

# Drinking Water Contaminants



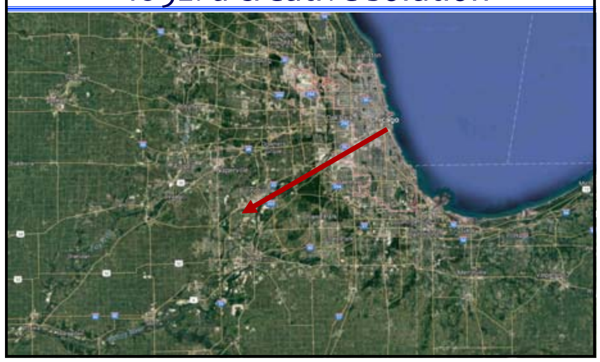
## Water Quality

- History of our understanding of waterborne disease
- Brief history of water treatment
- Drinking Water Standards: how do we decide what is allowed in the water we drink?

## The flush toilet contaminates safe drinking water with feces

- Toilets made cities habitable by carrying human waste "away"
- Unfortunately "away" was too close…
  - In the early 1800s new flush toilets and sewers carried the waste directly into rivers and streams
  - Chicago!
  - London drained its raw sewage into and withdrew its drinking water from the Thames River, both without any treatment.
  - Several of the drinking water intakes were below sewage outfalls!

## Chicago Sanitary and Ship Canal 1892: a creative solution



## Southwark and Vauxhall Water Company

- In 1850, the microbiologist Arthur Hassall wrote of the River Thames water they were using,"...a portion of the inhabitants of the metropolis are made to consume, in some form or another, a portion of their own excrement, and moreover, to pay for the privilege."
- Next Cartoon presents John Edwards, owner of the Southwark Water Company, posing as Neptune ("Sovereign of the Scented Streams"). He is seen crowned with a chamber-pot, seated on a stool on top of a cesspool which doubles as the water-intake for the Southwark Water Company customers in south London.

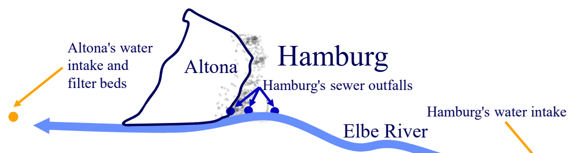
## Southwark and Vauxhall Water Company


Courtesy of the National Library of Medicine

## Drinking Water Treatment and Germ Theory

- 1829: First sand filter used to treat some of London's drinking water
- 1850: John Snow established the link between drinking water (from a contaminated well) and Cholera
- 1872: Poughkeepsie, NY installs first filter in US
- 1885: Sand filters are shown to remove bacteria
- 1892: Cholera outbreak in Hamburg, Germany

## 1892 Cholera outbreak in Hamburg Germany




- Large outbreak of Cholera in Hamburg
- 17,000 cases; 8,600 deaths
- Very few cases in neighborhoods served by Altona's filtered water supply
- Hamburg's sewers were upstream from Altona's intake!

## Altona vs. Hamburg: Cholera Cases

- ● Cholera cases
- ○ Cases in Altona acquired in Hamburg
- ■ Received water from Altona


Conclusions

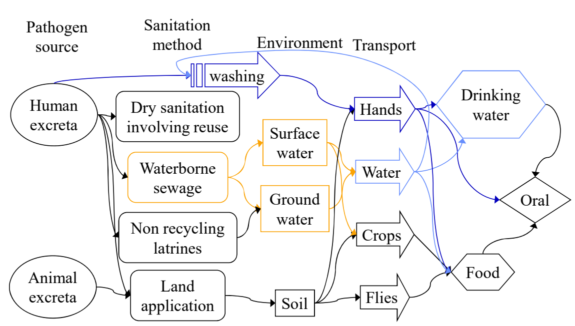
Cholera was waterborne

Slow sand filtration may have protected Altona

## Lake Titicaca in the Andes Mountains

## Fecal-Oral Pathways: a stochastic process

Hygiene
Water treatment
Sanitation




Will you see an immediate improvement in public health with the installation of a water treatment plant?


## Waterborne Threats to Human Health

- Infectious diseases
  - caused by viruses, bacteria, protozoa (pathogens)
  - https://confluence.cornell.edu/display/cee4540/Bad+Bugs
- Noninfectious diseases
  - acute: caused by short term exposure to harmful chemicals
  - chronic: caused by long term exposure to harmful chemicals
    - low levels of exposure to certain chemicals over a long period of time may cause cancer, liver and kidney damage, or central nervous system damage

## Propose a Drinking Water Standard

- You have been granted the authority to regulate drinking water quality. Create a standard for the concentrations of disease-causing organisms in drinking water.
- In the absence of technological/economic constraints,
  - Which pathogens would you regulate?
  - What concentration would you choose?
- Given technological and economic constraints how might you change your regulation?

Setting the standards EPA United States Environmental Protection Agency Office of Water

## Optimal Pathogen Exposure

- Should we be exposed to small doses of pathogens so we build up our resistance?
- How could we build pathogen exposure into our daily lives?
- Potential application
  - Common cold (continues to mutate)
  - Norwalk virus (Immunity, however, is not permanent and re-infection can occur after 2 years)
  - HIV (no immunity)
  - The case of Typhoid

- Early exposure to germs has lasting benefits. Nature, March 2012
- Immune systems of healthy adults 'remember' germs to which they've never been exposed, Stanford study Feb 2013

## Safe Drinking Water Act (1974)

- Specific standards for drinking water
  - primary ( mandatory)
  - secondary ( suggested upper limits for non-health related parameters)
- Applicable to all water supplies serving more than 25 people or having 15 or more service connections
- Enforced by U.S. Environmental Protection Agency

## Primary Standards: (Health) 6 Broad Categories

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

Where is "dirt"?

## Primary Standards: (Health)
### Inorganic chemicals (units of mg/L)

| Contaminant | U.S. EPA |
|---|---|
| Antimony | 0.006 |
| Arsenic | 0.01 |
| Asbestos (fiber >10 micrometers) | 7 MFL |
| Barium | 2 |
| Beryllium | 0.004 |
| Cadmium | 0.005 |
| Chromium (total) | 0.1 |
| Copper | Action Level=1.3; TT[8] |
| Cyanide (as free cyanide) | 0.2 |
| Fluoride | 4.0 |
| Lead | Action Level=0.015; TT[8] |
| Inorganic Mercury | 0.002 |
| Nitrate (measured as Nitrogen) | 10 |
| Nitrite (measured as Nitrogen) | 1 |
| Selenium | 0.05 |
| Thallium | 0.002 |

## Primary Standards: (Health) A Few Organic Chemicals (units of mg/L) see the complete list!

| Contaminant | MCLG | MCL |
|---|---|---|
| Acrylamide | zero | TT[2] |
| Alachlor | zero | 0.002 |
| Atrazine | 0.003 | 0.003 |
| Benzene | zero | 0.005 |
| 1-1-Dichloroethylene | 0.007 | 0.007 |
| Dioxin (2,3,7,8-TCDD) | zero | 0.00000003 |
| Epichlorohydrin | zero | TT[2] |
| Ethylbenzene | 0.7 | 0.7 |
| Ethelyne dibromide | zero | 0.00005 |
| Lindane | 0.0002 | 0.0002 |
| Polychlorinated biphenyls (PCBs) | zero | 0.0005 |
| Tetrachloroethylene | zero | 0.005 |
| Toluene | 1 | 1 |
| Total Trihalomethanes (TTHMs) | none[5] | 0.10 |
| Trichloroethylene | zero | 0.005 |
| Vinyl chloride | zero | 0.002 |
| Xylenes (total) | 10 | 10 |

## Primary Standards : (Health) Related to Microorganisms

| Contaminant | MCLG | MCL | |
|---|---|---|---|
| *Cryptosporidium* | zero | TT[3] | Cause disease |
| *Giardia lamblia* | zero | TT[3] | Cause disease |
| *Legionella* | zero | TT[3] | Cause disease |
| Viruses (enteric) | zero | TT[3] | Cause disease |
| Heterotrophic plate count | N/A | TT[3] | Indicators |
| Total Coliforms | zero | 5.0%[4] | Indicators |
| Turbidity | N/A | TT[3] | Pathogens are a subset of particles |

## Microbial Contaminants

- For microbial contaminants that may present public health risk, the MCLG is set at zero because ingesting one protozoa, virus, or bacterium may cause adverse health effects.
- The MCL is set as close to the MCLG as feasible, (the level that may be achieved with the use of the best available technology, treatment techniques, and other means which EPA finds are available), taking cost into consideration.

## Treatment Technique (TT)

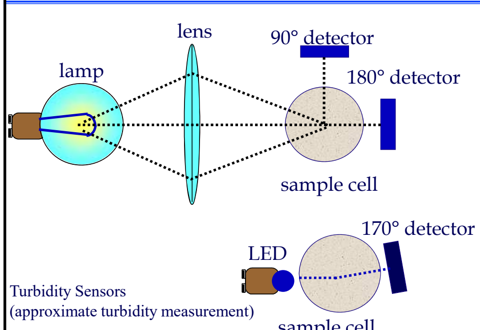
- When there isn't an economical and technically feasible method to measure a contaminant, a Treatment Technique is set rather than an MCL.
- A treatment technique is an enforceable procedure or level of technological performance which public water systems must follow to ensure control of a contaminant.
  - Surface Water Treatment Rule (disinfection and filtration)
  - Lead and Copper Rule (optimized corrosion control).

## Turbidity

- A measure of the scattering of light by particles in a suspension
- A turbid water sample appears cloudy or "dirty"
- High turbidity is the result of lots of light scattering caused by the particles in suspension
- Measured in NTU (Nephelometric Turbidity Units)

cloud

## Turbidity Measurements



## Secondary Standards: **Aesthetics**

| Contaminant | U.S. EPA, 1993 | WHO, 1984 |
|---|---|---|
| Aluminum | 0.5-0.2 mg/L | 0.2 mg/L |
| Chloride | 250 mg/L | 250 mg/L |
| Color | 15 color units | 15 color units |
| Copper | 1.0 mg/L | 1.0 mg/L |
| Corrosivity | Noncorrosive | |
| Fluoride | 2.0 mg/L | |
| Foaming agents | 0.5 mg/L | |
| Iron | 0.3 mg/L | 0.3 mg/L |
| Manganese | 0.05 mg/L | 0.1 mg/L |
| Odor (Threshold Odor Number) | 3 TON | |
| pH | 6.5-8.5 | 6.5-8.5 |
| Silver | 0.1 mg/L | |
| Sulfate | 250 mg/L | 400 mg/L |
| Total dissolved solids | 500 mg/L | 1000 mg/L |
| Zinc | 5.0 mg/L | 5.0 mg/L |

## What would you measure before drinking the water?

- Surface water (big concern is pathogens)
  - Turbidity (pathogens are particles)
  - Chlorine residual
- Ground water (big concern is still pathogens)
  - Turbidity
  - Chlorine residual
  - Arsenic and fluoride (depending on location)
  - Organic chemicals (agricultural and industrial)

## Effect of Chlorination on Inactivating Selected Bacteria

| Bacteria | $Cl_2$ (mg/l) | Time (min) | Ct Factor (mg-min/l) | Reduction(%) | Ct for pC* of1 | Reference |
|---|---|---|---|---|---|---|
| *Campylobacter jejuni* | 0.1 | 5 | 0.5 | 99.99 | 0.125 | Blaser et al, 1986 |
| *Escherichia coli* | 0.2 | 3 | 0.6 | 99.99 | 0.15 | Ram and Malley, 1984 |
| *Legionella pneumophila* | 0.25 | 60-90 | 18.75 | 99 | 9.4 | Kuchta et al, 1985 |
| *Mycobacterium chelonei* | 0.7 | 60 | 42 | 99.95 | 13 | Carson et al, 1978 |
| *Mycobacterium fortuitum* | 1.0 | 30 | 30 | 99.4 | 13.5 | Pelletier and DuMoulin, 1987 |
| *Mycobacterium intracellulare* | 0.15 | 60 | 9 | 70 | 17.2 | Pelletier and DuMoulin, 1987 |
| *Pasteurella tularensis* | 0.5-1.0 | 5 | 3.75 | 99.6-100 | 1.6 | Baumann and Ludwig, 1962 |
| *Salmonella typhi* | 0.5 | 6 | 3 | 99 | 1.5 | Korol et al, 1995 |
| *Shigella dysenteriae* | 0.05 | 10 | 0.5 | 99.6-100 | 0.2 | Baumann and Ludwig, 1962 |
| *Staphylococcus aureus* | 0.8 | 0.5 | 0.4 | 100 | -- | Bolton et al, 1988 |
| *Vibrio cholerae*(smooth strain) | 1.0 | < 1 | < 1 | 100 | -- | Rice et al, 1993 |
| *Vibrio cholerae* (rugose strain) | 2.0 | 30 | 60 | 99.999 | 12 | Rice et al, 1993 |
| *Yersinia enterocolitica* | 1.0 | 30 | 30 | 92 | 27 | Paz et al, 1993 |

## Effect of Chlorination on Inactivating Selected Viruses

| Viruses | $Cl_2$ (mg/l) | Time (min) | Ct factor (mg-min/l) | Reduction (%) | Ct for pC* of1 | Reference |
|---|---|---|---|---|---|---|
| Adenovirus | 0.2 | 40-50 sec | 0.15 | 99.8 | 0.06 | Clarke et al, 1956 |
| Coxsackie | 0.16-0.18 | 3.8 | 0.06 | 99.6 | 0.025 | Clarke and Kabler, 1954 |
| Hepatitis A | 0.42 | 1 | 0.42 | 99.99 | 0.105 | Grabow et al, 1983 |
| Norwalk | 0.5-1.0 | 30 | 22.5 | -- | -- | Keswick et al, 1985 |
| Parvovirus | 0.2 | 3.2 | 0.64 | 99 | 0.32 | Churn et al, 1984 |
| Poliovirus | 0.5-1.0 | 30 | 22.5 | 100 | -- | Keswick et al, 1985 |
| Rotavirus | 0.5-1.0 | 30 | 22.5 | 100 | -- | Keswick et al, 1985 |

## Effect of Chlorination on Inactivating Selected Protozoa

| Protozoa | $Cl_2$ (mg/l) | Time (min) | Ct Factor (mg-min/l) | Reduction (%) | Ct for pC* of 1 | Reference |
|---|---|---|---|---|---|---|
| *Cryptosporidium parvum* | 80 | 90 | 7200* | 90 | 7200 | Korich et al, 1990 |
| *Entamoeba histolytica* | 1.0 | 50 | 50 | 100 | -- | Snow, 1956 |
| *Giardia lamblia* | -- | -- | 68-389 | 99.9 | 30 | AWWA, 1999 |
| *Naegleria fowleri* | 0.5-1.0 | 60 | 45 | 99.99 | 11 | de Jonckheere and van de Voorde, 1976 |

How many pathogens does it take to make you sick?

https://confluence.cornell.edu/display/cee4540/Bad+Bugs

## Which pathogens are a big concern even with Chlorine?

- Pathogens with a small infective dose and high resistance to chlorine
  - *Cryptosporidium parvum*
  - *Giardia lamblia*

## Summary

- The causes of many waterborne disease have been identified
- Standards for microbiological and chemical contaminants have been set by US EPA and the World Health Organization
- Waterborne disease continues to be a significant public health concern especially for the poorest 2 billion
- Toilets (pollute the environment) and Sinks (clean our hands)