Drinking Water Operator Certification Training

Module: 4
Water Quality and Characteristics

This course includes content developed by the Pennsylvania Department of Environmental Protection (Pa. DEP) in cooperation with the following contractors, subcontractors, or grantees:

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Topical Outline

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IV. Inorganics

V. Organics

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Unit 1 – General Overview

Learning Objectives

- Outline a historical perspective of major water quality concerns and disease outbreaks.
- Name three common sources of water quality contaminants.
- List the general water quality contaminant classifications.

Water Clarity

By the 18th century, the removal of particles from water by filtration had been established as an effective means of clarifying water, although the degree of clarity was not measurable. Aesthetic concerns of smell, taste, and appearance motivated the clarification efforts. Standards were not in existence up to and including most of the 19th century.

Association of Water Quality with Disease

In 1855, Dr. John Snow proved empirically that cholera was a waterborne disease. In the 1880's, Pasteur demonstrated the particulate germ theory of disease based on the young science of bacteriology.

It was only after a century of generalized public health observations of deaths due to waterborne disease that the cause-and-effect relationship was firmly established. As a result of this understanding and the installation of appropriate forms of treatment, the virtual elimination of deadly waterborne diseases, including typhoid fever and cholera, had occurred in the developed countries by the end of the 19th century.

Waterborne Disease Epidemics

- 1854: Cholera outbreak in London.
- Late 19th century: Typhoid epidemics in Butler, Plymouth, New Haven, Nanticoke, and Reading, Massachusetts.
- 1993: A *Cryptosporidium* outbreak in Milwaukee resulted in 400,000 cases of cryptosporidiosis and at least 50 deaths.

Sources of Contaminants

Contaminant – Any physical, chemical, biological, or radiological substances or matter in water[1].

- Naturally occurring
  - ✓ Iron and manganese from watershed runoff and reservoir stratification.
  - ✓ *Giardia lamblia* contamination of surface water supply due to muskrat and beaver feces.
- Manmade pollution
  - ✓ Contamination of nearby groundwater supplies with volatile organic compounds (VOCs) due to application of industrial waste cleaners as dust control of dirt parking lots and roads.
  - ✓ Leaking underground petroleum storage tanks contaminating groundwater with VOCs.
- Byproducts of water treatment
  - ✓ Total Trihalomethanes (TTHM) are byproducts of the reaction between chlorination and the natural organic matter (NOM) contained in the source water.
  - ✓ Aluminum, resulting from an overdose of the coagulant aluminum sulfate (alum).

General Water Quality Contaminant Classifications

- Physical Characteristics
- Microbiological
- Inorganic constituents
- Organic compounds
- Radionuclides
- Disinfectant and disinfectant byproducts

Key points for Unit 1 – General Overview

- Filtration was used in the 18th century to clarify water and helped to improve taste, smell, and appearance.
- In 1855, Dr. John Snow proved that cholera was a waterborne disease.
- In recent times, 400,000 people got sick in Milwaukee in 1993 due to waterborne disease.
- Water contaminants include physical, chemical, biological, and radiological substances.
- Contamination can occur because of both natural and man-made causes.
- Disinfectants like chlorine are very effective in eliminating biological pathogens, but care must be taken so that harmful disinfection by-products (DBPs) such as THMs are not formed.

[1] *Public Law 93-523*.

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Unit 2 – Drinking Water Standards

Learning Objectives

- Outline the history of drinking water standards
- List the three step process in the development of the United States Environmental Protection Agency (USEPA) Safe Drinking Water Act
- Define the following regulatory standard classifications:
  - ✓ Primary Maximum Contaminant Level (PMCL)
  - ✓ Primary Maximum Contaminant Level Goal (PMCLG)
  - ✓ Secondary Maximum Contaminant Level (SMCL)
  - ✓ Maximum Disinfectant Residual Level (MDRL)
  - ✓ Maximum Disinfectant Residual Level Goal (MDRLG)
  - ✓ Treatment Technique (TT)
- List the major groups of water quality parameters regulated by the United States Environmental Protection Agency (USEPA)
- Identify the commonly used units of measurement for the major groups of water quality parameters

History of Drinking Water Standards

- For the most part, standards for drinking water quality were nonexistent up through and including much of the 19th century.

- In 1852, due to an improved understanding of the correlation between water and disease, a law was passed in London stating that all drinking water supplies should be filtered.

- By the year 1900, the number of municipal water systems in the United States had increased to over 3,000. However, only approximately 10 systems filtered their supplies. The result was major disease outbreaks due to the distribution of **contaminated** water. As a result, distribution of safe drinking water was a top priority in the early part of the 20th century.

- In the ensuing hundred years, emphasis of drinking water standards has shifted from acute health issues to more chronic, long-term health issues due to the presence of trace quantities of organic, inorganic, and microbiological contaminants in drinking water supplies.

Development of Drinking Water Standards

- 1893 – The U.S. Congress created the Interstate Quarantine Act which empowered the United States Public Health Service (USPHS) Surgeon General to establish drinking water regulations "to make and enforce such regulations as in his judgment are necessary to prevent the introduction, transmission, or spread of communicable diseases from foreign countries into the states or possessions, or from one state or possession into another state or possession.[1]"

- 1914 – USPHS promulgated (officially presented) the first federal water quality standards, which were only binding to water supplied to the public by interstate carriers. These standards required:
  - ✓ A 100 organism/mL limit for total bacterial count.
  - ✓ The *B. coli* (now *E. coli*) organism should not be present in more than one in five 10mL sample portions (equal to less than 2.2 organisms/100mL). The concept of maximum contaminant level (MCL) was conceived with this standard.

- 1925 – USPHS water quality revision and new standards:
  - ✓ The *B. coli* standard changed to a more stringent level of less than 1 organism/100 mL.
  - ✓ The establishment of physical and chemical constituent standards for color, chloride, iron, magnesium, and sulfate.

- 1942 – USPHS revised 1925 standards:
    - ✓ Bacteriological samples must be collected from several areas in the distribution system.
    - ✓ Tolerance limits (now MCL) were established for arsenic, fluoride, lead, and selenium.
    - ✓ Recommended limits were established for chloride, copper, iron, manganese, magnesium, phenols, sulfate, zinc, and total solids.
- 1946 – USPHS revised 1942 standards:
    - ✓ Added a tolerance limit for hexavalent chromium.
- 1962 – USPHS recommended the establishment of non-enforceable contaminant limits for 28 health-related chemical and biological impurities:
    - ✓ These included alkyl benzene sulfonates (synthetic detergents), barium, cadmium, carbon-chloroform extract (an approximate organic content, a qualitative indicator of the amount of dissolved organic matter, i.e., decayed plant material), cyanide, nitrate, and silver.
    - ✓ Radioactivity standards were added.
- 1974 – USEPA Safe Drinking Water Act (SDWA) was created largely due to the discovery of organic chemicals suspected of causing cancer commonly found in water supplies.
- 1986 – Safe Drinking Water Act Amendments. The National Research Council (NRC), under the National Academy of Sciences (NAS), published *Drinking Water and Health*, which served as the basis of revising regulations. Contaminants were divided into 5 classifications:
    - ✓ Microorganisms – measured in the following units:
        - ▪ Bacteria – colony forming units per 100 milliliters (CFU/100mL)
        - ▪ Protozoa – cysts per 1.0 milliliter (cysts/mL)
        - ▪ Viruses – particles per milliliter (particles/mL)
    - ✓ Inorganic solutes – milligrams per liter (mg/L), equivalent to and often interchangeably used with parts per million (ppm)
    - ✓ Organic solutes – micrograms per liter (µg/L), equivalent to parts per billion (ppb)
    - ✓ Radionuclides – picoCuries per liter (pCi/L)
    - ✓ Disinfectants and Disinfectant Byproducts – Disinfectants: milligrams per liter (mg/L); Disinfectant Byproducts: micrograms per liter (µg/L).

- 1996 – Additional Safe Drinking Water Amendments required the EPA to publish a maximum contaminant level goal (MCLG) and promulgate a National Primary Drinking Water Regulation (NPDWR) for every contaminant that:
    - ✓ Has an adverse effect on the health of persons.
    - ✓ Is known to occur or has a substantial likelihood to occur in public water systems with a frequency and at levels of public health concern.
    - ✓ In the sole judgment of the USEPA, regulation of the contaminant presents a meaningful opportunity for health risk reduction for persons served by public water systems.

Basis for Drinking Water Standards

The EPA has conducted several national surveys of public water systems. These surveys have provided the national statistically-based evaluations of the various contaminants found in raw and finished drinking water. These data have been and are still employed as part of the decision-making process on which contaminants should be regulated, and on the potential impact of the regulation.

Technical and scientific assessments require supporting documents for each contaminant, which are based on the following types of studies/factors:

- Toxicological studies (basic terminology/definitions relevant to these studies):
    - **Toxicology** – The study of adverse effects of chemicals on living things
    - **Carcinogenic** – Causing or inducing uncontrolled growth of aberrant cells into malignant tumors
    - **DWEL** – Drinking Water Equivalent Level
    - **Genotoxic** – Causing alteration or damage to genetic material in living cells
    - **Mutagenic** – Causing heritable alteration to genetic material within living cells
    - **RfD** – Reference dose
    - **Teratogenic** – Causing nonhereditary congenital malformations (birth defects) in offspring
    - **Acute** – Short term, high dose exposure to a contaminant
    - **Chronic** – Long term, low dose exposure to a contaminant

- Epidemiological studies
- Occurrence and human exposure
- Public perception
- Treatment technologies and costs
- Analytical methods and monitoring

The USEPA Safe Drinking Water Act (SDWA): A Three-Step Process

- EPA promulgated interim regulations based on the 1962 Public Health Service standards. These regulations became effective on June 1977 and included MCLs for 10 inorganic and 6 organic chemicals, plus turbidity, coliform bacteria, and radionuclides.

- The second step consisted of a two-year study conducted by the National Academy of Sciences (NAS) intended to gather information on all contaminants in drinking water that may have an adverse health impact.

- In the third step, the EPA promulgated more comprehensive drinking water regulations, and revised existing regulations based on the NAS two-year study results and other research. This resulted in the major SDWA amendment of 1986.

Terminology Used for Drinking Water Regulations

Maximum Contaminant Level Goal (MCLG) – A regulatory standard established as part of the amendment in 1986 to strengthen the SDWA. The MCLG is that level of a contaminant known to occur in drinking water below which there is no known or expected risk to health, based on toxicology reviews. MCLGs allow for a margin of safety and are non-enforceable public health goals. You may also see the MCLG referred to as the Primary MCLG or PMCLG.

Maximum Contaminant Level (MCL) – The highest level of a contaminant that is allowed in drinking water. MCLs are set as close to MCLGs as feasible, using the Best Available Treatment technology (BAT), and taking cost into consideration. MCLs are enforceable standards. You may also see the MCL referred to as the Primary MCL or PMCL.

Secondary Maximum Contaminant Level (SMCL) – The non-enforceable guidelines for contaminants that may adversely affect the aesthetic quality of drinking water. States were encouraged to establish regulations based on these standards.

Maximum Disinfectant Residual Level (MDRL) – The highest level of a disinfectant allowed in drinking water.

Treatment Technique (TT) – A regulatory standard established as part of the amendment to the SDWA in 1977. The TT was used in place of the MCL standard if it was not economically or technically feasible to determine the level of the contaminant.

Compliance Monitoring – EPA developed a standardized framework for monitoring source-related contaminants associated with chronic human health effects, which include the following: Volatile Organic Compounds (VOC), Pesticides, Radionuclides, and most Inorganic Chemicals.

- ✓ Nitrite, nitrate, and microbial contaminants are not included in this monitoring framework because they are associated with acute rather than chronic health concerns. In addition, those contaminants regulated by treatment technique and not by MCL, are not included in this framework.

Analytical methods and monitoring techniques – These are critical in the regulation of contaminants in raw and finished drinking water. The factors included in the selection process used by the USEPA for the approval of analytical methods are:

- ✓ Reliability (precision and accuracy) of the analytical results
- ✓ Specificity in the presence of interferences
- ✓ Availability and performance of laboratories
- ✓ Rapidity of analysis for routine use
- ✓ Cost of analysis

Best Available Technology (BAT) – As part of the amendment to the SDWA in 1977, the EPA was required to designate the most effective type(s) of water treatment for each contaminant regulated.

Exercise:

Try this exercise to test your knowledge of the regulatory terms we just reviewed. Place the letter of the definition before the correct term.

______ Maximum Contaminant Level

______ Treatment Technique

______ Maximum Disinfectant Residual Level

A. This is a regulatory standard that is used in place of the MCL when it is not feasible to determine the level of the contaminant.

B. The highest level of a disinfectant allowed in drinking water

C. The highest level of a contaminant that is allowed in drinking water

Establishment of Drinking Water Rules

Table 2-1
Drinking Water Regulations and Major Requirements

Regulation	**Major Requirements**
Surface Water Treatment Rule (Pennsylvania Filtration Rule)	Requires systems using surface water or ground water under the direct influence of surface water to disinfect their water. A disinfection system that achieves at least 99.9% (3.0-log) inactivation of *Giardia* cysts and 99.99% (4.0-log) inactivation of enteric viruses. A minimum of 90% (0.5-log) *Giardia* cyst inactivation must be provided by chemical disinfection (Pennsylvania Filtration Rule requires the disinfectant to be applied following filtration).
Long Term 1 Enhanced Surface Water Treatment Rule	A clarification/filtration system that achieves at least 99% (2.0-log) removal of *Cryptosporidium* oocysts. As of January 2005 (all size public water suppliers)**:** A clarification/filtration system which achieves a turbidity reduction less than or equal to 0.3 NTU in at least 95% of all representative samples on a monthly basis from all filters combined, and less than or equal to 1 NTU in 100% of all representative combined filter effluent samples. As of January 2005 (all size public water suppliers)**:** Individual filters must be monitored continuously for turbidity and recorded at least every 15 minutes. Exceeding turbidity triggering levels of 0.5 NTU and 1.0 NTU will require follow-up reporting to the PADEP, but are not violations. A disinfection profile requirement if preliminary TTHM and HAA5 monitoring results exceeds 80 percent of Stage 1-DBPR MCLs for these contaminants.
Stage 1 – Disinfectant/Disinfection Byproduct Rule	Treatment technique reduction requirement for total organic carbon (TOC) by enhanced coagulation to reduce levels of disinfectant byproduct precursors. Monitoring must be performed one time per month. TTHM concentration in the distribution system less than 80 μg/L. HAA5 concentration in the distribution system less than 60 μg/L. Compliance values based on a running four-quarter average.

Lead and Copper Rule	Production of stable, non-corrosive water that will minimize solubility of lead and copper in household plumbing so that the 90th percentile samples of these contaminants are less than their Action Levels.
Total Coliform Rule	Finished water in distribution system with zero total and fecal coliform and *E. Coli.*

Unit 2 Exercise

1. How did the increase in the number of municipal water systems in the U.S. contribute to major disease outbreaks in the early part of the 20th century?

2. Match the following terms with their definitions (place the letter of the term in the line in front of the definition):

Toxicology
_______ Mutagenic
_______ Acute
_______ Chronic
_______ Genotoxic

A. Causing heritable alteration to genetic material

B. Long term, low dose exposure to a contaminant

C. The study of adverse effects of chemicals on living things

D. Short term, high does exposure to a contaminant

E. Causing alteration or damage to genetic material

3. **True or False:** Maximum Contaminant Levels (MCL) are non-enforceable levels that relate to the taste and odor (aesthetic quality) of the water.

Key points for Unit 2 – Drinking Water Standards

- In 1900 there were 3000 municipal drinking water systems but only 10 were filtering the water.
- Drinking water regulations date from the 1893 Interstate Quarantine Act to the 1974 Safe Drinking Water Act (SDWA) and major amendments to the SDWA in 1986 and 1996.
- Primary Maximum Contaminant Levels (PMCL or MCL) are enforceable water quality standards.
- Secondary Maximum Contaminant Levels (SMCL) are non-enforceable guidelines for contaminants that affect the aesthetic quality of drinking water.
- Maximum Disinfectant Residual Level (MDRL) is the highest level of a disinfectant allowed in drinking water.
- A 2-log removal of Giardia cysts means that 99% of the cysts are removed from the drinking water.
- A 4-log inactivation of enteric viruses means that 99.99% of the virus is inactivated.
- The Total Coliform Rule requires that finished drinking water in the distribution system can have zero total and fecal coliform and zero *E. coli*.

[1] AWWA, *Water Quality and Treatment Handbook*, 5th Edition, 1999.

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 waster 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**
Cryptosporidium	TT	Zero
Giardia lamblia	TT	Zero
E. coli	TT	Zero
Fecal coliforms	TT	Zero
Legionella	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 *Escherichia coli (E. coli)*	gastroenteritis	10^7 CFU
Vibrio cholerae	cholera	$<10^6$ CFU
Salmonella	salmonellosis	10^5 CFU
Legionella	legionnaires' disease	unknown
Salmonella typhi	typhoid fever	10^7 CFU
Shigella spp.	bacillary dysentary	10^7 CFU
Campylobacter jejuni	gastroenteritis	unknown
Non-tuberculosis *mycobacteria* (NTM), On EPA CCL	respiratory infections	unknown
Helicobacter pylori, On EPA CCL	gastroenteritis, ulcers, stomach carcinoma	unknown

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

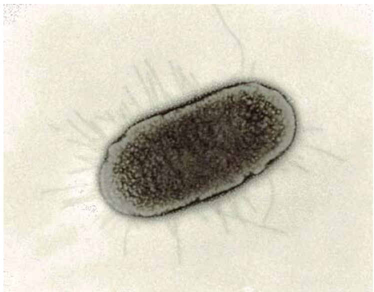


Figure 3-1 [1]
E.coli

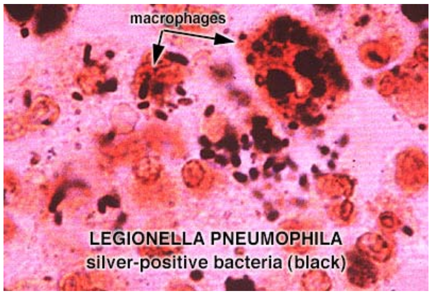


Figure 3-2 [2]
Legionella

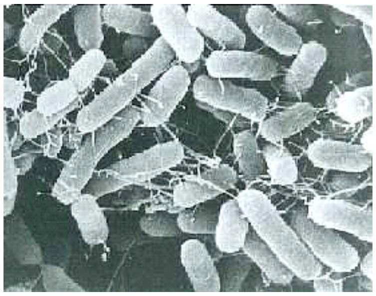


Figure 3-3 [3]
Salmonella

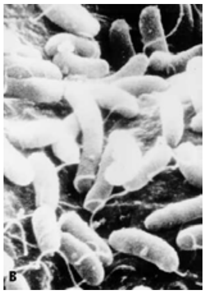


Figure 3-4 [4]
Vibrio cholorae

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
Giardia lamblia	giardiasis	5 µm to 15 µm	1 to 50 cysts
Cryptosporidium parvum	cryptosporidiosis	4 µm to 6 µm	30 to 130cysts
Entamoeba histolytica	amoebic dysentery	10 µm to 15 µm	unknown
Microsporidia	microsporidiosis	1 µm to 5 µm	unknown
Cyclospora	cyclosporiasis	7 µm to 9 µm	unknown

Source: Scott Tighe, Analytical Services Inc.

Figure F-49 *Giardia* cyst and *Cryptosporidium* oocyst, stained with fluorescent antibody stain, 1,000×

Figure 3-5 [5]
Giardia cyst and *Cryptospordium oocyst*

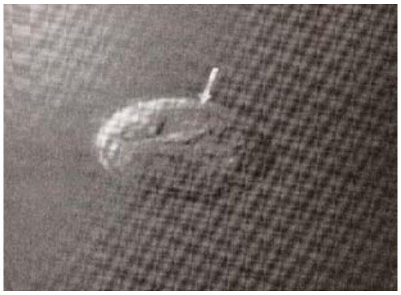
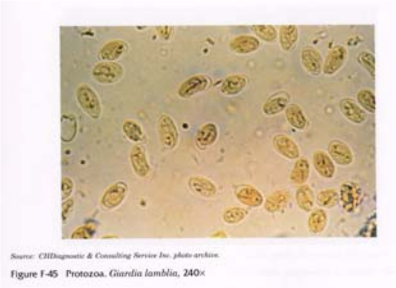


Figure 3-6 [6]
Giardia detail



Source: CHDiagnostic & Consulting Service Inc. photo archive.

Figure F-45 Protozoa. *Giardia lamblia*, 240×

Figure 3-7 [7]
Giardia lamblia

Figure 3-8 [8]
Giardia lamblia

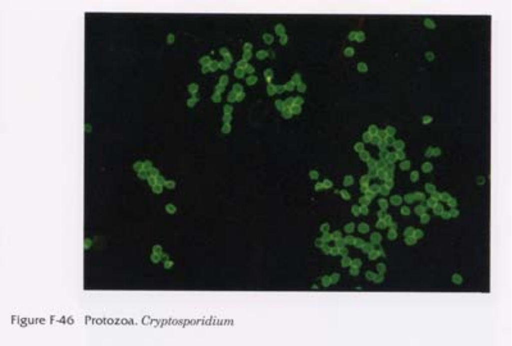


Figure F-46 Protozoa. *Cryptosporidium*

Figure 3-9 [9]
Cryptosposidium

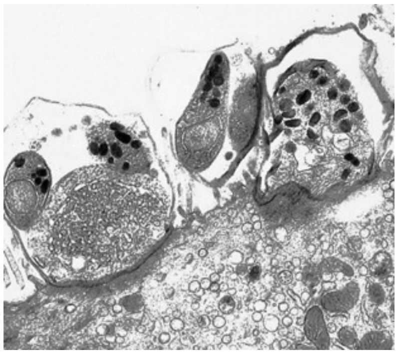


Figure 3-10 [10]
Cryptosporidium parvum
(stained dark)

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
Rotavirus	gastroenteritis	1 to 50 particles
Hepatitis A virus	infectious hepatitis	1 to 50 particles
Caliciviruses (Norwalk agent), On EPA CCL	gastroenteritis	unknown
Coxsackieviruses A & B, On EPA CCL	aseptic meningitis	unknown

CCL= Contaminant Candidate List (for possible future regulation)

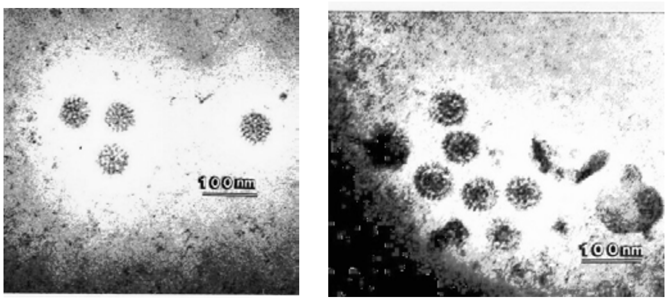


Figure 3-11 [11]
Rotavirus

Microbial Indicators

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

Can you think of any reasons for this procedure? ____

____

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

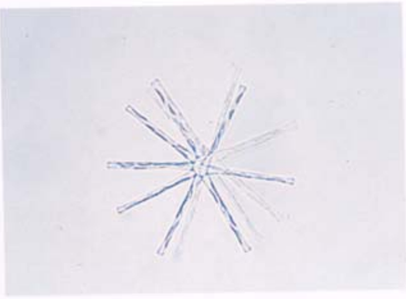
Indicator	Characteristics
Total coliforms	▪ Indicator of choice for many decades. ▪ Not a health threat in itself; it is used to indicate whether other potentially harmful bacteria may be present. ▪ Coliforms are naturally present in the environment, as well as in feces. Major Shortcomings: ▪ Only marginally 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/ *E. coli*	▪ *E. coli* is the major subset of fecal coliforms. ▪ Both fecal coliforms and *E. coli* are better indicators of recent fecal contamination than total coliforms. Major Shortcomings: ▪ 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)	▪ 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. Major Shortcoming: ▪ Does not provide an indication of the presence of pathogens.
Turbidity	▪ 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. Major Shortcomings: ▪ Provides no information on the nature of the particles.

Particle Counts	▪ 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. Major Shortcomings: ▪ 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)	▪ 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 (*Cryptosporidium*), and *Giardia* cysts. ▪ Used as a tool to evaluate filter effectiveness of surface water supplies. Major Shortcomings: ▪ Not for routine monitoring due to complexity of procedure and time required to perform analysis. ▪ Only identifies larger pathogens such as *Giardia* and *Cryptosporidium.*
Clostridium perfringens	▪ 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. Major Shortcomings: ▪ Insufficient data exists to consistently correlate *C. perfringens* with pathogenic microorganisms.
Coliphages	▪ Viruses that infect *E. coli.* ▪ 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

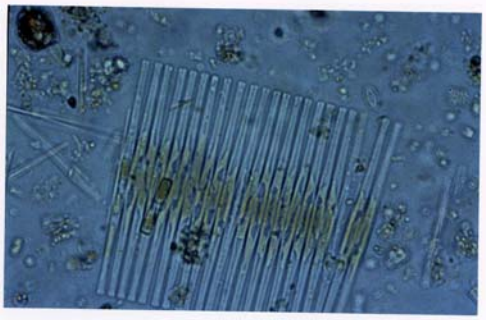
Microorganism	Impact on Water Supply
Algae blooms ▪ Taste & odor producers ▪ Filter cloggers	▪ Tastes & odors ▪ Poor settling ▪ Filter clogging ▪ Diurnal pH changes ▪ Oxidant demand
Iron bacteria ▪ Ribbon (stalk) formers - *Gallionella* ▪ Tube formers - *Crenothrix, Leptothrix, Sphaerotilus* ▪ Consortial heterotrophic incumbents	▪ Forms slimes which create localized anaerobic conditions inside wells and pipelines, leading to: – 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 ▪ Sulfur reducing bacteria (SRB)	▪ 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
Actinomycetes spp. (bacteria that constitute a considerable portion of microorganisms contained in lake and river bottom muds)	▪ Tastes & odors – earthy/musty odors from the metabolites Geosmin and Methyl Isoborneol (MIB)



Source: K. Hancock, CHDiagnostic & Consulting Service Inc.

Figure F-37 Algae. Diatom, *Asterionella*, unstained, bright-field microscopy, 120×

Figure 3-12 [12]
Asterionella



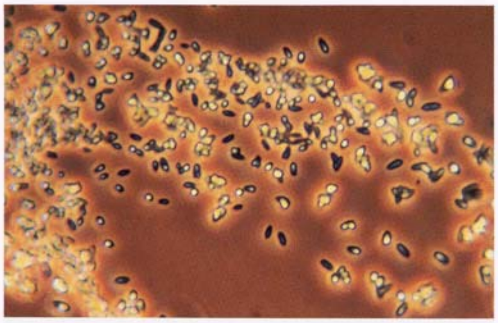
Source: K. Hancock, CHDiagnostic & Consulting Service Inc.

Figure F-38 Algae. Diatom, *Fragilaria*, unstained, bright-field microscopy, 240×

Figure 3-13 [13]
Fragilaria

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

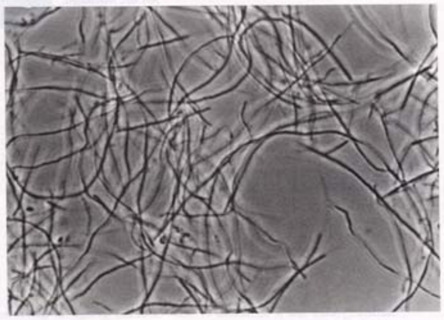
Figure 3-14 [14]
Iron Bacteria



Source: M. Richard, PhD, RBD Inc., Ft. Collins, Colo.

Figure F-5 Sulfur bacteria. *Thiobacillus* (note precipitated sulfur), 1,000×

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



Source: Scott Tighe, Analytical Services Inc.

Figure 1-1 Actinomycetes, phase contrast 1,000×

Figure 3-16 [16]
Actinomycetes

Exercise - Microorganisms

1. List three examples of regulated waterborne microorganisms.
    a. ______________________
    b. ______________________
    c. ______________________

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. Protozoa can survive in water for up to
    a. One hour
    b. One day
    c. One month
    d. One year

4. Best Available Technologies for treating water with bacteria include conventional filtration and disinfection.
    a. True
    b. False

5. List three examples of Microbial Indicators and give one shortcoming for each.
    a. ____
    b. ____
    c. ____

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	7×10^6 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	4	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

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 ($HCO3^-$), carbonate (CO_3^-), 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 µm 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 Affects

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.

Source: Stuart Smith.

Figure 2-9 Clogged versus cleaned impellers

Figure 3-17 [17]
Clogged vs. cleaned pump impellers

Source: Stuart Smith.

Figure 2-6 Partly-filled impeller channel

Figure 3-18 [18]
Partly filled pump impeller channel

Exercise - Inorganic Constituents

1. Give the Primary Maximum Contaminant Level (PMCL) for the following inorganic constituents.
    a. Arsenic ___________________
    b. Fluoride ___________________
    c. Cadmium __________________
    d. Mercury ___________________

2. List the Best Available Technologies (BATS) for treating water with the following inorganic constituents.
    a. Mercury ____
    b. Cadmium ____
    c. Arsenic ____

3. List three common inorganic constituents and their sources.
    a. ____
    b. ____
    c. ____

4. What could cause a metallic or salty taste in drinking water?

5. High levels of ______________________________ in drinking water could cause tooth discoloration.

6. Which of the following produce water with the highest hardness?
    a. Lake
    b. Well
    c. River
    d. Stream

7. **True or False:** Hard water is caused by iron in the water

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 - (δBHC)	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)	$3x10^{-8}$	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?

____

____

Exercise - Organic Compounds

1. SOC is an acronym for ___________________ _________________ ______________.
2. Synthetic Organic Chemicals can be further classified as __________________ Organic Compounds or ____________________ Organic Compounds.
3. List the Maximum Contaminant Level (MCL) for the following volatile organic compounds.
   a. Benzene _______________________________
   b. Ethylbenzene __________________________
   c. Vinyl Chloride _________________________
4. List three non-volatile organic compounds.
   1. ___________________
   2. ___________________
   3. ___________________
5. List the best available technologies (BATS) for removing Benzene from drinking water.

   ____

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

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

Acute and Chronic Health Affects

Table 3-16
Health Affect 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	MDRL	MDRLG	BAT
Chlorine – mg/L as Cl_2	4	4.0	DC
Chloramines – mg/L as Cl_2	4	4.0	DC
Chlorine dioxide – mg/L as ClO_2	0.3	0.8	DC

DC = Disinfection Control System
MDRL = Maximum Disinfectant Residual Level
MDRLG = Maximum Disinfectant Residual 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
Trichlorocetic 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

Exercise - Radionuclides and DBP

1. Besides alpha emitters, radium-226 and radium-228, what radionuclide must be monitored?

2. **True or False:** The source of most radionuclides is the erosion of natural deposits

3. Which of the following are reasons a water system measures chloramine?

    a. Use the chloramine result to determine how well reactions of chlorine with ammonia are working

    b. Determine if chlorine will react with hydrogen sulfide

    c. Determine the concentration of Total Available Chlorine (TAC) residual in the distribution system

    d. Determine the acidity of the water

4. List the Maximum Disinfectant Residual Levels (MDRLs) for the following disinfectants:
    a. Chlorine ___________
    b. Chloramines____________
    c. Chlorine dioxide __________

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.

[17] ibid.

[18] 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.

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Unit 4 – Water Quality Parameter Sampling and Monitoring for Treatment Process Optimization and Control

Learning Objectives

- Explain grab sample and composite sample techniques
- Explain two characteristics of on-line monitoring which make it preferable to grab sampling
- Explain the primary forces driving water quality monitoring
- State why total coliform are routinely monitored

Sampling Types

➊ Grab sample – A sample collected at a specific site that is representative of conditions at the time of sampling

➋ On-line sample – A continuously flowing sample, suitable for on-line analyzers

Characteristics of on-line monitoring:

- On-line monitoring provides data at a greater frequency than grab sampling, allowing real-time feedback for treatment process control and water quality characterization for operational and regulatory decisions
- On-line monitoring can be carried out at the manned on-site location, or at an unmanned, remote location
- Data produced can be used to assure customers and regulators of the consistent quality of the product water and the efficiency of the treatment process

➌ Composite sample – A sample collected at a specific site, portions of which are collected at varied time intervals

Sampling Frequency

In general, sampling frequency should be higher when there is considerable variation in water quality. The main factor that will affect the sampling frequency is DEP's regulations. Each rule has set monitoring frequencies. Your water system may want to collect additional samples. If so, consider these factors in determining the sampling frequency:

- The purpose of monitoring
- The intended use of the gathered data
- The relative importance of the sample location
- The expected variability of the measured parameter
- The financial resources that are available
- The frequency that will allow for timely feedback
- The impact of diurnal cycle and seasonal variations
  - ✓ The metabolic processes of algae have a diurnal impact on river and reservoir water quality. Algae cause the increase of pH during the daytime due to the removal of carbon dioxide.
  - ✓ Algae, which tend to be much more prevalent during summer and early fall (algae blooms), can increase the impact of algae byproducts such as tastes, odors, dissolved oxygen, pH, alkalinity, and disinfectant byproduct precursors.
  - ✓ Seasonal reservoir turnover due to temperature changes may require depth sampling for changes in contaminant levels of iron, manganese, pH, and nutrients (nitrates and phosphates).

The only way to determine if a water treatment process is producing the quality of water intended is to routinely monitor for water quality parameters relevant to the goals and regulatory requirements of treatment. Water quality monitoring must be ongoing to continuously update the status of treatment and to make any adjustments that may be required to assure that process optimization is maintained, regardless of changes in source water quality. A water quality monitoring program is defined by:

- The parameters to be analyzed
- The type of sampling utilized
- The frequency of sampling required
- The sample location(s)

Primary Driving Forces for Water Quality Monitoring

- Customer awareness and concern is an important force. The DEP requires public water suppliers provide all its customers with an annual Consumer Confidence Report (CCR). This has heightened consumers' awareness of water quality.
- Water quality regulations are increasingly stringent.
- Environmental regulations are increasing in terms of source water management as well as management of water discharges from the water treatment plant.

Secondary Driving Forces for Water Quality Monitoring

Technological Advances in Water Quality Testing Equipment

- Particle counters designed specifically for the municipal drinking water industry, which provide additional insight on the effectiveness of filter operations.
- On-line TOC (Total Organic Carbon) analyzers for continuous data updates of disinfectant byproduct precursor removal.

Security Issues

- Provide “real time” data of raw and treated water quality to assure that there has been no deliberate introduction of toxic contaminants to either the source water or processed water.
- Provide advanced warning in the event that an act of sabotage of a water system has occurred, thereby allowing the public water supplier time to take appropriate measures to protect the public’s health.

Water Quality Parameters and Monitoring for Disinfectants

Disinfectants

Disinfectants, such as concentrations of free chlorine or combined chlorine (chloramines), are measured for regulatory compliance and control (inactivation) of microorganisms, some of which may be pathogenic.

- **Primary disinfection** (finished water): Determine CT (chlorine residual (C) x contact time (T)) to assure compliance is maintained with disinfection CT requirement within the water treatment plant, as required by the EPA Surface Water Filtration Rule.

- **Secondary disinfection** (distribution water): The distribution system is the pipe conveyance system that delivers treated water to the customer. Determine if an adequate disinfectant residual (generally either chlorine or chloramine) is maintained in the distribution system. The EPA Total Coliform Rule (TCR) requires that samples, collected at representative locations within the distribution system, be tested for total coliform bacteria. If coliform bacteria are detected, an increase in disinfectant dose may be required to assure compliance with the TCR.

- The maximum allowable level of chlorine or chloramine disinfectant is regulated by the Maximum Residual Disinfectant Level (MRDL) stated within Stage 1 of the EPA Disinfection/Disinfectant Byproduct Rule.

Methods of Sampling

- Grab sampling protocol for bacterial samples
  - ✓ Sterile sample container required (bottle or plastic bag)
  - ✓ The sampler must not touch any portion of the bottle or bag that will come into contact with the water sample
  - ✓ Samples must be kept cool and must be analyzed within 24 hours since degradation may occur

- Grab sampling protocol for disinfectant residuals
  - ✓ Samples should be analyzed within a short time of collection due to dissipation of the disinfectant. Not suitable for laboratory analysis.

- On-line monitoring for disinfectant residual can be used to automatically control the chlorine feed rate to maintain a set chlorine residual
  - ✓ Disinfectant monitoring and feed rate control is used to minimize Disinfectant Byproduct (DBP) formation by preventing an excess chlorine dose, which would otherwise lead to the formation of higher levels of regulated disinfectant byproducts such as:
    - ▪ Total Trihalomethanes (TTHM)
    - ▪ Haloacetic Acids (HAA5)

- ✓ Combined chlorine (chloramine) disinfectant residual is measured to optimize the chlorine feed rate for reaction with ammonia in the process of producing chloramines. The development of the desired level of chloramines requires a carefully controlled ratio of chlorine to ammonia feed rates.

Water Quality Parameters and Monitoring for Bacteria

Total coliform are monitored for regulatory compliance, as an indicator of the microbiological safety of water and for control (inactivation) of microorganisms, some of which may be pathogenic.

- A public water supplier is required to collect daily distribution system samples for total coliform analyses to maintain compliance with the EPA TCR.
- Total coliform is a microbiological indicator used to assure that water delivered to the consumer is bacteriological safe.
- Monitoring for total coliform will assist in identifying any sources of contamination.
- Fecal coliform and/or E. coli are required to be analyzed following samples that are positive for total coliform to confirm that water is contaminated.
- Heterotrophic Plate Count (HPC) is a general indicator of the quantity of all types of bacteria, thereby a general indicator of the bacteriological quality of the water.

Analytical Tools

- Free and total chlorine – DPD Colorimetric – see Method 408.E of Standard Methods for the Examination of Water and Wastewater.

DPD is a commonly used method for measuring chlorine residual in water, using either a titrator (lab) or a color comparator field test kit (field). DPD is an abbreviation for N, N-diethyl-p-phenylene-diamine.

- ✓ Field test kit – the least accurate
- ✓ Bench analytical equipment
  - Colorimeter or spectrophotometer
  - Amperometric titration for the most accurate analytical results.

Amperometric titration is a method used to measure concentrations of strong oxidizers (such as chlorine), among other substances, based on the electric current that flows during a chemical reaction.

  - ✓ On-line analytical equipment for continuous monitoring of chlorine residual and optional output signal for controlling the chorine feed system
  - ✓ Water quality models used for determining compliance with the CT disinfection requirement
    - Utah Dept. of Health (DOH) CT Spreadsheet
    - USEPA CT Spreadsheet

- Coliform Bacteria analytical methods include:
  - ✓ M-ColiBlue24® for detecting and counting fecal and total coliform within 24 hours
  - ✓ MUG (4-methylumbelliferyl-fl-D-glucuronide) reagent used to detect E. coli due to fluorogenic product when hydrolyzed by an enzyme specific to E. coli

Monitoring Oxidant Residuals

Oxidation is key to the success of downstream physical processes for the removal of certain contaminants, in particular inorganic chemicals.

Oxidation Processes

Soluble fractions of raw water iron and manganese must be chemically pretreated with oxidants such as chlorine and potassium permanganate at doses that result in slight excesses of their respective residuals to assure effective removal of these inorganic contaminants by downstream processes.

Free Chlorine Residual

Typical sample sources include filter applied (filter influent) water and filtered (filter effluent) water.

The purpose of sampling is to assure the maintenance of a chlorine residual of 0.5 mg/L to 1.0 mg/L in the filter effluent to assure complete oxidation of soluble iron and manganese (this does not consider other chlorine requirements, such as disinfection requirements).

The sample must be analyzed immediately since chlorine dissipates over time.

Potassium Permanganate Residual

Typical sample source is filtered water.

The purpose is to assure that slight permanganate residual (a visual observation of a slight pink color will confirm permanganate residual) is being applied to the filter to maintain the filter media in the **regenerated** condition. Filter media in a **regenerated** condition for manganese removal is media that has a coating of manganese dioxide continuously applied. The manganese dioxide coating provides a catalytic reaction that adsorbs additional manganese from the filter applied water. Slight permanganate residual supplies this continuous replenishment of manganese dioxide to the media grain surface.

The sample should be collected and observed immediately since permanganate residual is consumed over time by other water quality contaminants.

Analytical Tools for Monitoring Oxidant Residuals

- Field test kits
  - ✓ A color comparator provides a “ballpark” reading of concentration, useful when accuracy is not essential.
    - Iron and Manganese
    - Free Chlorine – DPD method
- Bench analytical equipment
  - ✓ Colorimeter or spectrophotometer is used for more accurate analytical results than field test kits.
    - Iron and Manganese
    - Color
    - Free Chlorine – DPD method
    - Permanganate residual
  - ✓ The Amperometric titration method is used for most accurate measurements.
    - Free Chlorine
    - Permanganate residual
- On-line analytical equipment examples
  - ✓ DPD Colorimetric (chlorine only) – see Method 408.E of Standard Methods for the Examination of Water and Wastewater
  - ✓ Oxidation-Reduction Potential (ORP) meter

> 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). This is used as a qualitative measure of the state of oxidation in water treatment.

Monitoring the Effectiveness of Surface Water Treatment

The measurement of specific water quality parameters and indicators provides an indication of the effectiveness of surface water treatment, and if treatment is less effective than desired, the possible reason(s) why.

Water Quality and Indicators

- Charge density – a measurement of relative charge neutralization of particles in water, an indication of the degree of coagulation.

- Coagulation – the addition of a chemical compound (typically a metal salt such as alum (aluminum sulfate) or ferric chloride) to raw water to destabilize naturally occurring colloidal and suspended particles by neutralizing particle electrostatic charges (which are primarily negative). This results in these particles aggregating into larger particles (flocs) that can be more readily removed by downstream clarification and/or filtration processes.

- pH – coagulation is most effective within a specific pH range, depending on the coagulant used and the goals of treatment.

- Floc characteristics (size, density and water clarity between floc particles) – a visual evaluation (which is often conducted with jar test equipment) assists in determining the optimum pretreatment conditions (i.e., mixing, chemicals and doses) to develop the best floc for a particular treatment process.

- Color – the measurement of raw water color may help predict the coagulant demand and dose (particularly with supplies high or relatively high in natural organic matter). Color should be maintained at a consistent level, preferably zero, but certainly less than 5 color units (c.u.) in the filter effluent, regardless of the level of raw water color.

- Turbidity – the measurement of raw water turbidity may help predict the coagulant dose required. Levels of turbidity in the effluent of downstream processes should be maintained at a consistent level, regardless of the raw water turbidity, less than 2.0 NTU and preferably less than 1.0 NTU for clarification, and less than 0.10 NTU for filtration.

- Particle Counts – particle counting is an especially valuable tool for evaluating the performance of individual filters, the impacts of operating parameters such as flow adjustments and whether they need to be removed from service for backwashing. Particle counts should be maintained at a consistent level, regardless of the raw water particle counts. It is important to maintain the lowest filtered particle counts possible, using 25 counts/mL or less as a goal (particles > 2.0 µm in size).

- Alkalinity – a specific coagulant and dose requires at least a minimum alkalinity level be available for coagulation to be effective; measurement of this parameter aids in determining if additional alkali (e.g. lime) needs to be added and how much.
- Temperature – can have a significant impact on coagulation kinetics; cold water (particularly less than 40° F) significantly slows the speed of floc formation and optimum pH level with conventional coagulant salts such as alum and ferric sulfate.
- Coagulant residual
  - ✓ Aluminum – assists in optimizing alum dose; an aluminum level higher than the raw water level may indicate an overdose of alum or incorrect mixed water pH.
  - ✓ Iron – assists in optimizing ferric chloride or ferric sulfate dose; an iron level higher than the raw water level may indicate an overdose of ferric chloride or ferric sulfate.

Analytical Tools

- Field test kits include:
  - ✓ pH – portable pH meter
  - ✓ Turbidity – portable turbidimeter
  - ✓ Particle counts – bench particle counter

- Bench analytical equipment
  - ✓ Charge density – zeta potential meter
  - ✓ pH - bench pH meter
  - ✓ Alkalinity – burette titration
  - ✓ Turbidity – bench turbidimeter
  - ✓ Color – bench spectrophotometer
  - ✓ Floc characteristics – jar test apparatus

- On-line analytical equipment
  - ✓ Charge density – streaming current detector (SCD)
  - ✓ pH – on-line pH transmitter
  - ✓ Turbidity – on-line turbidimeter
  - ✓ Particle counts – on-line particle counter

  - ✓ Partnership for Safe Drinking Water – treatment process comparison software. Software compares to generally agreed-upon water treatment process design standards within the drinking water industry

- Water quality models
  - ✓ EPA WTP
  - ✓ Rothberg, Tamburini & Winsor (RTW) Model for Water Process and Corrosion Chemistry.
  - ✓ Walter – jar testing

Parameters and Equipment Commonly Used for Monitoring Natural Organic Matter

Natural organic matter is not a specific water contaminant, but rather an all-inclusive category of all types of microbiological debris in water, both animal and plant. Therefore, surrogates parameters used to quantify IT, such as total organic carbon (TOC), are necessarily non-specific and approximate.

Water Quality

- Taste and Odor (T&O) – Threshold odor test is used for monitoring the intensity of taste and odor in water—see American Water Works Association (AWWA) Manual of Practice No. 12, *Simplified Procedures for Water Examination*, and *Standard Methods for the Examination of Water and Wastewater*, Parts 2150, 2160, and 2170 for test procedures for odor and taste.

- True Color – A measurement of the concentration of colloidal matter, this a common analysis conducted in water treatment plant operator labs. True color, as opposed to apparent color, requires a filtration step through 0.45 µm filter paper prior to analysis to remove suspended material that otherwise would contribute to a color reading. The colloidal matter may consist of any or all of the following: iron and manganese; humus and other organic byproducts from the breakdown of plant matter; industrial waste. See American Water Works Association (AWWA) Manual of Practice No. 12, *Simplified Procedures for Water Examination,* and *Standard Methods for the Examination of Water and Wastewater*, Part 2120 for test procedures.

- UV_{254} – An indirect measurement of organic constituents in water by the absorbance of ultraviolet light in proportion to the concentration of organic matter. Historically, a wavelength of 253.7 nanometers (nm) (rounded off to 254) has been used. It is a wavelength that typically minimizes UV interference from constituents other than organic matter. Prior to performing a UV_{254} analysis, a filtration step is required using 0.45 µm filter paper to remove suspended material that otherwise would interfere with the UV_{254} reading. See *Standard Methods for the Examination of Water and Wastewater*, Part 5910 B. Ultraviolet Absorption Method for additional details.

- Total Organic Carbon (TOC) – A direct measurement of the total organic carbon content of the water.

Analytical Tools

- Bench analytical equipment
  - ✓ T&O is subjectively “measured” using a method that first heats a sample to increase taste and odor intensity for easier detection by taste and smell.
  - ✓ A flavor profile wheel can be used to aid in identification of the possible source(s) of the tastes and odors. See AWWA Research Foundation publication Advances in Taste and Odor Treatment and Control.

  - ✓ The measurement of true color and UV254 absorbance of a sample is easily accomplished with a spectrophotometer (equipped with a UV light), although the protocol requires a filtration step (0.45 µm filter paper) prior to analysis.
  - ✓ Total Organic Carbon analysis of a grab sample can be measured with laboratory analytical instruments dedicated to TOC analysis, utilizing various methods involving conversion of organic carbon to carbon dioxide.

- On-line analytical equipment – On-line TOC analysis can be measured with laboratory analytical instruments utilizing various methods involving conversion of organic carbon to carbon dioxide.

- Water quality models—See *Process Modeling and Control* published by AWWA Research Foundation.

UNIT 4 EXERCISE

1. A __________________ sample is collected at a specific site and is representative of the conditions at the time of sampling.

2. A sample from a continuously flowing source which is taken automatically is called a ________________________ sample.

3. A sample collected at a specific site, but portions of the sample are collected at different time intervals is called a _______________________ sample.

4. When there is considerable variation in water quality, the sampling frequency should be (pick the best answer):

   a. Higher _____
   b. Lower _____

5. Good insight into the effectiveness of filter operations can be provided by using a:
   a. pH meter
   b. particle counter
   c. flow meter
   d. thermometer

6. On-line monitoring for disinfectant ________________ can be used to automatically control the chlorine feed rate to maintain a set chlorine residual.

7. To assure that water delivered to the consumer is bacteriological safe, total coliform is used as a:

   a. Microbiological indicator
   b. Color comparator
   c. Turbidity measurement
   d. Taste and odor test

8. A DPD Colorimetric test using a color comparator field test kit is a common method for measuring chlorine residual in water.
   a. True _____ b. False ______

9. An on-line _____________ is an analytical instrument used to measure the effectiveness of the surface water treatment process. Readings from the instrument are in NTUs.
   a. Atomic absorption spectrometer
   b. Turbidimeter
   c. Spectrophotometer
   d. Gas Chromatograph

Key points for Unit 4 – Water Quality Parameter Sampling and Monitoring

- The three types of samples are: grab, on-line, and composite samples.
- The sampling frequency (how often samples are taken) should be higher when there are large variations in water quality.
- The DEP requires public water suppliers to provide customers with an annual Consumer Confidence Report (CCR).
- On-line monitoring for disinfectant residual can be used to automatically control the chlorine feed rate to maintain desired chlorine residual.
- DPD is a commonly used method for measuring chlorine residual in water in both lab and field situations.
- The pH has an influence on how effective the coagulation process will be.
- Temperature has an impact on floc formation. Water at less than 40^{o}F may have a very slow coagulation rate.
- Low alkalinity may require the addition of an alkali such as lime before proper coagulation can take place.