only difference between the two formulas is the unit for time. It is also important to note that the formula uses specific units for volume and flow…MILLION GALLONS and MILLION GALLONS PER DAY.

Therefore if you are given a volume in cubic feet, gallons, acre-feet or some other unit, you must convert to million gallons.

The same holds true for flow rates. If you are given a flow rate in cubic feet per second, gallons per minute, acre-feet per year or some other unit, you must convert to million gallons per day.

The following charts are helpful in illustrating how to use the pound formula. Look at the horizontal line as a division sign. Anything above the line is divided by anything below the line. Everything below the line (that are next to each other) would be multiplied together.

Here is an example.

Example *Page*6.8.1.1

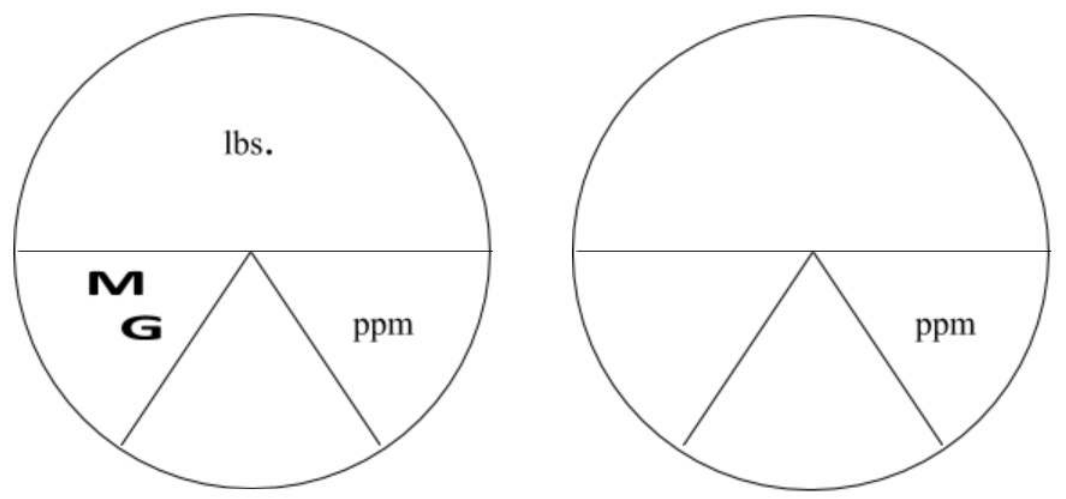


Figure *Page*6.8.1.1

MG(D) and ppm are the two variables below the line. Therefore, they would be multiplied by each other and multiplied by 8.34 lbs./gallon. Since lbs or lbs/day are above the line then you would divide the product of the values below the line.

In this class we will assume that any chemical we are using is in its pure form. In other words there is no adjustment for a lesser concentration form of a chemical. When chlorine is used, it is 100% chlorine.

In addition to drinking water treatment, wastewater treatment uses this same formula to calculate the chemical dosage needed to add certain chemicals to wastewater. Also, this formula is used to determine the amount of “waste” present in wastewater. A common way to measure the amount of organic waste is by the Biochemcial Oxygen Demand (BOD) test. Wastewater has a large amount of organic material that would put a certain demand on an aquatic system by depleting the available oxygen. The results of

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

Exercises 8.1

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

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Page 6.8.2: Food to Microorganism Ratio

Wastewater treatment relies on a biological process to treat the large amounts of organic material found in sewage. Bacteria consume the organic material (measured as BOD) and thus removes it from the wastewater. BOD can be thought of as food available to the bacteria.

The amount of bacteria in the system can also be measured by a test called the Mixed Liquor Suspended Solids (MLSS). The ratio of how much food (BOD) in pounds is available to the population of microorganisms (MLSS) in pounds, is critical to the proper operation of a conventional wastewater treatment plant. This ratio is a baseline to determine how much food a single pound of organisms will eat every day.

In aerobic wastewater treatment, operators supply bacteria with air in aeration tanks, so they can breathe. Typically, there is food available in the incoming wastewater for the bacteria. Under these conditions the microorganisms thrive and actually grow their population. If operators did not periodically "waste" the excess microorganisms from the system the MLSS would become too high and alter the F/M ratio.

To calculate the Food to Microorganism ratio (F/M) we need to determine the amount of BOD in pounds, being sent to through the treatment system as well as the amount of available MLSS in pounds, in the system. The equation for F/M is:

F/M = Pounds of BOD per day/Pounds of MLSS in tanks

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

Exercise 8.2

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

   Influent Q = 4.8 MGD

   Influent BOD = 425 mg/L

   Primary Effluent BOD = 272 mg/L

   MLSS = 2,100 mg/L

   Aeration Volume = 2,890,000 gallons

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Page 6.8.3: Mean Cell Residence Time (MCRT)

As we just learned with the F/M ratio, bacteria and microorganisms are essential to a properly functioning wastewater treatment plant. Another operational control parameter is the mean cell residence time (MCRT). This estimates how long a single bacteria or microorganism stays in the treatment process. The treatment process takes a certain amount of time to effectively remove the organic material and reduce the high amounts of ammonia. If the MCRT is to low then treatment will be insufficient. If the MCRT is too high then there is excess MLSS in the system which adds to the cost of operation.

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

For this introductory class we will use the following equation:

MCRT = Lbs under aeration/Lbs per day wasted

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

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

Exercise 8.3

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

   Influent flow = 10.5 MGD

   Primary Effluent BOD = 285 mg/L

   Aeration Volume = 5 MG

   MLSS = 2,280 mg/L

   WAS Q = 115 gpm

   WAS Conc. = 8,110 mg/L
3. An aeration tank has a volume of 375,000 gallons. The MLSS test results show there is 2,860 mg/L in the aeration tank. If a total of 2,100 lbs/day are wasted from the system, what is the MCRT of the facility?

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SECTION OVERVIEW

Page 6.9: Water Treatment Mathematics

Page 6.9.1: Detention Time

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Page 6.9.1: Detention Time

Detention Time is the amount of time it takes for a molecule of water to travel a certain distance. In a sedimentation basin it is the time it takes for a particle to travel across the basin. Water treatment operators calculate detention times for settling basins, flocculation basins, or rapid mixing chambers. The term “Contact Time” can also be applied using this formula. Contact Time is not to be confused with CT (Concentration Time). Contact Time is best described as the time a certain chemical is in contact with water. For instance, if you add chlorine to a water supply you can ask yourself “how long is it in contact with the water before a customer drinks the water?” For reference, Detention Times are commonly expressed in hours. However, as you will see when solving for Detention Time the resulting answer will not be in hours and will have to be converted.

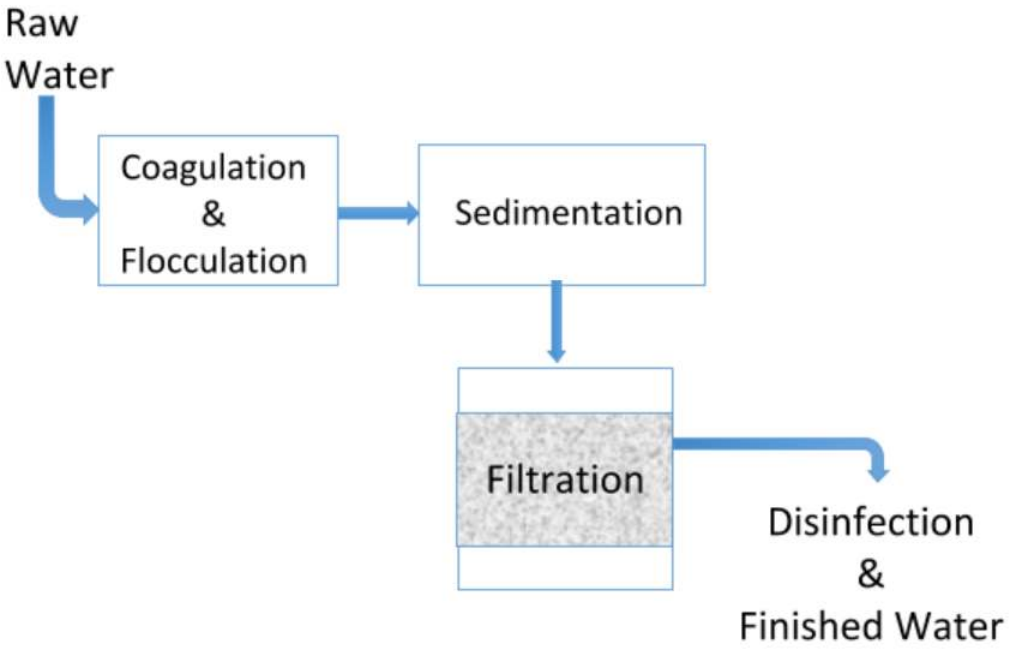


Figure ***Page*6.9.1.1**: Treatment Process Example

The following formula is used for calculating detention times.

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

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

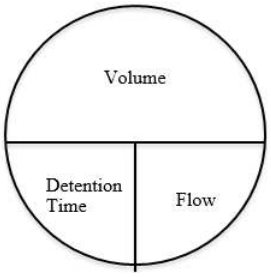


Figure ***Page*6.9.1.2**: Pie Wheel

“Units” are extremely important with this formula. There are three variables in this formula; Detention Time, Flow, and Volume. Here are some examples for each.

Detention Time – seconds, minutes, hours, days

Flow – cubic feet per second, gallons per minute, million gallons per day

Volume – cubic feet, gallons, million gallons

Take note at the above examples. If the units are similar (matching) then dividing volume by flow will yield a time (Detention Time). However, simply dividing a volume by a flow will not result in a time. For example, if you divide gallons by cubic feet per second there is no resulting answer. This is because “gallons” and “cubic feet” will not cancel each other.

When solving for Detention Time, the units for Volume and Flow must match. Solving for Detention Time is not the only variable to solve for with this formula. If Detention Time and Volume are given then you will be solving for Flow. Similarly, if Detention Time and Flow are given then you will be solving for Volume. In all of these examples, the units must be similar in order to cancel out and yield your answer.

Using the “unit” examples above, list all possible matches of units in order to cancel and yield an answer.

Volume	Flow	Detention Time

Remember, using the above examples will not provide any answer in HOURS. Always remember to convert your answer to the units specified in the question.

Exercise 9.1

1. What is the detention time in minutes of a 400,000 gallon sedimentation basin with an average flow rate of 5,000 gpm?An 80 foot tall standpipe is ¾ full. What is the pressure in psi at the bottom?
2. What is the detention time in hours through a 100,000 gallon reservoir with a flow rate of 750 gpm?A 12” pipeline is flowing water at a velocity of 3.5 fps. What is the corresponding flow rate?
3. It has been determined that a basin has a detention time of 2 hours and 10 minutes. If the flow through the basin is 2.67 cfs, what is the volume of the basin in gallons?An 18” pipe is flowing 1,500 gpm. What is the velocity?
4. What is the flow rate (in gpm) through a 40 foot wide, 10 foot deep, 50 foot long basin if the detention time is 1 hour and 55 minutes?ng 4.5 MGD at a velocity of 2.45 fps?
5. A 25 foot tall reservoir with a 120 foot diameter has a detention time of 3 hours and 22 minutes. What is the daily flow (in MGD) through the reservoir?A 28 foot tall water tank is sitting on a 75 foot tall hill. What is the pressure in a home at the bottom of the hill? (Assume the pressure gauge is 3 feet from the bottom of the home and the tank is full)
6. A 75 foot long, 30 foot wide, and 20 foot deep basin has a flow of 2.25 MGD. What is the detention time? (Express as hours, minutes, seconds – ex. 5 hours, 3 minutes, and 2 seconds)A home that is receiving water from a water tank that is on top of a 115 foot hill has a pressure of 57 psi. What is the water level in the tank?
7. A series of tracer studies determined that the detention time through a 2,350,000 gallon basin is 2 hours and 12 minutes. What is the daily flow (in MGD)?
8. If a flow of 4.45 cfs is moving through 2 miles of 36” diameter pipe, what is the detention time?
9. A treatment plant has a daily flow of 30 MG. There are two 200,000 gallon sedimentation basins. What is the detention time through the plant.
10. What is the volume of a reservoir that has a detention time of 29 minutes and a flow of 5.4 cfs?

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Page 6.9.2: Weir Overflow Rate

Another calculation is one that measures the flow of water over a structure called a “weir.” A weir is an obstruction used to raise the level of flow and evenly disperse it. It allows the measurement of flow to be easily calculated. In a treatment plant process weirs are commonly used to “skim off” the flow of water from the sedimentation process before the water travels to the filters. Weir overflow rates are typically expressed as gallons per minute per foot of weir. They can also be expressed as million gallons per day per foot of weir.

The important thing with this formula is that you determine the actual length of the weir and express it using the flow rate specified in the problem.

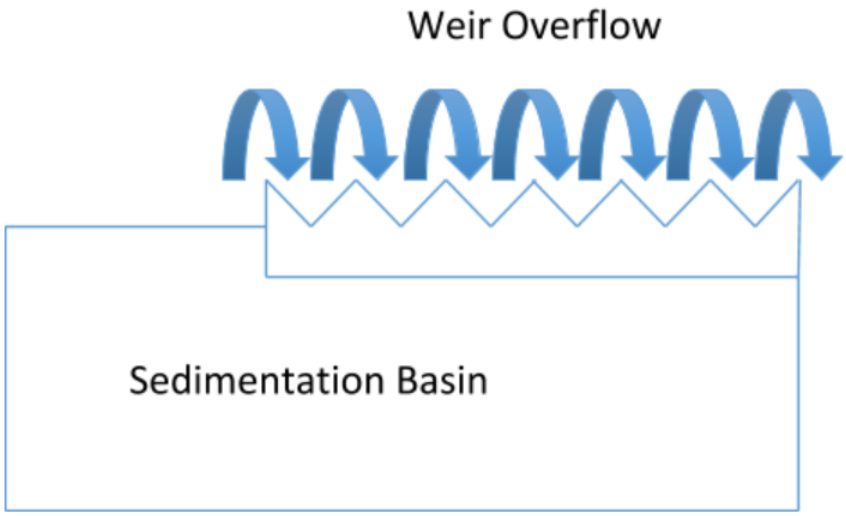


Figure ***Page*6.9.2.1**: Overflow

This formula is used:

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

Exercise 9.2

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

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Page 6.9.3: Filtration Rate

Filtration is the last stage in the treatment process for removing particles from the water. The filtration media can vary from sand to gravel to anthracite coal to garnet or a variety of materials layered to trap the remaining suspended solids in the water. Filtration rate is the measure of how much water passes through a certain sized filter over a specific time. Typically filtration rates are expressed in gallons per minute per square foot of filter area (gpm/ft^2). It is the flow of water through the surface area of a filter.

In the picture below a filter is 5 ft by 5 ft and divided into 1 ft by 1 ft sections. This is done to demonstrate how filtration rates are expressed (in 1 ft^2 sections).

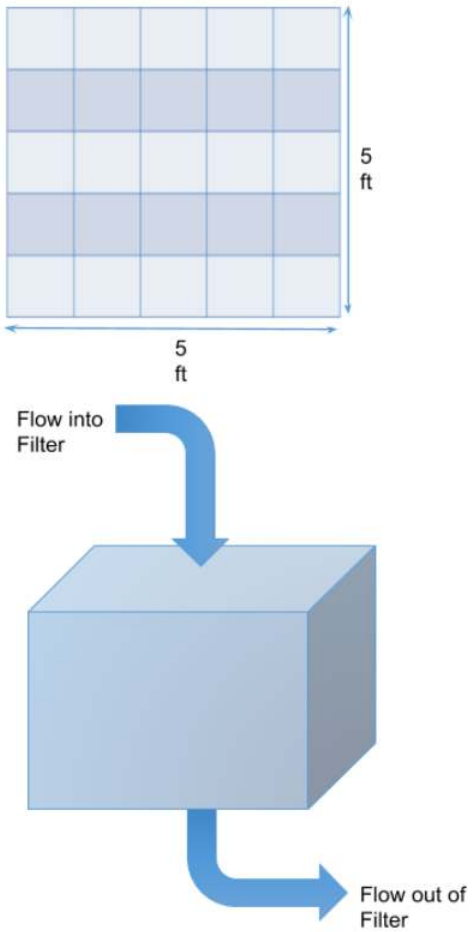


Figure ***Page*6.9.3.1**: Demonstration of how filtration rates are expressed

As flow enters a filter it travels down through the media and then out to either a finished water clear well for distribution or perhaps disinfected prior to delivery.

This is the formula used for Filtration Rates:

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

Since Filtration Rates are expressed as gpm/ft^2 then it only makes sense to convert the flow rate to gpm prior to dividing by the filter surface area. However, in this equation it is not necessary to do so prior to dividing.

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

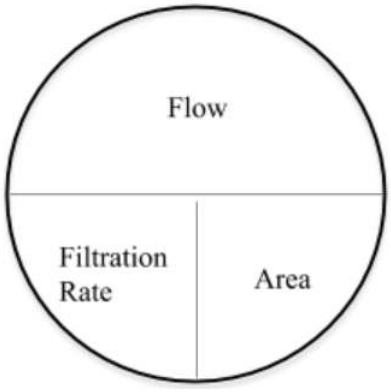


Figure *Page*6.9.3.2: Pie wheel for Filtration Rates

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

Example *Page*6.9.3.1

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

Solution

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

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

Example *Page*6.9.3.2

A water treatment plant has an average daily flow of 10.5 MGD. The filter at the end of the treatment process is 22 ft by 15 ft. What is the filtration rate expressed as gpm/ft^2?

Solution

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

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

Note that the units are million gallons per day per square feet and need to be converted to gpm/ft^2.

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

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

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

Then plug this into the filtration rate formula.

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

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

Exercise 9.3

(Express all filtration rates as gpm/ft^2)

1. A water treatment plant has a typical flow through a 175 ft^2 filter of 755 gpm. What is the filtration rate?
2. A circular filter with a diameter of 74 feet receives a flow of 2,200 gpm. What is the filtration rate?
3. A three-hour test revealed that 75,000 gallons passed through a filter with dimensions of 10 ft by 20 ft. Find the filtration rate.
4. A water treatment plant has a total of 4 filters. The plant is designed to treat a daily flow of 7.25 million gallons. The target filtration rate is 2.25 gpm/ft^2. Assuming that all 4 filters are identical in size, what is the area of each filter?
5. What is the rated capacity in MGD of a rapid sand filter that is 25 ft long and 16 feet wide when operated at a filtration rate of 1.75 gpm/ft^2?
6. It was determined that the optimum filtration rate of a filter with the dimensions of 12 ft wide and 18 feet long is 2.45 gpm/ft^2. What is the maximum flow rate in cfs?
7. A water treatment plant treated 70 million gallons through 3 identical filters in one week. If the average filtration rate was 3.15 gpm/ft^2, what is the area of each filter?

Periodically, filters will need to be cleaned. Cleaning is done through a routine process called backwash. As filters remove particles, the efficiency decreases and the flow rates slow. At predetermined intervals, treatment operators will backwash the filters. Backwashing is nothing more than reversing the flows. However, backwashing rates are typically 10 or more times greater than filtration rates.

8. After 6 hours in operation a 20ft by 30 ft filter required backwashing. Assuming a flow rate of 10,000 gpm, what was the backwash rate?
9. A 15 ft by 17 ft filter was backwashed at a rate of 22.5 gpm/ft^2 for 20 minutes. How many gallons were used for the backwashing process?
10. It was determined that a filter with a surface area of 725 ft^2 needs to be backwashed for 12 minutes using 94,500 gallons. What would the corresponding backwash rate be in gpm/ft^2?

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SECTION OVERVIEW

Page 6.10: Engineering and Construction

There are a number of different treatment and distribution water utility careers ranging from laborer to skilled technicians. Each has a very important function in making sure the water system is properly maintained and operates efficiently. Something that is often overlooked in many operator certification courses is a discussion on how a system is planned, designed, constructed, and repaired. While this section of the text will focus on several key aspects of introductory concepts of engineering and construction waterworks mathematics, the following paragraphs will highlight a general overview of the planning, design, construction, and repair processes.

Page 6.10.1: Planning

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Page 6.10.1: Planning

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

Pipeline Installation Project Planning

Budget

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

Environmental

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

Timing

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

Design

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

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

Stationing

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

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

Example *Page*6.10.1.1

If a station begins at "0" it is expressed as 0+00. One hundred feet from this station would be expressed as 1+00.

One foot sections increase as 0+01. Therefore, after ten feet, it would look like this 0+10.

The difference between station 101+00 and 100+00 is 100 feet.

If the beginning of a set of construction water plans start at station 100+00 and a valve is located at station 100+99 means the valve is located 99 feet from the start of the plans.

The following is an example of someone calculating the distance between two fire hydrants on a set of construction water plans.

Example *Page*6.10.1.2

Fire hydrant A is located at station 530+50

Fire hydrant B is located at station 527+00

What is the distance between fire hydrant A and B?

Solution

53,050 – 52,700 = 350 feet

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

Exercise 10.1

1. A set of construction water plans shows stationing to mark locations. The start of the plans has a station number of 01+50. The first fire hydrant on the plans is located at station 01+25. How many feet is the fire hydrant located from the start of the plans?
2. A water utility requires fire hydrants to be located 350 feet apart in residential areas. If a street is 1,500 feet long, begins at station 101+55 and the first fire hydrant is located at the start, how many fire hydrants will be installed?
3. A water valve is located at station 345+03 and another at 350+08. What is the distance between the two valves?
4. A domestic water service is located at station 102+45. Two more services need to be installed, one 75 below and one 75 above this station. What is the station of these two new services?
5. A water utility operator is looking at a set of water plans with the following information.

   Fire hydrant located at 534+00

   Valve located at 534+45

   Water service located at 532+99

   What is the total distance between these items?
6. An engineer is designing a water system for a cul-de-sac with 10 homes (5 on each side). The street begins at station 105+30. Each service must be one hundred feet apart and there must be a fire hydrant 25 feet past the second house on either side of the street. Answer the following two questions.

   a. What is the station for the last house on one side of the street?

   b. What is the station of the fire hydrant?
7. On a street 1,250 feet long, a fire hydrant is located at the end of the street at station 12+95. Three services are located at 10+33, 09+04, and 08+94, and a valve located 7 feet from the start of the street. What is the starting station number?
8. In the question above, what is the distance from the start point to each service?

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SECTION OVERVIEW

Page 6.11: Using What You Learned and Preparing for Certification Exams

This text provides a basic look in to water related math problems. Various concepts are introduced and several formulas to apply to those concepts are presented. However, sometimes there are water related math questions, which are basic in nature, but are not part of the framework of the core concepts in this text. This section will attempt to introduce some of those questions and delve into simple math problems presented in questions you may not have seen before.

Page 6.11.1: Examples

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Page 6.11.1: Examples

Let's start with a simple question:

Example *Page*6.11.1.1

The diameter of a circle is?

a. One-half the radius
b. Twice the radius
c. Twice the circumference
d. One-half the circumference
e. Both b and d

Solution

Upon first examination, the answer appears to be rather obvious. It is "b", twice the radius. However, whenever a multiple choice question uses an answer such as "e", both a and b, you need to take a deeper look. In order to rule out answers, you need to have a good understanding of the question.

1. One-half the radius – this one should be fairly easy to rule out since you know that twice the radius is the answer.
2. Twice the radius – the correct answer
3. Twice the circumference
4. One-half the circumference

Both of these answers require you to know the formula for circumference to make an educated guess as to whether or not either of these are correct.

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

Knowing this equation allows you to easily rule out both of these possible answers.

This was a fairly easy example. Now let's take a look at something a little more deceiving and requires additional work to solve.

Example *Page*6.11.1.2

One acre-foot of water contains?

a. 43,560 cubic feet
b. 325,829 gallons
c. 1,233,263 liters
d. Only a and b
e. All of the above

Solution

Upon first glance, most of you might say "b" is the correct answer. You would be correct, because one acre-foot does contain 325,829 gallons. However, there is a better answer.

If your next instinct tells you "d" is correct, then you would also be right. Remember, one acre of land is equal to 43,560 square feet. If you fill this land one foot deep, then it becomes 43,560 cubic feet. Therefore, both "a" and "b" are correct answers.

However, 1,233,263 liters is a large number and it might actually be equivalent to one acre-foot. Here is where you need to know how many liters are in a gallon.

1 gallon = 3.785 liters

Therefore, $325,829 \text{ gal } \times 3.785\text{L} = 1,233,262.7\text{L}$

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So, the best answer is “e” all of the above.

Meter reading is a common task for both water distribution and treatment operators. Mechanical equipment such as, meters, pumps and motors require maintenance and have a certain operating life. In addition, knowing how much water a utility pumps and sells is critical to a utilities revenue stream. There are flow meters and hour meters at various facilities in a water system. Understanding some of the terminology is critical to understanding how to solve some very basic math problems.

Example *Page*6.11.1.3

A water treatment operator had a start read of a certain pump on January 1 and an end read on January 31. If the start read was 1,200,425 gallons and the end read was 6,342,076 gallons how much water flowed through this pump?

a. 5,142 gallons
b. 51,416 gallons
c. 5,141,651 gallons
d. None of the above

Solution

This is a relatively simple subtraction problem but you need to know what “start” and “end” reads are. Flow meters can be read daily, weekly, monthly, etc. A “start” read is nothing more than the beginning read of a certain period. In this example a monthly read. The “end” is then the last read of a certain period. So in this example, letter “c” is the correct answer, 5,141,651 gallons flowed through this pump in the month of January. Do you notice anything else interesting with this question? All the answers have similar numbers, just an order of magnitude different. The certification exams often do this to try and confuse test takers. Sometimes people get confused and might see a comma as a decimal and will select the incorrect answer.

These are only a few examples of some very basic problems and some test taking tips when you finally begin taking operator certification exams. Below are a series of questions to further illustrate the subtle differences in ways of asking questions.

Exercise 11.1

1. How many gallons of water are in 2 acre-feet?
   a. 43,560
   b. 87,120
   c. 325,829
   d. 651,658
   e. Both b and d
2. A customer used 25 CCF in February and the ending read was 8052 CCF. If the ending reading in March was 8080 CCF, how many CCF did they use in March?
   a. 25 CCF
   b. 28 CCF
   c. Not enough information to solve
   d. None of the above
3. A pressure gauge reads 100 psi. This is equivalent to
   a. 43.3 feet
   b. 110 psig
   c. 2.31 feet
   d. 231 feet
   e. 231 psig
4. The volume of cylinder is calculated by multiplying its height by
   a. 3.14
   b. 3.14 x the radius

c. 0.785
d. 0.785 x the diameter
e. 0.785 x the diameter squared

5. At the beginning of the day, a totalizer on a pump station effluent meter reads 2,813,572 gallons. The next morning, the totalizer reads 4,612,931 gallons. The average daily flow during this 24-hour period was approximately
   a. 0.18 MGD
   b. 1.8 MGD
   c. 18 MGD
   d. 180 MGD
   e. 1,800 MGD
6. The past three year-end hour meter readings for a booster pump are 1152.1, 4433.3, and 7542.4. What is the greatest number of hours that the pump operated in a single year in this period?
   a. 7542.4 hours
   b. 6390.3 hours
   c. 3281.2 hours
   d. 3109.1 hours
7. A meter indicates 20 hundred-cubic feet (ccf) of water was delivered during a billing period. This is approximately
   a. 1,000 gallons
   b. 1,500 gallons
   c. 10,000 gallons
   d. 15,000 gallons
   e. None of the above
8. You are to excavate a pipe trench that is 300-feet in length, 6-feet deep, and 3-feet wide, and export all of the soil removed. Your dump truck holds 10 yards. How many trips will your truck need to make to complete the job?
   a. 5
   b. 10
   c. 15
   d. 20
   e. 25
9. A flow meter indicates a flow rate of 1,500 gallons per minute. How much water per day will flow through the meter in 110 hours?
   a. 132,353 cf
   b. 1,323,529 cf
   c. 990,000 gal
   d. 9,900,000 gal
   e. Both b and d

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