Drinking Water Operator Exam Study Guide

WT4 & WT5

Surface Water

Contents

General Regulatory

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

https://www.epa.gov/

- Mission: To protect human health and the environment.
- Federal agency that implements environmental laws written by Congress.
- Writes regulations and sets national standards for states and tribes to enforce through their own regulations.
- Indiana is in EPA Region 5, which includes Illinois, Michigan, Minnesota, Ohio, and Wisconsin.

Indiana Department of Environmental Management (IDEM)

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

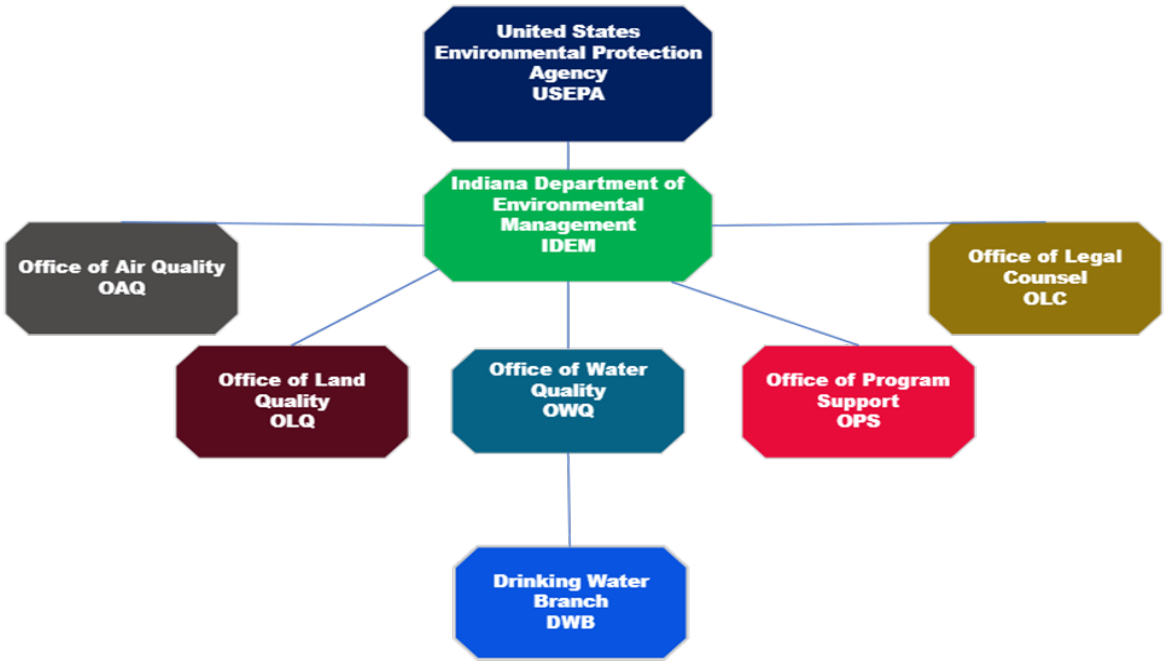
- Mission - to implement federal and state regulations to protect human health and the environment while allowing the environmentally sound operations of industrial, agricultural, commercial, and governmental activities vital to a prosperous economy.
- Indiana has applied for and been granted **primacy** by the EPA.
- State agency that implements environmental regulations.
- IDEM is headed by the Commissioner, Chief of Staff, and General Counsel.
- Divided into five (5) Offices:
    - Office of Air Quality
    - Office of Land Quality
    - Office of Water Quality
    - Office of Program Support
    - Office of Legal Counsel

Office of Water Quality (OWQ) https://www.in.gov/idem/cleanwater/

- Office within the IDEM with a mission to monitor, protect, and improve Indiana's water quality to ensure its continued use as a drinking water source, habitat for wildlife, recreational resource, and economic asset.
- Achieves mission by developing rules, guidance, policies, and procedures in the following areas:

    - Surface and ground water quality assessment.
    - Regulation and monitoring of drinking water supplies and wastewater facilities.
    - Protecting watersheds and wetlands.
      Providing outreach and assistance to the regulated community and the public while supporting environmentally responsible economic development.
    - Indiana's Water Quality Standards as mandated by the Clean Water Act are the measure used for these activities.

Figure 1 - Federal and State Environmental Hierarchies

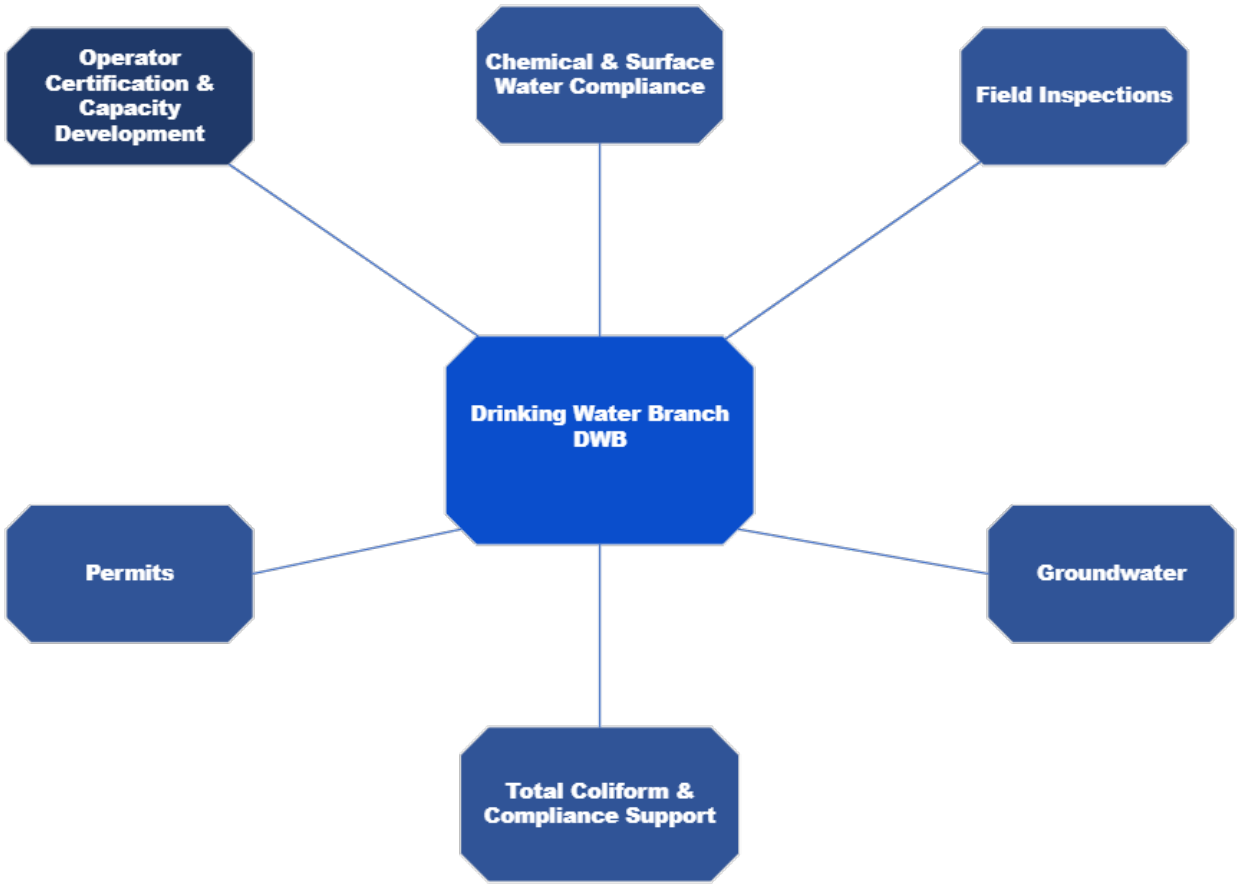


IDEM Drinking Water Branch – Operator Certification and Capacity Development Section

Drinking Water Branch (DWB) https://www.in.gov/idem/cleanwater/drinking-water/

- Branch of IDEMs Office of Water Quality that carries out the requirements of the federal **Safe Drinking Water Act (SDWA).**
- The Drinking Water Branch consists of six (6) sections:
  - Total Coliform & Compliance Support
  - Chemical & Surface Water Compliance
  - Field Inspections
  - Groundwater
  - Operator Certification and Capacity Development
  - Permits

Figure 2 - Drinking Water Branch Sections



IDEM Drinking Water Branch – Operator Certification and Capacity Development Section

Overview of Federal and State Regulations

Federal - Safe Drinking Water Act (SDWA) https://www.epa.gov/sdwa

- Established national drinking water standards to be administered and enforced by state agencies.
- Passed, or adopted, by Congress in 1974 to protect public health by regulating the nation's public drinking water supply.
- Applies to every public water system in the United States.
- Amended in 1986 and 1996 and requires many actions to protect drinking water and its sources.
- 1996 amendments greatly enhanced the existing law by recognizing the following as important component of safe drinking water.

    - Source water protection
    - Operator training
    - Providing funding for water system improvements
    - Public right-to-know

Surface Water Treatment Rule (SWTR)

https://www.epa.gov/dwreginfo/surface-water-treatment-rules

- Published (promulgated) in 1989.
    - 1996 SDWA amendments imposed deadlines (ESWTR)
    - Enhancements published in 1998, 2002, and 2006 (IESWTR, LT1ESWTR, LT2ESWTR)
- Requires surface water systems and groundwater under the direct influence of surface water (GUIDI) to use specific treatment types instead of meeting maximum contaminant levels (MCL) for:
    - *Cryptosporidium* (LT1ESWTR)
    - *Giardia Lamblia* (IESWTR)
    - Viruses

- *Legionella*
- Heterotrophic Bacteria

- *Giardia Lamblia* is a protozoan responsible for most waterborne disease outbreaks in the U.S.
  - The infection from it is called Giardiasis.
  - Causes gastrointestinal (GI) distress including:
    - Vomiting
    - Gas
    - Diarrhea
    - Fatigue
- Filtered water systems must have 2 log (99%) physical removal of *Cryptosporidium.*
  - *Cryptosporidium* is resistant to chlorine and other disinfectants.
  - It is an indicator that groundwater is under the direct influence of surface water.
- Filtration **and** disinfection must remove or inactivate:
  - 3 log (99.9%) of *Giardia Lamblia* cysts and *Cryptosporidium*.
  - 4 log (99.99%) of enteric viruses.
- Maximum Contaminant Level Goal (MCLG) for these pathogens is 0.
- Filtered water turbidity must be under 5 NTUs.

State - Indiana Administrative Code (IAC)

- Indiana regulations that govern how the federal regulations are enforced in the state of Indiana.
- DWB primarily utilizes IAC 327 Article 8.
- IAC establishes maximum contaminant levels (MCLs) for turbidity, microbiological contaminants, and radioactive contaminants.
- Public Notification: Violations of IDEM rules require notification to system consumers within a specific time frame.

- Tier I Violation – 24 hours (immediate notification) acute health risk
- Tier II Violation – 30 days
- Tier III Violation – 12 months

- When a system has complied with a public notification requirement, the system has ten (10) days to submit it to IDEM.

Operator Responsibility

- **The primary responsibility of a water treatment operator is to produce safe and pleasant drinking water.**
- Public Water System – At least 15 service connections or regularly serves 25 individuals daily at least 60 days per year.

Table 1 – Types of water systems

Type of System	**Characteristics**	**Examples**
Community	Serves the same population year-round.	Municipal Utility
Non-transient non-community	Serves the same population for at least 6 months, but not the entire year.	Factories, Schools, Churches
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

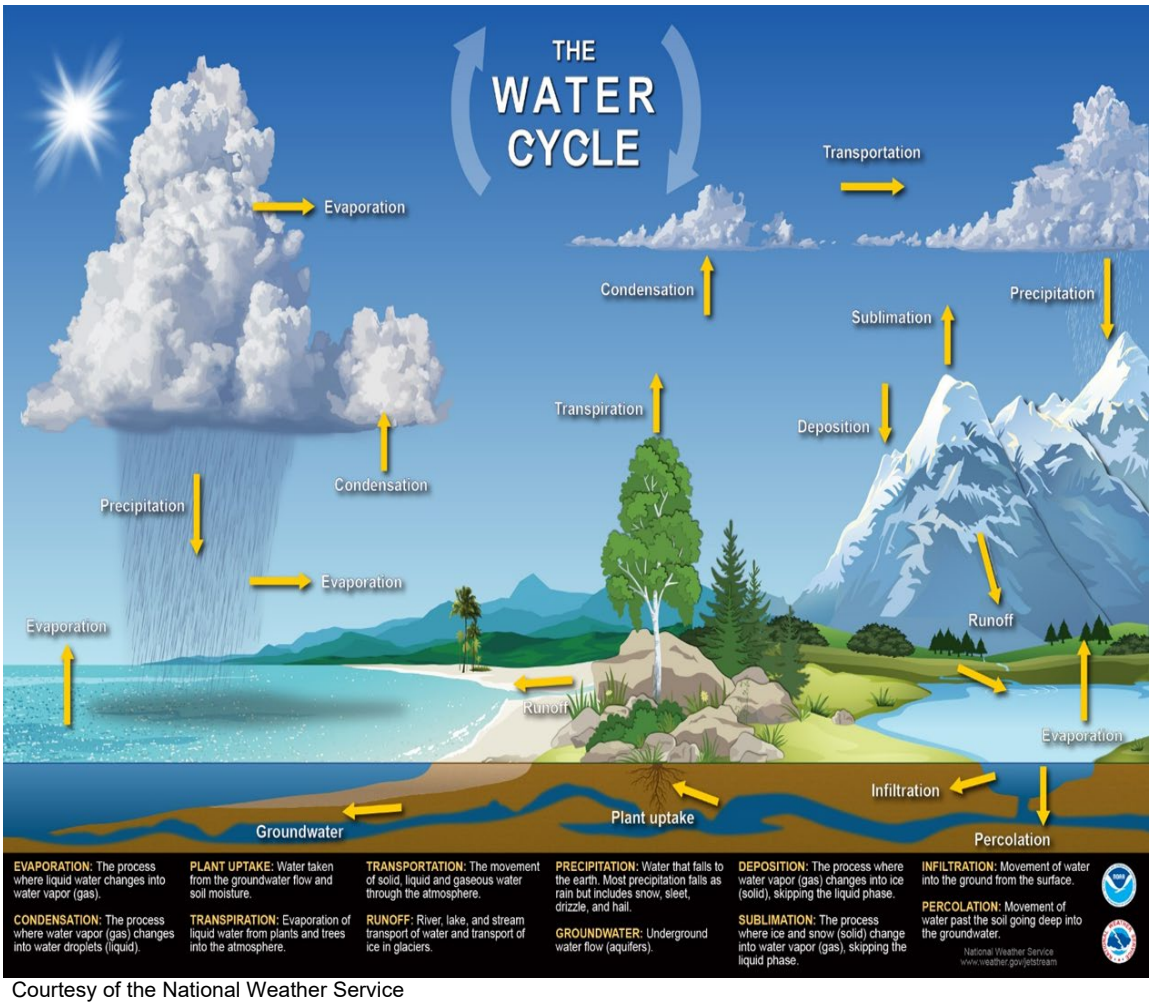
Administration

- Monthly Report of Operations (MRO)
- All community public water supplies that add chemicals to their water are required to make daily entries onto a monthly report of operations (MRO)
- The certified operator-in-charge must sign the report and submit the MRO to IDEM within 10 days following the end of each month
- Records need to be kept for as long as legally required:
    - Chemical analyses – 10 years
    - Bacteriological – 5 years
    - Sanitary Survey – 10 years
- Uniform Rate - A type of rate structure for charging customers to access the water

Source Water

Hydrological Cycle: The hydrological cycle covers the “continuous exchange” of water between the earth and the atmosphere

Figure 3 – The Water Cycle



Courtesy of the National Weather Service

- Condensation: The process of water vapor in the air turning into liquid water.
- Evaporation: The conversion of water from a liquid into a gas.

- Evapotranspiration: Evapotranspiration only covers water entering the atmosphere but does not include water moving from the atmosphere back to the earth.
- Precipitation: Water that falls to the earth. Most precipitation falls as rain, but includes snow, sleet, drizzle, and hail.
- Percolation: The slow seepage of water into and through the ground. The slow passage of water through a filter medium.
- Sublimation: The process where ice and snow (solid) change into water vapor (gas) skipping the liquid phase.
- Transpiration: The process of liquid water evaporating from plants and trees into the environment.
- Water expands roughly 9% between its liquid and solid forms (ice).

Figure 4 - Aquifer

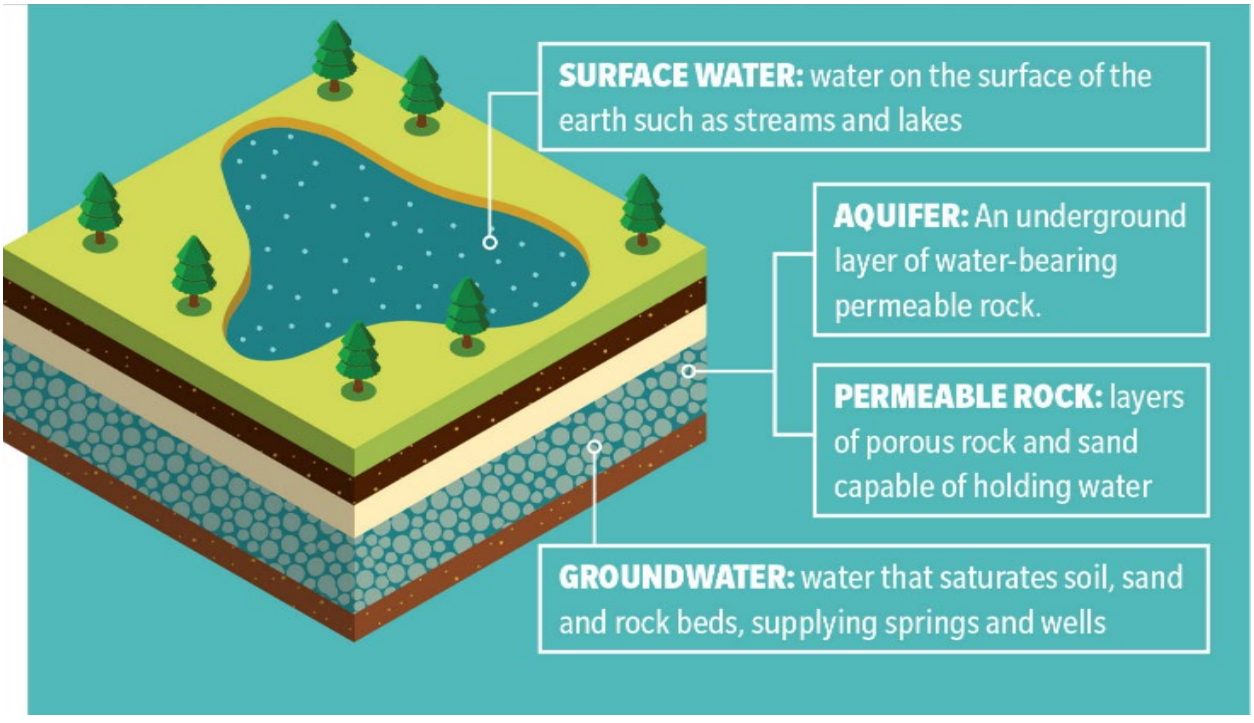


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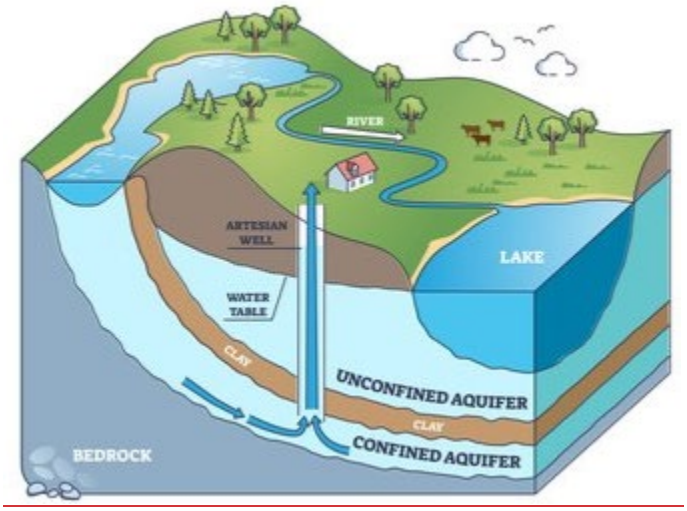
Figure 5 - Aquifer



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Surface Water

- Water on the surface of the Earth that accumulates from precipitation that does not percolate into the ground.
- Direct runoff drains into natural or artificial storage sites like streams, rivers, lakes and reservoirs.
- Softer than groundwater – does not contain as much calcium or magnesium.
- Contains more suspended solids, known as turbidity.
- More susceptible to contamination from microorganisms like bacteria and flagellates.
- Stratification occurs in surface water
    - The water will develop layers with different mineral and nutrient contents
    - Turnover, or overturn, will happen when temperature drastically changes.
        - The water at the bottom layer will move to the top layer.

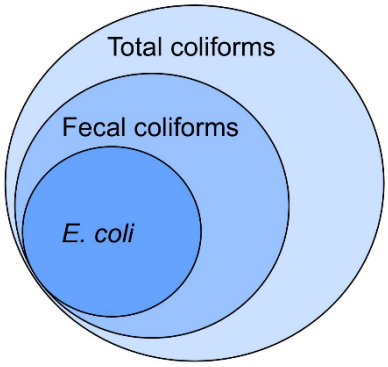
        - Water at the top will move to the bottom layer.
    - Turnover causes algal blooms during spring and fall.
        - Nutrients from the bottom layer that rise to the top provide food for algal growth.
    - Daytime photosynthesis of algae increases dissolved oxygen (DO) during the day.
    - DO goes down at night, when there is no sunlight for photosynthesis.

GWUDI – Groundwater Under the Direct Influence of Surface Water

- Groundwater that has surface water characteristics.
- GWUDI is pumped from wells, then treated.
- GWUDI shows signs of a surface water system if the temperature of the water changes with the seasons.
- A true groundwater system will not change more than a degree or two year-round.
- Also referred to as an unconfined aquifer.
- GWUDI systems are subject to the rules of Surface Water Treatment and require a WT4 or WT5 Operator Certification.

Revised Total Coliform Rule (RTCR)

Figure 6 – Coliform Diagram



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- The Revised Total Coliform Rule (RTCR) requires testing for total coliforms and *E. coli*.

- If a sample has the presence of total coliform bacteria, then a test needs to be done to determine the presence of *Escherichia coli* (E. coli).
    - Total Coliforms are used as an indicator that other potentially harmful bacteria may be present.
    - *E. Coli* (*Escherichia Coli*) bacteria that come from the fecal waste of mammals (i.e. humans, cows, dogs), which can cause acute gastrointestinal illness such as diarrhea, vomiting, and cramps.

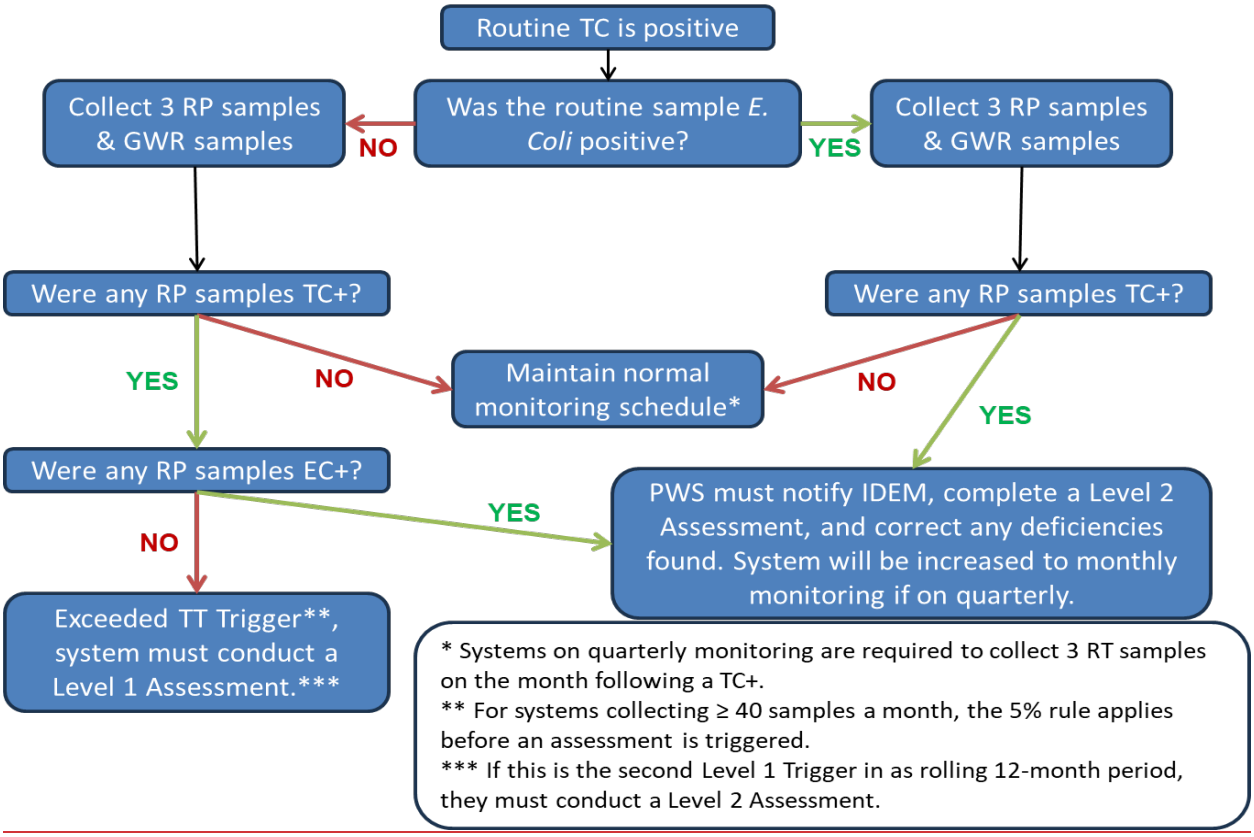
Sample Procedure:

- When sampling, it is best to 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.**
- 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 upstream and downstream.

If a sample tests positive for Coliform, IDEM must be notified within 24 hours!

Figure 7 – Coliform Assessment Flow Chart



Lead and Copper Rule (LCR)

- Dictates the monitoring requirements for lead and copper in systems.
- Lead and copper are based on “Action Levels” rather than “Maximum Contaminant Levels”.
- The action level for lead (Pb) is 0.015 mg/L.
- The action level for copper (Cu) is 1.3 mg/L.
- If the lead or copper concentrations reach the action level, the water system must take steps to reduce the amount of lead or copper.

- A system must first take one sample per six-month monitoring period for two consecutive monitoring periods (one calendar year).

- Then the system may reduce to once per calendar year for three years, then reduce to once every three years.

- If a system’s lead and copper sample exceed action levels, the system must sample once per six-month monitoring period again.

- Lead and copper samples are collected from cold water taps at homes and businesses.

- The sample containers are 1000 mL rather than 100mL like Coliform samples.

- When monitoring for lead and copper, the system must use the first-draw or first-flush of the system after it has been unused for six hours.

- The Lead and Copper Rule does not include cast iron pipes with lead joints.

Clarification, Sedimentation, Coagulation, & Flocculation

- Turbidity is the name for suspended matter in water.
- Coagulation, flocculation, sedimentation, and filtration (called conventional treatment) is the best process for removing turbidity from water.
- Large particles will settle out on their own through sedimentation.
- Particle size impacts their settling rate.
- Colloidal particles are small and will not settle with gravity.
- These particles have a positive or negative charge.
- The suspended and colloidal solids in natural water usually have a negative charge.
- Zeta potential measures the number of excess electrons on the surface of particles.
- Chemical coagulants have a positive or negative charge that neutralize the charge of the suspended particles, causing them to pull together and create large pieces called floc.
- Van der Waals forces cause the neutralized particles to pull together.
- Metal salts are common coagulants.
- Metal salts work better in water with high alkalinity.
- When Alum reacts with alkalinity it forms Aluminum Hydroxide.

Table 2 – Coagulants and Aids

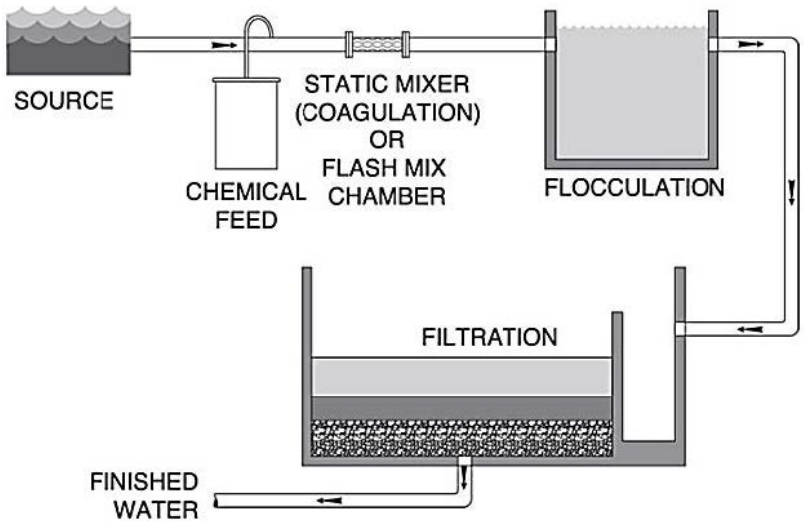
Primary Coagulant	**Aid**
Aluminum Sulfate (Alum)	Bentonite Clay (Weighting agent)
Ferrous Sulfate	Calcium Carbonate
Ferric Sulfate	Sodium Silicate (Activated silica)
Ferric Chloride	Cationic and Nonionic Polymers

- Coagulants are mixed into raw water.
- They can be added dry, with a volumetric or gravimetric feeder.

    - Dry feeders feed into a mixing tank to form a solution.
- Solution feeders are used for coagulants and coagulant aids.
    - The solution is typically pumped through a metering pump or peristaltic pump.
- Rapid mixing (flash mixing) is commonly used to quickly distribute the coagulant into the raw water.
    - They work by agitating the water quickly.
- Static mixers used fixed tubes, or veins, to distribute coagulant.
    - Static mixers can also lead to head loss.

- The coagulant's reaction is quick, taking only a few of seconds (1-5).
- Polyelectrolytes (Polymers) are used as coagulants, aids, or as both.
- Polymers can be cationic (positive charge), anionic (negative charge), or nonionic (no charge).
- Polymers used as a filtration aid can be overdosed, causing faster head loss.
- Using too much silica can clog filters.
- Weighting agents are used with color is high and turbidity and mineral content are low.
- Flocculation uses large paddles to slowly turn water with coagulants mixed in, in basins, creating larger pieces of floc that will settle easier.
    - Baffles are used to slow water flow in the basin.
    - Short circuiting happens when water moves from the inlet to the outlet of a basin too directly, reducing contact time.
- Detention time ranges from 15 to 45 minutes.
- The large floc develops in about 30 minutes.
- Direct filtration is used in treatment when turbidity, on average, is 25 ntu or lower.
- Direct filtration skips the sedimentation step.

Figure 8 - Direct filtration



EPA - How to Conduct a Sanitary Survey of Drinking Water Systems

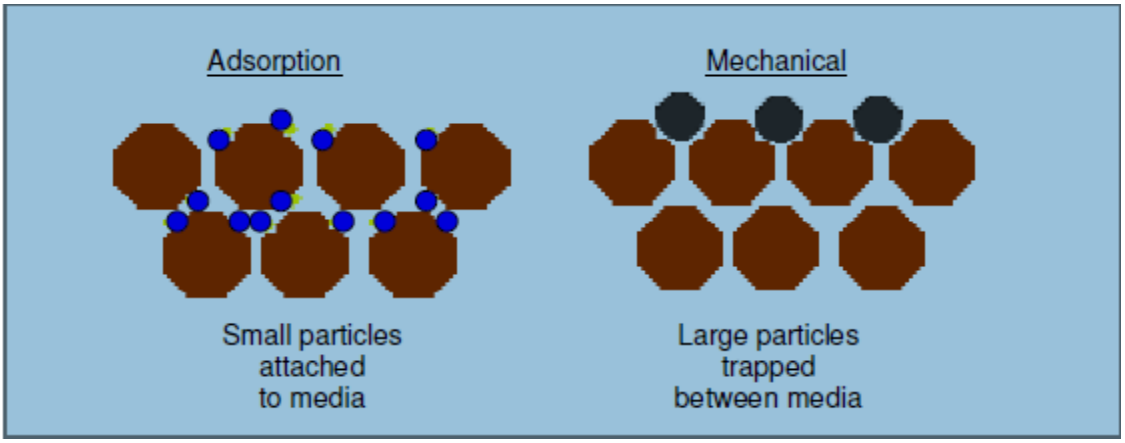
- Jar tests simulate coagulation.
  - They are used to determine the proper chemicals to use for different source water conditions.
- Sedimentation basins are used to clarify the water.
- Water enters the basin (influent), and slow movement allows large particles to settle to the bottom of the basin.
- Floc and sediment that settle to the bottom of the basin is called sludge.
- Water leaving the basin is called effluent water.
- Influent and effluent water are tested to determine contaminant removal percentages.
- Basins can be rectangular or circular.
- All basins have 4 zones.
  - Influent – decreases velocity of incoming water.
  - Settling – allows suspended matter to settle.
  - Effluent – allows slow, smooth currents to move water out of the basin without disturbing the settling solids.
  - Sludge – removes solids from the basin.
- Effluent launders collect the settled water leaving the basin.

    - Weirs are used to evenly distribute the overflow in the effluent launder.
- Shallow basins can reduce settling time.
- Surface area in settling basins is increased using plate and tube settlers.
    - Tube settlers angled between 50° and 60° are self-cleaning.
    - Inclined plates are placed at a 45° angle to allow sludge to flow downward.
- Sludge must be removed from the sludge zone.
    - Thick layers cause sludge to return to the clarified water.
    - Decaying sludge can cause taste and odor problems.
- Sludge and chemical residuals are dewatered before being sent to waste facilities.
    - Nonmechanical dewatering uses lagoons or drying beds to evaporate water.
    - Mechanical dewatering uses machines to press or spin water from the sludge, like vacuum filters, belt presses, or centrifuges.

Filtration

- Filtration removes suspended particles from water.
- Material in the filter is called media.
- Common filter media include:
    - Sand
    - Coal
    - Anthracite
    - Granular activated carbon (GAC)
- Dual-media and multimedia filters are more efficient than single-medium filters.
- Filter performance goals are included in the IESWTR.

Figure 9 – Adsorption vs. Mechanical Filtration



IDEM Drinking Water Branch – Operator Certification and Capacity Development Section

- Adsorption - particles suspended in the liquid **attach** to the filter media.
- Mechanical filtration - particles physically get trapped in the filter media.
- Slow sand filters are large and use gravity to filter water through a bed of sand.
    - They are older technology and not commonly used.
    - Cleaned by scraping about an inch of sand from the top and are not backwashed.
- Diatomaceous Earth (DE) filters can only be used for water with low turbidity.
    - They have high operating costs.

- Schmutzdecke - A mixture of fine sand and a sticky mat of suspended matter that forms on the surface of a sand filter.
    - Aids the sand filter in removing material.
- High-rate sand filters use dual or multimedia.
    - Coarse, less dense layers at the top.
    - Fine, denser layers at the bottom.

- Filter Pore Size – Micro > Ultra > Nano > Reverse Osmosis (RO)

- Microorganism size – Virus < Bacterium < Protozoa

- Pressure filter capacity is 6-12 gpm/ft^2
- Gravity filter is 1-2 gpm/ft^2.

- Air binding - Caused by the release of dissolved gases in saturated cold water when pressure decreases in filter beds.

- Head loss - As the filter accumulates contaminants, the water level will rise due to the build-up of particles from adsorption and mechanical filtration.
    - Operating experience will determine the head loss point at which the filter should be backwashed (cleaned).

- Reverse osmosis is the smallest of membrane technologies with microfiltration being the largest.
    - Uses a permeable membrane for filtration.
    - The membrane is fragile but highly effective for removing arsenic.

Filter Maintenance

- Filters will become clogged with media after periods of use
- Backwash cycles clean mechanical filters to extend their lifespan.
    - Backwashing reverses the flow through filter to remove entrapped material.
    - Backwash rates should be ramped up slowly to avoid damage to the filter.
        - The goal is to remove impurities without losing filter media.
        - Pressure filters should be backwashed when head loss equals 8 psi, when turbidities rise, or at least once a week.
- Gravel on the surface of a sand filter can indicate a “blown” or upset filter.

- Mudballs - Clumps of filter media and other material caused by an insufficient frequency of backwashing.

- To increase the length of a filter run, add a layer of anthracite.

Disinfection

- Disinfection is the process that inactivates pathogenic organisms.
  - Accomplishes this process by using chemical oxidants.
  - Systems that use chemical disinfection can reduce wellhead protection zone from 200 ft. to 100 ft.

Treatment Goals

- To provide clean, safe drinking water, without bad colors, odors or tastes.
- To remove or inactivate pathogens (protozoans, bacteria, viruses).
- To reduce natural and man-made chemical contamination to levels that meet regulatory guidelines and protect human health.
- To produce chemically stable water that will not corrode metal pipes and fixtures.
- **The following tables contain information on many common contaminants found in source water. A complete list of regulated contaminants can be found at** https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations

Table 3 – Associated health hazards and removal techniques for regulated contaminants

Contaminant	Removal Techniques	Health Hazards
Giardia and Cryptosporidium	Reverse osmosis, absolute one-micron filters, UV Light, and filters certified for cyst removal	Acute Gastrointestinal problems, such as vomiting and diarrhea
Bacteria and Viruses	Chemical treatment, Reverse osmosis, UV light	Dependent on bacterium or virus
Arsenic	Adsorption	Skin damage, circulatory system problems, increased cancer risk
Disinfection byproducts	Point-of-entry adsorptive media systems, aeration, carbon filtration, and reverse osmosis	Increased cancer risk.

Lead	Reverse osmosis, and some carbon filters	Impaired mental and physical development in children.
Copper	Reverse osmosis or ion exchange	Short term - Gastrointestinal distress Long term – Liver and kidney damage. People with Wilson's disease are especially susceptible.
Nitrates	Reverse osmosis or ion exchange	Methemoglobinemia, a.k.a. blue baby syndrome.
Pesticides	Some carbon filters	Increased cancer risk.
Radium	Ion exchange or reverse osmosis	Increased cancer risk.
Radon	Granular Activated Carbon and aeration	Increased cancer risk.

Chlorine

- Used to kill bacteria and viruses.
- Measured as free chlorine or total chlorine.
- Free chlorine is the concentration of residual chlorine present as a dissolved gas.
- (DPD) Color comparator is the simplest way to measure free chlorine residuals.
- Breakpoint chlorination is reached when dosage is increased and a corresponding increase in the chlorine residual happens.
- Contact time is required – CT value = (Free Chlorine)(Contact time).
- Ineffective against Cryptosporidium and Giardia.
- Used to precipitate dissolved iron, manganese and sulfur.
- Comes in gas (Cl_2), solid (calcium hypochlorite) and liquid (sodium hypochlorite) forms
- Cl_2 gas is fed through a vacuum hose that connects the tank to an injector.
    - Dissolves in water to form hypochlorous acid (HClO or HOCl).
    - High and low vacuum conditions on the chlorinator indicate a problem with supply or the injector.

- Cylinders are either 150lb or 1-ton.
- A full 1-ton cylinder weighs 3,700lbs and will need transportation and lifts rated for that weight.
- A 150 lb. cylinder has a max feed of 40-42 lbs./day.
- A 1-ton cylinder has a max feed of 400 lbs./day.
- The fusible plug on a 1-ton cylinder will melt at 160° F.

- Calcium Hypochlorite [$Ca(ClO)_2$] combined with water in a flash mixer to form a solution, then fed through an injector.
- Sodium Hypochlorite (NaOCl) is fed directly into the water being treated in its liquid form.
- Gas is the strongest disinfectant, followed by solid, then liquid.
    - Gas is the slowest to degrade and liquid is the fastest to degrade.
    - Chlorine gas is 2.5 times heavier than air.
    - Expansion ratio of liquid chlorine to gas is about 460:1
    - Gas requires more safety measures than liquid or solid.
    - Chlorine can generate harmful byproducts, THMs and HAAs.

- Clear wells - Water storage structures typically located at the end of a treatment train or well system.
    - Used for contact time when chemicals are added.

Safety Regulations for Cl

- **EPA**: A system with 2,500 pounds of chlorine for a single process must complete a risk management plan (RMP).

- **OSHA**: A system with 1500 pounds of chlorine for a single process must complete a site assessment under the process safety management (PSM) regulations.
    - The concentration of Chlorine immediately dangerous to life and health (IDHL) is 10 ppm.
    - The permissible exposure limit (PEL) is 1 ppm.

Ozone

- Colorless, unstable gas made of three oxygen atoms (O_3)
- Effective in eliminating bacteria and viruses, iron, manganese, and hydrogen sulfide gas.
- Will deactivate Cryptosporidium and Giardia.
- Usually generated by passing dry air through a high voltage electric discharge, or UV generator.
- High equipment and operating costs.
- Does not leave a residual
- Requires special mixing techniques.
- Potential fire hazards and toxicity issues.

Aeration

- Aeration oxidizes water to remove gases and other elements in treatment.
- Oxygen precipitates metals like iron and manganese for removal.
- The exchange of gases from air to water for oxidation is called stripping.
    - This oxidation will precipitate metals like iron and manganese.
    - This process reduces or removes hydrogen sulfide, radon, CO_2, and VOCs from water.

- Diffused aeration – introduces air bubbles into the water in a contact chamber.
- Spray aeration – water sprayed through nozzles on a pipe grid, which breaks it into smaller drops.
- Multiple-tray aerators – Water trickles through a series of trays with slots or a wire mesh bottom.
    - Coarse media such coke, ceramic balls, or stone are placed at the bottom to increase surface area.
    - Air is supplied at the bottom of the enclosure and travels upward, counter to the flow of water.

- Cascade aerators – Water is allowed to flow downward over a series of steps, causing the water to fall in thin layers from one level to another.
- Packed tower aeration (Air Stripping) – Cylindrical tower is filled with randomly dumped packing material to provide more surface area for contact between water and air.
- Aeration and stripping are the best processes for removing THMs.
    - Henry's law – $C = kP$ – the amount of a dissolved gas is directly proportional to its partial pressure about the liquid.

Disinfection Byproducts (DBPs)

- Organic material in water reacts with chlorine compounds used for disinfection.
- Increase cancer risk and may cause nervous system and organ damage.
- Prevented by delaying chlorine application or using alternative disinfection techniques like ozone and UV treatment.
- Removed using Granular Activated Carbon (GAC), nanofiltration, or reverse osmosis.

Table 4 – Disinfection Byproducts and MCLs

DBP Type	**MCL**	**Types**
Haloacetic Acids (HAAs or HAA5)	0.06 mg/L	Monochloroacetic acid, dichloroacetic acid, trichloroacetic acid, monobromoacetic acid, dibromoacetic acid.
Total Trihalomethanes (TTHM)	0.08 mg/L	Chloroform, bromodichloromethane, dibromochloromethane, bromoform.
Chlorite (ClO_2)	0.8 mg/L	N/A
Bromate (BrO)	0.01 mg/L	N/A

Volatile Organic Compounds (VOCs)

- Carbon based chemicals, often used in manufacturing.
- Can occur naturally.
- Increase risk of cancer and may cause organ and reproductive damage.
- Removed using Granular Activated Carbon (GAC), aeration, or RO.

Table 5 – Volatile Organic Compound Examples

VOC Type	MCL	Source
Benzene	0.005 mg/L	Gasoline, fuel and storage, Petrochemical drilling, processing and production, Landfill seepage
Toluene	1 mg/L	Gasoline additive; manufacturing and solvent operations, adhesives, glues
Carbon Tetrachloride	0.005 mg/L	Solvents and their degradation products, chemical plants, and industrial solvents / additives
Xylenes	10 mg/L	By-product of gasoline refining; paints, inks, detergents

Synthetic Organic Compounds (SOCs)

- Man-made organic chemicals.
- Used as pesticides, herbicides, and fuel additives.
- Removed using Granular Activated Carbon (GAC), aeration, or RO.

Table 6– Synthetic Organic Compound Examples

SOC Type	MCL	Source
Glyphosate	0.7 mg/L	Runoff from herbicide use.
Alachlor	0.002 mg/L	Runoff from herbicide used on row crops.

Ethylene dibromide (EDB)	0.00005 mg/L	Discharge from petroleum refineries.
Polychlorinated biphenyls (PCBs)	0.0005 mg/L	Runoff from landfills; discharge of waste chemicals.

Inorganic Chemicals (IOCs)

- Made of two or more elements.
- Do not usually contain carbon.
- If carbon is present, lacks carbon-to-carbon or carbon-to-hydrogen bonds.
- Removed using adsorption/absorption, GAC, filtration and ion exchange.

Table 7 – Inorganic Chemical Examples

IOC Type	**MCL**	**Source**
Arsenic	0.01 mg/L	Erosion of natural deposits.
Chromium	0.1 mg/L	Natural deposits, mining, electroplating, pigments.
Cyanide	0.2 mg/L	Electroplating waste, steel, plastic and fertilizer production, mining.
Mercury	0.002 mg/L	Natural deposits, industrial waste, landfill seepage.
Asbestos	7 million fibers per liter. (MFL)	Old pipes, naturally occurring, landfill seepage.

Nitrates

- Forms of Nitrogen found in water, including Ammonia (NH_3), Nitrates (NO_3) and Nitrites (NO_2).
- Caused by runoff from fertilizer use, leaking septic tanks, sewage, and erosion of natural deposits.
- Methemoglobinemia “blue baby syndrome” - Caused by nitrite (when nitrate reacts with chlorine it creates nitrite).
- MCL for Nitrate is 10 mg/L.
- MCL for Nitrite is 1 mg/L.
- Treatment methods included ion exchange, reverse osmosis, and electrodialysis.

Fluoride

- Occurs naturally in Groundwater.
- Fluoride is often added during treatment to improve dental health of consumers.
- Optimal fluoridation set by DHHS is 0.7 mg/L.
- Chemicals used in fluoridation include: hydrofluosilicic acid (HFS), sodium fluoride, and sodium fluorosilicate.
- MCL is 4 mg/L.
- MCLG is 2 mg/L
- Health impacts from excessive fluoride (fluorosis) include brown stains on teeth and bones.

Chemical Treatment

- Primarily used for disinfection.
- Used to aid coagulation and flocculation.
- Used to prevent biofilms and other growths in pipelines.
- Used to control taste and odor, and to remove color.
- Used to oxidize iron and manganese (more common in groundwater and GWUDI)

- Chlorine is effective for removing iron, sulfides, and color.
    - It can be used to control biological growth and as a flocculation aid.
- Potassium permanganate is effective for iron and manganese removal.
- Ozone is effective for removing iron, manganese, color, and controlling trihalomethane formation.
    - It is a powerful oxidant and is considered a health hazard at low concentrations.
- Fluoride is often added to promote public dental health.

Corrosion Control

- Corrosion is the destruction or damage of materials, especially metals, slowly through chemical action.
- Steps must be taken at the treatment to inhibit corrosion in the system.
- Corrosion can cause harmful metals like lead and copper to contaminate drinking water.
- Galvanic corrosion – dissimilar metals generate a current, which leads to a faster corrosion rate.
    - The further apart the metals are on the galvanic series, the faster the corrosion rate.
- Corrosion is controlled using several methods.
    - pH Adjustment
    - The pH of groundwater is usually between 6.0 to 8.5.
        - pH lower than 7 will cause corrosion in pipes.
        - A pH over 7 tends to deposit scale.
        - Raising the pH promotes precipitation of Calcium Carbonate (scale), which can offer protection against corrosion.
        - Potassium Permanganate used to soften water can lower the pH and cause corrosion.
- Cathodic Protection – sacrificial anodes, impressed current, or dissimilar metals are used to inhibit corrosion.

Monitor, Evaluate, Adjust

- Stabilization is the process of balancing the pH of finished water.
- It controls both corrosion and scaling.
- Low pH causes corrosion.
- pH and alkalinity are raised by adding chemicals like soda ash, caustic soda, and lime.
- Tuberculation is the build up of corrosion products in pipes.
- Low pH also favors the formation of haloacetic acids.
- Calcium carbonate precipitates out in water with a high pH, and precipitation is dependent on pH.
- Softening raises the pH, causing calcium carbonate precipitation.
- Calcium carbonate forms scale in pipes.
- High pH also favors the formation of TTHMs.
- Carbon dioxide is used to decrease alkalinity.
- Some bacteria produce carbon dioxide, which can lower pH and cause corrosion.
- If water is low in alkalinity and calcium, polyphosphates can be used to inhibit corrosion.
- Polyphosphates are a nutrient that feed bacteria.

Equipment

Meters

- A meter is a device used to measure the input or output of chemicals or water.
- Positive Displacement - Primarily used for lower flows (around .25 to 150 GPM); range from .5 inches to 2 inches.

- An example would be a rotameter.
- Used with chlorine/chemical feed.
- Suction and discharge valves should be open when in use.

- Turbine - Primarily used for flows at or above 150 GPM

  - Sizes range from three inches to 20 inches.
- Demand meter – used to measure average power load during a specific period.

Valves

Table 8 - Valves

Valve type	**Use**	**Notes**
Gate valve	To allow or stop the flow of water.	Most common valve in the water supply system. Generates the least head loss when fully open.
Check valve	To keep water flowing in a single direction.	Not considered a backflow prevention device, can cause water hammer if closed too quickly.
Bypass valve	Used to divert water flow around a treatment device.	Used with a gate valve.
Globe valve	Used to control flow rate, or throttle, water in a pipeline.	A fully open globe valve will have higher head loss than any other valve.
Butterfly valve	Controls flow using multiple circular flaps in the middle of the device.	Low maintenance and appropriate for very large flows.
Needle valve	Controls flow rate using a tapered plunger on a spin handle.	Best for precision flow control.

Chemical Feed Equipment

Table 9 – Chemical Feed Equipment

Type	Use	Notes
Hypochlorinator	To feed liquid chlorine solution into the water supply.	Scale is most likely to form in the suction and discharge hoses.
Diffuser	Used to evenly disperse a chlorine solution into the main water flow.	
Injector	Creates a vacuum and enables a chlorinator to work.	
Vacuum regulator	Stops flow of chlorine gas in the event of a leak.	
Induction Mixer	To uniformly combine chemicals.	Can be used with gas or liquid.

SCADA

- Supervisory Control and Data Acquisition – used to control and monitor treatment process.
- Contains hardware and software components.
  - Remote terminal units (RTUs)
  - Communications
  - Master Station
- Human machine interface (HMI).

Pumps

Table 10 - Pumps

Type of Pump	Best Use	Drawbacks
Positive Displacement	Use mechanical force to repeatedly move a fixed volume of liquid through the system. Consistent flow rate. Reciprocating or rotary. Used for chemical feeds.	Pulsation can cause cavitation. Restricted flow. Can be difficult to maintain and clogs easily.
Deep Well Turbines (Vertical Centrifugal Pumps)	Best for high-capacity, deep water wells. Made to operate both in the well (bowl and turbine) and above-ground (motor) with a drive shaft connecting the two. The largest of pump types, this pump operates at high pressure and has high efficiency.	High maintenance costs.
Jet	A centrifugal pump that uses a venturi, or a restriction at the nozzle of the suction pipe, to increase effectiveness of the pump.	Low efficiency.

Submersible	Made to operate within the well casing. Multistage (multiple impellers) centrifugal pump with submersible electric motor.	This pump is small and sealed, making it difficult or impossible to do maintenance or repairs, but reduces the likelihood of losing its prime.
Centrifugal	Used to pump water from shallow wells (less than roughly 25 feet of head). and can operate against a closed valve.	Narrow optimum operating range and efficiency point. Not self-priming.

Table 11 – 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	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 a fine mesh material. Prevents debris from entering and damaging the pump.	Screen can get clogged and will require cleaning.

Pump Maintenance

- An operator should be able to recognize failures, troubleshoot, adjust equipment and make minor repairs.
- An operator should have a maintenance program.

- Regularly check all equipment.
  - Routine maintenance is the first level of maintenance.
- Change the oil in a new pump after the first month of operation.
- Cavitation - caused by unusually low pressure within the pump
  - Indicated by pinging sounds.
  - Avoid this by monitoring the speed of the variable-speed pump.
- Monitor the temperature to avoid overheating.

- Ensure that packing does not dry out.
  - Must be replaced when packing gland can't be tightened any further.
- Lubricate bearings on the shaft line with grease or oil – do not use animal oil.
- Overlubricating bearings may result in overheating.
- Follow the manufacturer's maintenance schedule.
- Ensure proper alignment between any shafts.
- Stagger rings of packing so that the joints are between 90 – 180 degrees apart.
- Taking equipment such as filters or pumps off-line may require additional maintenance tasks.

Maintenance

See Filter Maintenance

See Pump Maintenance

Operations

- Operations describes the general running and maintenance of the plant.
- An operator is responsible for providing clean, safe drinking water to the population served.
- The primary concern if contamination is found is the health and safety of the public.
- Aside from disinfection and treatment, steps can be taken to secure your equipment and avoid contamination:
  - Gates, fences and cameras can be installed around storage tanks and buildings to deter entry.

    - Screens can be installed on vent openings, storage tanks, aerators and clear wells.
- Improper use of equipment can create problems in the distribution system.
- Shutting off a pump or closing valves too quickly can lead to water hammer.
    - Water hammer describes the oscillating pressure waves that move through a pipe when pressure in the system rapidly changes.
    - It can cause damage throughout the distribution system, leading to broken pipes, mains, or hydrants.
- Adjusting chemicals and their feed rates is the main way an operator controls the water treatment process.
- It is important to maintain chemical supplies and feeders.

System Design and Infrastructure

- Water height, or elevation, causes pressure head.
    - Pressure head is the amount of liquid that can be raised vertically by a given pressure.
- Friction head is the amount of energy needed for water to overcome the resistance in a pipe.
- Pumps can be arranged in a series to increase the discharge head.
- The operating temperature of a pump should not be more than 160° F.
- Corrosion resistant pipes should be used to carry chlorine gas solution because the pH range is 2-4.

Sample Collection and Interpretation

- Samples are taken to assess water quality and ensure contaminant goals are met.
- The size and procedure of the sample will depend on what type of sample is taken.
- The person taking the sample is responsible for its preservation.

Table 12 - Sample Collection

Sample Type	Volume	Procedure	Notes
Coliform	100mL	See RCTR	Best performed on an unthreaded faucet. Sodium thiosulfate powder in sample container neutralizes chlorine residuals.
Lead and Copper	1L (1000mL)	See LCR	Fill sample container to the shoulder. Ensure that water has had time to stand in the pipes.
Grab Sample	N/A	Taken at a single time. Provides snapshot of water quality at that point.	Best used to test for dissolved gases, coliform, chlorine residuals, DBPs and pH
Composite Sample	N/A	Taken at intervals throughout the day. Shows changes over time.	Should be stored under 40° F (4° C), but above freezing temperature. Never appropriate for coliform 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.

Lab Analysis

Lab analysis requires basic chemistry knowledge.

- Atom – basic unit of a chemical element
    - Made of a nucleus containing protons and neutrons that is surrounded by a cloud of electrons.
    - Electron clouds have rings, with the inner-most ring containing two electrons and each additional cloud containing up to eight electrons.
    - The outer most electron ring contains the valence electrons.
    - Valence electrons react with the valence electrons of other atoms to form chemical compounds.
    - Many metals have multiple valences.
    - The atomic number of an element indicates the number of electrons it contains.
- Ion – Charge carrying atom or molecule.
    - Anion – negative charge
    - Cation – positive charge
- Polarity – A molecule containing a positive charge at one end and a negative charge at the other
    - Water is polar, attracting both cations and anions.
    - Polarity makes water highly conductive.
        - TDS can impact water's conductivity.
- Water reaches maximum density at 4° C or 39.2° F.

- Polarity causes water to form rings, which decrease density, as it freezes.
    - This is why ice floats in water.
- Organic refers to chemical compounds containing carbon.
- Inorganic refers to chemical compounds lacking carbon, or a carbon-carbon or carbon-hydrogen bond.
- pH – Potential of hydrogen – See Water Quality

Lab Equipment

Table 13 – Common Lab Equipment

Name	Use
Volumetric Flask	Accurately measures volume.
Burette	Dispensing solutions.
Pipette	Precisely measuring and transferring liquids.

Safety

Regulatory Agencies

- OSHA – Occupational Health and Safety Administration – Responsible for setting workplace safety standards. (https://www.osha.gov/)
- NIOSH – National Institute of Occupational Safety and Health regulates and approves Personal Protective Equipment (PPE) such as masks.

Confined Space

- A confined space is a space that is large enough for a person to enter and conduct work, however, has limited means for entry or exit.
- Has unfavorable natural ventilation.
- Not designed for continuous occupancy.
- Contains hazards that cause bodily injury or death.

- This can reduce the amount of breathable air in the environment, especially when working with hazardous or toxic substances.
- Because of this, a confined space should **never** be entered unless you have the **appropriate training and permitting.**

- **The safe range for oxygen levels in a confined space is between 19.5% and 23.5%.**

- Confined space permits require the entry supervisor to know the conditions of the confined space.

    - The entry supervisor is also responsible for terminating entries.

- A Self-contained Breathing Apparatus (SCBA) can be used in confined spaces.

    - These units are fitted with a low-air pressure alarm to alert the wearer when they need to leave the area.

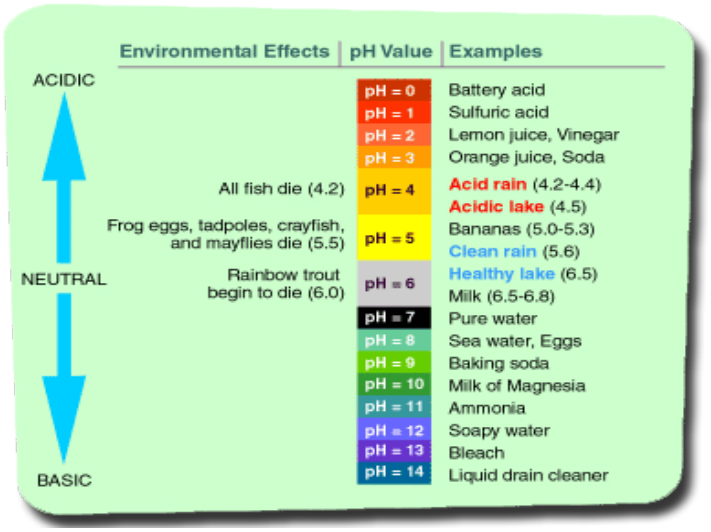
Security

- Physical structures should be secured
  - Fences and locked gates can be used as a barrier.
  - Cameras can be installed to deter entry.
- Computers should be password protected.
  - Multifactor authentication can be enabled for additional security.
- If contamination is discovered in the water supply, the most important concern is public health and safety.

Water Quality

- Although many areas impact water quality, the most common are detailed below.
- pH – Potential of hydrogen – measures the concentration of hydrogen ions

Figure 10 – pH Scale



USGS -usgs.gov

- Corrosivity – Acidic, with potential to damage or destroy pipes, causing materials to leach into drinking water.
- Alkalinity – Basic, measures ability to neutralize acids.
- Dissolved gases – Radon, methane, hydrogen sulfide and carbon dioxide may be harmful to human health or indicate contamination.
- Total dissolved solids (TDS) – may impact odor, taste or chemical consumption.
    - High organic content/turbidity can impact pH, as well as taste and odor.
- Temperature – affects TDS, dissolved gases, and chemical consumption.
- High concentrations of iron or manganese may cause staining of clothing and plumbing fixtures.
- Activated Carbon is used to remove objectionable tastes and odors.
    - Turbidity - A measure of the cloudiness of water. It is used to indicate water quality and filtration effectiveness.
    - Higher turbidity levels are often associated with higher levels of disease-causing microorganisms such as viruses, parasites, and some bacteria.
    - These microorganisms can come from soil runoff.
    - They can cause symptoms such as nausea, cramps, diarrhea, and associated headaches.
    - Customers will notice 5 NTU or more turbidity. Turbidity of 1-2 NTU is the optimum level.

Acronyms

AVB	Atmospheric Vacuum Breaker
CCC	Cross Connection Control
DBP	Disinfection Byproducts
DC	Double Check Valve
DHHS	Department of Health and Human Services
DO	Dissolved Oxygen
EDB	Ethylene Dibromide
EPA, USEPA	Environmental Protection Agency
ft.	Feet
GAC	Granular Activated Carbon
GPG	Grains Per Gallon
GPM	Gallons per Minute
GWUDI	Groundwater under the direct influence of surface water
HAAs or HAA5	Haloacetic Acids
IAC	Indiana Administrative Code
IDEM	Indiana Department of Environmental Management
LCR	Lead and Copper Rule
LSI	Langeliers Saturation Index
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
MFL	Million Fibers per Liter
MRO	Monthly Report of Operations
NIOSH	National Institute of Occupational Safety and Health
OSHA	Occupational Health and Safety Administration
OWQ	Office of Water Quality
pH	Potential of Hydrogen
PPE	Personal Protective Equipment
PSM	Process Safety Management
PVB	Pressure Vacuum Breaker
RMP	Risk Management Plan
RO	Reverse Osmosis
RP	Reduced Pressure
RTCR	Revised Total Coliform Rule
SCBA	Self-contained Breathing Apparatus
SDWA	Safe Drinking Water Act
SOC	Synthetic Organic Compounds
TDS	Total Dissolved Solids
THM	Trihalomethanes
UV	Ultraviolet
VOC	Volatile Organic Compounds

Glossary

Absorption	The process of one material being retained by another.
Adsorption	Adhesion of a substance to surface particles.
Aerobic	To metabolize using oxygen.
Anaerobic	To metabolize without using oxygen.
Anion	Negatively charged ion.
Aquifer	Saturated underground formation that will yield usable amounts of water to a well or spring.
Back pressure	Resistant pressure exerted against the forward flow.
Back siphonage	Backflow due to reduced pressure within a water system.
Backflow	Unwanted flow of water in the reverse direction.
Backwash	To clean a filter by reversing the flow of liquid though it.
Bacterium	Single celled organism that has a cell wall, but no organization within the cell or nucleus, some of which can cause disease.
Cation	Positively charged ion
Chemical	Substance used in, produced by, or concerned with chemistry.
Coliform	Bacteria always present in the digestive tracts of mammals and found in their waste.
Coagulation	Using a chemical additive to attract small particles in water, to form larger particles that will settle.
Community Water System	Serves the same population year-round.
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.
Conservation	To prevent wasteful use of a resource.
Cross connection	Any actual or potential connection between a drinking water system and a potential source of contamination.
Contaminant	Chemical or compound that does not belong in food or water, causing a negative impact on human health. SDWA defines a contaminant as any physical, chemical, biological or radiological substance or matter in water.
Drawdown	The lowering of the groundwater surface caused by withdrawal or pumping of water from a well.
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	Collection of small particles in water that come together to form a larger particle.
Flocculation	Treatment process that uses gentle stirring to bring suspended particles together, forming floc.
Gravity	Force that attracts and 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.
Ion Exchange	The exchange of ions of the same charge between an insoluble solid and a solution in contact with it.
Mechanical filtration	Suspended particles are physically trapped in the filter medium.
Meter	Device that measures the quantity or rate of something.
Non-transient non-community	Serves the same population for at least 6 months, but not the entire year.
Operator	Person who operates the facility.
Percolation	The slow seepage of water into and through the ground or the slow passage of water through a filter medium.
Pore	Small opening in a surface.
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.
Responsibility	State of being accountable for something.
Reverse Osmosis	Separation technique where pressure is applied to a solution to force the solvent through a semi-permeable membrane.
Sanitary Seal	A seal around the wellhead that prevents contamination of the well.
Schmutzdecke	Layer of solids and biological growth that form on top of a slow sand filter.
Sedimentation	Treatment process that allows particles to settle to the bottom of a structure or basin after flocculation has occurred.
Semipermeable	Allows some substances to pass through but not others.
Soluble	Able to be dissolved, especially in water.
Specific Capacity	A formula for determining if a well can adequately meet the demand of a proposed population or use.
Sublimation	The process where ice and snow (solid) change into water vapor (gas) skipping the liquid phase.
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.
Transpiration	The process of liquid water evaporating from plants and trees into the environment.
Turbidity	Cloudy, opaque or thick with suspended matter
Unconfined aquifer	The saturated formation in which the upper surface fluctuates with addition or subtraction of water.
Violation	Infraction, or rule breaking.
Virus	Submicroscopic infectious agent that replicates inside the cells of living organisms.
Water Table	The upper surface of an unconfined aquifer.