Lecture 3

HEALTH CONCERNS

Course: Water Reuse

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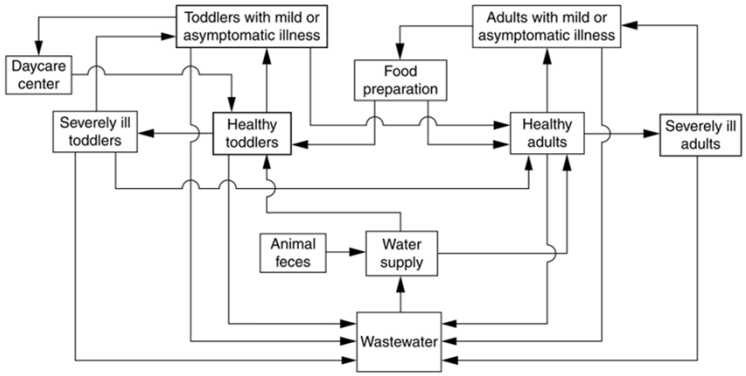
Cholera

- Historically, microorganisms were first identified as agents of waterborne disease during the cholera outbreak in England in the 1860s.

- In 1884, Theodor Escherich, isolated an organism from the feces of a cholera patient, which he initially thought was the cause of cholera. Later similar organisms were found in feces of every healthy individual. The organism was eventually named after him—Escherichia coli or E. coli.

Disease transmission



Protozoa vs. Bacteria

- Bacteria are simpler (first life forms)
- Protozoa and bacteria (usually) are unicellular, but protozoa are generally larger
- Protozoa feed on bacteria and other molecules by enveloping them
- Bacteria reproduce through binary fission, but protozoa have various methods
- Bacteria have no nucleus (prokaryote), but protozoa do (eukaryote)

Some groups of waterborne pathogens

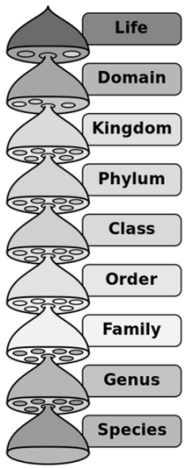
Group	Pathogen	Diseases and symptoms caused
Bacteria	*Salmonella*	Typhoid and diarrhea
	Shigella	Diarrhea
	Campylobacter	Diarrhea—leading cause in foodborne outbreaks
	Yersinia enterocolitica	Diarrhea
	Escherichia coli O157:H7 and other certain strains	Diarrhea, which can lead to hemolytic uremia syndrome in small children.
	Legionella pneumophila	Pneumonia and other respiratory infections
Protozoa	*Naegleria*	Meningoencephalitis
	Entamoeba histolytica	Amoebic dysentery
	Giardia lamblia	Chronic diarrhea
	Cryptosporidium parvum	Acute diarrhea, fatal for immunocompromised individuals
	Cyclospora	Diarrhea
	Microsporidia includes Enterocytozoon spp.	Chronic diarrhea and wasting, pulmonary, ocular, muscular, and renal disease
	Encephalitozoon spp.	
	Septata spp.	
	Pleistophora spp.	
	Nosema spp.	

Some groups of waterborne pathogens

Group	Pathogen	Diseases and symptoms caused
Cyanobacteria (blue-green algae)	Microcystis	Diarrhea from ingestion of the toxins these organisms produce
	Anabaena	Microcystin toxin is implicated in liver damage
	Aphantiomenon	
Helminths	*Ascaris lumbricoides*	Ascariasis
	Trichuris trichiora	Trichuriasis (whipworm)
	Taenia saginata	Beef tapeworm
	Schistosoma mansoni	Schistosomiasis (affecting the liver, bladder, and large intestine)
Viruses	Enteroviruses (polio, echo, coxsackie)	Meningitis, paralysis, rash, fever, myocarditis, respiratory disease, and diarrhea
	Hepatitis A and E	Infectious hepatitis
	Human Caliciviruses	
	Noroviruses	Diarrhea/gastroenteritis
	Sapporo	Diarrhea/gastroenteritis
	Rotavirus	Diarrhea/gastroenteritis
	Astroviruses	Diarrhea
	Adenovirus	Diarrhea (types 40 and 41), eye infections, and respiratory disease
	Reovirus	Respiratory and enteric infections

How to name living species

- According to convention, every biological species (except viruses because they are not living) bears a Latinized name that consists of two words.
- The first word is the genus (e.g., Giardia), and the second word is the species (e.g., lamblia).
- The first letter of the genus name is capitalized, and both the genus and species are either italicized or underlined (e.g., *Escherichia coli*)



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Log removal

- Because pathogens exist in large number, their removal or inactivation is often expressed as log removal:

$$\text{Log removal} = -\log\left(\frac{\text{conc}_{\text{out}}}{\text{conc}_{\text{in}}}\right) \qquad (3\text{-}1)$$

For example, if the concentration of *Giardia lamblia* is reduced from 100/L in the influent to 1/L in the effluent by activated sludge treatment process, the log removal due to the treatment is

$$\text{Log removal} = -\log\left(\frac{1}{100}\right) = 2 \text{ or } 99\% \text{ removal}$$

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E. Coli

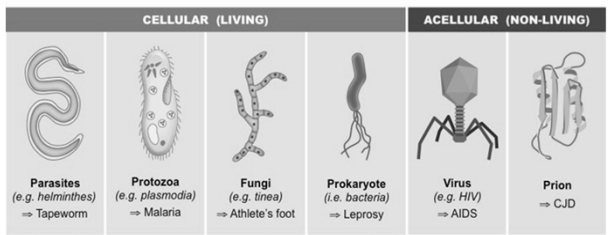
- E coli is a generally harmless bacteria but some strains are pathogenic.
- A particular strain, E. coli O157:H7, causes acute bloody diarrhea, and in some cases (5%) have resulted in hemolytic uremic syndrome (HUS), in which red blood cells are destroyed and the kidneys fail. One of the highest mortality rates of all waterborne diseases is due to HUS.
- A known microbial reservoirs for E. coli O157:H7 is healthy cattle. Transmission can occur also by ingestion of undercooked beef or raw milk.

Other common pathogens

- Giardia lamblia is the most common protozoa infection
- Cryptosporidium (especially the pavum and hominis species) is in the form of an oocyst. It enters animals and causes cryptosprridiosis which leads to sever diarrhea and presently has no pharmaceutical cure
- G. lamblia has been detected in treated wastewater effluent and is much more resistant to disinfection with chlorine than is bacteria.
- Chlorination is not effective on cryptosporidium.

Indicator organisms

- The number and variety of microbes that may be present in wastewater are considerable so measuring all possible pathogens is either impossible or impractical.
- Thus, tests for surrogate microorganisms (known as indicator organisms) are used



The ideal indicator

- Is present when fecal contamination is present (is a member of the intestinal microflora of warm-blooded animals)
- Is present in larger numbers than the target pathogen
- Exhibits greater (or the same) survival than the target
- Does not have a culturing procedure that is dangerous to laboratory scientists
- Can be isolated and quantified quickly, easily, and cheaply, compared to the target

Choosing an indicator

- To date, no ideal indicator organism has been found.
- Each person excretes 100-400 billion coliform bacteria per day, in addition to other kinds of bacteria. Thus, the presence of coliform bacteria has been taken as an indication that pathogenic organisms are also present, and the absence of coliform bacteria has been taken as an indication that the water is also free from disease producing organisms.
- The measurement and control of total coliforms (rather than only fecal coliforms) during disinfection is considered to be a more stringent treatment goal

Choosing an indicator

- While coliform bacteria serve well as indicators of bacterial pathogens, they may not predict the removal of enteric (fecal) protozoa, viruses, and helminths.
- A conservative standard for clean water would be a total coliform count of ≤ 1 coliform/100 mL (USA).
- In Iran if the wastewater has ≤ 1000 total coliform/100mL (and ≤ 400 fecal coliform/100mL) it can be discharged
- More recently, Giardia and Cryptosporidium have also been proposed as indicators in developed countries.

State-of-the-art targets

- The theoretical model of Regli proposes an annual risk of 10^{-4} of infection to be acceptable for drinking water.
- This means that less than one person per 10,000 consumers will be infected per year. While only a small percentage (~1 %) of infections result in disease.
- This leads to the following concentration in drinking water after treatment (unit operations + disinfection):

Viruses	**< 1 per 1,000 m^3**
Giardia	**< 1 per 100 m^3**
Cryptosporidium	**< 1 per 10 m^3**

Enterococci

- Used in conjunction with fecal coliform to determine the source of recent fecal contamination (man or farm animals)
- Two strains of fecal streptococci, *S. faecalis* and *S. faecium*, are the most human specific members of the fecal streptococcus group.
- EPA recreational water quality criteria:

CRITERIA ELEMENTS	Recommendation 1 Estimated Illness Rate 36/1,000		Recommendation 2 Estimated Illness Rate 32/1,000	
Indicator	GM (cfu/100 mL)	STV (cfu/100 mL)	GM (cfu/100 mL)	STV (cfu/100 mL)
Enterococci (marine & fresh)	35	130	30	110
E. coli (fresh)	126	410	100	320

N

Organism	Concentration in raw wastewater, MPN/100 mL[b]	Median infectious dose number (N_{50})
Bacteria		
Bacteroides	10^7–10^{10}	
Coliform, total	10^7–10^9	
Coliform, fecal[c]	10^5–10^8	10^6–10^{10}
Clostridium perfringens	10^3–10^5	1–10^{10}
Enterococci	10^4–10^5	
Fecal streptococci	10^4–10^6	
Pseudomonas aeruginosa	10^3–10^6	
Shigella	10^0–10^3	10–20
Salmonella	10^2–10^4	
Protozoa		
Cryptosporidium parvum oocysts	10^1–10^5	1–10
Entamoeba histolytica cysts	10^0–10^5	10–20
Giardia lamblia cysts	10^1–10^4	< 20
Helminth		
Ova	10^0–10^3	
Ascaris lumbricoides		1–10
Virus		
Enteric virus	10^3–10^4	1–10
Coliphage	10^2–10^4	

[a]Adapted in part from; Feacham et al. (1983); NRC (1996); Crook (1992).
[b]MPN = most probable number.
[c]*Echerichia coli* (enteropathogenic).

Natural processes

- In receiving waters, natural processes tend to reduce the concentrations of enteric microorganisms due to dilution and die-off.
- The natural inactivation or die-off rate is usually reported in terms of the time required for a 90 percent reduction in the viability of the microbial population.
- It is known that enteric pathogens generally survive longer at lower temperatures.

Freshwater survival rate

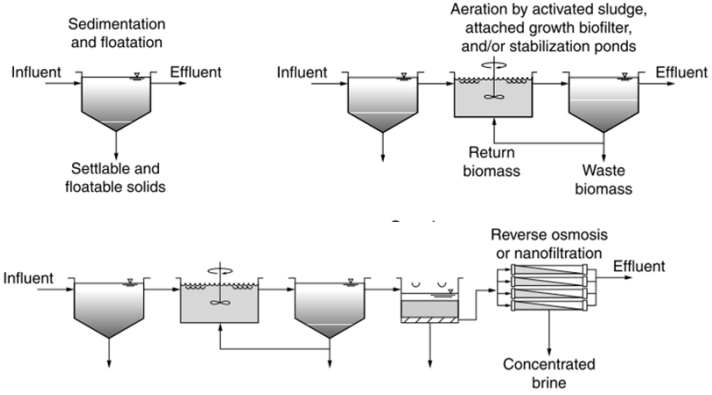
Microorganism	Time reported for 90 percent reduction in viable concentrations
Coliforms	0.83 to 4.8 d at 10 to 20°C, avg. 2.5 d
E. coli	3.7 d at 15°C
Salmonella	0.83 to 8.3 d at 10 to 20°C
Yersinia	7 d at 5 to 8.5°C
Giardia	14 to 143 d at 2 to 5°C 3.4 to 7.7 d at 12 to 20°C
Enteric viruses	1.7 to 5.8 d at 4 to 30°C

[a]Adapted from Feachem et al. (1983); Korhonen and Martikainen (1991); Kutz and Gerba (1988); McFeters and Terzieva (1991).

Types of treatment

Treatment level[b]	Description
Preliminary	Removal of wastewater constituents such as rags, sticks, floatables, grit, and grease that may cause maintenance or operational problems with the treatment operations, processes, and ancillary systems.
Primary	Removal of a portion of the suspended solids and organic matter from the wastewater.
Advanced primary	Enhanced removal of suspended solids and organic matter from the wastewater; typically accomplished by chemical addition or filtration.
Secondary	Removal of biodegradable organic matter (in solution or suspension) and suspended solids. Disinfection typically is also included in the definition of conventional secondary treatment.
Secondary with nutrient removal	Removal of biodegradable organics, suspended solids, and nutrients (nitrogen, phosphorus, or both nitrogen and phosphorus).
Tertiary	Removal of residual suspended solids (after secondary treatment), usually by granular medium filtration, surface filtration, and membranes. Disinfection is also typically a part of tertiary treatment. Nutrient removal is often included in this definition.
Advanced	Removal of total dissolved solids and or trace constituents as required for specific water reuse applications.

Types of treatment



Pathogen removal by processes

- Primary treatment does little to remove microbiological pathogens from wastewater. However, some protozoa and parasite ova and cysts will settle out.
- Secondary treatment reduces pathogens but does not eliminate them from the effluent, even with disinfection
- Reclaimed water derived from tertiary and advanced wastewater treatment processes is deemed safe for unrestricted landscape irrigation

Pathogen removal

Organism	Removal of organism for given treatment process, log units					
	Primary	Secondary		Tertiary		Advanced
	Plain sedimentation	Activated sludge	Trickling filter	Depth filtration	Microfiltration[b]	Reverse osmosis[c]
Fecal coliforms	<0.1–0.3	0–2	0.8–2	0–1	1–4	4–7
Salmonella	<0.1–2	0.5–2	0.8–2	0–1	1–4	4–7
Mycobacterium tuberculosis	0.2–0.4	0–1	0.5–2	0–1	1–4	4–7
Shigella	<0.1	0.7–1	0.8–2	0–1	1–4	4–7
Campylobacter	1	1–2		0–1	1–4	4–7
Cryptosporidium parbum	0.1–1	1		0–3	1–4	4–7
Entamoeba histolytica	0–0.3	<0.1	<0.1	0–3	2–6	>7
Giardia lamblia	<1	2		0–3	2–6	>7
Helminth ova	0.3–1.7	<0.1	1	0–4	2–6	>7
Enteric viruses	<0.1	0.6–2	0–0.8	0–1	0–2	4–7

[a]Adapted in part from Crook (1992).
[b]Wide range of values due to differences in performance of membranes from different manufacturers and imperfections or failure of the membrane (see Example 8-4 in Chap. 8).
[c]In theory, reverse osmosis should remove all organisms, however, due to imperfections or failure of the membrane some organisms may pass through with the permeate stream (see Example 8-4 in Chap. 8).

Effectiveness of unit operations

	Raw Conc.	Primary effluent		Secondary effluent		Tertiary effluent		AWT effluent[b]		Overall
		Conc.	%R[c]	Conc.	% R	Conc.	% R	Conc.	% R	% R
Conventional[d]										
CBOD	185	149	19	13	74	4.3	5	NA		98
TSS	219	131	40	9.8	55	1.3	4	NA		99+
TOC	91	72	21	14	64	7.1	8	0.6	7	99+
TS	1452	1322	9	1183	10	1090	6	43	72	97
Turb. (NTU)	100	88	12	14	74	0.5	14	0.27	0	99+
Ammonia-N	22	21	5	9.5	52	9.3	1	0.8	39	96
Nitrate-N	0.1	0.1	0	1.4	0	1.7	0	0.7	0	0
TKN	31.5	30.6	3	13.9	53	14.2	0	0.9	41	97
Phosphate-P	6.1	5.1	16	3.4	28	0.1	54	0.1	0	98
Nonconventional										
Arsenic	0.0032	0.0031	3	0.0025	19	0.0015	30	0.0003	40	92
Boron	0.35	0.38	0	0.42	0	0.31	13	0.29	3	17
Cadmium	0.0006	0.0005	17	0.0012	0	0.0001	67	0.0001	0	83
Calcium	74.4	72.2	3	66.7	7	70.1	0	1.0	88	99
Chloride	240	232	3	238	0	284	0	15	90	94
Chromium	0.003	0.004	0	0.002	32	0.001	24	0.001	28	83
Copper	0.063	0.070	0	0.043	33	0.009	52	0.011	0	83
Iron	0.60	0.53	11	0.18	59	0.05	22	0.04	2	94
Lead	0.008	0.008	0	0.008	0	0.001	93	0.001	0	91
Magnesium	38.5	38.1	1	39.3	0	6.4	82	1.5	13	96
Manganese	0.065	0.062	4	0.039	37	0.002	57	0.002	0	97
Mercury	0.0003	0.0002	33	0.0001	33	0.0001	0	0.0001	0	67
Nickel	0.007	0.010	0	0.004	33	0.004	11	0.001	45	89
Selenium	0.003	0.003	0	0.002	16	0.002	0	0.001	64	80
Silver	0.002	0.003	0	0.001	75	0.001	0	0.001	0	75
Sodium	198	192	3	198	0	211	0	11.9	91	94
Sulfate	312	283	9	309	0	368	0	0.1	91	99+
Zinc	0.081	0.076	6	0.024	64	0.002	27	0.002	0	97