Lecture 2

Why treat water and wastewater?

Reasons for treating:

Protect public health
Protect surface-water quality
Meet legal requirements

Specific concern: Pathogenic organisms
Pathogen = specific agent causing disease
Pathogenic = capable of causing disease

Pathogenic microorganisms

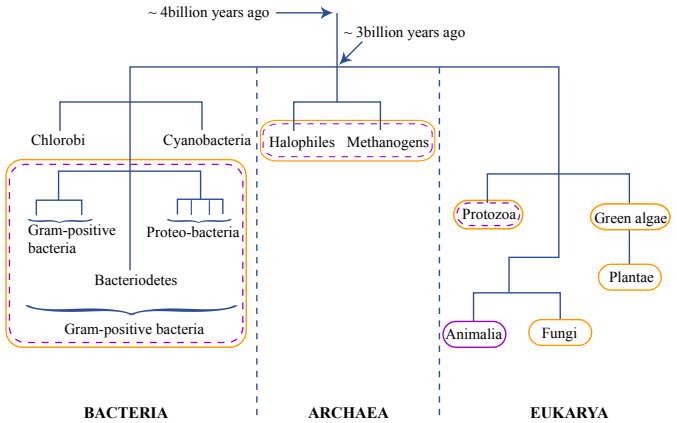


Figure by MIT OCW.

Biological pathogens

Pathogen	Size, µm
Bacteria	10^{-1} – 10
Viruses	10^{-2} – 10^{-1}
Protozoa	10 – 10^{2}
Nematode helminth worms	1 – 10^{5}
Trematode helminth worms	1 – 10^{5}
Tapeworms	~40 (egg) up 6 m (worm)

Note: filter sand is 100 to 10^{3} µm, can strain particles to ~30 µm

Adapted from: Mara, D. *Domestic Wastewater Treatment in Developing Countries*. London, UK: Earthscan, 2003, p. 23. Figure 3.1.

Escherichia coli

- Abbreviated as e. coli
- Resides in lower intestines of warm-blooded animals
- Usually non-pathogenic
- Used as indicator of fecal contamination

The images for this and subsequent slides, except where noted, are available from Dennis Kunkel Microscopy, Inc., 2004. http://www.denniskunkel.com/PublicHtml/Edu-Splash.asp Accessed January 29, 2005

Caption *E. coli* (0157:H7) hemorrhagic type. Gram-negative, enteric, facultatively anaerobic, rod prokaryote. Potentially fatal to humans, contracted when contaminated meat is cooked inadequately.

File Name: 96444C

Category: Bacteria

Type of Image: SEM

Magnification: x3,000-- (Based on a 35mm slide image of 24mm in the narrow dimension)

Keywords 96444C.TIF 0157:H7 bacilli bacillus bacteria bacterial pathogen bacterium contaminated meat E. coli Escherichia coli facultatively anaerobic Gram-negative hemorrhagic human disease infection prokaryote rod enteric bacterial pathogen intestinal tract infection enterohemorrhagic EHEC strain zoonoses zoonotic microorganism 0157

Non-copyright images at: http://www.lbl.gov/Publications/Currents/Archive/Mar-05-2004.html and http://www.niaid.nih.gov/biodefense/images/e_coli.jpg

Fecal streptococci

- Includes enterococci
- Also used as indicator of fecal contamination

Caption *Enterococcus faecium* - Gram-positive, VRE, coccus prokaryote (dividing); causes skin and wound infections. **File Name:** 96540E

Category: Bacteria

Type of Image: SEM

Magnification: x4,390-- (Based on a 35mm slide image of 24mm in the narrow dimension)

Keywords 96540E.TIF bacteria bacterial pathogen bacterium cocci coccoid coccus division Enterococcus faecium Gram-positive human disease infection prokaryote skin infection vancomycin resistant Enterococci VRE wound infection

Salmonella typhi

Causes typhoid fever

Other salmonella species cause gastroenteritis

Caption *Salmonella typhi* - Gram-negative, enteric, rod prokaryote (dividing); causes typhoid fever.

File Name: 96430B

Category: Bacteria

Type of Image: SEM

Magnification: x5,530-- (Based on a 35mm slide image of 24mm in the narrow dimension)

Keywords 96430B.TIF bacilli bacillus bacteria bacterial pathogen bacterium division Gram-negative human disease infection prokaryote rod Salmonella typhi typhoid fever enteric bacterial pathogen intestinal tract infection

Campylobacter spp.

Cause campylobacteriosis (diarrhea, cramping, abdominal pain, fever)

Source: Lethbridge Centre for Research, Agriculture and Agri-Food Canada, 2003. http://res2.agr.ca/lethbridge/emia/SEMproj/campSEM_f.htm. July 30, 2003. Accessed January 29, 2004

Legionella spp.

Cause
Legionnaire's disease (respiratory disease)

Caption *Legionella pneumophila* - Gram-negative, aerobic rod (or cocci, not shown)prokaryote; the cause of Legionnaire's disease (legionellosis or pneumonia).

File Name: 96459A

Category: Bacteria

Type of Image: SEM

Magnification: x4,230-- (Based on a 35mm slide image of 24mm in the narrow dimension)

Keywords 96459A.TIF aerobic bacilli bacillus bacteria bacterial pathogen bacterium Gram-negative human disease infection Legionella pneumophila legionellosis Legionnaire's disease pneumonia prokaryote rod

Pseudomonas aeruginosa

Causes:
dermatitis ("hot tub rash")
"swimmer's ear"

Caption *Pseudomonas aeruginosa* - Gram-negative, aerobic, enteric, rod prokaryote (dividing).This complicated, resistant bacteria causes skin infections, urinary tract infections and septicemia. This bacterium produces a blue-green pigment, pyocyanin, which characterizes the bluish pus produced by the infection.

File Name: 97270A

Category: Bacteria

Type of Image: SEM

Magnification: x3,000-- (Based on a 35mm slide image of 24mm in the narrow dimension)

Keywords 97270A.TIF aerobic animal pathogen antibiotic resistance antibiotic resistant bacilli bacillus bacteria bacterial pathogen bacterium biofilm bioflims blue-green pigment blue pus division enteric bacterial pathogen enteric pathogen Gram negative Gram-negative human disease infection nosocomial infection plant pathogen prokaryote Pseudomonas aeruginosa Pseudomonas putida Pseudomonas syringae polar flagella pseudomonad polar flagellum pyocyanin resistant bacterium rod septicemia siderophore siderophores skin skin infection soil microbe soil organism soil bacterium soil bacterium urinary urinary tract infection UTI

Shigella spp.

Causes bacillary dysentery

Caption: *Shigella dysenteriae* - Gram-negative, enteric, facultatively anaerobic, rod prokaryote; causes bacterial dysentery. This species is most often found in water contaminated with human feces.
File Name: 21200C
Category: Medical
Type of Image: SEM
Magnification: x2,200-- (Based on a 35mm slide image of 24mm in the narrow dimension)
Keywords 21200C.TIF bacteria Shigella dysenteriae rod bacilli bacillus prokaryote bacterium bacterial dysentery bacillary dysentery shigellosis enteric bacterial pathogen bacterial enteritis gastroenteritis intestinal tract infection human disease facultatively anaerobic Gram-negative polluted water

Vibrio cholera

Causes cholera

Caption *Vibrio cholerae* - Gram-negative, facultatively anaerobic, curved (vibrio-shaped) rod prokaryote; causes Asiatic cholera.

File Name: 96436B

Category: Bacteria

Type of Image: SEM

Magnification: x2,130-- (Based on a 35mm slide image of 24mm in the narrow dimension)

Keywords 96436B.TIF Asiatic cholera bacilli bacillus bacteria bacterial pathogen bacterium curved rod facultatively anaerobic Gram-negative human disease infection prokaryote Vibrio cholerae vibrio shaped

Vibrio vulnificus

- Responsible for three recent deaths in New Orleans
- "halophilic“ - lives in warm seawater
- May contaminate shellfish (raw oysters especially)

Polioviruses

Causes:
- poliomyelitis
- aseptic meningitis

Caption Polio virus; RNA virus, *Picornaviridae* Family.

File Name: 24314A

Category: Viruses

Type of Image: TEM

Magnification: x46,050-- (Based on a 35mm slide image of 24mm in the narrow dimension)

Keywords 24314A.TIF human human disease infection Family Picornaviridae polio RNA virus viral pathogen virion virus viruses

Other viruses

Enteric viruses – gastrointestinal illness

Adenoviruses – respiratory and eye infections

Noroviruses – Norwalk viruses – gastrointestinal illness (“cruise ship disease”)

Hepatitus A virus – infectious hepatitis

Cryptosporidium parvum

Causes gastrointestinal illness

Picture shows cyst stage

Caption *Cryptosporidium parvum* - protozoan (cyst stage) found in water contaminated by calf feces. A zoonotic microorganism, it passes in water to humans causing the microsporidial intestinal infection known as cryptosporidiosis.

File Name: 96058F

Category: Protozoa

Type of Image: SEM

Magnification: x2,310-- (Based on a 35mm slide image of 24mm in the narrow dimension)

Keywords 96058F.TIF AIDS animal disease aquatic calf feces contaminated fresh water cryptosporidiosis Cryptosporidium parvum cyst eukaryote human disease immunodeficiency intestine microsporidia microsporidial infection parasite parasitic plankton polluted pollution protozoa protozoal pathogen protozoan secondary infection zoonotic microorganism zooplankton

Entamoeba histolytica

Causes amoebic dysentery

Caption *Entamoeba histolytica* - dividing trophozoite with lobopodial extensions. A parasitic amoeba that causes amebic dysentery & ulcers (vegetative trophozoite stage). The amoeba moves by cytoplasmic extrusions / extensions and lobopodia. They invade the intestine but may spread to the liver, lungs and other tissues, causing abscesses to develop. Infection is caused by the ingestion of cysts in contaminated food or water. The cysts develop into the pathogenic trophozoite forms seen here. New cysts are carried out of the body in the feces. Entamoeba histolytica occurs worldwide, with up to 50% of the population being infected with it primarily in warmer climates. Amebic dysentery is spread by fecal contamination of food and water and is most common where sanitation is poor. **File Name:** 21063B

Category: Medical

Type of Image: SEM

Magnification: x700-- (Based on a 35mm slide image of 24mm in the narrow dimension)

Keywords 21063B.TIF 01.01.03 amebic dysentery amoeba amoebic dysentery animal disease aquatic colon infection contaminated fresh water dividing division dysentery Entamoeba histolytica eukaryote feces human disease intestine infection parasite parasitic plankton polluted water pollution protozoa protozoal pathogen protozoan zoonoses zoonotic microorganism zooplankton

Giardia lamblia

Causes gastrointestinal illness

Also called Giardia intestinalis

Caption *Giardia lamblia* - a human parasite of the gastrointestinal tract. The organism is spread by direct contact or through contaminated food and water. *Giardia* spp. are pear-shaped, with hair-like flagella for motility. They cause the disease giardiasis (or lambliasis), an infection of the small intestine most common in tropical areas. *Giardia* spp. attaches by means of sucking discs to microvilli in the human intestine. Abdominal cramps, swelling, diarrhea and nausea may occur.
File Name: 21071B
Category: Protozoa
Type of Image: SEM
Magnification: x1,000-- (Based on a 35mm slide image of 24mm in the narrow dimension)
Keywords 21071B.TIF protozoan protozoa Giardia lamblia eukaryote contaminated fresh water cyst giardiasis lambliasis human disease animal disease zoonoses zoonotic microorganism infection protozoal pathogen intestine feces polluted pollution parasitic parasite aquatic plankton zooplankton

Giardia lamblia

Right picture Caption *Giardia lamblia* - a protozoan (cyst stage) found in water contaminated by animal feces. Causes the protozoal infection known as giardiasis.

File Name: 96051F

Category: Protozoa

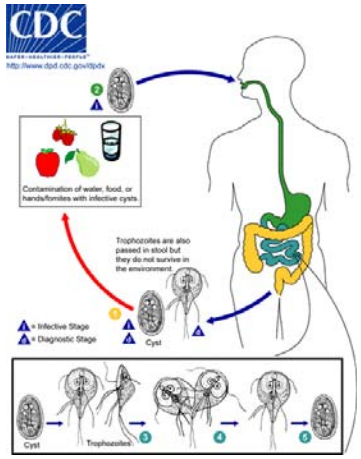
Type of Image: SEM

Magnification: x1,435-- (Based on a 35mm slide image of 24mm in the narrow dimension)

Keywords 96051F.TIF animal disease aquatic contaminated fresh water cyst eukaryote feces Giardia lamblia giardiasis human disease infection intestine parasite parasitic plankton polluted pollution protozoa protozoal pathogen protozoan zoonotic microorganism zooplankton zoonoses

Left picture Caption Protozoan infection (giardiasis) in human intestinal lumen (*Giardia* spp.).
File Name: 30005B
Category: Medical
Type of Image: TEM
Magnification: x1,820-- (Based on a 35mm slide image of 24mm in the narrow dimension)
Keywords 30005B.TIF animal disease Giardia giardiasis human disease infection intestine lumen parasite parasitic protozoa protozoal pathogen protozoan zoonotic microorganism eukaryote zoonoses |

Giardia life cycle



CDC, 2004. Laboratory Identification of Parasites of Public Health Concern, Parasites and Health, Giardiasis, Public Information Fact Sheet. *http://www.dpd.cdc.gov/dpdx/HTML/Giardiasis.asp?body=Frames/G-L/Giardiasis/body_Giardiasis_page1.htm. November 22, 2004. Accessed January 30, 2005.*

Cyclospora cayentanensis

Causes cyclosporiasis (diarrhea)

Soil-based helminth worms (nematodes)

Human hookworms:
Ancylostoma duodenale
Necator americanus

Ascaris lumbricoides – human roundworm

Trichuis trichiura – human whipworm

Water-based helminth worms (trematodes)

Schistosoma spp. – schistosomiasis (bilharzia or snail fever)

Clonorchis sinensis – liver fluke in East Asia

Fascukopis buski – liver fluke in East Asia

Infection rates approach 100% in developing countries

http://www.ips.it/scuola/concorso_99/acqua_1/infezioni.html

Caption Dog hookworm (nematode - *Anacyclostoma canium*). The adult parasites are small cylindrical worms 0.5 - 1.5mm long. The genus Ancylostoma have pairs of teeth on the ventral margin of the buccal capsule. The posterior end of the male worm is equiped with a characteristic copulatory bursa, used to catch and hold the female nematode during mating. The eggs are passed in the feces and once exposed to air they mature rapidly under optimal temperature and moisture. When mature they hatch to liberate a rhabditiform larvae. Larvae pass to the outside through human feces and subsequently re-enter their host by burrowing through the skin. After migrating through the lungs they settle in the gut and become sexually mature. The adult hookworms attach themselves to the intestinal wall using the buccal capsule teeth.

File Name: 23020A

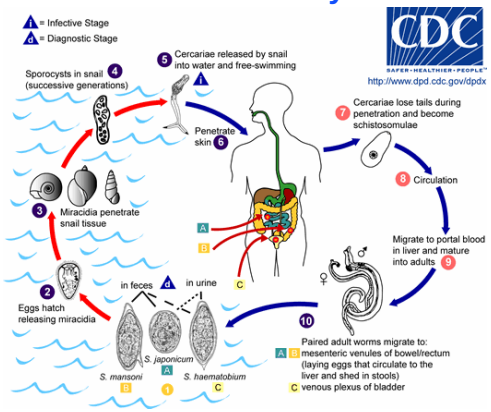
Category: Misc. Invertebrates

Type of Image: SEM

Magnification: x8-- (Based on a 35mm slide image of 24mm in the narrow dimension)

Keywords 23020A.TIF 01.01.03 animal disease buccal capsule buccal cavity copulatory bursa dog hookworm hookworm hookworm teeth human disease intestine invertebrate invertebrates misc. invertebrates nematode parasite parasitic stomodeum Nematoda Strongylida Anacyclostoma canium

Schistosoma life cycle



Source: CDC, 2004. Laboratory Identification of Parasites of Public Health Concern, Parasites and Health, Schistosomiasis, Public Information Fact Sheet. *http://www.dpd.cdc.gov/dpdx/HTML/Schistosomiasis.htm. May 5, 2004. Accessed January 30, 2005.*

Taeniases

Tapeworms

Attach to intestine wall

Caption Mammal intestine tapeworm (*Taenia taeniformis*). The adult has a head (scolex) with suckers and / or hooks that are used to attach to the host. Note the predominant hooks used for attachment to the intestinal wall. This species occurs most often in rabbits, cats and rodents. In some instances the tapeworm can be transmitted to humans. Tapeworms are a type of flatworm that can parasitize animal and human intestines. Body segments called proglottids are budded off from the head and neck region of the tapeworm while the tapeworm grows in the intestine. Tapeworms have no digestive systems of their own but absorb directly through their skin the food ingested and broken down by the host. Three well known species are: *Taenia solium*, the pork tapeworm; *Taenia pisiformis*, the dog tapeworm; *Taenia saginata*, the human tapeworm. Tapeworms can cause diarrhea, weight loss and abdominal discomfort in humans. Adult tapeworms may grow 5-10 meters in length.

File Name: 23312bw

Category: Misc. Invertebrates

Type of Image: SEM

Magnification: x22-- (Based on a 35mm slide image of 24mm in the narrow dimension)

Keywords 23312bw.tif 01.01.04 animal disease b/w cat tapeworm Cestoda cestode diarrhea dog tapeworm flatworm human disease intestine invertebrate invertebrates misc. invertebrates parasite parasitic Taenia Taenia taeniformis tapeworm zoonoses zoonosis zoonotic

Useful resources

Supplemental reading on Stellar web site for course 1.85

CDC fact sheets:
http://www.cdc.gov/ncidod/dpd/healthywater/factsheets.htm
http://www.cdc.gov/ncidod/diseases/index.htm
http://www.cdc.gov/ncidod/dpd/parasites/listing.htm

Pronunciation guide:
http://www.kcom.edu/faculty/chamberlain/Website/studio.htm

Images:
http://www.denniskunkel.com/

Chemical contaminants in drinking water

Organic chemicals
Disinfection byproducts
Inorganic chemicals
Radionuclides
Physical and aesthetic characteristics
"Emerging pollutants"

Organic chemicals

See:
http://www.epa.gov/safewater/mcl.html#organic

Chemical classes:
- Pesticides and herbicides
- Organic solvents
- Fuel components
- Polynuclear aromatic hydrocarbons

Organic chemical

Health effect of organic chemicals:
- Carcinogenicity – cause or suspected to cause cancer
- Teratogenicity (terra-tau-genicity) – cause birth defects
- Nervous system impairment
- Liver and other organ impairment
- Reproductive impairment

Disinfection byproducts

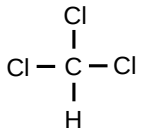
Disinfection with chlorine causes reaction byproducts with organic matter in water

Main classes of chemicals:
- TTHMs – Total trihalomethanes
- HAA5 – Five haloacetic acids

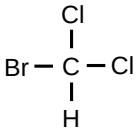
All are suspected human carcinogens

Trihalomethanes

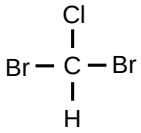
Chloroform



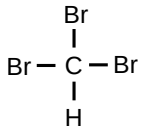
Bromodichloromethane



Chlorodibromomethane

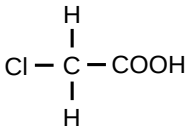


Bromoform

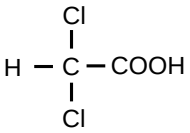


Five haloacetic acids

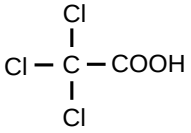
Monochloroacetic acid



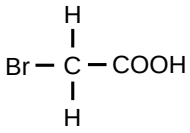
Dichloroacetic acid



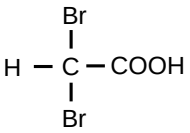
Trichloroacetic acid



Bromoacetic acid



Dibromoacetic acid



Inorganic chemicals

Chemical	Adverse effect
Antimony	Blood disorders
Arsenic	Skin damage, cancer
Barium	Increased blood pressure
Beryllium	Intestinal lesions
Cadmium	Kidney damage
Chromium	Dermatitis
Copper	Gastrointestinal, liver or kidney damage

Inorganic chemicals

Chemical	Adverse effect
Cyanide	Nervous system impairment
Fluoride	Dental fluorosis (staining), bone disease
Lead	Impaired mental development
Mercury	Kidney damage, birth defects
Nitrate	Methemoglobinemia (blue-baby syndrome)
Selenium	Hair loss, circulatory problems
Sodium	High blood pressure
Thallium	Blood, kidney, liver, intestinal effects

Radionuclides

Radioactive decay releases ionizing radiation which can cause cancer:

- Alpha particles – two protons and two neutrons
- Beta particles – electrons

Radium-226, Radium-228 – can cause cancer

Uranium – kidney damage, can cause cancer

Alpha radiation, radium and uranium all occur naturally

Physical and aesthetic characteristics

Property	Adverse effect
Turbidity	Harbors bacteria, interferes with treatment
Color, odor	Aesthetic
Silver	Cause argyria (turns skin blue)
Sulfate	Laxative effect
Chloride	Salty taste
TDS	Salty taste, scaling of pipes
Hardness	Cause deposits on bathroom fixtures

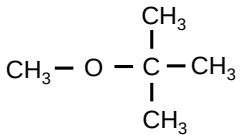
Physical and aesthetic characteristics

Property	Adverse effect
Iron	Stains laundry and fixtures
Manganese	Stains laundry and fixtures
Copper	Stains laundry and fixtures
Detergents	Causes water to foam
pH	Pipe corrosion, impaired taste
Phenols	Taste and odor

Emerging pollutants

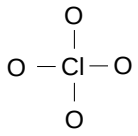
MTBE

Methyl tertiary butyl ether



Perchlorate

ClO_4^-



Drinking-water criteria

For regulated compounds:

http://www.epa.gov/safewater/mcl.html

For “emerging” pollutants:

http://www.epa.gov/safewater/mtbe.html

http://www.epa.gov/safewater/ccl/perchlorate/perchlorate.html

http://www.epa.gov/nerlesd1/chemistry/pharma/index.htm

U.S. Safe Drinking Water Act

Primary Drinking Water Standards:

- legally enforceable standards
- apply to public water systems
- protect public health by limiting the levels of contaminants in drinking water

Secondary Drinking Water Standards:

- non-enforceable guidelines
- regulate contaminants that may cause cosmetic effects or aesthetic effects
- recommended to water systems but compliance not required by EPA

Maximum Contaminant Levels (MCLs)

List of Contaminants & their MCLs

EPA 816-F-02-013
July 2002

Microorganisms | Disinfectants | Disinfection Byproducts | Inorganic Chemicals | Organic Chemicals | Radionuclides

- The links provided below are to either Consumer Fact Sheet, Rule Implementation web sites, or PDF files (ALL ABOUT PDF FILES)
- Alphabetical Version of this chart in PDF format EPA 816-F-03-016 June 2003 (396 K PDF FILE) (ALL ABOUT PDF FILES)

Microorganisms

Contaminant	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]	Potential Health Effects from Ingestion of Water	Sources of Contaminant in Drinking Water
Cryptosporidium (pdf file)	zero	TT[3]	Gastrointestinal illness (e.g., diarrhea, vomiting, cramps)	Human and fecal animal waste
Giardia lamblia	zero	TT[3]	Gastrointestinal illness (e.g., diarrhea, vomiting, cramps)	Human and animal fecal waste
Heterotrophic plate count	n/a	TT[3]	HPC has no health effects; it is an analytic method used to measure the variety of bacteria that are common in water. The lower the concentration of bacteria in drinking water, the better maintained the water system is.	HPC measures a range of bacteria that are naturally present in the environment

http://www.epa.gov/safewater/mcl.html

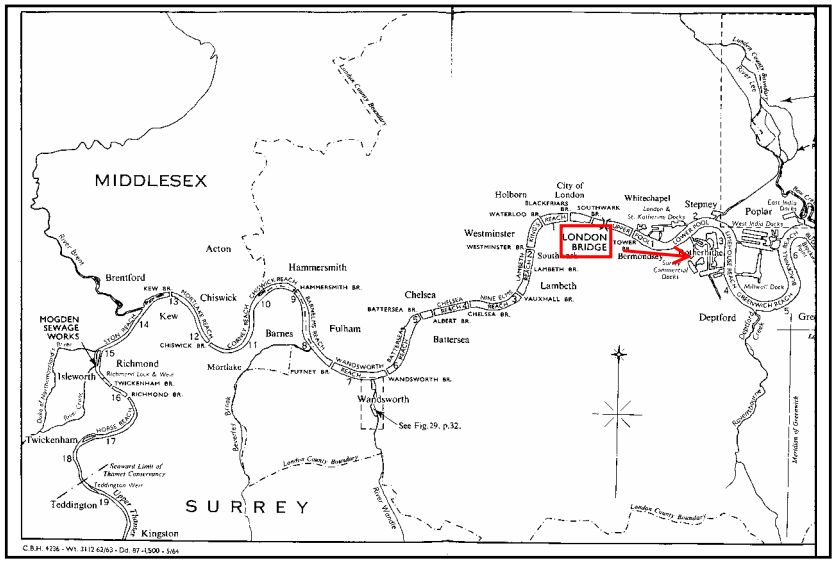
Maximum Contaminant Levels (MCLs)

Inorganic Chemicals

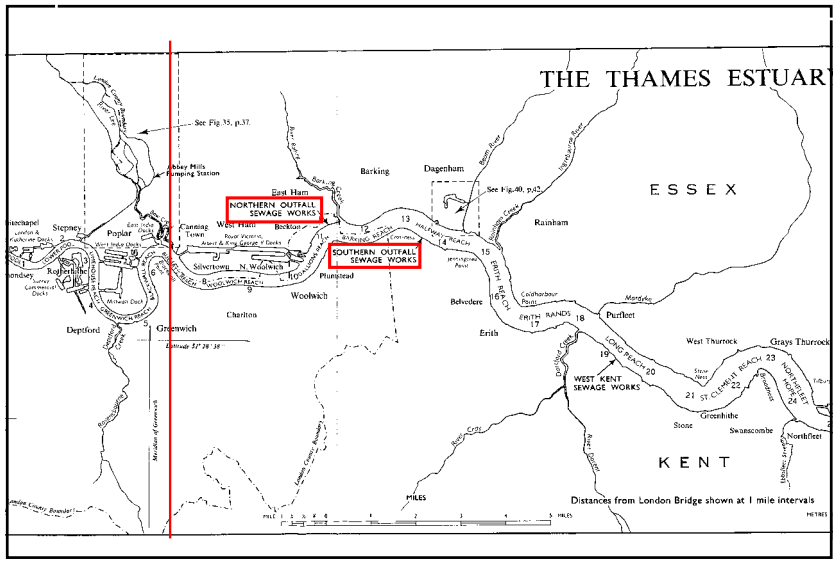
Contaminant	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]	Potential Health Effects from Ingestion of Water	Sources of Contaminant in Drinking Water
Antimony	0.006	0.006	Increase in blood cholesterol; decrease in blood sugar	Discharge from petroleum refineries; fire retardants; ceramics; electronics; solder
Arsenic	0[7]	0.010 as of 01/23/06	Skin damage or problems with circulatory systems, and may have increased risk of getting cancer	Erosion of natural deposits; runoff from orchards, runoff from glass & electronicsproduction wastes
Asbestos (fiber >10 micrometers)	7 million fibers per liter	7 MFL	Increased risk of developing benign intestinal polyps	Decay of asbestos cement in water mains; erosion of natural deposits
Barium	2	2	Increase in blood pressure	Discharge of drilling wastes; discharge from metal refineries; erosion of natural deposits
Beryllium	0.004	0.004	Intestinal lesions	Discharge from metal refineries and coal-burning factories; discharge from electrical, aerospace, and defense industries
Cadmium	0.005	0.005	Kidney damage	Corrosion of galvanized pipes; erosion of natural deposits; discharge from metal refineries; runoff from waste batteries and paints

Wastewater effects on receiving water

The estuary—looking downstream from near London Bridge



Images courtesy of Water Pollution Research Laboratory, 1964. Effects of Polluting Discharges on the Thames Estuary. Water Pollution Research Technical Paper No. 11. Water Pollution Research Laboratory, Department of Scientific & Industrial Research, London.

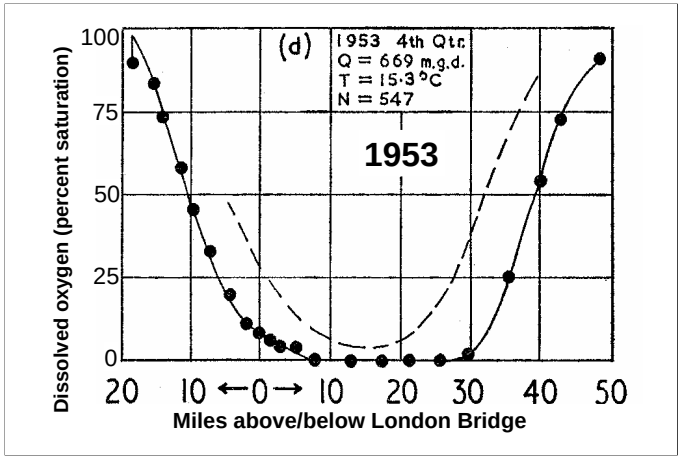


City of London WWTPs

Northern sewage works

Southern sewage works

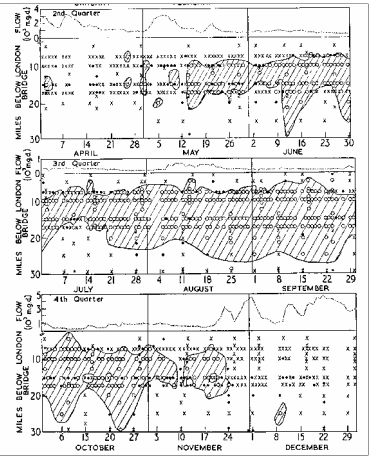
Images courtesy of Water Pollution Research Laboratory, 1964. Effects of Polluting Discharges on the Thames Estuary. Water Pollution Research Technical Paper No. 11. Water Pollution Research Laboratory, Department of Scientific & Industrial Research, London.



River is completely anaerobic (DO = 0) from River Mile 8 to River Mile 26.

Images courtesy of Water Pollution Research Laboratory, 1964. Effects of Polluting Discharges on the Thames Estuary. Water Pollution Research Technical Paper No. 11. Water Pollution Research Laboratory, Department of Scientific & Industrial Research, London.

Extent of anaerobic zone in 1952



The graph is a bit tricky to read. The horizontal axis is time and shows the duration of anaerobic conditions. Uninterrupted anaerobic conditions extend from mid-May to November. The vertical axis is distance in river miles and shows the length of the river experiencing anaerobic conditions. Only about ten miles are anaerobic in May but over 20 miles in September.

Images courtesy of Water Pollution Research Laboratory, 1964. Effects of Polluting Discharges on the Thames Estuary. Water Pollution Research Technical Paper No. 11. Water Pollution Research Laboratory, Department of Scientific & Industrial Research, London.

Pollution of the Thames River

Report of the Water Pollution Research Laboratory, January 15, 1965:

> Since the general introduction of the water-carriage system of sewerage in the first half of the nineteenth century, the disposal of the great volume of human and industrial wastes from so big a city as London has presented very serious problems… By 1949 the condition of the central reaches of the estuary had become particularly bad; during hot, dry weather from 20 to 30 miles of the waterway were anaerobic, with no detectable oxygen in solution, and under these conditions the malodorous gas hydrogen sulfide was given off to such an extent as to cause widespread complaints from the public, from ship owners, and from manufacturers with premises on the banks of the estuary.

Description of water pollution in the Thames River in 1949.

Timeline of important events affecting water quality in the river:

1856 – Metropolitan Board of Works established to construct sewage drainage to points downstream of city.

1866 – New sewers completed.

1878 – Steamship Princess Alice sunk near Barking; death toll alleged to be increased by river pollution.

1891 – Sedimentation channels constructed to provide primary treatment of sewage enhanced by addition of lime and ferrous sulphate.

1920-1940 – River goes anaerobic occasionally.

1932-1946 – Activated sludge secondary treatment constructed at Northern Sewage Works.

1947 – River stays anaerobic throughout July through September.

1950 – Anaerobic reach of river is 30 miles long, sulphide production becomes a concern.

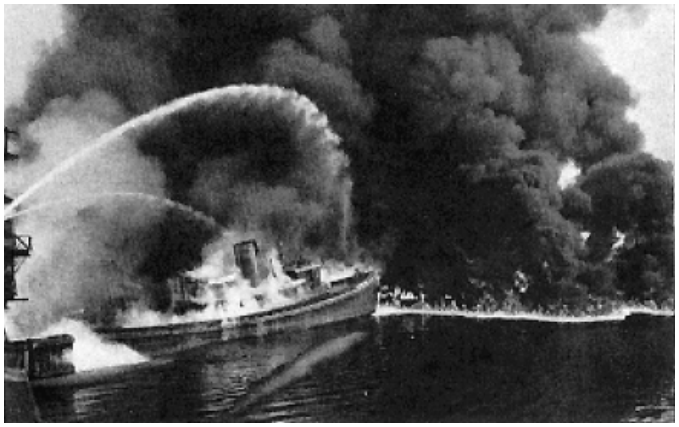
1954 – One quarter of sewage at Northern Works receives activated sludge secondary treatment. (Southern Works has only primary treatment.)

1963 – Southern Sewage Works adds secondary treatment.

Courtesy of Water Pollution Research Laboratory, 1964. Effects of Polluting Discharges on the Thames Estuary. Water Pollution Research Technical Paper No. 11. Water Pollution Research Laboratory, Department of Scientific & Industrial Research, London.

Wastewater effects on receiving water quality

Cayuhoga River – June 22, 1969



Source: Baogh, Brian, undated. HIUS 316 - Viewing America: the United States from 1945 to the Present. Corcorian Department of History, University of Virginia. http://www.vcdh.virginia.edu/HIUS316/mbase/docs/cuyahoga.html. Accessed January 30, 2005. Also from Yu, Paul, 1998. Cayuhoga River Pollution. http://www.grc.nasa.gov/WWW/K-12/fenlewis/Main.htm. Accessed October 31, 2005

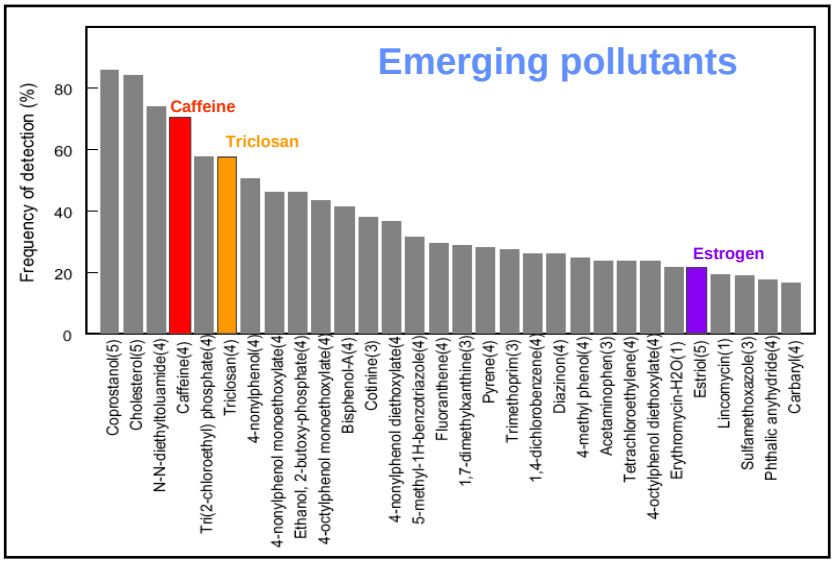
Mumford River, Mass. circa 1970

Courtesy of John E. Swedberg, used with permission.

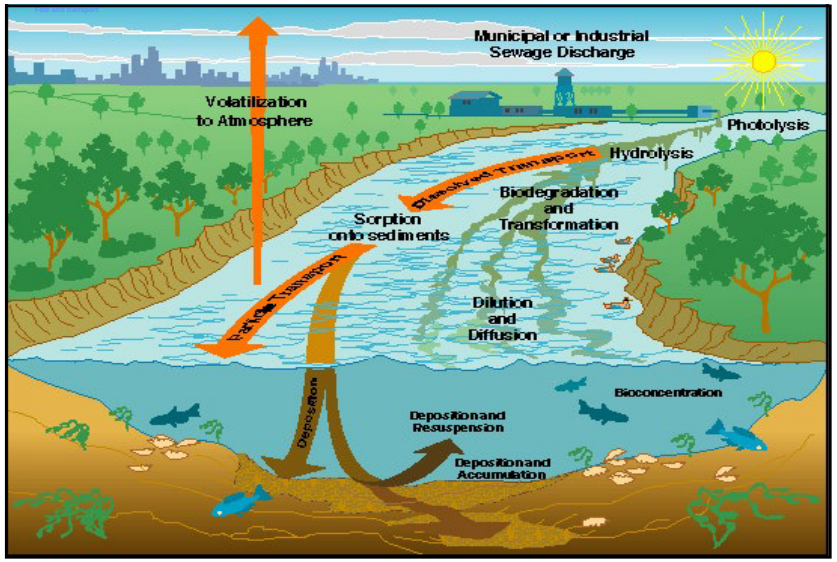
Blackstone River, Mass. circa 1970

Courtesy of John E. Swedberg, used with permission.

Source: Barnes, Kimberlee K., Dana W. Kolpin, Michael T. Meyer, E. Michael Thurman, Edward T. Furlong, Steven D. Zaugg, and Larry B. Barber, 2002. Water-Quality Data for Pharmaceuticals, Hormones, and Other Organic Wastewater Contaminants in U.S. Streams, 1999-2000. Open-File Report 02-94 U.S. Geological Survey, Iowa City, Iowa. http://toxics.usgs.gov/pubs/OFR-02-94/index.html, accessed October 31, 2005.



Source: Meade, Robert H., editor, 1995. Contaminants in the Mississippi River, 1987-92. Circular 1133. U.S. Geological Survey, Reston, Virginia. http://pubs.usgs.gov/circ/circ1133/, Accessed October 31, 2005.



Timeline of major environmental legislation

1970	Clean Air Act
1972	Federal Water Pollution Control Act
1974	Safe Drinking Water Act
1976	RCRA
1976	TSCA (Toxic Substances Control Act)
1977	Clean Water Act
1980	Superfund
1986	EPCRA (Emergency Planning and Community Right-To-Know Act)

Safe Drinking Water Act

1974 – Safe Drinking Water Act
- Required establishment of primary drinking water standards for public water supplies

1977 – DW Standards become effective
- Establish turbidity as health-based standard

1986 – SDWA Amendments
- Establishes current system of MCLs and MCLGs
- Added standards for radionuclides and disinfection by-products

Safe Drinking Water Act

1989 – Surface water treatment rule
- Aimed at reducing Giardia and other pathogens
- Sets filtration as technology standard

1993 – Milwaukee water supply contamination
- Cryptosporidium contamination causes 400,000 illnesses and more than 50 deaths

1996 – SDWA Amendments
- Increased source water protection

Safe Drinking Water Act

1998 – Enhanced surface water treatment rule
- Lowers turbidity standard
- Requires 99-percent removal of Cryptosporidium

1998 – D/DBP Rule
- Lowered standards for THMs, added HAA5

2001 – Revised standard for arsenic

Clean Water Act

Pre-1972 – Limited controls
- Limited refuse in navigable waters
- Provided some funding for wastewater treatment

1965 – Water Quality Act
- Requires states to establish stream standards
- Wastewater controls required as needed to protect stream water quality

Clean Water Act

1972 – Federal Water Pollution Control Act Amendments
- Established National Pollutant Discharge Elimination System
- Emphasized technology-based discharge limits (new control paradigm)
- Dramatically increased funded for treatment

Clean Water Act

1977 – Clean Water Act

- Included controls on toxic pollutants

1987 – Water Quality Act

- Added permit requirements for stormwater

Comparison of standards

Water-quality constituent	Units	U.S. EPA	European Union	World Health Organization
E. coli	number/100 ml	Detected in <5% of samples	0	0
Arsenic	µg/l	10	10	10
Copper	mg/l	1.3	2	2
Lead	µg/l	15	10	10
Nitrate	mg/l as N	10.0	11.3	11.3
TTHM	µg/l	100	100	200/100/100/60[a]
Chloride	mg/l	250	250	250
Iron	µg/l	300	200	No guideline
Benzene	µg/l	5	1	10
Carbon tetrachloride	µg/l	5	4	4
Tetrachloroethylene	µg/l	5	10[b]	40
Trichloroethylene	µg/l	5		70

a Chloroform/bromoform/dibromodichloromethane/bromodichlorodimethane
b Sum of trichloroethylene and tetrachloroethylene