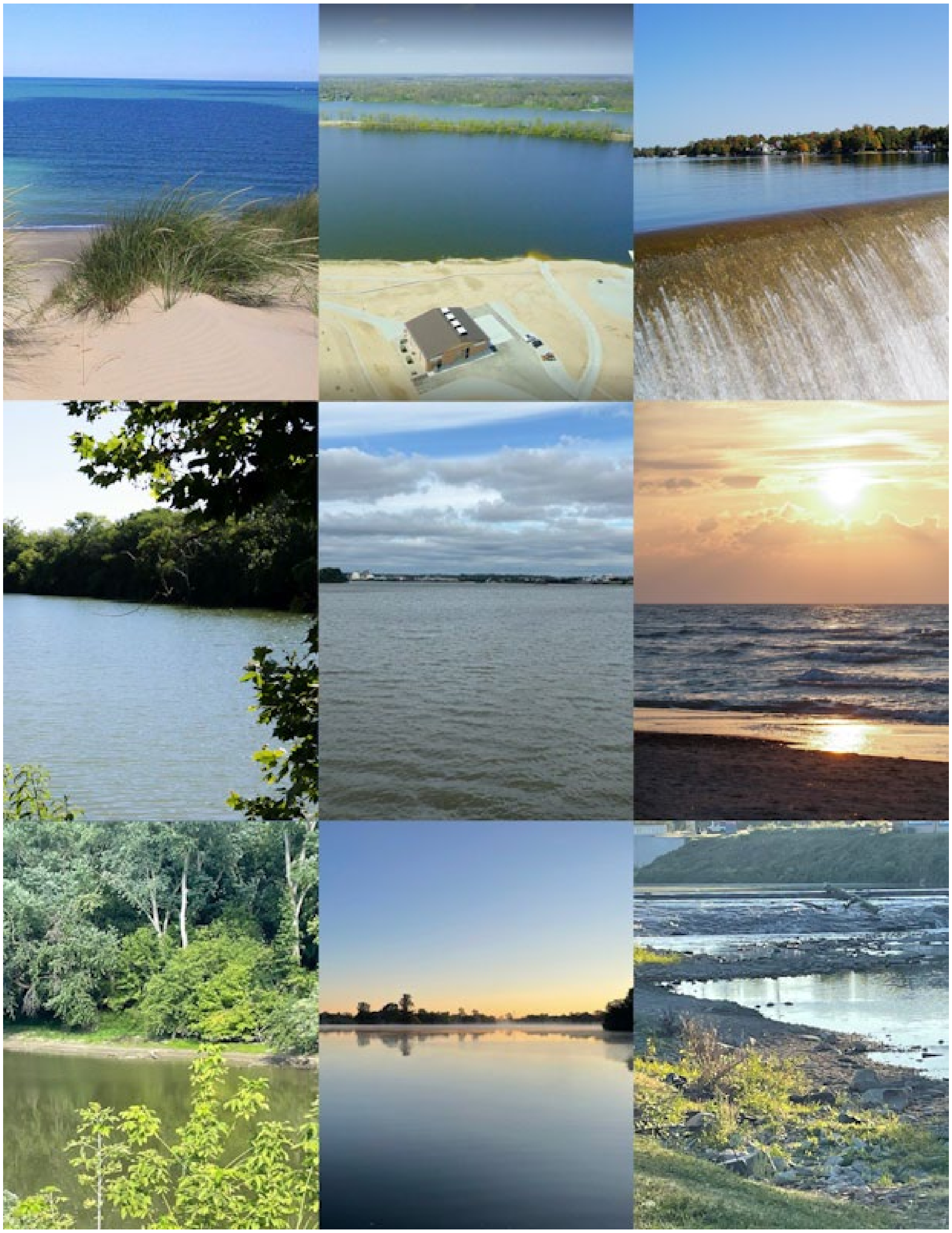
INDIANA DRINKING WATER OPERATOR TRAINING

Surface Water Treatment

First Publication December 2025



Introduction

This manual provides a basic overview of surface water treatment for community and non-transient water systems. It is designed to be used in conjunction with other resources, such as textbooks, videos, and training courses. It is not meant to encompass every question that might be encountered on the Operator Certification examination. It was designed to supplement other study materials and resources. No textbook or manual can replace hands-on experience.

Many thanks to the operators, contractors, trainers, and IDEM employees who worked to make this manual accurate and relevant. None of you want to be called out, but you are appreciated. Special thanks to the Environmental Protection Agency, Missouri DNR, Pennsylvania Bureau of Safe Drinking Water, National Weather Service, and United States Geological Survey for the use of their images.

For additional resources, please refer to the Resources section of this manual.

Chapter 1 – Source Water and Regulation

Learning Objectives

- List the components of the Hydrological (Water) Cycle.
- Identify surface water sources and explain the special considerations required for using them as a drinking water source.
- Describe various types of intake structures and impoundments.
- Identify federal regulatory bodies and explain federal drinking water legislation.
- Identify state regulatory bodies and explain state drinking water regulations.

- Explain the different system classifications and recognize the duties for each classification.
- List requirements and tiers of public notification and demonstrate knowledge of when each tier should be used.
- Identify the requirements in the Consumer Confidence Report.
- Describe the permit application process and the circumstances which would require an IDEM construction permit.

Hydrological Cycle (Water Cycle)

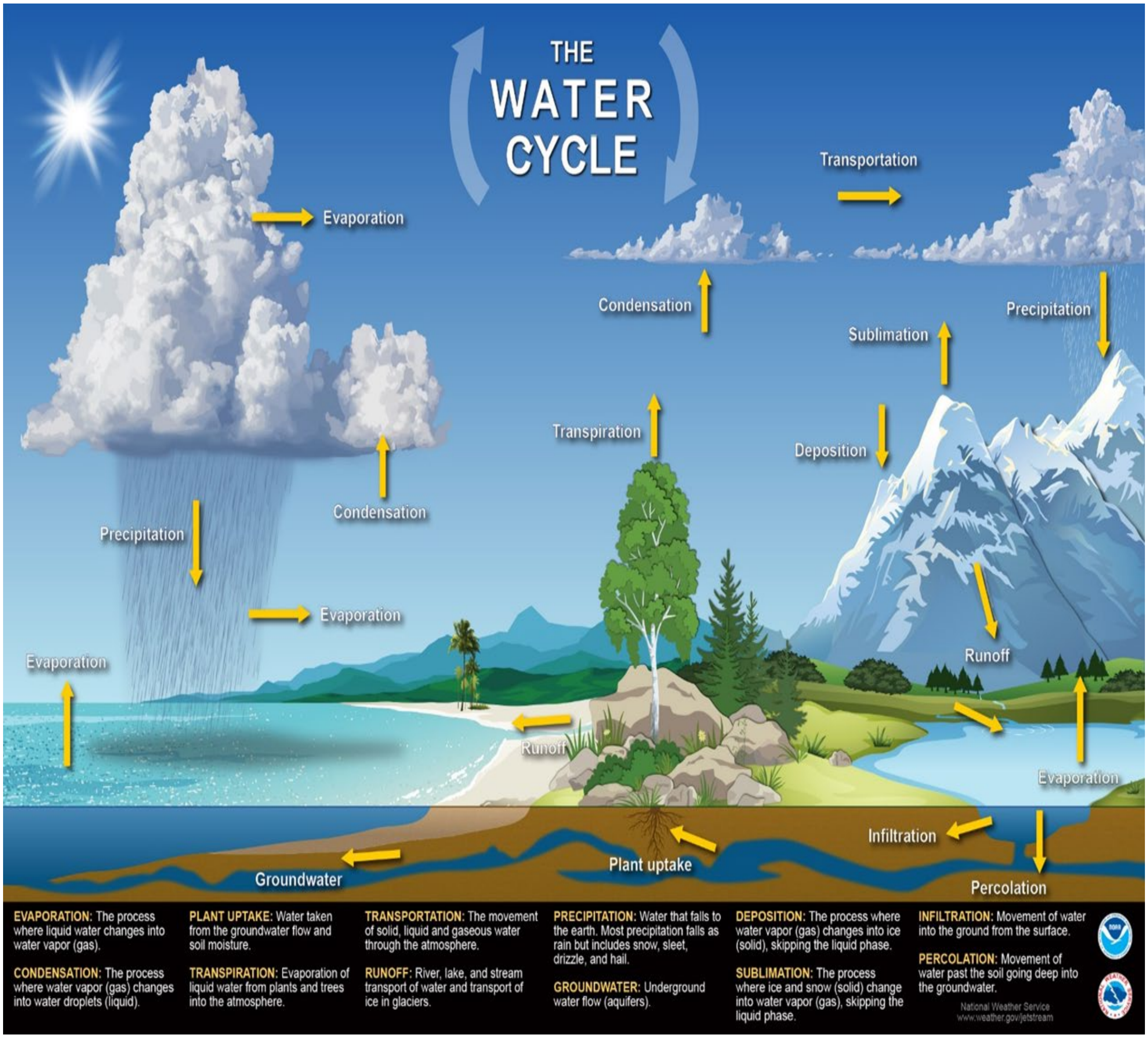
Water is a chemical compound made of two Hydrogen atoms and one Oxygen atom sharing a covalent bond (H_2O). All lifeforms on Earth require water to survive. Drinking water professionals provide an essential service, by ensuring safe, clean water is available to their customers.

Water exists on earth one of three states of matter: solid, liquid, or gas. Most chemicals and compounds become denser as they move from gas or liquid state to a solid state. Water is one of the few that is less dense as a solid than it is as a liquid. Ice is roughly 9%, or 1/9, less dense than liquid water.

The hydrological cycle covers the “continuous exchange” of water between the earth and the atmosphere. The hydrological cycle, also known as the water cycle, shows the movement of water through those phases as it travels through the land, sky, and ocean.

Figure 1.1 illustrates the movement of water through the hydrological cycle. Table 1.1 lists each component, or phase, of the water cycle.

Figure 1.1 – The Water Cycle



EVAPORATION: The process where liquid water changes into water vapor (gas).

CONDENSATION: The process where water vapor (gas) changes into water droplets (liquid).

PLANT UPTAKE: Water taken from the groundwater flow and soil moisture.

TRANSPIRATION: Evaporation of liquid water from plants and trees into the atmosphere.

TRANSPORTATION: The movement of solid, liquid and gaseous water through the atmosphere.

RUNOFF: River, lake, and stream transport of water and transport of ice in glaciers.

PRECIPITATION: Water that falls to the earth. Most precipitation falls as rain but includes snow, sleet, drizzle, and hail.

GROUNDWATER: Underground water flow (aquifers).

DEPOSITION: The process where water vapor (gas) changes into ice (solid), skipping the liquid phase.

SUBLIMATION: The process where ice and snow (solid) change into water vapor (gas), skipping the liquid phase.

INFILTRATION: Movement of water into the ground from the surface.

PERCOLATION: Movement of water past the soil going deep into the groundwater.

Courtesy of the National Weather Service

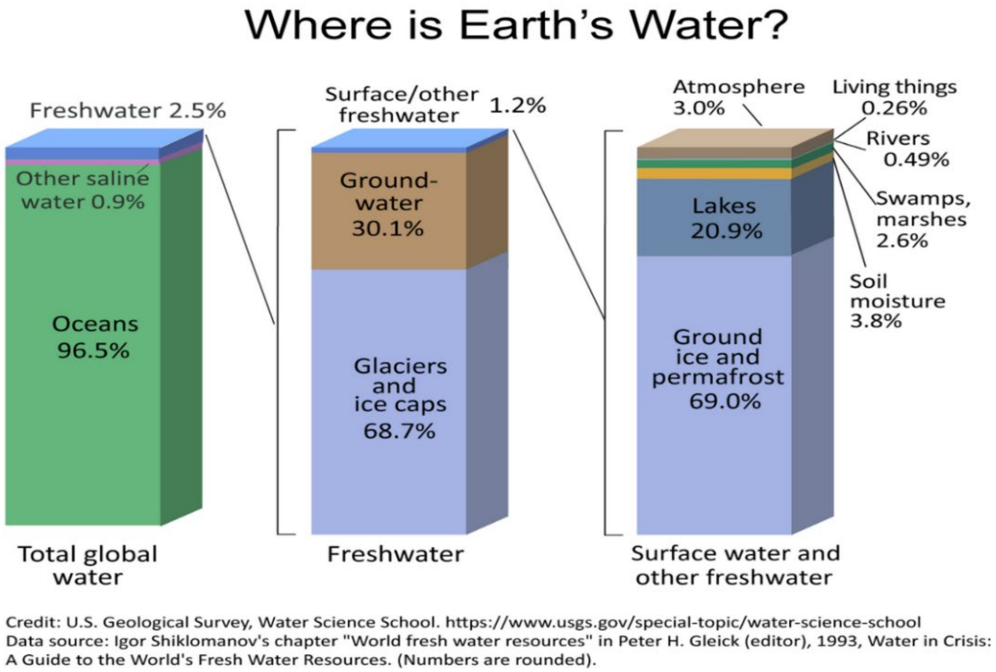
Table 1.1 – Phases of the Hydrological Cycle

Phase	**Process**
Condensation	The process of water vapor in the air becoming liquid water.
Deposition	The process where water vapor changes from a gas to a solid, skipping the liquid phase.
Evaporation	The conversion of water from a liquid to a gas.
Evapotranspiration	Liquid water evaporates from land and soil into the atmosphere.
Precipitation	Water that falls to the earth in liquid form as rain, snow, sleet, and hail.
Percolation	The slow seepage of water through the ground, or the slow passage of water through filter media.
Sublimation	The process of solid water (snow or ice) changing to gaseous water (water vapor), skipping the liquid phase.
Transpiration	The process of liquid water evaporating from plants and trees into the environment.

Because of the water cycle, the amount of water on earth has remained mostly constant. Roughly 70% of the Earth's surface is made of water. Of the available water on Earth, only around 2.5% is fresh water, and only a percentage of that is available for consumption. Because of this, it is important to conserve water.

Figure 1.2 shows the composition of the Earth's water.

Figure 1.2 – Where is Earth's Water

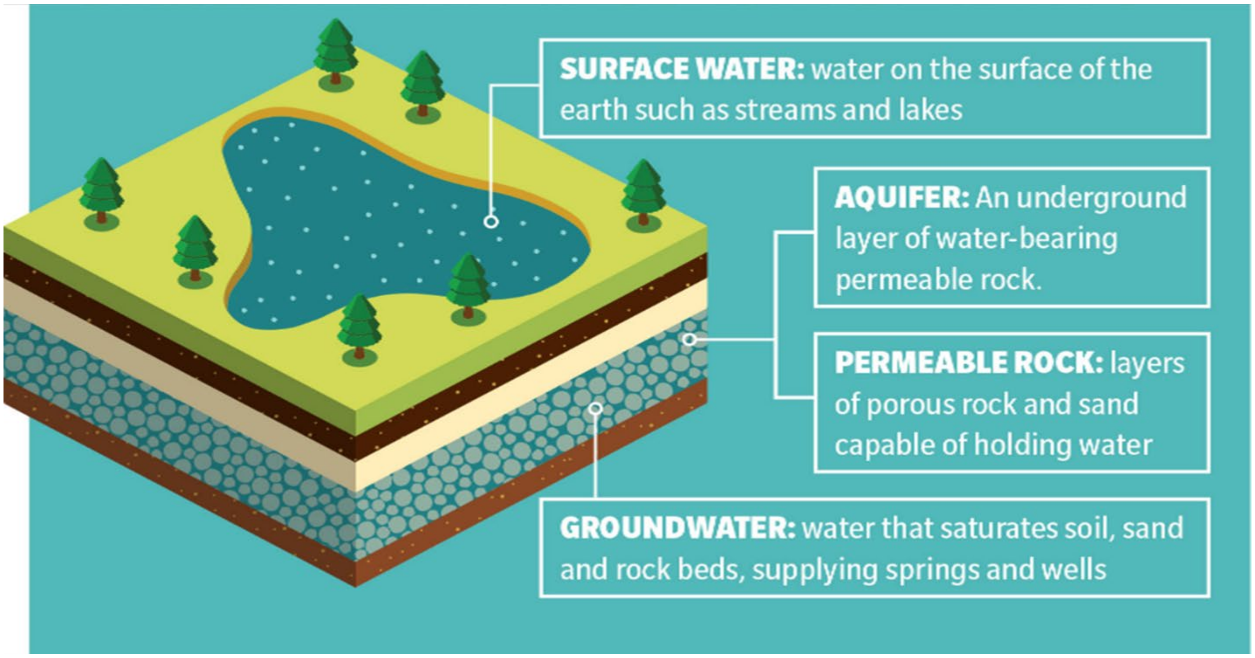


Surface Water as a Source

During the water cycle, precipitation falls to Earth. Water saturates the soil, where it either percolates down or is taken in by plant and tree roots. Once the soil is saturated, water that cannot infiltrate or enter the soil will run off to streams, rivers, lakes, reservoirs, and wetlands. This process is called surface runoff.

Water that exists above ground and receives surface runoff is known as surface water. The water under the Earth's surface is known as groundwater. The water that percolates through the ground can collect in geologic formations called aquifers. Figure 1.3 shows a cross section of surface water and groundwater.

Figure 1.3 – Surface and Groundwater

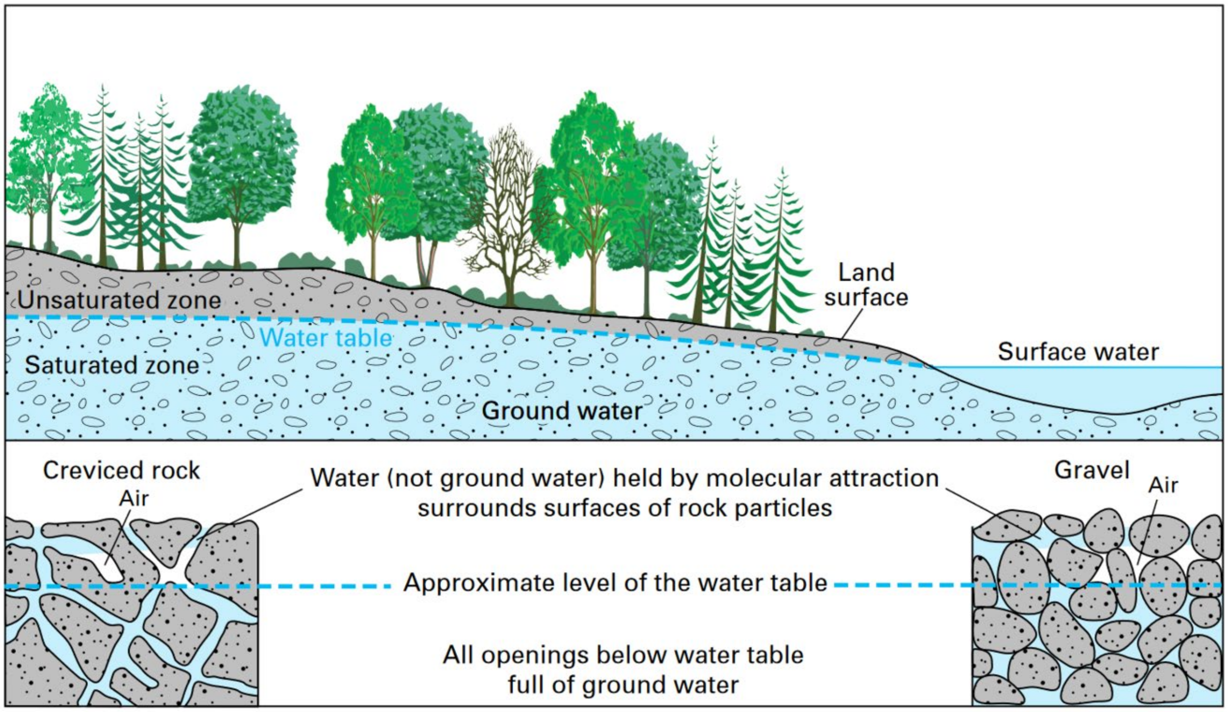


Stock Image

Surface water may flow, like in a river or stream, or be stationary, like a lake, reservoir or pond. Water moves from areas of higher elevation to areas of lower elevation, and follows the path of least resistance, so drainage zones are separated by areas of high ground known as ridges. Water will percolate through soil until it is saturated. Once the soil is saturated, it flows in rivulets to a larger body, like a stream, river, or lake.

The water table is a line that separates the unsaturated zone of soil from the saturated zone, where the ground can’t hold any more water. Bodies of surface water above the water table recharge the aquifers as water slowly moves through the ground at the bottom. If the water table is above the bottom of a surface water body, it will recharge the body as water seeps into the formation. Figure 1.4 shows how water moves through the ground.

Figure 1.4 – How Groundwater Occurs in Rocks



How ground water occurs in rocks.

Courtesy of USGS

Aquifers can be accessed using wells. Typically, groundwater is less susceptible to contamination, however, it may be higher in dissolved metals and minerals, like iron, manganese, and calcium carbonate. Some common groundwater contaminants include coliform bacteria, nitrates, arsenic, and synthetic organic compounds (SOCs). The properties and treatment techniques for groundwater can be found in the Indiana Drinking Water Operator Training Manual: Groundwater.

Since surface water is open to the environment, it is susceptible to many forms of contamination. Unlike groundwater, which typically has consistent properties year-round, surface water will experience changes in physical and chemical properties at different times of year.

Systems may draw water from rivers, lakes, or reservoirs. Each body of water has different concerns regarding water quality and necessary treatment techniques. They all share the same challenge for treatment operation: the water quality changes frequently and adjustments to treatment processes must be made to account for those changes.

Turnover/Overturn

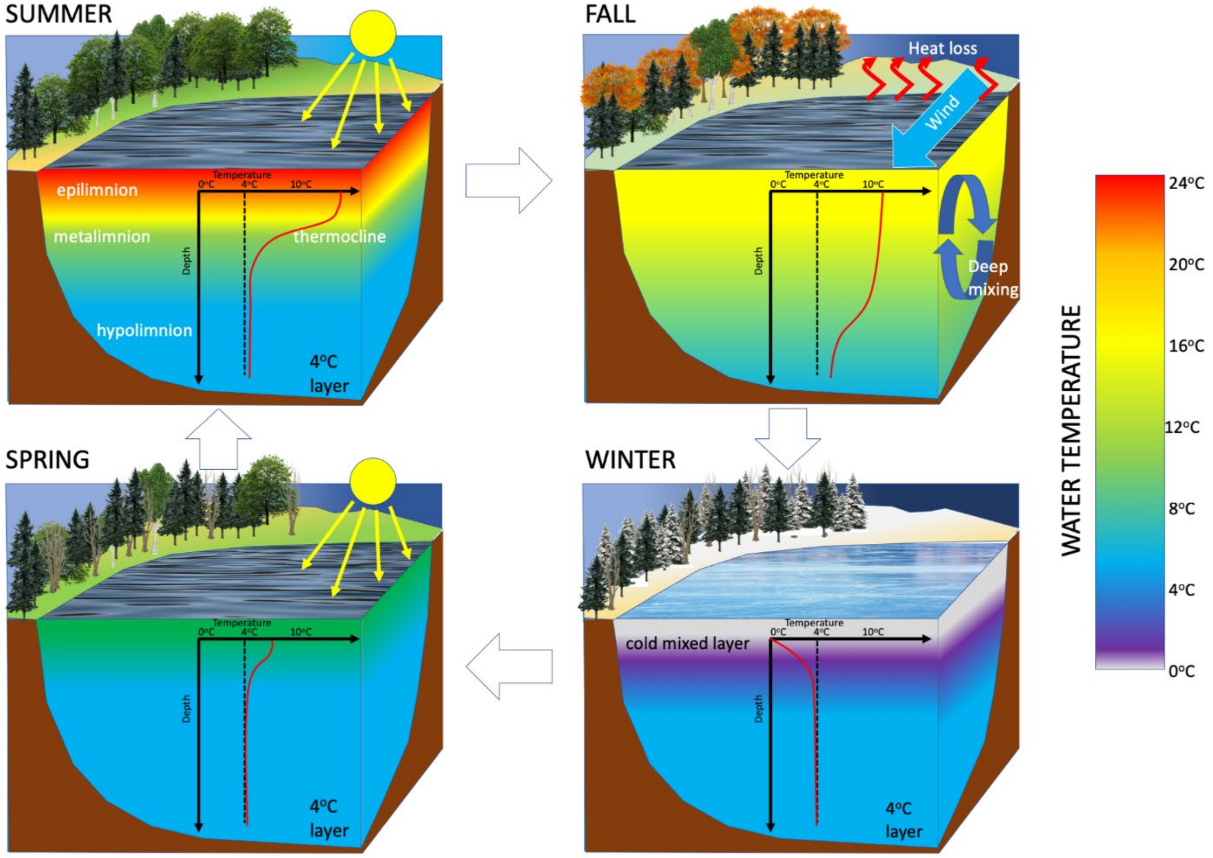
Water reaches its maximum density at 39.2° F, 4° C. In large bodies of water, like lakes and rivers, the water sits in layers based on temperature. Colder, denser water sits at the bottom and warmer water is at the surface. This is known as stratification. The water sits in three layers, as described in table 1.2 below.

Table 1.2 – Stratification Layers

Layer Name	Characteristics
Epilimnion	Top layer of warm water close to the surface. This layer is mixed by wind as it blows across the surface.
Metalimnion or thermocline	Middle layer where the temperature decreases quickly the deeper the water is.
Hypolimnion	Bottom layer where water is the coldest. Low in dissolved oxygen, which causes anaerobic decay of organic matter.

When temperatures change, this impacts the layers of water in a stratified lake or reservoir. As the air temperature gets colder, water in the epilimnion also cools, until it is just above freezing. This causes the water at the top to reach maximum density, making it sink to the bottom. The water at the bottom moves upward as it is displaced, lifting the sediment and organic matter from the bottom with it. When this happens, it is called turnover or overturn. Some areas only experience one major temperature change annually and go through a single destratification per year. These are known as monomictic. Other areas experience two seasonal turnover events and are called dimictic. Figure 1.5 shows the stratification and turnover of a dimictic lake.

Figure 1.5 – Stratification and Turnover of a Dimictic Lake



Wikimedia Commons

Seasonal turnover is a major concern for surface water treatment facilities. Not only does the temperature change impact treatment processes, but the shift can increase turbidity, organic matter, and dissolved metals and minerals, which must be removed.

Some systems may choose to destratify their source water. This can be accomplished by introducing air at the bottom. A bubbler or diffuser is placed on the bottom of the lake or reservoir. The increased air allows mixing to occur, preventing stratification. This technique may also be used to control algae growth.

Aquatic Plants and Animals

A primary concern for surface water sources is plant life and vegetation. Aquatic plants increase dissolved oxygen during photosynthesis. Under anaerobic (without oxygen) conditions, they will increase dissolved carbon dioxide. Plants also produce organic matter, which impacts tastes, odors, and the formation of disinfection byproducts.

Plants play an important role in the health of body of water, so removing all plants is not generally the best practice. If plant growth is heavy, some plants may be removed. The depth of the water and type of plants growing will determine the best method for removal. In shallow areas, they may be pulled by hand or by using a rake. In deeper water, dredging or chemical removal is more effective. Table 1.3 shows the different methods of removing plants from lakes, ponds, and reservoirs.

Table 1.3 – Aquatic Plant Removal Techniques

Method	Description
Harvesting	Removes the plants by pulling or cutting them. Sometimes machines are used. May not be appropriate for large or deep bodies of water.
Dewatering	Draining the body of water until the plants are exposed. The body of water will remain dry until the plant roots have died from dehydration. Not a practical option for a large body of water.
Dredging	A dragline or device is dragged along the bottom of a water body, pulling up plants and disturbing the bottom surface.
Shading	Uses a cover or the addition of clay to the water to block out light and keep the plants from photosynthesizing. Adding clay increases turbidity and covers are not feasible for large bodies.
Lining	Installing an impermeable liner on the bottom of the body of water to keep plants from taking root. Best for settlement ponds, since the water must be drained before a liner can be placed.

Biological	Uses specific species of insects, fish, snails, or crayfish that feed on the aquatic plants. Due to the dangers of invasive species in water bodies, the Department of Natural Resources (DNR) should be consulted.
Chemical	Herbicides introduced to the water to kill aquatic plants. This is a last resort, which should be done by a professional, and the DNR should be consulted.

Algae are a diverse group of aquatic plants. They can be single-celled and free-floating, attach to structures and rocks, or be rooted to the bottom. They come in many colors, shapes and sizes. Algae can indicate the overall health of a body of water, and it can also negatively impact water health.

In water treatment facilities, algae can cause taste and odor issues, shorten filter runs, and in some cases, release toxins that are harmful to human health. The taste and odor issues often increase chemical feed requirements, resulting in higher expenses for the utility. Shortened filter runs can complicate the treatment process.

Water that is high in nutrients, like phosphates and nitrates, promotes algal growth. Heavy algal growth is referred to as a bloom. Algal blooms tend to occur in warmer months, into fall, as nutrients are carried by runoff from agricultural fields and decomposing organic matter provides food.

The most common issue caused by algal growth is taste and odor complaints. The reproduction and decomposition of algae can cause the following taste and odor issues, depending on the exact species:

- Musty
- Earthy
- Fishy
- Septic
- Grassy

Some species of algae, particularly in the blue-green family, produce toxins that are harmful to humans and animals. These are referred to as cyanobacteria. Blue-green algae also produce chemicals that cause earthy and musty odors at low concentrations, like geosmin and methylisoborneol (MIB).

Like other aquatic plants, algae will produce dissolved oxygen during photosynthesis in the daytime and produce carbon dioxide during nighttime respiration. This causes changes in pH that impact treatment processes. The photosynthesis and oxygen release during the day can increase the pH to 9 or above. This impacts chlorine demand, which increases treatment costs. The carbon dioxide released at night can lower the pH to acidic levels, which impacts coagulation chemicals.

Algae come in many forms and sizes. Diatoms are single-celled, free-floating forms of algae. They are known for clogging filters and shortening filter runs. Diatoms aren't the only form of algae that impact filters. Many species with filament structures will also clog filters.

Dosing with chlorine is one method of controlling algae at the intake, however, this can cause high levels of disinfection byproduct, since algae are organic. Potassium permanganate will also oxidize and kill algae but will not produce harmful byproducts.

Treating the source to control algae is often the preferred method. Copper sulfate ($CuSO_4$) has been used to control algae in ponds, lakes, and reservoirs for many years. The dosage depends on the alkalinity of the water. Lakes with methyl orange alkalinity over 40 mg/L as calcium carbonate ($CaCO_3$) should dose at 5.4 lbs/acre. Lakes with alkalinity below that should dose at 0.9 lbs/acre.

Copper sulfate can be dispersed in the water by dragging it in a burlap sack behind a boat in a zig-zag pattern in small bodies of water. For larger bodies, the copper sulfate is mixed with water and mechanical sprayers and spreaders are used. It loses concentration in deeper waters, so it is generally only applied within a couple of feet beneath the surface. Copper sulfate comes in crystalline form, with crystals that vary in size. The type of algae and chemical properties of the water will determine the size of the crystals used.

Chelated copper is another form of copper algicide. When applying a copper compound to control algae, it is important to keep the area wildlife and plants that promote a healthy environment in mind. Applying these chemicals requires a permit from the Indiana Department of Natural Resources (DNR). The permit will specify the allowable dosage for your water source.

Aside from organisms that cause human health impacts, water treatment facilities may experience operational problems from invasive aquatic animals. Zebra mussels and Asiatic clams are two invasive species that can cause issues in water treatment applications.

Zebra mussels made their way into the Great Lakes from Europe in the 1980's. They spread quickly into connected waterways because the female zebra mussel can lay between 30,000 – 40,000 eggs each breeding cycle and because their larvae are free-floating, allowing currents to carry them great distances.

As they mature, zebra mussels attach to solid surfaces. Surface water intake structures are a common location where the mussels attach. This can clog intakes, decreasing flow into the treatment plant. Another concern is that they cause taste and odor problems as they die and decay on the intakes. This decay increases organic matter, which can increase chlorine or oxidant demand, increase chemical costs and potentially increase disinfection by-products.

Zebra mussels are filter feeders, removing plankton and nutrients from the water. Since they are invasive, they will remove the nutrients needed for native species to survive. This impacts the water's ecology and may cause problems with algae, taste and odor problems from native species die-off, and changes in dissolved oxygen, carbon dioxide, and pH.

Zebra mussels can be controlled through chemical, physical, and mechanical methods. In most cases, a combination of all three methods is used. Table 1.4 describes different methods of zebra mussel control, their type, benefits, and drawbacks.

Table 1.4 – Zebra Mussel Control Techniques

Method	**Type**	**Benefits**	**Drawbacks**
Oxidation with Chlorine	Chemical	Effective in killing adults and larvae at the intake.	Potential to create disinfection by-products, decaying mussels may cause taste and odor problems, limits the biological effects of sand filters, environmental concerns.
Oxidation with permanganate	Chemical	Kills adults and larvae without generating disinfection by-products.	Not as effective in killing as chlorine.
Molluscicides	Chemical	Effective in killing adults and larvae	Negative environmental impacts, dead adults must be manually removed from intake structure or decay will cause taste and odor problems.
Antifouling coatings	Chemical	Discourages larvae from attaching to intake.	Expensive and must be reapplied frequently, negative environmental impact.
Sand infiltration beds	Physical	Prevents larvae from entering intake structures.	Costly and may reduce intake pressure.
Thermal	Physical	Water is heated to a temperature above zebra mussel tolerance, discouraging them from settling in the intake.	Requires system design to implement, adult mussels attached to intake must be physically removed after they die.

Strainers and screens	Mechanical	Mesh size keeps juveniles and adults from entering intake structures.	Larvae are likely to pass through.
Scraping	Mechanical	Attached mussels are physically scraped from intake structures.	Labor intensive and system design and operational concerns may make the process inefficient from a cost perspective.

Impoundments, Dams, and Intakes

An impoundment describes a non-flowing body of water, like a pond, or reservoir, where water is stored prior to treatment. Ponds may be suitable for small systems, but a larger system will use a reservoir. A reservoir is a man-made body of water. They may be dug or built in a valley near a river. Water is often diverted from a river to fill a reservoir with a dam. During times of heavy runoff, like snowmelt or spring rain, the excess flow fills the reservoir. When dryer conditions occur, water is released back into the river to increase flow.

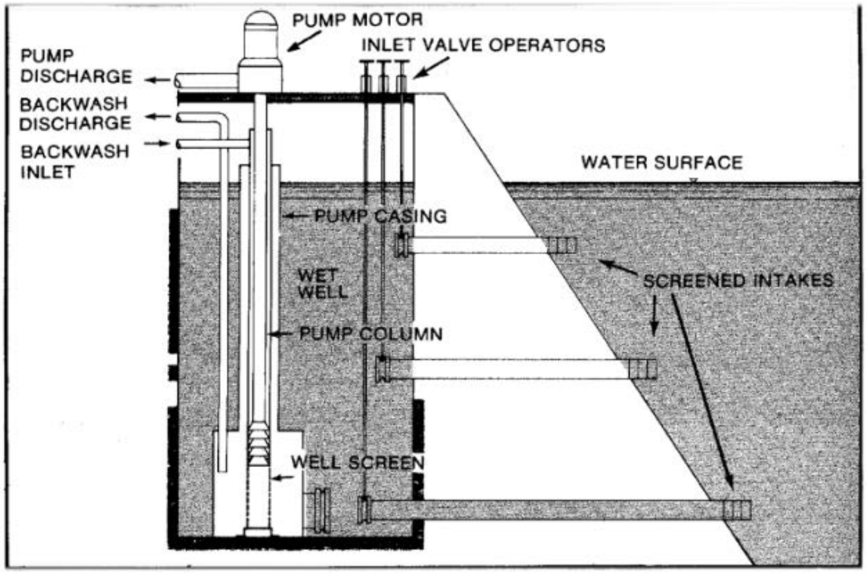
A dam is a structure used to stop or control the flow of water. Dams can be made of concrete or earthen material. The type of dam constructed depends on the geology of the area. Earthen dams are more common in areas with plenty of backfill material, like dirt and gravel, and a bedrock subsurface. Concrete dams are more common in areas with loose soil or sandy terrain that lack bedrock under the ground surface. Systems may use a dam in conjunction with an impoundment, like a pond, reservoir, or quarry to control flow or water levels in the primary source.

Dams must have a spillway to prevent accumulated water in the reservoir from rising over the top of the dam. If water overtops the dam, it can cause damage, or complete failure of the dam. Dams are designed and constructed based on 100-year flood conditions or greater. Regardless of design and construction considerations, they may be prone to flooding or low flow conditions. Emergency plans that cover operational issues with dams are necessary.

Many were federally constructed and continue to be federally managed. Some utilities do own the dams at their sources, and the operator is responsible for some maintenance. In those instances, the operator should refer to their system procedures. Dam maintenance is beyond the scope of this manual.

Intake structures are the mechanism that delivers water to the treatment plant from the source. For impoundments with dams, those intakes may be built into the dam. Intakes can be single-level or multilevel, fixed or movable, and surface level or submerged. Their design and placement depend on the water source. A deep lake might require a different type of intake than a river, for example. They should be constructed to prevent debris and wildlife from entering the structure. Figure 1.6 shows a multilevel intake on a reservoir dam.

Figure 1.6 – Multilevel Intake



Courtesy of the EPA

Placement of an intake structure should maximize flow and minimize any debris or sediment intake. An intake too close to the bottom of a water source can pull sediment from the bottom into the structure. In larger bodies of water, multilevel intakes may be better suited to avoid the water quality changes stratification and turnover cause.

As an operator, it is important to understand where your intakes are located. A clogged or blocked intake can decrease flow to the plant. A bar screen can keep larger matter from entering the intake. For algae and scum, a fine mesh strainer may be appropriate. Traveling screens are often used between the bar screens and the raw water pumps to remove small matter. They consist of a mesh strainer on a pulley mechanism. When head loss reaches a certain point, the submerged portion of the screen is moved to an accessible part of the mechanism for cleaning, and a clean area of screen replaces it at the intake.

Intake structures should be inspected regularly to ensure they remain operational. A maintenance program should be in place based on manufacturer's recommendations. Some systems must perform maintenance annually, while others may only require maintenance every 2-5 years. Submerged intakes may require divers or submersible cameras for inspection, while surface level intakes may be easier to access. If metal is used to protect your intake structure, it should have a corrosion resistant coating applied or use cathodic protection.

Common problems and concerns for surface intakes include:

- Icing over of intake in cold weather.
- Increased sediment or debris during warmer months (leaves, algae, tree branches).
- Aquatic pests like zebra mussels attached to intake surface.
- Changes in water quality due to seasonal shifts in temperature, organic matter, and dissolved gases.

Federal Regulations

United States Environmental Protection Agency (U.S. EPA, USEPA, or EPA)

https://www.epa.gov/

The United States Congress is responsible for creating federal laws and regulations. Due to environmental disasters like the fire on the Cuyahoga River and publications detailing the hazards of chemicals released into the environment, President Nixon signed the National Environmental Policy Act (NEPA) on January 1, 1970. The Environmental Protection Agency (EPA) was established in December of 1970.

The mission of the EPA is “To protect human health and the environment”. It does so by enforcing the rules and regulations enacted by Congress. In 1972 the Federal Water Pollution Control Act, commonly referred to as the Clean Water Act, was passed. It was enacted to restore and maintain water quality in the U.S. through pollution control and assistance in wastewater treatment.

The Clean Water Act has undergone multiple revisions but has maintained its core functions from the original 1972 legislation:

- Establish structure for regulating pollutant discharges into U.S. waterways.
- Granted authority to the EPA to create pollution control programs and set wastewater standards for industry.
- Maintained existing water quality standards for surface water contaminants.
- Outlawed pollution discharges into navigable waters, unless granted a provisional permit.
- Funded grant program for sewage treatment plant construction.
- Recognized the need to address critical problems caused by nonpoint source pollution.

The Safe Drinking Water Act (SDWA)

https://www.epa.gov/sdwa

The SDWA was originally adopted in 1974, with amendments passed in 1986 and 1996, to protect public health by regulating the drinking water supply. It authorizes the EPA to set national health standards for drinking water to protect consumers from naturally occurring and man-made contaminants. Table 1.5 defines the EPA SDWA health standards. A full list of regulated contaminants and their allowable amounts is available on the EPA's SDWA website.

Table 1.5 – SDWA Standards

Contaminant Class	What it Means	Enforceable?
Maximum Contaminant Level Goal (MCLG)	The level of contamination below which there is no known or expected health risk.	No
Maximum Contaminant Level (MCL)	The highest level of contamination is allowed in drinking water. It is set as close to MCLG as possible, using the best and most cost-effective technology available.	Yes
Secondary Maximum Contaminant Level (SMCL)	Non-mandatory levels for systems to manage taste, color and odor.	No

The SDWA defines a public water system as having at least 15 service connections or serving 25 or more people per year, at least 60 days out of the year. Community systems serve the same residents, while noncommunity systems serve non-residents and have either transient or non-transient populations. Table 1.6 explains the types of public water systems.

Table 1.6 – Public Drinking Water Systems

Type of System	**Characteristics**	**Examples**
Community	Serves the same population of 25 or more year-round.	Municipal Utility, Mobile Home Parks, Neighborhoods
Non-transient non-community	Serves the same population of 25 or more for at least 6 months, but not the entire year.	Factories, Schools, Daycare Centers
Transient non-community	Provides water to 25 or more people for at least 60 days/year, but not the same people on a regular basis.	Gas stations, Campgrounds, Rest Areas, Churches

The 1996 SDWA Amendment enhanced the existing legislation, which focused on treatment as a means of providing safe drinking water, to include additional methods.

- Consumer Confidence Reports – requires all community water systems to prepare and distribute an annual report providing detailed information on water quality, potential contaminants, and their impact on human health.
- **Cost-Benefit Analysis** – requires a thorough cost-benefit analysis of any proposed new water system to ensure the benefit of creating the system will justify the cost.
- **Drinking Water State Revolving Funds** – established for states to assist water systems with improvements and source water protection.
- **Microbial Contaminants and Disinfection Byproducts** – strengthened protection for microbial contaminants like Cryptosporidium while also adding protections to control the byproducts from chemical disinfection. Includes the Stage 1 Disinfectants and Disinfection Byproducts Rule and the Interim Enhanced Surface Water Treatment Rule.

- **Operator Certification** – requires water system operators to be certified to ensure safe operation. The operator certification guidelines were issued in February of 1999 and outline the minimum standards for certification and recertification.
- **Public Information and Consultation** – Emphasizes consumers' right to know about what is in their drinking water. The EPA distributes public information, holds public meetings, and works with states, tribes, water systems and environmental groups to accomplish this.
- **Source Water Assessment Programs** – Requires states to conduct testing on drinking water sources like lakes, rivers, streams, reservoirs and groundwater wells. The goal is to find out how susceptible to pollution these sources are and to identify potential sources of contamination.

The SDWA allows the EPA to grant primacy to states. This gives the state authority to enforce the federal regulation. The state must adopt standards at least as stringent as the standards included in the federal legislation. The EPA divides the states into regions and has offices throughout the country. Indiana is in EPA region 5, which also includes Illinois, Michigan, Ohio, Wisconsin, and 35 Tribes.

SURFACE WATER TREATMENT RULES (SWTRS)

In 1989, the EPA developed the Surface Water Treatment Rule (SWTR) to enhance protection from disease-causing organisms, or pathogens, in surface water sources and groundwater under the direct influence of surface water (GWUDI). The rules specifically target *Giardia lamblia, Cryptosporidium, Legionella,* and other enteric viruses.

The Rule requires specific treatment techniques to be used for surface water and GWUDI sources, such as disinfection and filtration. It underwent several updates in the 1990's and 2000's. These updates are listed below:

- Interim Enhanced Surface Water Treatment Rule (IESWTR) – 1998
- Filter Backwash Recycling Rule (FBRR) – 2001
- Long Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR) – 2002
- Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) – 2006

Each of these revisions added new requirements for systems using surface water and GWUDI as a source. Current regulatory requirements for surface water and GWUDI systems are as follows:

- Maximum Contaminant Level Goal (MCLG) for *Cryptosporidium, Giardia lamblia, Legionella,* and enteric viruses is zero.
- *Giardia lamblia* - must achieve 99.9%, or 3-log removal or inactivation.
- Viruses – must achieve 99.99%, or 4-log removal or inactivation.
- Turbidity cannot exceed 1 Nephelometric Turbidity Unit (NTU) and 95% or more samples for turbidity must be less than or equal to 0.3 NTUs.
- Heterotrophic Place Count (HPC) cannot exceed 500 bacterial colonies per milliliter.
- Recycled filter backwash water must either go through the system's full treatment process or be sent to an alternate location approved of by the state.
- Systems that do not use filtration must include *Cryptosporidium* in their watershed control provisions.

The contaminants listed above do not have a Maximum Contaminant Level (MCL). The basis of the SWTR and its enhancements is that the log removal requirements will ensure public health and safety.

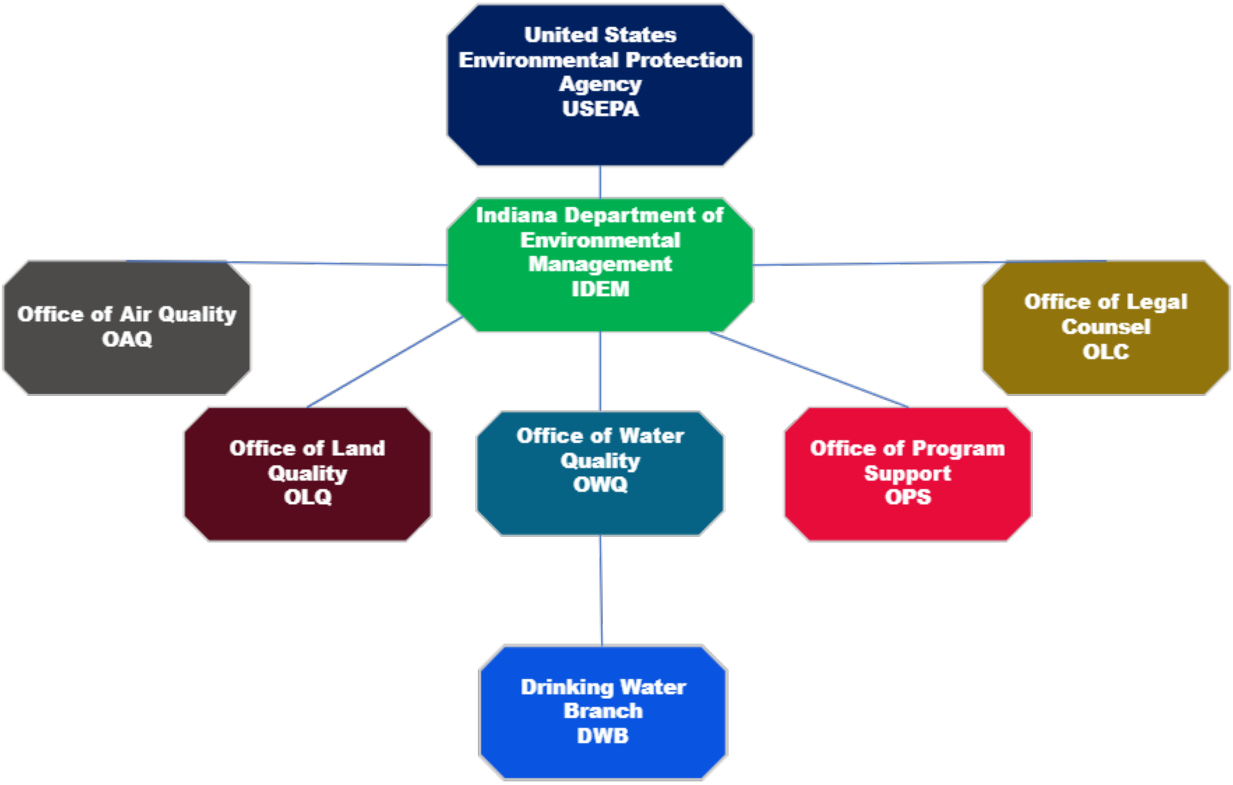
State Regulations

Indiana Department of Environmental Management (IDEM)

https://www.in.gov/idem/

The Indiana Department of Environmental Management (IDEM) is the agency responsible for enforcing environmental laws in Indiana. It applied for and was granted primacy by the EPA. Figure 1.7 shows the hierarchy of the EPA and the different IDEM offices.

Figure 1.7 – Federal and State Environmental Hierarchies



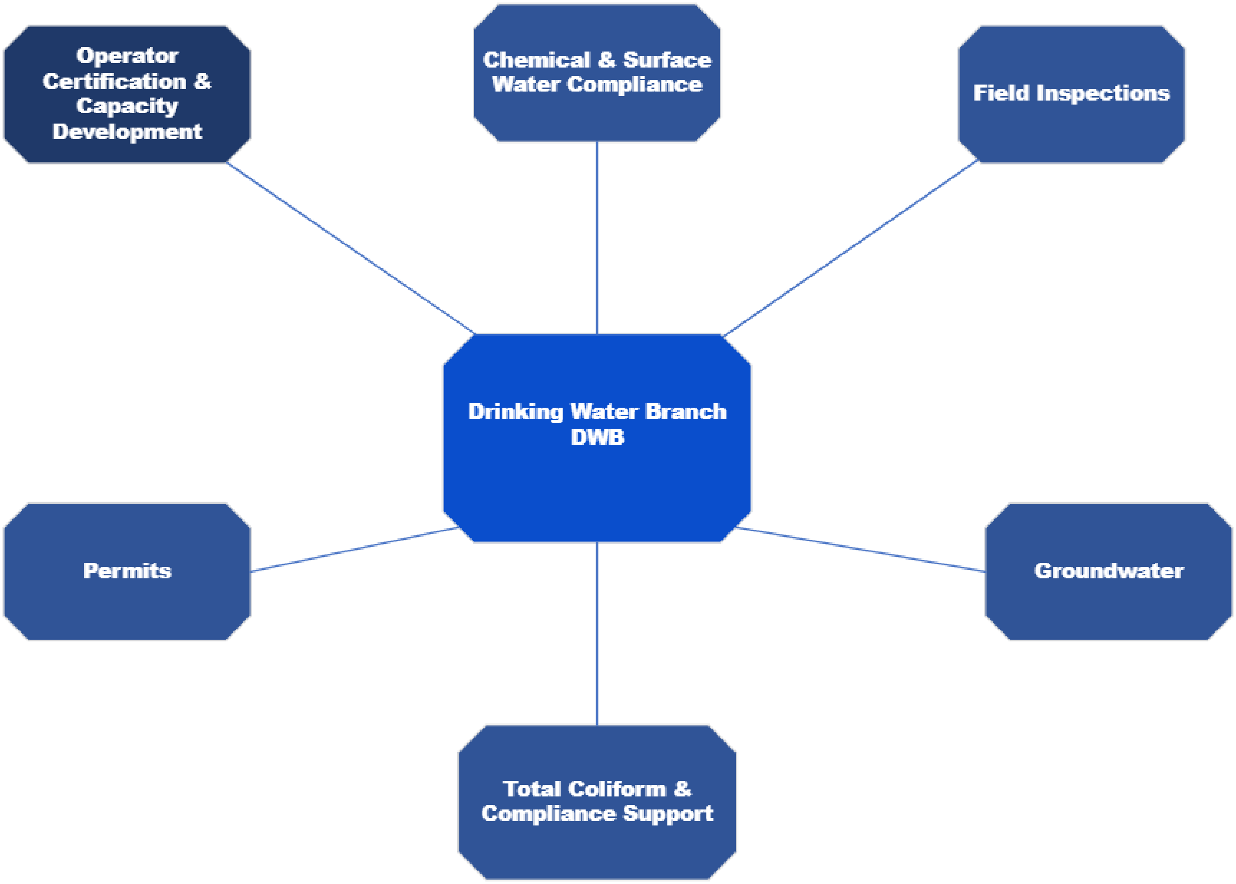
Each office of IDEM is responsible for protecting different parts of the environment. The Office of Water Quality (OWQ) works to ensure that Indiana waterways, wetlands and aquifers are protected from contamination. There are many branches in OWQ, but the Drinking Water Branch oversees program areas that regulate the drinking water supply.

Drinking Water Branch (DWB)

https://www.in.gov/idem/cleanwater/drinking-water/

The Drinking Water Branch is part of the Office of Water Quality and works to ensure Hoosiers have water that is safe for drinking and other consumption. Figure 1.8 shows the six sections in the DWB.

Figure 1.8 - Drinking Water Branch Sections



The six sections in the DWB work together to monitor contaminants, protect source water, inspect treatment facilities for compliance, review and approve system plans for new and existing treatment facilities, and administer an operator certification program.

Indiana Administrative Code (IAC)

Indiana Administrative Code (IAC) are the administrative rules or laws passed by the Indiana State Legislature. The rules that pertain to the OWQ are contained in Title 327. Rule 12 of Article 8 in Title 327 regulates public water supplies. Refer to Table 2 on page 4 for the definitions of public water supplies.

System Classifications and Operator Responsibilities

System Classifications

327 IAC 8-12-2 separates public water systems into two categories: Treatment and Distribution. Treatment plants will fall into one of six categories based on population size and technology. Distribution systems will fall into one of three categories, based on population size. Tables 1.7 and 1.8 provide details on these different classifications.

Table 1.7 – Water Treatment and Distribution Operator Classifications

Operator Class	**Characteristics**
WT1	• Serve a population less than or equal to five hundred • (500) people • Acquire water from one (1) of the following: ○ Ground water ○ Purchase • Have one (1) of the following: ○ Ion exchange softening process for cation removal ○ Inline filtration device with no chemical treatment

WT2	• Acquire water from one (1) of the following: ○ Ground water ○ Purchase • Utilize chemical feed to achieve one (1) of the following: ○ Disinfection ○ Fluoride standardization, or Water stabilization
WT3	• Acquire water from one (1) of the following: ○ Ground water ○ Purchase • Utilize chemical feed • Have one (1) of the following: ○ Pressure or gravity filtration ○ Ion exchange processes if the population served is five hundred one (501) or greater ○ Lime soda ○ Reverse osmosis
WT4	• Serve a population less than or equal to ten thousand (10,000) people • Acquire water from one (1) of the following: ○ Surface water ○ Ground water under the direct influence of surface water
WT5	• Serve a population of ten thousand one (10,001) or more people • Acquire water from one (1) of the following: ○ Surface water ○ Ground water under the direct influence of surface water
WT6	• Utilizes newly emerging treatment technology not commonly in use for drinking water treatment in Indiana, as determined by the Commissioner of IDEM.

Table 1.8 -Distribution System Operator Classifications

Operator Class	**Characteristics**
DSS (Distribution System Small)	• Serve a population of less than three thousand three hundred one (3,301) • Have no components other than: ○ pressure tanks; or ○ storage tanks
DSM (Distribution System Medium)	Meet one (1) of the following: • Serve a population greater than or equal to three thousand • three hundred one (3,301) but less than or equal to ten thousand (10,000) people and have no mechanical means of movement of water other than one (1) of the following: ○ Pressure tanks ○ Storage tanks • Consist of the following: ○ Pump ○ Storage tanks ○ Booster pumps to storage tanks
DSL (Distribution System Large)	• Serve a population greater than or equal to ten thousand one (10,001) people, or more • Consist of the following: ○ Storage tanks ○ Booster pumps to the distribution system ○ Mechanical devices for the movement of water beyond storage

Treatment classes WT1, WT2 and WT3 cover systems that acquire water supply from either purchase or groundwater. Treatment classes, WT4 and WT5 both acquire water from surface water or groundwater under the direct influence of surface water (GWUDI), but the population served determines their classification.

Ensuring your system is classified correctly is important, as each classification may have different regulatory requirements. Your facility may need reclassification if any of the following situations occur:

- The system uses special equipment or emerging technology.
- Features of design require a change in operation.
- A change is required by law.
- IDEM Commissioner determines a new classification requirement.
- Change in source water.

Some non-community non-transient, and community systems serving 100 or fewer people may qualify for Facility Specific Operator (FSO) certifications. If you have questions regarding your system classification, please contact IDEM.

Groundwater Under the Direct Influence of Surface Water (GWUDI)

Some groundwater is directly influenced by surface water. This means that the groundwater has been infiltrated by a surface water source and will show properties of surface water. This also means that it is more likely to become contaminated than water that is not influenced by surface water.

GWUDI falls under the same treatment rules and operator classifications as a surface water facility. Some things that might indicate your groundwater is influenced by surface water include:

- Changes in temperature (warming or cooling of more than a few degrees)
- Increased Turbidity
- Increased Organic Content
- Increase in disinfection chemicals needed to maintain a residual

Operator Responsibilities

An operator is responsible for drinking water quality from the treatment facility to the customer's tap. The primary goal of an operator is to protect human health and safety. It is also important to provide aesthetically pleasing finished water, without any foul colors, tastes, or odors.

IDEM requires all public water systems to have a designated operator who is the Certified Operator in Responsible Charge (CORC). The CORC is designated by the owner or governing body and is responsible for the operations of the treatment or distribution facility. They make decisions regarding daily operations which impact water supply and quality. A facility may have multiple operators, but there is only one CORC. Table 1.9 details CORC requirements for each facility grade.

Table 1.9 – CORC Requirements

Operator Grade	CORC Requirements
All Grades	• The certified operator will be able to provide adequate supervision to all units involved. • Before undertaking multiple operator positions of responsible charge, a letter signed by the certified operator is submitted to the owner or governing body of each water treatment plant and water distribution system to be under the responsible charge of the certified operator providing the following information: ○ The name and location of each water treatment plant and water distribution system to be under the responsible charge of the certified operator. ○ The number of hours per week the certified operator shall work at each water treatment plant and water distribution system.

DSS	• Be monitored daily by a dependable person or automated system. • Meet the following conditions based on system size and type: ○ A community water system must have a certified operator on site for a minimum of two (2) daily visits every week. ○ A non-transient noncommunity water system serving greater than five hundred (500) individuals must have a certified operator on site for a minimum of one (1) daily visit every week. ○ A non-transient noncommunity water system serving five hundred (500) or fewer individuals must have a certified operator on site for a minimum of one (1) daily site visit every two (2) weeks.
DSM	• Be monitored daily by a dependable person or automated system. • Have a certified operator on site for a minimum of three (3) daily visits every week.
DSL	• Be monitored daily by a dependable person or automated system. • Have a certified operator on site for a minimum of five (5) daily visits every week.
WT1	• Be monitored daily by a dependable person or automated system. • Have a certified operator on site for a minimum of three (3) daily visits every week.
WT2	• Be monitored daily by a dependable person or automated system. • Have a certified operator on site for a minimum of five (5) daily visits every week.
WT3	• Be monitored daily by a dependable person or automated system. • Have a certified operator on site for a minimum of five (5) daily visits every week.
WT4	• Must have a certified operator on site during water treatment plant operation unless the plant is equipped with an automated system approved by the commissioner.
WT5	• Must have a certified operator on site during water treatment plant operation unless the plant is equipped with an automated system approved by the commissioner.

Required Qualifications

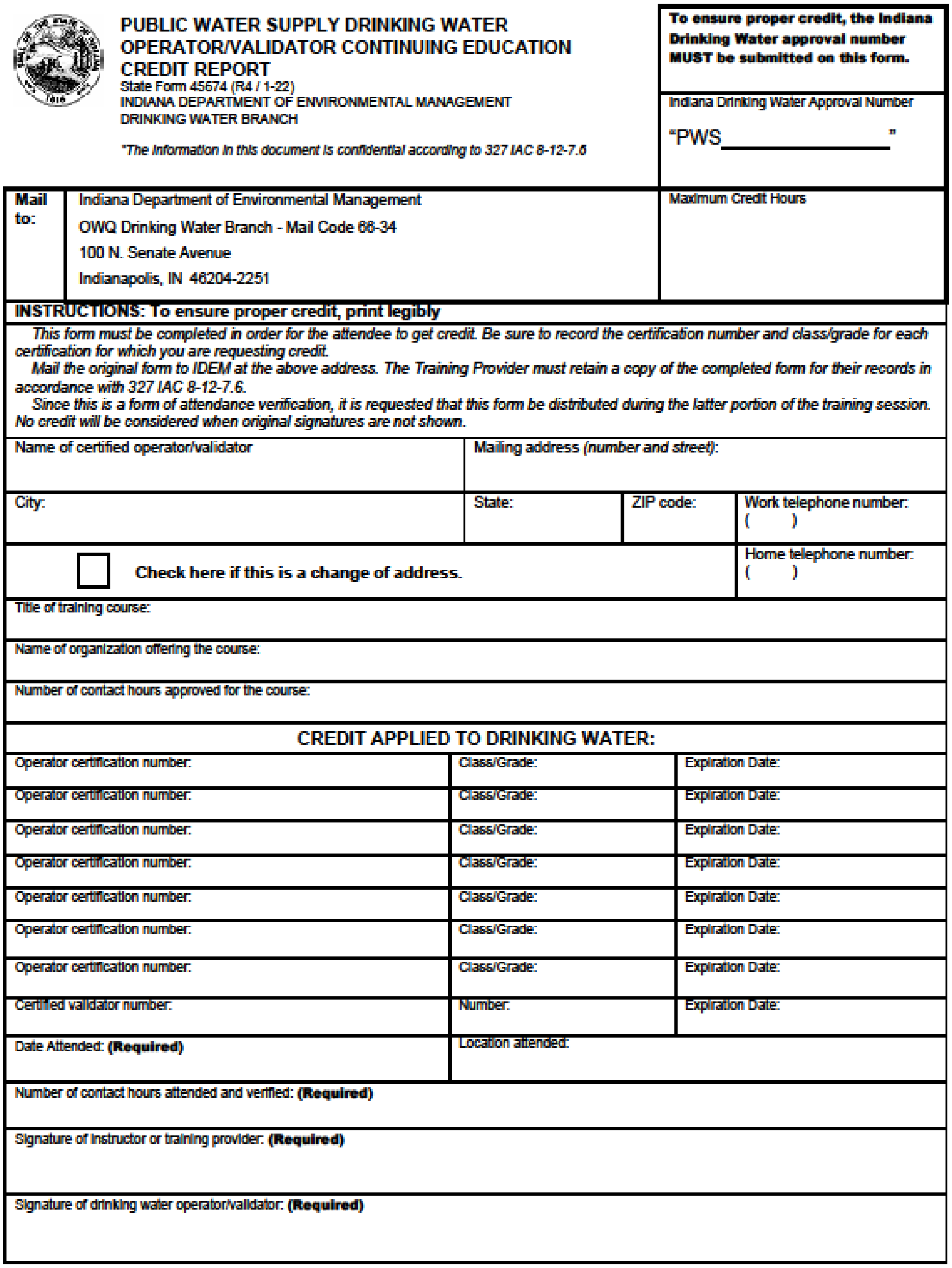
Many different skills are required to successfully operate a treatment facility or distribution system, as outlined in 327 IAC 8-12-3 (b). Operators of all grades must possess the following skills and qualifications:

- Understanding of basic scientific principles.
- Understanding basic sanitation principles.
- Ability to read and write in English for the purpose of interpreting service manuals, reading work orders and creating written reports.
- Ability to make simple and complex calculations.
    - Multiplication and division
    - Decimals, fractions and percentages
    - Converting units of measurement
    - Calculating volume of pipes and storage structures
    - Calculating appropriate dosages for various chemicals
    - Reading a linear scale
- Strong organizational skills for record keeping and maintaining necessary supplies.
- **High School Diploma or its equivalent.**

An operator must also pass a certification examination unless otherwise exempted by statute or rule. A score of 70% or more is required to pass a certification examination. Passing the operator examination demonstrates a level of professional competence.

Figure 1.9 is the form for submitting CEU hours. Table 1.10 details the experience and education requirements for each operator grade and the continuing education requirements to renew certification. Renewal for all operator grades requires Continuing Education Unit (CEU) hours. 70% of the CEUs must be technical for renewal.

Figure 1.9 – Continuing Education Credit Report



PUBLIC WATER SUPPLY DRINKING WATER OPERATOR/VALIDATOR CONTINUING EDUCATION CREDIT REPORT

State Form 45674 (R4 / 1-22)
INDIANA DEPARTMENT OF ENVIRONMENTAL MANAGEMENT
DRINKING WATER BRANCH

"The information in this document is confidential according to 327 IAC 8-12-7.6

To ensure proper credit, the Indiana Drinking Water approval number MUST be submitted on this form.

Indiana Drinking Water Approval Number

"PWS________________"

Maximum Credit Hours

Mail to:

Indiana Department of Environmental Management
OWQ Drinking Water Branch - Mail Code 66-34
100 N. Senate Avenue
Indianapolis, IN 46204-2251

INSTRUCTIONS: To ensure proper credit, print legibly

This form must be completed in order for the attendee to get credit. Be sure to record the certification number and class/grade for each certification for which you are requesting credit.

Mail the original form to IDEM at the above address. The Training Provider must retain a copy of the completed form for their records in accordance with 327 IAC 8-12-7.6.

Since this is a form of attendance verification, it is requested that this form be distributed during the latter portion of the training session. No credit will be considered when original signatures are not shown.

Name of certified operator/validator	Mailing address *(number and street)*:		
City:	State:	ZIP code:	Work telephone number: ( )
☐ **Check here if this is a change of address.**			Home telephone number: ( )

Title of training course:

Name of organization offering the course:

Number of contact hours approved for the course:

CREDIT APPLIED TO DRINKING WATER:

Operator certification number:	Class/Grade:	Expiration Date:
Operator certification number:	Class/Grade:	Expiration Date:
Operator certification number:	Class/Grade:	Expiration Date:
Operator certification number:	Class/Grade:	Expiration Date:
Operator certification number:	Class/Grade:	Expiration Date:
Operator certification number:	Class/Grade:	Expiration Date:
Operator certification number:	Class/Grade:	Expiration Date:
Certified validator number:	Number:	Expiration Date:
Date Attended: **(Required)**	Location attended:	

Number of contact hours attended and verified: **(Required)**

Signature of instructor or training provider: **(Required)**

Signature of drinking water operator/validator: **(Required)**

https://www.in.gov/idem/forms/idem-agency-forms/#owq_cert_education

Table 1.10 – Qualifications, experience, and renewal requirements

Operator Grade	Work Experience and Qualifications	Renewal Requirements
Operator in Training (OIT)	• Current employment at a WT3, WT4, or WT5 treatment system or a DSL distribution system.	Not eligible for renewal.
WT1	• Minimum of 1 year experience. • The ability to maintain inventories. • Ability to order supplies and equipment. • Ability to interpret chemical and bacteriological sample reports.	10 CEU hours
WT2	• Maintain inventories. • Order supplies and equipment. • Interpret chemical and bacteriological sample reports. • Attain one (1) of the following acceptable work experience requirements: o One (1) year in the operation of a Class WT 2 water treatment plant. o Two (2) years in the operation of a Class WT 1 water treatment plant.	15 CEU hours
WT3	• Maintain inventories. • Order supplies and equipment. • Interpret chemical and bacteriological sample reports. • Attain the following acceptable work experience at a minimum: • Two (2) years in the operation of a Class WT3 water treatment plant. o Successful completion of educational work at college level in: ▪ Engineering ▪ Chemistry ▪ Science related to water treatment may be substituted for work experience required at the ratio of four (4) semesters or six (6) quarters of schooling for a maximum substitution of one (1) year of experience.	25 CEU hours

WT4	• Maintain inventories. • Order supplies and equipment. • Interpret chemical and bacteriological sample reports. • Attain the following acceptable work experience at a minimum: • Two (2) years in the operation of a Class WT4 water treatment plant. ○ Successful completion of educational work at college level in: ▪ Engineering ▪ Chemistry ▪ Science related to water treatment may be substituted for work experience at the ratio of four (4) semesters or six (6) quarters of schooling for a maximum substitution of one (1) year of experience.	30 CEU hours
WT5	• Ability to use conversion factors. • Ability to solve simple mathematical equations. • Understand the following: ○ Simple chemical laboratory equipment. ○ The bacteriological procedures used in water supply work. • Maintain inventories. • Order supplies and equipment. • Attain the following acceptable work experience at a minimum: ○ One (1) of the following: ○ Three (3) years in the operation of a Class WT5 water treatment plant. ○ Five (5) years in the operation of a Class WT4 water treatment plant. ○ Successful completion of educational work at college level in: ▪ Engineering ▪ Chemistry ▪ Science related to water treatment may be substituted for work experience at the ratio of four (4) semesters or six (6) quarters of schooling for one (1) year of experience, up to a maximum of two (2)years of experience. ○ Two (2) years in the operation of a WT3 water treatment plant may be substituted for one (1) year of experience required, with up to a maximum substitution of two (2) years' experience.	30 CEU hours

WT6	• Operator qualifications determined by the commissioner on an individual plant basis in response to the specialized nature of the water treatment plant.	30 CEU hours
DSS	• Attain a minimum of one (1) year of acceptable work experience in the operation of a Class DSS water distribution system.	10 CEU hours
DSM	• Attain one (1) of the following acceptable work experience requirements: ○ One (1) year in the operation of a Class DSM water distribution system. ○ Two (2) years in the operation of a Class DSS water distribution system.	15 CEU hours
DSL	• Maintain inventories. • Order supplies and equipment. • Interpret chemical and bacteriological sample reports. • Attain one (1) of the following acceptable work experience requirements: ○ One (1) year in the operation of a Class DSL water distribution system. ○ Three (3) years in the operation of a Class DSM water distribution system. ○ Five (5) years in the operation of a Class DSS water distribution system. ○ An acceptable number of years of experience approved by the commissioner if gained in operation of a combination of the various classifications of water distribution systems.	15 CEU hours

A Certified Operator may operate a facility of a different grade. Below are the allowable facility grade operations for each grade. DSS, WT1 and WT6 can only operate facilities of their respective operator classification.

- DSM can operate a DSS system.
- DSL can operate a DSM or DSS system.
- WT2 can operate a WT1 facility.
- WT3 can operate a WT2 or WT1 facility.
- WT4 can operate a WT1 or WT2 facility.
- WT5 can operate a WT1, WT2, or WT4 facility, a non-transient, non-community DSS system serving 500 or fewer individuals, or a community DSS system serving 100 or fewer individuals.

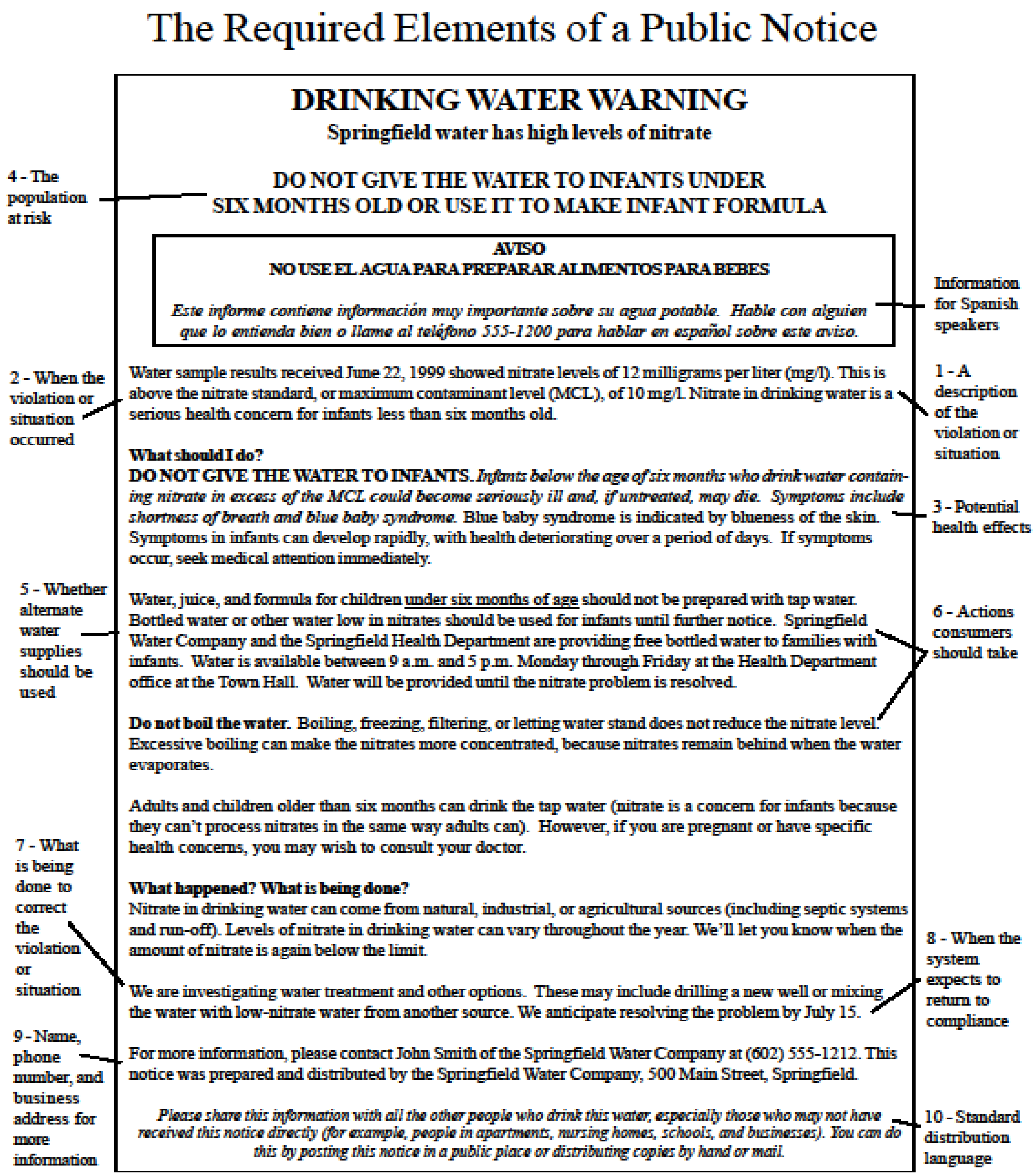
Public Notification

If a public water system violates the EPA or IDEM's drinking water regulations, or if their drinking water poses a health risk, it is required to notify consumers of the violation. This process is called Public Notification. The EPA set strict requirements on the contents of the notification:

- A description of the violation that occurred, including the contaminant(s) of concern, and the contaminant level(s).
- When the violation or situation occurred.
- The potential health effects (including standard required language).
- The at-risk population, including subpopulations who are vulnerable if exposed to the contaminant in their drinking water.
- Whether alternate water supplies need to be used.
- What the water system is doing to correct the problem.
- Actions consumers can take.
- When the system expects a resolution to the problem.
- How to contact the water system for more information.
- Language encouraging broader distribution of the notice.

Figure 1.10 Is an example of a public notification from the SDWA website.

Figure 1.10 – The Required Elements of a Public Notice



The Required Elements of a Public Notice

DRINKING WATER WARNING

Springfield water has high levels of nitrate

DO NOT GIVE THE WATER TO INFANTS UNDER
SIX MONTHS OLD OR USE IT TO MAKE INFANT FORMULA

AVISO
NO USE EL AGUA PARA PREPARAR ALIMENTOS PARA BEBES

Este informe contiene información muy importante sobre su agua potable. Hable con alguien que lo entienda bien o llame al teléfono 555-1200 para hablar en español sobre este aviso.

Water sample results received June 22, 1999 showed nitrate levels of 12 milligrams per liter (mg/l). This is above the nitrate standard, or maximum contaminant level (MCL), of 10 mg/l. Nitrate in drinking water is a serious health concern for infants less than six months old.

What should I do?
DO NOT GIVE THE WATER TO INFANTS. *Infants below the age of six months who drink water containing nitrate in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue baby syndrome.* Blue baby syndrome is indicated by blueness of the skin. Symptoms in infants can develop rapidly, with health deteriorating over a period of days. If symptoms occur, seek medical attention immediately.

Water, juice, and formula for children under six months of age should not be prepared with tap water. Bottled water or other water low in nitrates should be used for infants until further notice. Springfield Water Company and the Springfield Health Department are providing free bottled water to families with infants. Water is available between 9 a.m. and 5 p.m. Monday through Friday at the Health Department office at the Town Hall. Water will be provided until the nitrate problem is resolved.

Do not boil the water. Boiling, freezing, filtering, or letting water stand does not reduce the nitrate level. Excessive boiling can make the nitrates more concentrated, because nitrates remain behind when the water evaporates.

Adults and children older than six months can drink the tap water (nitrate is a concern for infants because they can't process nitrates in the same way adults can). However, if you are pregnant or have specific health concerns, you may wish to consult your doctor.

What happened? What is being done?
Nitrate in drinking water can come from natural, industrial, or agricultural sources (including septic systems and run-off). Levels of nitrate in drinking water can vary throughout the year. We'll let you know when the amount of nitrate is again below the limit.

We are investigating water treatment and other options. These may include drilling a new well or mixing the water with low-nitrate water from another source. We anticipate resolving the problem by July 15.

For more information, please contact John Smith of the Springfield Water Company at (602) 555-1212. This notice was prepared and distributed by the Springfield Water Company, 500 Main Street, Springfield.

Please share this information with all the other people who drink this water, especially those who may not have received this notice directly (for example, people in apartments, nursing homes, schools, and businesses). You can do this by posting this notice in a public place or distributing copies by hand or mail.

4 - The population at risk

Information for Spanish speakers

2 - When the violation or situation occurred

1 - A description of the violation or situation

3 - Potential health effects

5 - Whether alternate water supplies should be used

6 - Actions consumers should take

7 - What is being done to correct the violation or situation

8 - When the system expects to return to compliance

9 - Name, phone number, and business address for more information

10 - Standard distribution language

https://www.epa.gov/dwreginfo/required-elements-public-notice-public-water-systems

There are three categories of public notification, known as tiers. Table 1.11 explains each tier and its requirements, and examples of violations that could occur.

Table 1.11 - Public notification tier system

Tier	Requirements	Delivery Method	Examples
Tier 1 (Acute Violation, Immediate Notice)	Any situation which has the potential for immediate harm to human health. The water system has 24 hours to notify its consumers.	Broadcast media outlets such as television, radio, and newspapers. The notices should also be posted in public places or personally delivered to customers.	Fecal coliform, nitrate/nitrite, waterborne disease outbreak, exceedance of Lead Action Level.
Tier 2 (Notice as soon as possible)	Any situation where contaminant levels are exceeded, or water hasn't been properly treated, but does not pose an immediate health threat. The water system should notify consumers ASAP but must do so within 30 days of the violation.	Media, public posting or through the mail.	MCL violations not considered tier 1 violations, monitoring and testing procedure violations, failure to comply with Violation & Enforcement conditions.
Tier 3 (Annual Notice)	Violations that do not have a direct impact on human health. The system has up to one year to provide notice to customers.	Media, public posting, through the mail, or through the Consumer Confidence Report.	Monitoring and testing procedures not requiring Tier 1 or Tier 2 notice, operation under Violation & Enforcement, exceeding an SMCL.

Most contaminants cause health issues over an extended period. Contaminants like coliform, nitrate, and lead and copper are considered immediate health risks, while contaminants like mercury, volatile and synthetic organic compounds, and asbestos have a cumulative effect and may not require immediate public notification.

Consumer Confidence Reports

327 IAC 8-2.1 establishes the purpose and standards for Consumer Confidence Reports (CCR). The federal requirement for CCRs was established in the 1996 amendments to SDWA. All Community water systems must publish an annual CCR.

The CCR should be published no later than July 1st, and must include the following elements:

- The water source(s).
    - Types, such as surface or groundwater.
    - Commonly used name.
    - Location of the body or bodies of water.
- A source of water assessment.
    - Availability of the water.
    - The means to obtain the water.
- Any source of water assessment from the IDEM commissioner.
    - Must include a summary of potential sources of contamination.
    - Must include language provided by the commissioner, or an approved summary written by the operator.
- Definitions for MCL and MCLG
- Information on any Level 1 or Level 2 assessments.
- Terms and definitions, if applicable, for:
    - Action level
    - Maximum residual disinfectant level (MRDL)
    - Maximum residual disinfectant level goal (MRDLG)
    - Treatment technique
- Regulated contaminants, with data displayed in a table.
- Any MCL violations
    - Length of the violation
    - Potential health effects
    - Actions taken to address the violation
- Violations for monitoring and compliance data.
- Telephone number of the owner, operator or designee of the CWS as a source of additional information regarding the report.

If 20% or more of the community residents do not speak English, the report must contain information in the language spoken by those residents. A report must prominently display the following language:

"Some people may be more vulnerable to contaminants in drinking water than the general population. Immuno-compromised persons, such as persons with cancer undergoing chemotherapy, persons who have undergone organ transplants, people with HIV/AIDS or other immune system disorders, some elderly, and infants can be particularly at risk from infections. These people should seek advice about drinking water from their health care providers. U.S. Environmental Protection Agency and Centers for Disease Control guidelines on appropriate means to lessen the risk of infection by Cryptosporidium and other microbial contaminants are available from the Safe Drinking Water Hotline at (800) 426-4791.".

A copy of the report should be delivered directly to each consumer. A good faith effort must also be made to share the report with consumers who do not get water bills, and can include, but is not limited to, any of the following methods.

- Posting on the internet.
- Mailing to postal patrons in metropolitan areas.
- Advertising the availability of the report in the news media.
- Publication in a local newspaper.
- Posting in public places or buildings.
- Delivering multiple copies for distribution in places such as apartment buildings or large private employers.
- Delivery to community organizations.

Communities serving 100,000 or more people must post the current year’s report to a publicly accessible site on the Internet. Copies of the CCR must be retained for a minimum of 5 years.

Permitting

A public water system must obtain an individual construction permit IDEM prior to the construction of a new or existing public water system. A permit is required for the construction, installation, or modification of sources, facilities, equipment, or devices of a public water system including water distribution systems. Construction may not begin until the commissioner has issued a valid permit. Permit Section personnel review permit applications to ensure that the system is properly designed, that adequate water is available, and to verify that the system or equipment complies with all applicable standards and regulations prior to the issuance of the permit.

Public water system construction is governed by the Indiana Administrative Code (IAC) and the Indiana Code. Public water system construction rules can be found at 327 IAC 8-3. The governing statute can be found at IC 13-18-16.

Plans and specifications for the construction, installation, or modification of sources, facilities, equipment, or devices of a public water system must be submitted to the commissioner with a permit application. The plans and specifications must be complete and of sufficient detail to show all proposed construction, changes, or modifications that may affect the sanitary quality, chemical quality, or adequacy of the public water system involved. The applicant shall supply any additional data or material considered appropriate by the commissioner for a review of the plans and specifications.

Plans, specification and related material is to be submitted electronically to the Drinking Water Branch, Permits Section at dwpermits@idem.in.gov. An automatic response will be generated letting the applicant know the application was received. A preliminary review of the application will check for completeness. If determined to be initially complete the applicant will be notified, and the application will be assigned to a review engineer. The public notice of application receipt will be issued at this time. Time frames for reviewing a complete application are 60 days for wells and mains and 120 days for applications related to treatment.

Water main extensions may also be permitted under the general construction permit rules through a notice of intent (NOI) to construct. NOI means a written notification indicating a responsible person has elected to comply with the terms of the general construction permit rule instead of applying for an individual construction permit. The general permit rule applies only to main extensions that meet the requirements of the rule found at 327 IAC 8-3.5. A complete NOI application including fee is to be submitted electronically to dwnoi@idem.in.gov. Plans and specifications are not to be submitted with the NOI application but must be available on site for review by IDEM. The applicant will receive an automated response. If accepted the project may begin 30 days after submitting the application. Any issue with the application will be brought to the attention of the applicant. If those issues can be resolved the NOI will be accepted and construction may begin 30 days later.

IC 13-18-16-1Submission of plans and specifications; issuance of permit; determination

Sec. 1. (a) A permit is required for the construction, installation, or modification of:

(1) sources;
(2) facilities;
(3) equipment; or
(4) devices;

of a public water system, including water distribution systems.

(b) Plans and specifications for the construction, installation, or modification of sources, facilities, equipment, or devices of a public water system must be submitted to the commissioner with a permit application. The plans and specifications must be complete and of sufficient detail to show all proposed construction, changes, or modifications that may affect the sanitary quality, chemical quality, or adequacy of the public water system involved. The applicant shall supply any additional data or material considered appropriate by the commissioner to a review of the plans and specifications.

(c) Unless otherwise provided in rules adopted under section 8(b) of this chapter, plans and specifications must be submitted to the commissioner with the permit application for water distribution systems.

(d) Construction, installation, or modification of a public water system may not begin until the commissioner has issued a permit under subsection (a).

(e) In determining whether to issue a permit under this section, the commissioner shall proceed under IC 13-15.

Practice Exam

1) Which of these is NOT a part of the hydrological cycle?
    a. Transpiration
    b. Evaporation
    c. Standardization
    d. Percolation

2) Which of these is not a surface water source?
    a. Pond
    b. Lake
    c. River
    d. Aquifer

3) Which pathogen is not targeted by the Surface Water Treatment Rule (SWTR)
    a. Malaria
    b. Giardia Lamblia
    c. *Legionella*
    d. *Cryptosporidium*

4) IDEM can set drinking water regulations because it has been granted _________ by the EPA.
    a. Sovereignty
    b. Primacy
    c. Delegation
    d. Funding

5) Which of these is NOT a required qualification to become an operator?
    a. Ability to read and write in English
    b. Ability to perform complex calculations
    c. Strong organizational skills
    d. College coursework

6) Which system classification filters and treats groundwater?
    a. WT1
    b. WT2
    c. WT3
    d. WT4

7) Which treatment grade serves a population of 500 or fewer?
    a. DSS
    b. WT1
    c. WT2
    d. WT4

8) The SDWA was passed in what year?
    a. 1969
    b. 1974
    c. 1999
    d. 2004

9) Laws passed by the Indiana State Legislature are called _________.
    a. Indiana Statutory Laws (ISL)
    b. Indiana Foundational Code (IFC)
    c. Indiana Administrative Code (IAC)
    d. Indiana Secret Code (ISC)

10) ALL Operators are required to have __________________.
    a. An engineering license
    b. A high school diploma or its equivalent
    c. Two years of experience with a utility
    d. Coursework in chemistry

11) The Consumer Confidence Report must be submitted by ____________.
    a. April 1st
    b. July 1st
    c. October 30th
    d. December 31st

12) Exceeding the lead and copper action level requires a ________ public notification
    a. Tier 1
    b. Tier 2
    c. Tier 3
    d. Tier 4

Chapter 2 – Sampling, Monitoring, Lab Analysis, & Record Keeping

Learning Objectives

- List the different types of sampling techniques.
- Identify best sampling practices and sampling sites.
- Know the sample volume and procedure for coliform, lead and copper.
- Distinguish between when a Level I Assessment and a Level II assessment should be performed.
- Compare types of contaminants sampled and methods of sampling for each contaminant.
- Define basic scientific terms.
- Select appropriate glassware for different laboratory processes.
- Differentiate between testing procedures for water quality parameters and process control.
- Explain the importance of good record keeping.

Sampling

Basic Sampling

To ensure water quality, it is important to collect samples from various points in the treatment plant and distribution system. It is important to wash or sanitize your hands and avoid touching surfaces with the mouth or lid of the sample container. Contact with dirty hands or surfaces can contaminate the sample and lead to false positives for some contaminants.

Before obtaining a sample, remove any of the following:

- Strainers
- Aerators
- Hoses

Table 2.1 lists sampling types and techniques. Additional details on coliform and lead & copper sampling can be found in their respective sections.

Table 2.1 – Sample Types and Techniques

Sample Type	Volume	Procedure	Notes
Coliform	100mL	See RTCR (Revised Total Coliform Rule)	Best performed on an unthreaded faucet. Sodium thiosulfate powder in sample container neutralizes chlorine residuals.
Lead and Copper	1L (1000mL)	See LCR (Lead and Copper Rule)	Fill sample container to the shoulder. Ensure that water has had time (6-8 hours) to stand in the pipes.
Grab Sample	N/A	Taken at a single time. Provides a snapshot of water quality at that point.	Best used to test dissolved gases, coliform, chlorine residuals, Disinfection Byproducts (DBPs) and pH
Composite Sample	N/A	Taken at intervals throughout the day. Shows change over time.	Should be stored under 40° F (4° C), but above freezing temperature. Never appropriate for coliform or pH sampling.
Continuous Sample	N/A	Continuously collected at desired points in the treatment system.	May be used to monitor raw source water or chemical residuals in the distribution system.

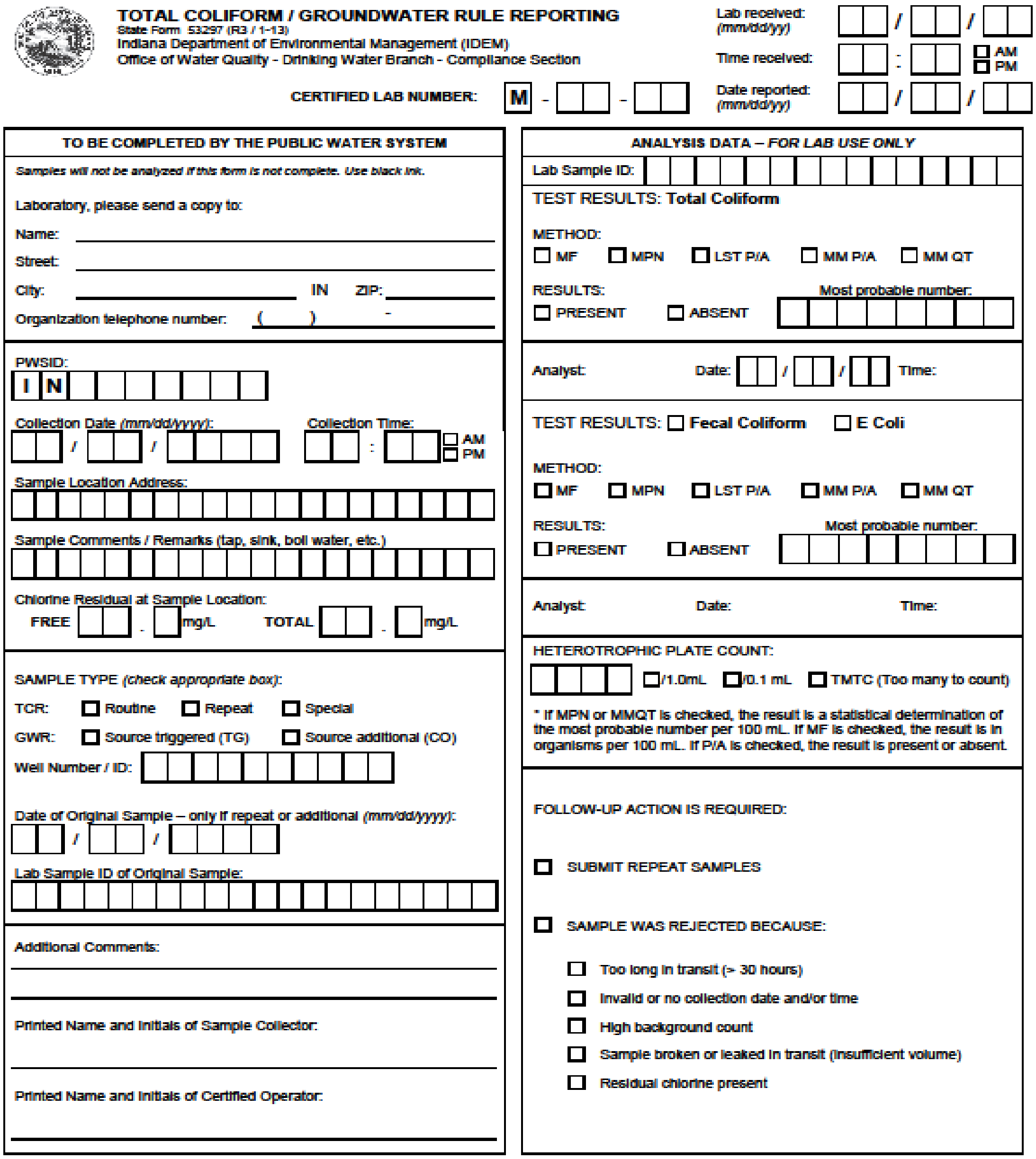
Samples should represent the water system. Avoid sampling in the locations listed below.

- Fire hydrants
- Yard hydrants
- Mop sinks
- Drinking fountains
- Hose bibs
- Storage tanks

When sending the sample to a lab for analysis, it is important to include the correct form for the sample type. All lab report forms can be found on IDEM's website on the forms page: https://www.in.gov/idem/forms/idem-agency-forms/#owq_public_water.

The lab should transmit the completed report directly to IDEM. If you do receive a non-compliance letter regarding your reporting requirements, you have 10 days from the end of the monitoring period to send the report to IDEM directly, or have the lab send the report. The operator is ultimately responsible for providing IDEM with any required lab documentation. Figure 2.1 is the IDEM Coliform Lab Report Form.

Figure 2.1 – IDEM Total Coliform/Groundwater Rule Reporting



TOTAL COLIFORM / GROUNDWATER RULE REPORTING
State Form 53297 (R3 / 1-13)
Indiana Department of Environmental Management (IDEM)
Office of Water Quality - Drinking Water Branch - Compliance Section

Lab received: (mm/dd/yy) / /
Time received: : ☐ AM ☐ PM
CERTIFIED LAB NUMBER: M - -
Date reported: (mm/dd/yy) / /

TO BE COMPLETED BY THE PUBLIC WATER SYSTEM

Samples will not be analyzed if this form is not complete. Use black ink.

Laboratory, please send a copy to:
Name:
Street:
City: IN ZIP:
Organization telephone number: ( ) -

PWSID: I N

Collection Date *(mm/dd/yyyy)*: / /
Collection Time: : ☐ AM ☐ PM

Sample Location Address:

Sample Comments / Remarks (tap, sink, boil water, etc.)

Chlorine Residual at Sample Location:
FREE . mg/L TOTAL . mg/L

SAMPLE TYPE *(check appropriate box)*:
TCR: ☐ Routine ☐ Repeat ☐ Special
GWR: ☐ Source triggered (TG) ☐ Source additional (CO)
Well Number / ID:

Date of Original Sample – only if repeat or additional *(mm/dd/yyyy)*:
/ /
Lab Sample ID of Original Sample:

Additional Comments:

Printed Name and Initials of Sample Collector:

Printed Name and Initials of Certified Operator:

ANALYSIS DATA – *FOR LAB USE ONLY*

Lab Sample ID:

TEST RESULTS: **Total Coliform**

METHOD:
☐ MF ☐ MPN ☐ LST P/A ☐ MM P/A ☐ MM QT

RESULTS: Most probable number:
☐ PRESENT ☐ ABSENT

Analyst: Date: / / Time:

TEST RESULTS: ☐ **Fecal Coliform** ☐ **E Coli**

METHOD:
☐ MF ☐ MPN ☐ LST P/A ☐ MM P/A ☐ MM QT

RESULTS: Most probable number:
☐ PRESENT ☐ ABSENT

Analyst: Date: Time:

HETEROTROPHIC PLATE COUNT:
☐ /1.0mL ☐ /0.1 mL ☐ TMTC (Too many to count)

* If MPN or MMQT is checked, the result is a statistical determination of the most probable number per 100 mL. If MF is checked, the result is in organisms per 100 mL. If P/A is checked, the result is present or absent.

FOLLOW-UP ACTION IS REQUIRED:

☐ SUBMIT REPEAT SAMPLES

☐ SAMPLE WAS REJECTED BECAUSE:

- ☐ Too long in transit (> 30 hours)
- ☐ Invalid or no collection date and/or time
- ☐ High background count
- ☐ Sample broken or leaked in transit (insufficient volume)
- ☐ Residual chlorine present

https://www.in.gov/idem/forms/idem-agency-forms/#owq_public_water

Some samples require a raw water sample and samples from specific points in the system. Figure 2.2 shows a basic site sampling plan, with a routine sample tap, along with upstream and downstream taps.

Figure 2.2 – Simple Site Sampling Plan

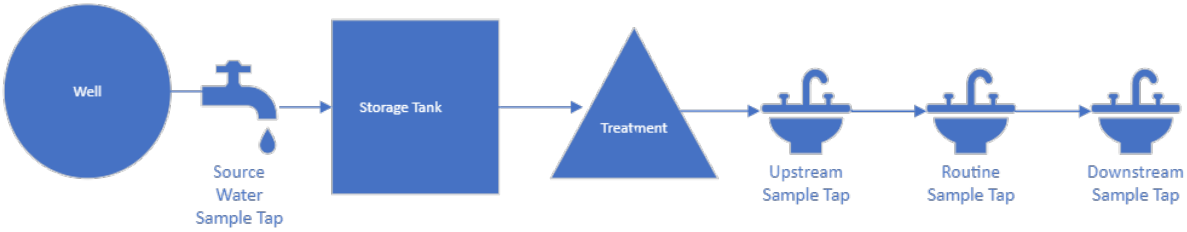
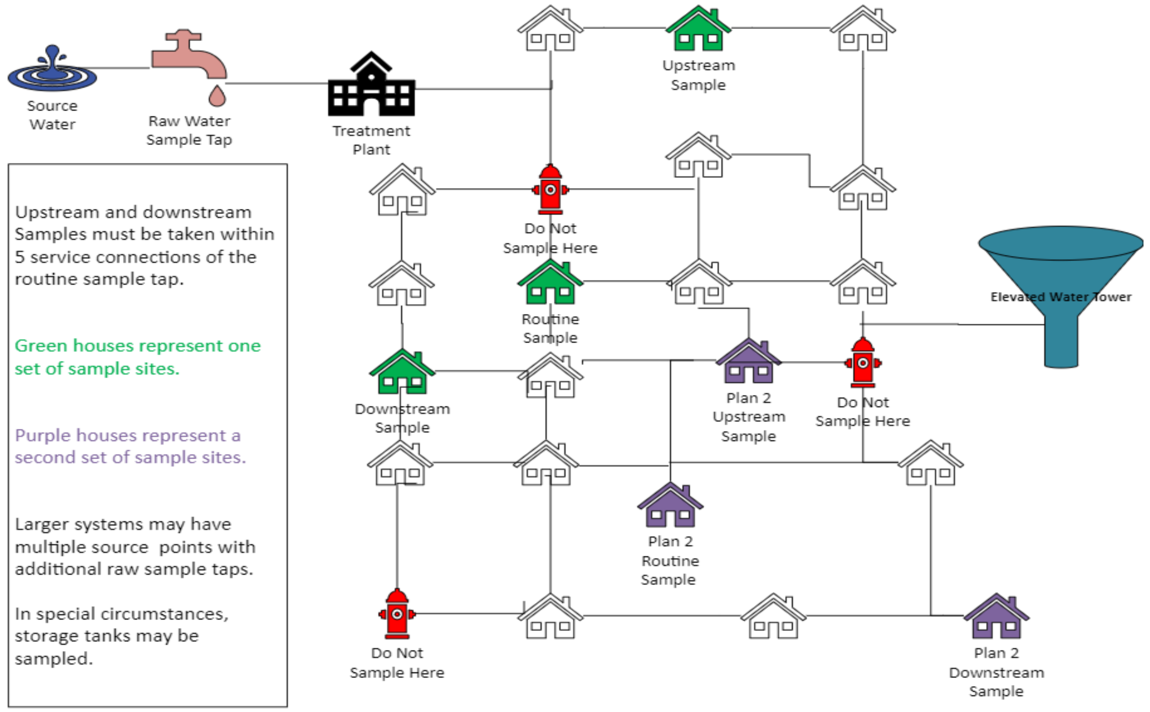


Figure 2.3 shows a site sample plan and an alternate site sample plan. Note that the sample sites are within 5 service connections of the routine sample tap.

Figure 2.3 – Site Sample Plan with Alternate Plan



Upstream and downstream Samples must be taken within 5 service connections of the routine sample tap.

Green houses represent one set of sample sites.

Purple houses represent a second set of sample sites.

Larger systems may have multiple source points with additional raw sample taps.

In special circumstances, storage tanks may be sampled.

When creating a site sampling plan, the upstream and downstream samples must be within 5 service connections of the routine sample tap.

Site Sampling

Samples for contaminants are required under the National Primary Drinking Water Regulations (NPDWRs). Some contaminants that must be sampled under the law include:

- Coliform (bacterial or Bac-T)
- Lead and Copper
- Turbidity
- Nitrates and Nitrites
- Trihalomethanes (THMs)

These contaminants, or chemicals, pose a public health risk, so it is important to submit the legally required samples. Samples should be taken from representative points throughout the distribution system.

Table 2.2 Lists commonly sampled contaminants, proper sample containers, holding temperature, and holding time.

Table 2.2 – Sample Guidelines

Contaminant	Sample Container	Holding Temperature	Holding Time
Biological (Bacteria)	Plastic	4° C – 10° C	30 Hours
Nitrate	Plastic or glass	4° C	48 Hours
Nitrite	Plastic or glass	4° C	48 Hours
Fluoride	Plastic	N/A	1 month
Free Chlorine	Glass	N/A	None, analyze immediately.
Haloacetic Acids (HAA5)	Glass	4° C	14 days
Metals (Lead, Copper, Mercury)	Plastic	N/A	14 days

Samples must be sent to the lab with a chain of custody form, noting the sample type, sampler, and sample location. Some samples require a preservative, such as an acid, to be added, so it is important to transfer the sample to the lab as soon as possible.

To ensure that samples are taken from representative points, submit a site sampling plan to IDEM. IDEM will then either approve the plan or let you know what corrections need to be made.

The number of samples required depends on system classification, population size, and type of contaminant. Some contaminants may qualify for reduced monitoring, if previous samples show low or no contamination for that chemical or compound.

Under the RTCR, if the initial sample tests positive, additional sampling is required. Repeat samples must be taken from the initial sampling tap. Samples must also be taken within 5 service connections upstream and downstream, along with a raw sample from the source. Three routine samples and source water samples from each source should be taken.

IDEM will send correspondence once we are notified of a positive coliform sample, outlining the next steps. Sometimes there are delays between when the lab tests the sample and sends the results to IDEM. If you receive a positive coliform lab report, you should immediately collect repeat samples and not wait for further guidance from IDEM.

If these samples test positive, Level 1 and Level 2 Assessments must be performed. In these assessments, an IDEM approved assessor will evaluate a water system, looking for sources and sites of potential contamination. Triggers for these assessments are outlined below:

- Level 1 Assessment
    - System incurs a positive Total Coliform (TC) sample, followed by a TC positive repeat sample.
    - System takes no repeat samples or an insufficient number of repeat samples following a positive TC sample.
    - An operator can perform a Level 1 Assessment.
- Level 2 Assessment
    - System incurs an *E. Coli* MCL violation (positive sample).
        - An IDEM Representative MUST complete this Level 2 Assessment.
    - The system has a second Level 1 Assessment within a rolling 12-month period.
    - Voluntary Level 2 Assessment.
    - A Level 2 Assessor must be approved by IDEM and certified under the RTCR.

Both Level 1 and Level 2 Assessments must be completed within 30 days of the trigger. Any corrective action noted in the Assessment must also be completed within 30 days.

Monitoring & Contaminants

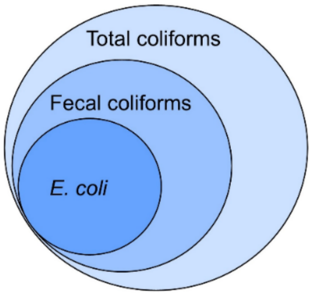
Contaminants

Coliform (RTCR)

The Revised Total Coliform Rule (RTCR) requires testing for total coliforms and *Escherichia coli (E. coli).* Earlier versions of the rule used several different tests. The revision requires a Presence/Absence (P/A) test. If the test is positive for coliform bacteria, additional samples are required. In additional testing, a Heterotrophic Plate Count (HPC) test might be performed.

Total Coliforms may indicate the presence of other harmful bacteria. *E. coli* is a bacterium found in the fecal waste of mammals (i.e. humans, cows, dogs), which can cause acute gastrointestinal illness. Symptoms of gastrointestinal illness include diarrhea, vomiting, and cramps. Figure 2.4 illustrates how *E. coli* and other fecal coliforms relate to total coliforms.

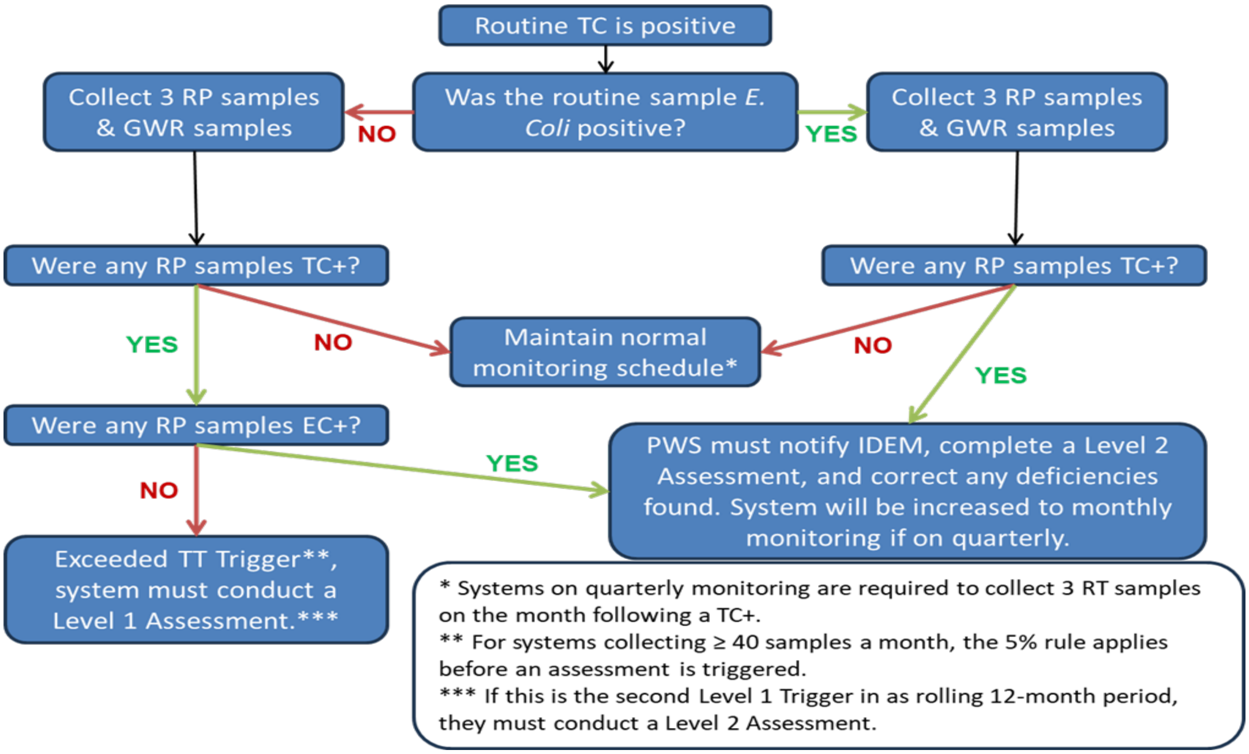
Figure 2.4 – Coliforms



Stock Image

If a sample is positive to total coliform bacteria, then additional testing is needed to determine the presence of *(E. coli)*. Figure 2.5 is a flowchart, showing the actions needed if the presence of coliform is detected in a sample. **If a sample tests positive for Coliform, IDEM must be notified within 24 hours!**

Figure 2.5 – Positive Coliform Sample Flowchart



* Systems on quarterly monitoring are required to collect 3 RT samples on the month following a TC+.
** For systems collecting ≥ 40 samples a month, the 5% rule applies before an assessment is triggered.
*** If this is the second Level 1 Trigger in as rolling 12-month period, they must conduct a Level 2 Assessment.

IDEM Drinking Water Branch – Operator Certification and Capacity Development Section

The population served determines the number of coliform analysis samples required. If a routine sample tests positive for total coliforms, additional samples must be taken from the original tap, along with samples pulled from taps upstream and downstream. The proper coliform sampling procedure is listed below.

- Use a clean faucet that has a dedicated hot and cold tap.
- Flush the system thoroughly, disinfect the faucet, flush again, then take the sample.
- Ensure the lid of the container is facing down, is not placed on a counter, and is not touched.
- Fill the container without splashing or rinsing.
- **Following the sample, a system has thirty (30) hours to get the sample to a lab.**
- **The sample should be kept between 4° and 10° Celsius.**

Nitrate

Nitrates(NO_3-) and Nitrites (NO_2-) are chemicals formed from Nitrogen found in water. They are caused by runoff from agricultural, specifically fertilizers, along with leaking septic tanks, sewage, and the erosion of natural deposits.

Nitrates have an MCL of 10 mg/L and nitrites have an MCL of 1 mg/L. Nitrates react with chlorine to produce nitrites. These nitrites cause a condition in infants called methemoglobinemia, also known as "blue-baby syndrome". This condition interferes with the oxygen carrying capacity in blood, and causes shortness of breath, blue skin, and possible death. Nitrate or nitrite concentrations above the MCL are considered serious health hazards and require a Tier 1 public notification. Treatment for these compounds is done at the treatment facility, but samples should be taken throughout the distribution system.

Grab samples should be taken from source water, just after treatment, and at representative sites throughout the distribution system. Samples should be collected in clean plastic or glass containers, kept between 4° C – 10° C, and preserved with sulfuric acid. Samples should be sent to the lab with the appropriate sample form completed but can be held for up to 28 days.

Lead and Copper Rule (LCR)

The 1986 SDWA amendment banned the use of lead in piping materials. The EPA published its initial regulations on lead (Pb) and copper (Cu) in drinking water in 1991. These regulations are known as the Lead and Copper Rule (LCR). It had revisions in 2000, 2004 , 2007, and 2021. Lead and copper service pipes deteriorate due to corrosion, which causes these metals to dissolve into the drinking water. Both lead and copper can cause adverse health effects.

Lead and copper have an "action level" instead of an MCL. The rule requires that lead and copper levels be monitored at the customer's tap. Below are the sampling steps for lead and copper:

- Sample containers are 1000 mL in volume.
- Pull the sample from an unthreaded, cold-water tap.
- Ensure that the system has not been used for at least 6 hours – first-draw or first-flush.
- Samples are required every six months.

- If a system does not exceed action levels, sample frequency can be reduced to annually.
- If a system does exceed action levels, it must return to biannual sampling.

If the 90th percentile of samples exceeds action levels, meaning if 10% of samples exceed action levels, the water system MUST take action to lower the lead and copper levels. A Tier 1 Public Notification is required, also. Table 2.3 provides information on lead and copper action levels and their health hazards.

Table 2.3 – Lead and copper

Contaminant	Action Level	Health Hazards
Lead	0.015 mg/L (15 ppb)	• Impairs cognitive development in children. • Causes memory problems in adults. • Can cause kidney damage, anemia, and increased blood pressure.
Copper	1.3 mg/L (1.3 ppm)	• Stomach upset, cramps, diarrhea, vomiting. • Kidney and liver damage. • People with Wilson's disease are particularly susceptible.

Chemical & Contaminant

SDWA regulates over 90 contaminants, including the ones listed in previous sections. A complete list of regulated contaminants, their MCLs, and their MCLGs can be found at https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations.

Treatment to remove these contaminants is discussed in future chapters. It is important to draw samples according to the schedule for your system classification. These samples should be drawn from locations representative of the water system's population. Some of the SDWA regulated contaminants include:

- Arsenic (As)
- Synthetic Organic Compounds
- Inorganic Chemicals
- Volatile Organic Compounds
- Radionuclides

For additional sampling guidance, refer to the EPA's *Quick Guide to Drinking Water Sample Collection:* *https://www.epa.gov/sites/default/files/2015-11/documents/drinking_water_sample_collection.pdf*.

Laboratory Analysis

It is necessary to test water to determine things like pH, temperature, hardness, or alkalinity, to effectively treat it. Once treatment is complete, testing is required to determine chlorine residual, pH, turbidity, and other factors, to assess how well processes are working. While some tests may be done in the field, others must be performed in a laboratory, or lab. This is a room or building, containing specialized equipment and chemicals, where tests are performed. Not all systems have an in-house lab and will send samples to an outside lab for analysis. Regulated contaminants must be analyzed by a state approved lab.

Although a system may not have a lab, it can be helpful to know some scientific and laboratory terminology. The resources section includes several textbooks which include chapters on lab analysis, if more in-depth information is needed. Table 2.4 lists some common lab terms and definitions.

Table 2.4 – Lab Terms and Definitions

Term	**Definition**
Element	A substance that cannot be broken down further by chemical methods. Represented on the Periodic Table of Elements.
Atom	The smallest form of an element or a singular unit of an element.
Chemistry	The study of the properties and interactions of elements.
Chemical	Something used in, produced in, or relating to chemistry.
Electron	Negatively charged subatomic particle that surrounds the nucleus (center) of an atom.
Valence	Number of electrons in the outer ring of an atom which determines an element’s reactivity with other elements.
Compound	Combination of elements which makes up a new substance. Can be stable or unstable.
Ion	Element or compound holding a positive or negative charge.
Ionic Bond	Compound which forms from the attraction of positive and negative ions.
Covalent Bond	Chemical bond formed from elements sharing their available electrons.
Acid	Compound that can donate a proton (Hydrogen Ion) or accept an electron pair (Hydroxide Ion) in chemical reactions. Corrosive.

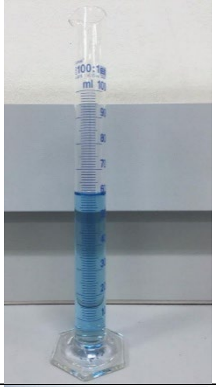
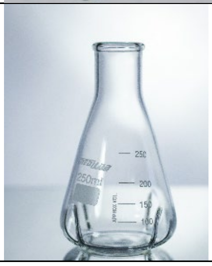
Base	Compound that can accept a proton (Hydrogen Ion) or donate an electron pair (Hydroxide Ion). Caustic.
Salt	Ionic compound that forms in an acid/base reaction. Salts will dissolve in water, dissociating into free ions.
Alkalinity	A chemical property of water that allows it to neutralize acids.
Solution	Liquid mixture where one chemical or compound (solute) is dissolved in a liquid chemical or compound (solvent).
Normal Solution	Solution where the concentration of solute in a solvent measures one gram per liter (1 g/L)
Standard Solution	Solution where the exact concentration of solute to solvent is known, typically expressed in milligrams per liter (mg/L) or micrograms per liter (μ/L).
Titrate	Process of adding a solution of known strength to a liquid, drop by drop, until a certain reaction occurs. Often used to test pH or hardness.

Equipment used for analysis will vary, depending on which tests are being performed. Always refer to any manufacturer's documentation for using any lab equipment and follow the procedures and standards required by your system.

Lab Glassware

The equipment used for testing in a lab varies depending on purpose and scope. The glassware used in a lab is consistent across industries. Lab glassware is made of borosilicate because of its ability to withstand extreme temperature variances. Table 2.5 lists some common glassware used in lab analysis, an image, and their purpose.

Table 2.5 – Lab Glassware

Item	Image	Purpose
Test Tube		Used for mixing, heating, or observing small amounts of chemical.
Beaker		Used for mixing, heating, or observing larger quantities of chemicals. They have volume markers for approximate measurements but are not appropriate for precise measurements.
Graduated Cylinder		Used for measuring precise volumes of liquid. Due to the flanged base, it is not advisable to heat chemicals in a graduated cylinder.
Erlenmeyer Flask		Used heating or observing chemicals and measuring approximate volumes. It’s not as good for mixing as a beaker, since it doesn’t have a pour spout.

Mohr Pipette		Used to measure and deliver precise volumes of liquid. Liquid should be drawn using a suction bulb and should not be drawn using your mouth.

Image Credit – Wikimedia Commons

Water Quality Monitoring

Many different factors are monitored to assess water quality. Hardness, alkalinity, pH, temperature, and turbidity are some of the most common parameters tested at the treatment plant. They may be evaluated from the source water to determine chemical concentration. Testing for these things after treatment is referred to as process control. For example, many plants have online analyzers for turbidity and chlorine residuals, to ensure filtration and disinfection are performing properly. When monitoring process control, the samples should be collected after the treatment is performed and may be taken once all treatment is complete.

Bacteriological sampling is required of any public water system. If your system uses chlorine for disinfection bacteria, the chlorine residual should be checked at the same time as the bacteriological sample is pulled. Lack of chlorine residual could indicate contamination between the treatment plant and the sample site, as an example. The N,N diethyl -1, 4 p-phenylenediamine sulfate (DPD) color test is the most used test for chlorine, both free and total. DPD is added to the sample, and the color is used to determine how much chlorine is in the sample. If a system's disinfectant is consumed before reaching the end of the distribution system, it could be a sign of contamination.

Records

Good record keeping is very important. These records show compliance with drinking water regulations. Non-compliance could result in penalties, or violations. IDEM requires retention of reports as listed in Table 2.6.

Table 2.6 – Record Retention Requirements

Record Type	How Long to Keep
Bacteriological Analyses	5 Years
Chemical Analyses	10 Years
Actions to Correct Violations	3 Years
Sanitary Survey Reports	10 Years
Variance or Exemption	5 Years
Turbidity Results	5 Years
All Lead/Copper Data	12 Years
Monitoring Plans for RTCR, LCR & DBPRs	As long as subject to rule(s)

Courtesy of the EPA

Aside from records required by law, it is helpful to keep maintenance records for equipment, lines and structures in your distribution system. If you do not already have a system map, making records during repair and replacement of lines can help with creating a system map.

Keep detailed records for pumps, motors, and engines used as backup power supply. Records from initial installation and routine maintenance are helpful when troubleshooting problems with these devices. Some helpful records include:

- Make, model, and serial number of the device
- Specifications and capacity
- Warranty information
- Date and location of installation
- Part numbers for parts subject to wear and tear
- Initial test results from the equipment
- Manufacturer's inspection and maintenance schedules
- Contact information for local service representatives

Records of storage tank maintenance, cleaning, and repairs. Tank location should be recorded and included on any system maps. It is good practice to keep records for contractors who perform repairs and maintenance, as well as customer service contact information from equipment manufacturers or local service representatives.

Records can be kept in files on site or can be stored digitally. Manuals, repair purchase orders, and correspondence from the manufacturer or repair personnel may provide details needed for smooth operation to future operators.

Practice Exam

1) Coliform samples should be 100mL and be taken as a __________.
    a. Composite sample
    b. Continuous sample
    c. Grab sample
    d. All the Above

2) Which type of sample is taken at a single point in time?
    a. Grab
    b. Continuous
    c. Composite
    d. All the Above

3) Which of these locations is best for pulling required samples?
    a. Mop sink
    b. Storage tank
    c. Fire hydrant
    d. Dedicated sample station

4) A system has _____ days from the end of the monitoring period to report lab results to IDEM.
    a. 10
    b. 15
    c. 20
    d. 30

5) Sample sites should be within ___ service connections of the routine sample tap.
    a. 2
    b. 5
    c. 10
    d. 15

6) Biological or bacteria samples have a hold time of _____ hours.
    a. 6
    b. 12
    c. 24
    d. 30

7) What material should be used to contain heavy metal samples, like lead and copper?

   a. Plastic
   b. Glass
   c. Metal
   d. Polypropylene

8) Sanitary Survey Reports must be kept for ______ years.

   a. 5
   b. 10
   c. 15
   d. 20

9) A Level 1 Assessment ___________________.

   a. Must be performed by a laboratory
   b. Is a good substitution for routine coliform sampling
   c. Can be performed by an operator
   d. Is triggered when a system tests positive for *E. Coli*

10) Lead was banned for used in piping materials in ________.

   a. 1972
   b. 1986
   c. 1996
   d. 2002

11) Which of these is used for mixing, heating, or observing small amounts of chemical?

   a. Test Tube
   b. Beaker
   c. Mohr Pipette
   d. Erlenmeyer Flask

12) Which of these are NOT a record that should be kept to enhance future operations?

   a. Warranty information on equipment
   b. Specifications and capacity for equipment
   c. Expired chemicals
   d. Contact information for local service representatives

Chapter 3 – Coagulation, Flocculation, and Sedimentation

Learning Objectives

- List the process steps for conventional treatment.
- Describe the equipment used in each stage and explain how it functions.
- Identify common coagulants describe the chemical process of coagulation.
- Explain rapid mixing and identify the equipment used in the process.
- Describe the flocculation process and explain the operational concerns for forming settleable floc.

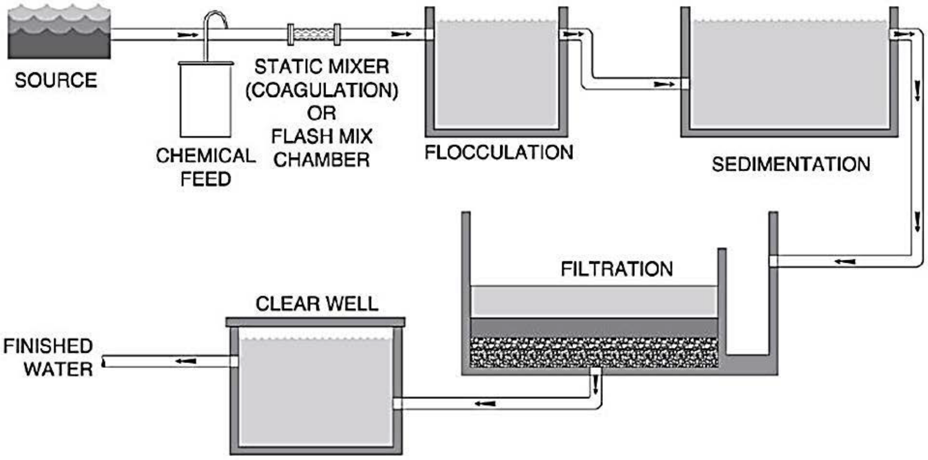
Surface water carries suspended matter. Turbidity is the term used to describe suspended matter in water. While groundwater may also contain turbidity, surface water will have higher levels because it lacks the protection of the ground's surface that an aquifer has. Turbidity consists of large particles that will settle out with gravity, known as settleable solids, and small particles that stay in suspension, known as nonsettleable solids.

The SWTRs contain turbidity requirements because these nonsettleable solids can harbor pathogens like bacteria and protozoans. They may also contain organic matter that can increase disinfection by-products in facilities where chlorine is used for disinfection. The treatment steps taken to remove turbidity from water are known as conventional treatment. These steps include:

- Coagulation – adds chemicals that allow fine particles to group together, called floc
- Flocculation – slowly mixes the water containing coagulants to form larger pieces of floc
- Sedimentation – slows the flow of water, allowing large pieces of floc to settle out
- Filtration – traps smaller floc that was not heavy enough to settle during sedimentation

Figure 3.1 shows the process flow of conventional treatment

Figure 3.1 Conventional Treatment Process Flow



Courtesy of the EPA

Filtration is covered in Chapter 6. This chapter explains the coagulation, flocculation, and sedimentation processes, along with the chemicals and equipment they use.

Coagulation

Coagulation describes the process of chemically altering water to allow nonsettleable solids to collect into settleable clumps, known as floc. A solid is considered nonsettleable if it does not settle to the bottom of a tank within four hours. These particles resist settling either because of size or particle charge. Nonsettleable solids have three classifications:

- Suspended solids
- Colloidal solids
- Dissolved solids

Suspended solids are fine particles that resist settling because of drag forces. A piece of gravel will sink to the bottom of a pool of water in a short amount of time. If that gravel were crushed to dust, the fine particles would resist settling because they have more total surface area than the larger piece of gravel. That surface area increases the drag, allowing the particles to remain suspended.

Colloidal solids include fine silts and color causing particles, bacteria, and viruses. They are invisible to the naked eye, though high concentrations cause discoloration in water. Because they are very fine, they can pass through filters without proper coagulation.

Dissolved solids can be organic or inorganic. Water is a powerful solvent, so dissolved solids include salts, metals, gases, and other chemicals. Some dissolved solids, like heavy metals, some gases, and nitrate, are enforceable under the National Primary Drinking Water Regulations (NPDWR). Total Dissolved Solids (TDS) have a secondary standard of 500 mg/L. Secondary standards are not enforceable, since they do not cause a threat to human health, however they do cause taste, odor, and color problems, known as aesthetic concerns.

Surface water contains more natural organic matter (NOM) than groundwater sources. Much of turbidity, whether colloidal, suspended, or dissolved, is organic. The organic matter generally has a negative charge. A negative electrical field keeps the fine matter in suspension. Zeta potential describes the electrical resistance created by the negative charge.

Van der Waals force is the opposite of zeta potential and describes the attraction of elements in nature with opposite electrical charges. To stay suspended, the zeta potential must be greater than the van der Waals force.

Coagulant chemicals lower the zeta potential of turbidity, allowing the van der Waals force to pull the particles together. In many cases, the coagulant chemical carries a positive charge that neutralizes the negative charge of the fine particles. Aluminum and iron salts are commonly used because they dissolve into cations with a +3 charge, known as trivalent ions. Trivalent ions are between 50 – 60 times more effective in coagulation than bivalent (+2) ions and between 700 – 1,000 times more effective than monovalent ions (+1).

Like any chemical, water temperature will impact the effectiveness of coagulants. In most cases, the warmer the water, the faster the chemical reacts. Aluminum sulfate, commonly known as alum, is one of the most popular coagulant chemicals used. With alum, pH and alkalinity are also critical for a proper reaction and the neutralization reaction occurs within 1-2 seconds under proper conditions, forming aluminum hydroxide ($Al(OH)_3$). Waters low in alkalinity may require additional treatment, such as addition of lime.

Enhanced coagulation describes refining the coagulation process to maximize removal of organic content. Humic and fulvic acids are commonly found in surface waters. These compounds interact with chlorine used in disinfection to form disinfection byproducts (DBPs). With enhanced coagulation, the effective coagulant pH is much narrower than with basic coagulation.

Aside from neutralizing the charge of the turbidity particles, coagulants form a precipitate that the neutralized particles adsorb or adhere to. Throughout the process of coagulation and flocculation, these particles increase in size until they are heavy enough for gravity to pull them out of suspension during the sedimentation phase.

Table 3.1 shows commonly used coagulants, their chemical formulas, and important considerations.

Table 3.1 – Coagulants

Coagulant	Chemical Formula	Important Considerations
Aluminum Sulfate (Alum)	$Al_2(SO_4)_3 \bullet 14(H_2O)$	Temperature, alkalinity, and pH are critical to the reaction. Temperature will impact the optimum pH. Alum consumes 0.5 mg/L of alkalinity for every 1 mg/L used. pH should be between 5.8 – 8.5 for proper floc to form. For enhanced coagulation, to reduce trihalomethanes (THMs), pH should be between 5.5 – 7. Floc formed is gelatinous, more prone to shearing, and more difficult to dispose of than the floc formed using iron salts.
Ferrous Sulfate	$FeSO_4 \bullet 7H_2O$	Effective in more acidic pH range than alum. Forms a stronger floc but is more corrosive. Will cause more color issues when overdosed.
Ferric Sulfate	$Fe_2(SO_4) \bullet 9H_2O$	Also has a wider and lower pH range of effectiveness than alum and produces a strong floc but is corrosive.

Ferric Chloride	$FeCl_3 \bullet 6H_2O$	Wide pH range of effectiveness, strong floc, corrosive.
Aluminum polymers (Poly Aluminum Chloride, Poly Aluminum Sulfate)	*Polymers consist of organic chains, forming large molecules	Wider pH range of effectiveness and lower dosage than alum, forms stronger floc. More expensive than alum.

Note that a ratio of coagulant to water is provided in the chemical formula. Water must be mixed with the coagulant, which forms a slurry to be introduced into the treatment process. This is often accomplished with dry feeders, such as volumetric or gravimetric feeders. The slurry may be stored in a day tank or fed directly into the flash or rapid mixer using positive displacement pump, such as a diaphragm or peristaltic pump.

Alkalinity is a key factor in the effectiveness of any metal salt as a coagulant. Proper dosage is also important. The reaction must complete to form the metal hydroxide and neutralize the zeta potential. Lime and soda ash are often used with coagulants to adjust alkalinity and pH. Other coagulant aids, like weighting agents and polymers, can be added to optimize the process.

Bentonite clay is a common coagulant aid for waters low in turbidity. They add density to the water being treated, allowing stable flocs to form.

Sodium silicate ($NaSiO_3$) is often used with alum as a coagulant aid, increasing the coagulation rate and reducing the alum dosage needed. It must be activated by the operator by adding hypochlorous acid to reduce the alkalinity. Activated silica also produces stronger floc. When using activated silica, dosage is important, since too little will not gel and too much slows floc formation, and can clog filters later in the treatment process.

Polymers are another coagulant aid used to generate stable floc and decrease coagulant dosage. Cationic polymers have a positive charge and are a common additive in the coagulation process. Anionic polymers have a negative charge. They do have applications as a coagulant aid, but since most turbidity has a negative charge, cationic polymers are used more frequently. Anionic polymers are neutral, containing both positive and negative ions. The correct polymer will be dependent on source water quality and other treatment processes. Polymers may also be used as filter aids.

Because the chemical reaction between raw water and coagulants happens so quickly, the initial application must be at the correct concentration. Flash mixing or rapid mixing occurs after the initial reaction. The flash mixing process is short, taking between 30 – 60 seconds. Rapid mixing times over 60 seconds often result in poor floc formation.

Rapid mixing can occur through several methods:

- Hydraulic mixing uses the flow to mix the coagulant by moving through chambers with baffles or throttling valves.
- Mechanical mixing involves paddles, vertical turbines, or propellers which mix the coagulant slurry through the water being treated, like a blender would mix a smoothie. In some cases, an inline blender is used, mixing the slurry in as the water moves through the pipe.
- Pumped blenders send the slurry and water through a pump, where the impeller mixes the slurry and water together and discharges into the flocculation basins. Corrosion within the pump is a concern with this method.

Figure 3.1 shows a static inline mixer as part of the conventional treatment process.

Flocculation

Flocculation describes the process of slowly and gently stirring water after coagulant dosage and mixing to generate larger clumps of settleable floc. Water travels through basins with equipment that stirs the water. The speed of flocculation is critical in the forming of settleable floc.

Flocculation basins may use vertical or horizontal paddles for stirring. Many flocculation basins are tapered, slowing the paddle speed as the water travels through the basin. This is effective because as the floc particles grow larger, the become susceptible to shearing, or breaking apart. By slowing the agitation as the water travels through the basin, the larger pieces stay intact as they move into the settlement basin. The speed of the paddles is known as “tip speed”. By the time water reaches the final set of paddles, the tip speed should be around 1 ft/sec.

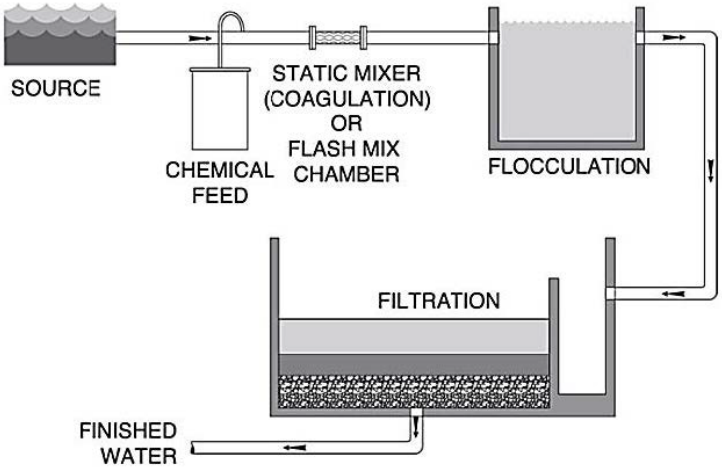
Don't shear your floc!

Generally, the contact time in the flocculation basin should range between 15 – 45 minutes, with a water velocity between 0.5 – 1.5 ft/min. As with any process, the appropriate detention time and water velocity depend on source water quality.

The water velocity through the flocculation basin is controlled by the inlet structure, outlet structure, and paddle speed. Baffles and weirs may also be used to control flow rate. When water travels too quickly through a basin for the process to complete, it is known as “short circuiting”. Short circuiting can occur in the flocculation stage or the sedimentation stage.

In conventional treatment, the goal is to produce large, heavy pieces of floc that will settle out in the sedimentation basins. Some systems with low source water turbidity may use direct filtration. In direct filtration, the sedimentation stage is skipped, and the water moves directly from coagulation to the filtration stage. To avoid clogging the filters, small floc, known as pinpoint floc, is generated during the flocculation stage. Figure 3.2 shows the setup of a direct filtration treatment process.

Figure 3.2 – Direct Filtration



Courtesy of the EPA

In practice, treatment plants usually have multiple flocculation basins. This allows for increased production during peak demand times, as well as avoiding interruption of the treatment process when a flocculation basin is taken offline for cleaning and maintenance.

Jar Testing

Jar testing is the process used to determine chemical dosage, polymer or coagulant aid dosage, mixing time, flocculation time, and paddle speed. With the changes in water quality found in surface water, jar testing is an important part of process control.

In a jar test, multiple samples are collected, and each sample will have a variable changed to view the different outcomes. It is important to only change one variable at a time to effectively control the process. If the goal is to find coagulant chemical dosage, tip speed, temperature, alkalinity, and pH must be the same. If the goal is to find the best contact time, tip speed, dosage, alkalinity, and pH must remain consistent.

Once one variable is found, other variables can be tested. For example, once the optimum coagulant dosage is found using a jar test, another test can be run to find the best polymer dosage.

Sedimentation

The process of sedimentation, also called clarification, allows the large clumps of floc to settle out of the treated water. Water movement is slowed as the flocculated water enters the basin. It slowly travels through the basin, where the clarified water exits. The floc settles at the bottom of the basin, forming sludge. The sludge can be collected for reuse or disposal.

Sedimentation basins can be circular or rectangular. When the flow moves in a straight line through a basin, it is referred to as rectilinear flow. If the flow moves from a center point outward, it is referred to as radial flow. When the flow moves through the basin in a circular pattern, it is referred to as a spiral flow.

In a rectilinear flow basin, the influent water comes in one end and the effluent discharges at the opposite end. It is important to keep a consistent flow rate through the basin. The bottom is frequently sloped towards the inlet end to make sludge collection more efficient and keep sludge from breaking away at the effluent end and moving back into the process.

In spiral and radial flow basins, the influent water comes from the outside edges of the basin, known as a peripheral feed. In spiral flow basins, the influent comes in at an angle, allowing for the circular motion. The bottom of these basins is often angled towards the center, or in a conical shape for easier sludge removal.

Shallow basins and plate and tube settlers may be used to decrease detention time. Shallow basins may have multiple levels to increase surface area. Plate and tube settlers may be constructed inside a shallow basin. Plates or tubes made from fiberglass or steel are placed to angle towards the bottom of the basin. Sediment collects on the plates and tubes. When the angle is greater than 50° - 60°, the settlers are considered self-cleaning, since the sludge will slide down the sloping tube or plate.

All sedimentation basins will have an influent zone, a settling zone, an effluent zone and a sludge zone. The location of these zones will vary based on the design of the basin and aren’t clearly delineated. Operational control often defines the different zones.

Effluent launders collect the clarified water to move it to the filtration process. They are often troughs lined with weirs. The weirs allow for a uniform flow rate as the clarified water flows over the notches and down into the collection troughs. The collection troughs move the water to an outlet pipe which moves water to the filters.

Important considerations in the sedimentation process include:

- Influent speed and turbulence – these should be carefully controlled to avoid stirring sediment from the sludge zone.
- Influent and effluent turbidity to evaluate process control
    - Raw water with turbidity over 10 NTU must have effluent turbidity of 2 NTU or less.
    - Raw water with turbidity of 10 NTU and below must have effluent turbidity of 1 NTU or less.
        - The raw water turbidity measurements apply to the 95th percentile, or 5% of the raw water samples.
- Short-circuiting – where the water travels to quickly through the basin, not allowing for proper detention time.

Figure 3.3 shows an aerial view of a large conventional surface water treatment operation, with flocculation and sedimentation basis, along with catwalks to view the process.

Figure 3.3 – Aerial View of Conventional Treatment Process

Courtesy of Citizens Energy Group

Sludge Removal

The sludge collected during the sedimentation phase must be removed from the basin regularly. If it remains in the basin, it can interfere with processes or harbor harmful bacteria. The rate of sludge removal will depend on which coagulation chemicals are used, the volume of water treated, and the number of sedimentation basins.

Like with flocculation basins, it is good practice to have multiple sedimentation basins, so that a basin is available when one is taken offline for cleaning, maintenance, and sludge removal. Some basins may have rakes or arms that move the sludge to collection basins.

The removed sludge may be reused in the process, but it is often disposed of. It may require chemical treatment or dewatering. Drying lagoons are a low-cost option to dewater sludges. Sludge may be mechanically dewatered using vacuum filtration, belt presses or centrifuges.

Practice Exam

1) The coagulation, flocculation, sedimentation, and filtration process for water treatment is known as _________.
    a. Specialized Treatment
    b. Conventional Treatment
    c. Sanitary Treatment
    d. Rolling Treatment

2) Enhanced coagulation is used to _____.
    a. Lower organic matter in water and prevent harmful disinfection by products.
    b. Lower the amount of coagulant chemical used and save money.
    c. Lower the acidity of water and prevent corrosion in the distribution system.
    d. Lower the flocculation and settlement time and increase production.

3) Which of these is not a coagulant chemical?
    a. Ferric sulfate
    b. Alum
    c. Ferric Chloride
    d. Ozone

4) Zeta potential describes a _______charge.
    a. Negative
    b. Positive
    c. Neutral
    d. Expensive

5) Polymers are ________
    a. Metals
    b. Bases
    c. Organic
    d. Acids

6) What is the optimum pH range for enhanced coagulation with alum?
    a. 5.5 – 7
    b. 6.5 – 8.5
    c. 7 – 9
    d. 9 – 11

7) Weighting agents are used to aid coagulation when waters are low in ________.
   a. Alkalinity
   b. Turbidity
   c. Acidity
   d. Hardness

8) Flocculation describes the process of _________.
   a. Rapidly mixing coagulation chemicals into raw water.
   b. The flight pattern of birds roosting for the evening.
   c. Slow, gentle stirring of water to generate settleable floc.
   d. Adding chlorine at the beginning of the treatment process to precipitate iron and manganese.

9) The detention time in the flocculation basin should be between _______.
   a. 5 – 10 minutes
   b. 15 – 20 minutes
   c. 20 – 60 minutes
   d. 15 – 45 minutes

10) A _____ is used to determine concentration of coagulation chemicals, aids, and polymers
   a. Jar Test
   b. Qualitative analysis
   c. Litmus test
   d. Polygraph test

11) Tube settlers with an angle of 50° - 60° are considered ________.
   a. Ineffective
   b. Self-cleaning
   c. A safety hazard
   d. Efficient

12) ______ are considered a low-cost option for dewatering sludge.
   a. Centrifuges
   b. Belt presses
   c. Drying lagoons
   d. Vacuum filters

Chapter 4 - Specialized Treatment, Fluoridation, Ion Exchange & Aeration

Learning Objectives

- Describe the reasons for removing hardness, iron, and manganese from water.
- Explain the difference between precipitation and sequestration.
- Define corrosion and explain the different methods of controlling it.
- Identify the MCL and SMCL for fluoride, and the chemicals used for adding fluoride to water.
- Describe how activated carbon works and identify the constituents it removes.
- List the constituents that make up hardness and examine the methods used to remove it.
- Compare lime/soda ash softening and ion exchange and identify the benefits and drawbacks of each method.
- Describe the process of aeration and list the constituents it removes.

Specialized Chemical Treatment

Specialized chemical treatment describes chemicals added to water for purposes other than disinfection. Chemical precipitation and sequestration of iron and manganese are examples of specialized chemical treatment. Other types of specialized chemical treatment include corrosion control, fluoridation, taste and odor control, and softening. The sections below describe these processes.

Some chemicals use a dry feeder and others use a pump. Details about chemical feed pumps and dry feeders can be found in Chapter 5.

Iron and Manganese Removal

Iron (Fe) and manganese (Mn) are found in both groundwater and surface water but are more common in groundwater because the dissolved oxygen (DO) in surface water reacts with them to form insoluble compounds. Manganese may be more of a concern for surface water systems than iron. They cause no known health problems in the concentrations found in groundwater and surface water; however, they produce unwanted colors, tastes, or odors, known as aesthetic problems.

There is a secondary standard, known as a Secondary Maximum Contaminant Level (SMCL) for both iron and manganese. The SMCL for iron is 0.3 mg/L and for manganese it is 0.05 mg/L. Concentrations above this may cause taste and odor problems, staining of clothing, or staining and clogging of fixtures. Failure to remove iron and manganese will not impact public health, but it will lead to customer complaints. Iron will cause reddish-brown or brown stains and manganese will cause black stains. They promote the growth of certain bacteria, especially iron, which promote slime growth in pipes and fixtures.

Iron and manganese have insoluble stable forms, and soluble unstable forms. The ions for the insoluble and soluble compounds are changed during oxidation-reduction reactions and will have a different valence in each form. A full explanation of valences and oxidation-reduction reactions is beyond the scope of this manual. For more detailed information regarding valences and oxidation reduction reactions, refer to *AWWA Principles and Practices of Water Supply Operations: Basic Science Concepts and Applications, Fourth Edition.*

The insoluble forms of iron and manganese are ferric (Fe^{+3}) and manganic (Mn^{+4}). Anaerobic (without oxygen) conditions in aquifers and deep parts of surface water reduce these ions to a soluble form. Certain bacteria can also reduce the stable ferric and manganic forms.

Once reduced, they become ferrous (Fe^{+2}) and manganous (Mn^{+2}) and are dissolved in the water. These forms are unstable. When they encounter oxygen or an oxidizing agent, they are oxidized into their insoluble, stable forms. There are two methods of controlling iron and manganese in water:

- Precipitation
- Sequestration

Precipitation describes the process of oxidizing dissolved, unstable iron and manganese and chemically converting them to their insoluble, stable form. It is the most common process for iron and manganese control. Once the metals are oxidized, they form a precipitate that can be settled or filtered out of the water.

Sequestration describes the process of keeping the iron and manganese in their soluble forms. This is done using chemicals such as polyphosphates. Sequestering delays the oxidation reaction, keeping iron and manganese in solution longer.

More details for each of these methods are described in the sections below.

Precipitation

Precipitation is the most common method of controlling iron and manganese in groundwater. Multiple processes are available to precipitate iron and manganese from water:

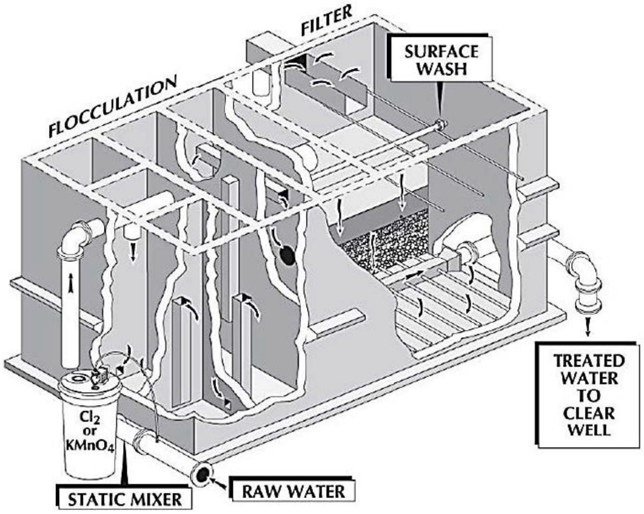
- Chemical Oxidation
    - Chlorine
    - Potassium or Sodium Permanganate
- Aeration
- Ion Exchange

Chemical oxidants, like chlorine and potassium or sodium permanganate, are fed as the water enters the treatment facility. Potassium permanganate ($KMnO_4$) and sodium permanganate ($NaMnO_4$) should be fed as early as possible in the process to allow completion of the reaction. They will turn the water purple when initially fed, and can result in purple or pink water, if the reaction is not complete.

Oxidants like these interact with ferrous and manganous forms in solution and oxidize them into their ferric and manganic forms. Once in the insoluble form, they are removed using sedimentation basins and filtration. Sedimentation is particularly important for raw water with high concentrations of iron and manganese, because allowing sedimentation prior to filtration will increase the length of filter runs and help avoid quickly fouling them.

Jar tests are used to determine the best process and chemical dosage. pH adjustments to the raw water may be necessary to optimize the oxidation reaction. It is also important to allow enough detention time for the reaction to be completed. Systems may use a combination of chlorine and potassium permanganate to ensure optimum iron and manganese removal. Figure 4.1 shows the chemical oxidation and filtration process.

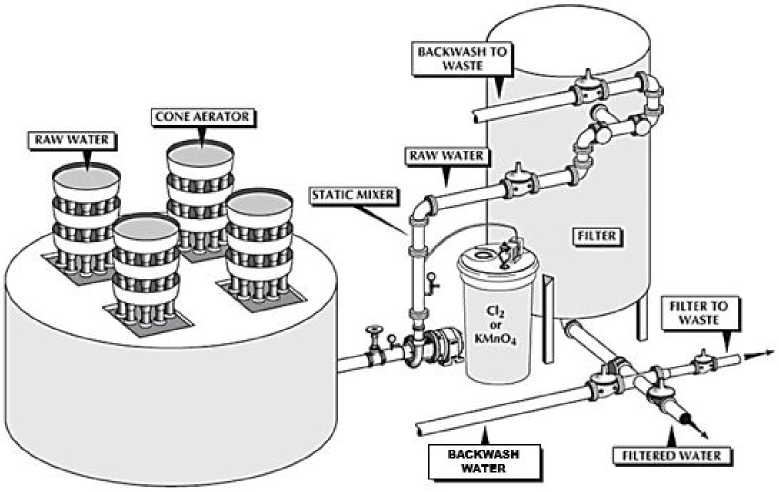
Figure 4.1 – Oxidation and Filtration



Courtesy of the EPA

Aeration is the process of manually adding dissolved oxygen to raw water. The raw water feed is pumped into an aeration tower, where oxygen enters the water as it moves down through the tower. Once aeration is complete, the precipitates are settled and filtered out. Aeration may be used in combination with chemical oxidation. Figure 4.2 shows the configuration of an aeration system with a chemical oxidant. More details on types of aerators and the other contaminants they treat can be found later in the chapter.

Figure 4.2 – Aeration and Filtration



Courtesy of the EPA

Ion exchange can be used for iron and manganese removal but has limited application in large-scale water treatment. It may be appropriate for concentrations below 2 mg/L, in waters with very low or no dissolved oxygen (DO) content.

While ion exchange is limited in its application for iron and manganese removal, it is highly effective in other treatment processes. Information on using ion exchange for softening and nitrate removal is covered later in this chapter.

Sequestration

Sequestration describes the process of adding a chemical to raw water to keep iron and manganese in their soluble form. In this process, iron and manganese are not removed from the water and continue through the treatment and distribution process in their soluble form.

Because it does not remove them from the water, sequestration is only appropriate for iron concentrations under 1 mg/L and manganese concentrations below 0.3 mg/L. Unlike oxidation, sequestration is not dependent on other water quality parameters, like pH, however higher water temperature can reduce effectiveness when combined with aeration or chlorination.

Polyphosphates or sodium silicates are the chemicals used to sequester iron. It is important to apply sequestering agents before the raw water is exposed to oxygen or disinfectants, since oxygen and chlorine will convert the dissolved iron or manganese into their insoluble forms.

In addition to sequestration, polyphosphates are also used in corrosion control. If the raw water iron and manganese concentrations are low enough for sequestration, this can be an added benefit. Sequestration typically has low-cost chemicals and equipment and does not require as much space as oxidation and filtration methods.

It is important to note that polyphosphates provide nutrients for bacteria and algae. Because of this, slime and algal growths can happen in the distribution system, causing taste and odor problems. If it is discharged into surface waters, it can lead to algal growth, requiring additional treatment. Polyphosphates degrade over time and will eventually revert to orthophosphates.

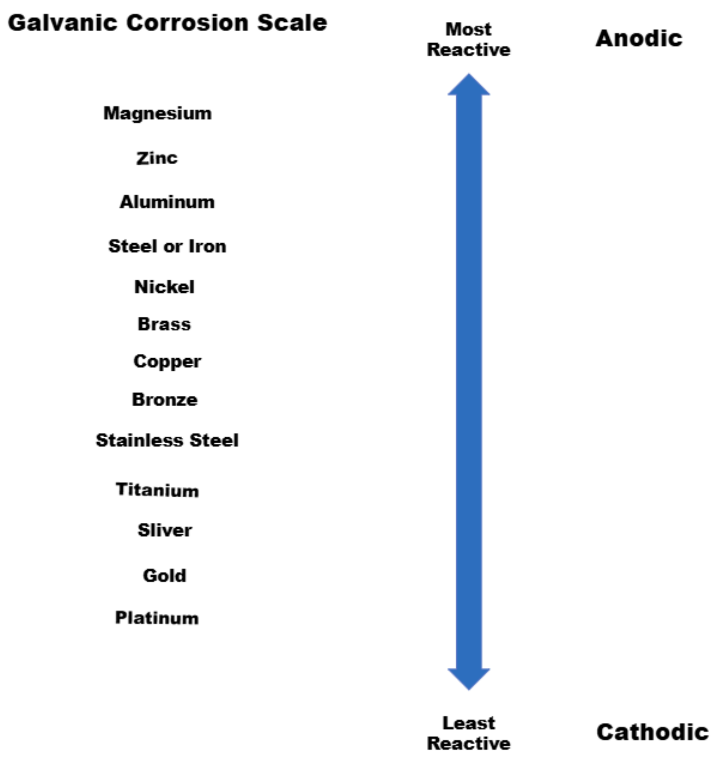
Corrosion Control

Corrosion describes the gradual breakdown of a substance or material. It can be caused by electrochemical reactions, like oxidation-reduction reactions (redox) and galvanic reactions. Steel tanks, and copper, lead, steel, or cast-iron service lines are particularly susceptible to corrosion. These metals can precipitate from the pipes into the water supply, causing health concerns or customer complaints.

Corrosion promotes the growth of bacteria, slimes, and biofilms by creating tubercules in the pipes. These can lead to customer complaints regarding color, taste, and odor. The treatment facility is responsible for ensuring non-corrosive, stable water is being sent to the distribution system

Pipes and storage tanks may use non-chemical methods to control corrosion. Understanding galvanic corrosion and ensuring proper metals are used in tanks, pipes and fittings are examples of non-chemical methods used. Figure 4.5 shows the galvanic scale of metals.

Figure 4.5 – Galvanic Corrosion Scale



A pipe can be galvanized by coating it in zinc. Because zinc is an anodic, reactive metal, it will corrode faster than the pipe will. Cathodic protection is the process of running an electrical current through water or soil in contact with metal and attaching sacrificial anodes to the metal structure. Cathodic protection provides a high level of corrosion control.

Anodic metals are more reactive, and cathodic metals are less reactive. When these metals work with electricity, it helps concentrate the corrosion on sacrificial anodes and not the metal being protected. When these metals are combined without a sacrificial anode, the electrical activity will cause the anodic metal to deteriorate.

Water Chemistry and Chemical Corrosion Control

Several chemical properties of water influence corrosion and corrosion control:

- Alkalinity
- pH
- Total dissolved solids (TDS)
- Dissolved gases
- Hardness

Alkalinity describes water's ability to neutralize acids and its buffering capacity. Buffering capacity describes the ability to resist changes in pH when an acid or base is added. Alkalinity consists of carbonate (CO_3^{2-}), bicarbonate (HCO_3^-), and hydroxide (OH^-) ions. It is important to note that alkalinity does not equal pH. Water with high alkalinity has a greater capacity to neutralize acid.

pH is a measure of hydrogen ion activity. A pH below 7 indicates that something is acidic. 7 is considered neutral, and anything above 7 is basic. The pH scale ranges from 0 to 14, with 0 being a strong acid and 14 being a strong base. The pH of raw water impacts how it interacts with chemical treatment and disinfection. In water, any pH below 7 is considered corrosive. It is often a good practice to maintain a pH between 7.5 to 8 in finished water.

Total dissolved solids (TDS) is a measure of minerals in solution. The dissolved solids take the form of ions and are referred to as salts. In solution, these minerals take on a positive or negative charge and will increase the electrical conductivity of water. This increased electrical activity can lead to corrosion.

Dissolved gases, like oxygen and carbon dioxide, interact with water and its dissolved solids. Dissolved oxygen (DO) will combine with dissolved solids, like calcium and magnesium, which form scale on the inside of pipes and protect them from corrosion. Carbon dioxide forms a weak acid in water, contributing to corrosion.

Hardness refers to a special class of total dissolved solids. Calcium and magnesium are the main components of hardness, though iron, manganese and strontium can also cause hardness. These ions in solution will form a precipitate when they encounter dissolved gases in water, forming scales. These scales coat the inside of pipes, adding protection against corrosion.

Chemical Corrosion Control

Chemical treatment for corrosion control is known as stabilization. In this process, chemicals are added to either raise the pH or control scale. Stabilization can have the following impacts on finished water and the distribution system:

- Improves water quality by removing metals that cause taste and odor problems, or promote bacterial growth
- Maintains distribution equipment in the system by extending the life of pipes and valves
- Assists in meeting state and federal compliance regulations by keeping lead and copper below action levels.

If water is acidic (pH below 7), pH and alkalinity can be chemically raised to prevent corrosion. Lime, or calcium hydroxide ($Ca(OH)_2$), is frequently used to raise the pH of water. Lime may also be used for softening. Caustic Soda, or sodium hydroxide (NaOH), may also be used if the water has enough hardness and alkalinity.

Soda ash, or sodium carbonate (Na_2CO_3), may be added with lime or caustic soda to increase alkalinity. Sodium bicarbonate ($NaHCO_3$) may be used in place of soda ash, since it will increase the alkalinity but have less impact on the pH.

Before adding either of these chemicals to water for stabilization, it is important to perform a jar test to evaluate the chemical dosage.

When softening is used in treatment, many systems will reduce, but not eliminate, the constituents that make up hardness. This is because the scale they form can provide protection from corrosion to the interior of pipes.

If water does not have adequate hardness or alkalinity, corrosion inhibiting chemicals can be used. These chemicals form a protective film on the interior of pipes. Polyphosphates and silicates are the main chemicals used to inhibit corrosion. These same chemicals are also used to sequester iron and manganese. Zinc Orthophosphate and sodium zinc phosphate are the main chemicals used to inhibit corrosion. These chemicals provide nutrients for biological growth and may cause taste and odor problems. If chemical disinfection is used, corrosion control chemicals should be added post-clearwell, since they may react with disinfection chemicals .

Each of these treatment techniques has benefits and drawbacks. Table 4.1 details how many corrosion control techniques work, how effective they are, and potential drawbacks.

Table 4.1 – Corrosion Control Chemicals

Treatment	**Effectiveness**	**Drawbacks**
Lime/ Lime and Soda Ash or Sodium Bicarbonate	Effective in water with low pH and hardness. Provides good protection against corrosion in copper, lead, asbestos cement, galvanized, and steel pipe.	Oversaturation can lead to calcium deposits in the distribution system.
Caustic Soda/ Caustic soda and Soda Ash or Sodium Bicarbonate	Effective in waters with low pH and adequate hardness to protect against corrosion of lead pipes.	Requires more alkalinity and hardness than lime and may cause pipe tuberculation if Caustic Soda is used on its own.
Phosphates (Sodium zinc phosphate, zinc orthophosphate)	Forms a film on the pipe interior and may provide protection to asbestos cement pipe. At higher pH, often achieved by adding lime, they are effective to control corrosion in lead, copper and steel pipes.	Not effective at low pHs. May cause slimes and bacterial growths inside of pipes.
Silicates	Work best with high pH and high alkalinity water, typically produced with lime softening.	May interact with other processes and cause pitting in copper and steel pipes.

The techniques listed above either raise the pH or work with water that already has high pH or alkalinity. In some cases, lowering the pH may be necessary to reach the optimum treatment or finished water pH. When it is necessary to lower the pH, carbon dioxide (CO_2) can be added. Carbon dioxide forms a weak acid when it dissolves in water. Lime softening often requires the addition of carbon dioxide for recarbonation. Sulfuric acid may also be used to decrease pH.

Fluoridation

Fluoride is a naturally occurring element. Most drinking water sources in Indiana contain natural fluoride. The natural fluoride concentration is generally between 0.1 -0.2 mg/L, though it may be higher or lower, depending on the amount of fluoride in surrounding soil.

In the early 20th century, through observation and controlled studies, it was discovered that fluoride prevented tooth decay. In the 1950's, public water systems began adding fluoride to increase the concentration when natural levels were too low to improve dental health. A major impact of adding fluoride was improving dental health in young children and teenagers.

Fluoride in concentrations above 4 mg/L can cause brown staining on teeth. This is called dental fluorosis. Because it can have negative impacts on health at higher concentrations, fluoride has both an MCL and an SMCL. The MCL for fluoride is 4.0 mg/L. The SMCL is 2.0 mg/L.

In 2015, the Indiana Department of Health and Human Services (IDOH) reduced the recommended fluoride level in drinking water to 0.7 mg/L. This concentration is high enough to prevent tooth decay, but low enough to avoid dental fluorosis.

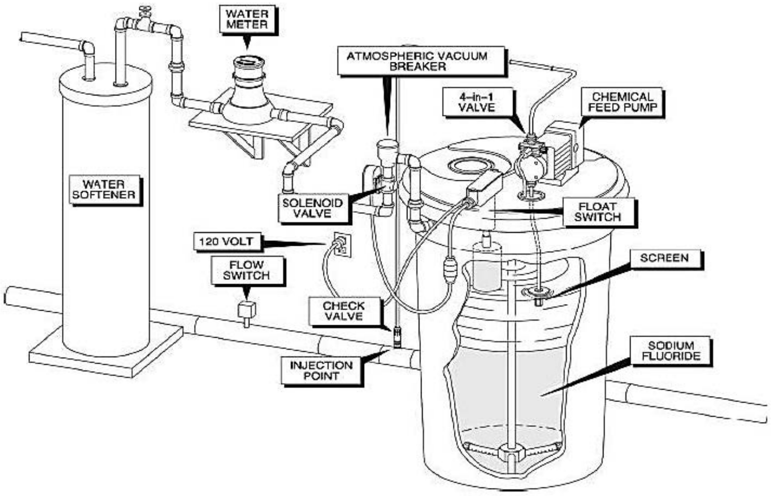
Fluoridation is not mandated in Indiana. IDOH strongly encourages addition of fluoride in water systems whose source water is low in natural fluoride. A system adding fluoride must monitor If a system's naturally occurring fluoride content is above 4.0 mg/L, treatment to remove it is necessary. Systems that add fluoride to water must, at a minimum, test fluoride concentration every day. Continuous monitoring is recommended.

Table 4.2 provides details on the chemicals used to add fluoride to drinking water. Figure 4.6 depicts the chemical feeder for fluoridation, called a saturator.

Table 4.2 – Fluoridation Chemicals

Name	**Chemical Formula**	**% Available Fluoride**	**Benefits**	**Drawbacks**
Sodium Silicofluoride	Na_2SiF_6	60%	Powder form is less expensive to ship.	Limited solubility.
Hydrofluosilicic Acid (Hydrofluorosilicic Acid, HFS, Silly Acid)	H_2SiF_6	79%	Most used. Easy-to-feed liquid.	Expensive to ship. Highly corrosive.
Sodium Fluoride	NaF	45%	Easier to feed than other powdered forms of fluoride.	High cost. Uses bulky saturators.

Figure 4.6 – Fluoride Saturator



Courtesy of the EPA

It is important to note that these chemicals are dangerous, and that careful handling is important for operator's safety. Proper protective clothing and equipment should be used when handling fluoride chemicals. If a system uses fluoride, they should provide safety training for storage and handling.

Activated Carbon

Activated Carbon is used to control taste and odor problems in groundwater not resolved by iron and manganese removal, and to remove organics. It is particularly effective at removing synthetic organic compounds (SOCs) and disinfection byproducts (DBPs).

Activated carbon works through adsorption. In adsorption, the contaminants stick, or adhere, to the adsorption agent. The adsorption ability of activated carbon will depend on the surface area of the particle. Particles with more surface area will have higher adsorption capacity.

Granular Activated Carbon (GAC) is often used as a filter medium. In a filter, it is layered on top of sand or gravel. More details on activated carbon as a filter medium can be found in the Filtration chapter.

A contactor, which is a closed pressure tank, is another way to use GAC. Groundwater may also be passed through an open bed of GAC.

Powdered Activated Carbon (PAC) can be fed directly into water through a dry feed of a slurry. Dry feeders use a hopper and gravity to add PAC to water. Dry PAC is dangerous to handle, so a slurry is an alternate way to feed PAC.

Carbon is activated by exposing it to high heat in the presence of steam. It may be made from wood, coconut shells, coal, or other organic materials. After time, the adsorption capabilities of the activated carbon become exhausted. Once it is exhausted, it should be regenerated or replaced.

Softening and Ion Exchange

Softening describes the treatment process used to remove hardness. Ion exchange is a form of softening which is also used to remove some chemical contaminants, like nitrate. To understand the process of softening, you must understand the property of hardness in water.

Hardness is a physical property of water. It is caused by minerals like calcium and magnesium dissolving in water as it moves through soils with high mineral content, or rock formations like limestone. Hardness can be temporary or permanent. The term "hard water" comes from the fact that it is hard to produce soap lather in water with high mineral content. When water is considered "soft", it produces soap scum.

Temporary hardness is made of carbonate and bicarbonate ions. Permanent hardness is made of chlorides and sulphates. Temporary hardness is also called carbonate hardness, while permanent hardness is called non-carbonate hardness. Temporary hardness can be boiled out of water, but permanent hardness cannot.

Hardness is measured as calcium carbonate, but there are other mineral salts that make up hardness in water. Table 4.3 lists several common compounds that form hardness, their chemical formula, and whether they are temporary or permanent forms of hardness.

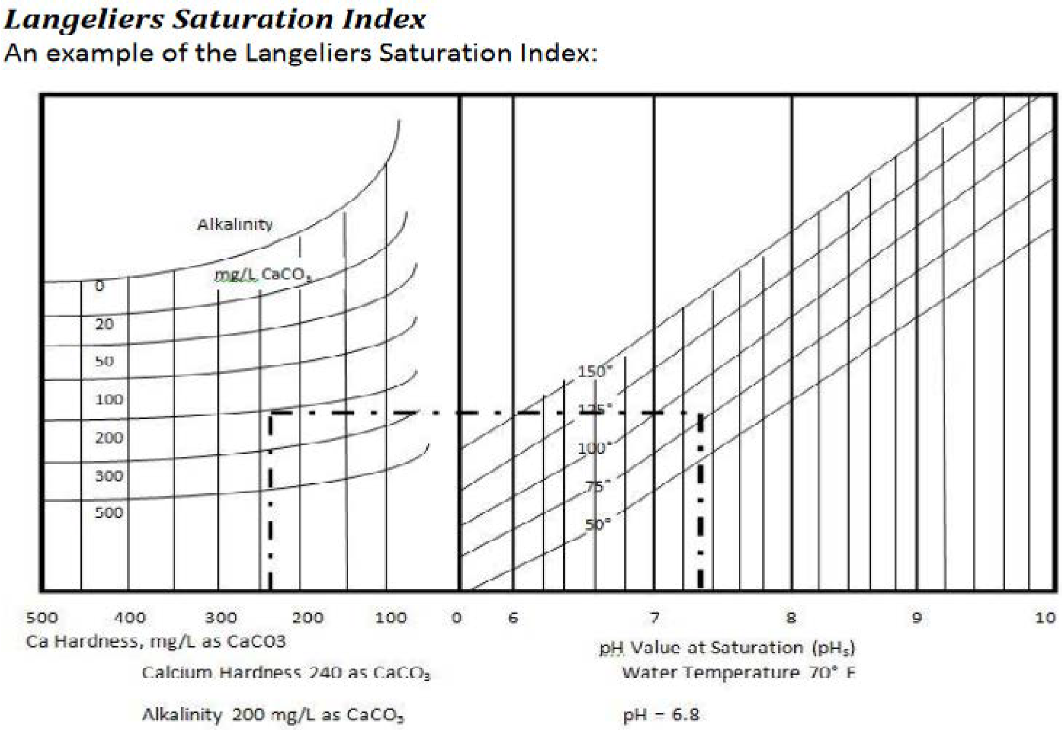
Table 4.3 – Compounds That Form Hardness

Compound	Chemical Formula	Type of Hardness
Calcium Carbonate	$CaCO_3$	Temporary
Calcium Bicarbonate	$Ca(HCO_3)_2$	Temporary
Magnesium Carbonate	$MgCO_3$	Temporary
Magnesium Bicarbonate	$Mg(HCO_3)_2$	Temporary
Calcium Sulfate	$CaSO_4$	Permanent
Calcium Chloride	$CaCl_2$	Permanent
Magnesium Sulfate	$MgSO_4$	Permanent
Magnesium Chloride	$MgCl_2$	Permanent

Calcium and Magnesium ions are cations, meaning they have a positive charge. The positive charge for each of these ions is +2, so they may be noted as Ca^{+2} and Mg^{+2}. When softening with lime or lime and soda ash, the process causes these soluble metal salts to form insoluble precipitates, which are settled and filtered out. Ion exchange uses salt, usually sodium chloride (NaCl), to exchange the sodium cation for the calcium or magnesium ion.

The Langelier's Saturation Index is used to evaluate hardness in water. A positive Langelier's index number indicates water that is scale forming. A negative Langelier's index indicates water that is corrosive. A zero on the Langelier's index is considered neutral. A full explanation of the Langelier's index is beyond the scope of this manual. Figure 4.7 is a graph of the Langelier's index. Table 4.4 shows hardness ratings for water based on the Langeliers index.

Figure 4.7 – Langelier's Saturation Index



Courtesy of the AWWA

Table 4.4 – Hardness measured on mg/L of Calcium Carbonate

Hardness Range	Classification
0 – 60 mg/L	Soft - Corrosive
61-120 mg/L	Moderately Hard
121 – 180 mg/L	Hard
181 +	Very Hard

Courtesy of the EPA

There are other methods used to measure and evaluate hardness in water, but the Langelier's Saturation Index is the industry standard. Classifications by Sawyer & Briggs or Ficke consider water with calcium carbonate content of 300 mg/L and above very hard. Refer to your system's guidance for the appropriate tool to measure the hardness of your source water.

Lime Softening

The process of lime softening raises the pH of water to a level where hardness constituents, like calcium and magnesium, form a precipitate that settles out. There are two forms of lime, anhydrous, or quick lime (CaO) and slaked lime, or hydrated lime [$Ca(OH)_2$]. Anhydrous means "without water", so CaO is formed by heating limestone until it forms a powder. Slaked lime is formed by adding water to anhydrous lime. This reaction generates heat, with temperatures above 160° F once the reaction is complete.

When lime is applied, it is mixed with water to form a slurry. The slurry is then fed into the water near the beginning of the treatment process. Lime softening is a pH dependent process. For calcium to precipitate in lime softening, the pH must be above 10. For magnesium to precipitate, the pH must be above 11.

Once the precipitate is formed, the water will move to a flocculation tank to form larger pieces, which will then settle out as the water moves to a settlement basin. After the floc settles, the water then moves to the filter, where any remaining precipitate is filtered out. The precipitate that is removed forms a sludge. This sludge is removed from the sedimentation tanks and must be dewatered, or dried, and disposed of.

Because of the high pH required to form precipitate in lime softening, the pH must be lowered, during the process of stabilization, or recarbonation. This is usually done by adding carbon dioxide (CO_2), which forms a weak acid in water.

Because of the need for flocculation, settlement, stabilization, and sludge removal, lime softening is more common in surface water facilities, since many of those processes are already required under the Surface Water Treatment Rule and its revisions. Several groundwater facilities in Indiana have adopted a fluid bed reactor process to remove hardness from their source water.

Fluid bed reactors use lime pellets inside of a tank. As the water passes through the tank, the pH increases to form precipitates, which then form pellets of hardness inside the reactor bed. This process allows the treatment plant to skip any clarifying stages and dewaters the residue, which is collected in a hopper or basin.

Chemicals other than lime may be used to lower the pH of water to form hardness precipitate. Soda Ash (Na_2CO_3), or sodium carbonate, is often used in combination with lime especially when there is noncarbonate hardness. Sodium Hydroxide (NaOH), or caustic soda, may be used in place of lime/soda softening. Caustic soda may be easier to use and handle than lime and will remove both carbonate and noncarbonate hardness.

Lime softening will not remove all hardness from water. A certain amount of lime scale may be desirable for corrosion control. Lime softening is lower in cost than ion exchange, however the chemicals used in the lime softening process are more hazardous than those used in ion exchange. Caution should be used when handling and storing these chemicals.

A few key points to keep in mind with lime, lime/soda ash, and caustic soda treatment:

- Water’s alkalinity will increase 1.28 mg/L for every mg/L of lime added.
- Twice the lime required to remove calcium bicarbonate is needed to remove the same amount of magnesium bicarbonate.
- Soda ash dosage is based on the noncarbonate, or permanent hardness.
- If the pH is not adjusted using recarbonation, filters must be monitored for carbonate deposits.
- Lime will increase pH, harness and alkalinity.
- Slaked lime becomes less soluble as temperature increases.
- Lime softening is the most effective method for removing hardness.
- The lime/soda ash process can generate water with 30 – 40 mg/L hardness.

Ion Exchange

Ion exchange describes the process of transferring ions from one dissolved salt, or ionic compound to another. It can be categorized as either cation exchange or anion exchange. In cation exchange, the positively charged ions in a solution with two or more salts will be switched with each other. In anion exchange, the negatively charged ions will be switched. Ion exchange uses a brine of sodium chloride (NaCl) inside of a tank filled with resin.

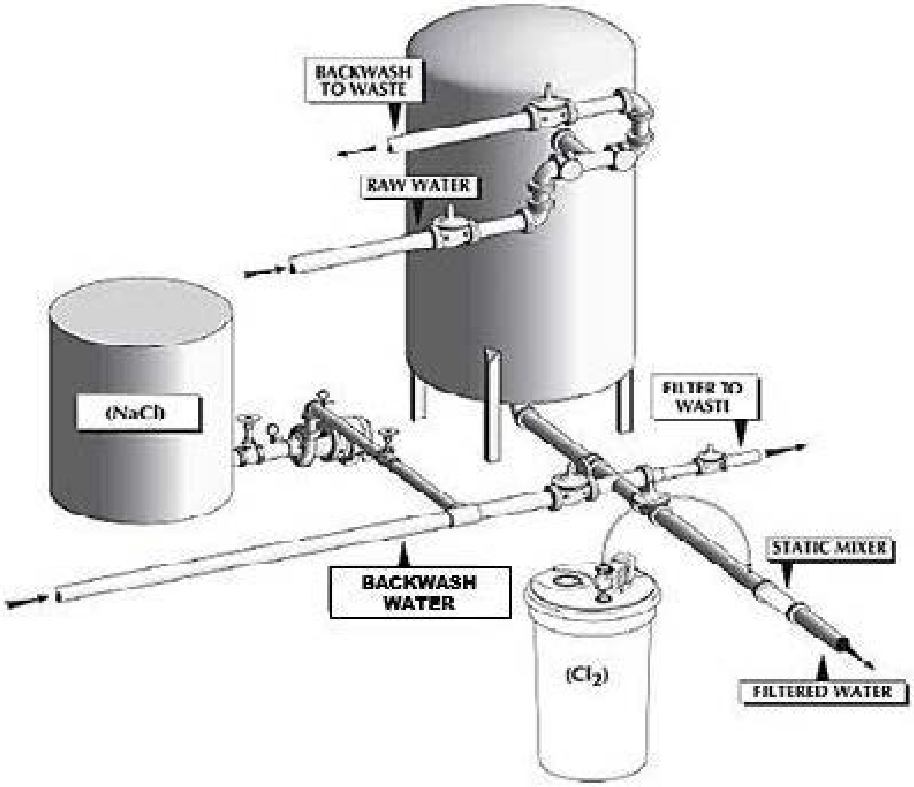
In addition to removing hardness, ion exchange is also used to remove arsenic (in the form of arsenate) and nitrate. Because these contaminants are commonly found in groundwater, and due to the involved process with traditional lime softening, ion exchange is used more frequently in groundwater systems. Ion exchange is a costly process, so this must be considered when assessing treatment techniques.

Unlike lime softening, ion exchange will remove all hardness from water. Since soft water is aggressive, or corrosive, many systems will blend softened water with unsoftened water to achieve slightly scale forming finished water. Ion exchange hardness constituents are not measured as calcium carbonate but are instead measured in grains per gallon (GPG). One GPG equals 17.1 mg/L.

Softeners act similarly to filters, but instead of having sand or gravel inside, they contain a resin. The resin contains zeolites, which allow the cations to “park” in the resin and wait for cations from the water’s hardness to pass through for exchange. In the past, resin was made of silica, which has natural zeolites. Current technology uses a polystyrene resin. A concentrated brine of sodium chloride is added to the softener. The sodium ions cling to the resin. When the hard water encounters the resin, the calcium and magnesium ions change place with the sodium ions held in the resin. Some units feed from the top, like a gravity filter, while others feed from the bottom. The pressure downflow softener is one of the most common systems currently used.

Figure 4.8 shows an ion exchange softening configuration that might be found in a treatment facility. The collage in figure 4.9 shows, from left to right, the fiberglass tanks, pump, and pipes. Fiberglass is often used in softening systems because it resists corrosion.

Figure 4.8 – Ion Exchange



Courtesy of the EPA

Figure 4.9 – Fiberglass Softening Tanks, Pump, and Pipes

Once all the sodium ions in the resin have been exchanged with calcium and magnesium, it is considered exhausted and must be regenerated with the concentrated sodium chloride brine. The waste is then pumped out of the softening tank.

With any type of softener, there are four basic steps involved in the process:

1) Service – this is the part of the process when the softening happens.
2) Backwash – this part of the process loosens waste from the resin.
3) Brine – this part of the process is where the concentrated sodium chloride brine is pumped into the softener.
4) Rinse – after the brine has enough contact time, a clear rinse is used to remove waste.

Figure 4.10 shows a control panel for a softening unit along with the valves and pipes that move water through the four stages.

Figure 4.10 – Control Panel, Valves, and Pipes of a Softening Unit

During the service stage, the hard water passes through the resin, where the calcium and magnesium cations are exchanged for sodium ions. Exchange resin prefers higher valences, so with a valence of +2, the resin will attract those ions and release the sodium ion, which has a valence of +1.

If aluminum cations are present in the water, those will take preference over the +2 calcium and magnesium ions, since aluminum has a valence of +3. Earlier in the chapter, recall that insoluble iron has a valence of +3 and manganese +4, so the resin will also exchange with these ions before exchanging with calcium and magnesium.

The capacity of a softener will depend on the TDS content in the water, its size, and the surface area of the resin bed. Water with high TDS or high sodium content may leak hardness. Many use a strong acid cation exchange resin, which has a softening capacity range of 20,000 – 30,000 grains of hardness removal per cubic foot of resin. The capacity of a softening unit can be calculated using the hardness of the water and the capacity of the specific resin type and size used in the unit.

The backwash stage reverses the softening process. Clear water is pumped in the opposite direction of the treatment flow direction. The water should be pumped in slowly, at a steady rate, and the bed should expand between 75% - 100%. During the expansion, the backwash water shears and scrubs the resin bed. During this process, it is normal to lose some resin. A steady loss of resin may indicate a problem with the resin bed. It is important to monitor the backwash effluent for resin loss for this reason.

The brine stage, also called the regeneration stage, is where the concentrated brine solution is pumped into the softening unit to recharge the resin. The sodium cations from the brine will replace the calcium and magnesium cations trapped in the resin from the softening process. The concentration of the brine is an important factor in the regeneration stage. Rock salt or pebble salt should be used. Large blocks of salt may take too long to form a solution and table salt is too fine for softening applications. Ice melt and road salt are not sodium chloride salts and should not be used in softening.

The optimum brine concentration typically ranges from 10% - 14%. It takes between 5lbs – 15lbs of salt to reach the proper concentration. A weak brine solution will require more contact time to regenerate the resin. A brine solution that is too highly concentrated can break up the resin by causing osmotic shock. Refer to manufacturer's documentation and your system's procedures for preparing the correct brine concentration for your softening units.

The flow rate of the brine should be roughly 1 – 2 gallons per minute (gpm) for the first 55 minutes. After that, the rate should be increased to 3 – 5 gpm for approximately 5 minutes. The slow flow allows for contact time within the resin, while the faster flow rate flushes the calcium and magnesium from the resin for drainage.

During the rinse cycle, a clear rinse is applied to the softening unit. This rinse removes the calcium and magnesium that was dislodged from the resin bed and removes it to a waste discharge unit. The rinse process usually lasts between 20 – 40 minutes. It is important to monitor the rinse process to ensure the waste is properly removed. Otherwise, the effluent from the softening unit may have a salty taste. Sampling and tasting the wastewater near the end of the rinse cycle will help with monitoring taste issues.

The waste from the rinse stage must be properly disposed of, since it will be highly concentrated with calcium, magnesium, and chloride ions. This waste is often corrosive and can be toxic to the environment. It is often held in a tank and slowly released into the sanitary sewers to avoid upsetting any biological processes at the wastewater treatment plant. With a National Pollution Discharge Elimination System (NPDES) permit, the treatment facility may be able to slowly discharge the brine waste into receiving waters. Follow your system guidance when discharging softener waste.

Aeration

Aeration describes the process of adding oxygen to the water mechanically, or manually. Chemicals are not used in aeration. Instead, the water is passed through an aeration device. Aeration is typically the first process performed at a treatment facility. It is used to remove the following constituents:

- Iron and Manganese
- Volatile Organic Compounds
- Carbon Dioxide
- Radon
- Hydrogen Sulfide
- Methane
- Taste and odor problems

Aeration systems can be described as either water-into-air, air-into-water, or a combination of both. Water-into-air aerators spray droplets of water into vessels filled with air, while air-into-water aerators intro introduce air bubbles into volumes of water. Combination aerators make use of both water-into-air and air-into-water. Table 4.5 lists the different types of aerators, which type they are, how they work, and the constituents they are best used to remove.

Table 4.5 – Aerators and Their Features

Aerator	Type	How it Works	Removes
Cascade	Water-into-air	Water splashes down through a series of steps or rings. The aeration occurs as the water splashes down from one tier to the next.	Iron Partially removes dissolved gases.

Cone	Water-into-air	Works similarly to a ring cascade aerator. Water enters at the top through a vertical feed pipe. The water then travels down through cone-shaped nozzles at the bottom of each tier of pans until it reaches the bottom.	Iron Partially removes dissolved gases.
Slat-and Coke-Tray	Water-into-air	A set of stacked trays that contain wooden slats are filled with pieces of coke that measure around 6 inches. Air is introduced as the water splashed down through the trays. The sides may slope into splash aprons which protect the water from freezing and wind loss.	Iron Partially removes dissolved gases.
Draft	Water-into-air	Has a similar configuration to slat-and-coke, or cone aerators. They can have either a positive draft or an induced draft. Positive drafts contain a blower which introduces air at the top of the tower. Induced drafts pulls air upwards from vents at the bottom.	Dissolved gases Iron and Manganese.

Spray	Water-into-air	Spray nozzles connected to a pipe manifold provide a fine mist of water droplets within the structure. Sprays are often combined with cascade and draft aerators. The spray created a fountain effect and spray aerators may be found as a decorative feature at the water plant.	Increases dissolved oxygen Iron and manganese
Packed Tower	Water-into-air	Also known as air strippers, packed tower aerators consist of a tank, known as the tower, which is filled with packing material in irregularly shaped materials. Plastic, ceramic, and stainless steel are materials frequently used for packing.	Volatile Organic Compounds (VOCs)
Diffuser	Air-into-water	Steel or concrete tank containing piping, manifolds, and diffusers that distribute compressed air within the water. The bubbles from the diffusers rise through the water, creating a mixing pattern. They can use either a centrifugal or positive-displacement blower.	Increases dissolved oxygen to remove tastes and odors.

Draft Tube	Air-into-water	Often used to add aeration to an existing basin or tank. A draft tube connected to a submersible pump is inserted into the tank or basin. The pump pulls air through the tube, and a turbine impeller distributes it through the water in the tank.	Increases dissolved oxygen More common in wastewater treatment.
Mechanical	Combination	Mixing blades are mounted to the end of a vertical shaft and powered by a motor. Surface aerators, submerged aerators, combination mechanical aerators, and draft-tube surface aerators are the four types of mechanical aerators.	Dissolved gases Iron and Manganese Tastes and odors
Pressure	Combination	Compressed air is continuously added to a tank or pressurized pipe.	Iron and Manganese

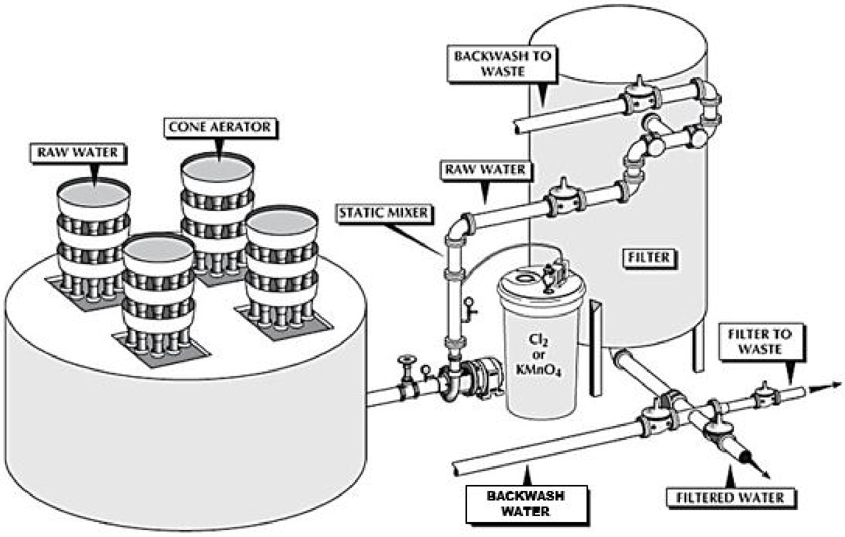
Because they are typically the first treatment step, aerators are located outside of the main treatment plant. Raw source water is pumped into the aerator at the top of the structure, with water moving down through the aerator. Figure 4.11 shows the exterior structure of a cascade aerator.

Figure 4.11 – Cascade Aerator

Packed tower aeration is the best available technology for removing VOCs. Henry’s constant is used to calculate the volatility of a substance. Henry’s law states that amount of gas dissolved in a liquid is directly proportional to the partial pressure of the gas above the liquid. The formula to calculate the factor for a given gas is $C = kP$ where C is solubility of the gas at a given temperature for a liquid, k is Henry’s constant, and P is the partial pressure of the gas. To remove a volatile compound from water with packed tower aeration, the factor of the gas should be greater than 100. Packed tower aeration relies on an air-to-water ratio to effectively remove VOCs. The minimum ratio should be 25:1. The maximum ratio should not be more than 80:1.

Aerators in general rely on the principle that the more surface area available in water, the greater the ability is to increase the dissolved oxygen content. Figure 4.12 shows a cone aerator feeding to a filter at a treatment facility. Figure 3.13 shows the components of a dual aerator-filter unit. Clockwise from top left: Air intake, lengthwise top view, air intake and sprayer access, filter, and sprayer.

Figure 4.12 – Aeration and Filtration



Courtesy of the EPA

Figure 4.13 – Combination Aerator/Filtration Unit Components

Practice Exam

1) Which of these chemicals is used to sequester iron?
   a. Lime
   b. Zinc orthophosphate
   c. Potassium permanganate
   d. Sodium chloride

2) When adding an oxidant to precipitate iron and manganese, where should it be applied during the treatment process?
   a. Early in the treatment process, as close to the source as possible
   b. After disinfection, but before filtration
   c. During filtration
   d. As it is leaving the treatment plant

3) Which of these metals is more reactive (anodic)?
   a. Gold
   b. Platinum
   c. Titanium
   d. Zinc

4) Which of these is NOT a method of corrosion control?
   a. Galvanic protection of pipes
   b. Water stabilization
   c. Increasing dissolved oxygen
   d. Cathodic protection

5) The SMCL for fluoride is _____.
   a. 1.0 mg/L
   b. 2.0 mg/L
   c. 3.0 mg/L
   d. 4.0 mg/L

6) Activated carbon is NOT an effective treatment method for which contaminant?
   a. Synthetic Organic Compounds (SOCs)
   b. Disinfection Byproducts (DBPs)
   c. Nitrates
   d. Tastes and odors

7) The main constituents of hardness in water are _______.
    a. Iron and manganese
    b. Calcium and magnesium
    c. Boron and argon
    d. Potassium and sodium

8) ________ and ____ cause temporary hardness, while sulfates and chlorides cause permanent hardness.
    a. Aldehydes and ketones
    b. Esters and alcohols
    c. Phenols and hydrocarbons
    d. Carbonates and bicarbonates

9) The chemical formula for quick lime is _____.
    a. CaO
    b. $NaOH$
    c. $NaCl$
    d. HCl

10) To precipitate magnesium using lime softening, the pH must be above ___.
    a. 7
    b. 9
    c. 11
    d. 13

11) The final step in the ion exchange process is ______.
    a. Service
    b. Backwash
    c. Brine
    d. Rinse

12) Aeration will remove all the following constituents except for ________.
    a. Iron and Manganese
    b. Synthetic Organic Compounds (SOCs)
    c. Radon
    d. Volatile Organic Compounds (VOCs)

Chapter 5 – Disinfection & Disinfection Byproducts (DBPs)

Learning Objectives

- Define a pathogen and list the types of pathogens that require disinfection, along with the illnesses they cause and their symptoms.
- Compare the different methods of disinfection and assess their effectiveness against the different types of pathogens.
- Identify the methods of chlorine disinfection, compare the disinfection strength of each, and describe the benefits and drawbacks of each one.
- List the parts of a chlorinator and describe the function of each.
- Examine the safety precautions used when working with chlorine gas and list best safety practices.
- Compare UV and Ozone disinfection to chlorine disinfection and examine the benefits and drawbacks.
- Explain the formation of disinfection byproducts, list the maximum contaminant level for each type, and compare the methods of prevention and removal.
- Identify the methods and equipment used for chemical delivery and select the appropriate system for common chemicals used in disinfection and treatment.

Disinfection

Disinfection describes the process of inactivating pathogens. A pathogen is an organism that causes disease, illness, or infection. Note that all pathogens are contaminants, but not all contaminants are pathogens. Chemicals and compounds are non-biological contaminants that require removal. The term disinfection only applies to contamination caused by living organisms.

Viruses, bacteria, and protozoa are examples of pathogens. They are invisible to the naked eye and require a microscope for viewing. Sizes will range based on species, but protozoa are larger than bacteria, and bacteria are larger than viruses. They may also be referred to as microorganisms. Table 5.1 lists pathogens commonly found in water, their type, source, and the human health impacts they cause.

Table 5.1 – Waterborne Pathogens

Pathogen	**Type**	**Source**	**Illness**	**Symptoms**
Cryptosporidium	Protozoan	Human and animal feces	Gastrointestinal	Diarrhea, vomiting, and cramps
Giardia lamblia	Protozoan	Human and animal feces	Gastrointestinal	Diarrhea, vomiting, and cramps
Escherichia coli (E. Coli)	Bacterium	Human and animal feces	Gastrointestinal	Diarrhea, vomiting, and cramps
Legionella	Bacterium	Occurs naturally in water, multiplies in heating systems	Legionellosis, Legionnaire's Disease	Respiratory problems, Severe pneumonia in the case of Legionnaire's disease
Norwalk, norovirus, rotavirus	Viruses	Human and animal feces	Gastrointestinal	Diarrhea, vomiting, and cramps
Picornaviridae HAV	Virus	Human body fluids and feces	Hepatitis A	Yellowing of skin and eyes (jaundice), fatigue, diarrhea, joint and abdominal pain
Salmonella Typhi	Bacterium	Contaminated food and water, close contact with someone who carries the bacteria.	Typhoid Fever* *Typhoid fever is uncommon in the U.S.*	Fever, stomach cramps, constipation or diarrhea, headache.

The table above is not a comprehensive list of waterborne diseases. While vomiting and diarrhea may not seem life threatening, they can lead to death in vulnerable populations including infants, young children, the elderly, and those with compromised immune systems. Disinfection is a critical step in providing safe drinking water.

Chlorine

Chlorine is the most common disinfectant and has been used in water treatment since the early 1900's. It is a greenish-yellow gas that is heavier than air. Chlorine gas is compressed or cooled to reach its liquid state and stored in metal tanks. It is fed into water as a gas or a liquid from these tanks using chemical pumps. It works by penetrating the cell wall of pathogens and attacking critical enzymes within the cell.

Chlorine gas is highly toxic in low concentrations. The maximum residual disinfectant level is 4.0 mg/L or ppm, and the minimum disinfectant residual is 0.2 mg/L or ppm. It is subject to many safety regulations. Because of this, alternative chlorine compounds or other disinfection methods may be preferred to chlorine gas. Table 5.2 lists the forms of chlorine used in water treatment, their common names, chemical formulas, available chlorine content, and properties.

Table 5.2 – Chlorine and Chlorine Compounds

Name	**Common Name**	**Chemical Formula**	**Percent Available Chlorine**	**Properties**
Chlorine Gas or Liquid Chlorine	Chlorine Gas	Cl_2	100	Greenish-yellow, strong odor
Calcium Hypochlorite	High Test Hypochlorite (HTH)	$Ca(ClO)_2$	65 – 70	Solid white powder or tablets, strong odor
Sodium Hypochlorite	Bleach	$NaClO$	5 – 15	Liquid solution with a slight yellow or greenish color and a strong odor.

CHLORINE GAS

Chlorine gas comes in 150lb cylinders, one-ton containers, or railroad cars (for high production systems). Since chlorine is 2.5 times heavier than air and will expand to roughly 460 times its volume when it is not contained, chlorine cylinders and ton containers are very heavy and must withstand high internal pressure. They are usually made of steel.

A 150lb chlorine cylinder weighs roughly 250lbs – 285lbs and is stored and transported in a vertical position. A one-ton container weighs about 3700lbs and is transported and stored in a horizontal position. 150lb chlorine cylinders should be moved with hand trucks and one-ton containers are moved with a lift or hoist mounted to a rail. They should be firmly secured during transportation and storage. Chains are used to secure 150lb cylinders and trunnions secure ton containers. Figure 5.1 shows a one-ton chlorine container, the rack and trunnions, and the lift for moving it. Figure 5.2 shows 150lb Chlorine cylinders attached to a chlorinator with a safety valve shutoff actuator.

Figure 5.1 – One-Ton Chlorine Container

Figure 5.2 – 150lb Chlorine Cylinders and Chlorinator

It is important to control temperature when storing and feeding chlorine, since high temperatures will cause the liquid chlorine inside the containers to expand as it transitions to its gaseous state. It should not be stored with any other chemicals. Empty containers will still contain some chlorine, so they should also be restrained and stored away from other chemicals.

While chlorine gas is not combustible, it does support combustion and can replace oxygen in combustion reactions. It is reactive with many different chemicals, including ammonia, hydrocarbons, and other flammable materials. When chlorine gas encounters water it forms an acid. Because of its reactivity, chlorine gas is stored and fed from isolated rooms, with a gas-tight panel separating them from the rest of the facility. The access door should open to the outside, be equipped with panic hardware, and remain locked. The wall separating it from the plant or the access door must have a window for viewing interior conditions.

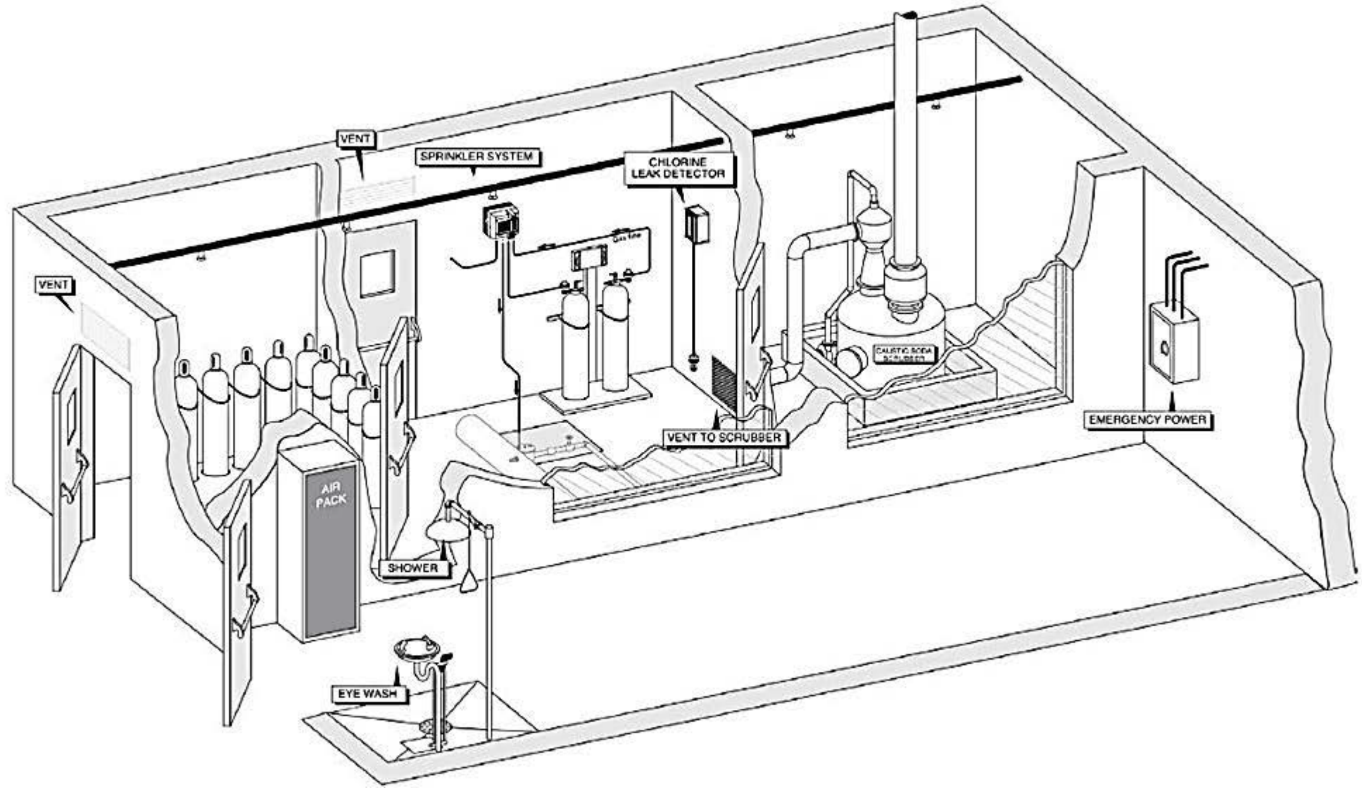
Chlorine rooms require a ventilation system with exhaust intake located near the floor and discharge at the top of the room. Air intake should be opposite the exhaust intake. Air within the room should be exchanged every 1 -4 minutes. The light switch and the switch for the exhaust system should be located outside of the room.

Chlorine feed equipment and empty containers must be separated within the room. Figure 5.3 shows an example of 150lb cylinders being stored, with the full containers separated from the empty ones.

Figure 5.3 – Chlorine Cylinder Storage

The temperature range within the room should stay between 65° and 70° F. The room must contain a panic button and an eyewash and shower station, in case of human exposure. Figure 5.4 shows an example of the interior of a chlorine room.

Figure 5.4 – Chlorine Room



Courtesy of the EPA

Chlorine gas is fed into the water using a chlorinator. These mechanisms may differ somewhat, but will contain the following four components:

- Scale
- Valves and piping
- Chlorinator
- Injector or diffuser

Cylinders and containers in use are placed on a scale. The scale serves two purposes: recording the amount of chlorine used and calculating the amount of chlorine remaining in the container. Containers are marked with a tare weight. This is the weight of the container when it is empty. Weight measurements are also used in operational planning for maintaining adequate chemical supplies. Figure 5.5 shows two one-ton containers on a scale, hooked up to a safety valve shutoff actuator.

Figure 5.5 – Ton Container with Safety Valve Shutoff Actuator

Valves and piping connect the container to the chlorinator. A valve is the connection point for the piping. Note that a one-ton container will have two valves: one to feed liquid and one to feed gas. A chlorinator may be directly mounted to a tank. Multiple tanks may be connected to the chlorinator using a manifold. This allows more than one tank to feed the chlorinator and makes replacing empty tanks easier. Flexible tubing made of copper, rated at 500 psig, connects each container to the chlorinator or the manifold. The supply lines will have additional valves to isolate leaks in the line. Figure 5.6 shows a valve controller. Figure 5.7 shows chlorinator piping.

Figure 5.6 – Chlorine Valve Controller

Figure 5.7 – Chlorinator Piping

Chlorinators are used to measure, meter, and control the flow of gas from the cylinder into the water. They can connect directly to the container or be contained in a free-standing cabinet. Chlorinators work using a vacuum system. Table 5.3 lists components in a common chlorinator and their purpose. Figure 5.8 is an example of a rotameter.

Table 5.3 – Chlorinator Components

Chlorinator Component	**Purpose**
Gas Inlet	Allows gas to enter the chlorinator
Vacuum Regulator	Maintains constant vacuum condition
Vacuum Gauge	Shows vacuum measurement on the chlorinator
Rotameter	Shows chlorine feed rate
Differential Regulating Valve	Regulates chlorine gas pressure
Diaphragm Check Valve	Regulates the vacuum, which adjusts the feed rate
Vacuum Relief Valve	Reduces vacuum conditions by allowing air to enter the system
Manual Feed Rate Adjuster	Used to manually adjust the feed or override automatic feed.

Figure 5.8 – Rotameter

Table 5.3 is not comprehensive. Please refer to your system's documentation for specifics on your feed system. Most systems are equipped with an automatic switchover system. This provides a back-up chlorinator, should the primary system fail.

The chlorine gas travels through the chlorinator, where it is mixed with water. This solution is then dispersed into the water being treated through an injector or a diffuser. The gas passes through a venturi nozzle, where it is mixed in with water that flows around the nozzle, creating a solution of hypochlorous acid and hypochlorite ions. This solution travels downstream through corrosion resistant piping, where it feeds into the water being treated. A strainer is used upstream of the injector to filter out material that might clog the injector, like rust or grit.

A diffuser is another device used to introduce the chlorine solution into the water being treated. It is a short length of pipe with multiple holes, or perforations, that quickly and uniformly distributes the chlorine solution into a tank, basin, or pipe.

When using chlorine gas, each type of container has a maximum daily feed rate. This is because releasing gas from a container too quickly can cause the valve or nozzle to form ice crystals or freeze. For 150lb cylinders, the maximum daily feed is 42lbs. For one-ton containers, the maximum daily feed is 400lbs. Systems that require a feed of 2000lbs or more per day require a chlorine vaporizer. A chlorine vaporizer is a heater, which, when used with the liquid feed of a container, allows for much higher feed output.

Chlorine reacts with water to form hypochlorous acid (HOCl) and hydrochloric acid (HCl), also known as muriatic acid. Hypochlorous acid is the most effective disinfectant of the chlorine compounds. In higher pHs, it will break apart to form the hypochlorite ion (OCl^-). A pH of 5 will provide the highest concentration of hypochlorous acid. A pH above 6 will cause the HOCl to dissociate into the hypochlorite ion. At a pH of 9 or higher, little to no HOCl will remain.

CHLORINE GAS SAFETY REGULATIONS

Due to the hazards involved in using chlorine gas for disinfection, it is subject to more regulations than chlorine compounds used for disinfection. The regulations for chlorine rooms were covered in the previous section. If a facility is adding chlorine gas disinfection to their existing treatment facility, or a new facility with chlorine gas is being built, a scrubber may be required to mitigate any chlorine gas escaping from the facility.

The short-term permissible exposure limit (PEL), as set by the Occupational Safety and Health Administration (OSHA), is 1 ppm. The time weighted average (TWA), which is an employee's average airborne exposure in any 8-hour shift of a 40-hour workweek, is 0.5 ppm. Chlorine odor can be detected at concentrations as low as 0.3 ppm. The concentration considered immediately dangerous to life and health (IDLH) is 10 ppm. Chlorine gas will damage mucous membranes, the upper respiratory system, and the lungs.

A Self-Contained Breathing Apparatus (SCBA) is a respirator. SCBA is required safety equipment for chlorine gas facilities. SCBA should be kept outside of the chlorine room. They must create a seal around the face, to protect the nose and mouth, and should not be worn by people with beards and sideburns. Since a chlorine leak is considered Immediately Dangerous to Life and Health (IDLH), positive pressure SCBA is required.

Chlorine rooms must be equipped with leak detectors. The leak detection systems should be tested and calibrated regularly. A small bottle of ammonia can be used to check for leaks at connections, such as when changing the tank, or the connection to the injector. Chlorine and ammonia form a gas called ammonium chloride. When the ammonia encounters a small chlorine leak, a dense white smoke forms at the leak location. Ammonium chloride gas is toxic in low concentrations, so this method should not be used for large leaks.

Emergency repair kits must be available, also. Emergency Kit A is used for 150lb cylinders. Emergency Kit B is used for one-ton containers. Emergency Kit C is used for rail cars. Image 5.9 shows Emergency Kit B.

Figure 5.9 – Chlorine Emergency Kit B

Chlorine changes from liquid to gas inside a cylinder or container at 157° F. Both 150lb cylinders and one-ton containers have fusible plugs. These plugs will melt between 158° - 165°F, allowing the chlorine to escape as a gas, instead of causing ruptures in the container due to pressure. A one-ton container will have three fusible plugs at each end. Figure 5.10 shows the fusible plug for a 150lb cylinder on the left side and the three fusible plugs on a one-ton container on the right side.

Figure 5.10 – Chlorine Cylinder Fusible Plug

A Safety Data Sheet (SDS) should be kept in a location known to all plant personnel. The SDS includes information on interactions, hazards, proper storage, and safety procedures following a leak or human exposure. OSHA requires a Process Safety Plan (PSP) if a system has the capacity to store 1500lbs of chlorine or more and are required to do a site assessment plan under the Process Safety Management (PSM) regulations. If more than 2500lbs of chlorine are used in a single process at the facility, a Risk Management Plan(RPM) is also required. If a significant chlorine leak occurs, contact the Chemical Transportation Emergency Center for hands-on assistance.

HYPOCHLORITE COMPOUNDS

Calcium Hypochlorite and sodium hypochlorite are chlorine compounds used as an alternative to chlorine gas. They are considered safer to handle and store than chlorine gas, however, caution should still be used, along with personal protective equipment. Both are still capable of causing damage to the skin, eyes, lungs and clothing, so safety goggles, gloves, masks, and aprons should be worn when handling them. They do not contain as much available chlorine as chlorine gas does and are more expensive by volume.

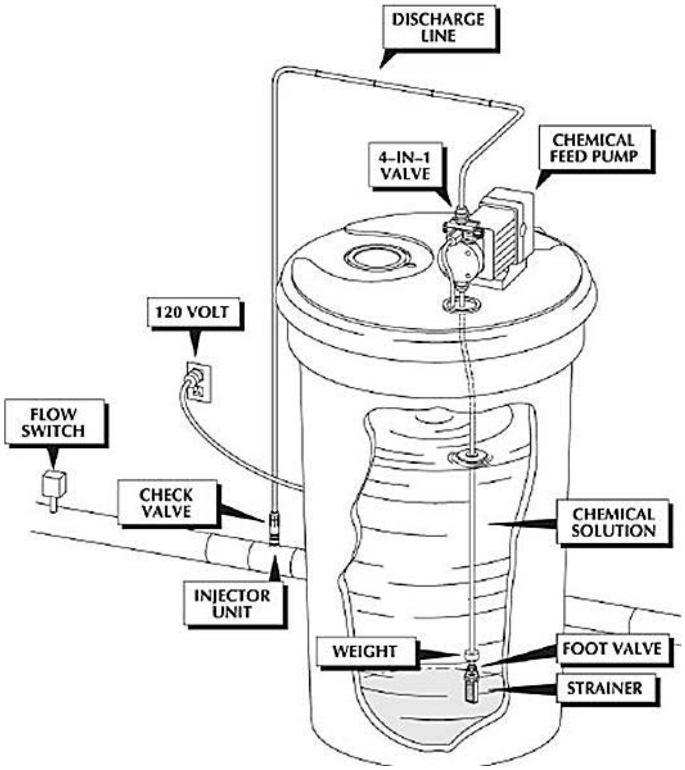
Calcium Hypochlorite is commonly called High Test Hypochlorite (HTH). It is a white solid and has between 65% - 70% available chlorine. It should not be stored near organic compounds, since its reaction with organics generates heat and produces oxygen. This makes it a fire hazard. It should be added to water carefully, since this reaction also produces heat. Water should not be added directly to HTH.

Sodium hypochlorite is commonly called bleach. It comes as a liquid solution and is generally light yellow in color. It has available chlorine ranging from 5% - 15%. Solutions used for household cleaning and disinfection will be in the lower range and industrial applications will be in the higher range in most cases. Solutions in the 12% - 15% range may lose between 2% to 4% of available chlorine per month.

Temperature and exposure to light accelerate the degradation process. Since ordering a month's supply of chemicals is a good administrative practice, it is important to be aware of this loss. Because of this, it is critical to properly rotate inventory, using the First In, First Out (FIFO) practice.

Both forms of hypochlorite are fed through a Hypochlorinator. These devices consist of a tank that holds the solution, tubing, a pump, an injector, and valves for controlling flow. Some configurations include a mixing tank that connects to the day tank that feeds the solution. Figure 5.11 shows a Hypochlorinator.

Figure 5.11 – Hypochlorinator



Courtesy of the EPA

ALTERNATIVE CHLORINE COMPOUNDS FOR DISINFECTION

There are several reasons why a system might use an alternative form of chlorine for disinfection. Persistent residuals or reduction of disinfection by-products (DBPs) are two of the primary reasons. These alternatives are formed by introducing other compounds to the chlorine gas reaction with water. Chloramines are generated from the interaction of chlorine with ammonia (NH_3). Chlorine dioxide (ClO_2) is generated by combining chlorine with sodium chlorite ($NaClO_2$).

CHLORINE DIOXIDE

Chlorine dioxide is an unstable gas that quickly breaks down when exposed to air or water. It is generated on site for this reason. There are several methods available for generating chlorine dioxide:

- Adding chlorine to water followed by a solution containing hydrochloric acid and sodium chlorite.
- Injecting chlorine gas under vacuum conditions into a chlorite solution. (Preferred method for larger systems)
- Adding hydrochloric acid to a chlorite solution.

Chlorine dioxide is a strong oxidant that will effectively inactivate most pathogens. It is less reactive with Trihalomethanes (THMs) and haloacetic acids (HAAs). Its residual is not as long lasting as some other methods of disinfection, so many systems will add chlorine after chlorine dioxide disinfection is complete to create a persistent residual. The maximum residual disinfectant level (MRDL) is 0.8 mg/L. The minimum residual for chlorine dioxide is 0.1 mg/L. Although it does not form organic DBPs as readily as chlorination, it does produce chlorite. Chlorite is a regulated under SDWA, with an MCL of 1.0 mg/L. Chlorite can cause anemia in infants and young children, along with damage to the central nervous system. Granular Activated Carbon (GAC) is effective at removing chlorite.

Groundwater tends to be lower in the humic and fulvic acids that generate THMs and HAAs. Like chlorine, it will also precipitate iron and manganese, making it a good alternative to chlorine disinfection in many systems.

CHLORAMINES

Chloramines are the product of chlorine's interaction with ammonia. Their formation is a critical step in the breakpoint chlorination curve which is covered in the next section. They originally received attention in 1900, when it was found that the cost of chlorination might be reduced. The practice was adopted in 1915 in Ottawa, Canada and in 1917 in Denver, Colorado. Indianapolis started using chloramines in 1954, and their use has grown in popularity because of the reduction in unwanted disinfection byproducts.

Chloramines do not have the disinfection capacity of hypochlorous acid or chlorine dioxide; however, they have a longer-lasting residual than either of those disinfectants. They are approximately 80 times less effective than chlorine gas, and require long contact times, but can last up to 27 days throughout the network.

There is no direct measurement approved by the EPA for chloramines. We rely on the measurements for total chlorine and free chlorine to estimate their concentration and their residual is measured as Cl_2. The MRDL for chloramines is also 4.0 mg/L. The minimum residual is 0.5 mg/L. There are three different chloramines generated from the interaction between chlorine and ammonia (NH_3):

- Monochloramine (NH_2Cl)
- Dichloramine ($NHCl_2$)
- Trichloramine or Nitrogen Trichloride (NCl_3)

Dichloramine and trichloramine have a higher disinfection capacity than monochloramine. Although monochloramine has a lower disinfecting capacity than the other chloramines, it is the preferred product of the chlorine/ammonia reaction. Dichloramine and trichloramine will give water the "swimming pool" odor and impact the taste in concentrations of 0.8 mg/L and 0.02 mg/L, respectively. The formation of specific chloramines is dependent on the concentration of ammonia and the water pH.

At a normal groundwater pH between 6.5 – 7.5, both monochloramines and dichloramines will form. Dichloramines will exclusively form at a pH of 5.5. At a pH of 4 or lower, trichloramines will form.

A concentration of three parts chlorine to one part ammonia (3:1) favors the formation of monochloramines. Concentrations of 4:1 and 5:1 are frequently used, but they have less ammonia available for rechlorination. Ratios above 5:1 may lead to incomplete nitrification. Ammonia may be added before, during, or after chlorination. Adding ammonia before and during chlorination may produce fewer THMs and unwanted byproducts, but adding ammonia post-chlorination will allow for greater contact time. It may be necessary to add ammonia post-chlorination to comply with regulatory disinfection standards.

Critical Factors in Chlorine Disinfection

The two main factors that impact the effectiveness of any form of chlorine are concentration and contact time. Other factors that impact disinfection effectiveness include temperature, pH, turbidity, and total dissolved solids (TDS). The concentration and contact time for each form of chlorination are different. Deactivation of specific pathogens also differs for each type. Generally, a minimum contact time of 10 minutes is required.

CT Values are used to calculate a disinfectant's effectiveness. T equals the amount of contact time a disinfectant has from its application to the point where the residual is measured. C is the disinfectant residual in mg/L. Multiplying these two measurements (C x T) produces a measure of effectiveness for the disinfectant.

Chlorine dose, chlorine demand, and chlorine residual are factors in process calculation. Flow volume measured in million gallons per day (MGD), and chlorine feed measured in pounds per day (lbs/day) are used, along with conversion factors, to calculate chlorine dosage. Chemical dosage calculations are beyond the scope of this manual, but a simple process formula is:

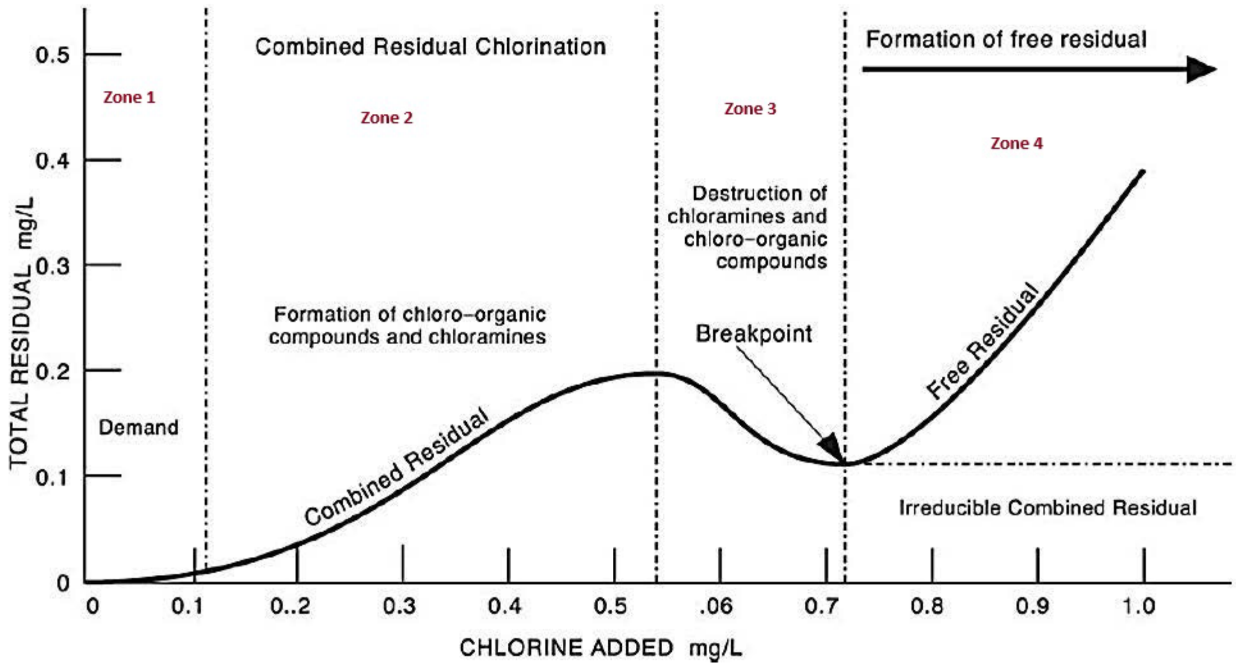
Chlorine dose = Chlorine demand + Chlorine residual.

The application point of chlorine will impact the demand and residual. In groundwater systems, application of chlorine as it enters the system will precipitate iron. Early application can foul the filters if it is not done early enough in the process to allow settlement. Chlorination post-filtration allows for filtration of contaminants that will exhaust the chlorine and allows a persistent residual to remain. Chlorine may be applied at intermediate points in the treatment process, depending on the qualities of the source water.

Breakpoint Chlorination

When chlorine is introduced to raw water, it will interact with minerals, organics, and ammonia. Once these reactions are complete, it is referred to as a breakpoint. After the breakpoint, free chlorine becomes available, creating a residual. Figure 5.12 shows the chlorination breakpoint curve.

Figure 5.12 – Breakpoint Chlorination Curve



Stock Image

The Zones of the chlorination breakpoint curve are sometimes called stages. In Zone 1, the chlorine reacts with iron, manganese, and other inorganics to form precipitates. In Zone 2, chlorine reacts with organics and ammonia to form chloro-organics and chloramines. The chlororganics and chloramines make up the combined residual in Zone 2. In Zone 3, the added chlorine destroys the chloro-organics and chloramines. At the end of Zone 3, as it changes to Zone 4, Breakpoint is achieved. After the breakpoint, additional chlorine will be free residual, and the chlorine will be able to remove tastes and odors. Once you reach Zone 4, there is a direct correlation between the chlorine dose and the chlorine residual. The percentage of the total chlorine residual should be 85% - 90% free chlorine.

Ozone

Ozone (O_3) is a toxic gas that occurs naturally when UV light interacts with oxygen (O_2) in the atmosphere. Ozone will also occur at surface level when UV light interacts with air pollution, forming smog. It is produced commercially by running air or oxygen through a chamber with electrodes at each end. Ozone is bluish in color and has a strong odor. Electrical fires, arc welding, and lightning also generate ozone.

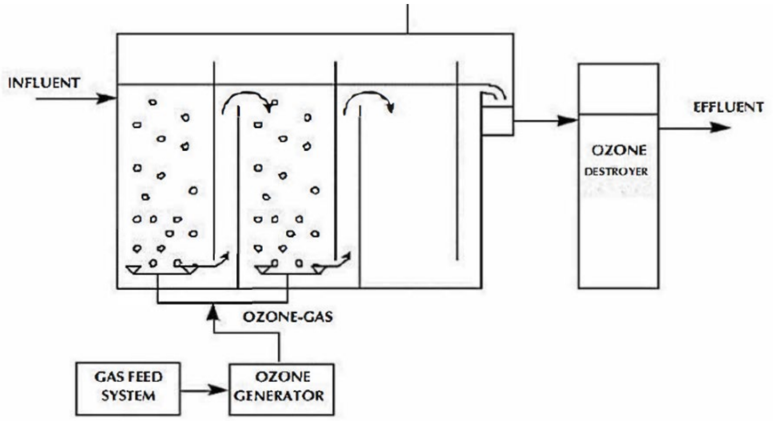
Unlike oxygen, ozone has an unstable structure, making it a very powerful oxidant. It is faster and more effective than chlorine and can inactivate organisms, like Giardia and Cryptosporidium, that chlorine cannot penetrate. It is expensive to generate, so many systems use more cost-effective methods for disinfection. If the source water contains bromides, the DBP bromate will be generated. Bromate is a carcinogen, with an MCL of 0.01 mg/L. Systems using ozone for disinfection must test for bromate.

An ozonation system consists of:

- Air supply – can be dried, compressed air or pure oxygen.
- Ozone generator – typically a chamber with electrodes at each end that produce an arc of electricity across the chamber.
- Contactor – introduces ozone to the water, generally a series of glass bubbler tubes or ceramic plates.
- Ozone destruction unit – a catalytic converter that destroys any remaining ozone in the water after disinfection is complete.

Figure 5.13 shows a basic ozone generator set up and its components.

Figure 5.13 – Ozone Generation



Courtesy of the EPA

A compressed air supply will be equipped with an air dryer and moisture monitor. It is important that the air supply be dry for production to occur. Moisture in the air supply makes this process ineffective and can produce nitrous oxides. When compressed air is used, it generates around 2% ozone.

Some systems feed pure oxygen to their ozone generators. It is a more expensive source of oxygen; however, it does not require drying or moisture control. When pure oxygen is used, it generates roughly 5% - 7% ozone.

While glass tube-bubblers are the most common way of introducing ozone into the water, another method may be used. These methods include:

- Spray chambers
- Injectors
- Packed columns
- Turbine mixers

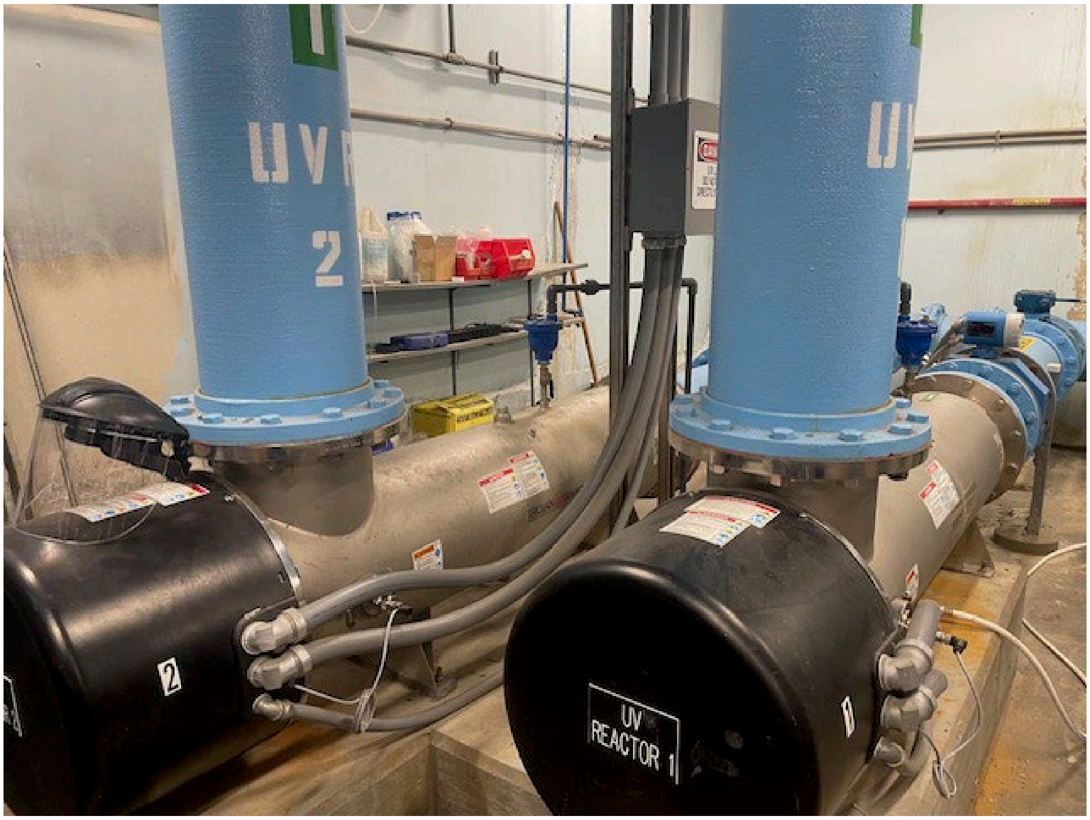
Ozone is toxic to humans. OSHA set the 8-hour exposure limit at 0.1 ppm. Because of this, any ozone not consumed in the disinfection process must be destroyed. The ozone destruction unit acts as a scrubber, using a catalytic reaction to convert the ozone back to oxygen.

Ultraviolet (UV) Disinfection

Ultraviolet (UV) disinfection uses chambers containing UV light bulbs to inactivate pathogens. The bulbs usually contain mercury, but some will contain antimony or use a combination of mercury with argon gas. UV disinfection works by damaging cellular genetic material. With the correct dosage, it can achieve 4 log inactivation of bacteria, viruses and protozoa. Dosage consists of light wavelength and exposure time.

Unlike other forms of disinfection, UV does not generally produce disinfection byproducts. It does have certain limitations. It must emit light within the wavelength range of 200 – 280 nanometers (nm) to have a germicidal effect. It is less effective in water containing more than 1 nephelometric turbidity unit (NTU) and will be less effective in waters containing organic matter or metal precipitates, like iron and manganese. This is because turbidity, organic matter, and metal precipitates can foul the bulbs or shield pathogens from the UV light. For most applications, UV treatment is applied after filtration. Figure 5.14 shows a typical UV reactor.

Figure 5.14 – UV Reactor



Because of the potential for iron and organic matter to foul the bulbs, most reactors are equipped with a UVT device. This is a device that monitors the light emission from the bulbs within the reactor. The target operation emission is 90% of the reactor's capacity. If the efficiency drops, the bulbs, which are encased in a quartz sleeve, can be cleaned with an internal device that squeegees the fouling material from the sleeve.

UV treatment has no residual. To maintain a disinfectant residual throughout the distribution system, chlorine or another disinfectant with a persistent residual must be added after UV treatment.

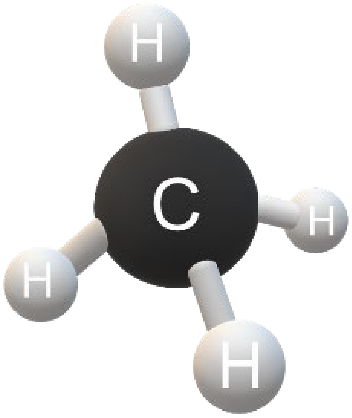
UV treatment is expensive, as well. It is recommended that at least two units be installed at a treatment facility. A low-pressure mercury lamp may last up to 10,000 hours before needing replacement, but they can be costly to replace. Mercury contamination from a broken bulb is also a concern.

Disinfection Byproducts (DBP)

Disinfection byproducts (DBPs) are the unwanted chemicals formed when disinfectant chemicals interact with organics and other contaminants in source water. Some of these chemicals are known carcinogens and are regulated under the Stage 1 and Stage 2 Disinfection Byproduct Rules, published by the EPA in 1998 and 2006, respectively. They apply to community water systems and non-transient non-community systems. Systems that use only UV disinfection are not subject to their monitoring requirements.

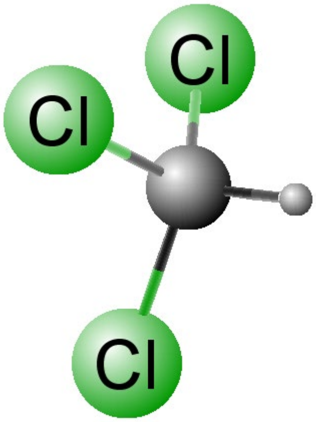
The previous section mentioned the byproducts from each type of disinfection. Chlorine gas and hypochlorination are the two largest contributors to DBPs. When chlorine encounters organics and other constituents in water with a pH above 7, it favors the formation of trihalomethanes THMs. Methane (CH_4) is a hydrocarbon consisting of one carbon with a hydrogen atom bonded to each of its available valence electron spots. Chlorine and Bromine (Br_2) are part of a chemical group called halogens. When a trihalomethane is formed, bromine or chlorine replaces three of the hydrogen atoms bonded to the carbon atom. Figure 5.15 shows the chemical structure of methane. Figure 5.16 shows the THM chloroform ($CHCl_3$).

Figure 5.15 – Methane Molecule



Wikimedia Commons

Figure 5.16 – Chloroform Molecule



Wikimedia Commons

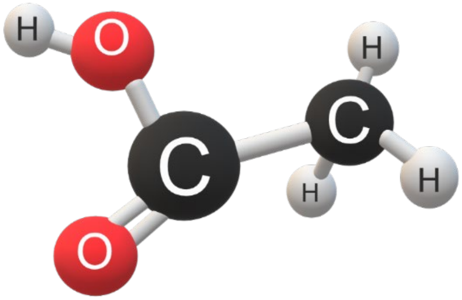
Chlorine and bromine can replace the hydrogen atoms in several different combinations. Table 5.4 lists the different trihalomethanes, their chemical formula and their maximum contaminant level goal (MCLG). Individual THMs do not have a maximum contaminant level (MCL). They are evaluated using the local running annual averages (LRAAs) of Total Trihalomethane (TTHM), which is the sum of four trihalomethanes (see Table 4.4). The MCL for TTHMs is 0.080 mg/L, or 80 parts per billion (ppb).

Table 5.4 – THMs and Their MCL

Trihalomethane Name	**Chemical Formula**	**Maximum Contaminant Level Goal (MCLG) in mg/L**
Chloroform	$CHCl_3$	0.07
Bromoform	$CHBr_3$	0
Bromodichloromethane	$CHBrCl_2$	0
Dibromochloromethane	$CHBr_2Cl$	0.06

Water with a pH below 7 favors the formation of haloacetic acids (HAAs). Acetic acid, also known as vinegar, is an organic acid with the chemical formula $C_2H_4O_2$. The two carbon atoms share a bond, and the molecule has a methyl group attached to one of the carbon atoms and a carboxyl group attached to the other. Humic and fulvic acids are organic acids found in water. When they encounter chlorine, they form haloacetic acids, with the chlorine replacing hydrogen in the methyl group of the acid, on the right side of the acetic acid molecule pictured in Figure 5.17 below.

Figure 5.17 – Acetic Acid Molecule



Wikimedia Commons

Table 5.5 lists five haloacetic acids and their chemical formulas. Individual HAAs do not have an MCL. They are evaluated using the LRAAs of Total Haloacetic Acids (HAA5), which is the sum of five haloacetic acids (see Table 4.5). The MCL for total HAA5 is 0.060 mg/L, or 60 ppb.

Table 5.5 – Haloacetic Acids

Haloacetic Acid	**Chemical Formula**
Monochloroacetic acid	$C_2H_3ClO_2$
Dichloroacetic acid	$C_2H_2Cl_2O_2$
Trichloroacetic acid	$C_2HCl_3O_2$
Monobromoacetic acid	$C_2H_3BrO_2$
Dibromoacetic acid	$C_2H_2Br_2O_2$

Under the Stage 2 Disinfection Byproduct Rule (DBPR), systems must monitor TTHM and HAA5 if they use chlorine for disinfection. The Stage 2 DBPR is commonly referred to as the 80/60 rule, since THMs have an MCL of 80 ppb and HAA5 have an MCL of 60 ppb. Systems that use chlorine dioxide must also monitor for chlorite and systems that use ozone must monitor for bromate. Monitoring frequency and number of samples required are based on system size and source water type. Table 5.6 shows the population size, monitoring frequency, and sampling locations for groundwater systems subject to the Stage 2 DBPR.

Table 5.6 – Routine DBPR Compliance Monitoring for Surface Water Systems

Population	**Monitoring Frequency***	**Total THM/HAA Sample Sets per Monitoring Period**	**Highest THM Locations**	**Highest HAA Locations**	**Existing Stage 1 DBPR Locations****
< 500	Every 365 days (Annually)	2	1	1	N/A
500 – 9,999	Every 90 Days (Quarterly)	2	1	1	N/A
10,000 – 49,999	Every 90 Days (Quarterly)	4	2	1	1
50,000 – 249,999	Every 90 Days (Quarterly)	8	3	3	2
250,000 – 999,999	Every 90 Days (Quarterly)	12	5	4	3
1,000,000 – 4,999,999	Every 90 Days (Quarterly)	16	6	6	4
≥ 5,000,000	Every 90 Days (Quarterly)	20	8	7	5

*** All systems must monitor during peak historical month for THM and HAA concentration.**

**** If no existing Stage 1 DBPR locations are available, replace them with the Highest THM and Highest HAA, alternating each sampling period.**

To determine the sample sites with the highest THM/HAA concentrations, an Initial Distribution System Evaluation (IDSE) is performed. Compliance is measured using a locational running annual average (LRAA). Sample locations with the highest concentration of THM or HAA are used to calculate the LRAA. Systems whose THM concentrations are at 0.040 mg/L or lower, and whose HAA concentrations are at 0.030 mg/L or lower, qualify for a reduced monitoring schedule. Table 5.7 provides the reduced monitoring frequency and sampling requirements for systems by population.

Table 5.7 – Stage 2 DBPR Reduced Compliance Monitoring for Surface Water Systems

Population	Monitoring Frequency	Details
< 500	Cannot Be Reduced	
500 – 3,300	Annually	1 individual THM sample At location/during the week with the single highest THM result 1 individual HAA sample At location/during the week with the single highest HAA result
3,301 – 9,999	Annually	2 THM/HAA sample sets At location/during the week with the single highest THM result At location/during the week with the single highest (or 2nd highest) HAA result
10,000 – 49,999	Quarterly	2 THM/HAA sample sets At location/during the week with the highest THM LRAA At location/during the week with the highest (or 2nd highest) HAA LRAA
50,000 – 249,999	Quarterly	4 THM/HAA sample sets At locations/during the weeks with the 2 highest THM LRAAs At locations/during the weeks with the 2 highest HAA LRAAs
250,000 – 999,999	Quarterly	6 THM/HAA sample sets At locations/during the weeks with the 3 highest THM LRAAs At locations/during the weeks with the 3 highest HAA LRAAs
1,000,000 - 4,999,999	Quarterly	8 THM/HAA sample sets At locations/during the weeks with the 4 highest THM LRAAs At locations/during the weeks with the 4 highest HAA LRAAs
> 5,000,000	Quarterly	10 THM/HAA sample sets At locations/during the weeks with the 5 highest THM LRAAs At locations/during the weeks with the 5 highest HAA LRAAs

Chemical Feeds

Chemicals are introduced into the treatment process in a variety of ways. Previous sections in the chapter described chlorinators, hypochlorinators, and ozone disbursement. This section goes into more detail on positive displacement pumps, dry chemical feeders, and the maintenance of chemical feed equipment.

Positive Displacement Pumps

A positive displacement pump is a small pump that uses vacuum or pressure to deliver a measured amount of fluid. They are designed to move fluid in a single, forward direction. There are two types of positive displacement pumps: Reciprocating and Rotary.

Reciprocating pumps use a piston, plunger, or diaphragm to push a measured amount of chemical solution into the water being treated. A back-and-forth motion creates the vacuum and pressure for the feed.

A rotary pump moves in a circular motion to deliver the chemical solution. Gears or lobes create a vacuum in a tube, which steadily feeds the liquid or solution into the water being treated.

Positive displacement pumps are a common chemical feed device because they deliver an accurate and predictable flow with consistent pressure. They can handle a wide range of viscosities. They are generally inexpensive to operate.

Peristaltic Pumps

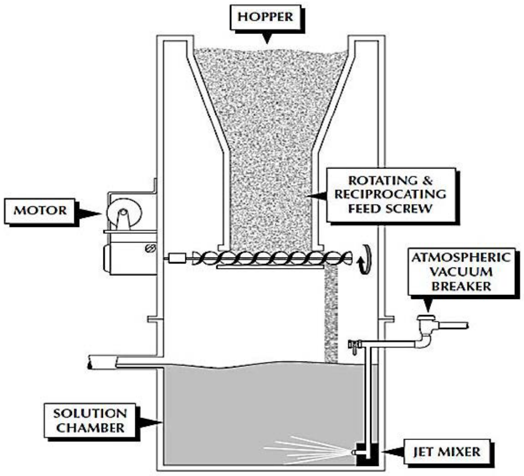
A peristaltic pump is a specific type of rotary pump often found in treatment facilities. It may be used in chlorinators and hypochlorinators, fluoride feeds, or to feed alum, activated carbon, or potassium permanganate. A peristaltic pump consists of a rotor that moves a series of rollers and a hose. The rollers move the hose, creating suction to pull fluid into the hose at the beginning of the cycle, and using pressure to push the fluid out of the hose at the end of the cycle. Figure 5.18 shows a series of peristaltic pumps connected to a day tank.

Figure 5.18 – Peristaltic Pump Chemical Feed

Dry Feeders

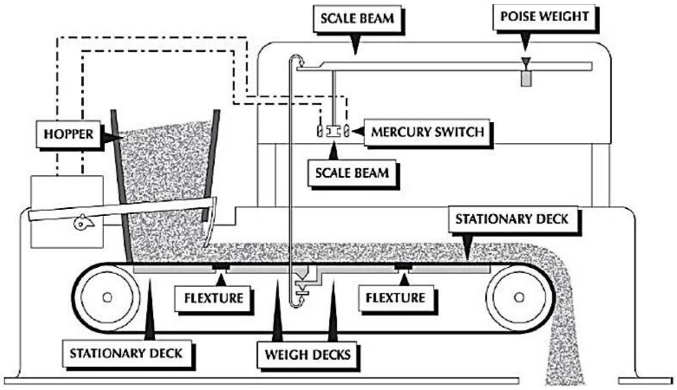
Dry feeders are used to feed solid chemicals into the treatment process. There are two types of dry feeder: Volumetric and gravimetric. Volumetric dry feeders feed a specific volume of chemical into the process, while gravimetric feeders administer a specific weight of chemical. Figure 5.19 shows a volumetric dry feeder. Figure 4.20 shows a gravimetric belt feeder.

Figure 5.19 – Volumetric Dry Feeder



Courtesy of the EPA

Figure 5.20 – Gravimetric Belt Feeder



Courtesy of the EPA

Dry feeders are often found in surface water treatment operations for administering coagulating chemicals. In a groundwater facility, they're used in lime and soda ash softening processes, and for feeding activated carbon. Their use has declined in recent years, since the dust collection requirements became regulated.

Chemical Feed Pump Maintenance

A major concern for gas chlorination feeds is a chlorine gas leak. Small leaks can be detected using ammonia. A white gas will form where the ammonia encounters the chlorine gas. To prevent leaks:

- Use a new gasket every time a chlorine cylinder or container is replaced.
- Inspect supply lines regularly.
- Replace supply line valves annually.

The rate of feed can also indicate a problem with a gas chlorinator. A plugged supply line or empty container can cause high-vacuum conditions. A failed injector or break in the vacuum line can cause low-vacuum conditions.

The most frequent problems with positive displacement pumps are clogged lines and broken diaphragms. Some good preventative maintenance practices include:

- Checking operations and recording outputs daily.
- Weekly cleaning of the building and chemical storage tanks or day tanks.
- Checking valve operations monthly.

Dry feeders should be regularly inspected for build-up and cleaned, if necessary. It is also important to make sure necessary parts are lubricated and to inspect belts and gears.

With any chemical feed system, regularly inspecting equipment and following manufacturer's guidelines is essential.

Practice Exam

1) Legionella infection includes which of the following symptoms?
    a. Diarrhea, vomiting, and cramps
    b. Fatigue, joint and abdominal pain
    c. Respiratory problems
    d. Impaired mental abilities

2) Which form of chlorine contains 100% available chlorine?
    a. Gas
    b. Calcium hypochlorite
    c. Sodium hypochlorite
    d. Chlorine dioxide

3) Which of these has no disinfection capacity?
    a. Hypochlorous acid
    b. Sodium chloride
    c. Monochloramine
    d. Hypochlorite ion

4) Which part of a chlorinator shows the chlorine feed rate?
    a. Manual feed rate adjuster
    b. Vacuum regulator
    c. Rotameter
    d. Gas inlet

5) 150lb chlorine cylinders use Emergency Kit ____.
    a. A
    b. B
    c. C
    d. D

6) Chlorine dioxide produces the DBP ______.
    a. Bromate
    b. Chloroform
    c. Trichloroacetic acid
    d. Chlorite

7) Iron and manganese are removed in which zone of the chlorination breakpoint curve?
   a. Zone 1
   b. Zone 2
   c. Zone 3
   d. Zone 4

8) Which of these is not a component of an ozonation system?
   a. Injector
   b. Air supply
   c. Contactor
   d. Ozone destruction unit

9) UV disinfection can achieve __ log inactivation of bacteria, viruses, and protozoa.
   a. 2
   b. 3
   c. 4
   d. 5

10) The Stage 2 Disinfection byproduct rule uses a local running annual average of total haloacetic acids, which is the sum of ___ haloacetic acids.
   a. 4
   b. 5
   c. 6
   d. 7

11) Which of these is not commonly fed through a peristaltic pump?
   a. Chlorine
   b. Alum
   c. Activated carbon
   d. Ozone

12) Which of these is NOT a best practice for maintaining a chemical feed pump?
   a. Changing the tubing each time a chlorine cylinder is replaced
   b. Using a new gasket when a chlorine container is replaced
   c. Regularly inspecting supply lines
   d. Replacing supply line valves annually

Chapter 6 – Filtration & Storage

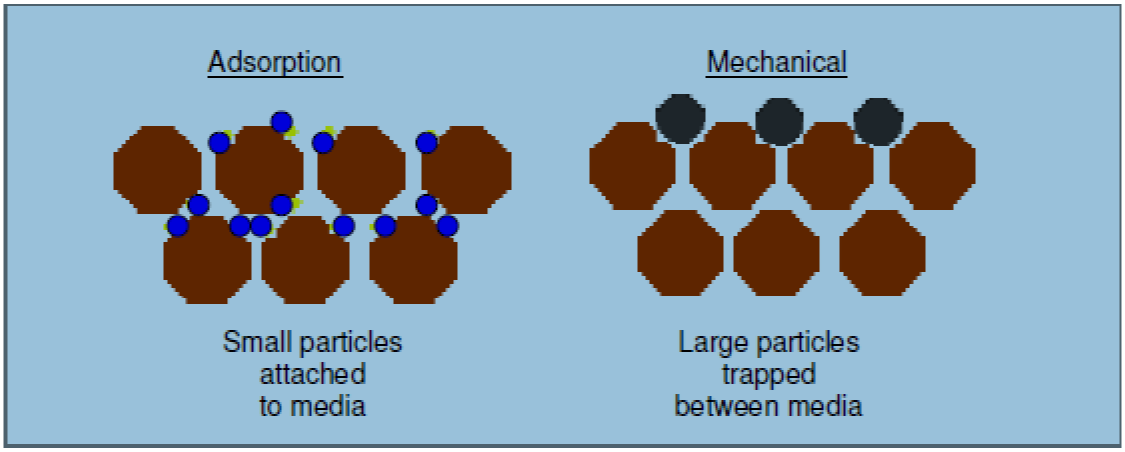
Learning Objectives

- Describe adsorption and differentiate it from absorption.
- Contrast gravity and pressure filters.
- List the different types of gravity filter media and summarize how each is used.
- Explain the filter backwash process and describe the common problems associated with inadequate backwash procedures.
- Compare the different types of membrane filtration and list the constituents each type will remove.
- Summarize the features and uses for ground level storage tanks and clear wells.

Filtration

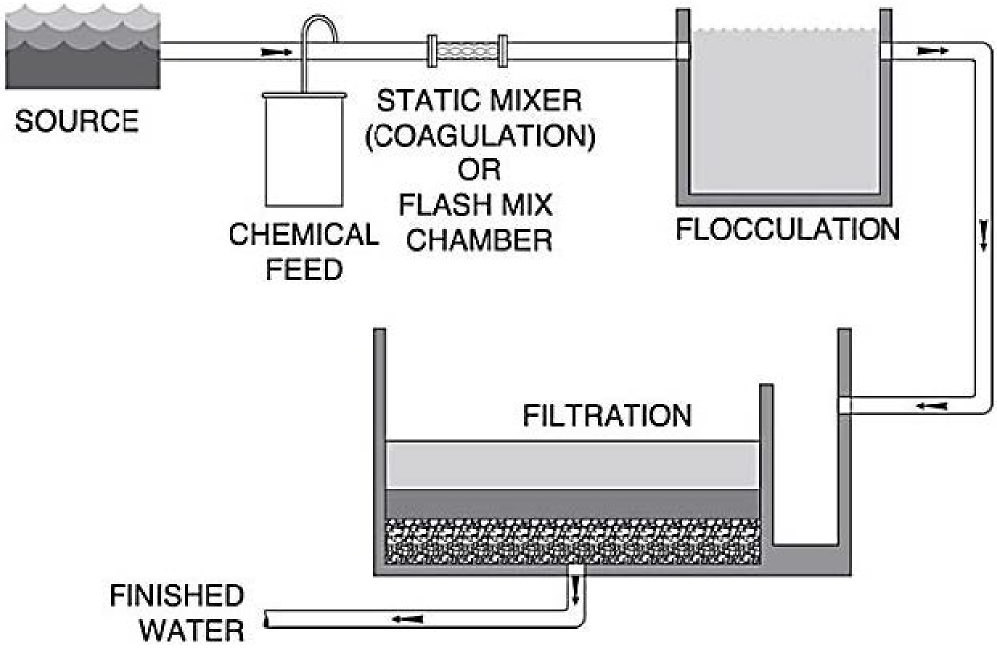
Filtration describes the process of sending water through a tank or bed of fine media, where particulates and contaminants are trapped. Filters will either mechanically trap matter through absorption, or the matter will adhere to the filter media through adsorption. Figure 6.1 shows the difference between absorption and adsorption.

Figure 6.1 – Adsorption vs. Absorption



Conventional treatment describes the process of sedimentation, coagulation and flocculation, followed by filtration. This process is common when surface water is the source. Direct filtration skips the sedimentation step. Groundwater plants generally use direct filtration. Figure 6.2 shows a typical set up of a direct filtration system.

Figure 6.2 – Direct Filtration



Courtesy of the EPA

Filters may have a single medium or multimedia. It is selected based on strength, permeability, and uniformity. Some common filter materials include:

- Sand
- Gravel
- Anthracite
- Granular Activated Carbon (GAC)
- Garnet Sand

Filters are categorized as either gravity or pressure filters. In gravity filters, the force of gravity pulls the water through the filter media. In pressure filters, the filter is contained within a pressure vessel that water is pumped through.

Gravity Filters

Gravity filters consist of tanks, usually made of concrete or steel, which hold the media, the media or medium itself, underdrains, pipes for influent and effluent water transmission, a wash water line, and wash troughs. Influent water enters the filter, where it travels through the media. Filtered water leaves through the effluent water line, where it is stored in a clearwell or transmitted to the distribution system.

There are four main types of gravity filter:

- Slow sand filters
- Rapid sand filters
- High-rate filters
- Deep-bed filters

Table 6.1 lists the type of filter, filtration rate in gallons per minute per square foot (gpm/ft^2), media and length of filter run for sand filters.

Table 6.1 – Gravity Filter Characteristics

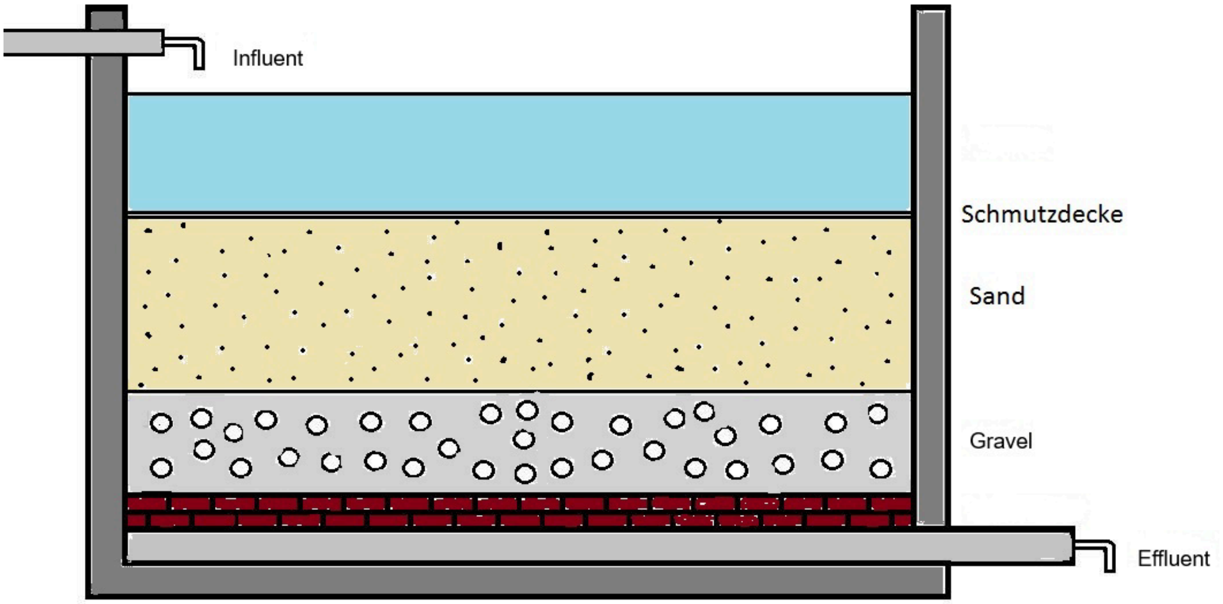
Type	**Filtration Rate (gpm/ft^2)**	**Media**	**Filter Run**
Slow Sand Filter	0.05	Sand	20 – 60 days
Rapid Sand Filter	2.0	Sand	12 – 36 hours
High-rate Filters	3 – 8	Sand and coal or sand, coal, and garnet sand	12 – 36 hours

Slow Sand Filters

Slow sand filters consist of a bed of sand about 3 feet deep on top of an underbed of gravel. The type of sand used is very important. It must be the appropriate effective size (ES) and uniformity coefficient (UC) for the filter. Permeability is also an important factor in sand selection. If the sand is too fine, water is unable to flow through the filter. Slow sand filters use a finer grain of sand than other types of sand filter. They are not as common as they used to be, but have the benefit of low construction, operation, and maintenance costs.

On top of the sand is the Schmutzdecke. This is a sticky layer of fine sand and biological matter that sits on the surface of the filter. As water passes through the filter, it traps additional matter. It is an important part of the way a slow sand filter works. Figure 6.3 shows a typical slow sand filter configuration.

Figure 6.3 – Slow Sand Filter



Wikimedia Commons

Slow sand filters do not require backwash. When water stops passing through the filter, they are cleaned by scraping off around an inch of sand from the top. This can be done using a machine or manually. Once the depth of the sand is reduced to around 2ft, new sand is added to restore its original depth. It can take a day or two for the schmutzdecke to develop once a slow sand filter has been cleaned.

Rapid Sand Filters

Rapid sand filters use a coarser grain of sand than slow sand filters. This allows them to filter at a faster rate than slow sand filters. While they work in similar ways, rapid sand filters used more of their bed depth and do not rely on a schmutzdecke in their filtration process. Backwashing is used to clean them when the media is saturated.

Because filters are taken offline for backwash, a system using rapid sand filters need at least two filters available. If a single filter does not have the capacity to meet demand, additional filters are necessary.

High-Rate Filters

High-rate filters use dual or multimedia to filter. Dual media high-rate filters often use a layer of sand topped with a layer of anthracite. A common configuration for a multimedia is a layer of garnet sand, with a layer of silica sand in the middle, and a layer of anthracite on top.

Typically, the coarsest material is on the top. This layer has the lowest specific gravity, which is its weight, relative to water. Layering using specific gravity is important, because it will remain stratified, even after backwashing. The upper, coarser, layer traps larger particles, and smaller particles are trapped in the ensuing fine layers. This allows the filter to use more surface area and produce at a faster rate.

High-rate filters, along with Rapid Sand filters, generally require a rate-of-flow controller to manage the influent water flow. They also often have a loss-of-head indicator, which shows the head loss of the filter and can indicate when it is time to backwash the filter. Generally, filters should be backwashed when head loss reaches 8 feet. Another meter that can indicate when backwashing is necessary is a turbidimeter. Turbidimeters measure turbidity in water. If filter effluent increases in turbidity, it indicates that backwashing is needed. Figure 6.4 shows a turbidimeter.

Figure 6.4 – Turbidimeter

Deep-bed Filters

Deep bed filters consist of a single filter medium that measures between 48 inches to 72 inches deep. They use a coarser medium, like sand or anthracite. They allow for a higher filtration rate than a dual or multimedia filter, however they may be more difficult to backwash, since fine particles can get trapped in the lower parts of the filter bed.

ACTIVATED CARBON

Granular Activated Carbon (GAC) may be used during the filtration process to address taste and odor concerns. GAC adds adsorption to the filtration process. It will occupy the top layer of the filter for dual, or multimedia filters or may be used as the single medium in a deep-bed filter. GAC can be expensive and requires special storage and handling. Alternate methods of using activated carbon may be more cost effective.

Pressure Filters

Pressure filters work similarly to gravity filters, and filter at about the same rate as rapid sand filters. They contain filter media, like sand, supported by a gravel bed. The main difference between the two is that pressure filters are completely enclosed, creating a pressure vessel containing filter media. Figure 6.5 shows a line of pressure filter tanks outside of a treatment facility.

Figure 6.5 – Pressure Filters

Pressure filters can be horizontal, as pictured in the above image, or vertical. Pressurized water is sent through the influent pipe, and as more water enters the chamber, it displaces water already inside the filter, which then moves out through the effluent pipe. Valves ensure that influent and effluent water travel through the appropriate pipes.

Because the filter is completely enclosed, it is not possible to monitor the backwash procedure. Backwash can be done manually or automatically. For filters that are backwashed frequently, automatic backwashing, with automated valves, is a good practice.

Diatomaceous Earth Filters

Diatomaceous earth (DE) filters are a pressure filter that uses diatomaceous earth as a medium. Diatoms are microscopic plants that live in water. Diatomaceous earth is the skeletal remains of those diatoms. Inside the filter, a blade is coated with diatomaceous earth, using treated water to create a slurry. Water passes through the diatoms, where they filter contaminants.

DE filters are not appropriate for water with turbidity over 10 ntu. They can be difficult to maintain, as a filter cake coating the blade is necessary, but sometimes hard to achieve. They also generate more waste than sand or multimedia filters.

Filter Aids

Filter aids are polymers introduced to water prior to filtration. They are long chains of organic compounds, also called polyelectrolytes, that are water soluble. They can have a positive charge (cationic), a negative charge (anionic), or be neutral (nonionic). Polymers help the small particles being filtered come together, or coagulate, by using electrical attraction known as zeta potential. This enables the filter to trap the floc more effectively. They also coat the filter media, allowing for better adsorption.

Polymers are selected using traits found in the raw source water. Temperature, pH, turbidity, and TDS all impact how polymers work. A polymer that is effective for one source may be ineffective for another. Nonionic and anionic polymers are best suited for filtration. Polymers are also used in the coagulation process.

It is critical to use the correct dosage. Using too little will make the polymer less effective and the particles will not form floc. Using too much can cause the particles to bind too well, causing them to stick in the upper part of the filter media. This creates head loss and reduces the length of filter runs.

Filter Backwash

Backwashing is how filters are cleaned. Over time, material collects in the filter until the filter is no longer effective. This can be indicated by head loss or increased turbidity in the effluent water. Backwashing reverses the flow of water through a filter to loosen material trapped in the filter media, called floc. The water used for backwash must be clean, treated water, since using untreated water will foul the filter.

At the beginning of the backwash process, a filter is drained until there is only a few inches of water remaining. Jets of water, called a surface wash, are applied to the surface to break up particles near the top of the filter. Treated water is then forced into the filter from underneath the bed at a velocity that will expand the filter bed and agitate the media. The surface wash should be turned off a minute or two before the backwash water is turned off, to allow the media to settle back into layers, or restratify. Some filters use air scouring to increase bed agitation instead of a surface wash. In this process, high-pressure air is used to break up floc build-up near the top of the filter.

Wash water troughs at the top of the filter collect the water and floc that is released from the filter, carrying it to a waste tank, basin, or pond. If the backwash water is introduced too forcefully, it can lead to filter media loss.

When backwashing a filter, it is important that the wash water be distributed evenly across the filter bed. Although there are many types of underdrains used in gravity filters, all types are designed to distribute water during backwash. If sections of the underdrain become clogged, this can lead to uneven backwashing.

Once the backwashing process is complete, a filter should be allowed to rest before bringing it back online. The rest period can be as short as half an hour or as long as a couple of days. It allows the media to settle and properly stratify. If the resting period is longer than a few days, bacteria may grow in the filter media. Once the filter is brought back online, it will need to ripen to reach full efficiency. Ripening is a period where matter begins to cling to the grains of the filter media, making it more efficient at trapping other matter.

Many of the problems encountered with filters come from improper backwashing. It is important to follow the backwashing procedure developed by your specific system. Table 6.2 lists common problems associated with filters, their description, and troubleshooting tips.

Table 6.2 – Common Filter Operational Problems

Filtration Issue	Description	Troubleshooting
Sand Boil	Backwash water is introduced too quickly, blowing the gravel bed into the upper filter media.	Probe the filter with a metal rod in a grid pattern at least once a year to measure media and bed depth.
Air Binding	Negative pressure, or negative head, sometimes generated by cold water, causes air bubbles to form in the media. The trapped air bubbles increase the filter's resistance, shortening the filter run. When the filter is backwashed, the air is released, leading to media loss.	Keep water levels in the filter at a maximum and backwash filters frequently.
Mudballs	Grains of filter media collect floc and clump together. As weight increases, these clumps sink into the filter bed, causing uneven distribution across the filter. Mudballs may also cause filter media to crack or separate from the bed walls.	Use appropriate backwash rates and ensure proper agitation of media during backwash.
Bed Shrinkage	Filter media becomes compacted and develops cracks. Water being treated travels through the cracks instead of through the media, resulting in ineffective filtration.	Ensure proper backwash rates to fully expand the bed and loosen floc trapped within the bed so that it is removed.
Media Loss	Excessive backwash rates or surface washing cause filter media to escape the filter via the wash water troughs.	It is normal to lose some media during backwash. Maintaining bed expansion at approximately 20% and turning off surface washers a minute or so before the backwash cycle ends is the best way to avoid this. Monitoring troughs for excessive filter media can alert an operator of developing problems.

Membrane Treatment

Membrane technology describes treatment processes that pass water through sheets of synthetic material with microscopic holes. Surface water systems using membrane filtration are classified as WT6, but groundwater systems that used membranes are classified as a WT3. It is important to understand the basic function and types of membrane. Membrane technology falls under one of four types:

- Microfiltration (MF)
- Ultrafiltration (UF)
- Nanofiltration (NF)
- Reverse Osmosis (RO)

These membranes are referred to as semi-permeable, since water can pass through, but contaminants are filtered out. The pores for each of these membrane types differ in size, so they will be effective for different contaminants based on pore size.

Microfiltration can remove bacteria, cysts, suspended solids, asbestos fibers, silt, and clays. It has the largest pore size of the membrane filtration methods, with a minimum size of 0.1 microns. It is ineffective at removing viruses, metal ions, and dissolved salts.

Ultrafiltration can remove the same contaminants as microfiltration is but can also remove viruses and humic acids. It has a minimum pore size of about 0.05 microns.

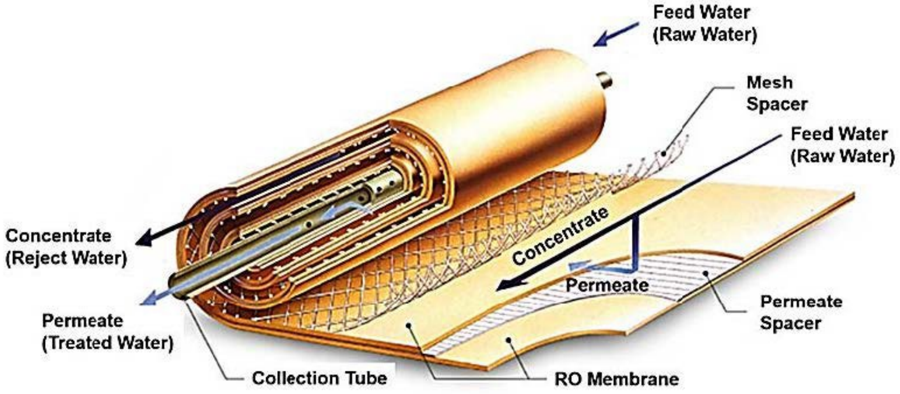
Nanofiltration will remove the same contaminants as the previous two methods. It will also remove dissolved salts and some metal ions. Its minimum pore size is around 0.005 microns.

Reverse Osmosis has the smallest pore size of the membrane filtration technologies. It can remove the above listed contaminants and is fully effective at removing metal ions. Its minimum pore size is about 0.0001 microns.

Many membrane filtration systems consist of a series of pressure tanks that hold a membrane core. The flow through these cores can be either crossflow, which flows from inside the membrane outward, or dead-end, which flows from top to bottom. The material is often made of polyvinylidene fluoride (PVDF), polypropylene, of polysulfone, though other plastics may be used.

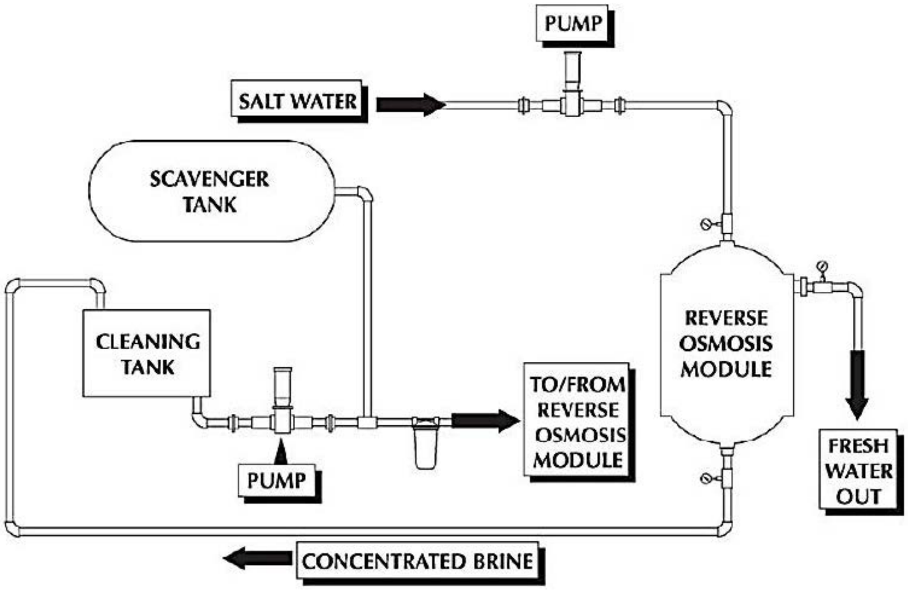
The cores can be hollow fiber or spiral wound. The core material must be resistant to oxidation and acids, as oxidants and acids are used to clean the membranes. Image 6.6 shows an example of a reverse osmosis spiral wound core. Image 6.7 shows a basic reverse osmosis setup.

Figure 6.6 – Spiral Wound Reverse Osmosis Core



Courtesy of the EPA

Figure 6.7 – Reverse Osmosis Unit



Courtesy of the EPA

Storage

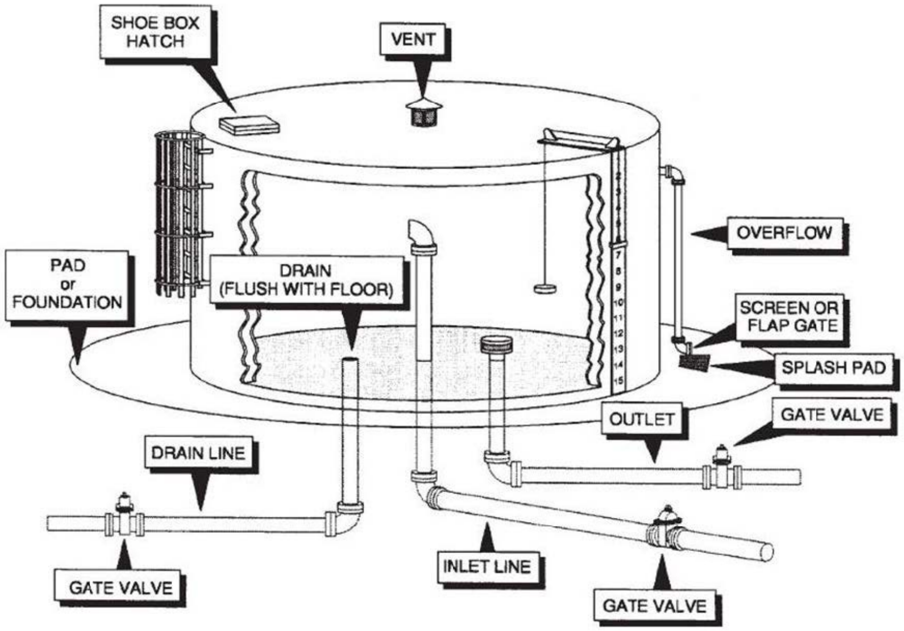
While most storage tanks will be found in the distribution system, storage may be necessary at the treatment facility. This can allow for additional disinfectant contact time. In the case of smaller systems, it may be necessary for primary storage to remain near the treatment facility, due to limited funds and available locations for storage. Systems using filtration may require storage for the water used in filter backwash.

Ground Level Storage Tanks

Gound level tanks provide storage in areas where elevated tanks are not suitable, due to topography or community objection. A large area of land is required for a ground level tank. They are usually constructed of steel and have a ladder to access the top of the tank. Figure 6.8 is an example of a ground level storage tank. Figure 6.9 is a diagram showing the components of a ground level storage tank.

Figure 6.8 – Ground Level Storage Tank

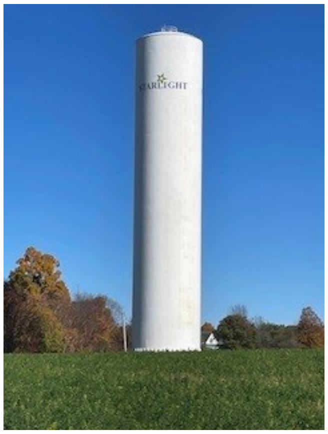
Figure 6.9 – Ground Level Storage Tank Diagram



Courtesy of the EPA

A standpipe tank is a specific type of ground level storage tank that will always be taller than it is wide. Standpipes offer more pressure than ground level tanks that are wider than they are tall. They may be used at the treatment plant to provide pressurized water for filter backwash, or in the distribution system to provide adequate pressure and supply for firefighting events. Figure 6.10 shows a standpipe tank.

Figure 6.10 – Standpipe Tank



Clear Wells

Clear wells store finished water at the treatment facility. They are typically used to provide contact time for chemical treatment and to ensure a persistent disinfectant residual throughout the distribution system. This is especially important for systems that chlorinate or disinfect post-filtration, since the minimum contact time for chlorine is 10 minutes. They can be located above or below ground. If a facility uses filtration, a clearwell is used to store filtered water from the plant.

Practice Exam

1) Which of these materials provide adsorption?
    a. Garnet sand
    b. Anthracite
    c. Silica sand
    d. Granular activated carbon

2) Which of these is NOT a type of gravity filter?
    a. Slow sand
    b. Diatomaceous earth
    c. Deep bed
    d. Rapid sand

3) The filtration rate is measured in _______.
    a. Milligrams per liter
    b. Gallons per hour
    c. Feet
    d. Gallons per minute per square foot

4) Which of these is not a component of a gravity filter?
    a. Hopper
    b. Tank
    c. Underdrain
    d. Wash troughs

5) Which of these is NOT a type of pressure filter?
    a. Vertical
    b. Horizontal
    c. Deep bed
    d. Diatomaceous earth

6) Diatomaceous earth filters should be used in water will less than _____ ntu of turbidity.
    a. 1
    b. 5
    c. 10
    d. 15

7) Filter aids are _____ that are introduced to water prior to filtration.
   a. Polymers
   b. Media
   c. Diatoms
   d. Bacteria

8) Matter trapped by filter media is called _____.
   a. Schmutz
   b. Floc
   c. Mud
   d. Ick

9) Which of these is not a common filter operational problem?
   a. Schumutzdecke
   b. Air binding
   c. Sand boil
   d. Mud balls

10) Which of these is NOT a type of membrane technology
   a. Ultrafiltration
   b. Nanofiltration
   c. Reverse osmosis
   d. Superfiltration

11) The pore size for a reverse osmosis membrane is about ______ microns.
   a. 0.1
   b. 0.01
   c. 0.001
   d. 0.0001

12) Which of these storage structures will provide pressurized water for filter backwash?
   a. Clear well
   b. Standpipe
   c. Ground level tank
   d. Hyperbaric tank

Chapter 7 – System Protection and Instrumentation

Learning Objectives

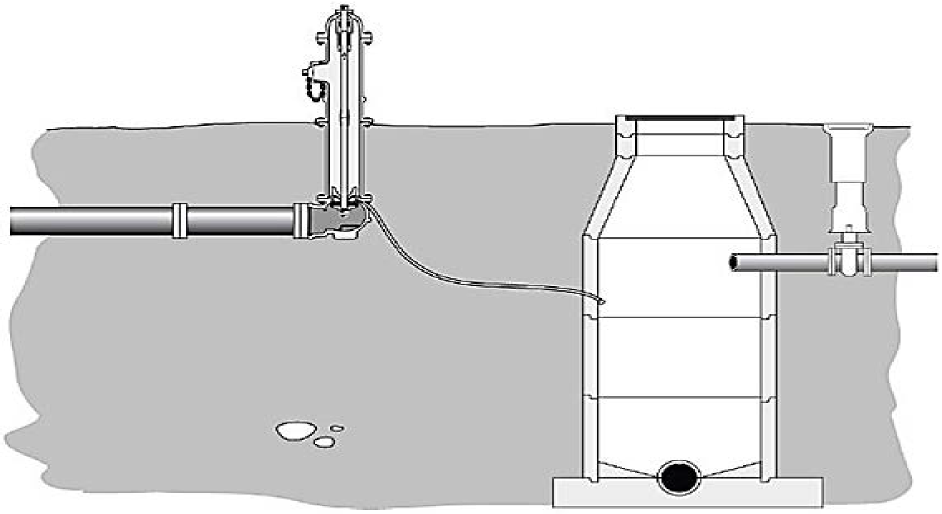
- Define a cross-connection and differentiate backflow from backpressure.
- List the devices used for backflow prevention and discuss the level of protection provided by each.
- Explain the different types of instruments used for system monitoring.
- Describe telemetry and the way data moves from sensors to monitoring devices.
- Identify common types of meters and explain the applications for each.
- Summarize the function and features of a SCADA system.
- Explain the importance of system security.
- List examples of physical security.
- Recognize common types of cyberattacks and identify cybersecurity best practices.
- Identify safety hazards in the workplace and describe proper precautions for those hazards.
- Define a confined space and list some of the additional safety measures they require.

Cross Connection Control

A cross-connection is an unprotected connection, or potential connection, between the distribution or treatment system and a water source of unknown quality. Cross-connections have the potential to open the PWS to contamination through backflow.

Cross-connections can exist from a variety of sources: Other water systems, sewers, septic tanks, private wells, irrigation systems, fire hydrants, factories and hospitals. They can occur from either pipe-to-pipe, or pipe-to-water connections. Figure 7.1 illustrates a direct cross-connection.

Figure 7.1 – Direct Cross-connection

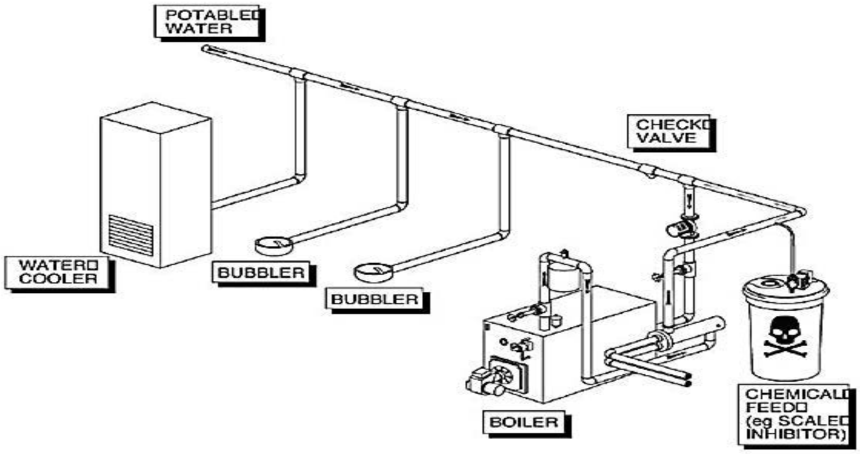


Courtesy of the EPA

While many hazards may apply to distribution, there is the potential for cross-connection within the treatment plant. Chemical feeds are an example of a potential cross-connection within the treatment plant. It is important to understand potential cross-connections within the treatment facility and use appropriate backflow prevention devices.

Contamination in the potable water system can occur through either backpressure or backsiphonage. Backpressure is when the non-potable water source is at a higher pressure than the potable water source. The pressure from the non-potable source pushes the contaminated water into the distribution system, like blowing through a straw. Figure 7.2 illustrates backflow from back-pressure.

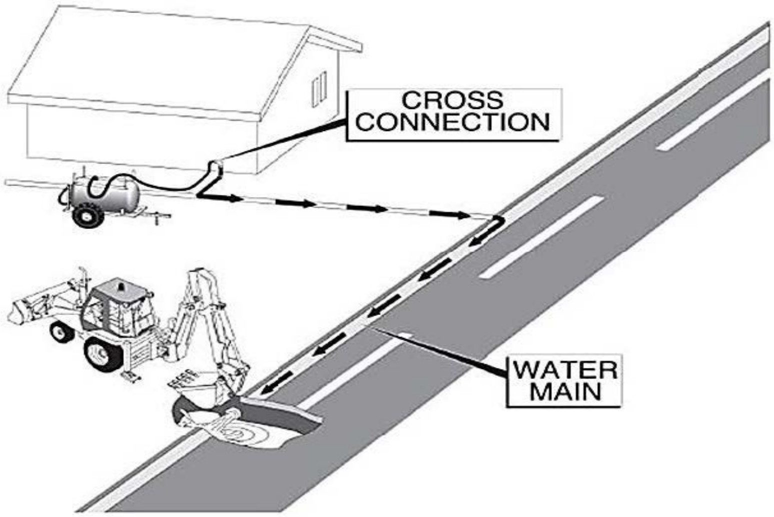
Figure 7.2– Backflow from Back-pressure



Courtesy of the EPA

Backsiphonage can occur when there is a vacuum condition (negative pressure) in a pipe. The negative pressure or negative head will pull non-potable or untreated water in, like sucking through a straw. Figure 7.3 shows backsiphonage from a direct cross-connection. While it shows a cross-connection outside of the treatment plant, it illustrates how negative pressure can pull a contaminant into the potable water supply.

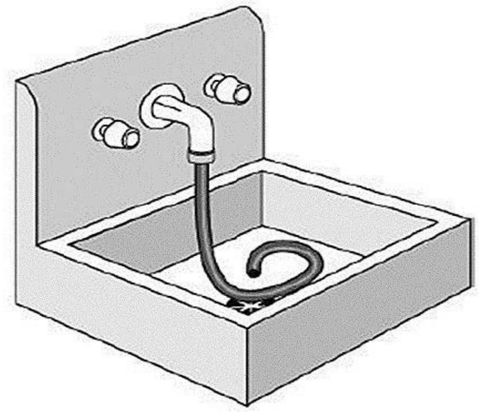
Figure 7.3– Backflow from Backsiphonage



Courtesy of the EPA

An indirect cross-connection can also cause backsiphonage, especially during a fire-fighting event, which requires high volume and pressure. Figure 7.4 shows a hose connected to a utility sink. If the hose were submerged in a chemical, such as floor degreaser, a vacuum condition in the distribution system would cause that chemical to be sucked into the distribution system.

Figure 7.4 – Indirect Cross-connection From Utility Sink



Courtesy of the EPA

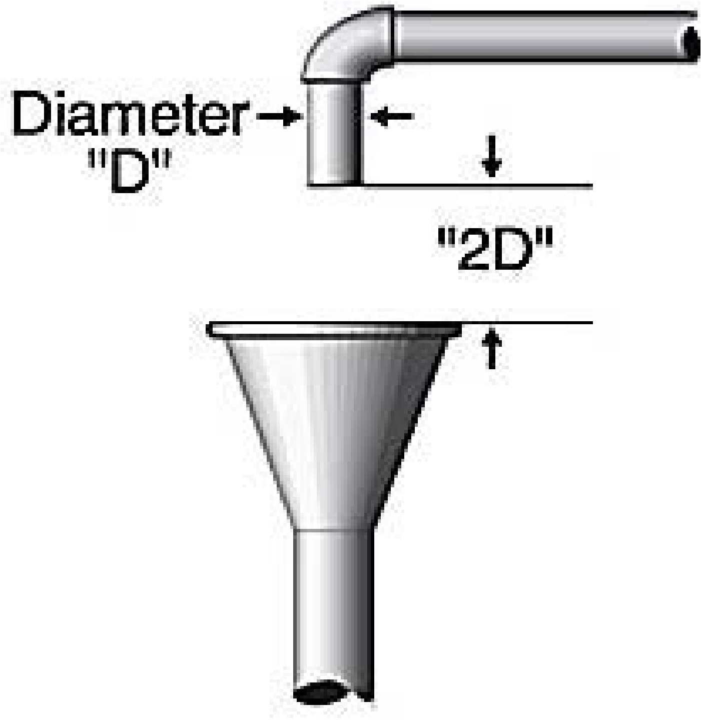
Backflow Prevention

While not all cross-connections will result in contamination of a PWS, they should all be treated as if they will. Backflow prevention devices are used to prevent system contamination from a cross-connection.

Choosing the correct backflow prevention device depends on the degree of hazard posed by the cross-connection. Those with a high degree of hazard require a high degree of protection from a backflow prevention device. An approved backflow prevention device has a shutoff valve, test cock, and can be tested inline.

An air gap is the best method of backflow prevention; however, they can be easily eliminated and must be maintained. An approved air gap must be at least one inch, or twice the diameter of the pipe it's protecting. An air gap provides low and high hazard protection against backsiphonage and backpressure. Figure 7.5 is an illustration of an air gap.

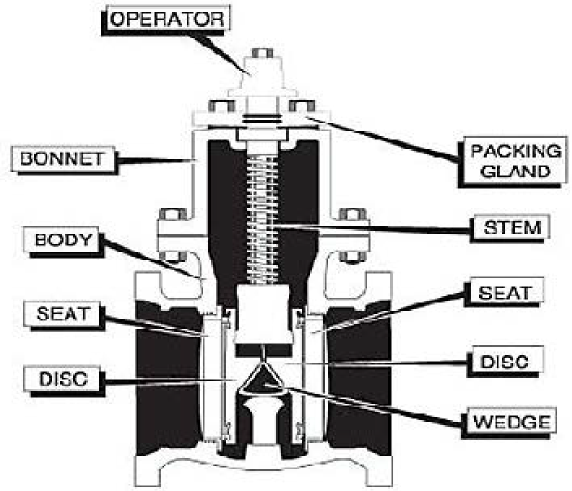
Figure 7.5 – Air Gap



Courtesy of the EPA

Because air gaps can be compromised, other devices and assemblies are used to prevent backflow. An atmospheric vacuum breaker (AVB) is a device that provides low and high hazard protection backsiphonage. An air inlet valve and a check seat cause the device to open when water flows through. When pressure falls below atmospheric pressure, the air-inlet port breaks the vacuum. Figure 7.6 diagrams an AVB.

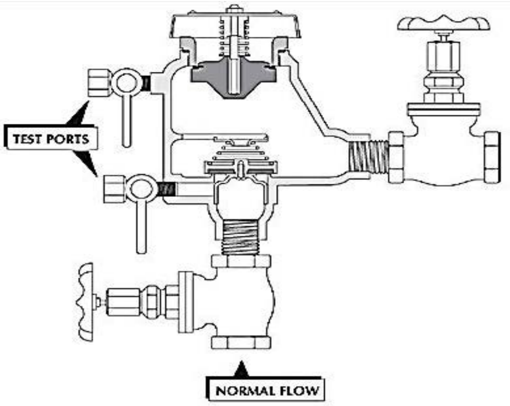
Figure 7.6 – Atmospheric Vacuum Breaker



Courtesy of the EPA

A pressure vacuum breaker assembly (PVB) contains an internally loaded check valve and an independently operated, loaded air-inlet valve on the discharge side of the check valve. In low pressure conditions, the check valve will close to break the vacuum. If the valve does not seal, the air-inlet engages, breaking the vacuum. It prevents backsiphonage in low and high hazard conditions. Figure 7.7 diagrams a PVB. Figure 7.8 is a photo of a PVB.

Figure 7.7 – Pressure Vacuum Breaker Diagram



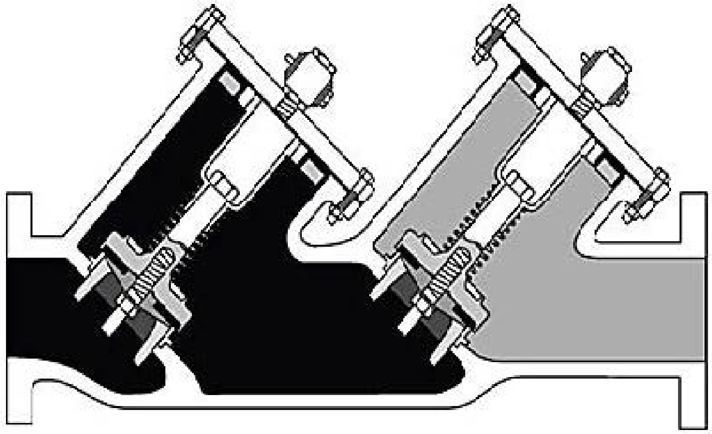
Courtesy of the EPA

Figure 7.8 – PVB Photo

Courtesy of the EPA

A double check valve backflow prevention assembly (DC) consists of two internally loaded, independently functioning check valves, two shutoff valves, and four test cocks. During backpressure conditions, one of the check valves will close, preventing the backflow. If that valve fails, the first check valve will close. DCs are appropriate for low hazard backpressure and backsiphonage. Figure 7.9 shows a double check valve assembly.

Figure 7.9 – Double Check Valve Assembly

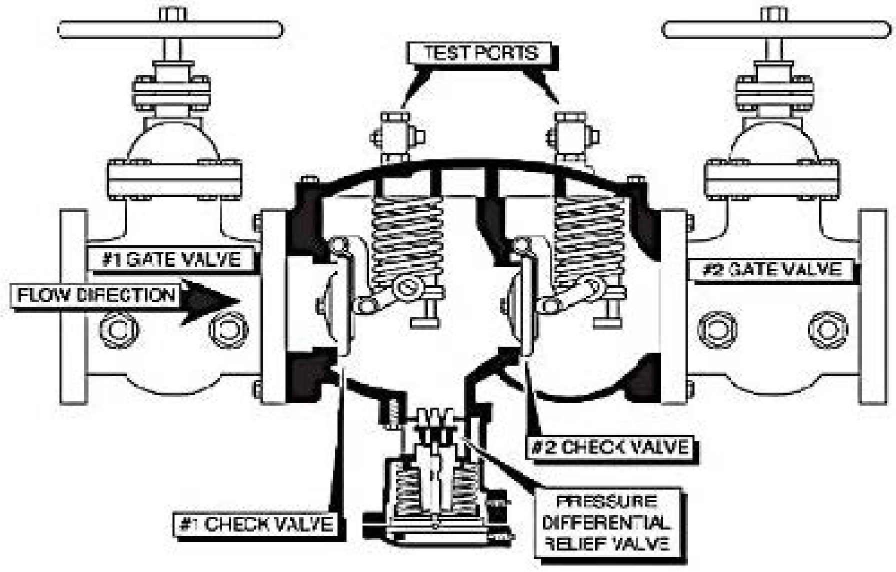


Courtesy of the EPA

A reduced-pressure principle backflow prevention assembly has two internally loaded check valves that act independently, a mechanically independent pressure relief valve located between the check valves and below the first check valve. It also contains two resilient-seated shutoff valves and for resilient-seated test cocks. It is appropriate for both low and high hazard backpressure and backsiphonage. Of the devices and assemblies listed, it provides the highest level of protection. It should never be installed below ground level.

During normal flow, both check valves will be open. In the event of backpressure, both check valves will close, and the second check valve will stop the pressure from traveling between the two checks. In the event of backsiphonage, the inlet pressure is reduced, and the first check valve will cause the relief valve to open and discharge water. Figure 7.10 shows a diagram of an RP assembly and figure 7.11 is a photo of an RP assembly.

Figure 7.10 – Reduced Pressure Principle Assembly Diagram



Courtesy of the EPA

Figure 7.11– Reduced Pressure Principle Assembly Photo

Courtesy of the EPA

Backflow prevention devices and assemblies must be approved by independent organizations that have developed design and performance standards, such as the American National Standards Institute (ANSI) and the American Society of Mechanical Engineers (ASME). They must be installed properly and cannot be modified. They must be tested annually, and records of test performance should be kept for three years. For more information on backflow prevention, refer to the AWWA *Manual of Water Supply Practices M14: Backflow Prevention and Cross-Connection Control, Recommended Practices.*

Instrumentation

Meters

Meters are used in both treatment facilities and throughout the distribution system to measure the flow of water in specific areas. Some common uses for meters include:

- Meters at customer connections to bill for water usage
- Meters at the water source to measure production
- Meters in transmission lines to measure pressure
- Meters in treatment facilities to ensure proper blending from different sources

Measuring production and usage flows helps water systems anticipate demand. It can also alert them to water loss in the system. There are several types of meters. Displacement, or positive displacement, meters are appropriate for low flows. Velocity, or current, meters are best for high flows. Compound meters can measure both low and high flows. Table 7.1 lists the different types of meters, how they work, best uses, and drawbacks.

Table 7.1 – Meters

Meter (Type)	**How it Works**	**Best Use/Benefits**	**Drawbacks**
Nutating-disk (Displacement)	• A small disk inside a chamber moves specific volume of water out per cycle. • Movement is transmitted to a register. • Sizes range from 0.6 inches to 2 inches.	• Residential and small commercial customers. • Sensitive to small flows and accurate over a wide range of flows.	• Will under register with excessive wear. • Not designed for continuous use. • Designed to run at half of their maximum operating capacity.

Piston (Displacement)	• Water displaces piston inside a chamber. • Motion is transmitted to a register.	• Residential and small commercial	• Head loss is a little higher than nutating-disk meter.
Turbine (Velocity)	• Has a propeller or rotor that turns when water flows through. • Speed of the propeller is proportional to the flow of water. • Movement is transmitted to a register.	• Large, continuous flows, like mains. • Can be installed within a pipe section or saddle mounted. • Low friction/head loss.	• Low flows will not register. • Not designed for stop-and-go flows.
Venturi (Velocity)	• Constriction in the pipeline called a venturi tube. • Pressure through the throat, or constriction, is measured. • Pressure on the other side of the throat is measured, then compared to the throat pressure. • Proportional calculation of the change is made and recorded.	• Larger pipelines. • Little friction loss. • Very low maintenance.	• Not designed for low flows. • More expensive than other types. • Requires large area for installation. • Not easy to install.

Magnetic, or Mag (Velocity)	- Water flows through a small magnetic field. - Flow generates a small current that is proportional to water flow. - Current is measured and mathematically converted to measure of flow.	- Large lines where water needs to flow unrestricted. - They don't cause head loss. - Highly accurate.	- Not as accurate near areas where water velocity is distorted, like bends or valves. - Will not measure fluids that don't conduct electricity. - Can be expensive and complicated to install and maintain.
Proportional (Velocity)	- A proportion of the total flow is diverted through a bypass meter. - Bypass meter measures water. - Gears in the bypass meter are adjusted to record total flow.	- Accurate for measuring high flows. - Commonly used to meter lines used for firefighting.	- Not accurate for low flows.
Compound (Both)	- Made of three combined parts. - Displacement meter, turbine meter, and automatic valves. - Automatic valves send water through the appropriate meter based on flow.	- Can measure both high and low flows. - Best used in schools, hospitals, and hotels, where flow and demand frequently change.	- May have inaccuracies in the change between high and low flow. - Expensive to install and maintain.

When selecting meters, some important questions to ask are:

- Will it measure high flow or low flow?
- Will the meter result in unnecessary head loss?
- What is the lifespan of the meter vs. the cost?
- How easy will it be to install and maintain?
- How accurate does it need to be?

Instrumentation refers to the devices used to monitor and control the system. Meters are an example of an instrument used to read water volume. Other examples of instrumentation include:

- Gauges
- Electronic pipe finders
- Electrical sensors
- Process analyzers
- Pitot meters

Instruments can be broken down into three main categories: Primary instruments, secondary instruments, and control systems.

Primary instruments measure things. They measure pressure, flow, water levels, temperature, etc.

Table 7.2 lists commonly used primary instruments in the distribution system, their function, and examples.

Table 7.2 – Instruments

Instrument	**Function**	**Examples**
Flowmeter	Used to measure water flow and flowing water volumes.	Averaging pitot meter Venturi meter Vortex Turbine or Propeller Weirs
Pressure gauges and sensors	Used to measure water pressure	Bourdon C-tube Bellows Diaphragm Variable capacitance
Level sensors	Used to measure water level in storage or chemical tanks. *Pressure sensors can be used as level sensors, if they are placed at the bottom of the tank.	Float-operated level sensor Bubbler Admittance probe Variable resistance level sensor
Temperature sensors	Used to measure temperature for chemical treatment, monitoring pumps, or detecting system abnormalities.	Resistant temperature devices (RTDs) Thermocouples
Electric power sensors	Used to measure current and voltage to motors and other electrically powered equipment.	Motor current sensor
Equipment status sensors	Used to monitor the status of equipment such as pumps, motors, blowers, etc.	Vibration sensors Position transmitters Discrete sensors

Secondary instruments respond to and display information from the primary instruments. Usually, they are panel mounted. They transmit signals from the primary instruments either electrically or pneumatically. Most modern secondary instruments use electronic transmission. Pneumatic might be used in high hazard or temperature areas.

Pneumatic transmission has limited range, and requires pipes and a supply of clean, dry air to transmit signals. They are low maintenance, resistant to electromagnetic fields (EMF), and safe in hazardous locations. They do not perform well in low temperatures.

Electronic transmission is basically unlimited in range, but it relies on electricity, so any electrical failure would take the instrument offline. It is also subject to EMF interference and requires corrosion protection. Electronic transmission is much faster than pneumatic and has a lower cost of installation.

Control instruments are used to control components in the system, like pumps and valves. The secondary instruments transmit the signals from primary instruments to a control panel. From the control panel, processes can be automatically or manually controlled.

Automatic control processes use either feedforward or feedback control. Feedforward control measures certain input values and uses them to calculate other input values. For example, a feedforward chlorinator would use the flow and the desired chlorine residual to calculate chlorine dosage.

Feedback controls measure the output of multiple processes and use them to adjust the inputs. This process is reactive and only responds to errors. Using the chlorinator as an example again, the free chlorine in a tank would be measured. If the concentration goes below 2 mg/L, the feedback control would increase the chlorine dosage to maintain the desired residual.

Telemetry

Telemetry describes the process of transmitting information over long distances. All telemetry systems consist of a transmitter, a channel, and a receiver. The transmitter is the device that collects and sends information. The channel is the pathway used to send information. The receiver is the device that receives information.

Information from the transmitter to the receiver is either analog or digital. In analog systems, the sensor on the transmission side sends mechanical signals, like a pulse, which travel through the delivery channel and are interpreted by the receiver.

Digital transmission uses binary 0/1, or on/off, electrical signals to send data from the transmitter to the receiver. As with analog transmission, a receiver interprets these signals.

Transmission channels may be wired, like copper wiring, telephone lines, or fiber optic cables. They can also be wireless, like radio waves or satellite systems. The proper transmission channel will depend on each system and the sensors and equipment used.

Supervisory Control and Data Acquisition (SCADA)

Supervisory Control and Data Acquisition (SCADA) systems provide monitoring and control for a water system. An operator can monitor and control things like storage tank levels, system pressure, and valves from a computer or handheld electronic device. SCADA systems are also used to monitor and control treatment processes.

SCADA systems work digitally but can receive analog input for things like pressure level, flow, and temperature. The digital control system has the following components:

- Process instrumentation and control devices
- Input/output (I/O) interface
- A central processing unit (CPU)
- Communication interfaces
- Human machine interface (HMI)

Process instrumentation and control devices consist of the sensors and mechanisms in the system. Pressure sensors, valves, and meters are examples.

The I/O interface sends and receives data between the process instruments and the control devices.

The CPU holds programming instructions for the control system. It can gather the data and react based on what instructions it has been programmed with.

The communication interface allows the computer control system to send data to and from outside computers, business systems, process control systems, and equipment.

The HMI is the computer terminal or device that an operator uses to read and/or control the system.

A SCADA system gathers data from instruments throughout the system, inputs it into the CPU, communicates it with other devices, and interfaces with a human on a computer terminal or handheld device.

That data can be used to create reports and analyze trends. A SCADA system can be used to project future demand or create regulatory reports. They can be used to generate maintenance schedules or emergency response procedures.

Because of the complete control available through a SCADA system, it is important to maintain security. SCADA systems should never be connected to public facing internet, default passwords should be changed, and passwords should never be shared.

Additional information on Instrumentation can be found in *American Water Works Association Instrumentation & Control Manual of Water Supply Practices M2, Third Edition.*

Security

Public Water systems are vulnerable to many different types of threats. Natural or environmental disasters can interrupt or contaminate the water supply. Malicious acts like vandalism and terrorism are also threats. The America's Water Infrastructure Act of 2018 (AWIA) requires community water systems serving a population of more than 3,300 people to conduct vulnerability assessments.

Identifying vulnerabilities is the first step in securing and protecting them. Areas to assess include:

- Pipes and constructed conveyances
- Water collection
- Physical barriers
- Treatment and pretreatment
- Storage
- Distribution
- Computer, electronic, and automated systems
- Chemical handling and storage

This is not a comprehensive list. An online threat assessment tool (VSAT2), and a small systems checklist, are available on the EPA's website. AWIA requires that risk assessments be reviewed every five years. Emergency Response Plans (ERP) should be updated based on these assessments. Certification of the review must be submitted to the EPA, but the assessment and ERP should be kept on file at the utility.

Physical Security

Regardless of size, it is important to protect your system from outside threats. Physical security describes methods used to prevent unauthorized entry and the protection of buildings and supplies. Some methods of physically securing your water system include:

- Gates and fences around physical structures throughout the system
- Locks to secure doors and gates
- Security cameras at treatment plants, storage tanks, and booster stations
- Requiring identification from visitors
- Requiring visitors to sign in and out
- Running background checks on potential employees
- Alarms to indicate unauthorized entry
- Proper storage and use of all chemicals

In addition to the list above, situational awareness is a critical factor of security. Situational awareness involves being aware of your environment and surroundings and knowing if something or someone is out of place. If you notice something out of place, like an unattended bag, or an unfamiliar vehicle parked outside the utility, it should be reported. If you see something, say something. Well trained and aware employees are one of the most effective security practices.

Cybersecurity

Cybersecurity describes the practice of securing your computing resources from attack or unauthorized use. Drinking water systems are increasingly targeted in cyberattacks. Types of attack could include:

- Denial of Service (DoS) – Floods a server with traffic so that it is unavailable to legitimate users.
- Phishing – Attempt to collect secure or personal information by impersonating a legitimate website or entity.
- Spyware – Software that monitors computer activity without the user's knowledge.
- Ransomware - Software that locks authorized users out of a system until a price is paid to the hacker.
- Bad actors using unsecured internet-facing devices to access operational technology and potentially changing or controlling treatment processes

Employee education is one of the most important parts of an effective cybersecurity program. Ensuring employees are aware of potential threats and using good security practices is critical. Other best practices for cybersecurity are listed below.

- Conduct a cybersecurity assessment.
- Make sure devices that connect to the public internet do not contain sensitive information.
- DO NOT connect SCADA systems to public facing internet.
- Change all default passwords immediately.
- Disable unused computer network ports.
- Secure computer network ports that are in use.
- Require multi-factor authentication (MFA).
- Create an inventory of all Information Technology (IT) and Operational Technology (OT) assets.
- Document critical settings for IT and OT.
- Create a cybersecurity incident response plan.
- Backup critical systems and data regularly.
- Store a backup at a different location and use a different media type.
- Install software and operating system updates and patches in a timely manner.
- Employing a qualified Chief Information Security Officer (CISO).

Emergency Response Plan

An emergency response plan is a document that outlines how the water system will respond in the event of an emergency. A comprehensive emergency response plan can enable a utility to minimize damage, contamination, or loss of service to customers during an emergency. Some examples of emergencies that would require a response plan include:

- Natural disasters, such as earthquakes, tornadoes, floods or fires.
- Cyberattacks
- Chemical spills
- Terrorist attacks

The first step in creating an emergency response plan is completing a vulnerability assessment. Once the system vulnerabilities are assessed, a system can better plan for an emergency response. Depending on system size and chemicals used, an emergency response plan may be required by law. Below are some key elements of an emergency response plan.

- Create a list of personnel within the organization and their responsibilities.
- Provide training for employees to carry out the plan (drills and simulations).
- Work with state and local agencies like IDEM, the Department of Health, and fire departments to develop procedures.
- Create a list of contacts and a chain-of-command, including:
    - Plant supervisor
    - Head of the utility
    - Police Department
    - Fire Department
    - Medical professionals
    - Nearby hospitals
- Provides personal protective equipment (PPE) for employees.

Workplace Safety

General Safety

Utilities of all sizes are required to have a workplace safety program by OSHA. Managers are responsible for developing the program, updating it, and ensuring employees receive safety training. The goals of a safety program include:

- Providing a safe workplace
- Creating a written safety policy
- Setting attainable safety standards
- Providing necessary training

Managers should make sure safety practices are followed, investigate any accidents or injuries, fix any unsafe working conditions, and make sure tools and work areas are properly maintained. They should ensure that all employees have personal protective equipment (PPE) and access to first aid supplies.

Employees are responsible for following safety policies and procedures. They should report any safety hazards to a supervisor immediately. They should regularly inspect their PPE equipment for damage and request replacement for any items that are damaged or not properly working. Some examples of PPE include:

- Hard hats
- Safety vests (reflective, neon)
- Safety shoes (steel-toed, slip-resistant, waterproof, electrical hazard)
- Masks
- Gloves
- Goggles
- Ear plugs
- Coveralls

Even with a comprehensive safety program in place, hazards will still exist. A hazard is a situation that could result in injury, disability, or death. Some of the most common hazards found in the treatment facility include confined spaces, heavy equipment, hand tools, electricity, water, and heights. Each hazard has its own safety considerations.

Heavy equipment is used in and around the treatment facility to lift equipment, like pumps and chlorine containers and to move heavy objects like large pipes or valves. Some examples include forklifts, lifts (cherry pickers), and wenches. Some equipment requires a special license for operation. While each machine has its own best safety practices, some general safety measures include wearing proper protective equipment, staying out of range of the machine if you’re not operating it, and being aware of your surroundings if you are the operator.

Hand tools may be used to repair other equipment. It is important to use the correct tool for the job. Other safety precautions for hand tools include wearing appropriate PPE, inspecting tools for damage before and after use, and avoiding laying them on machines or equipment with moving parts.

Drowning is the main risk when working around water. Water also conducts electricity. Avoid using power tools when in contact with water. Use extra caution when working around water, especially if the depth is unknown, or it is moving.

Falls from high places can cause injury, disability, or death. When working in high places, like aerators and catwalks, use special PPE, like harnesses and connecting devices. OSHA requires training and certification when working at heights of 6 ft. or higher.

Chemicals are a major hazard in water treatment. Ensure that chemicals are stored properly, and that chemicals that have dangerous reactions with each other are stored separately. Retain the Safety Data Sheet (SDS) for all chemicals used in treatment and distribution.

Electricity

Electricity is a hazard when working on pumps and other system processes that require electrical power. Electric shock can cause burns, cardiac arrest, or death.

When using power tools, ensure that they are in proper condition, and that the power cord is not damaged. If possible, avoid using power tools in standing water. Wearing work boots that protect against electrical hazards is also good practice. Tools and other powered devices can create arc-flash, where the current can jump from the powered device, through the air, to another grounded object.

Ensure extension cords are rated for the tool and job condition. The cord should be rated to carry the proper voltage, should be in good condition, and if used outdoors, should be approved for outdoor use.

The power supply should be disconnected anytime you are performing maintenance on pumps and machinery. The breaker to the machine being worked on should be turned off, and a tag with your name should be attached to the breaker. This process is called lockout/tagout. By tagging the breaker, it alerts other employees that the power supply should remain locked. Only the employee who locked and tagged the breaker should remove the tag once work is completed.

Lockout/tagout should also be used on pipelines and valves when there is potential for high water pressure, air pressure, or steam.

Ground-fault interrupters (GFI), or ground-fault circuit interrupters (GFCI) are devices that can be installed in an electrical system or built into a power cord that will provide some protection from electrical shock. The may also prevent electrical fires. GFIs work by interrupting electrical current when they detect surges.

Confined Spaces

A confined space is defined by OSHA as an area that:

- Has limited or restricted means of entry or exit
- Is not designed for continuous human occupancy
- Is large enough for an employee to bodily enter and perform work

Some examples of confined spaces include:

- Tanks
- Pits
- Trenches
- Manholes
- Tunnels

Some potential dangers of confined spaces are:

- Low oxygen levels
- High oxygen levels
- Toxic gases
- Falling objects
- Electricity
- Water
- Death

Safety precautions before entering a confined space could include:

- Testing and monitoring air quality
- Using proper equipment for entry and exit
- Using PPE
- Using proper lighting
- Alerting coworkers when you plan to enter or exit the space

Approximately two thirds, or 67%, of deaths in a confined space are would-be rescuers. Staying aware and alert when working on equipment in the system is important. If an incident occurs, contact emergency personnel. Do not try to rescue a co-worker in distress unless you have emergency response training.

Some confined spaces may require a permit for entry. A permit-required space will have one or more of the following characteristics:

- Has, or may have, a dangerous atmosphere
- Has, or may have, materials that would engulf the occupant
- Has, or may have, the ability to trap the occupant
- Has a known health or safety hazard

Confined spaces that require a permit for entry must have designated personnel who monitor the space and control entry. Table 7.3 lists those personnel, their functions, and responsibilities.

Table 7.3 – Permit Entry Confined Space Personnel

Title	**Function**	**Responsibilities**
Authorized Entrant	The person(s) entering the confined space.	Be aware of hazards posed in confined space. Properly use all equipment. Communicate with the attendant when needed. Alert the attendant if conditions in the space become dangerous. Exit the space when directed by the entry supervisor or any signs of danger are recognized.
Entry Supervisor	Supervises, or controls, the entry of the confined space.	Know the hazards posed by the confined space. Know the conditions inside of the confined space. Ensure permit is filled out correctly. Ensure tests required by permit have been performed on the space. Terminate entry or cancel permit if conditions in the space become dangerous. Remove unauthorized entrants.

Authorized Attendant	Stays outside of the entrance to the confined space.	Know the hazards posed by the confined space. Know the behavioral effects of exposure to the hazards in the confined space. Maintain an accurate count of authorized entrants into the space and be able to identify them. Stay outside of the space during all operations until relieved by another attendant. Communicate with entrants and monitor activities inside and outside of the space. Summon rescuers, if needed.

Practice Exam

1) What is a cross-connection?
    a. The connection from a main to a service line
    b. An unprotected connection to a water source of unknown quality
    c. The spot where a main connects with a storage tank
    d. The point where the treatment plant connects to the distribution system

2) Which backflow prevention assembly provides the highest level of protection?
    a. Check Valve
    b. Atmospheric vacuum breaker
    c. Reduced pressure principle
    d. Pressure vacuum breaker

3) Which of these meters is best to measure low flows?
    a. Venturi
    b. Turbine
    c. Proportional
    d. Nutating-disk

4) Which of these is NOT a primary instrument?
    a. Flowmeter
    b. Pressure gauge
    c. Level sensor
    d. Control panel

5) A telemetry system consists of what three parts?
    a. Transmitter, channel, and receiver
    b. Cathode, anode, and wire
    c. Proton, neutron, and electron
    d. Main, corporation stop, and service line

6) Which SCADA component holds the control system programming instructions?
    a. HMI
    b. I/O
    c. Communication interfaces
    d. CPU

7) Which of these is NOT a physical security measure?
   a. Locks to secure doors and gates
   b. Changing default passwords
   c. Requiring visitors to sign in and out
   d. Alarms to indicate unauthorized entry

8) Which of these is NOT a cybersecurity measure?
   a. Not connecting SCADA to the public facing internet
   b. Requiring MFA
   c. Running background checks on potential employees
   d. Disable unused computer network ports

9) Which of these is an example of an emergency that would require a response plan?
   a. Supply chain disruption of treatment chemicals
   b. Pump failure at the source
   c. Main break
   d. Terrorist attack

10) Which of these is NOT an example of PPE?
   a. Hairnet
   b. Masks
   c. Ear plugs
   d. Safety shoes

11) Which of these situations would NOT require a lockout/tagout?
   a. Repairing a pump
   b. Repairing a boiler
   c. Replacing a valve
   d. Backwashing a filter

12) Which of these is NOT a potential hazard of confined spaces?
   a. Toxic gases
   b. Falling objects
   c. Killer bees
   d. Low oxygen levels

Chapter 8 – Hydraulics, Pumps, Valves, and System Maintenance

Learning Objectives

- Interpret the basic principle of hydrology and apply them to system operation.
- Define the different types of pressure and explain how they relate to plant operation.
- Compare different valve types and recognize appropriate use for each type.
- Describe head loss and list the valves that cause it.
- Identify the parts of a centrifugal pump.
- List common pump failures and explain the possible causes for each.
- Explain the importance of regular inspection and maintenance of pumps.

Hydraulics

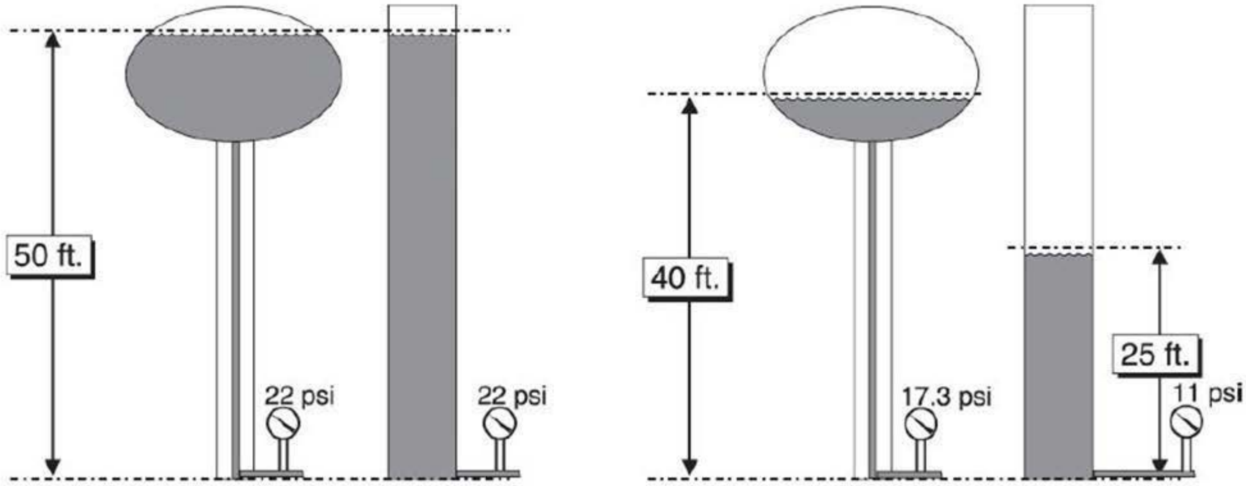
Hydraulics is the study of fluid movement or fluid under pressure. It is important to understand how water will move though the distribution system.

- Pressure is the amount of force exerted per unit of area.
  - It is usually expressed as pounds per square inch (psi) but may sometimes be expressed in kilopascals (kPa).
    - 1 psi = 2.31 ft. of head
    - 1 psi = 6.895 kPa
    - Pressure is measured with a pressure gauge.
      - Referred to as gauge pressure – pounds per square inch gauge (psig)
      - Gauges can be calibrated in feet of head.
      - 1 psig = 2.31 ft head

- Static pressure, Head, or Pressure Head describes the pressure of water that is not moving.
  - Think of it like the pressure of air in a bottle or compressor tank.

- Dynamic pressure, velocity head, or velocity pressure is the expression of moving water as energy.
    - Think of it like the extra pressure felt from the wind blowing.
- The static pressure is directly related to the height/depth of the water.
    - 8ft. of water in a narrow standpipe will exert the same amount of pressure as 8ft. of water in a tank with a 50ft. diameter. See Figure 8.1.

Figure 8.1 – Static Pressure in Elevated Tank and Standpipe



Courtesy of the EPA

- Hydrostatic Pressure is a specific type of static pressure that is solely affected by the weight of a fluid.
- Absolute Pressure is the measure of pressure exerted by a gas or liquid when compared to a perfect vacuum, or zero pressure.
    - Absolute Pressure = Gauge Pressure + Atmospheric Pressure.
- Atmospheric pressure is the pressure exerted by air, also known as barometric pressure.
    - Atmospheric Pressure - constant at 14.7 psi = 101.3 kPa.

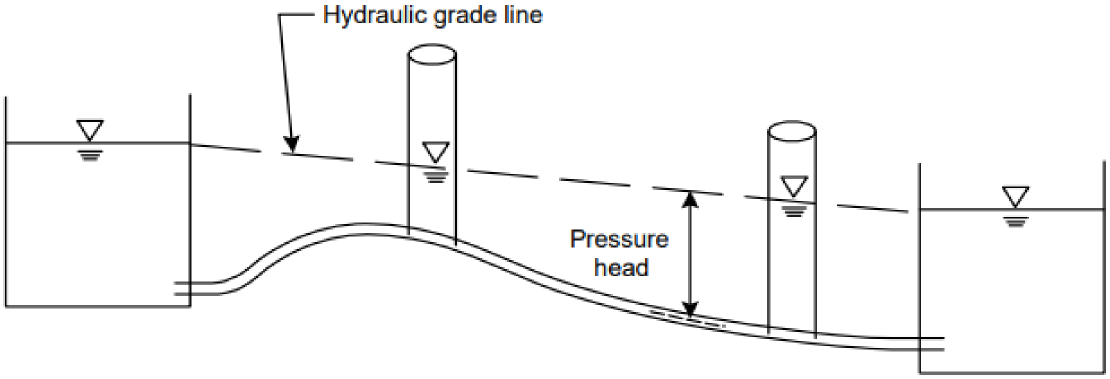
- Static pressure is the measure of the energy of water at a specific point in the system.
    - Expressed in feet or meters.
    - If head at a point is 60 ft. (26 psi), the pressure is as if a 30-foot column of water was there.

- Dynamic Pressure is the measure of additional energy of water because it is moving
    - Expressed in feet or meters.
    - Dynamic Pressure $= \frac{V^2}{2*g}$
        - Fluid Velocity (V) is a measure of flow rate
            - $V = \frac{Q}{A}$ Where Q is quantity of water and A is the area of the pipe.
            - g = acceleration due to gravity = 32 ft/s^2

- Velocity (V) is the measure of speed of movement.
    - $V = \frac{Q}{A}$ Where Q is quantity of water and A is area of the pipe.
- Total Dynamic Head (TDH) measures the pressure a pump must generate to move fluid through a system.
    - TDH = Static Lift + Static Pressure + Dynamic Pressure + Friction Loss.
        - Static Lift: vertical distance from source water surface to pump intake
        - Friction Loss: pressure losses from moving through the system (pipes, bends, etc.)

Water will always move from an area of higher pressure to an area of lower pressure. Figure 8.2 shows the Hydraulic Grade Line.

Figure 8.2 – Hydraulic Grade Line



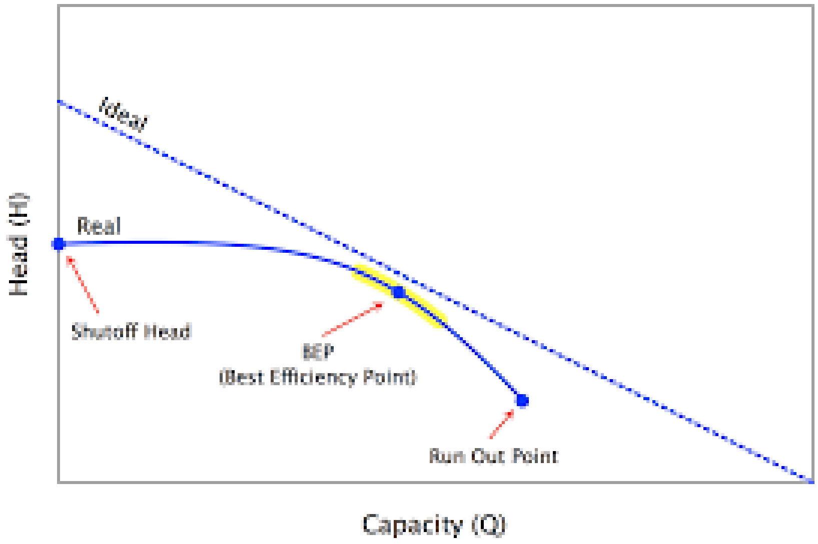
Courtesy of the Pennsylvania Bureau of Safe Drinking Water

Pumps

Pumps are used to withdraw water from the source, move water through the different treatment processes, feed chemicals, and transmit water to the distribution system. The pumps used to withdraw water from the source, move water through the plant, and transmit water to the distribution system are covered in this chapter. Information on positive displacement pumps can be found in Chapter 4.

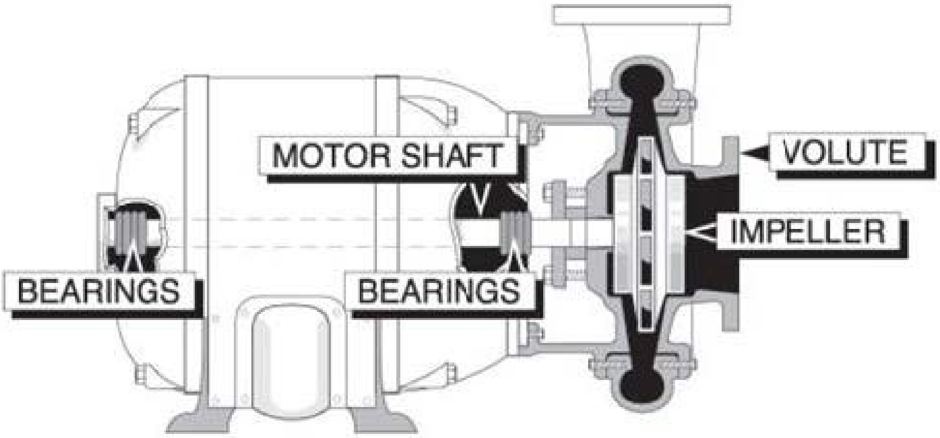
Centrifugal pumps are one of the most common types of pumps found in water treatment and distribution. In a centrifugal, or rotary pump, a motor turns a shaft to power the pump. This causes water to travel through a suction pipe, where it will spin through an impeller, which is often called the heart of the pump, increasing the velocity and thus the energy of the water. The energy of the water is converted to pressure as it moves through the discharge pipe. Figure. 8.3 shows a pump curve, illustrating how the work expended by the pump transfers energy to the water. Figure 8.4 shows a close-coupled horizontal centrifugal pump. Figure 8.5 is a cutaway of a centrifugal pump. Table 8.1 lists and describes the basic components of a centrifugal pump.

Figure 8.3 – Pump Curve



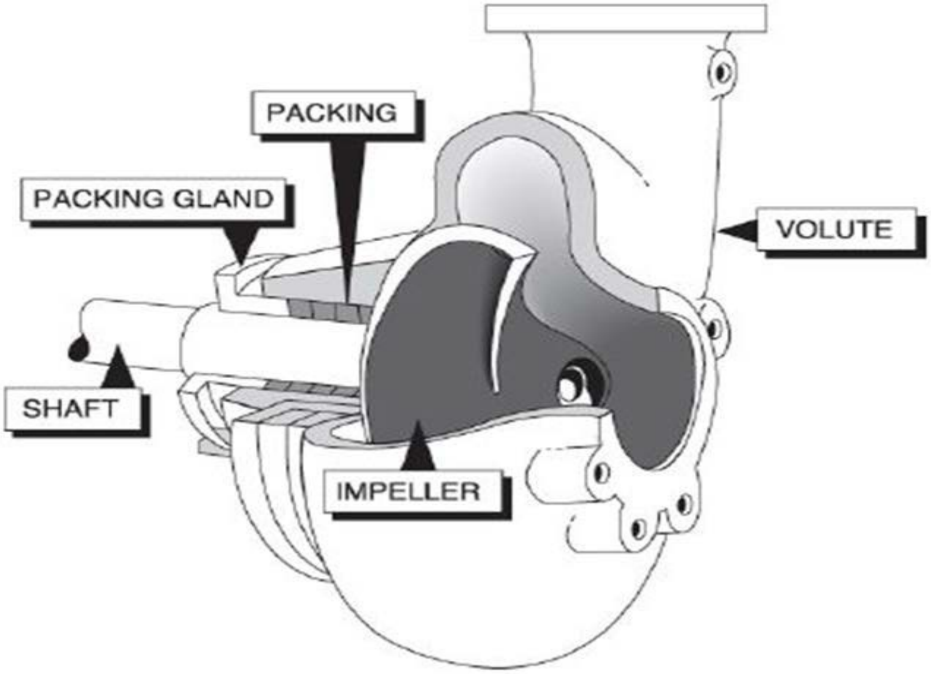
Wikimedia Commons

Figure 8.4 – Centrifugal Pump Horizontal Close-coupled



Courtesy of the EPA

Figure 8.5 – Centrifugal Pump Cutaway



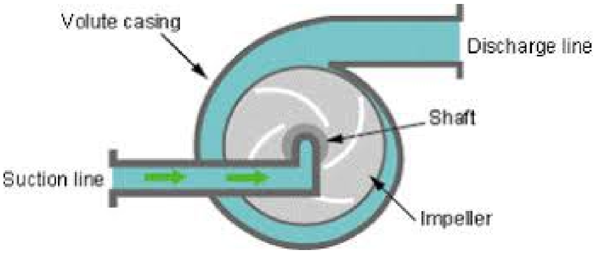
Courtesy of the EPA

Table 8.1 – Pump components

Component	**Purpose**	**Troubleshooting**
Suction pipe	Moves water from the source to the pump.	Avoid cavitation by listening for pinging noises. Keep line free of obstacles and clogs. Ensure valves are open.
Impeller	Propeller housed inside a case. Moves the water, converting kinetic energy into pressure.	Ensure it is free from debris, primed, and turning in the correct direction. Check power supply, voltage, and frequency if it is running at the wrong speed.
Discharge pipe	Moves the water away from the pump.	Flow can be checked with a flowmeter. If flow is restricted, check the impeller.
Motor	Converts electrical energy to mechanical energy to move the pumps parts.	Check the temperature to avoid overheating. Ensure amp draw is within range of ratings on motor nameplate.
Shaft	Transfers torque from the motor to the impeller.	Check the bearings for wear. Open and close valves slowly to avoid water hammer. Ensure proper coupling and alignment.
Water screen	Made of fine mesh material. Prevents debris from entering and damaging the pump.	Screen can get clogged and will require cleaning.

Centrifugal pumps can be housed in a horizontal or vertical case. The shape of the case enables the pump to convert the velocity of the water created by the impeller into pressure. To convert the velocity into pressure, the casing must have an increasing cross section. A volute is often used to house the impeller. It slightly resembles a nautilus shell in its shape, to allow for the increasing cross section. Figure 8.6 shows an interior view of an impeller inside of a volute case.

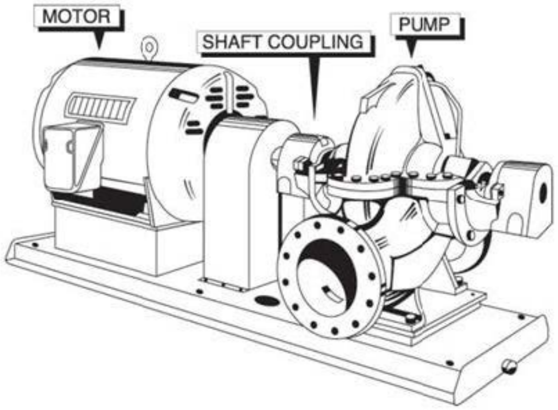
Figure 8.6 – Impeller Inside of Volute Case



Wikimedia Commons

A centrifugal pump with a single impeller is a single-stage pump. Multi-stage pumps have more than one impeller, which can be sequential or parallel to each other. The number of sequential impellers, housed in separate casings determines the number of stages a pump has. Multi-stage pumps do not increase output; however, the multiple stages do increase pressure head. They are often used as high-service pumps to send water into the distribution system. Horizontal case, or horizontal-split case pumps are frequently used to transmit water through the various treatment processes. Figure 8.7 shows a horizontal-split case pump.

Figure 8.7 – Horizontal-split Case Pump

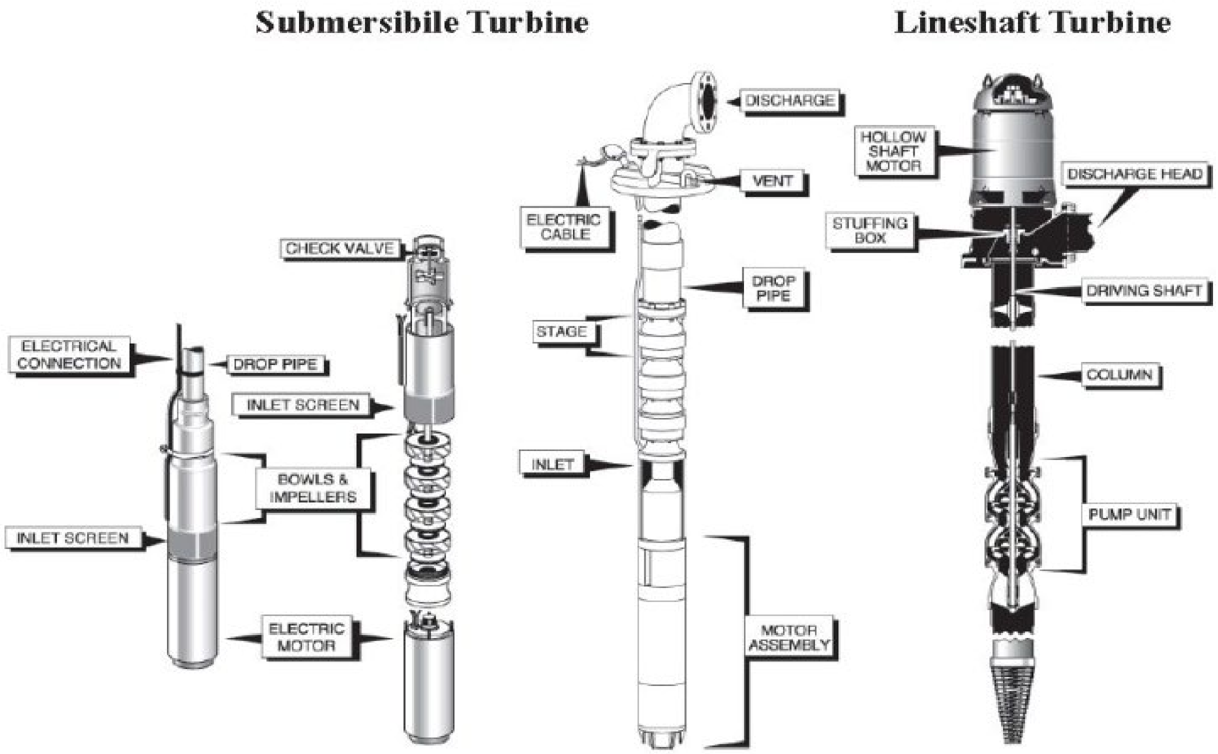


Courtesy of the EPA

A vertical turbine pump is a type of centrifugal pump housed in a vertical casing with a constant cross-sectional area. They use channels or veins to convert the water velocity into pressure. A shaft-type vertical turbine is often used for deep-well pumping. These pumps have multiple stages. The drive unit is located at the surface, and the impeller and diffuser bowls are submerged.

Figure 8.8 shows a cross-section of a submersible and line shaft turbines.

Figure 8.8 – Submersible and line shaft turbines



Courtesy of the EPA

Table 8.2 lists some advantages and disadvantages of centrifugal and turbine pumps.

Table 8.2 – Pump Types and Their Advantages and Disadvantages

Pump Type	**Advantages**	**Disadvantages**
Centrifugal	Simple construction. Wide range of capacities. Adaptable to several drive types. Low cost when compared to output. Can operate against a closed discharge valve for a short time without sustaining damage.	Typically, not self-priming. May run backwards if it is stopped with the discharge valve open. Flow capacity is dependent on discharge pressure. Efficiency is limited based on discharge flows and heads.
Turbine	Simple construction. Flow is uniform at constant speed and head. Adaptable to several drive types. Relatively efficient under the right head conditions.	High initial and repair costs. Unable to pump water with suspended matter in it. Internal parts require lubrication. Efficiency is limited to a narrow range of discharge flow and head conditions.

Smaller systems may use a submersible pump for their wells. These pumps are completely under water, including the motor. They tend to be lower in cost, making them a good choice for private wells and small systems. The main drawback is that, when something breaks, they must be removed to be repaired. In most cases, it is cheaper to replace them than to repair them.

A combination centrifugal-jet pump is another type of pump that may be used for private wells. They are also relatively low-cost to install and low maintenance. Due to their lack of efficiency, they are not suitable for a public water supply.

Pump Maintenance

The best resource for operating and maintaining pumps and other equipment is the manufacturer's documentation. Refer to any manuals provided for maintenance schedules and operating instructions.

Packing and bearings should be checked regularly. Ensure that the oil level is in the normal operating range, and change it as directed by the manufacturer. Listen for any unusual noises. These can indicate abnormal operating conditions.

Low pressure at the suction end of a pump can cause some of the water entering the pump to vaporize, creating air bubbles. This condition is called cavitation. The air bubbles make a pinging sound, like gravel or marbles hitting the metal inside the pump or discharge pipes. These air bubbles can cause damage to the pump or the pipes on the discharge side. Table 8.3 lists common issues with centrifugal pumps and their potential causes.

Table 8.3 – Pump Troubleshooting

Problem	**Possible Cause**
Water is not coming out of the pump.	• Pump is not primed • Debris in the impeller • Malfunctioning valve • Rotating in the wrong direction
Low flow from pump.	• Air pocket or leak in the suction line • Speed is too low • Valve is clogged or malfunctioning • Air is leaking into the pump through the stuffing boxes
Low pressure from pump.	• Rotating in the wrong direction • Impeller is damaged • Wearing rings are worn • Speed is too low
Noise or vibration from pump.	• Bearings are worn • Shaft is bent • Misaligned • Rotor is out of balance

Pump overheats or seizes.	• Pump is not primed • Bearings are worn • Suction lift is too high • Pump is not properly lubricated
Bearings wear too quickly.	• Misaligned • Shaft is bent • Pump is not properly lubricated • Dirt or debris on bearings
Packing wears too quickly.	• Worn bearings • Packing gland is too tight • Incorrect packing is used • Misaligned

Notice that many of the operating problems can be caused by the same issue, such as misalignment and not priming the pump. Table 8.3 is not a comprehensive list of all pump problems and possible causes. The American Water Works Association (AWWA) and California State University Sacramento (CSUS) publish textbooks and manuals with more detailed information.

Variable Frequency Drives (VFD)

VFDs are smart control systems for a pump that vary the electrical power that goes to it. When used they allow a pump to turn on and off less aggressively, which prolongs its life. They also allow systems to cycle their pump on and off less often because the pumps can run at less than 100% capacity.

Valves

Valves are used to control the flow of water. They are used throughout the distribution system to control treatment processes, and with pumps and other operating equipment. Some functions of valves include:

- Starting or stopping water flow
- Regulating pressure or flow speed
- Backflow prevention
- Pressure relief
- Isolating sections of pipe for repair

Most valves move in one of two ways: rotary or linear stroke. In a rotary valve, the stem turns the internal mechanism 90° to open or close the valve. In a linear stroke valve, many turns of the stem are required to move the internal mechanism up or down.

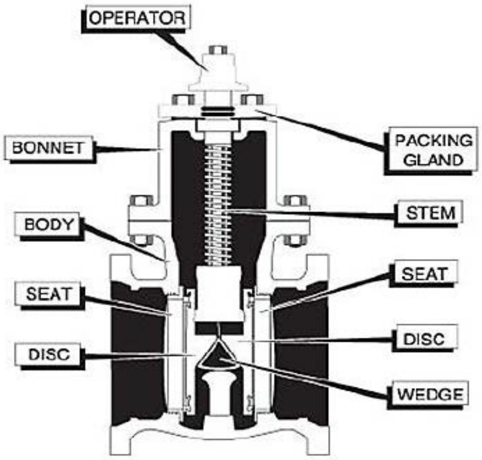
One of the most common valves found in the distribution system is the gate valve. It is a linear stroke valve used to start or stop the flow of water, and for isolating sections of pipe for repair. They work by raising and lowering a disk inside of the valve with a wheel or screw on the outside of the valve. They are available in multiple sizes and configurations.

They are not appropriate for throttling water flow, as the gate, or disk, can be damaged by the water flow if it is not fully raised. Gate valves take time to open and close properly, so they are not well suited for frequent use. Figure 8.9 shows a gate valve. Figure 8.10 is a cross section of a gate valve.

Figure 8.9 – Gate Valve

Courtesy of the EPA

Figure 8.10 - Gate Valve Cross Section

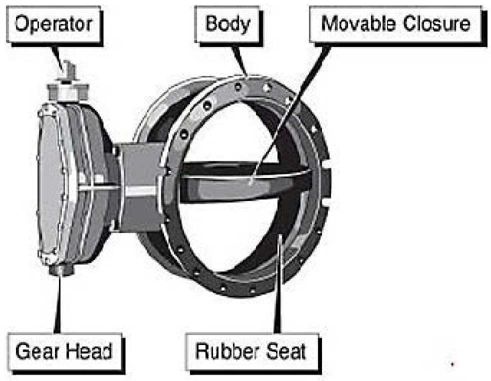


Courtesy of the EPA

Because of the difficulty opening and closing a gate valve, especially the larger ones, bypass valves are often used to bypass gate valves. Bypass valves are smaller in diameter and can reduce the pressure generated on the disk of a larger gate valve. They also allow for a lower volume flow without having to operate the main valve.

Butterfly valves are a rotary valve with a disk that rotates to open and close the valve. They are best used for isolation and automatic control functions. They are easy to install and operate, and less expensive than other types of valves. Head loss is higher with butterfly valves than with gate valves. Figure 8.11 shows a butterfly valve.

Figure 8.11 – Butterfly Valve

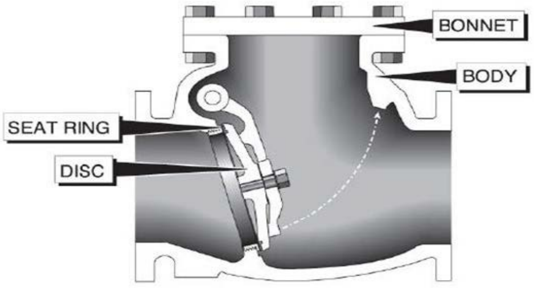


Courtesy of the EPA

Gate and butterfly valves are two examples of valves used to control the flow of water. Other valves are used to control or regulate pressure. Along with backflow prevention valves, which are covered in the next section, these are considered special-purpose valves.

A check valve keeps water flowing in one direction. When water is going in the right direction, a flap opens to allow water to pass. When pressure comes from the wrong direction, it pushes the flap closed, keeping water from flowing in the wrong direction. Figure 8.12 shows a swing check valve.

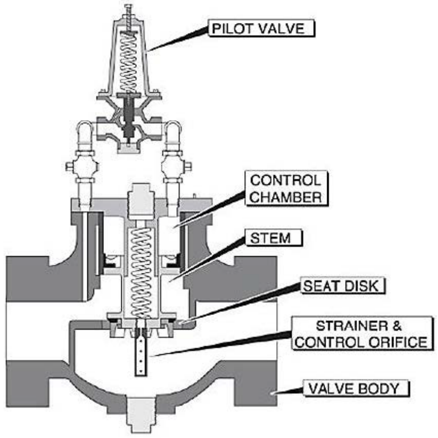
Figure 8.12 – Swing check valve



Courtesy of the EPA

Pressure relief valves are used to relieve pressure in water lines. Reducing pressure, when necessary, helps a system avoid damage to pipes and appurtenances. When the pressure reaches a certain limit, spring loaded stems release disks, venting the excess pressure. Figure 8.13 shows a pressure relief valve assembly.

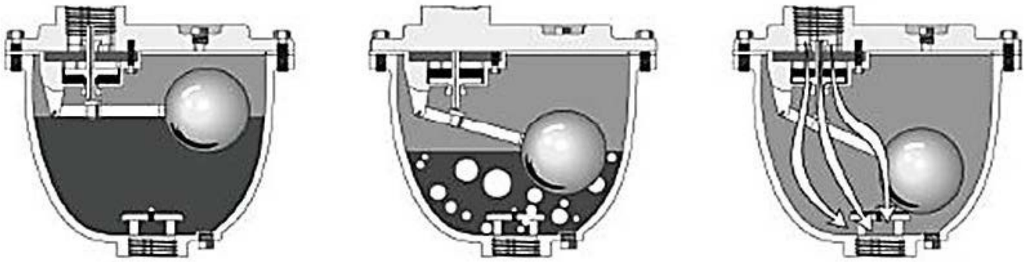
Figure 8.13 – Pressure Relief Valve



Courtesy of the EPA

An air release valve allows air bubbles trapped in a pipeline to escape. They're installed at high points in the system and use a ball float device to open and close the valve. As air enters the system, water is displaced, causing the ball to sink and the valve to open, releasing the trapped air. Figure 8.14 shows an air release valve and how it functions.

Figure 8.14 – Air release valve



Courtesy of the EPA

These are just a few of the valves used in the distribution system. Table 8.4 lists other valves commonly used, their application, advantages, and drawbacks.

Table 8.4 – Valves – Uses and Drawbacks

Valve	Type	Application	Advantages	Drawbacks
Globe	Linear stroke	Flow and pressure regulation	High sealing capacity Resistant to wear	High friction loss Heavy Expensive in larger sizes
Piston	Linear stroke	Flow control	On/Off operations Some flow control	High head loss Sediment can get trapped, causing excessive wear
Needle	Linear stroke	Precise flow throttling Appropriate for use on hydraulic lines to valve actuators	Precise flow control	Small and limited in their application
Plug	Rotary	Flow Control Appropriate for use where slurries, solids, or grit will flow through the valve	Low friction loss Slow shutoff minimizes surges	Heavy Expensive
Cone	Rotary	Flow control Appropriate for high velocities, like pump discharge	Low flow resistance Good flow control	Large and heavy Expensive Difficult and expensive to maintain

Ball	Rotary	Flow control and pressure throttling Appropriate for use at customer connections and curb stops and in pump discharge	Low flow resistance High pressure capability Multiple types of actuators can be used	High initial cost Large sizes are heavy and difficult to install More susceptible to water hammer
Foot valve	Special Purpose	Valve found at the base of a pump or pipeline. Functions like a ball check valve, allowing water to flow in, but blocking it from flowing out of the pump or pipe. It allows the pump to stay primed and includes a screen to keep debris from entering the pump or line.	N/A	N/A

For more comprehensive information on valves, refer to the American Water Works Association (AWWA) *Manual of Water Supply Practices M44 - Distribution Valves: Selection, Installation, Field Testing, and Maintenance.*

System Maintenance

Routine maintenance is important to avoid future problems or failures in the system. A routine maintenance plan should be developed to ensure repairs can be made before a failure occurs. Always refer to the manufacturer’s documentation regarding maintenance schedules for any equipment.

Regular walk-throughs are important for ensuring proper operation. Paying attention to the normal sounds made by plant equipment is helpful in noticing maintenance issues. If something sounds different, it may require additional inspection or repair work.

Valves should be exercised regularly. When valves are not used, they can get stuck in one position. Any meters throughout the plant should be tested in accordance with their size. Large meters should be tested every 1-4 years. Small meters should be tested every 5-10 years. Meters can be recalibrated if they are reading incorrectly but will eventually have to be replaced. The lifespan of the meter depends on the size and type.

Any maintenance performed should be documented. Refer to the section on record keeping for more information on what should be recorded.

Practice Exam

1) Which part of the pump spins the water, creating velocity?
   a. Volute
   b. Impeller
   c. Motor shaft
   d. Bearings

2) Which part of the pump is turned by the motor, transferring torque to the impeller?
   a. Shaft
   b. Volute
   c. Discharge pipe
   d. Suction pipe

3) Which part of the pump prevents debris from entering it?
   a. Motor
   b. Shaft
   c. Water screen
   d. Impeller

4) Which type of pump is frequently used for a deep well?
   a. Peristaltic
   b. Pneumatic
   c. Diaphragm
   d. Vertical turbine

5) Which type of valve is commonly used at the bottom of a well or pipe?
   a. Gate
   b. Foot
   c. Globe
   d. Needle

6) What is the best resource for operating and maintaining a pump?
   a. The internet
   b. The utility maintenance supervisor
   c. Pumps for Dummies
   d. The Manufacturer’s documentation and manuals

7) What is the name for the condition where air bubbles enter the pump?
   a. Cavitation
   b. Air binding
   c. Backsiphonage
   d. Backpressure

8) Which of these is NOT a possible cause if water is not coming out of the pump?
   a. Pump is not primed
   b. A groundhog built a den at the wellhead
   c. Debris is in the impeller
   d. It is rotating in the wrong direction

9) Which of these is a possible cause for low pressure from the pump?
   a. Open gate valve
   b. Air binding
   c. Impeller is rotating in the wrong direction
   d. Water is too warm

10) Which of these is NOT a possible cause for the pump overheating or seizing?
   a. Bearings are worn
   b. Suction lift is too high
   c. Pump is not primed
   d. Water is too warm

11) Hydrostatic pressure describes _________.
   a. Electrical movement
   b. The pressure of moving water
   c. The pressure created by the weight of water
   d. The force of movement of water

12) Which of these valves is best for precise flow throttling?
   a. Gate
   b. Butterfly
   c. Needle
   d. Check

Appendices

Acronyms

ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
AVB	Atmospheric Vacuum Breaker
AWIA	America's Water Infrastructure Act of 2018
AWWA	American Water Works Association
CCC	Cross Connection Control
CCR	Consumer Confidence Report
CEU	Continuing Education Unit
CISO	Chief Information Security Officer
CORC	Certified Operator in Responsible Charge
CPU	Central Processing Unit
CSUS	California State University, Sacramento
CWS	Community Water System
DBP	Disinfection Byproduct
DBPR	Disinfection Byproduct Rule
DC	Double Check Valve Assembly
DE	Diatomaceous Earth
DHHS	Department of Health and Human Services
DO	Dissolved Oxygen
DoS	Denial of Service
DWB	Drinking Water Branch
EMF	Electromagnetic Field
EPA, USEPA	Environmental Protection Agency
ERP	Emergency Response Plan
ES	Effective Size
FBRR	Filter Backwash Recycling Rule
FIFO	First In, First Out
FSO	Facility Specific Operator
ft.	Feet
GAC	Granular Activated Carbon
GFCI	Ground-fault Circuit Interrupters
GFI	Ground-fault Interrupters
GPG	Grains Per Gallon
GPM	Gallons per Minute

GWUDI	Groundwater under the direct influence of surface water
HAAs or HAA5	Haloacetic Acids
HDPE	High-density Polyethylene
HMI	Human Machine Interface
HPC	Heterotrophic Plate Count test
HTH	High Test Hypochlorite
I/O	Input/Output
IAC	Indiana Administrative Code
IDEM	Indiana Department of Environmental Management
IDHL	Immediately Dangerous to Life and Health
IDOH	Indiana Department of Health and Human Services
IT	Information Technology
kPa	kilopascal
L	Liter
lbs	Pounds
LCR	Lead and Copper Rule
LRAA	Local Running Annual Average
LT1ESWTR	Long Term 1 Enhanced Surface Water Treatment Rule
LT2ESWTR	Long Term 2 Enhanced Surface Water Treatment Rule
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
MF	Microfiltration
MFA	Multi-factor Authentication
MFL	Million Fibers per Liter
mg	milligram
MGD	Million Gallons per Day
MRDL	Maximum Residual Disinfectant Level
MRDLG	Maximum Residual Disinfectant Level Goal
MRO	Monthly Report of Operations
NEPA	National Environmental Policy Act
NF	Nanofiltration
NIOSH	National Institute of Occupational Safety and Health
NPDES	National Pollution Discharge Elimination System
NPDWR	National Primary Drinking Water Regulations
NTU	Nephelometric Turbidity Unit
OIT	Operator in Training
OSHA	Occupational Safety and Health Administration
OT	Operational Technology
OWQ	Office of Water Quality
P/A	Presence/Absence test

PAC	Powdered Activated Carbon
PEL	Permissible Exposure Limit
pH	Potential of Hydrogen
ppb	Parts per Billion
PPE	Personal Protective Equipment
ppm	Parts per Million
PSC	Potential Sources of Contamination
psi	pounds per square inch
psig	pounds per square inch gauge
PSM	Process Safety Management
PSP	Process Safety Plan
PVB	Pressure Vacuum Breaker
PVC	Polyvinyl Chloride
PVDF	Polyvinylidene Fluoride
PWS	Public Water System
PWSID	Public Water System Identification Number
RCPP	Reinforced Concrete Pressure Pipe
RMP	Risk Management Plan
RO	Reverse Osmosis
RP	Reduced Pressure Principle Assembly
RTCR	Revised Total Coliform Rule
RTD	Resistant Temperature Devices
SCADA	Supervisory Control and Data Acquisition
SCBA	Self-contained Breathing Apparatus
SDS	Safety Data Sheet
SDWA	Safe Drinking Water Act
SMCL	Secondary Maximum Contaminant Level
SOC	Synthetic Organic Compounds
SWTR	Surface Water Treatment Rule
TC	Total Coliform
TDH	Total Dynamic Head
TDS	Total Dissolved Solids
THM	Trihalomethanes
TOT	Time of Travel
TTHM	Total Trihalomethanes
TWA	Time Weighted Average
UC	Uniformity Coefficient
UF	Ultrafiltration
USGS	United States Geological Survey
UV	Ultraviolet

Glossary

Absorption	The action of something being soaked up by another substance or object.
Acid	Compound that can donate a proton (Hydrogen Ion) or accept an electron pair (Hydroxide Ion) in chemical reactions. Corrosive.
Acute	Serious or severe.
Adsorption	The process of one substance adhering to another.
Aerobic	To metabolize using oxygen.
Alkalinity	A chemical property of water that allows it to neutralize acids.
Amendment	Change to a legislative policy or act
Anaerobic	To metabolize without using oxygen.
Anhydrous	Lacking water.
Anion	Negatively charged ion.
Appurtenance	Equipment or accessories that belong to a larger, more important thing.
Aquifer	Saturated underground formation that will yield usable amounts of water to a well or spring.
Atom	The smallest form of an element or a singular unit of an element.
Backflow	Unwanted flow of water in the reverse direction.
Backpressure	Resistant pressure exerted against the forward flow.
Backsiphonage	Backflow due to reduced pressure within a water system.
Bacterium	Single celled organism that has a cell wall, but no organization within the cell or nucleus, some of which can cause disease.
Base	Compound that can accept a proton (Hydrogen Ion) or donate an electron pair (Hydroxide Ion). Caustic.
Beaker	Lab glassware used for mixing, heating, or observing large amounts of chemical.
Bituminous	Made from bituminous coal, shale, or tar.
Cation	Positively charged ion

Cavitation	Condition where water vaporizes inside of a pump, creating air bubbles which can damage the pump.
Chemical	Substance used in, produced by, or concerned with chemistry.
Chemical	Something used in, produced in, or relating to chemistry.
Chemistry	The study of the properties and interactions of elements.
Coagulation	Process of small particles coming together to make a larger, more solid particle.
Coliform	Bacteria that are always present in the digestive tracts of mammals and found in their waste.
Community Water System	Serves the same population year-round.
Compliance	To follow established rules or guidelines.
Compound	Combination of elements which makes up a new substance. Can be stable or unstable.
Condensation	The process of water vapor in the air turning into liquid water.
Confined aquifer	formation between low permeability layers that restrict movement of water vertically into or out of the saturated formation.
Confined space	Space with limited or restricted entry or exit that is large enough for an employee to bodily enter and perform work but not designed for continuous human occupancy.
Conservation	To prevent wasteful use of a resource.
Contaminant	Chemical or compound that can cause a negative impact on human or animal health. SDWA defines contaminant as "any physical, chemical, biological, or radiological substance or matter in water."
Corrosion	Breakdown of a substance or material due to interaction with chemicals or its environment.
Covalent Bond	Chemical bond formed from elements sharing their available electrons.
Cross connection	Any actual or potential connection between a drinking water system and water system of unknown quality. A connection that could contaminate the system.

Dam	Structure made to stop or control the flow of water.
Deposition	Process of water vapor changing to solid form, skipping the liquid phase.
Disinfection	Process of inactivating or killing pathogenic microorganisms, like bacteria, viruses, and flagellates, typically using a chemical.
Distribution	To spread something out to a group of people or customers.
Drawdown	The lowering of the groundwater surface caused by withdrawal or pumping of water from a well.
Electron	Negatively charged subatomic particle that surrounds the nucleus (center) of an atom.
Element	A substance that cannot be broken down further by chemical methods. Represented on the Periodic Table of Elements.
Epilimnion	Top layer of warm water close to the surface. This layer is mixed by wind as it blows across the surface.
Erlenmeyer Flask	Lab glassware used for observing, heating and measuring approximate chemical volumes.
Evaporation	The conversion of water from a liquid into a gas.
Evapotranspiration	Water moving from the earth into the atmosphere by evaporation from soil and transpiration from plants.
Filtration	Removing solid particles from water by using a filter that allows liquid to pass while retaining the solid particles.
Floc	A clumped mass of fine particles.
Flocculation	Process of slow, gentle stirring of water containing coagulants to form settleable floc.
Galvanic	Producing, causing, or related to an electric current.
Graduated Cylinder	Lab glassware used for measuring precise volumes.
Gravity	Force that attracts an object toward the center of the earth.
Groundwater	Water that exists underground in saturated zones.
Head	Body of water kept at a certain height to supply necessary pressure, or the pressure exerted by a body of water kept at a certain height.
Hydraulics	The study of fluid movement or fluid under pressure.

Hypolimnion	Bottom layer where water is the coldest. Low in dissolved oxygen, which causes anaerobic decay of organic matter.
Impoundment	Non-flowing body of water where water is stored before treatment.
Intake	Structure that connects a surface water treatment facility to the source of water to be treated and allows it to enter the plant.
Ion	Element or compound holding a positive or negative charge.
Ionic Bond	Compound which forms from the attraction of positive and negative ions.
Legislation	Law passed, or adopted, by a governing body
Metalimnion or thermocline	Middle layer where the temperature decreases quickly the deeper the water is.
Meter	Device that measures the quantity or rate of something.
Mohr Pipette	Lab glassware used for delivering precise volumes of liquid.
Monitor	To observe or keep record of something.
Non-transient non-community	Serves the same population for at least 6 months, but not the entire year.
Normal Solution	Solution where the concentration of solute in a solvent measures one gram per liter (1 g/L)
Operator	Person who operates the facility.
Pathogen	Microscopic organism known to cause illness or disease.
Percolation	The slow seepage of water into and through the ground or the slow passage of water through a filter medium.
Permeable	Allows liquid or gas to pass through.
Porosity	The amount of small spaces or holes in a solid substance.
Precipitation	Water that falls to the earth.
Pressure	Continuous physical force used on or against an object.
Primacy	Preeminence, or ranking first in importance.
Protozoan	Microscopic single-celled, motile organism that has organization within the cell wall and nucleus, which may cause illness in humans.

Regulation	Rule or law. The process of enforcing a rule or law.
Responsibility	State of being accountable for something.
Salt	Ionic compound that forms in an acid/base reaction. Salts will dissolve in water, dissociating into free ions.
Sample	Small part of a whole, often used for analysis.
Saturation	Degree to which something is dissolved or absorbed.
Sedimentation	Process of allowing heavier matter contained in water to settle out.
Soluble	Able to be dissolved, especially in water.
Solution	Liquid mixture where one chemical or compound (solute) is dissolved in a liquid chemical or compound (solvent).
Specific Capacity	A formula for determining if a well can adequately meet the demand of a proposed population or use.
Standard Solution	Solution where the exact concentration of solute to solvent is known, typically expressed in milligrams per liter (mg/L) or micrograms per liter (μ/L).
Stratification	Process of forming layers based on density.
Sublimation	The process where ice and snow (solid) change into water vapor (gas) skipping the liquid phase.
Surface Runoff	Water from precipitation that cannot infiltrate the ground and travels to streams, rivers, lakes, reservoirs, and wetlands.
Surface Water	Water that exists on the Earth's surface.
Synthetic	Man-made, not occurring naturally.
Telemetry	Measurement and transmission of data from remote sources to display equipment in another location.
Test Tube	Lab glassware used for mixing, heating, or observing small amounts of chemical.
Titrate	Process of adding a solution of known strength to a liquid, drop by drop, until a certain reaction occurs. Often used to test pH or hardness.
Transient non-community	Provides water to 25 or more people for at least 60 days/year, but not the same people on a regular basis.

Transmission	The process of transporting something from one location to another.
Transpiration	The process of liquid water evaporating from plants and trees into the environment.
Tubercule	Bump or knob that grows or forms on a surface.
Turbidity	Cloudy, opaque or thick with suspended matter
Turnover/Overturn	Seasonal change in stratified body of water where the surface layer (epilimnion) cools and becomes denser, causing it to sink to the bottom, pushing the water at the bottom (hypolimnion) upward.
Unconfined aquifer	The saturated formation in which the upper surface fluctuates with addition or subtraction of water.
Valence	Number of electrons in the outer ring of an atom which determines an element's reactivity with other elements.
Valve	Mechanical device that controls the movement of a liquid or gas through a pipe or duct.
Violation	Infraction, or rule breaking.
Virus	Submicroscopic infectious agent that replicates inside the cells of living organisms.
Volatile	Evaporates easily at normal temperature and pressure.
Water hammer	Condition where a rapid change in pressure within the pipe generates a sonic wave that oscillates back and forth, causing damage to the pipe or outside structures connected to the pipe.
Water Table	The upper surface of an unconfined aquifer.

Chemical Names and Formulas

Acetic acid (Vinegar)	$C_2H_4O_2$
Aluminum Sulfate (Alum)	$Al_2(SO_4)_3 \bullet 14(H_2O)$
Ammonia	NH_3
Arsenic	As
Bicarbonate	HCO_3^-
Bromine	Br_2
Bromodichloromethane	$CHBrCl_2$
Bromoform	$CHBr_3$
Calcium Bicarbonate	$Ca(HCO_3)_2$
Calcium Carbonate	$CaCO_3$
Calcium Chloride	$CaCl_2$
Calcium hydroxide (Lime)	$Ca(OH)_2$
Calcium hypochlorite (High Test Hypochlorite - HTH)	$Ca(ClO)_2$
Calcium Sulfate	$CaSO_4$
Carbon dioxide	CO_2
Carbonate	CO_3^{2-}
Chlorine dioxide	ClO_2
Chlorine Gas	Cl_2
Chloroform	$CHCl_3$
Copper	Cu
Copper Sulfate	$CuSO_4$
Dibromoacetic acid	$C_2H_2Br_2O_2$
Dibromochloromethane	$CHBr_2Cl$
Dichloramine	$NHCl_2$
Dichloroacetic acid	$C_2H_2Cl_2O_2$
Ferrous Sulfate	$FeSO_4 \bullet 7H_2O$
Ferric Sulfate	$Fe_2(SO_4) \bullet 9H_2O$
Ferric Chloride	$FeCl_3 \bullet 6H_2O$
Hydrochloric acid (Muriatic acid)	HCl
Hydrofluosilicic Acid (Hydrofluorosilicic Acid, HFS, Silly Acid)	H_2SiF_6
Hydroxide	OH^-
Hypochlorite ion	OCl^-
Hypochlorous acid	HOCl
Iron	Fe
Lead	Pb
Magnesium	Mg
Magnesium Bicarbonate	$Mg(HCO_3)_2$

Magnesium Carbonate	$MgCO_3$
Magnesium Chloride	$MgCl_2$
Magnesium Sulfate	$MgSO_4$
Manganese	Mn
Methane	CH_4
Monobromoacetic acid	$C_2H_3BrO_2$
Monochloramine	NH_2Cl
Monochloroacetic acid	$C_2H_3ClO_2$
Nitrate	NO_3
Nitrite	NO_2
Sodium permanganate	$NaMnO_4$
Oxygen	O_2
Ozone	O_3
Potassium permanganate	$KMnO_4$
Quick lime (Anhydrous lime)	CaO
Sodium bicarbonate	$NaHCO_3$
Sodium carbonate (Soda Ash)	Na_2CO_3
Sodium chloride (Table salt)	NaCl
Sodium chlorite	$NaClO_2$
Sodium Fluoride	NaF
Sodium hydroxide (Caustic soda)	NaOH
Sodium hypochlorite (Bleach)	NaClO
Sodium Silicofluoride	Na_2SiF_6
Sodium Silicate	$NaSiO_3$
Trichloramine (Nitrogen trichloride)	NCl_3
Trichloroacetic acid	$C_2HCl_3O_2$
Water	H_2O

Practice Exam Answer Keys

Chapter 1

1	C
2	D
3	A
4	B
5	D
6	C
7	B
8	B
9	C
10	B
11	B
12	A

Chapter 2

1	C
2	A
3	D
4	A
5	B
6	D
7	A
8	B
9	C
10	B
11	A
12	C

Chapter 3

1	B
2	A
3	D
4	A
5	C
6	A
7	B
8	C
9	D
10	A
11	B
12	C

Chapter 4

1	B
2	A
3	D
4	C
5	B
6	C
7	B
8	D
9	A
10	C
11	D
12	B

Chapter 5

1	C
2	A
3	B
4	C
5	A
6	D
7	A
8	A
9	C
10	B
11	D
12	A

Chapter 6

1	D
2	B
3	D
4	A
5	C
6	C
7	A
8	B
9	A
10	D
11	D
12	B

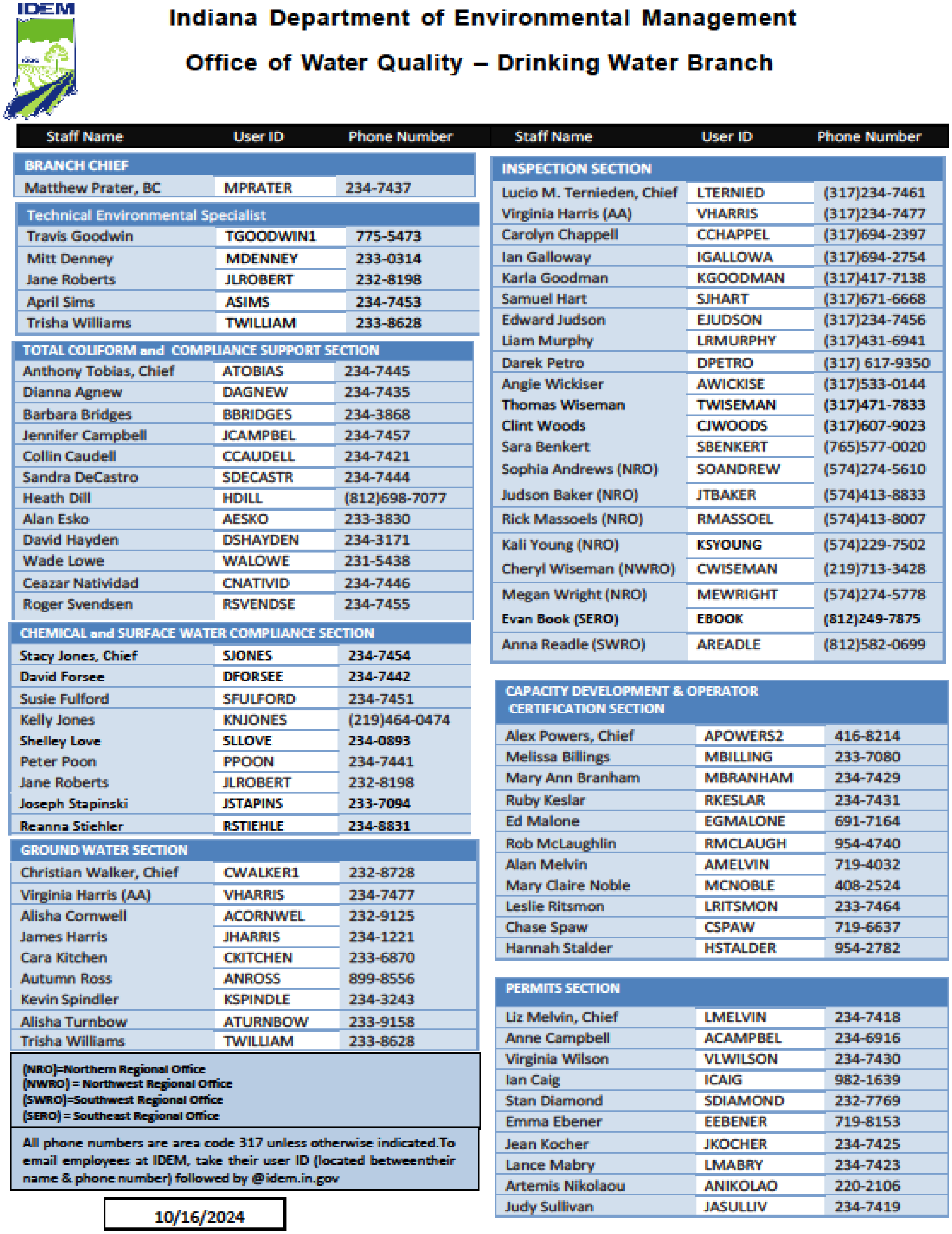
Chapter 7

1	B
2	C
3	D
4	D
5	A
6	D
7	B
8	C
9	D
10	A
11	D
12	C

Chapter 8

1	B
2	A
3	C
4	D
5	B
6	D
7	A
8	B
9	C
10	D
11	C
12	C

Contacts



Indiana Department of Environmental Management

Office of Water Quality – Drinking Water Branch

BRANCH CHIEF

Staff Name	User ID	Phone Number
Matthew Prater, BC	MPRATER	234-7437

Technical Environmental Specialist

Staff Name	User ID	Phone Number
Travis Goodwin	TGOODWIN1	775-5473
Mitt Denney	MDENNEY	233-0314
Jane Roberts	JLROBERT	232-8198
April Sims	ASIMS	234-7453
Trisha Williams	TWILLIAM	233-8628

TOTAL COLIFORM and COMPLIANCE SUPPORT SECTION

Staff Name	User ID	Phone Number
Anthony Tobias, Chief	ATOBIAS	234-7445
Dianna Agnew	DAGNEW	234-7435
Barbara Bridges	BBRIDGES	234-3868
Jennifer Campbell	JCAMPBEL	234-7457
Collin Caudell	CCAUDELL	234-7421
Sandra DeCastro	SDECASTR	234-7444
Heath Dill	HDILL	(812)698-7077
Alan Esko	AESKO	233-3830
David Hayden	DSHAYDEN	234-3171
Wade Lowe	WALOWE	231-5438
Ceazar Natividad	CNATIVID	234-7446
Roger Svendsen	RSVENDSE	234-7455

CHEMICAL and SURFACE WATER COMPLIANCE SECTION

Staff Name	User ID	Phone Number
Stacy Jones, Chief	SJONES	234-7454
David Forsee	DFORSEE	234-7442
Susie Fulford	SFULFORD	234-7451
Kelly Jones	KNJONES	(219)464-0474
Shelley Love	SLLOVE	234-0893
Peter Poon	PPOON	234-7441
Jane Roberts	JLROBERT	232-8198
Joseph Stapinski	JSTAPINS	233-7094
Reanna Stiehler	RSTIEHLE	234-8831

GROUND WATER SECTION

Staff Name	User ID	Phone Number
Christian Walker, Chief	CWALKER1	232-8728
Virginia Harris (AA)	VHARRIS	234-7477
Alisha Cornwell	ACORNWEL	232-9125
James Harris	JHARRIS	234-1221
Cara Kitchen	CKITCHEN	233-6870
Autumn Ross	ANROSS	899-8556
Kevin Spindler	KSPINDLE	234-3243
Alisha Turnbow	ATURNBOW	233-9158
Trisha Williams	TWILLIAM	233-8628

(NRO)=Northern Regional Office
(NWRO) = Northwest Regional Office
(SWRO)=Southwest Regional Office
(SERO) = Southeast Regional Office

All phone numbers are area code 317 unless otherwise indicated.To email employees at IDEM, take their user ID (located betweentheir name & phone number) followed by @idem.in.gov

10/16/2024

INSPECTION SECTION

Staff Name	User ID	Phone Number
Lucio M. Ternieden, Chief	LTERNIED	(317)234-7461
Virginia Harris (AA)	VHARRIS	(317)234-7477
Carolyn Chappell	CCHAPPEL	(317)694-2397
Ian Galloway	IGALLOWA	(317)694-2754
Karla Goodman	KGOODMAN	(317)417-7138
Samuel Hart	SJHART	(317)671-6668
Edward Judson	EJUDSON	(317)234-7456
Liam Murphy	LRMURPHY	(317)431-6941
Darek Petro	DPETRO	(317) 617-9350
Angie Wickiser	AWICKISE	(317)533-0144
Thomas Wiseman	TWISEMAN	(317)471-7833
Clint Woods	CJWOODS	(317)607-9023
Sara Benkert	SBENKERT	(765)577-0020
Sophia Andrews (NRO)	SOANDREW	(574)274-5610
Judson Baker (NRO)	JTBAKER	(574)413-8833
Rick Massoels (NRO)	RMASSOEL	(574)413-8007
Kali Young (NRO)	KSYOUNG	(574)229-7502
Cheryl Wiseman (NWRO)	CWISEMAN	(219)713-3428
Megan Wright (NRO)	MEWRIGHT	(574)274-5778
Evan Book (SERO)	EBOOK	(812)249-7875
Anna Readle (SWRO)	AREADLE	(812)582-0699

CAPACITY DEVELOPMENT & OPERATOR CERTIFICATION SECTION

Staff Name	User ID	Phone Number
Alex Powers, Chief	APOWERS2	416-8214
Melissa Billings	MBILLING	233-7080
Mary Ann Branham	MBRANHAM	234-7429
Ruby Keslar	RKESLAR	234-7431
Ed Malone	EGMALONE	691-7164
Rob McLaughlin	RMCLAUGH	954-4740
Alan Melvin	AMELVIN	719-4032
Mary Claire Noble	MCNOBLE	408-2524
Leslie Ritsmon	LRITSMON	233-7464
Chase Spaw	CSPAW	719-6637
Hannah Stalder	HSTALDER	954-2782

PERMITS SECTION

Staff Name	User ID	Phone Number
Liz Melvin, Chief	LMELVIN	234-7418
Anne Campbell	ACAMPBEL	234-6916
Virginia Wilson	VLWILSON	234-7430
Ian Caig	ICAIG	982-1639
Stan Diamond	SDIAMOND	232-7769
Emma Ebener	EEBENER	719-8153
Jean Kocher	JKOCHER	234-7425
Lance Mabry	LMABRY	234-7423
Artemis Nikolaou	ANIKOLAO	220-2106
Judy Sullivan	JASULLIV	234-7419

Resources

Office of Water Programs/University Enterprises, Inc. (2018). Water Treatment Plant, Volumes 1 and 2, (7th Edition). Pearson Education, Inc.

American Water Works Association. (2016). Water Treatment: Grades 1, 2, 3 &4.

American Water Works Association. (2001). Instrumentation and Control: Manual of Water Supply Practices M2. (3rd Edition).

American Water Works Association. (2004). Problem Organisms in Water: Identification and Treatment: Manual of Water Supply Practices M7. (3rd Edition).

American Water Works Association. (2006). Waterborne Pathogens: Manual of Water Supply Practices M48. (2n Edition).

American Water Works Association. (2015). Backflow Prevention and Cross-Connection Control Recommended Practices: Manual of Water Supply Practices M14. (4th Edition).

American Water Works Association. (2016). Distribution Valves: Selection, Installation, Field Testing, and Maintenance: Manual of Water Supply Practices M44. (3rd Edition).

Indiana Administration Code Title 327 Water Pollution Control Division. Article 8. Public Water supply. (1987). http://iac.iga.in.gov/iac//iac_title?iact=327

Safe Drinking Water Act. 42 USC Chapter 6A, Subchapter XII: Safety of Public Water Systems (1974). https://uscode.house.gov/view.xhtml?req=granuleid%3AUSC-prelim-title42-chapter6A-subchapter12&saved=%7CZ3JhbnVsZWlkOlVTQy1wcmVsaW0tdGl0bGU0Mi1zZWN0aW9uMzAwZg%3D%3D%7C%7C%7C0%7Cfalse%7Cprelim&edition=prelim

EPA 816-R-17-001, Office of Water. How to Conduct a Sanitary Survey of Drinking Water Systems: A Learner’s Guide. (2019).

Pennsylvania Department of Environmental Management. Drinking Water Operator Certification Training: Student Manual, Module 8: Distribution Systems. (2023).