<u>**WATER SUPPLY**</u>

When a municipal water supply is not available, the burden of developing a safe water supply rests with the owner of the property.

Public water system:

- At least 15 service connections
- Regularly serves average of at least 25 individuals daily at least 60 days out of the year

Community water system:

- At least 15 service connections used by **year-round** residents
- Regularly serves at least 25 **year-round** residents
- Generally serve cities and towns
- May also serve special residential communities

Non-community water systems:

- **Transient community water system (TWS)**
  - Serve travelers and other transients at locations such as highway rest stops, restaurants, and public parks
  - Serve at least 25 people a day (**but not same people**) for at least 60 days of the year
- **Non-transient noncommunity water system (NTNCWS)**
  - Serve **same 25 people** for **at least 6 months per year**, but not year-round
  - Examples are schools and factories

- 3/4 of all illnesses in the developing world are associated with inadequate water and sanitation.

Factors influencing movement of groundwater:

- Type of geological formation
- Permeability
- Rainfall and infiltration
- Hydraulic gradient

Travel of pollution through the ground:

- **Microbiological pollutants travel a short distance through sandy loam or clay soil**
- **Microbiological pollutants travel great distances (indefinite) through coarse gravel, fissured rock, dried-out cracked clay, or solution channels in limestone**
- Removal of bacteria from liquid percolating through a given depth of soil is inversely proportional to the particle size of the soil
- **Chemical pollution can travel great distances**

- Sand and gravel alone do NOT prevent travel of viruses long distances in groundwater
- **Fine loamy sand over coarse sand and gravel effectively removes viruses**
- Helminth eggs and protozoa cysts do not travel great distances through *most* soils because of their greater size
- **Wellhead** = surface + subsurface surrounding well
- **Radius of drawdown cone/circle of influence** due to hydraulic gradient
  - Fine sand = 100–300 ft
  - Coarse sand = 600–1,000 ft
  - Gravel = 1,000–2,000 ft

(See Minimum Separation Table 1.2, Page 9 in Salvato's Water, Wastewater, Soil and Groundwater Treatment and Remediation) for specific distances in feet sources should be away from various structures.

From Table 1.2:

Source	To Well/Suction Line	To Stream, Lake, or Water Course	To Property Line or Dwelling
House sewer	25 (cast iron) 50 otherwise	25	
Septic tank	50	50	10
Absorption field	100	100	20

All sewage-contaminated waters must be presumed to be potentially dangerous.

Water cycle and geology:

- **Groundwater helps nourish vegetation through the root system by traveling up the plant and coming out as transpiration from the leaf**
- Average annual precipitation in U.S. = 30 in
  - 72% evaporates and transpires
  - 28% contributes to groundwater recharge and stream flow

Surface water:

- Streams
- Lakes
- Reservoirs
- Swamps
- Ponds
- Rivers
- Creeks

Classification and characteristics of geological formations:

- Igneous rock
  - Formed by cooling and hardening of molten rock masses
  - NOT usually good sources of water (though basalts are an exception)

- **Sedimentary rock**
  - Results from deposition, accumulation, and consolidation of materials weathered and eroded from older rocks by water, ice, or wind and the remains of plants, animals, or material precipitated out of solution
  - **Deposits of sand and gravel generally yield large quantities of water**
  - Sandstones, shales, and certain limestones may yield abundant groundwater, but results may be erratic
- Metamorphic rock
  - Produced by alteration of igneous and sedimentary rocks via heat or pressure
  - Small quantity of water is available
- Karst areas
  - Formed by movement of underground water
  - Can be quite porous, so groundwater movement can be rapid
  - Well water is easily contaminated from nearby and distant sources
- Glacial drift
- **Porosity**
  - Measure of amount of water that can be held by a rock or soil in its pores or voids, expressed as a % of the total volume
  - **Effective porosity/specific yield** is the volume of water that will *drain* freely out of a saturated rock or soil by gravity, expressed as a % of the total volume of the mass
- **Permeability**
  - Expressed as **hydraulic conductivity** (or standard coefficient of permeability)
  - The rate of flow of water at 60 degrees F in gal/day through a vertical x-section of 1 sq ft, under a head of 1 ft, per ft of water travel
- Transmissivity
  - The hydraulic conductivity times the saturated thickness of the aquifer

Groundwater flow:

- Can be expressed via Darcy's law ($Q = KIA$)

Groundwater classification:

- Class I
  - Highly vulnerable to contamination
  - Irreplaceable
  - Ecologically vital
- **Class II**
  - All other groundwaters which are currently used or are potentially available for drinking water or other beneficial use
- Class III
  - NOT potential sources of drinking water

Water quality:

- Standards for tap water based on the National Primary Drinking Water Standards (NPDWS) developed under the Safe Drinking Water Act (SDWA) of 1974 as amended in 1986 and 1996
- Maximum contaminant levels (MCLs) are enforceable
- Raw and finished water should be continually monitored
- **Water treatment plant should have:**
  - **Well-equipped lab**
  - **Certified operator**
  - **Qualified chemist**

Sampling:
- Types:
  - Continuous (turbidity and particle counting)
  - **Grab** (instantaneous)
    - **Most <u>drinking water</u> samples are of this type**
  - **Composite** (accumulation of grab samples of equal volume)
    - **Most <u>wastewater</u> samples are of this or the flow-weighted type**
  - **Flow-weighted composite** (proportional to volume of flow)
- Drinking water samples should be collected at times of max water usage
- Sampling tap should be clean, not leaking
- Tap should be **flushed for 2–3 min before sample collection**
  - Except when testing for metals or bacteria in household plumbing
- **1-inch air space** should be left on top of the bottle **for a bacteriological sample**
- Bottle should be **completely filled for a chemical sample** (no air bubble at top)
- Sanitary technique and **glass or plastic sterile bottle** prepped by the lab should be used
- Types of sample collection containers:
  - 1 L plastic (polyethylene) containers = **inorganic** analyses
  - 40 mL glass vials or 1 L glass bottles w/Teflon-lined closure = **organic** analyses
  - 1 or 2 L clean, wide-mouth bottles = **microscopic** examination
- Hands or faucet must not touch the edge of the lip of the bottle or the plug part of the stopper
- Sample should be taken from a faucet that does NOT have an aerator or screen
- Flaming of the tap is optional
- A household water softener or other treatment unit may introduce contamination
- **If sampling chlorinated water, sample bottle should contain sodium thiosulfate to dechlorinate**
- All **samples should be examined promptly after collection within 6–12 hrs** if possible
- If routine sampling results in a “positive” indication of coliform bacteria, repeat sampling must be performed to verify its presence
- **Effectiveness of treatment processes can be measured using tests for** the following 6 mo prior to and 12 mo after process is put into use:
  - **Total coliforms**

        - **Fecal coliforms**
        - **Fecal streptococci**
        - **Standard plate count**
            - The total number of colonies of bacteria developing from measured portions of the water being tested
- Drinking water will normally contain some nonpathogenic bacteria; it is almost never sterile

Bacterial examinations:
- **Bacterial examinations for drinking water should ALWAYS include, at a minimum, total coliform tests**
- **Coliforms are indicative of fecal contamination or sewage pollution**
    - **Presence of <u>ANY</u> coliform organism in drinking water is danger sign**
    - E. coli makes up about 95% of the fecal coliforms
    - **Gas formation within 24–48 hours is indicative of a positive coliform test**
    - If fewer than 40 samples/mo, < 1 should be positive
    - If 40 or more samples/mo, < 5.0% should be positive
- **Clostridia sporulates** can survive indefinitely in the environment
    - They are more resistant than E. coli and streptococci
    - **Their presence indicates past or possibly intermittent pollution**
- **Fecal coliforms** are indicative of fresh and possibly dangerous pollution

Virus examination:
- Viruses range in size from 0.02–0.1 μm
- Enteroviruses may be more resistant to treatment and environmental factors than fecal bacteria, persist longer in the water environment, and remain viable for many months
- Coagulation, flocculation, settling, and rapid sand filtration; slow sand filtration; and lime-soda softening processes remove 99% or more of viruses
- **pH > 11 inactivates viruses**
- Free chlorine is more effective than combined chlorine
- **Turbidity can shield viruses and make chlorination only partially effective**
    - Turbidity = clay, silt, organic/inorganic matter in water
- **<u>EPA requires 99.99% removal</u> and/or inactivation of enteric viruses**

Protozoa and helminths examination:
- Giardia cyst is about 10–15 μm
    - Giardia inactivated by 1 ppm chlorine in 45 min
    - Sand filters are ineffective…giardia cysts pass through
    - Transmission via person-to-person contact, hygiene, contaminated water
    - Diatomaceous earth filters effective at giardia removal
    - Filter size that is effective at giardia cyst removal = 5 μm pore size
- Cryptosporidium oocyst is about 3–6 μm
- Helminths are 50–60 μm

- Because of resistance of protozoa and helminthes to normal chlorination and the lack of routine procedures for water-treatment plant operation control, **complete water treatment is required for ALL drinking water**
- The most common disease, spread by *Dracunculus medinensis* in drinking water, is **dracontiasis** (a.k.a., Guinea-worm infection)

Physical examination:

- Odor should be < 3 threshold odor number (TON)…absent or very faint
- Activated carbon adsorption, aeration, chemical oxidation, and coagulation and filtration will usually remove odors and tastes
- **MCL for turbidity should be < 0.5 NTU in 95% of samples** taken every month and **must *never* exceed 1 NTU**
- **Utility must maintain a minimum of 0.2 mg/l free chlorine residual**
- Color should be < 15 true color units (goal is < 3)
    - Color can be controlled at the source via watershed management
    - Coagulation, flocculation, settling, and rapid sand filtration should reduce color to < 5 units
    - Coagulation is the major factor
- Water temp should preferably be < 60 degrees F

Microscopic examination:

- Algae contain chlorophyll and require sunlight for growth
- **"Plankton" includes algae** and small animals such as cyclops and daphnia
- **Red tides** caused by dinoflagellates have been correlated w/mass fish mortality
    - Coagulation, flocculation, sedimentation, and filtration do NOT remove algal toxins, nor does activated carbon treatment
- Protozoan and other small animals are **zooplankton**, which feed on algae and bacteria
- Examination involves collection of water samples from specified locations and depths
- Sample is preserved by addition of formaldehyde if not taken immediately to lab
- Microorganisms are reported as the number of areal standard units per ml
    - Areal standard unit represents area of 20 microns square or 400
    - One micrometer = 0.001 mm
    - **When > 300 areal standard units or organisms per ml is reported, treatment with copper sulfate is indicated** to prevent possible trouble with tastes and odors or short filter runs
    - Appearance of even 1 areal standard unit of a microorganism may be an indication to start immediate copper sulfate treatment if past experience indicates that trouble can be expected

Chemical examinations:

- Gas chromatographic mass spectrometry is best method for identifying and quantifying specific organic compounds in an unknown sample

- **Alkalinity should be in range of 30–100 mg/l** as calcium carbonate to prevent corrosion, but up to 500 mg/l is acceptable
  - Excessive alkalinity can cause pH change of lacrimal fluid around eye leading to eye irritation
  - Insufficient alkalinity will cause alum to remain in solution and lessens effectiveness of coagulation (floc formation not permitted)
- Calcium carbonate, calcium bicarbonate, magnesium bicarbonate, and magnesium carbonate cause hardness as well as alkalinity
- MCL for **arsenic** = 0.01 mg/l
  - Probably lethal oral dose is 5–20 mg/kg
  - There is evidence of relationship between certain cancers and high levels of arsenic in drinking water
- MCL for **barium** = 2 mg/l
  - Barium is a muscle stimulant
  - Can be harmful to nervous system and heart in large quantities
  - **Fatal dose is 550–600 mg**
  - Can be removed by weak acid-ion exchange
- MCL for benzene = 0.005 mg/l
  - Associated w/high increased risk of leukemia
  - Shown to cause cancer in lab animals
- MCL for cadmium = 0.005 mg/l
  - Large concentrations may be related to kidney damage, high blood pressure, chronic bronchitis, and emphysema
- MCL for CO_2 < 10 mg/l
  - Limited only due to corrosion potential
- Waters high in chlorides and low in alkalinity are particularly corrosive
- MCL for cyanide < 0.2 mg/l
  - Readily destroyed by conventional treatment
- Dissolved oxygen content should be < 2.5–3.0 mg/l
- MCL for fluorides < 4 mg/l
  - Concentrations > 4 mg/l can cause teeth of children to become mottled and discolored
  - Water containing 0.7–1.2 mg/l natural or added is beneficial to kids while they are developing permanent teeth
- **High concentrations of free ammonia usually indicate "fresh pollution" of sanitary significance**
  - High = 0.10 mg/l or greater
  - Moderate = 0.01–0.10 mg/l
  - Low = 0.015–0.03 mg/l
  - Can be removed by breakpoint or superchlorination
- Hardness is due primarily to calcium and secondarily to magnesium carbonate and bicarbonate, calcium sulfate, calcium chloride, magnesium sulfate, and magnesium chloride
  - **Desirable hardness should be 50–80 mg/l**
    - Soft = 0–60
    - Moderately hard = 61–129

    - Hard = 121–180
    - Very hard > 180
  - Hardness > 200 mg/l may cause buildup of scale and flow reduction in pipes
  - Higher mortality rates from cardiovascular disease are found in people with softened water than in those with hard water
- Hydrogen sulfide levels should be < 0.05 mg/l
- Water should have a soluble iron level of < 0.1 mg/l to prevent
- Lead should not exceed 5 μg/l in the distribution system
  - In young children, about 20% of lead exposure comes from drinking water
  - The Safe Drinking Water Act Amendments of 1986 require that any pipe, solder or flux used in installation or repair of any public water system or any plumbing connected to a public water system shall be lead free
    - **Solder and flux with < 0.2% lead are considered lead free**
    - **Pipes and pipe fittings with < 8.0% lead are considered lead free**
  - **Exposure to lead in tap water is more likely in new homes (< 5 yrs old)**
  - Flushing standing water out of faucet for 1 min will minimize lead concentration but does not solve problem
- MCL for manganese < 0.05 mg/l
  - Presence in higher concentrations causes black-brown staining of plumbing fixtures and laundry when chlorine bleach is added
  - May give metallic taste to water
- MCL for mercury < 0.002 mg/l
  - Some mercury compounds are highly toxic affecting CNS and kidneys
  - Taken up by aquatic food chain…accumulates in larger and predatory fish
- **Presence of methylene blue active substances (MBASs) in a well-water supply is objectionable and an indication of sewage pollution**
  - Level of MBASs in surface water is also an indication of sewage pollution
  - Carbon adsorption can remove MBASs in drinking water
- MCL for nitrate < 10 mg/l
  - Manure and fertilizer contain large concentrations
  - **Nitrates disclose evidence of "previous" pollution of water** that has been modified by self-purification processes to a final mineral form
    - Low < 0.1 mg/l
    - Moderate = 0.1–1.0 mg/l
    - High > 1.0 mg/l
  - Concentrations > 3.0 mg/l indicate significant manmade contribution
  - **Concentrations > MCL appear to be cause of methemoglobinemia (a.k.a., blue baby syndrome)**
  - Removal can be achieved via anion exchange, reverse osmosis, distillation, and electrodialysis
- Nitrite concentrations > 0.001 mg/l are of sanitary significance
  - Indicate water subject to pollution that is in process of change associated with natural purification
- Conventional water treatment does NOT adequately remove pesticides
  - Powdered or granular activated carbon treatment may also be necessary
- **pH values in range of 6.5–8.5 is suggested**

    - Corrosion is associated w/pH of < 6.5 to 7.0 and with carbon dioxide, alkalinity, hardness, and temperature
  - About 100 μg/l complex phosphate interferes w/coagulation
  - **Polychlorinated biphenyls (PCBs) give an indication of the presence of industrial wastes**
    - Cause skin disorders in humans and cancer in rats
    - Manufacture was prohibited in U.S. under Toxic Substances Control Act of 1976
    - MCL for drinking water is 0.0005 mg/l
    - Activated carbon adsorption and ozonation plus UV are possible treatments
  - Radioactivity
    - **Radon is the major natural source of radionuclides**
  - MCL for radon = 300 pCi/l for drinking water
    - Aeration is effective for removal
  - MCL for sodium in drinking water = 200 mg/l
  - Total dissolved solids (TDS) should be < 500 mg/l
  - MCL for zinc < 5.0 mg/l
    - Zinc may contribute to corrosiveness of water

- A sanitary survey is needed to determine the reliability of a water system to continuously supply safe and adequate water to the consumer.

- When water is obtained from a stream or creek, all land and habitation above the water supply should be investigated (inspection of the entire watershed drainage area).

- **All surface water supplies must be considered of doubtful sanitary quality unless given adequate treatment.**

Ground water:
  - Includes:
    - **Dug, bored, driven and drilled wells**
    - **Rock and sand or earth springs**
    - **Infiltration galleries**
  - Groundwater contains more dissolved minerals than surface water
  - **There is more than 100x more water stored underground than in all the surface streams, lakes, and rivers**
  -

Location of groundwater supplies:
  - Should take into consideration recharge tributary wellhead area
    - **Wellhead** is the surface and subsurface area surrounding a water well or well field supplying a public water system, through which contaminants are reasonably likely to move toward and reach such water or well field
  - Probable sources and travel of pollution through the ground

- Well construction practices and standards
- Depth of well casing and grouting
- Type of sanitary seal provided at point where pump lines pass out of casing
- A well for a private home should preferably have a well yield of at least 500 gal/hr
- **300 gal/hr min is specified for domestic water use in serving a 3-bdrm home**

Source and protection of water supply:

- Surface water supplies are all subject to continuous or intermittent pollution and must be treated to make them safe to drink
- **Minimum required treatments are:**
  - **Coagulation**
  - **Flocculation**
  - **Sedimentation**
  - **Filtration**
  - **Chlorination**
- Drilled wells are more dependable water sources than other types of wells
- **Annular space around casing is best sealed with cement grout**
- Boiling will NOT remove chemical contaminants
- Chemical contamination indicates the aquifer has been polluted
- If sewage disposal system is suspected of contamination, dye can be used as a tracer…solution will appear in well water in 12–24 hrs
- **Infiltration gallery should be located 20 ft or more from a lake or stream** or under the bed of a stream or lake if installed under expert supervision
- **Presence of detergents is evidence that wastewater from one's own sewage disposal system or from a neighbor's system is entering the water supply source**
- For household treatment units**:**
  - Reverse osmosis and distillation are most effective for inorganic contamination
  - Granular and activated carbon are most effective for organic contamination
- **Desalination (desalting) is the conversion of seawater or brackish water to fresh water for potable and industrial purposes**