Water Quality and Treatment

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Organization of Presentation

1. Water Sources and Prevalent Issues
2. Characteristics of Water
3. Water Contaminants
4. Water Treatment Stages
5. Case Study: Treating Wash Water
6. Case Study: Treating Wastewater

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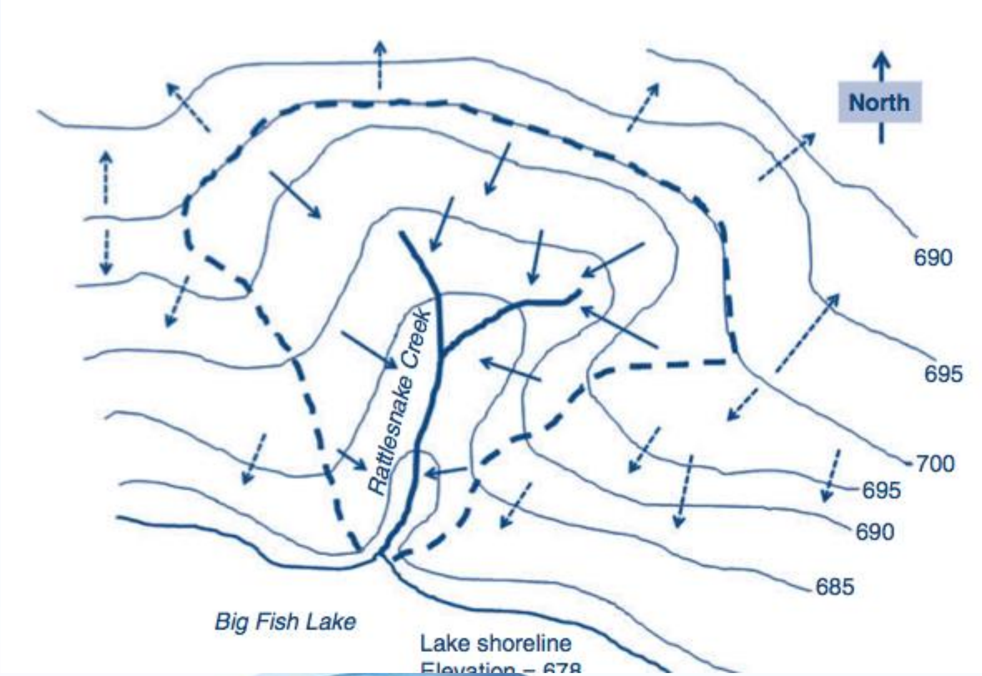
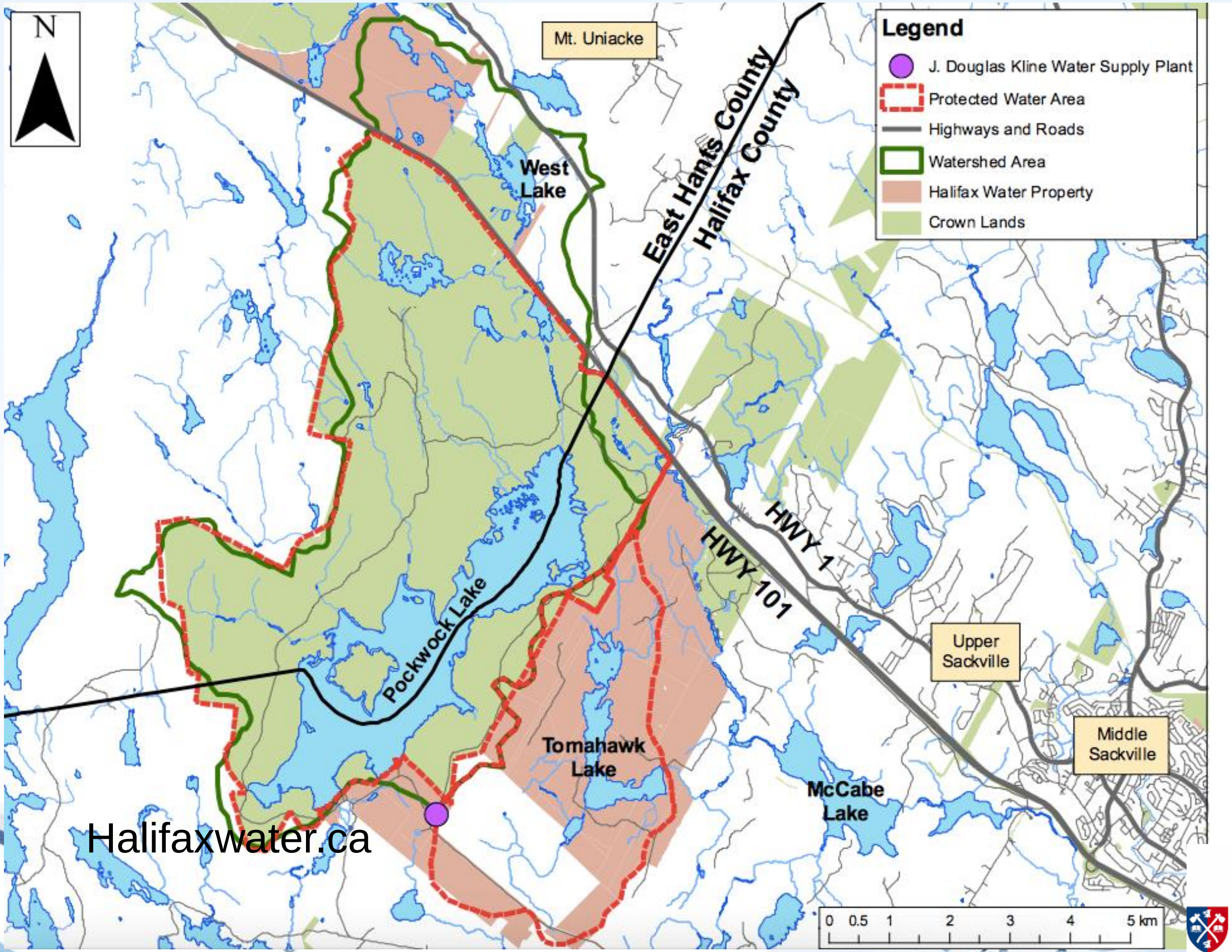
Watershed

- A watershed is the land area that drains to a point of concern (i.e., a lake, river, reservoir)
  - Drainage is due to gravity
  - Precipitation that falls within a watershed must drain somewhere
    - Boundaries are determined by topography



Pockwock Lake Watershed



Halifaxwater.ca

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Sources of Fresh Water

- Rivers
  - Rivers are often a receiving body for waste discharge and surface runoff
  - Major water quality issues tied to **organic matter**
- Lakes
  - Water quality influenced by the magnitude and routing of the chemical and energy fluxes passing through biogeochemical cycles
  - **Reservoir** – open air storage area used to prevent flood and/or to provide water in times of drought
  - Major water quality issues for lakes and reservoirs are closely tied to **thermal stratification** and **eutrophication:** Oxygen depletion, Algal blooms
- Groundwater

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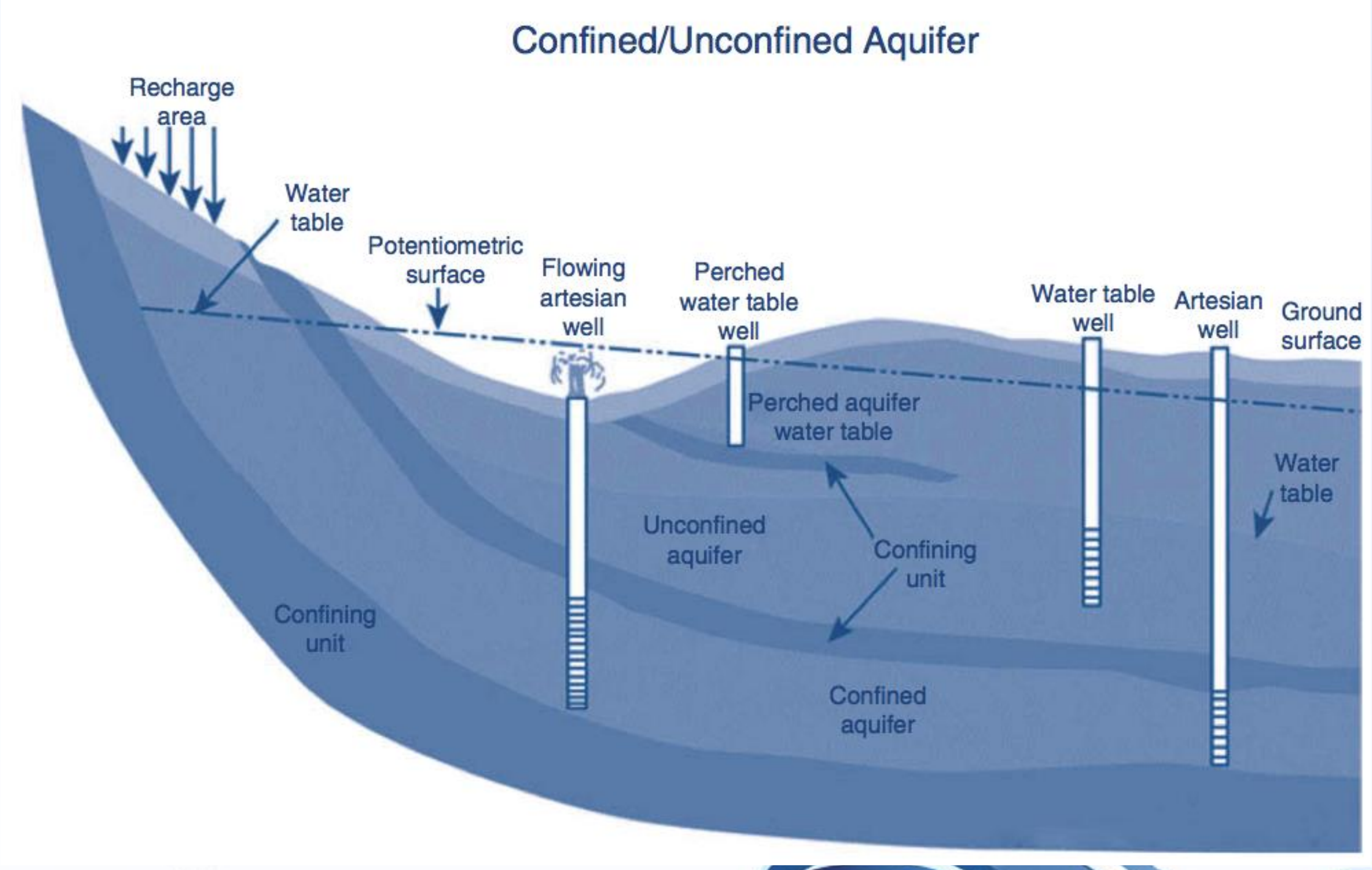
Groundwater Aquifers



Sources of Groundwater Pollution

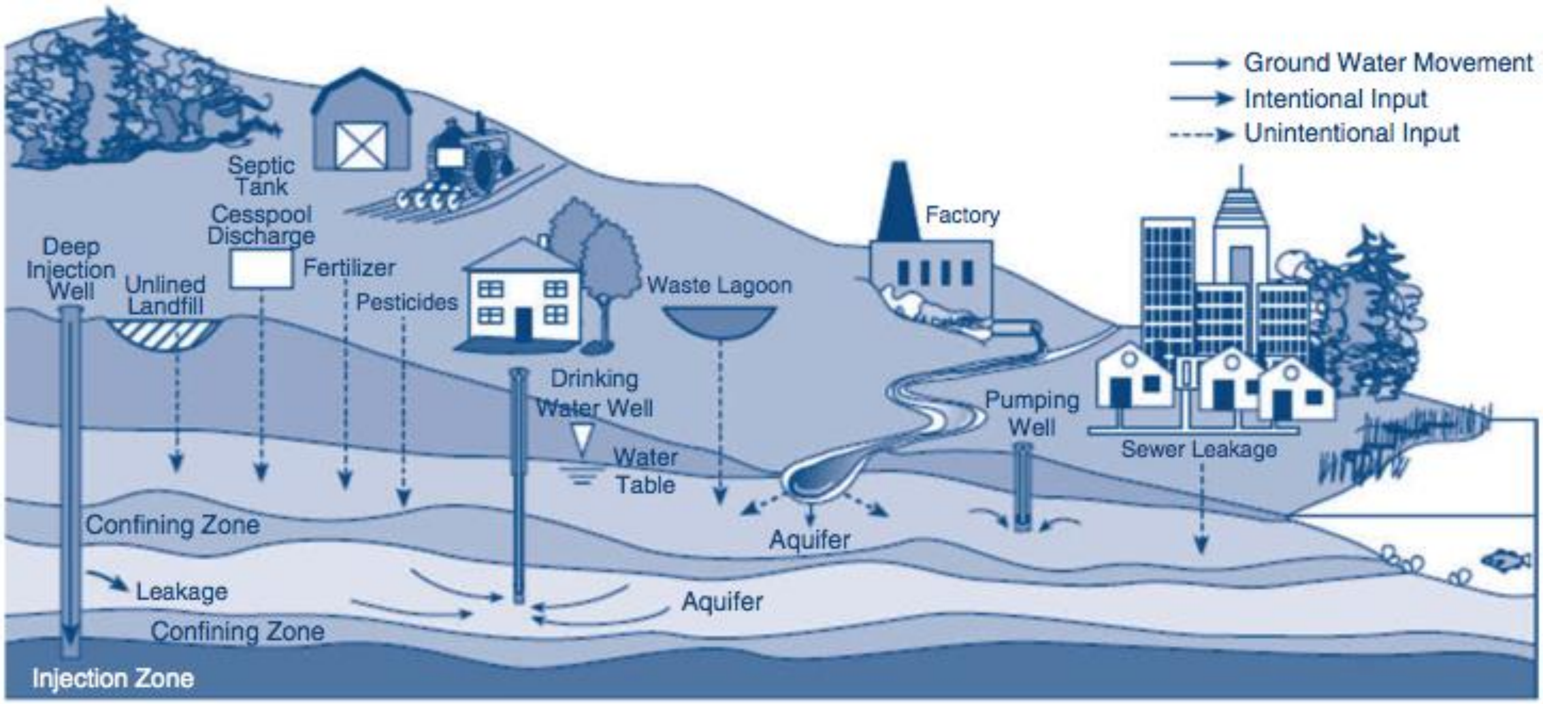


Figure / 7.33 Groundwater Contamination Can Occur from Intentional and Unintentional Inputs of Point and Nonpoint Sources of Pollution (Adapted from EPA, 2000).

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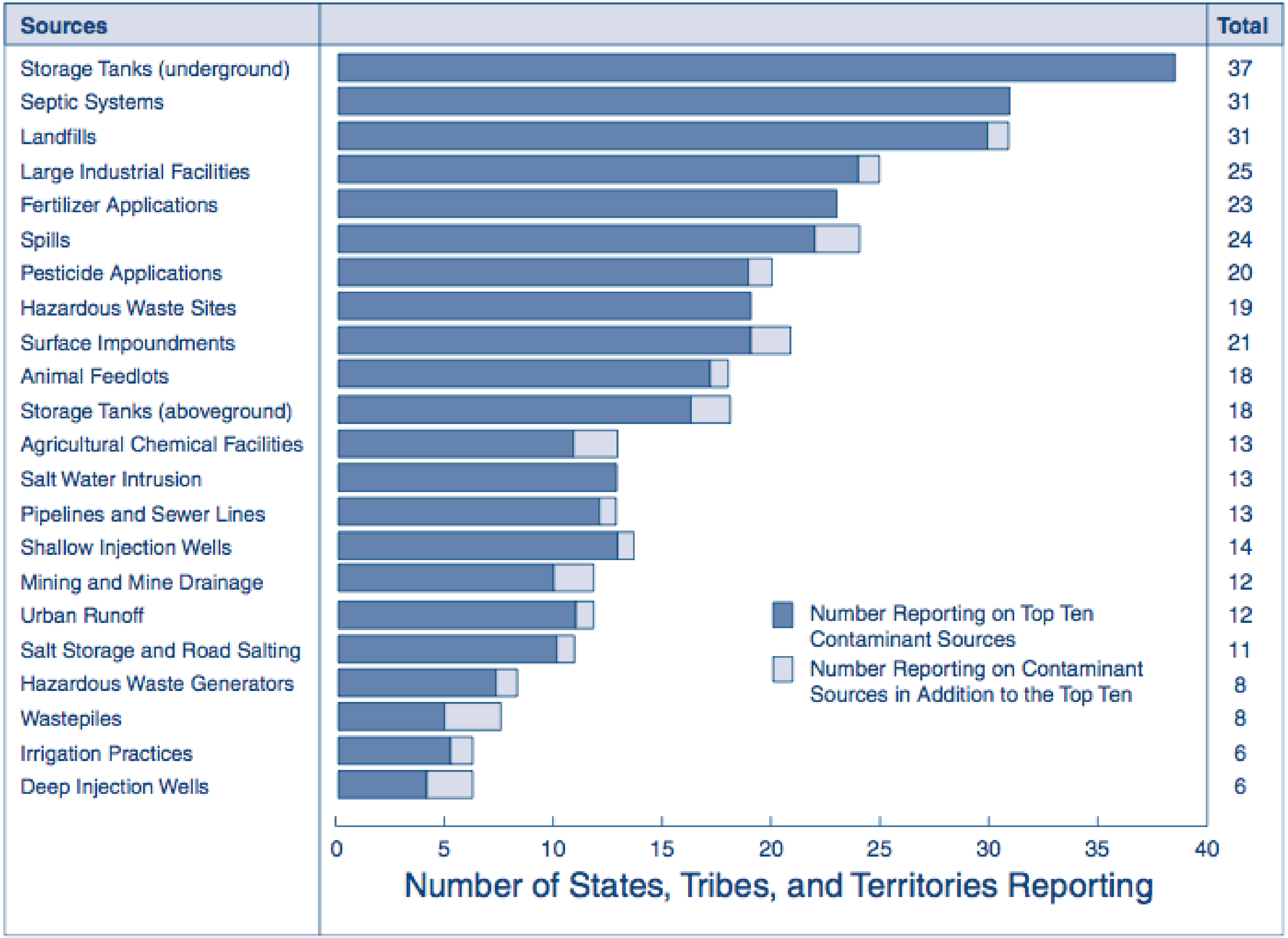

Figure / 7.34 Major Sources of Groundwater Contamination Identified by Stat
and Territories and Reported to EPA (From EPA, 2000).

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Characteristics of Water

We treat our drinking water to be both potable and palatable:

Potable Water – water that is **safe** to drink and will not cause adverse health effects

- Free from illness-causing physical, biological or chemical contaminants

Palatable – water that is **aesthetically acceptable** to drink

- Free from objectionable physical, biological or chemical contaminants
- May not be **safe**

Characteristics Water

- We characterize water using a number parameters. These fall under three major categories:
  - Physical
  - Chemical
    - Inorganic
    - Organic
  - Biological
    - Microorganisms

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Physical Characteristics of Water

- Major physical characteristics of water include:
  - Turbidity
  - Particulate
  - Color
  - Taste
  - Odour
  - Temperature

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Turbidity

- A measure of water clarity
  - Often caused by small particles
- Measured using a turbidimeter
  - Suspended particulate interferes with the passage of light
  - Measures the interference of the light passage through water
- Reported in nephelometric turbidity units (NTU)

Turbidity

- Groundwater: < 1 NTU
  - Stable
- Lakes: 1 - 20 NTU
  - Typically quite stable but can vary during turnover events, algal blooms, run-off
- Rivers: 10 - 4000 NTU
  - Highly variable due to precipitation, turbulence, run-off

Particulate

- When considering particulate we think of size and number
  - WTPs are sometimes equipped with continuous particle counters which can count the number of particles in specific size ranges (1 – 60 um)
  - Certain size ranges may indicate microbial contamination
- Also recall:
  - TS = TSS + TDS; TDS = VDS + FDS

Colour

- Colour in water may result from the presence of natural metallic ions (e.g., iron and manganese), dissolved organic matter
- **Apparent colour** – colour from dissolved contaminants and suspended contaminants
- **True colour** – colour due to dissolved contaminants only
- Mainly an aesthetic parameter

Guidelines for Canadian Drinking Water Quality Summary Table (October 2014)

Type[1]	Parameter (approval, reaffirmation)	MAC (mg/L)	Other value (mg/L)	Common sources of parameter in water	Health considerations	Comments
T	Colour (1979, 2005)		AO: ≤ 15 TCU	Naturally occurring organic substances, metals; industrial wastes		May interfere with disinfection; removal is important to ensure effective treatment.

Taste and Odour

Common taste and odour issues for drinking water:

- Rotten egg smell
  - H_2S
- Earthy/musty taste and odour
  - Often from the decay of algae, i.e., Geosmin, MIB
  - Geosmin detectable at ng/L range
- Chlorine
  - Detected as low as 0.010 mg/L
- Metallic taste
  - Dissolved iron, manganese, copper

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Geosmin in Halifax Water Supply

CBCnews | Nova Scotia

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Canada > NS > Photo Galleries

Stinky Halifax water will cost millions to fix

By Blair Rhodes, CBC News Posted: Dec 13, 2013 5:55 PM AT | Last Updated: Dec 16, 2013 10:16 AM AT

An unusual organic matter is creating a strange smell in some Halifax tap water, but officials say it is safe to drink. (CBC)

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A stinky water problem that prompted complaints from dozens of Halifax residents has returned, and finding a permanent fix could take years and cost millions of dollars.

The problem is geosmin, a by-product of algae that isn't harmful, but can

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Temperature

- Impacts many physical and chemical parameters of water, recall:
  - Density
  - Viscosity
  - Vapour pressure
  - Reaction rates
    - ~double every 10C
- These impact the design and operation of WTPs

Summary of Physical Characteristics

Table / 8.3

Physical Characteristics of Natural Water

Turbidity	Turbidity measures the optical clarity of water. It is caused by the scattering and absorbance of light by suspended particles in the water. A turbidimeter is used to measure the interference of the light passage through the water. Turbidity is reported in terms of **nephelometric turbidity units (NTU)**. The World Health Organization reports that a turbidity of <5 NTU is usually acceptable but may vary depending upon the availability and resources for treatment. In the United States, many water utilities aim to treat the water to <0.1 NTU.
Particles	Particles in natural waters are solids larger than molecules but generally not distinguishable by the unaided eye. They may adsorb toxic metals or synthetic organic chemicals. Water treatment considers particles in the size range 0.001–100 μm. Particles larger than 1 μm are called **suspended solids**, while particles between about 0.001 and 1 μm can be considered **colloidal particles** (though some researchers go as low as 0.0001 μm). Constituents smaller than 0.001 μm are called **dissolved particles**. **Natural organic matter (NOM)** comprises colloidal particles and **dissolved organic carbon (DOC)**. The DOC is the portion of NOM that can be filtered through a 0.45 μm filter. It is not classified in terms of size.
Color	Color is imparted to water by dissolved organic matter, natural metallic ions such as iron and manganese, and turbidity. Most people can detect color at more than 15 true color units for water in a glass.
Taste and odor	Taste and odor can originate from dissolved natural organic or inorganic constituents and biological sources present in raw waters. They can also be an outcome of the water treatment process.
Temperature	Surface water temperatures may vary from 0.5°C to 3°C in the winter and 23°C to 27°C in the summ Groundwater can vary from 2.0°C to 25°C depending upon location and well depth.

Inorganic Chemical Characteristics

- pH
- Hardness
  - caused by divalent metallic cations
  - Ca^{2+}, Mg^{2+}, Sr^{2+}, Fe^{2+}, Mn^{2+}, etc.
- Alkalinity
- Buffering capacity

Inorganic Chemical Constituents

Major Ionic Species:

Cations	Anions
Calcium (Ca^{2+})	Bicarbonate(HCO_3^-)
Magnesium (Mg^{2+})	Sulphate (SO_4^{2-})
Sodium (Na^+)	Chloride (Cl^-)
	Nitrate (NO_3^-)

Minor Ionic Species:

Cations	Anions
Aluminum (Al^{3+})	Carbonate (CO_3^{2-})
Ammonium (NH_4^+)	Hydroxide (OH^-)
Iron (Fe^{2+})/Fe^{3+}	Phosphates (PO_4^{3-})

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Summary of Select Inorganic Chemical Constituents

Table / 8.4

Major Dissolved Constituents Found in Water

Constituent	Source	Problem in Water Supply	Range in Natural Waters
Calcium and magnesium	Surface water and groundwater	Above 60 mg/L can be considered nuisance as hardness.	For calcium, less than 1 mg/L to more than 500 mg/L. Surface water concentrations of magnesium are less than 10 mg/L up to 20 mg/L. Groundwater concentrations are less than 30 mg/L up to 40 mg/L.
Chloride	Surface water and groundwater; saltwater intrusion	Above 250 mg/L can impart salty taste. Below 50 mg/L can be corrosive to some metals.	Typical surface water is usually less than 10 mg/L.
Fluoride	Surface water and groundwater Some water utilities add fluoride in the form of sodium fluoride or hydrofluorosilic acid at doses of about 1.0 mg/L	Toxic to humans at concentrations of 250–450 mg/L; fatal at concentrations above 4.0 g/L.	For surface water with total dissolved solids (TDS) concentrations less than 1,000 mg/L, fluoride is usually less than 1.0 mg/L.
Iron and manganese	Surface water and groundwater	Taste threshold of iron for many consumers is around 0.01 mg/L. Iron can impart a brownish color to laundry and bathroom fixtures. Manganese ion can impart a dark brown color. At concentrations around 0.4 mg/L, manganese can impart an unpleasant taste to water and can stain laundry and fixtures.	In oxygenated surface waters, the concentration of total iron is usually less than 0.5 mg/L. In groundwater that has low bicarbonate and dissolved oxygen, iron concentrations can range from 1.0 to 10.0 mg/L. The concentration of manganese ion in surface water and groundwater may be less than 1.0 mg/L.
Nitrate	Surface water and groundwater can contain high concentrations of nitrate from runoff from fertilizers found in urban and agricultural watersheds.	Very high nitrate concentrations may produce infant methemoglobinemia.	
Sulfur	Surface water and groundwater	Groundwater low in dissolved oxygen can contain reduced sulfur compounds, which impart objectionable odors such as that of rotten eggs. Sulfates are also corrosive in concrete structures and pipes.	Sulfate concentrations in freshwater can approach 10 mg/L.

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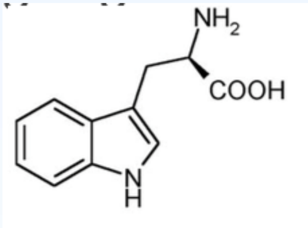
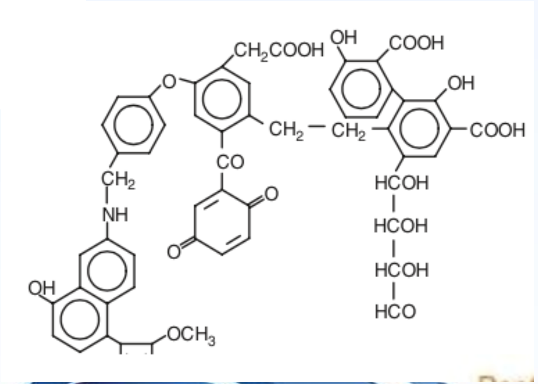
Organic Chemical Constituents

- Organic compounds contain carbon and other elements
- **Natural organic matter (NOM):**
  - C H O N P S
  - Amino acids
  - Humic acid
  - Proteins





Presence of NOM complicates the water treatment process…

Table / 8.6

Effect of Natural Organic Matter (NOM) on Water Treatment Processes

Water Treatment Process	Effect
Disinfection	NOM reacts with, and consumes, disinfectants, which increase required dose to achieve effective disinfection.
Coagulation	NOM reacts with, and consumes, coagulants, which increase required dose to achieve effective turbidity removal.
Adsorption	NOM adsorbs to activated carbon, which depletes adsorption capacity of the carbon.
Membranes	NOM adsorbs to membranes, clogging membrane pores, and fouling surfaces. This leads to decline in water passed through the membrane.
Distribution system	NOM may lead to corrosion and slime growth in distribution systems (especially when oxidants are used during treatment).

SOURCE: Adapted from Crittenden et al., 2012.

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Quantifying Organic Matter

We use **surrogate parameters** to quantify organic matter in water:

- **Measure carbon**
  - Total organic carbon (TOC)
  - Dissolved organic carbon (DOC)
    - Sample is filtered through 0.45 um filter to removal particulate
- **Measure oxygen demand**
  - BOD, COD
- **Measure absorbance at specific wavelengths**
  - UV absorbance at 254 nm (UV254)
  - Specific UV absorbance (SUVA)

Drinking Water Contaminants

- Major drinking water contaminant categories:
  - Microbial Contaminants
  - Organic Contaminants
  - Inorganic Contaminants



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Drinking Water Contaminants: *Organic*

- Can lead to color, odour and taste issues
  - Often aesthetic concerns, not necessarily any health implications
    - Natural organic matter (color), geosmin (odour, taste)
- Can substantially impact treatment efficacy
- Natural organic matter is a precursor to disinfection by-product (DBP) formation

Drinking Water Contaminants: *Inorganic*

- **Naturally occurring:** arsenic, iron, manganese, nitrate
- **Introduced though the treatment or distribution process:**
  - Aluminum and ferric iron (coagulation)
  - Fluoride (finish chemical for dental health)
  - Disinfection by-products (chlorination)
  - Lead, copper (leaching from distribution system)

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Drinking Water Contaminants: *Microbial*

- Typically associated with gastrointestinal illness
- Common microbial contaminants:
  - **Bacteria:** *E. coli*, salmonella, *v. cholerae*
  - **Viruses:** Hepatitis A, adenovirus, rotavirus
  - **Protozoan:** cryptosporidium, giardia
- **Main treatment method is disinfection**
  - Bacteria, viruses very receptive to inactivation with chlorine
  - Protozoan are ‘large’ and typically require filtration
    - Cryptosporidium is chlorine resistant, UV receptive

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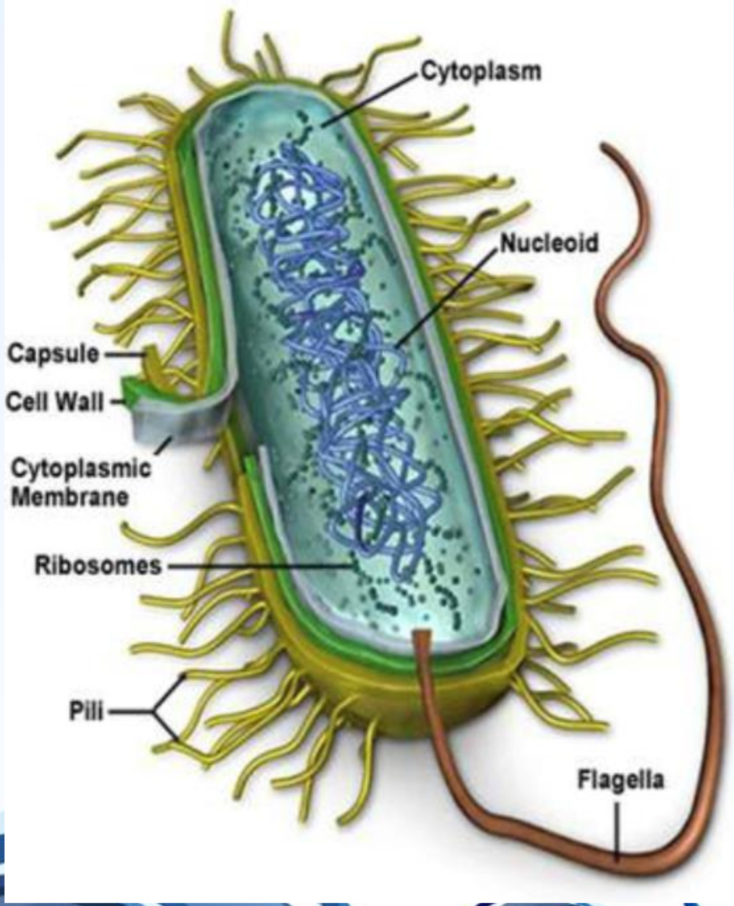
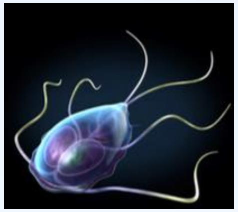
Bacteria

- Non-pathogenic strains are vital to some engineered systems for treatment of water and wastewater
- Pathogenic bacteria typically reside in stomach and/or intestines and cause gastroenteritis
- Common pathogenic bacteria:
  - *Vibrio cholera*
  - *Salmonella*
  - *Shigella dysenteriae*
  - *Escherichia coli*

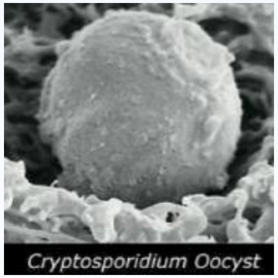


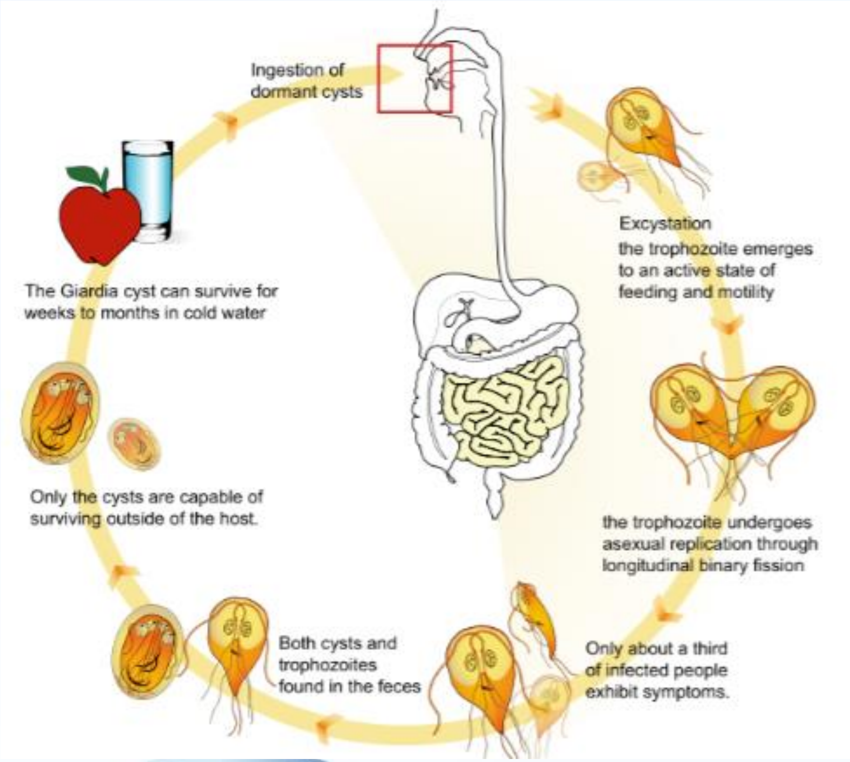
Protozoa

- *Giardia lamblia*



- *Cryptosporidium parvum*





Viruses

- Poliovirus types 1, 2, 3
  - Fever, headache, stiff neck and back, muscle pain
- Human adenovirus type 2
  - Lung, eye, urinary tract infections
- Ritoavirus A
  - Gastroenteritis and dehydration

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Microbiological: Coliforms & *E. coli*

- The MAC for ***E. coli*** in drinking water is **none detectable per 100 mL** (Health Canada)
- The MAC for **total coliforms** in water leaving a treatment plant and in non-disinfected groundwater leaving the well is **none detectable per 100 mL** (Health Canada)
  - Total coliforms should be monitored in the distribution system; detection of total coliforms from consecutive samples from the same site or from more than 10% of the samples collected in a given sampling period should be investigated.

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Microbial Constituents and the *Guidelines for Canadian Drinking Water Quality*

Parameter (approval)	Guideline	Common sources	Health considerations	Applying the guideline
Enteric protozoa: *Giardia* and *Cryptosporidium* (2012)	Treatment goal: Minimum 3 log removal and/or inactivation of cysts and oocysts	Human and animal faeces	*Giardia* and *Cryptosporidium* are commonly associated with gastrointestinal upset (nausea, vomiting, diarrhoea). Less common health effects vary. *Giardia* infections may include prolonged gastrointestinal upset, malaise and malabsorption. *Cryptosporidium* infections, in immunocompromised individuals, can occur outside the gastrointestinal tract including in the lungs, middle ear, and pancreas.	Monitoring for *Cryptosporidium* and *Giardia* in source waters will provide valuable information for a risk-based assessment of treatment requirements. Depending on the source water quality, a greater log removal and/or inactivation may be required.
Enteric viruses (2011)	Treatment goal: Minimum 4 log reduction (removal and/or inactivation) of enteric viruses	Human faeces	Commonly associated with gastrointestinal upset (nausea, vomiting, diarrhoea); less common health effects can include respiratory symptoms, central nervous system infections, liver infections and muscular syndromes.	Routine monitoring for viruses is not practical; characterize source water to determine if greater than a 4 log removal or inactivation is necessary.
Escherichia coli (*E. coli*) (2012)	MAC: None detectable per 100 mL	Human and animal faeces	The presence of *E. coli* indicates recent faecal contamination and the potential presence of microorganisms capable of causing gastrointestinal illnesses; pathogens in human and animal faeces pose the most immediate danger to public health.	*E. coli* is used as an indicator of the microbiological safety of drinking water; if detected, enteric pathogens may also be present. *E. coli* monitoring should be used, in conjunction with other indicators, as part of a multi-barrier approach to producing drinking water of an acceptable quality.

Parameter (approval)	Guideline	Common sources	Health considerations	Applying the guideline
Total coliforms (2012)	MAC of none detectable/100 mL in water leaving a treatment plant and in non-disinfected groundwater leaving the well	Human and animal faeces; naturally occurring in water, soil and vegetation	Total coliforms are not used as indicators of potential health effects from pathogenic microorganisms; they are used as a tool to determine how well the drinking water treatment system is operating and to indicate water quality changes in the distribution system. Detection of total coliforms from consecutive samples from the same site or from more than 10% of the samples collected in a given sampling period should be investigated.	Total coliforms should be monitored in the distribution system because they are used to indicate changes in water quality. In water leaving a treatment plant, total coliforms should be measured in conjunction with other indicators to assess water quality; the presence of total coliforms indicates a serious breach in treatment. In a distribution and storage system, detection of total coliforms can indicate regrowth of the bacteria in biofilms or intrusion of untreated water. In non-disinfected groundwater, the presence of total coliforms may indicate that the system is vulnerable to contamination, or it may be a sign of bacterial regrowth.
Turbidity (2012)	Treatment limits for individual filters or units: - Conventional and direct filtration: ≤ 0.3 NTU[1] - slow sand and diatomaceous earth filtration: ≤ 1.0 NTU[2] - membrane filtration: ≤ 0.1 NTU[3]	Naturally occurring particles: *Inorganic*: clays, silts, metal precipitates *Organic*: decomposed plant & animal debris, microorganisms	Filtration systems should be designed and operated to reduce turbidity levels as low as reasonably achievable and strive to achieve a treated water turbidity target from individual filters of less than 0.1 NTU. Particles can harbour microorganisms, protecting them from disinfection, and can entrap heavy metals and biocides; elevated or fluctuating turbidity in filtered water can indicate a problem with the water treatment process and a potential increased risk of pathogens in treated water.	Guidelines apply to individual filter turbidity for systems using surface water or groundwater under the direct influence of surface water. The decision to exempt a waterworks from filtration should be made by the appropriate authority based on site-specific considerations, including historical and ongoing monitoring data. To ensure effectiveness of disinfection and for good operation of the distribution system, it is recommended that water entering the distribution system have turbidity levels of 1.0 NTU or less. For systems that use groundwater, turbidity should generally be below 1.0 NTU.

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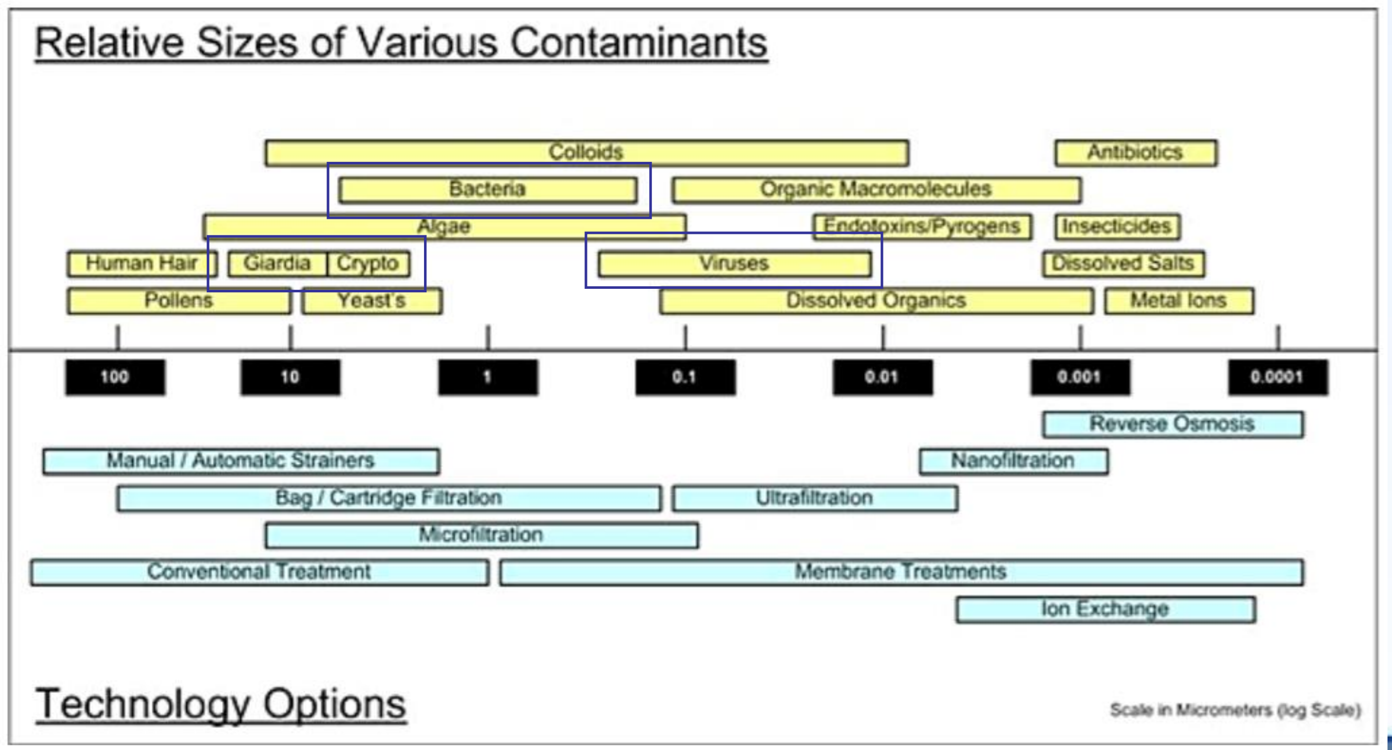
Log Removal and Filtration Spectrum



Drinking Water Contaminants: *Other*

- Pharmaceuticals and personal care products (PPCPs)
  - Prescription and over-the-counter drugs
  - Veterinary drugs (hormones, antibiotics)
  - Dietary supplements
  - Consumer products (cosmetics, sunscreen, cleaning products)
- Enter drinking water through
  - Excreting of unmetabolized medication into waste water collection
  - Disposing of unused medications in sinks and toilets
  - Washing into water while bathing
  - Discharge from manufactring processes
  - Improper commercial disposal
  - Excretion and run-off to source water from farm animals

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Synthetic Organic Compounds (SOCs)

– Surfactants

– Pesticides

– Cleaning solvents

– Pharmaceuticals

– Personal care products

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Pharmaceuticals in Drinking Water

Occurrence and concentrations of pharmaceutical compounds in groundwater used for public drinking-water supply in California

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ABSTRACT

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Persistence of pharmaceutical compounds and other organic wastewater contaminants in a conventional drinking-water-treatment plant

Paul E Stackelberg[a], Edward T Furlong[b], Michael T Meyer[c], Steven D Zaugg[b], Alden K Henderson[d], Dori B Reissman[d]

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Abstract

In a study conducted by the US Geological Survey and the Centers for Disease Control and Prevention, 24 water samples were collected at selected locations within a drinking-water-treatment (DWT) facility and from the two streams that serve the facility to evaluate the potential for wastewater-related organic contaminants to survive a conventional treatment process and persist in potable-water supplies. Stream-water samples as well as samples of raw, settled, filtered, and finished water were collected during low-flow conditions, when the discharge of effluent from upstream municipal sewage-treatment plants

Contaminates in Wastewater

- **Direct Discharge Areas of Concern:**
- Decomposition of organic matter (BOD)
- Pathogenic microorganisms
- Nutrients
- Toxic compounds (acute/chronic)
- Emerging issues ...
  - (EDCs/PhACs)

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Organic Matter: DO and BOD

- To appreciate the impact waste may have on a receiving water, it is necessary to understand
  - The demand on a river's oxygen resources (i.e., Biochemical Oxygen Demand, BOD)
  - The capacity of water to hold oxygen (Dissolved Oxygen saturation, DO)
  - The rate at which oxygen can be resupplied from the atmosphere (reaeration)
- When high BOD waste is added to water, the rate at which DO is consumed may exceed the rate at which oxygen is supplied
  - At DO < 4-5 mg/L reproduction of fish is impaired
  - Anaerobic conditions can cause a lack of biodiversity and poor aesthetics

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Thermal Stratification

- Lakes and rivers have a very different means of mass transport
  - Rivers are essentially completely mixed
  - Lakes undergo **thermal stratification** in temperate latitudes
    - Lake divides into layers, restricting mass transport

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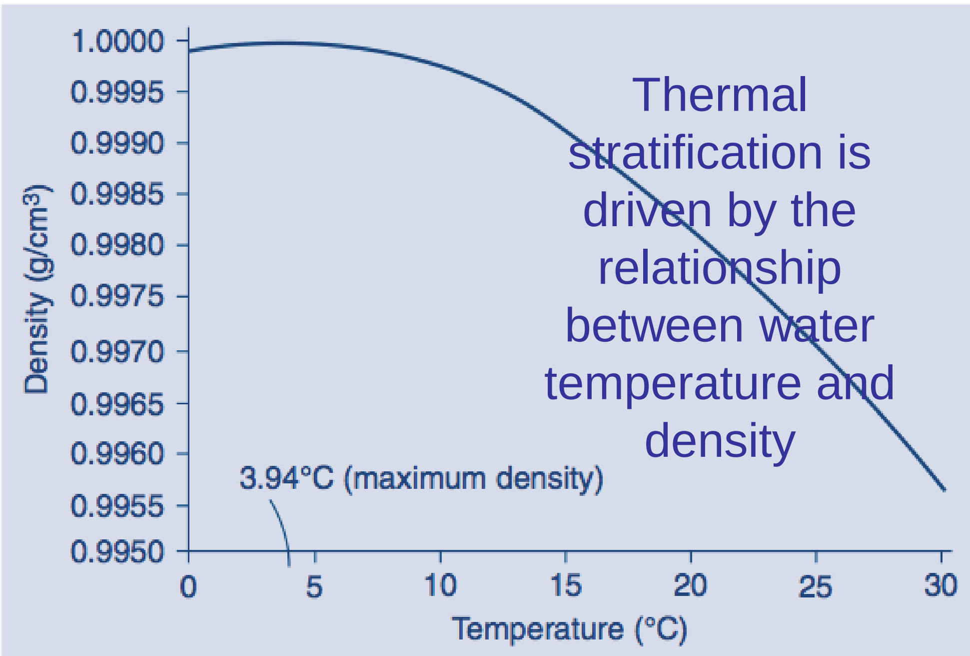
Thermal Stratification



Thermal stratification is driven by the relationship between water temperature and density

Figure / 7.23 **Maximum Density of Water** The maximum density occurs at 3.94°C. Thus, water at approximately 4°C will be found below colder waters (ice at 0°C) in winter and warmer waters (20°C) in the summer.

(From Mihelcic (1999). Reprinted with permission of John Wiley & Sons, Inc.).

- **Max density = ~4C**
- **Winter:** Ice thus floats; lakes freeze from the top down
- **Summer:** an upper layer of warm, less dense water floats on a lower layer of cold, denser water.

Thermal Stratification

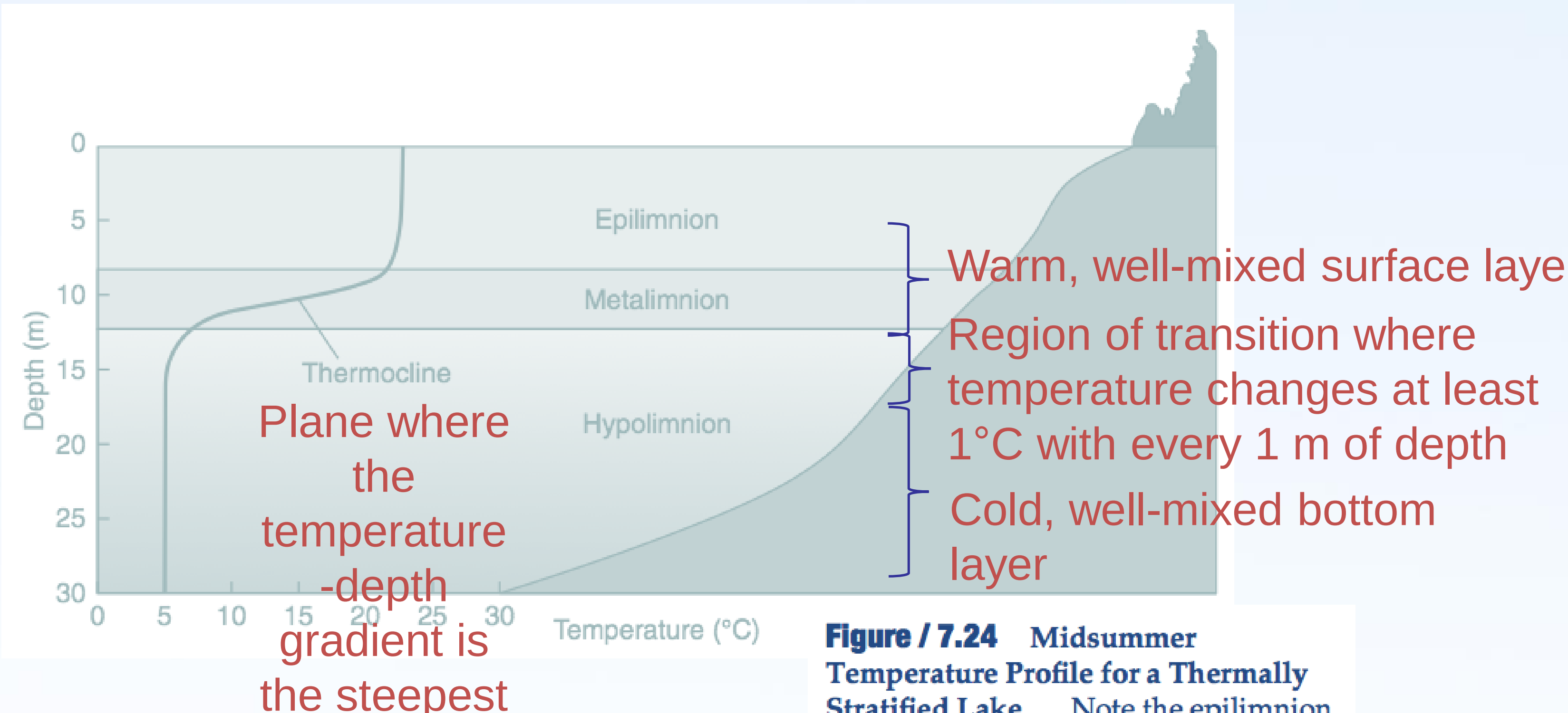


Figure / 7.24 **Midsummer Temperature Profile for a Thermally Stratified Lake** Note the epilimnion, metalimnion (with a thermocline), and hypolimnium.

(Adapted from Mihelcic (1999). Reprinted with permission of John Wiley & Sons, Inc.).

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Organic Matter, Thermal Stratification and Oxygen Depletion

- Organic matter produced in well-lit upper waters settles to the bottom, where is decomposes, consuming oxygen
- There is little resupply of O_2 under stratified conditions
  - Depletion of oxygen in the hypolimnion may result
- Oxygen depletion can accelerate:
  - Cycling of chemicals in lake sediments (e.g., iron, manganese, phosphorus)
  - Generation of undesired and potentially hazardous chemical species (NH_3, H_2S, CH_4)
  - Local extinction of fish

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Nutrient Limitation and Trophic State

- **Trophy** – the rate at which organic matter is supplied to lakes, both from the watershed and through internal production
- Growth of algae and macrophytes in lakes is influenced by light, temperature and the supply of growth-limiting nutrients
  - Regionally, light and temperature are more or less constant
- Therefore, trophy is determined primarily by growth limiting nutrients
  - Typically this is phosphorus for lakes; nitrogen for bays and estuaries

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Eutrophication

Table / 7.20

Classification of Water Bodies Based on Their Trophic Status

Oligotrophic	Nutrient poor; low levels of algae, macrophytes, and organic matter; good transparency; abundant oxygen
Eutrophic	Nutrient rich; high levels of algae, macrophytes, and organic matter; poor transparency; often oxygen-depleted in the hypolimnion
Mesotrophic	Intermediate zone; often with abundant fish life because of elevated levels of organic-matter production and adequate supplies of oxygen

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Engineered Lake Management to Control Eutrophication and Anoxic Conditions

- Point source control
  - Municipal waste water
- Non-point source control
  - Fertilizer run-off
- Diversion
  - Land applications
- Dredging
  - Removing sediment
- Hypolimnetic aeration
  - Adding oxygen

Water Treatment Stages

- Contamination can occur at three main stages in the water treatment process:
  - At the source

  - In the water treatment plant

  - In the distribution system

Multiple Barrier Approach

- Most systems employ the multiple barrier approach to water treatment to address contamination
- This approach has **four** major considerations:
  A. Source Water Protection
  B. Physical Water Treatment Process
  C. Distribution System
  D. Operator Training



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A. Source Water Protection

"The first barrier to the contamination of drinking water involves protecting the sources of drinking water."

- Justice Dennis O'Connor,

Walkerton Inquiry 2002

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A. Source Water Protection

- In Nova Scotia, water utilities are required to develop a **Source Water Protection Plan**
- This involves
  1. Forming an advisory committee
  2. Determining protected area boundary
  3. Identifying potential contaminants and assessing risk
  4. Developing a Source Water Protection Management Plan
  5. Developing a monitoring program to evaluate effectiveness of the Source Water Protection Plan

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A. Source Water Protection

- Watershed Protection Plan
  - Patrolling, monitoring water quality, controlling activities (recreation, forestry, highway salting, boron-coating of utility poles)
- Watershed Designation
  - Prohibited by NSE Act from interacting with watershed through fishing, swimming, boating; no motorized vehicles
- Difficult to control entire watershed
  - Private owners

B. Physical Water Treatment Process

- Water sources vary in terms of physical, chemical and microbiological parameters therefore treatment plant designs vary too!
- Types of source water:
  - Ground Water (well)
  - Surface Water (pond, lake, river)
  - Ground water under the direct influence of surface water (GUDI)
- System incorporates redundancies

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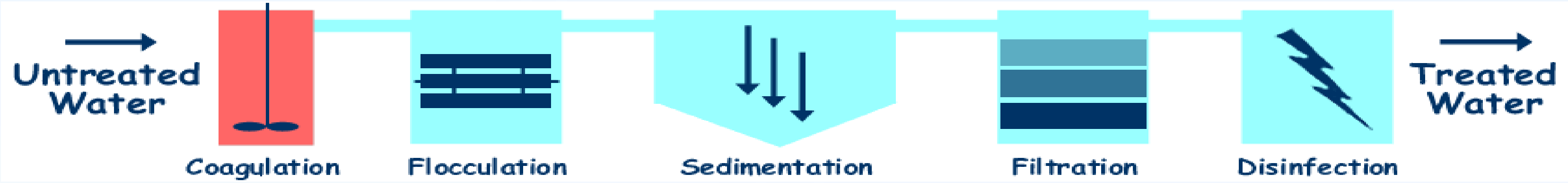
B. Physical Water Treatment Process



Oxidation

- Addition of a chemical to
  - Oxidize inorganic, organic and microbial contaminants
- Common oxidants include
  - Potassium permanganate
    - Iron, manganese, taste, odour, color, organic matter, disinfection by-products
  - Hydrogen peroxide, ozone, UV light, chlorine
    - Organic matter, microbial contaminants

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Coagulation, Flocculation and Sedimentation

- **Coagulation:** Addition of chemical to
  - Destabilize charged particles to remove turbidity
    - organic matter, bacteria
  - Draw dissolved contaminants out of solution
    - organic matter, color
- **Flocculation:** Slow mixing to allow contaminant aggregates to form
- Combined process draws dissolved contaminants out of solution making them amenable to removal via settling, floating and/or filtration

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Coagulation, Flocculation and Sedimentation

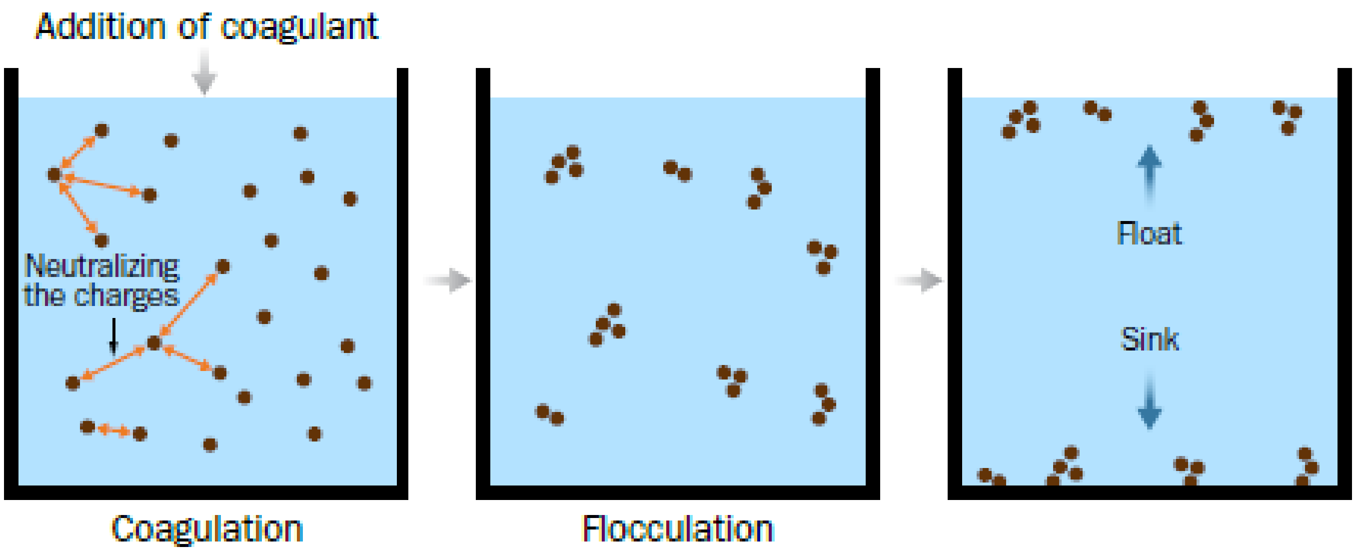

Figure 8.28. The process of coagulation and flocculation.

Source: OMAFRA

Coagulation, Flocculation and Sedimentation

- **Potential Health Implications:**
  - Aluminum residual in drinking water and waste water streams
  - Velocity gradients in flocculation tanks can influence aluminum carryover from coagulation
  - Aggregate size must be amenable to sedimentation and/or filtration process in order to properly remove aggregated contaminants
  - Waste sludge

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Filtration

- Required treatment step for surface water sources in Nova Scotia
- Water filtered through granular media and/or membranes
  - **Media:** sand, anthracite, granular activated carbon or combinations (i.e. sand-anthracite)
  - **Membranes:** microfiltration (0.1-2 um), ultrafiltration (0.01-0.1 um), nanofiltration (0.001-0.01 um), reverse osmosis (0.0001 um)

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Filtration

- **Potential Health Implications:**
  - Monitoring is required to prevent contaminant breakthrough
    - Thresholds for effluent turbidity, headloss and filter run time
  - Cleaning is required to prevent contaminant breakthrough
    - Backwashing (reverse flow to dislodge trapped contaminants, backwash water goes to waste)

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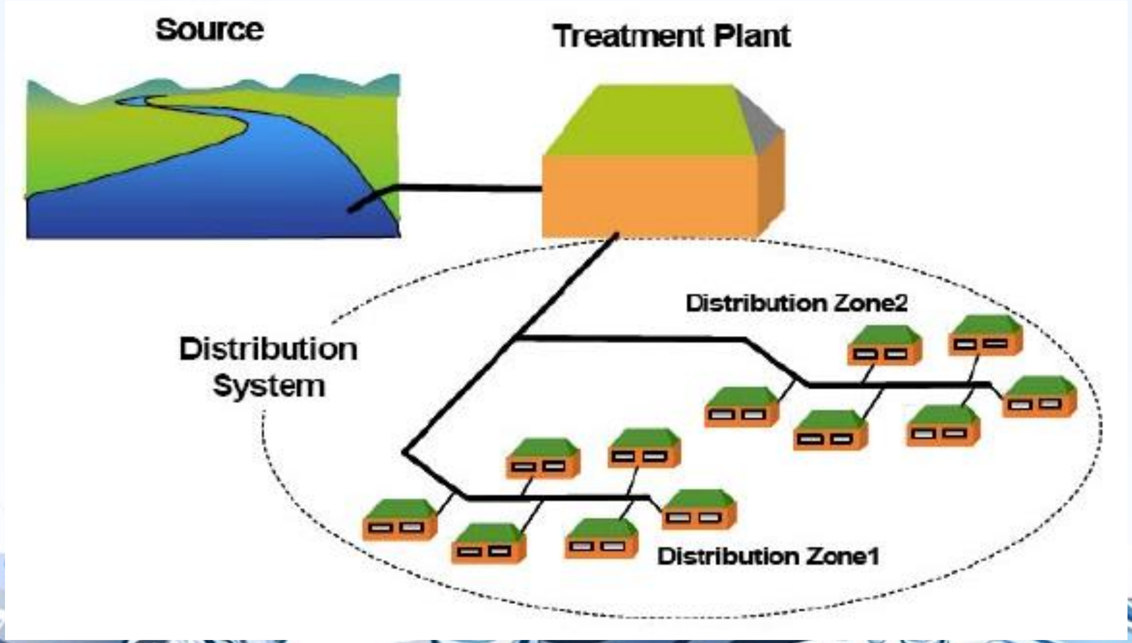
C. Distribution System

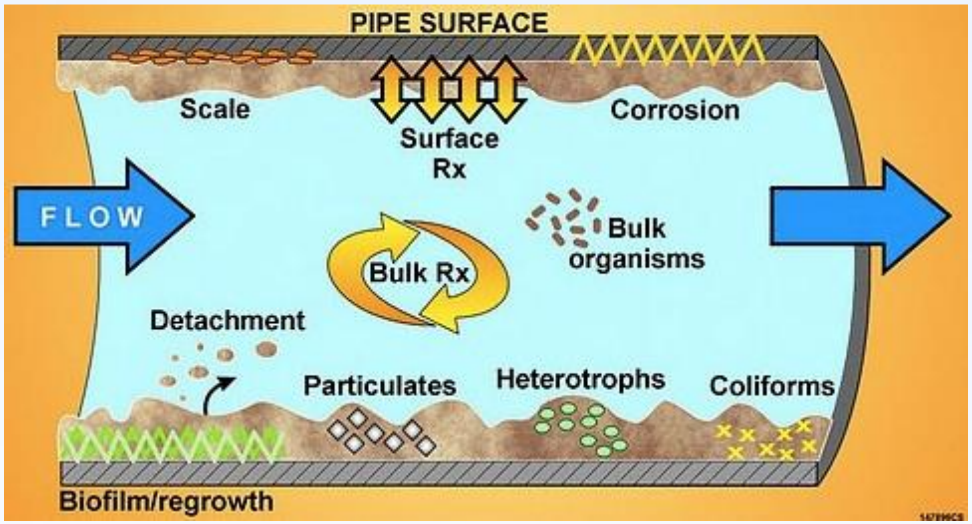
- Series of storage tanks, disinfectant booster stations, water mains and premise plumbing used to bring treated water to consumer



C. Distribution System

- **Health Implications**
  - Biological regrowth
    - Sloughing of biofilm leading to high microbial concentrations at the tap
  - Corrosion
    - Pitting: area for microbial attachment and subsequent biofilm attachment
    - Metal leaching: lead, copper
  - Pressure fluctuations, increased residence time
    - Potential for high contaminant concentration exposure if inorganic deposits or biofilm are dislodged from piping
  - Main breaks
    - Infiltration of contaminants from surrounding soil

C. Distribution System



Biofilm

Inorganic
Deposits

Disinfection

Disinfection Options: Overview

Disinfectant	Maintain Residual?	Disinfection Capacity	By-product Formation
Chlorine	Yes	Medium	THM/HAAs
Chlorine Dioxide	Yes	Medium to high	Chlorite
Chloramines	Yes	Medium	Nitrate
UV	No	High	Minimal

Disinfection

- Common disinfectants
  - Chlorine, chloramines, chlorine dioxide, UV light, (hydrogen peroxide, peracetic acid)
- Must supply residual protection to prevent regrowth in the distribution system
  - Chlorine is very common
  - UV does not provide residual
- Goal is to reduce microbial load in water, not sterilization

Disinfection

- Health implications
  - **Too much disinfectant:** eye and/or nose irritation, anemia, stomach irritation
  - **Too little disinfectant:** exposure to potentially harmful microbial contaminants
  - Reactions with inorganic and organic contaminants to produce disinfection by-products which may cause health effects (carcinogenic)
  - Changeover from chlorine to chloramines to reduce DBP formation have resulted in high lead leaching in some areas

Chlorine

- Chlorine is the most widely used chemical for disinfection of water
- Chlorine is usually added to water as the gaseous form or as sodium hypochlorite
- Gaseous and sodium hypochlorite hydrolyze to:

$$NaOCl + H_2O \rightarrow Na^+ + HOCl + OH^-$$

$$Cl_2 + H_2O \rightarrow HOCl + H^+ + Cl^-$$

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Chlorine

- After breakpoint, free chlorine is the dominant disinfectant
- Presence of a free chlorine residual is an indicator of adequate disinfection
- Free chlorine is typically adjusted to maintain a minimum level of **0.2 mg/L** throughout a drinking water distribution system

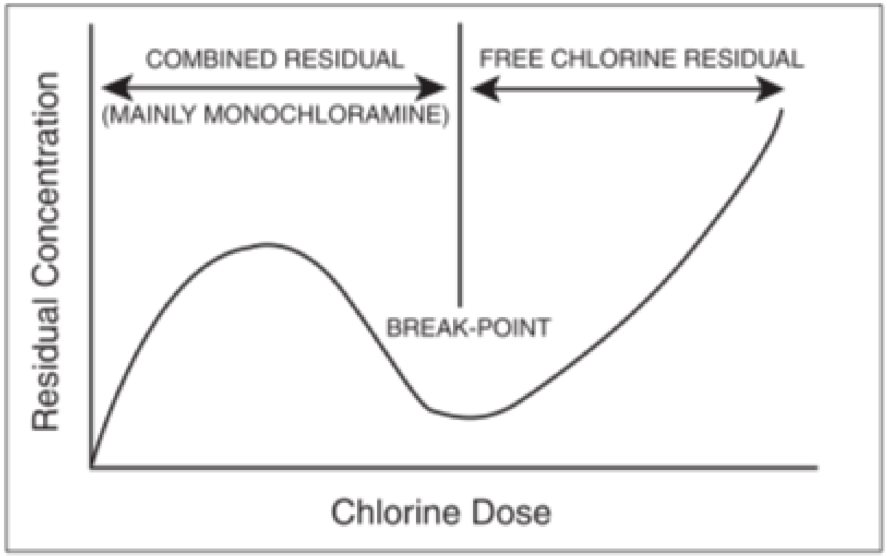

Figure: https://www.hach.com/cms-portals/hach_com/cms/documents/pdf/LIT/L7019-ChlorineAnalysis.pdf

Ultraviolet Light

- Benefits:
  - Accumulative literature indicates UV light is effective against *all* pathogenic microorganisms that are relevant to present drinking water practices, including chlorine-resistant pathogens
  - UV avoids DBP formation
  - Potential for Synergistic Effects
- Drawbacks:
  - No residual
  - Cell repair
  - Particle shielding
  - Deposition on lamps
  - Absorbance of UV light by organic matter
  - Point of application

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UV: Some Terms

- **UV Dose –** the UV energy per unit area incident on a surface, typically reported in units of mJ/cm^2 or J/m^2. The UV dose received by a waterborne microorganism in a reactor vessel accounts for the effects on UV intensity of the absorbance of the water, absorbance of the quartz sleeves, reflection and refraction of light from the water surface and reactor walls, and the germicidal effectiveness of the UV wavelengths transmitted
- **UV Intensity –** the power passing through a unit area perpendicular to the direction of propagation (mW/cm^2)

Source: USEPA, 2006

UV: Dosages

- Must first decide if the water is suitable for UV disinfection
- Water quality is based on the UV demand of the water, and generally includes turbidity and UV transmittance (UVt) as factors
- UVt is determined by finding the UV absorbance of the water (UVa)
  - Measured by a spectrophotometer set at a wavelength of 254 nm and a 1-cm wide cuvette containing the water
  - The measurement gained shows the absorption of energy per unit depth
- The percent transmittance can then be calculated using the equation: $UVt = 100 \times 10^{-A}$

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UV: Dosages

Source Water Quality	Absorbance (absorbance units/cm)	Percent Transmittance (%)
Excellent	0.022	95
Good	0.071	85
Fair	0.125	75

Source: DeMers and Renner, 1992

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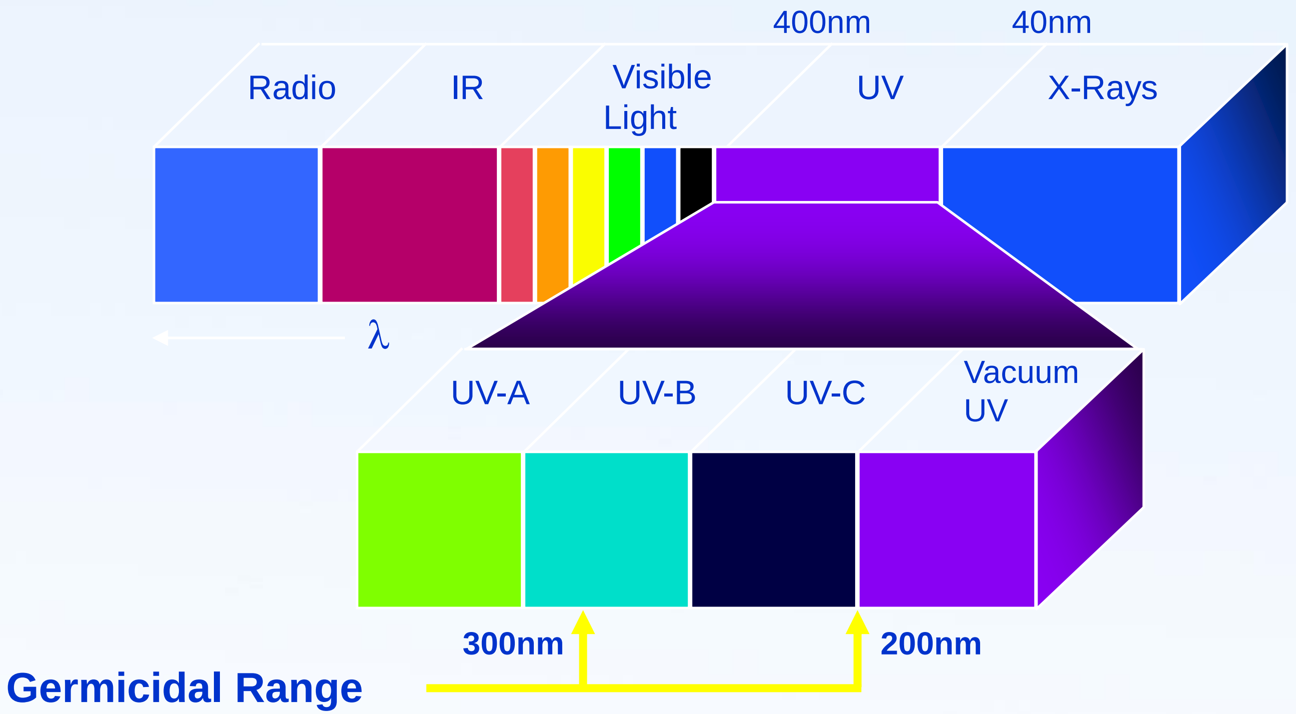
UV: Light Spectrum



Malley, 2000
www.iuva.org

UV: Reactors

- **UV** reactors can be classified as “closed vessel” or “open channel”
- Generally closed vessels are used because they have a smaller footprint, less airborne pollution, less exposure and simplicity in installation
- Closed vessels have water flowing through the chamber under pressure so that there is no free surface – maximum output
- Traditional: Low-, Medium-pressure
- Emerging: UV LEDs

UV: How does is disinfect?

- The general principle is that UV penetrates the outer wall and disrupts the nucleic acids, DNA and RNA of a cell or virus
- This renders the cell incapable of reproducing – it can't infect a host that has ingested it
- DNA can absorb UV light in the range of 200 – 300 nm but peaks around 260 nm (LP: 254 nm)

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UV: Disinfection Kintetics

- Literature has shown that the inactivation of cells by UV light can be described by first-order kinetics
- Inactivation is defined as the reduction of the concentration of culturable micro-organisms N due to the exposure to a concentration disinfectant C during a specific contact time t.
- Can use the same model used for chemical disinfectants developed by Chick (1908) and Watson(1908)

Source: Hijen et al., 2006

UV: Disinfection Kinetics

$$\log_{10}\left(\frac{N}{N_t}\right) = -k \times Fluence$$

- Where N_t is the microbial concentration after contact time t
- N is the original culturable concentration of microorganisms
- k (cm^2/mJ) is the inactivation constant for individual species: high for UV-sensitive microorganisms
  - Developed from experimental research

UV: Disinfection Kinetics

Species	Fluence (mJ/cm^2)	k (±CI; r^2)
Salmonella typhi	2-10	0.515 (0.047; 0.83)
Legionella pneumophila	1–12	0.400 (0.040; 0.92)
Escherichia coli O157	1-7	0.642 (0.082; 0.85)
Bacillus subtilis	5-78	0.059 (0.007; 0.91)
C. parvum	0.9-13.1	0.225 (0.07; 0.37)

Source: Hijen, 2006

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UV: Disinfection Kinetics

UV Dose Requirements –millijoules per centimeter squared (mJ/cm^2) (USEPA, 2006)

Target Pathogens	Log Inactivation							
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
Crypto	1.6	2.5	3.9	5.8	8.5	12	15	22
Giardia	1.5	2.1	3.0	5.2	7.7	11	15	22
Virus	29	58	79	100	121	143	163	186

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UV: Disinfection Kinetics

- Tchobanoglous (1997) specifically showed a relationship between coliform survival and UV dose:

$$N = f \cdot D^n$$

- Where: *N = Effluent coliform density, /100mL*

  D = UV dose, mW×s/cm2

  n = Empirical coefficient related to dose

  f = Empirical water quality factor

- The water quality factor is dependent on turbidity and UV transmittance

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UV: Other Considerations

- Particle shielding
  - Not only organic materials can shield pathogens, thereby reducing disinfection capacity
- Absorption of UV light
  - Humic material strong absorber and limiting factor in disinfection (Lund and Hongve, 1994; Allard, 1994)
- Upstream Practices
  - Should be designed to maximize UV disinfection
  - Coagulation, flocculation, filtration, activated carbon: removal of material
  - Oxidation (with chlorine or ozone): can increase the UVt
  - Use of other absorbers – ferric iron and permanganate
- Fouling
  - Hardness, temperature, pH, alkalinity, etc., all affect the rate of fouling
- Byproducts

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Disinfection of Agricultural Wash Water

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Project Site Description

- Freshly harvested spinach washed, dried and packaged for sale
- Wash water drawn from 2 groundwater wells
- 3 immersion wash basins dosed with 100 mg/L H_2O_2
- 1 final well water spray before product drying
- Total wash time ~ 45 seconds

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Research Approach

1

Comprehensive sampling plan during the spinach harvesting season to evaluate chemical treatment methods being used, and to evaluate the quality of wash-water for the processing of spinach.

2

Determination of the optimal treatment option available by testing the effectiveness in the removal of *E. coli* between

Chlorine and Hydrogen Peroxide.

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Sampling Program Description

- Collect wash water from 1st, 2nd & 3rd stage wash basins
- Collect well water from Well 1, Well 2, and final product rinse
- Measure samples for:
  - pH
  - Temperature
  - Turbidity
  - Residual H_2O_2
  - HPC
  - Coliforms
  - *E coli*

- Collect and measure 1st stage basin wash water over 2-hour period

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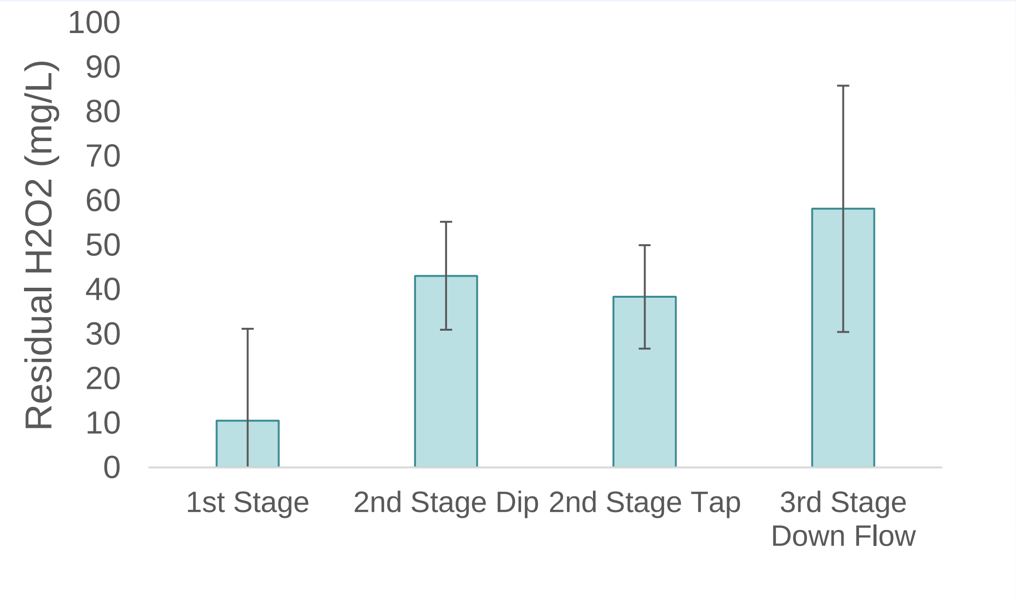
Sampling Program Results



H_2O_2 residual:

- Most of the H_2O_2 in the 1st stage wash is consumed, with residual levels typically < 10 mg/L
- Higher H_2O_2 residual (40 to 60 mg/L) maintained in 2nd and 3rd wash stages

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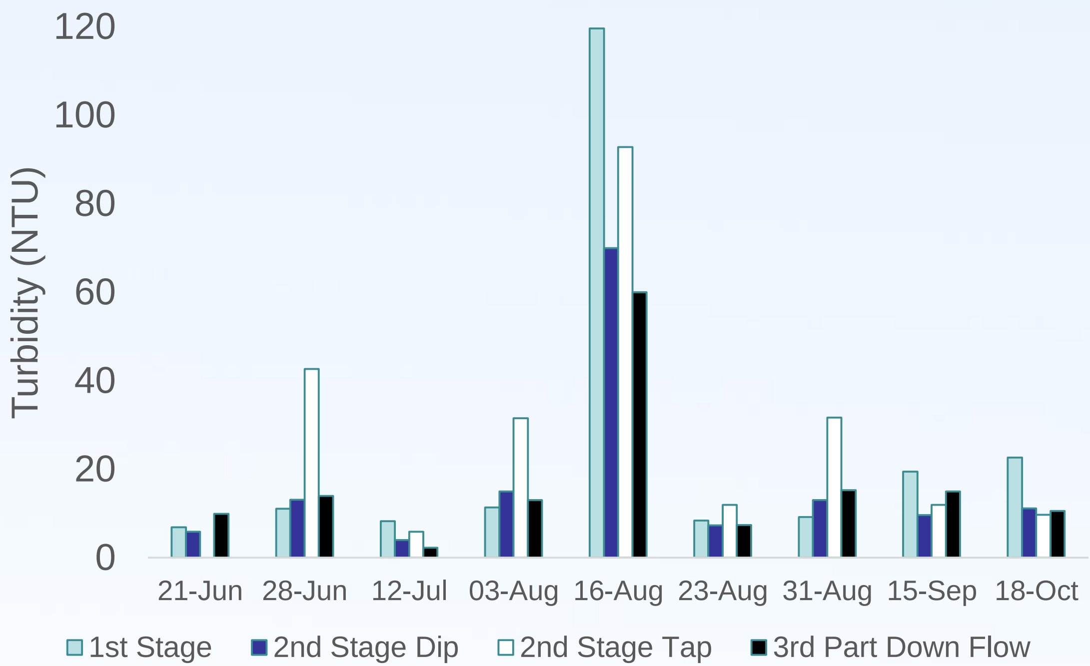
Sampling Program Results

Turbidity:

- Turbidity levels were highly variable in wash basin
- Ranged from 7 to 120 NTU in 1st stage wash basin
- Wash water turbidity was more dependent on the day of sampling than on the stage in the wash process



Sampling Program Results

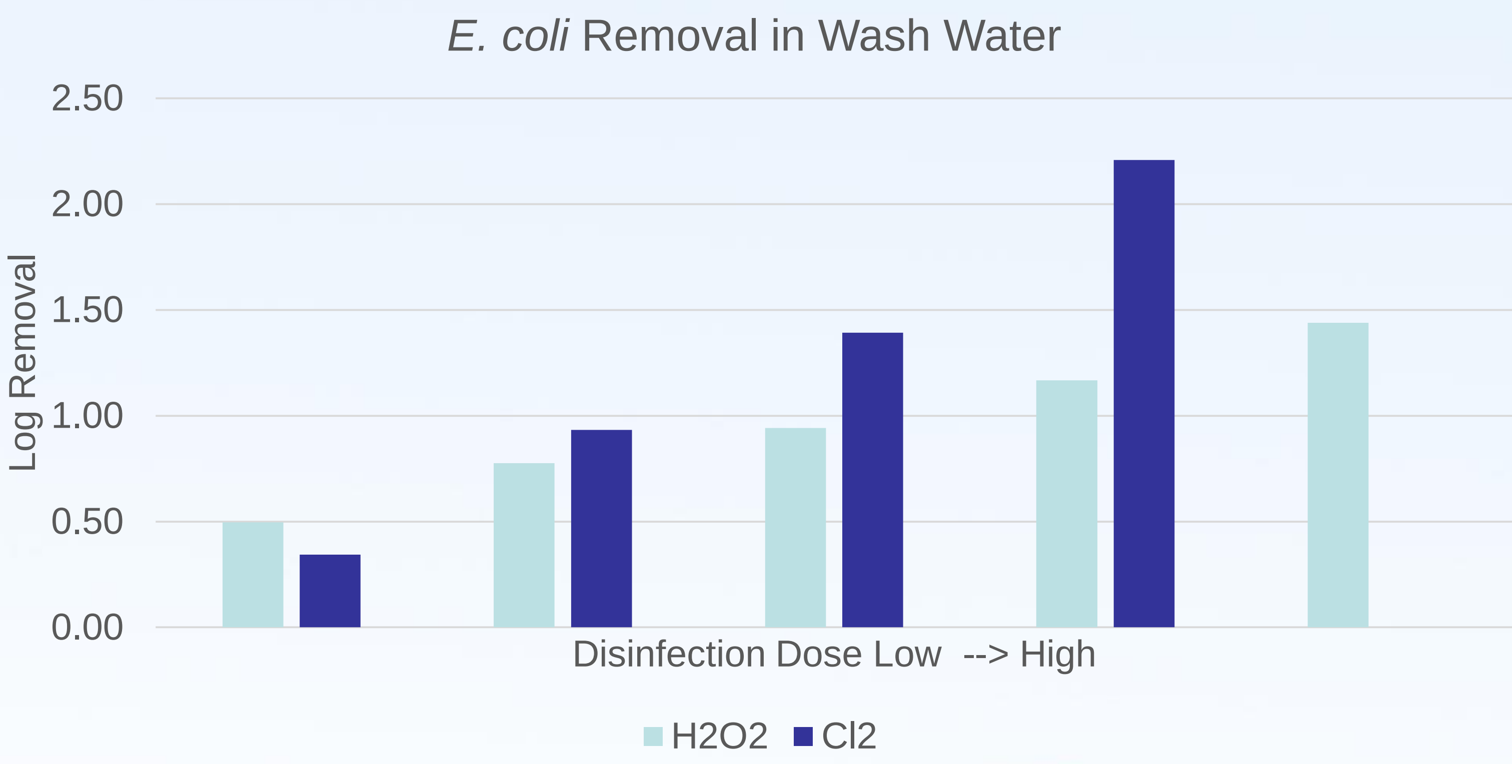
Coliforms and *E coli*:

- Coliforms and *E coli* detected in 1^{st} stage wash basin for every sample
- No coliforms or *E coli* detected in subsequent wash basins
- Positive detections of coliforms in well water and final spray water
- 2 positive detections of *E. coli* in final spray water

Table 1. Positive detections of coliforms and *E coli* over 6 sampling days for well and wash water

	Coliforms		*E coli*	
	# detections	Average coliforms per 100 mL	# detections	Average coliforms per 100 mL
Well #1	4	7	0	0
Well #2	2	2	0	0
1^{st} stage	6	3.2×10^4	6	1.6×10^4
2^{nd} stage dip	0	0	0	0
2^{nd} stage tap	0	0	0	0
3^{rd} stage down flow	0	0	0	0
Final spray	6	230	2	3

Comparison of Disinfectants



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Agricultural Wastewater Treatment

Project Site Description

- Fruit and vegetable processing plant that discharged process water into a local waterway
- Mainly under compliance with local regulations but failed a Fish Test
- Needed to evaluate cause of failure through water quality monitoring program, and to consider treatment options
  - Coagulation/Flocculation/Settling
  - Sequence-batch Reactor

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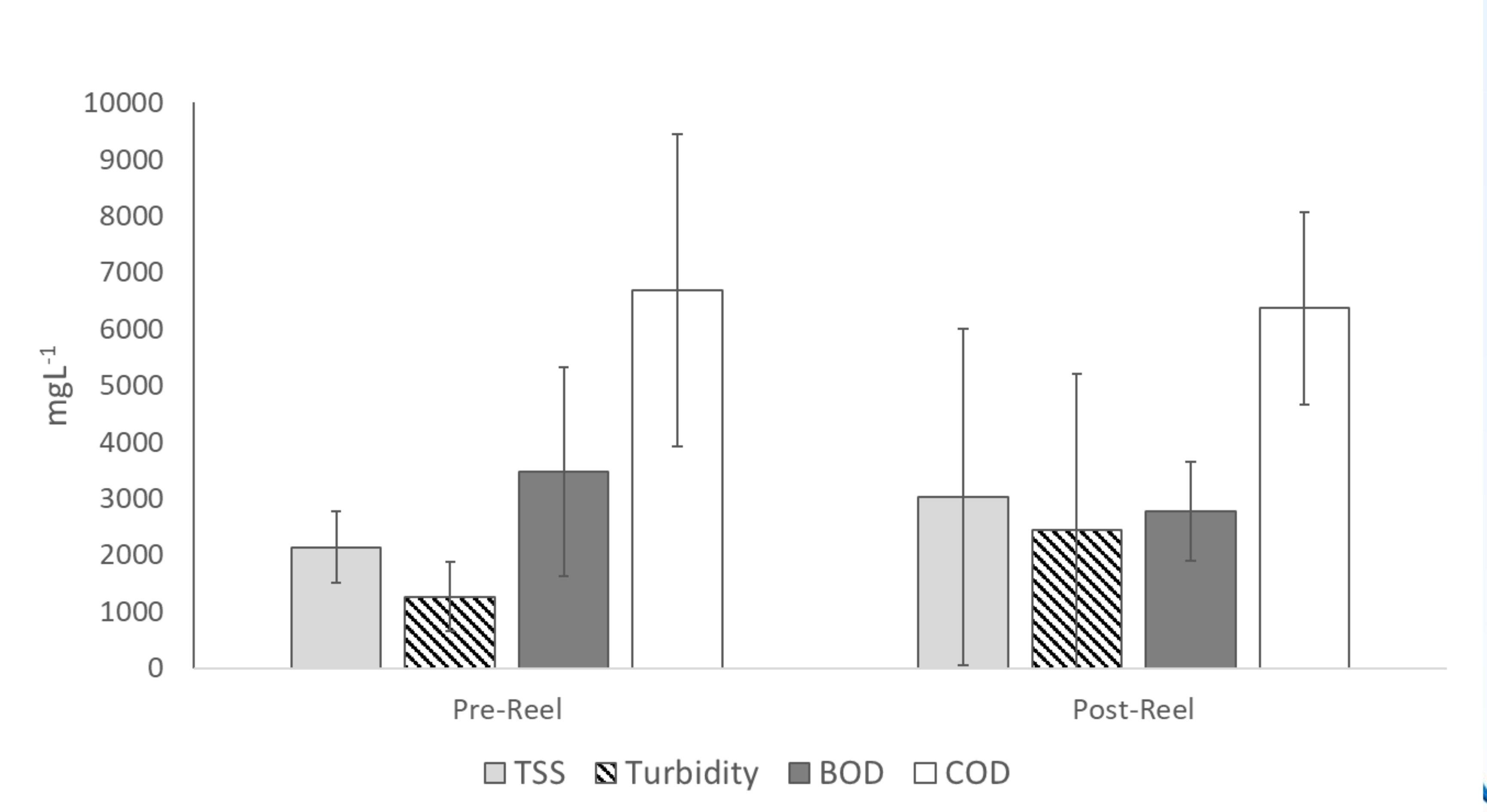
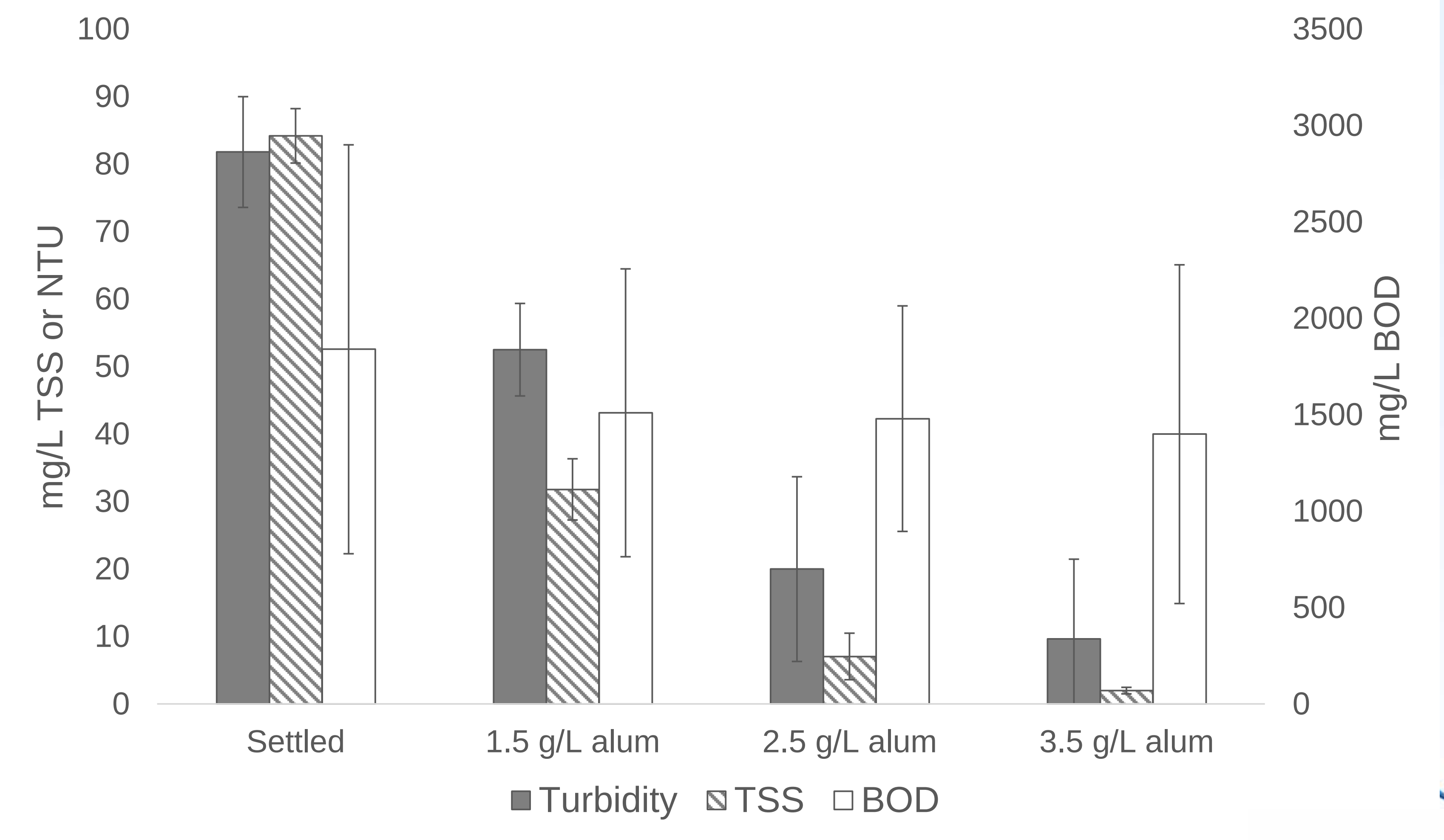
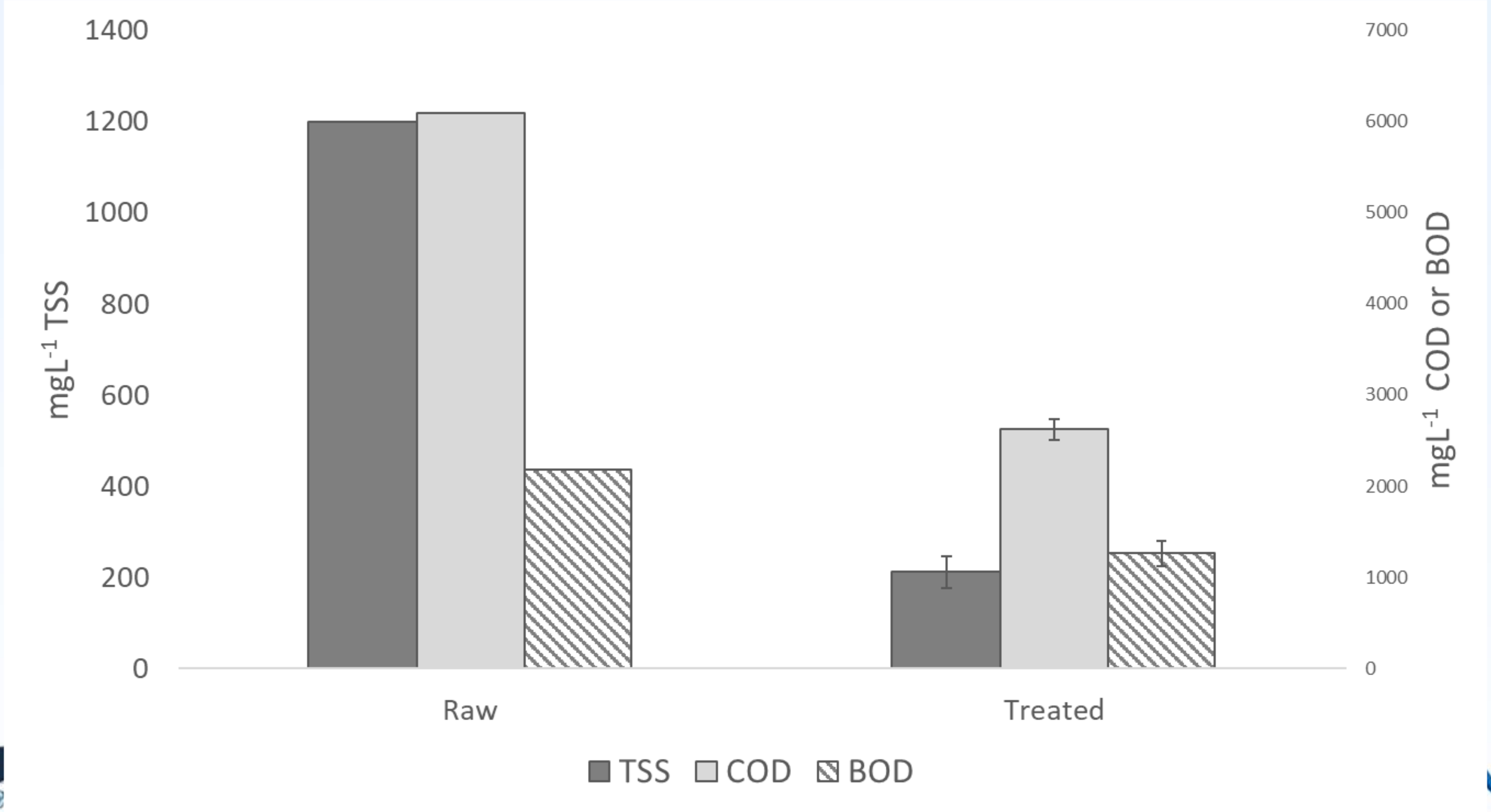
Monitoring Results



Coagulation/Flocculation Results



SBR Results



1400
1200
1000
800
600
400
200
0
mgL-1 TSS
7000
6000
5000
4000
3000
2000
1000
0
mgL-1 COD or BOD
Raw
Treated
TSS
COD
BOD

Thank you!

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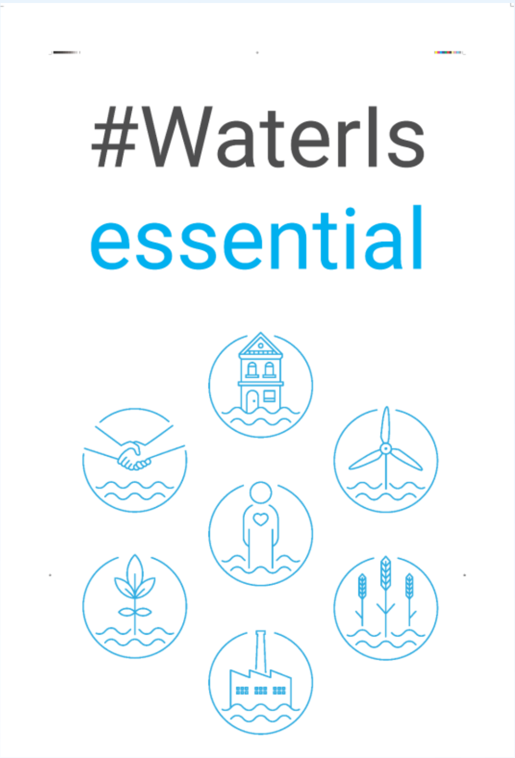

1.0 Water Quality Standards

1.3 SURROGATE PARAMETERS

In general, drinking water & wastewater treatment plants are designed using several ubiquitous parameters

A) PHYSICAL PARAMETERS

PARTICULATE MATTER

Drinking Water

Wastewater

1. Turbidity (clarity)

- < 1 NTU (Canada)
- < 0.1 NTU (direction of WTPs)
- Halifax Regional Water Commission achieves 0.05 NTU after filtration

2. Total Suspended Solids

- < 20 mg/ L or < 10 mg/ L
- Highly dependent on receiving water

1.0 Water Quality Standards

3. pH

- Drinking water: 6.5 – 8.5
- Wastewater: 6.0 – 9.0

B) CHEMICAL PARAMETERS

1. Organic Matter

Drinking water:

- Generally quantified by Total Organic Carbon (TOC)
- No direct guideline in Canada or U.S.
- Enhanced Surface Water Treatment Rule (U.S.) require low TOC of 2 to 3 mg/ L

1.0 Water Quality Standards

Wastewater:

- Generally quantified by Biochemical Oxygen Demand (BOD_5)
- In Canada, most common target is 20 mg/ L
- "20/20" Rule often applied to achieve 20 mg/ L BOD and 20 mg/ L TSS

Municipal Wastewater Discharge Limitations in Atlantic Canada (ENLA, 2007)

Point of Discharge	BOD5 (mg/ L)	TSS (mg/ L
Fresh water lakes & low flow streams	5	5
Rivers & estuaries	20	20
Open coastline	30	30

1.0 Water Quality Standards

2. Chlorine Residual

Drinking water:

- 0.2 mg/ L free chlorine at Tap
- Maximum allowable is 4 mg/ L

Wastewater:

- 0.5 – 1.0 mg/ L
- Goal is to kill coliform bacteria, not fish

1.0 Water Quality Standards

3. Disinfection By-Products (DBPs)

Only apply to drinking water

- Total trihalomethanes (TTHMs) < 100 µg/ L
- Haloacetic acids (HAAs) < 80 µg/ L

1.0 Water Quality Standards

4. Metals

Wide variety of guidelines depending on DW vs WW

Examples:

- Aluminum (DW): Canada → 0.1 mg/ L
- Mercury: US EPA → 10 µg/ L for WW, 2 µg/ L for DW

For next class, find guidelines for Arsenic in Drinking Water:

Canada & U.S.

1.0 Water Quality Standards

C) MICROBIOLOGICAL

Drinking water:

1. Total Coliform

- No sample should contain no more than 10 CFUs per 100 mL; none of which should be fecal in origin.
- No consecutive samples from the same site should show the presence of coliform organisms.
- Not more than 10% of the samples based on a minimum of 10 samples should show the presence of coliform microorganisms.

1.0 Water Quality Standards

2. Fecal Coliforms

- 0 / 100 mL
- Zero really means ZERO!
- E. Coli preferred test

E.Coli are species of bacteria that inhabits the large intestines of mammals (including humans)

- Most strains are harmless (i.e., do not cause disease)
- However some forms are enteropathogenic

E. coli O157:H7

1.0 Water Quality Standards

Wastewater

1. Fecal Coliform

- Lab results can be highly variable

Municipal Wastewater Discharge Limitations in Atlantic Canada (ENLA, 2007)

Point of Discharge	**Fecal Coliform**
Fresh Water Lakes and Low Flow Streams	200 / 100 mL
Rivers and Estuaries	1000 / 100 mL
Open Coastline	5000 / 100 mL