

Drinking Water Operator Certification Training



General Overview Volume II

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Topical Outline

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- I. Definitions
- II. Types of Water
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 - B. Surface Water
 - C. Groundwater
- III. Hydrologic Cycle
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 - C. Perched Water Table
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 - D. Crystalline Rock Aquifers
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 - A. Wells
 - B. Springs
 - C. Infiltration Galleries, Radial Collector

Unit 1 – Introduction to Groundwater

Learning Objectives

- Define evaporation, transpiration, evapotranspiration, groundwater, and water table.
- List three types of water and explain each.
- Explain the steps in the Hydrologic Cycle.



Evaporation – the change by which any substance is converted from a liquid and carried off as a vapor. It is one of the processes of returning moisture to the atmosphere. Water on any surface (especially ponds, streams, lakes, and oceans) is warmed by the sun until it turns into vapor, or its gaseous form, and rises into the atmosphere.



Evapotranspiration – the combined net effect of evaporation and transpiration.



Groundwater – underground water located in the zone of saturation below the water table.



Hydrologic Cycle – the exchange of water between the earth and the atmosphere through evapotranspiration and precipitation.



Infiltration – the entry of water into the soil through cracks, joints, and pores in the soil and rock structure. This is also referred to as percolation.



Surface Runoff – the movement of water, usually from precipitation, across the land surface toward stream channels, lakes, depressions, or other low spots.



Surface Water – water found on the surface of the land. Usually refers to puddles, ponds, lakes, streams, rivers, and oceans.



Transpiration – the direct transfer of water from the leaves of living plants to the atmosphere. Plants take up water through the roots and then lose some through pores in the leaves. As warm air passes over the leaf surface the moisture evaporates into the air.



Water Table – the boundary below which all of the spaces and cracks in the soil and rock are filled with water.



Zone of Saturation – the area below the groundwater table.

Water is one of earth's basic materials. It can be found around, on, and within the earth.



Atmospheric Water

Atmospheric water is the water that is found in the air **surrounding** the earth. It can be seen as clouds, fog, and forms of precipitation like rain, snow, and sleet.



Surface Water

Surface water is water that is **on top** of the earth's surface. This water can be fresh water or salt water and can be seen as oceans, lakes, rivers, or streams.

- ▶ Fresh water – water which is or can be treated to be drinkable.
- ▶ Salt water – water which contains too much dissolved salt and other minerals to be drinkable.

Groundwater

Groundwater is water that is found **below** the earth's surface. It includes both fresh water and salt water. Groundwater is found in saturated soil, as shown below, or in fractures in the bedrock.

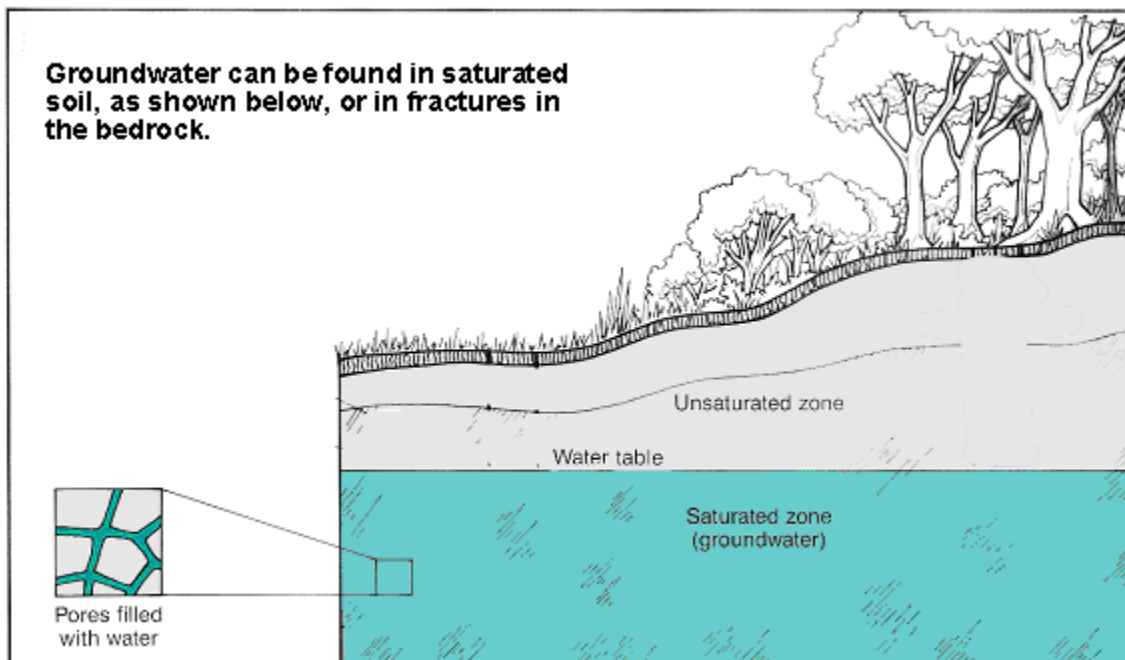


Figure 1.1 - Groundwater

Sources of Groundwater for Drinking Include:

- ▶ Water obtained from dug, drilled, bored, jetted or driven wells.
- ▶ Water obtained from Infiltration Galleries and Radial Collectors.
- ▶ Water obtained from springs.
 - To be classified as a groundwater source, springs must not come into contact with any potential surface water. Therefore, the spring source must be developed within a “springhouse” to protect the source quality.
 - Additionally, the spring source must be evaluated and tested to assure that surface water will not directly contaminate the spring.

Groundwater sources are subject to the direct influence of water that has been classified as a surface water source. If it is determined that the groundwater source has been influenced by surface water, the groundwater source would then require treatment as surface water.

Overview

The physical exchange of water between the earth and the atmosphere through evaporation and precipitation is known as the **Hydrologic Cycle**.

The **Hydrologic Cycle** is continuous—no starting or ending point.

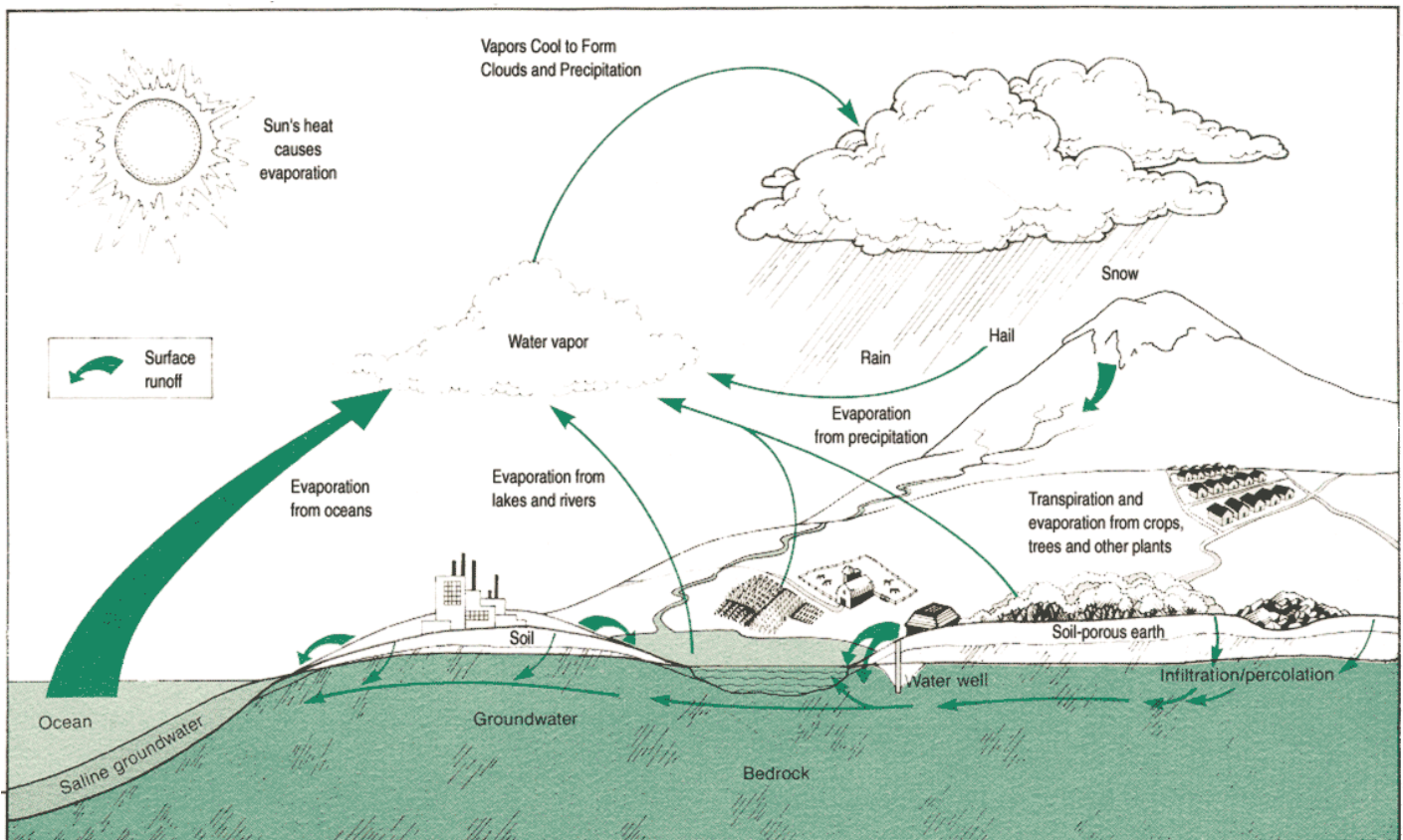


Figure 1.2 - Hydrologic Cycle¹

Process

Precipitation

Rain or snow falls on the land surface.

- Some of the water flows on the surface to lakes, streams, and wetlands as surface runoff.

Evaporation

Most of the precipitation evaporates back into the atmosphere from the ground surface where it condenses and falls again as precipitation.

Infiltration

The remaining water infiltrates into the ground where one of two things occurs.

- ① Some water is taken up by plant roots and transpired by plants back into the atmosphere where it condenses and falls again as precipitation. This is known as **Transpiration**.

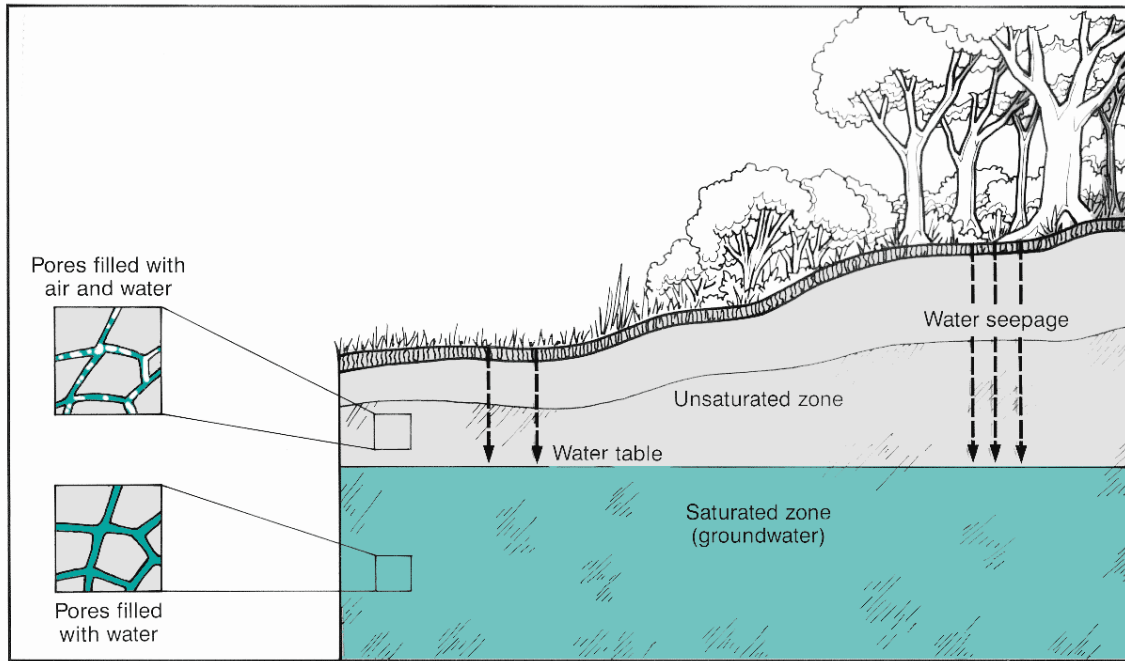


Figure 1.3 - Groundwater Infiltration ²

- ② The remaining water filters down through an unsaturated zone where the spaces (pores) between the soil particles and rock contain both air and water.

Eventually water reaches the Water Table—the boundary below which all of the spaces and cracks in the soil or rock are filled with water—recharging the groundwater system.

- Zone of Saturation – area where all pore spaces are filled with water
- Water Table – the top of the zone of saturation
- Water below the water table is in Groundwater Storage

Discharge

The Groundwater moves through the ground, eventually surfacing at an area of discharge—a spring, stream, lake, or wetland.

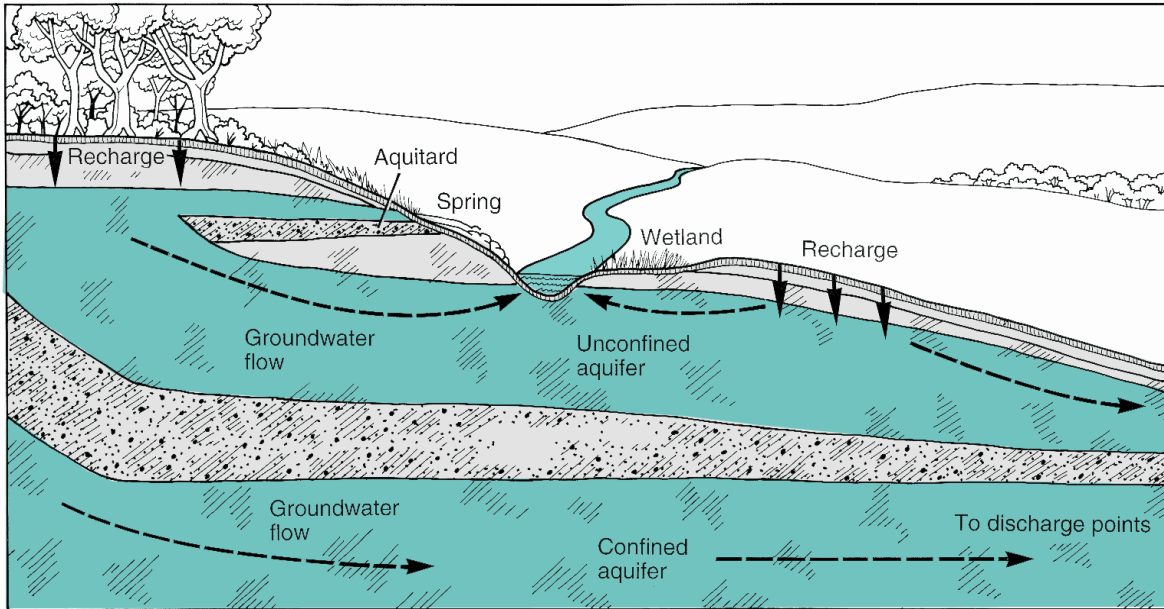


Figure 1.4 - Groundwater Movement ³

The Water Cycle is complete when **evaporation** from the surface returns this water back to the atmosphere.

Regardless of its origin, water moves physically between the subsurface, surface, and atmosphere via the Hydrologic Cycle.

Hydrologic Cycle in Pennsylvania

Precipitation

Each year, on average, 41 inches of precipitation falls in Pennsylvania.

- ◆ 6 inches enters streams and lakes directly either as surface runoff or as flow from the unsaturated zone.
- ◆ 20 inches returns to the atmosphere through evaporation and transpiration (evapotranspiration).
- ◆ Remaining 15 inches infiltrates and moves downward to the zone of saturation to recharge groundwater.

Groundwater Recharge

In Pennsylvania, most groundwater recharge occurs in the spring.

- ◆ Plenty of water from rain and snow melt.
- ◆ Plants not yet actively growing and are not taking water from the soil.
- ◆ Amount of sunlight is less, so evaporation is less.

Following spring recharge, the water table usually lowers steadily during the summer, fall, and winter.

Recharge Rates

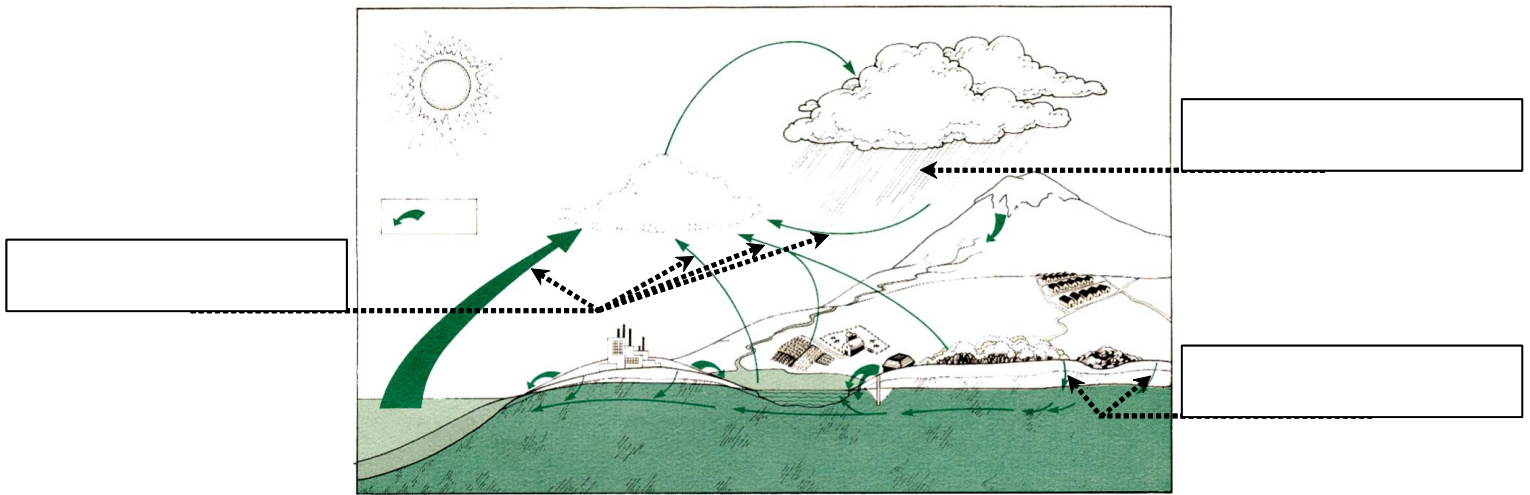
Recharge or infiltration rates vary with type of land cover. Generally,

1. The higher percentage of impervious area in urban areas (sidewalks and roads) results in higher surface runoff and lower infiltration (lower recharge).
2. Forested areas have higher infiltration (higher recharge) due to limited impervious area and therefore less surface runoff.



Unit 1 Exercise

1. On the diagram below, label the following parts of the Hydrologic Cycle: Precipitation, Evaporation and Infiltration.





Key points for Unit 1 – Introduction to Groundwater

- The three types of water are: atmospheric water, surface water, and groundwater.
- Surface water can be classified as fresh water or salt water.
- Groundwater can be either fresh water or salt water.
- The water table is the boundary below which all of spaces and cracks in soil and rock are filled with water.
- Springs can be considered a groundwater source if they are protected from coming into contact with surface water.
- Infiltration of surface water through the water table and into the zone of saturation is also called percolation.
- The hydrologic cycle is continuous and involves the physical changes that water undergoes which are precipitation, evaporation, infiltration, and discharge of water.
- Most groundwater recharge occurs in the spring in Pennsylvania.
- Groundwater in Pennsylvania can contain both fresh water and salt water.

¹ “Illustration 1—Hydrologic cycle, water is constantly on the move” <http://pa.lvw.org/wren/> (24 March 2003).

² “Illustration 2—Groundwater is the water that fills all the spaces in the saturated zone” <http://pa.lvw.org/wren/> (24 March 2003).

³ “Illustration 5—Groundwater generally flows from upland recharge areas to lowland discharge areas” <http://pa.lvw.org/wren/> (24 March 2003).

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Unit 2 – Aquifers

Learning Objectives

- List four types of groundwater aquifers found in Pennsylvania
- Identify on a map, the location of Pennsylvania's principal groundwater aquifers.
- Describe the geology of each of the four aquifers.
- List three common types of groundwater sources found in Pennsylvania.



Aquifer - A water-bearing stratum of rock, sand, or gravel.

A stratum is a layer of earth. Therefore, an aquifer could be a layer of limestone, which contains or carries water.

There are three types of Aquifers: Unconfined Aquifer, Confined Aquifer, and, Perched Aquifer or Perched Water Table.

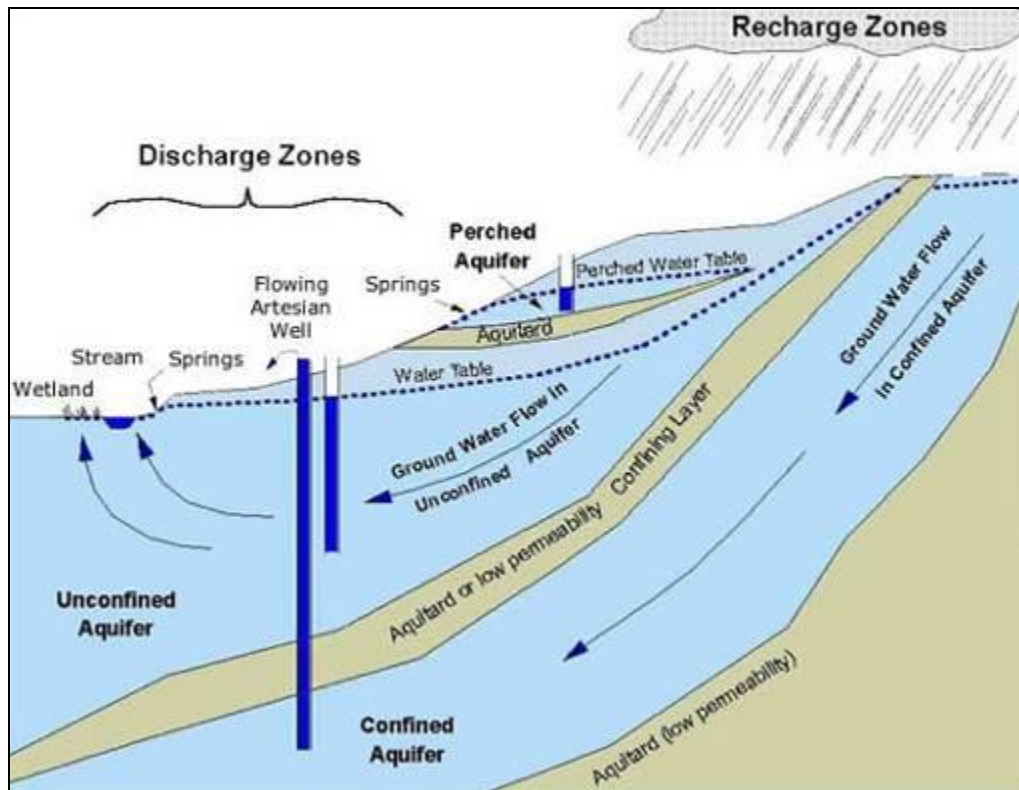


Figure 2.1 - Types of Aquifers

Unconfined Aquifer or Water Table Aquifer

- Groundwater that is not surrounded by soil or rock on all sides.
- Groundwater is under atmospheric pressure.
- This type of aquifer may feed such surface water sources as springs or streams

Confined Aquifer

- Groundwater is sandwiched between two impermeable layers or aquitards.
- Confined Aquifers are under pressure greater than atmospheric.

Perched Water Table

- Groundwater collects above an impermeable layer above the water table.
- The Perched Water Table usually doesn't hold much water.

In Pennsylvania groundwater aquifers are divided into four groups based upon their geology: Sand and Gravel Aquifers, Sandstone and Shale Aquifers, Carbonate Rock Aquifers and Crystalline Rock Aquifers. Each of these has distinct locations, geologies, yields and qualities. The following map and charts help to illustrate these factors.

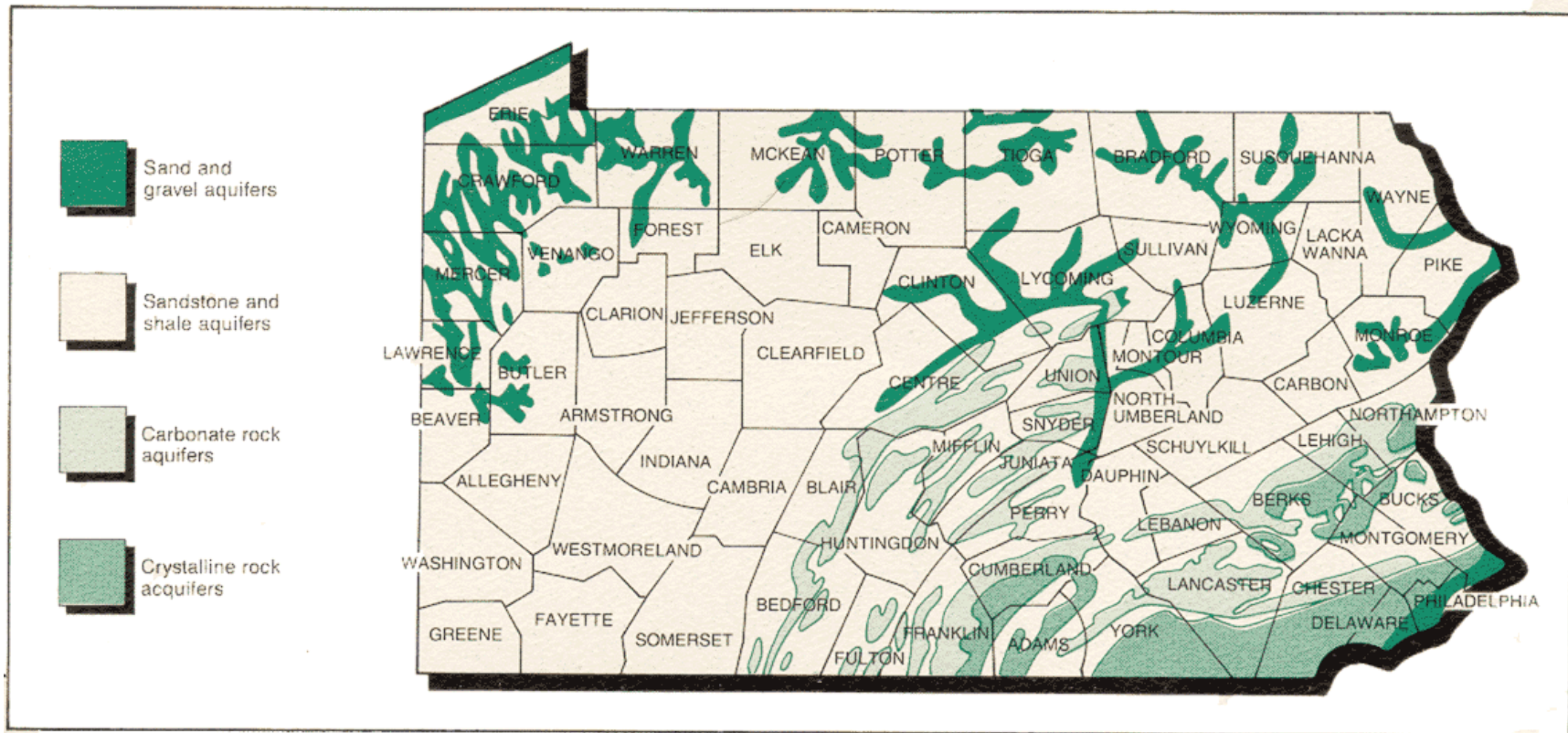


Figure 2.2 - Pennsylvania's Aquifer Distribution¹

Sand and Gravel Aquifers

Location	<ul style="list-style-type: none"> ◆ Southeastern coastal plain, along Delaware River ◆ Along Lake Erie shoreline ◆ In most major stream valleys
Geology	<ul style="list-style-type: none"> ◆ Unconsolidated sand and gravel deposits of various geologic formations ◆ Vertically separated by clayey or silty confining layers <ul style="list-style-type: none"> ➢ retard vertical flow ➢ 60 – 75% of recharge is from upland runoff ➢ Contain saline water in places, especially near salt water coastline
Yields	<ul style="list-style-type: none"> ◆ Contain large quantities of water ◆ Easily withdrawn ◆ Well yields of 100 – 800 gallons per minute (gpm) <ul style="list-style-type: none"> ➢ Yield in excess of 1000gpm are common
Quality	<ul style="list-style-type: none"> ◆ Quality is variable, but generally good to excellent ◆ Typical quality: <ul style="list-style-type: none"> ➢ Dissolved solids – 250 milligrams per liter (mg/l) ➢ Hardness – 140 mg/l (hard) ➢ pH – 7.2 ➢ Iron – 0.1 mg/l ➢ Nitrate – if found is generally due to surface contamination by fertilizer, animal wastes, or sewage. ◆ Especially susceptible to contamination by human activities.

Sandstone and Shale Aquifers

Location	<ul style="list-style-type: none"> ♦ Predominant bedrock aquifer in PA ♦ Located in the sandstone, siltstone, and shale areas throughout the state.
Geology	<ul style="list-style-type: none"> ♦ Consolidated sedimentary rock ♦ Almost flay-lying to gently folded ♦ Principal coal-bearing formations, consisting of cyclic sequences of sandstone, shale, conglomerate, clay, coal, and minor limestone. ♦ Sandstones are the principal water-yielding units ♦ Springs common <ul style="list-style-type: none"> ‣ Low permeability rocks, such as shale, siltstone, or ironstone retard vertical water movement. ‣ Lateral water movement surfaces at intersections with valley wall.
Yields	<ul style="list-style-type: none"> ♦ Interlayered – can be more than one water bearing zone in a vertical thickness ♦ Well yields are lower than sand and gravel aquifers <ul style="list-style-type: none"> ‣ Well yields of 20 to 400 gpm ♦ Wells located on fracture intersections can have substantially increased yields
Quality	<ul style="list-style-type: none"> ♦ Quality of freshwater is somewhat variable but generally satisfactory ♦ Typical quality <ul style="list-style-type: none"> ‣ Dissolved solids – 230 milligrams per liter (mg/l) ‣ Hardness – 95 mg/l (moderately hard) ‣ Water from shale aquifers usually reported to be hard ‣ Water from sandstone aquifers usually reported to be soft <ul style="list-style-type: none"> ▪ pH – 7.3 ▪ Iron – 0.1 mg/l ♦ Fresh groundwater circulates only to shallow depths ♦ Saline water or brine not far below – separated only by a thin transition zone ♦ Improper construction/ plugging of oil and gas wells, and coal mining operations present contamination problems

Carbonate Rock Aquifers

Location	<ul style="list-style-type: none"> ◆ Limestone and dolomite geologic formations located in the valleys of central and southeastern PA ◆ Caves, solution channels, and sinkholes of these regions are caused by water dissolving portions of the carbonate rock
Geology	<ul style="list-style-type: none"> ◆ Complex geologic structure ◆ Sedimentary rock layers are folded and displaced to the northwest ◆ Many fractures, faults, and slippage planes
Yields	<ul style="list-style-type: none"> ◆ Contain large quantities of water ◆ Water movement generally along fractures, bedding planes, and solution channels ◆ Spring yields of 100 to more than 2000 gpm ◆ Well yields of 100 to 1000 gpm, or more, are common <ul style="list-style-type: none"> ▶ Wells located on fracture intersections can have substantially increased yields
Quality	<ul style="list-style-type: none"> ◆ Quality is somewhat variable, but generally suitable for water supply ◆ Typical quality <ul style="list-style-type: none"> ▶ Dissolved solids – 330 milligrams per liter (mg/l) ▶ Hardness – 280 mg/l (very hard) ▶ pH – 7.4 ▶ Iron – 0.1 mg/l ◆ Brackish water at depth ◆ Contains relatively large amounts of dissolved solids ◆ In some coal-mining area groundwater is mixed with acidic mine water, resulting in large concentrations of iron, manganese, sulfate, and dissolved solids

Crystalline Rock Aquifers

Location	<ul style="list-style-type: none"> ◆ Most of southeastern Pennsylvania
Geology	<ul style="list-style-type: none"> ◆ Dense, almost impermeable bedrock ◆ Complex assortment of metamorphic and igneous rocks ◆ Water yields primarily from secondary porosity and fractures
Yields	<ul style="list-style-type: none"> ◆ Rock formations have very small fractures ◆ Storage capacity and well yield are relatively low ◆ Almost all recharge is from precipitation ◆ Variable yields – dependent on factors such as type of rock; number, size and spacing of fractures; degree to which fractures are interconnected; and topographic setting of the well ◆ Generally small yields of 5 to 25 gpm
Quality	<ul style="list-style-type: none"> ◆ Quality is generally suitable for drinking and other uses, but iron, manganese, and sulfate occur locally in objectionable concentrations ◆ Typical quality <ul style="list-style-type: none"> ➢ Dissolved solids – 230 milligrams per liter (mg/l) ➢ Hardness – 160 mg/l (hard) ➢ pH – 7.6 ➢ Iron – 0.1 mg/l

Types of Groundwater Sources

Groundwater sources are of three types: wells, springs, and infiltration galleries and radial collectors. These three sources provide raw water to a treatment plant.



Raw water is any untreated water source.

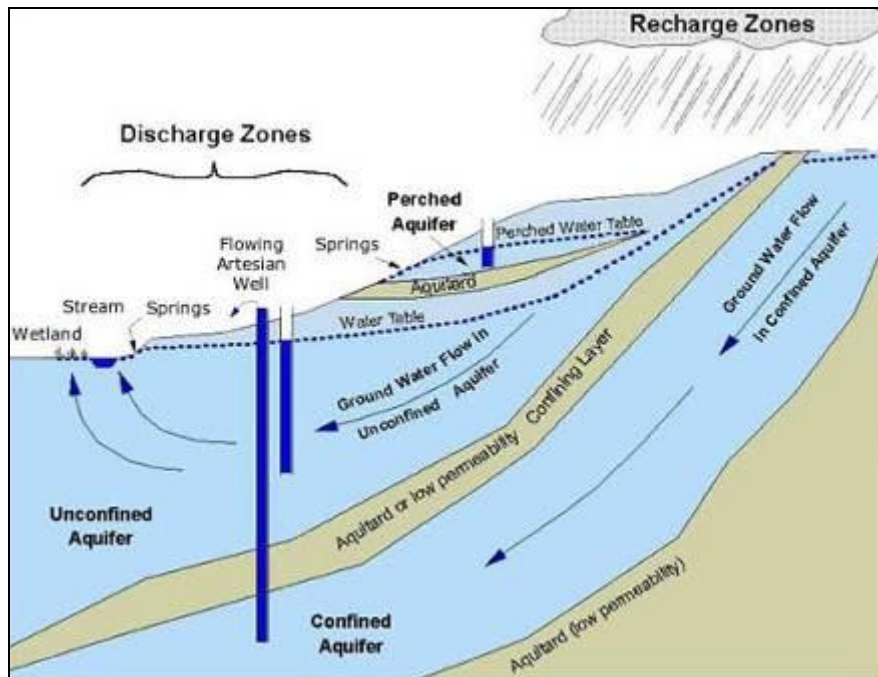


Figure 2.3 - Water Source Placement

Wells

Wells are dug or drilled holes extending below the water table.

Types of Wells

- Perched Aquifer Well
 - Dry up during dry season
 - Aren't good places for wells

- Unconfined Aquifer Well
 - Water level in well is at the water table level

- Confined Aquifer Well
 - Artesian wells
 - Water level in well higher than water table level because the water is under pressure
 - Water level can be higher than top of well casing – Flowing Artesian

Springs

Springs are groundwater that surfaces where the water table intersects the land surface.

- ☑ To be considered as groundwater, it must be collected in a spring house or well box before water is exposed to surface conditions.
- ☑ Springs originate from unconfined or perched aquifers

Infiltration Galleries, Radial Collectors

Both infiltration galleries and radial collectors collect groundwater and are constructed below the water table.

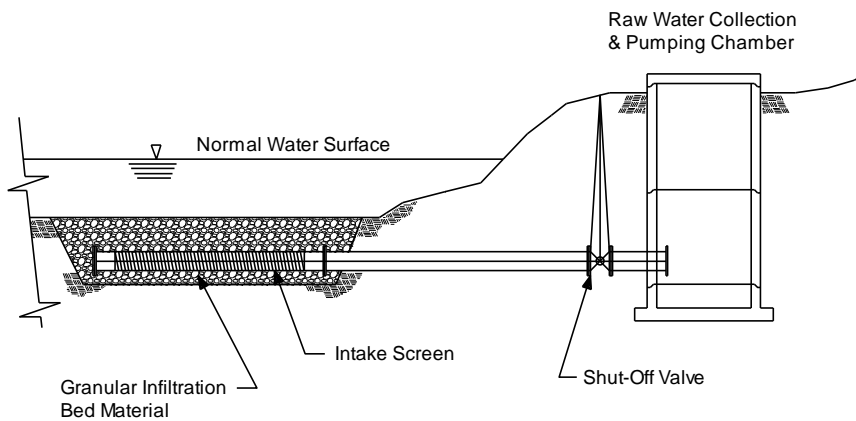


Figure 2.4 – Infiltration Gallery

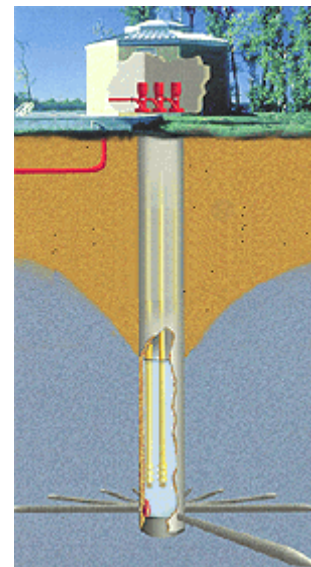


Figure 2.5 – Radial Collector²



Unit 2 Exercise

1. List the three types of groundwater sources.

A. _____

B. _____

C. _____

2. **True or False:** A stratum is a layer of earth.

3. Which one of the following best defines the term **aquifer**?

- a. A low lying area where water pools
- b. Water-bearing stratum of rock, sand, or gravel
- c. Impervious stratum near the ground surface
- d. Treated water leaving the water system

4. List the three types of aquifers.

A. _____

B. _____

C. _____



Key points for Unit 2 – Aquifers

- An aquifer is a water-bearing layer of rock, sand, or gravel.
- The three general types of aquifers are: unconfined, confined, and perched aquifers.
- Based on their geological properties, Pennsylvania's aquifers are classified into one of four basic groups.
- Pennsylvania's four basic aquifer groupings are:
 - Sand and gravel aquifers
 - Sandstone and shale aquifers
 - Carbonate rock aquifers
 - Crystalline rock aquifers
- Sand and gravel aquifers may contain large amounts of water.
- Sandstone and shale aquifers are the most commonly occurring aquifer in Pennsylvania.
- Carbonate rock aquifers may contain large amounts of water. Caves and sinkholes may be common in these areas. Water hardness may be a problem.
- The three types of groundwater sources are:
 - Wells
 - Springs
 - Infiltration galleries and radial collectors
- A spring can be considered groundwater only if the spring water is collected in a spring house or well box to prevent the spring water being exposed to surface conditions.

¹ "Illustration 12—Map of Pennsylvania Aquifers" <http://pa/lwv.org/wren/> (24 March 03).

² "Ranney Collector Wells" http://www.laynechristensen.com/ranney_collector_wells.html (05 May 2003).

Topical Outline

Unit 3 – Water Quality Classifications

Introduction: Physical Characteristics

- I. Microorganisms
 - A. Definitions
 - B. Disease Outbreaks
 - C. Current List of Regulated Waterborne Pathogenic Microorganisms and Indicators
 - D. Common Sources of Waterborne Pathogenic Microorganisms
 - E. Three Categories of Microorganism Agents of Waterborne Disease
 - F. Microbial Indicators
 - G. General Groups of Nuisance Microorganisms and Aesthetic Concerns

- II. Inorganic Constituents
 - A. Standards and BATS for Inorganic Constituents That May Occur in Drinking Water Supplies
 - B. Common Sources of Inorganic Constituents
 - C. General Inorganic Chemical and Treatment Terminology
 - D. Acute and Chronic Health Affects
 - E. Aesthetic Concerns

- III. Organic Compounds
 - A. General Categories of Organic Compounds
 - B. Regulations
 - C. Common Sources

- IV. Radionuclides
 - A. Types and Sources of Radionuclides
 - B. Standards and BATS for Radionuclides
 - C. Acute and Chronic Health Affects

- V. Disinfectants and Disinfection Byproducts (D/DBP)
 - A. Disinfectants
 - B. Disinfectant Byproducts

Unit 3 – Water Quality Classifications

Learning Objectives

Physical Characteristics

- List the four physical characteristics of water

Microorganisms

- List three currently regulated waterborne pathogenic microorganisms (pathogens)
- Name the six common sources of pathogens
- List three indicators of microbiological contamination

Inorganic Constituents

- Name three regulated inorganic constituents that occur in drinking water supplies
- Name five common sources of inorganic constituents

Organic Compounds

- Name four common sources of SOCs
- Describe one BAT for treatment

Radionuclides

- List two regulated radionuclides
- Name two common sources of radionuclides

Disinfectants and Disinfection Byproducts (D/DBP)

- List three regulated disinfectants and disinfection byproducts
- Name a common precursor of disinfectant byproducts
- Describe two BATS for treatment

Physical Characteristics

There are four characteristics of water that are commonly used to define the physical properties. These include:

- **Turbidity** – Measurement of the cloudiness of water due to suspended particles. Higher turbidity levels are often associated with higher levels of disease-causing microorganisms.
- **Taste and Color** – Suspended matter, bacteria, algae, organic waste and chemical pollutants can cause various tastes and colors in water. Organic substances, such as algae and tannins released from vegetation, can cause color. Higher concentrations of some elements, such as iron, calcium, sodium, magnesium, and chloride, can make the water taste bad or bitter.
- **Temperature** – Degree of hotness or coldness of water. The temperature of water can affect such things as dissolved oxygen level, metabolic rate of aquatic organisms, and your treatment process.

Definitions



Waterborne pathogenic microorganisms – Microbial agents of human diseases that are present in and conveyed by drinking water supplies.



Etiologic – A causal agent of disease.



Endemic – Prevalent disease not associated with an outbreak.



Epidemiology – The study of the distribution and determinants of disease.



Heterotrophic – Microorganisms that use organic carbon for growth and energy (includes almost all waterborne bacterial pathogens with the exception of cyanobacteria).



Autotrophic – Microorganisms that use carbon dioxide or bicarbonate ion for growth and energy (includes iron and most sulfur bacteria).



Indicator – Surrogate organisms and other water quality parameters used as a sign of a water system's vulnerability to the presence of pathogenic microorganisms.



Plankton – Microscopic aquatic life forms (both animal and plant) living free-floating and suspended in natural waters.



Phytoplankton – Algae.

Disease Outbreaks

- It is estimated that only 1 in 25 diseases of waterborne origin is ever recognized. In the majority of outbreaks an infectious agent is never identified.
- Most disease outbreaks involve groundwater systems.
- A significant portion of disease is probably endemic, rather than associated with an outbreak.

Current List of Regulated Waterborne Pathogenic Microorganisms and Indicators

Table 3-1
Current list of Regulated Waterborne Microorganisms

Microorganism/Indicator	Regulation	Goal
<i>Cryptosporidium</i>	TT	Zero
<i>Giardia lamblia</i>	TT	Zero
<i>E. coli</i>	TT	Zero
Fecal coliforms	TT	Zero
<i>Legionella</i>	TT	Zero
Viruses (enteric)	TT	Zero
Heterotrophic plate count (HPC)	TT	NA
Total coliforms	Max 5% of monthly readings positive	Zero
Turbidity	PS: < 0.3 NTU – 95% of readings; 1.0 NTU max	NA
	TT = Treatment Technique	NA = Not Applicable

Common Sources of Waterborne Pathogenic Microorganisms

- Naturally occurring
- Municipal wastewater treatment plant discharge
- Industrial wastewater treatment plant discharge
- Non-point sources such as run-off from farm fields and developed areas
- Waterfowl droppings
- Septic fields

Three Categories of Microorganism Agents of Waterborne Disease

Bacteria

- Survival in water is usually for a short period of time
- Size ranges from 0.2 µm to 15 µm (microns)
- Reproduction consists of binary fission and can occur in water
- Best Available Technology (BAT) for treatment
 - ✓ Conventional filtration
 - ✓ Disinfection

Bacterial Disease Examples
Table 3-2

Organism/Group	Disease	Infectious Dose Estimate
Pathogenic <i>Escherichia coli</i> (<i>E. coli</i>)	gastroenteritis	10 ⁷ CFU
<i>Vibrio cholerae</i>	cholera	<10 ⁶ CFU
<i>Salmonella</i>	salmonellosis	10 ⁵ CFU
<i>Legionella</i>	legionnaires' disease	unknown
<i>Salmonella typhi</i>	typhoid fever	10 ⁷ CFU
<i>Shigella spp.</i>	bacillary dysentary	10 ⁷ CFU
<i>Campylobacter jejuni</i>	gastroenteritis	unknown
Non-tuberculosis <i>mycobacteria</i> (NTM), On EPA CCL	respiratory infections	unknown
<i>Helicobacter pylori</i> , On EPA CCL	gastroenteritis, ulcers, stomach carcinoma	unknown

CCL = Contaminant Candidate List (for possible future regulation), CFU = Colony Forming Units per mL

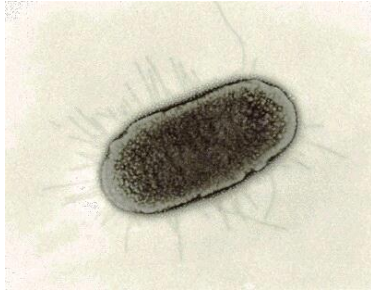


Figure 3-1 ¹
E.coli



Figure 3-2 ²
Legionella

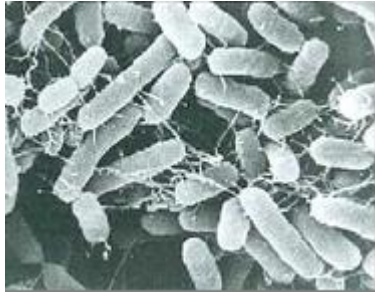


Figure 3-3 ³
Salmonella



Figure 3-4 ⁴
Vibrio cholerae

Protozoa

- Survival in water up to one year
- Size ranges from 3 µm to 25 µm
- Reproduction is not possible in water
- Best Available Technology (BAT) for treatment
 - ✓ Conventional filtration
 - ✓ Disinfection
- May cause disease even in very low numbers

Table 3-3
Protozoa Disease examples

Organism/Group	Disease	Size	Infectious Dose
<i>Giardia lamblia</i>	giardiasis	5 µm to 15 µm	1 to 50 cysts
<i>Cryptosporidium parvum</i>	cryptosporidiosis	4 µm to 6 µm	30 to 130cysts
<i>Entamoeba histolytica</i>	amoebic dysentery	10 µm to 15 µm	unknown
<i>Microsporidia</i>	microsporidiosis	1 µm to 5 µm	unknown
<i>Cyclospora</i>	cyclosporiasis	7 µm to 9 µm	unknown

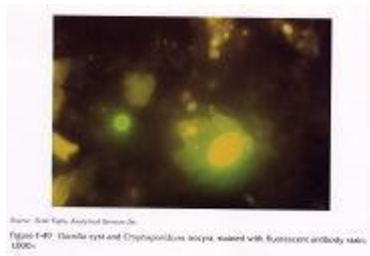


Figure 3-5⁵
Giardia cyst and *Cryptosporidium* oocyst

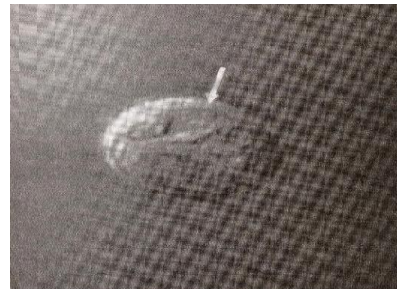


Figure 3-6⁶
Giardia detail

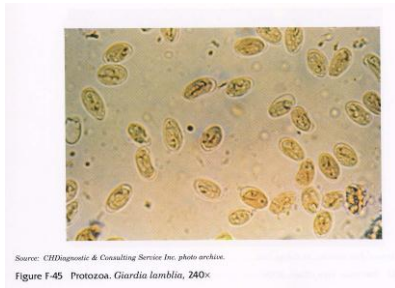


Figure 3-7⁷
Giardia lamblia



Figure 3-8⁸
Giardia lamblia



Figure 3-9⁹
Cryptosporidium

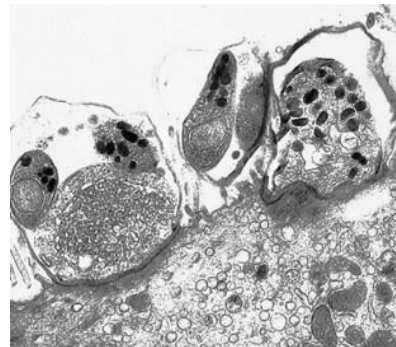


Figure 3-10¹⁰
Cryptosporidium parvum
(stained dark)

Viruses

- Survival in water extended up to five months
- Size ranges from 0.02 µm to 0.3 µm
- Reproduction—dependent on a host cell
- Many waterborne species, with over 120 identified to date, are responsible for a variety of diseases. Infectious viruses may be present in waters that meet the total coliforms standard. Coliphages, viruses that infect *E coli* bacterium, may be adopted as viral indicators.
- Best Available Technology (BAT) for treatment
 - ✓ Conventional filtration
 - ✓ Disinfection
- Viruses may cause disease even in very low numbers

Table 3-4
Virus Disease Examples

Organism/Group	Disease	Infectious Dose
<i>Rotavirus</i>	gastroenteritis	1 to 50 particles
<i>Hepatitis A virus</i>	infectious hepatitis	1 to 50 particles
<i>Caliciviruses (Norwalk agent),</i> On EPA CCL	gastroenteritis	unknown
<i>Coxsackieviruses A & B,</i> On EPA CCL	aseptic meningitis	unknown

CCL= Contaminant Candidate List (for possible future regulation)

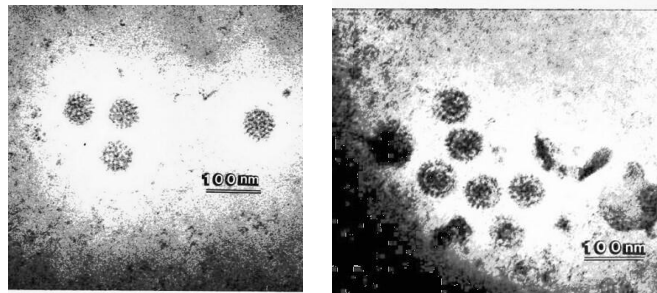


Figure 3-11 ¹¹
Rotavirus

Microbial Indicators

Microbial indicators are often used in place of testing for waterborne pathogenic microorganisms.

Ideal microbial indicators should have the following characteristics to be effective:

- Present in large numbers in fecal matter
- Present when the pathogenic microorganism is present
- High ratio of indicators to pathogens
- Stable and non-pathogenic
- Absent in uncontaminated water
- Should respond similarly to natural conditions and be at least as susceptible to treatment as the pathogenic microorganism
- Easily detected by simple, inexpensive lab tests in the shortest time with accurate results
- Should be suitable for all types of drinking water supplies

Table 3-5
Examples of Microbial Indicators

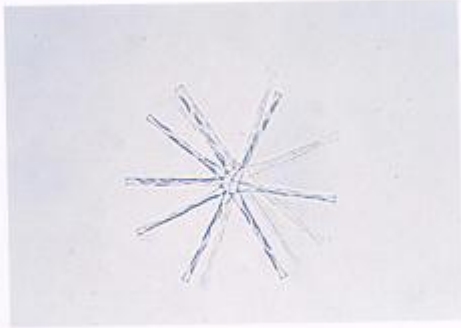
Indicator	Characteristics
Total coliforms	<ul style="list-style-type: none"> ▪ Indicator of choice for many decades. ▪ Not a health threat in itself; it is used to indicate whether other potentially harmful bacteria may be present. ▪ Coliforms are naturally present in the environment, as well as in feces. <p><u>Major Shortcomings:</u></p> <ul style="list-style-type: none"> ▪ Only marginally effective for predicting the presence of protozoan and some virus pathogens because of its much greater susceptibility to chlorine disinfection. ▪ May proliferate in distribution system biofilms, making determination of distribution system integrity difficult.
Fecal coliforms/ <i>E. coli</i>	<ul style="list-style-type: none"> ▪ <i>E. coli</i> is the major subset of fecal coliforms. ▪ Both fecal coliforms and <i>E. coli</i> are better indicators of recent fecal contamination than total coliforms. <p><u>Major Shortcomings:</u></p> <ul style="list-style-type: none"> ▪ Do not distinguish between human and animal fecal waste. ▪ Densities too low to be used for indicators of treatment effectiveness or post treatment contamination.
Heterotrophic Plate Count (HPC)	<ul style="list-style-type: none"> ▪ An analytic method used to measure the variety of bacteria that are common in water. ▪ It is a general indicator of the biological quality of drinking water; the lower the concentration of bacteria in drinking water, the better maintained the water system is. ▪ A sudden increase in HPC numbers may suggest a problem with treatment, including disinfection practices. <p><u>Major Shortcoming:</u></p> <ul style="list-style-type: none"> ▪ Does not provide an indication of the presence of pathogens.
Turbidity	<ul style="list-style-type: none"> ▪ Turbidity is a nonspecific measurement of the cloudiness of water due to light-scattering particles relative to the amount of light scattered due to a reference suspension. ▪ It has been used for decades as an indicator of water quality and filtration effectiveness (e.g., whether the treatment process is susceptible to the passage of disease-causing organisms). ▪ Higher turbidity levels are often associated with higher levels of disease-causing microorganisms, particularly those microorganisms that associate with particles. ▪ Turbidity may provide adsorption/encasement sites for pathogenic organisms, protecting them from disinfection processes. <p><u>Major Shortcomings:</u></p> <ul style="list-style-type: none"> ▪ Provides no information on the nature of the particles.

Particle Counts	<ul style="list-style-type: none"> ▪ A measurement of number and size of particles in water. ▪ It can be used to determine overall log reduction of particles through the entire treatment process. ▪ It is a particularly sensitive indicator of filtration effectiveness and for assessing filter operational problems. ▪ It generally provides an earlier indication of filter breakthrough than turbidity. ▪ Higher particle count levels may be associated with higher levels of disease-causing microorganisms such as viruses, parasites, and some bacteria. <p><u>Major Shortcomings:</u></p> <ul style="list-style-type: none"> ▪ Does not distinguish between living and nonliving particles, and between particles from the source water and those due to the addition of chemicals. ▪ No standardization between different manufacturers' equipment.
Microscopic Particulate Analysis (MPA)	<ul style="list-style-type: none"> ▪ Used as a tool to define whether a groundwater source is under the direct influence of surface water via microscopic sample screening for the presence of plant debris, pollen, rotifers, crustaceans, amoebas, nematodes, insects/larvae, algae, coccidia (<i>Cryptosporidium</i>), and <i>Giardia</i> cysts. ▪ Used as a tool to evaluate filter effectiveness of surface water supplies. <p><u>Major Shortcomings:</u></p> <ul style="list-style-type: none"> ▪ Not for routine monitoring due to complexity of procedure and time required to perform analysis. ▪ Only identifies larger pathogens such as <i>Giardia</i> and <i>Cryptosporidium</i>.
<i>Clostridium perfringens</i>	<ul style="list-style-type: none"> ▪ Bacterium consistently associated with human fecal matter. ▪ Not a pathogen, but is excreted in greater numbers than fecal pathogens. ▪ Forms spores that are extremely resistant to environmental stresses and disinfection. ▪ Analysis is simple and inexpensive. <p><u>Major Shortcomings:</u></p> <ul style="list-style-type: none"> ▪ Insufficient data exists to consistently correlate <i>C. perfringens</i> with pathogenic microorganisms.
Coliphages	<ul style="list-style-type: none"> ▪ Viruses that infect <i>E. coli</i>. ▪ Field trials currently underway for validation of coliphages as viral indicators. ▪ Present in human wastewater. ▪ Far easier to analyze than human or animal viruses. ▪ Environmentally robust, with long survival times in water. ▪ Structurally similar to human enteric viruses.

General Groups of Nuisance Microorganisms and Aesthetic Concerns

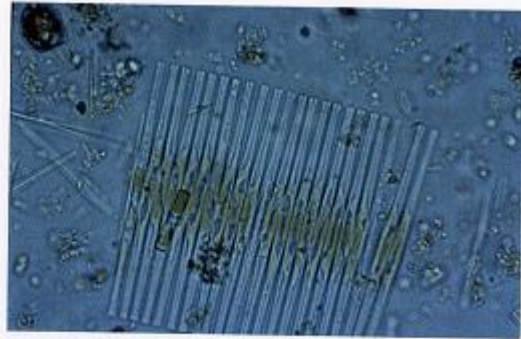
Table 3-6
Examples of Nuisance Microorganisms

Microorganism	Impact on Water Supply
Algae blooms <ul style="list-style-type: none"> ▪ Taste & odor producers ▪ Filter cloggers 	<ul style="list-style-type: none"> ▪ Tastes & odors ▪ Poor settling ▪ Filter clogging ▪ Diurnal pH changes ▪ Oxidant demand
Iron bacteria <ul style="list-style-type: none"> ▪ Ribbon (stalk) formers - <i>Gallionella</i> ▪ Tube formers - <i>Crenothrix</i>, <i>Leptothrix</i>, <i>Sphaerotilus</i> ▪ Consortial heterotrophic incumbents 	<ul style="list-style-type: none"> ▪ Forms slimes which create localized anaerobic conditions inside wells and pipelines, leading to: <ul style="list-style-type: none"> – Corrosion initiation and tuberculation – Plugging of hydraulic conveyance facilities – “Red water” problems due to bioaccumulation of iron and manganese and subsequent release due to sloughing off of slimes – Tastes & odors
Sulfur bacteria <ul style="list-style-type: none"> ▪ Sulfur reducing bacteria (SRB) 	<ul style="list-style-type: none"> ▪ Severe taste & odor ▪ Initiates corrosion ▪ Reduces equipment efficiencies, (e.g. partial clogged pump) ▪ Reacts with large quantities of sulfates and generates hydrogen sulfide as it grows; hydrogen sulfide reacts with dissolved metals (esp. iron) generating black sulfide particles
<i>Actinomyces</i> spp. (bacteria that constitute a considerable portion of microorganisms contained in lake and river bottom muds)	<ul style="list-style-type: none"> ▪ Tastes & odors – earthy/musty odors from the metabolites Geosmin and Methyl Isoborneol (MIB)



Source: K. Hanzack, CH2Diagnostic & Consulting Service Inc.
Figure F-37 Algae. Diatom, *Asterionella*, unstained, bright-field microscopy, 120x

Figure 3-12 ¹²
Asterionella



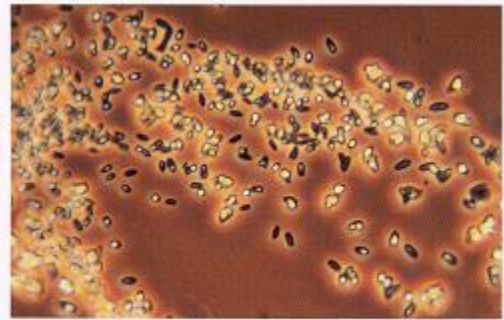
Source: K. Hanzack, CH2Diagnostic & Consulting Service Inc.
Figure F-38 Algae. Diatom, *Fragilaria*, unstained, bright-field microscopy, 240x

Figure 3-13 ¹³
Fragilaria



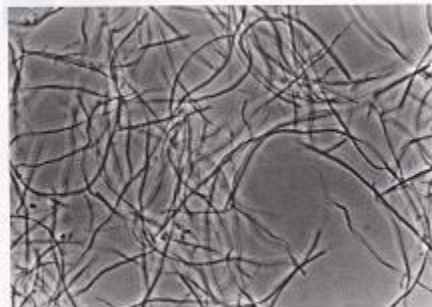
FIGURE 2-21. Scale With Enveloping, Shell-like Layer (Unfavorable conditions), Filamentous Structures of Iron Bacteria

Figure 3-14 ¹⁴
Iron Bacteria



Source: M. Richard, P.D., RRD Inc., Ft. Collins, Colo.
Figure F-5 Sulfur bacteria, *Thiobacillus* (note precipitated sulfur), 1,000x

Figure 3-15 ¹⁵
Sulfur Bacteria
Thiobacillus (stained dark)



Source: Scott Tigue, Asadipal Service Inc.
Figure 1-1 Actinomycetes, phase contrast 1,000x

Figure 3-16 ¹⁶
Actinomycetes

INORGANIC CONSTITUENTS: Inorganics are chemicals that do not contain carbon chains (matter that is not of plant or animal origin). These include such things as metals and salts. Many inorganic chemicals are naturally occurring at low levels. However, higher level can cause human health and environmental problems.

Standards and BATS for Inorganic Constituents That May Occur in Drinking Water Supplies

Table 3-7
Regulated Waterborne Inorganic Constituent Standards

Parameter	MCL	SMCL	PMCLG
Antimony - mg/L	0.006	NA	0.006
Arsenic - mg/L	0.01	NA	Zero
Asbestos - fibers/L >10 µm	7x10 ⁶ fibers	NA	NA
Barium - mg/L	2.0	NA	2
Beryllium - mg/L	0.004	NA	0.004
Cadmium - mg/L	0.005	NA	0.005
Chromium (total) - mg/L	0.1	NA	0.1
Lead - mg/L	0.015 (Action Level)	NA	Zero
Copper - mg/L	1.3 (Action Level)	1.0	1.3
Mercury, Total (inorganic) - mg/L	0.002	NA	0.002
Nickel - mg/L	0.1	NA	0.1
Selenium - mg/L	0.05	NA	0.05
Thallium - mg/L	0.002	NA	0.0005
Zinc - mg/L	NA	5.0	NA
Iron - mg/L	NA	0.3	NA
Manganese - mg/L	NA	0.05	NA
Aluminum - mg/L	NA	0.05-0.20	NA
Silver - mg/L	NA	0.1	NA
Chloride - mg/L	NA	250	NA
Sulfate - mg/L	NA	250	500
Sodium - mg/L	NA	NA	20
TDS - mg/L	NA	500	NA
Nitrate (as N) - mg/L	10	NA	10
Nitrite (as N) - mg/L	1	NA	1
Nitrate + Nitrite (both as N) - mg/L	10	NA	10
Fluoride - mg/L	2	2.0	4

MCL = Primary Maximum Contaminant Level
 SMCL = Secondary Maximum Contaminant Level
 PMCLG = Primary Maximum Contaminant Level Goal
 NA = Not Applicable

Table 3-8
BATS for Inorganic Constituents

Parameter	GAC	Oxidation	Coagulation/Filtration	Ion Exchange	Membranes	Lime Softening	Activated Alumina	Corrosion Control
Metals								
Antimony			X		X (RO)			
Barium				X (Cation)	X (RO,ED)	X		
Beryllium			X	X	X (RO)	X		
Cadmium			X	X (Cation)	X (RO)	X		
Chromium (+3)			X	X (Cation)	X (RO)	X		
Chromium (+6)			x	X (Anion)	X (RO)	X		
Lead*								X
Manganese		X	X (w/preoxidation)	X (Cation)		X		
Mercury	X		X		X (RO)	X		
Molybdenum				X (Anion)	X (RO, NF)			
Nickel				X (Cation)	X (RO)	X		
Thallium				X (Anion)			X	
Miscellaneous Inorganics and Inorganic Ions								
Arsenic (+3)			X (w/preoxidation)		X (RO,, ED) (RO, NF, ED)			
Arsenic (+5)			X (w/preoxidation)		X (RO, ED) (RO, NF, ED)			
Boron				X	X (RO, NF)	X		
Nitrate				X (Anion)	X (RO, ED)			
Nitrite				X (Anion)	X (RO)			
Nitrate and Nitrite				X (Anion)	X (RO)			
Sulfate				X	X (RO,NF, ED)			
Selenium (+4)			X	X (Anion)	X (RO, ED)	X	X	
Selenium (+6)				X (Anion)	X (RO, ED)	X	X	
Fluoride					X (RO)		X	

ED = Electrodialysis/Electrodialysis Reversal (membrane process used both to demineralize brackish water and seawater, and soften hard water; limited to removing ionic contaminants, not effective for removing pathogens and organics).

GAC = Granular activated carbon

NF = Nanofiltration (membranes containing slightly larger diameter pores than RO; used for softening hard waters and removing disinfectant byproduct precursors (organics)).

OX = Oxidation

RO = Reverse osmosis (desaltation)

* Consumers with high lead levels can reduce lead in their drinking water from their kitchen sink taps by running the tap water for 30 seconds.

Common Sources of Inorganic Constituents

Table 3-9
List and Sources of Inorganic Constituents

Parameter	Naturally Occurring	Industrial Discharges	Stormwater Runoff	Distribution System Pipe Corrosion	Water Treatment Product
Metals					
Antimony		Petroleum refineries; fire retardants; ceramics; electronics; solder			
Asbestos	Erosion of natural deposits	Mining discharge		Decay of asbestos cement pipe	
Barium	Erosion of natural deposits	Drilling wastes; metal refineries; brick and ceramic manufacturers			
Beryllium		Metal refineries and coal-burning factories; electrical, aerospace, and defense industries			
Cadmium	Erosion of natural deposits	Metal refineries; waste from electroplating	Runoff from waste batteries and paints	Galvanized pipe corrosion	
Chromium (total of valence states III & VI)	Erosion of natural deposits	Steel and pulp mills; waste from electroplating, garbage and fossil fuel combustion			
Lead	Erosion of natural deposits			Corrosion of distribution system lead pipe and household plumbing systems	
Copper	Erosion of natural deposits			Corrosion of household plumbing systems	Copper salts used for algae control in reservoir

INORGANIC CONSTITUENTS

Mercury, Total (inorganic)	Erosion of natural deposits	Refineries and factories	Runoff from landfills and croplands		
Nickel	Erosion of natural deposits				
Thallium		Leaching from ore- processing sites; electronics, glass, and drug factories			
Iron	Erosion of natural deposits			Corrosion of distribution pipe	Overdose of iron salt coagulant
Manganese	Erosion of natural deposits	Discarded batteries; steel alloys; agricultural products			coagulant
Aluminum	Erosion of natural deposits				Overdose of alum coagulant
Silver					Some domestic treatment systems
Sodium	Erosion of natural deposits				Sodium hypochlorite, caustic soda, soda ash
Zinc	Erosion of natural deposits			Corrosion of galvanized pipe	Some phosphate- based corrosion inhibitors

General Inorganic Chemical and Treatment Terminology



Alkali – Certain soluble salts, such as sodium, potassium, magnesium, and calcium that have the property of combining with acids to form neutral salts. The most commonly used alkali in water treatment contains either sodium (caustic soda, soda ash) or calcium (lime).



Alkalinity, Total – The capacity of water to neutralize acids due to the water's content of carbonate, bicarbonate, hydroxide, and possibly minor amounts of other radicals, expressed in terms of calcium carbonate equivalent. It is a measure of how much acid must be added to a liquid to lower the pH to 4.5, using a titration procedure.



Alkalinity, Bicarbonate (HCO_3^-) – A form of all alkalinity when pH is less than 8.3, commonly referred to as natural alkalinity.



Alkalinity, Phenolphthalein – A measurement of that portion of total alkalinity, contributing to pH greater than 8.3, which can include bicarbonate (HCO_3^-), carbonate (CO_3^{2-}), and hydroxide (OH^-).



Amperometric Titration – A method used to measure concentrations of strong oxidizers, among other substances, based on the electric current that flows during a chemical reaction.



Anion – An elemental atom or compound with a negative charge.



Buffer – Water whose chemical makeup neutralizes acids or bases without a great change in pH.



Buffer Capacity – A measure of the capacity of water for offering a resistance to changes in pH.



Calcium Carbonate Equivalent (CaCO_3) – An expression of water quality constituents in terms of their equivalent value to calcium carbonate.



Cation – An elemental atom or compound with a positive charge.



Catalyst – A substance that can “speed up” a chemical reaction without being permanently changed.



Colloidal – The dispersion of extremely small particles ($< 1.0 \mu\text{m}$ in size) in water that cannot settle naturally, primarily due to electrostatic repulsive forces of particle surface charges.



Coagulation – The addition of a chemical compound (typically a metal salt) to water in order to destabilize colloidal and suspended particles by neutralizing particle electrostatic charges (which are primarily negative). The result is that these particles aggregating into larger particles (flocs) that can be more readily removed by clarification and/or filtration processes.



Colorimetric Measurement – A method of determining the concentrations for a range of water quality parameters by measuring a sample's color adsorption following the addition of analyte-specific reagent(s).



Conductivity – A surrogate for ionic strength; a measure of the ability of a water to carry an electric current, which depends on the presence of ions, their total concentration, mobility, valence and the temperature of the water during the measurement. Expressed in mhos (or more commonly micromhos), the reciprocal of electrical resistance units of measure, ohms. A ratio between conductivity and TDS is site-specific; however, typically it is in the range of 55% to 70% TDS: conductivity. Measurement of conductivity may help determine the amount of ionic reagent needed to affect precipitation or neutralize reactions in water treatment.



DPD – A commonly used method for measuring chlorine residual in water, using either burette titration or a color comparison to a standard. DPD is an abbreviation for N, N-diethyl-*p*-phenylene-diamine.



Gram Equivalent Weight – The gram molecular weight of a compound (or atomic weight, for elements) divided by the valence state of an element or compound.



Gram Molecular Weight – The molecular weight of a compound (or atomic weight, for elements) in grams.



Hardness, Total – The presence of divalent metallic cations in water due to dissolution of minerals (primarily salts of calcium and magnesium) in geologic formations by natural waters; supersaturated concentrations of these dissolved minerals may result in scaling of distribution systems, hot water heaters, boilers, etc. Highest hardness usually occurs in wells (groundwater sources) as opposed to rivers or lakes.



Hardness, Calcium – That portion of total hardness that is due to calcium ions.



Hardness, Carbonate – That portion of total hardness equivalent to the total alkalinity.



Hardness, Magnesium – That portion of total hardness that is due to magnesium ions.



Hardness, Noncarbonate – That portion of total hardness that is in excess of alkalinity.



Insoluble – A solid element or compound that is incapable of being dissolved.



Kinetics – The speed or velocity of chemical reactions, which depend on factors such as temperature, pH, presence of catalysts, etc.



Mole – Refers to the molecular weight in grams of an element or compound (same as gram molecular weight).



Normality – The number of gram equivalent weights of a solute per liter of solution.



Organic complex – An element or compound associated with Dissolved Organic Carbon (DOC).



Oxidation – A metal or metal-like element loses electrons to a nonmetal, thereby gaining stability as it transforms from a soluble phase to a solid phase.



Oxidation-Reduction Potential (ORP) – The electrical potential required to transfer electrons from one compound or element (the oxidant, or oxidizer) to another compound or element (the redundant, or reducer). The measurement is used as a qualitative indicator of the state of oxidation in water treatment.



Percent Saturation – The amount of a substance that is dissolved in a solution compared with the amount that could be dissolved in the solution, expressed as a percent.



pH – The measurement of hydrogen ion activity which affects many chemical reactions.



Precipitation – The physical and chemical reactions due to supersaturation of specific dissolved chemical ions that result in conversion of some or all of those ions into solid particles so that equilibrium is restored to a solution (the separation from a solution of an insoluble substance).



Reagent – A pure chemical substance that is used in chemical tests to measure, detect, or examine other substances.



Soluble – A dissolved phase of an element or compound.



Solute – The dissolved component of a solution.



Standard Solution – A solution in which the exact concentration of a chemical or compound is known.



Stoichiometry – The methodology by which the quantities of reactants and products in chemical reactions are determined.



Titration – The analytical method whereby a chemical solution of known strength is added drop by drop until a specific end point is reached, identified by a color change, precipitate or pH change. This method is commonly used for determining levels of alkalinity and hardness.



Total Dissolved Solids – A surrogate for ionic strength in water, consists mainly of dissolved inorganic salts. Site specific, but typically in the range of 55% to 70% of conductivity reading.

Acute and Chronic Health Effects

Table 3-10
Health Effects of Waterborne Inorganic Constituents

Parameter	Potential Health Affects
Antimony	Increase in blood cholesterol; decrease in blood sugar
Arsenic	Can cause Blackfoot disease or problems with circulatory systems. May increase the risk of contracting skin cancer.
Asbestos	Increased risk of developing benign intestinal polyps; suggestions of elevated risk for developing kidney and pancreatic cancer
Barium	Chronic exposure may lead to increase in blood pressure
Beryllium	Intestinal lesions
Cadmium	Chronic exposure may cause liver and kidney damage
Chromium	Allergic dermatitis; Chromium VI is toxic
Lead	Infants and children: delays in physical or mental development; children could show slight deficits in attention span and learning abilities. Adults: kidney problems; high blood pressure.
Copper	High short term exposure: gastrointestinal distress; anemia. Long term exposure: liver or kidney damage. People with Wilson's Disease should consult their personal doctor if the amount of copper in their water exceeds the action level.
Mercury (inorganic)	Auto-immune kidney damage
Nickel	Possible mutagenic, chromosomal aberration
Selenium	Hair or fingernail loss; numbness in fingers or toes; circulatory problems
Thallium	Hair loss; changes in blood; kidney, intestine, or liver problems
Zinc	Excessive zinc interferes with iron & copper adsorption
Silver	Skin discoloration, a cosmetic effect related to silver ingestion; does not impair body function
Sulfate	Laxative effect above 1000 mg/L, above 600 mg/L for infants
Sodium	Contributes to hypertension
Nitrate (as N) Nitrite (as N) Nitrate + Nitrite (both as N)	Infants below the age of six months who drink water containing nitrate and/or nitrite in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome.
Fluoride	Chronic high levels: bone fluorosis (pain and tenderness of the bones); acute overdosing due to excess fluoride feed (20 mg/L to 200 mg/L) can result in nausea, diarrhea, abdominal pain. Safe and effective dose is considered to be 0.7 to 1.2 mg/L.

Aesthetic Concerns

Table 3-11
List of Aesthetic Concerns

Standards Related to:	Possible Water Quality Contributor(s)	Possible Indication of:
Metallic or salty taste	Copper, Iron, Manganese, Zinc, pH, Total Dissolved Solids(TDS), Sulfate, Chloride	Improper treatment, resulting in corrosion of pipe materials
Color	Aluminum, Copper, Iron, Manganese, Total Dissolved Solids (TDS)	Improper and/or inadequate source water treatment; corrosion of pipe materials
Cosmetic effects	Silver	Possible evidence of Argyria, a skin discoloration, due to leaching from home water treatment devices containing silver for disinfection
Tooth discoloration and/or pitting in children	Fluoride	High levels of fluoride in water supply; excessive fluoride feed
Corrosion and staining	Copper, Iron, Manganese, Zinc, pH, Total Dissolved Solids(TDS), Chloride	Improper and/or inadequate treatment, contributing to passage of raw water contaminants and/or corrosion of pipe materials leading to staining (blue-green, brown, black) of plumbing fixtures, laundry, etc.
Scale and sediments	Iron, pH, Total Dissolved Solids (TDS), Aluminum.	High levels of hardness, excessive alkali feed and/or deficient treatment may result in scale formation and sediments, mineral deposits which build up on the insides of water mains, hot water pipes, boilers, and heat exchangers, restricting or even blocking water flow.

General Categories of Organic Compounds

- Synthetic (man-made) Organic Chemicals (SOC)
- Natural Organic Matter (NOM)

Regulations

- Synthetic Organic Chemicals (SOC) are generally classified as either Volatile Organic Compounds (VOC) or non-volatile organic compounds.
- NOM is regulated in the Disinfection/Disinfectant Byproduct Rule which is discussed later in this Unit.

Standards and BATS for Volatile Organic Compounds (VOC)

Table 3-12
Standards and BATS for VOCs

Volatile Organics	MCL [parts per million (ppm)]	BAT
Benzene	0.005	GAC, PTA
Carbon Tetrachloride	0.005	GAC, PTA
(Mono) Chlorobenzene	0.1	GAC, PTA
o-Dichlorobenzene	0.6	GAC, PTA
p-Dichlorobenzene	0.075	GAC, PTA
1,2 Dichloroethane	0.005	GAC, PTA
1, 1 Dichloroethylene	0.007	GAC, PTA
cis - 1,2 Dichloroethylene	0.07	GAC, PTA
trans-1,2 Dichloroethylene	0.1	GAC, PTA
1,2 Dichloropropane	0.005	GAC, PTA
Ethylbenzene	0.7	GAC, PTA
Methylene Chloride (Dichloromethane)	0.005	PTA
Styrene	0.1	GAC, PTA
Tetrachloroethylene (PCE)	0.005	GAC, PTA

Volatile Organics	MCL [parts per million (ppm)]	BAT
Toluene	1.0	GAC, PTA
1,2,4 Trichlorobenzene	0.07	GAC, PTA
1,1,1 Trichloroethane	0.2	GAC, PTA
1,1,2 Trichloroethane	0.003	GAC, PTA
Trichloroethylene (TCE)	Zero	GAC, PTA
Vinyl Chloride	Zero	PTA
Xylenes	10.0	GAC, PTA

PTA = Packed Tower Aeration, GAC = Granular Activated Carbon
 TT = Treatment Technique, PAP = Polymer Addition Practices

Standards and BATS for Non-Volatile Organic Compounds

Table 3-13
 Standards and BATS for Non-Volatile Organic Compounds

Non-Volatile Organics	MCL (ppm)	BAT
Acrylamide	TT	PAP
Alachlor	0.002	GAC
Aldicarb (proposed)	(0.003)	GAC
Aldicarb sulfone (proposed)	(0.002)	GAC
Aldicarb sulfoxide (proposed)	(0.004)	GAC
Atrazine	0.003	GAC
Benzo(a)pyrene	0.0002	GAC
Carbofuran	0.04	GAC
Chlordane	0.002	GAC
2,4 D	0.07	GAC
Dalapon	0.2	GAC
Dibromochloropropane (DBCP)	0.0002	GAC, PTA
Di(2-ethylhexyl)adipate	0.4	GAC, PTA
Di(2-ethylhexyl)phthalate	0.006	GAC
Dinoseb	0.007	GAC

Non Volatile-Organics	MCL (ppm)	BAT
Diquat	0.02	GAC
Endothall	0.1	GAC
Endrin	0.002	GAC
Epichlorohydrin	TT	PAP
Ethylene Dibromide (EDB)	0.00005	GAC, PTA
Glyphosate	0.7	OX
Heptachlor	0.0004	GAC
Heptachlor epoxide	0.0002	GAC
Hexachlorobenzene	0.001	GAC
Hexachlorocyclopentadiene	0.05	GAC, PTA
Lindane - (δ BHC)	0.0002	GAC
Methoxychlor	0.04	GAC
Oxamyl (Vydate)	0.2	GAC
Pentachlorophenol	0.001	GAC
Pichloram	0.5	GAC
Polychlorinated Biphenals (PCB)	0.0005	GAC
Simazine	0.004	GAC
2,3,7,8 TCDD (Dioxin)	3×10^{-8}	GAC
Toxaphene	0.003	GAC
2,4,5 TP (Silvex)	0.05	GAC

Common Sources



Can you think of some examples and common sources of Natural Organic Compounds (NOMs)?



Can you think of some common sources of Synthetic Organic Chemicals (SOCs), volatile and non-volatile?

Types and Sources of Radionuclides

Table 3-14
Types and Sources of Radionuclides

Parameter	Source
Gross alpha emitters	Erosion of natural deposits of certain minerals that are radioactive and may emit a form of radiation known as alpha radiation
Radium 226+228	Erosion of natural deposits
Uranium	Erosion of natural deposits

Standards and BATS for Radionuclides

Table 3-15
Standards and BATS for Radionuclides

Parameter	MCL	BAT
Radium 226 + 228 - pCi/L	5	LS, IX, RO
Beta-particle and Photon Emitters - Mrem/yr	4	CF, IX, RO
Uranium - µg/L	30	CF, LS, AX
Gross Alpha Emitters - pCi/L	15	CF, RO

MM = Multimedia IX = Ion Exchange
 AR = Aeration RO = Reverse Osmosis
 AX = Advanced Oxidation LS = Lime Softening
 CF = Coagulation/Filtration

MCL = Maximum Contaminant Level, MCLG = Maximum Contaminant Level Goal

Acute and Chronic Health Affects

Table 3-16
Health Effect of Radionuclides

Parameter	Potential Health Affects
Beta particle & photon emitters	Increased risk of cancer
Alpha emitters	Increased risk of cancer
Radium 226+ 228	Increased risk of cancer
Uranium	Increased risk of cancer, kidney toxicity

Disinfectants

Standards and BATS for Disinfectants

Table 3-17
List of Regulated Disinfectants and BATS

Parameter	MRDL	MRDLG	BAT
Chlorine – mg/L as Cl ₂	4.0	4.0	DC
Chloramines – mg/L as Cl ₂	4.0	4.0	DC
Chlorine dioxide – mg/L as ClO ₂	0.8	0.8	DC

DC = Disinfection Control System
MRDL = Maximum Residual Disinfectant Level
MRDLG = Maximum Residual Disinfectant Level Goal

Parameters for Monitoring

- Chlorine is measured to:
 - ✓ Determine the concentration of Free Available Chlorine (FAC) residual in the distribution system.
 - ✓ Optimize reactions with soluble iron and manganese, hydrogen sulfide, ammonia, and taste & odor compounds.
 - ✓ Control levels of Disinfectant Byproduct (DBP) formation by minimizing chlorine dose.
- Chloramine is measured to:
 - ✓ Determine the concentration of Total Available Chlorine (TAC) residual in the distribution system.
 - ✓ Optimize reactions of chlorine with ammonia, which generate chloramines.
- Chlorine dioxide is measured to:
 - ✓ Optimize reactions with taste & odor compounds, soluble iron and manganese.
 - ✓ Control levels of DBP formation by minimizing chlorine dioxide dose.
- Ozone is measured to:
 - ✓ Optimize reactions with taste & odor compounds, soluble iron and manganese.
 - ✓ Control levels of DBP formation by minimizing ozone dose.

Disinfectant Byproducts

Standards and BATS for DBPs

Table 3-18
Disinfectant Byproducts, Standards, and BATS

Parameter	MCLG	MCL	BAT
Total Trihalomethanes	NA	0.080	AD, PR, DC/EC+GAC
Chloroform (THM)	NA	NA	EC
Bromodichloromethane (THM)	Zero	NA	EC
Dibromochloromethane (THM)	0.06	NA	EC
Bromoform (THM)	Zero	NA	EC
Total Haloacetic Acids (HAA5)	NA	0.06	EC/GAC
Trichloroacetic Acid	0.3	NA	EC
Dichloroacetic Acid	Zero	NA	EC
Bromate	Zero	0.010	DC
Chlorite	0.8	1.0	DC

NA = Not applicable

AD = Alternative Disinfectants

DC = Disinfection System Control

EC = Enhanced Coagulation

GAC = Granular Activated Carbon

PR = Precursor Removal

MCL = Maximum Contaminant Level

MCLG = Maximum Contaminant Level Goal

**Unit 3 Exercise**

Using the workbook, answer the following questions:

1. List one example of a regulated waterborne microorganism.
 - a. _____
2. Waterfowl droppings, septic fields, and run-off from farm fields are some of the common sources of waterborne pathogenic microorganisms.
 - a. True
 - b. False
3. List one characteristic of an effective microbial indicator.
 - a. _____
4. A sudden increase in Heterotrophic Plate Count (HPC) may suggest a problem with treatment, including disinfection practices.
 - a. True
 - b. False
5. List the Maximum Disinfectant Residual Level (MDRL) for chlorine _____
6. Give the Primary Maximum Contaminant Level (PMCL) for cadmium _____
7. Hard water is caused by iron in the water:
 - a. True
 - b. False

**Key points for Unit 3 – Water Quality Classifications**

- Waterborne pathogenic microorganisms present in drinking water can cause disease in humans.
- Drinking water disease outbreaks most often involve groundwater systems.
- Waterfowl droppings, septic fields, and farm run-off are common sources of waterborne pathogenic microorganisms.
- The three categories of microorganism agents of waterborne disease are bacteria, protozoa, and viruses.
- Microbial indicators are often used in place of testing for waterborne pathogenic microorganisms.
- A colloidal suspension of extremely small particles in water will not settle naturally and requires chemical additives or special techniques to remove the particles.
- The process of coagulation involves adding a chemical compound (like alum) to water to destabilize colloidal and suspended particles to form a floc that can be removed by settling and/or filtration.
- Colorimetric testing methods are used to measure a water sample's color adsorption after adding specific reagents to the water.
- A measurement of pH indicates the hydrogen ion activity which affects many chemical reactions.
- Organic compounds are classified as Synthetic Organic Chemicals (SOC) or Natural Organic Matter (NOM).
- Common chemical disinfectants are chlorine, chloramines, chlorine dioxide, and ozone.

¹ New York Department of Health Website, Wadsworth Center.

² *ibid.*

³ *ibid.*

⁴ *ibid.*

⁵ *Problem Organisms in Water: Identification and Treatment*, American Water Works Association Research Foundation, 1995.

⁶ *Giardia and Cryptosporidium in Water Supplies*, American Water Works Association Research Foundation, 1991.

⁷ *Problem Organisms in Water: Identification and Treatment*, American Water Works Association Research Foundation, 1995.

⁸ New York Department of Health Website, Wadsworth Center.

⁹ *Problem Organisms in Water: Identification and Treatment*, American Water Works Association Research Foundation, 1995.

¹⁰ *ibid.*

¹¹ *ibid.*

¹² *Problem Organisms in Water: Identification and Treatment*, American Water Works Association Research Foundation, 1995.

¹³ *ibid.*

¹⁴ *Internal Corrosion of Water Distribution Systems*, American Water Works Association Research Foundation.

¹⁵ *Problem Organisms in Water: Identification and Treatment*, American Water Works Association Research Foundation, 1995.

¹⁶ *ibid.*

Additional Resources Used

American Water Works Association Research Foundation

American Water Works Association Manual of Practice 12, *Simplified Procedures for Water Examination & Iron and Manganese Handbook*, AWWA 1999, Elmer O. Sommerfield.

AWWA Teleconference, The Basics of Waterborne Pathogens, March 2002.

Topical Outline

Unit 4 – Fundamentals of Chemistry

The Structure of Matter

Classification of Matter

Physical Properties of Matter

Unit 4 – Fundamentals of Chemistry

Learning Objectives

- List three states of matter and explain the difference among them.
- List and define four physical properties of matter.
- Explain the difference between elements, compounds and mixtures.
- List the primary differences between a physical and a chemical change of matter

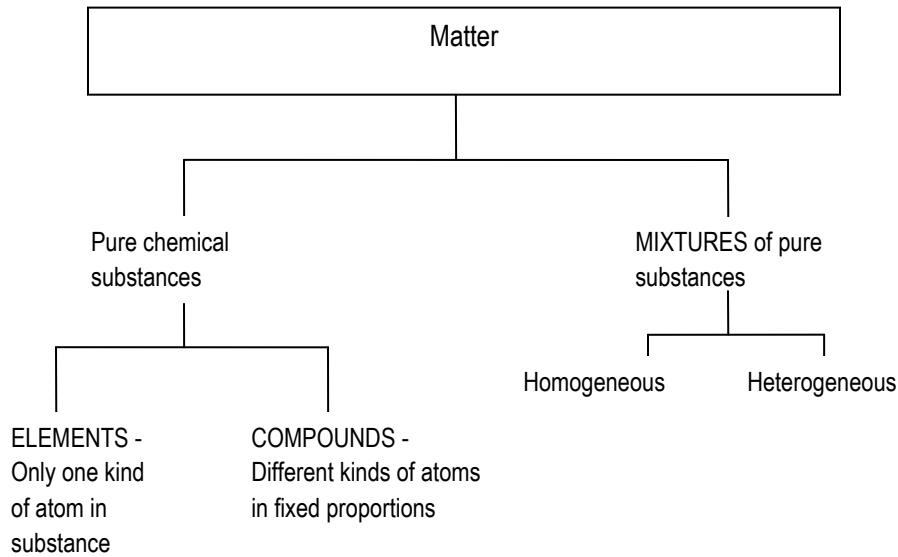


Figure 4.1 Classification of Matter

States of Matter

Matter exists in three states.

- ◆ A solid state in which the matter has a fixed shape and a fixed volume. Solid matter is characterized by rigidity. Examples of matter that exist in a solid state include things such as a desk, the floor or even a piece of paper in this workbook.
- ◆ A liquid state in which the matter has no fixed shape but has a fixed volume. Liquid matter is a relatively incompressible fluid. Examples of matter in the liquid state include things such as milk, water and gasoline.
- ◆ A gas state in which the matter has no fixed shape and no fixed volume. Matter in the gaseous state is easily compressible. Examples of matter in the gaseous state include hydrogen sulfide, methane, natural gas or the air that we breathe.

Under certain conditions, a material substance can exist in all three states. For example, at room temperature, water is a liquid, but below 32° F, it becomes a solid - ice. If water is heated, it will eventually boil and become a vapor or gas.

Physical Properties of Matter

A physical property is an observable characteristic which does not involve a change in the chemical identity of the material.

Mass



Mass is the amount of matter present in a given object. It is expressed in units such as pounds (lbs) or grams (g).

- ◆ Since mass is the amount of material in an object, it stays the same no matter what force is acting on it. This is what differentiates “mass” and “weight.”
- ◆ All matter, including chemicals and substances, are commonly described on the basis of “mass.”

Weight



Weight is the mass of an object being acted upon by gravity. The weight of an object is proportional to its mass.

- ◆ There is less gravitational force on the moon than on Earth; therefore, an object on the moon will weigh less than the same object on Earth. The mass of the object remains the same but the weight is different.

Density



Density is the mass of a substance per unit of volume of the substance. All matter has mass and volume; therefore, all matter has a density.

- ◆ Density is important because it can be used to relate how a solution compares to water.
- ◆ Density is expressed as a mass per volume, such as mg/L or lbs/ft² and is calculated as follows:

$$\text{Density (d)} = \frac{\text{Mass (m)}}{\text{Volume (v)}}$$

Density of Water

- ◆ By definition, 1 Liter of water = 1 kilogram of mass, therefore:
Density of water = 1,000 grams per 1,000 milliliters
= 1,000 grams / 1,000 ml
= 1 g/ml or 1 g/cm³

- ◆ Water has a density of 1 g/ml, 1 g/cm³ or 8.34 lbs/gallon. If you weigh a gallon of water, it will weigh 8.34 lbs. Likewise, if you weigh a milliliter of water it will weigh 1 gram.
- ◆ Substances with a greater density will displace those with less density. If a solution has a higher density than water, it will sink in the water; however, if a solution has a lower density than water, it will float on the water. For example, lead will sink in water but oil will float on the water.

Specific Gravity



Specific gravity is the weight or density of a substance compared to the weight or density of the same volume of water. **Water has a specific gravity of 1 (no units) at 4° C (39° F).**

$$\text{Specific Gravity} = \frac{\text{Weight or density of a substance}}{\text{Weight or density of water}}$$

- ◆ Specific gravity is used to check chemical purity. It is also used to calculate volume for a given weight of chemical or to calculate weight for a given volume of chemical.

Calculating Specific Gravity

- ◆ Specific gravity is calculated by comparing the weight of a given volume of a substance to the weight of the same volume of water.
- ◆ Water has a density of 1 gram/milliliter (g/ml) so its specific gravity is equal to its density.

Example

Calculate the specific gravity of 1 ml of a substance that weighs 2 grams.

$$\text{Specific Gravity} = \frac{\text{Weight}}{\text{Density}}$$

$$\text{Specific Gravity} = \frac{2 \text{ gm/ml}}{1 \text{ gm/ml}}$$

$$\text{Specific Gravity} = 2$$

In this example, the substance is twice as dense as water.

Calculating the Weight of a Gallon of Chemical

- ◆ To calculate the weight of a gallon of a chemical, multiply the specific gravity of the chemical by the weight of a gallon of water.

Example 1: Calculate the weight of a gallon of 50% NaOH (sodium hydroxide or caustic soda), given that a 50% solution of caustic soda has a specific gravity of 1.53.

Weight, lbs/gal = (Specific gravity of substance) x (weight of a gallon of water)

$$\text{Weight, lbs/gal} = (1.53) \times (8.34 \text{ lbs/gal})$$

Weight = A gallon of 50% solution of NaOH weighs **12.8 lbs**

Calculating the Weight of a Chemical Solution in a Drum or Tank

Example 2: What would be the weight of a 55 gallon drum of the coagulant Sternpac if the specific gravity of the product is 1.27?

NOTE: This formula is found on the bottom of the 3rd page of the formula sheet you will receive during the exam.

Weight, lbs = (gallons of drum or tank) x (Specific gravity of substance) x (weight of a gallon of water)

$$\begin{aligned} \text{Weight, lbs} &= 55 \times 1.27 \times 8.34 \\ &= \mathbf{583 \text{ lbs}} \text{ [weight of 55 gallon drum]} \end{aligned}$$

Calculating the Number of Gallons of a Chemical Solution in a Drum or Tank

Example 3 Calculate the number of **gallons** of 2,000 pounds of 12% NaOCl (sodium hypochlorite), given its specific gravity of 1.12.

Weight, lbs/gal = (specific gravity of substance) x (weight of a gallon of water)

Step 1: Solve weight equation (lbs/gal) for 1 gallon of chemical

$$\text{Weight, lbs/gal} = (1.12) \times (8.34 \text{ lbs/gal})$$

Weight = A gallon of 12% solution of NaOCl weighs 9.3 lbs

Step 2: Calculate the numbers of gallons of 2,000 lbs. of 12% NaOCl

$\frac{(\text{total weight of chemical in lbs})}{\text{Weight of 1 gallon of solution}} = \text{gallons of 12\% NaOCl}$

$$\frac{2,000 \text{ lbs}}{9.3 \text{ lbs}} = 215 \text{ gallons of 12\% NaOCl}$$

To show you how the units cancel, here are the Step 2 unit cancellation steps:

$$? \text{ gal} = \frac{1 \text{ gal}}{9.3 \text{ lbs}} \times \frac{2000 \text{ lbs}}{1} \frac{1}{9.3} = 215 \text{ gallons}$$

Practice Problems:

1. The specific gravity of Aqua Mag is 1.4. How much (in lbs) does a one gallon weigh?

$$? \text{ lbs/gal} = (\text{S.G.}) \times (8.34 \text{ lbs/gal}) = \underline{\hspace{2cm}}$$

2. How much does a 30 gallon drum of 60% fluorosilic acid weigh (in lbs) if it has a specific gravity of 1.46?

$$\text{Weight, lbs/gal} = (\text{gallons}) \times (\text{S.G.}) \times (8.34 \text{ lbs/gal})$$

$$? \text{ lbs} = 30 \text{ gallons} \times 1.46 \times 8.34 = \underline{\hspace{2cm}} \text{ lbs}$$

3. Your plant has a 10,000 gallon tank of Aluminum Chloride. The specific gravity of Aluminum Chloride is 1.2. How much (in pounds) does the tank of Aluminum Chloride weigh when the tank is full?

$$\text{Weight, lbs/gal} = (\text{gallons}) \times (\text{S.G.}) \times (8.34 \text{ lbs/gal})$$

$$? \text{ lbs} = 10,000 \times 1.2 \times 8.34 = \underline{\hspace{2cm}} \text{ lbs}$$

Converting temperatures between the Fahrenheit and Celsius scales

$$0.555 (^\circ\text{F} - 32) = ^\circ\text{C}$$
$$(1.8 \times ^\circ\text{C}) + 32 = ^\circ\text{F}$$

(NOTE: 0.555 = 5/9 which is on the formula/conversion sheet)

Problem:

Convert 10 $^\circ\text{C}$ = ? $^\circ\text{F}$

Problem Set Up and Calculation:

Step 1: Select correct conversion formula which is _____

Step 2: Insert known value into formula: $(1.8 \times \underline{\hspace{1cm}}) + 32$

Step 3: Complete the math within the parentheses $(1.8 \times 10) = \underline{\hspace{1cm}}$

Step 4: Do the addition (step 3 + 32) for final answer = $\underline{\hspace{1cm}}$ $^\circ\text{F}$

Density of Water

- Water is most dense at 4 $^\circ\text{C}$ (39 $^\circ\text{F}$).
- The density of water is a consideration in various aspects of water treatment. For example, the settling rate of a particle becomes much slower as the temperature drops. The colder the water temperature becomes, the longer particles take to settle out. This means that longer periods of time or lower flow rates are required for colder water temperatures.

Changes of Matter

Matter can undergo both physical and chemical changes.

- ◆ A physical change in matter is a change in the form of matter but not in its chemical identity. Examples include dissolving and distillation.
- ◆ A chemical change in matter is a change in which one or more kinds of matter are transformed into a new kind of matter. Examples include burning or rusting.

**Physical and Chemical Changes**

Review the following statements and mark whether the change is physical or chemical.

	PHYSICAL	CHEMICAL
1. Drinking water is obtained from ocean water by evaporation and condensation.		
2. Sodium is obtained from sodium chloride.		
3. Pulverizing rock salt.		
4. Burning wood.		
5. Dissolving sugar into water.		
6. Rusting of Iron.		
7. The evaporation of alcohol.		



Unit 4 Exercise

1. Define the term matter and list the three states of matter.

2. Differentiate between mass, weight, density and specific gravity.

3. Explain the difference between a physical and a chemical changes in matter.

4. List and define three classes of matter.

Key Points for Unit 4 – Fundamentals of Chemistry

- Matter exists in three states: solid, liquid and gas.
- Density is the mass of a substance per unit of volume of the substance. Density can be used to relate how a solution compares to water.
- Water has a density of 8.34 lbs/gallon.
- Specific gravity is the density of a substance compared to the weight of the same volume of water.
- Specific gravity is used to calculate volume for a given weight of chemical or to calculate weight for a given volume of chemical.
- $\text{Weight, lbs/gal} = (\text{Specific gravity of substance}) \times (\text{weight of a gallon of water})$.
- When calculating the weight of a drum or tank of solution, use this formula:

$$\text{Weight, lbs} = (\text{gallons of drum or tank}) \times (\text{Specific gravity of substance}) \times 8.34$$

- Temperature conversions from °C to °F and vice versa are as follows:
 - $(1.8 \times ^\circ\text{C}) + 32 = ^\circ\text{F}$
 - $0.555 (^\circ\text{F} - 32) = ^\circ\text{C}$
- Water is most dense at 4 °C (39 °F).