Water Pollution I

- Introduction—Case Study
- Water Resources, Usage
- The Major Water Pollutants
  - Oxygen-demanding Wastes, Pathogens, Nutrients, Salts, Thermal Pollution, Heavy Metals, Pesticides, Volatile Organic Compounds, Acidity
Case study: Exxon Valdez oil spill

- March 1989
- Oil tanker Exxon Valdez ran aground in Prince William Sound, Alaska
- Spilled 11 million gallons of oil (~125 olympic swimming pools)
2001...

- Water pollution issues can be persistent
- 7 of 21 species have returned to pre-spill populations

http://www.evostc.state.ak.us/
Water resources

- 70% of the Earth is covered by water
- Freshwater is < 3% of water (including ice caps)
- 98% of available freshwater is groundwater
- Primary source of freshwater is precipitation
- 65% of precipitation returns to the atmosphere
• Distribution across globe is very uneven:
  → Water-rich countries have ~ 100,000 m³/person in runoff
  → Water-poor countries have ~ 200–2000 m³/person in runoff

• For drinking water, need ~ 1 m³/person/year

• Developed countries use 30 m³/person/year for domestic use, the rest is for agriculture and industry
  → Ex. 1 pound of beef takes ~ 1 m³ of water to produce
Water usage

- Currently, human societies consume $4 \times 10^{12}$ m$^3$/year
- There are $5 \times 10^{13}$ m$^3$ available water in accessible resources
- This means without rainfall, all water would be consumed in ___ years

1980 Per Capita Usage Comparison

N. America 2230 m$^3$/person

Europe 656 m$^3$/person

Developing countries 20–30 m$^3$/person
• Of fresh water used in the world:
  → 6% is domestic and recreation
  → 73% is irrigated agriculture (27% in US)
  → 21% is used in industry (65% in US)

When it comes to water, what we eat matters . . .
WATER USE BY SECTOR*
Selected countries

Billion cubic meters:
- Agriculture
- Industry
- Domestic

China: 404.6
India: 460.0
Brazil: 33.5
Germany: 39.8
USA: 291.0
Japan: 58.5
Argentina: 21.5
UK: 7.2
France: 29.6
Egypt: 47.4
Lithuania: 0.0243
Gabon: 0.0072

* Latest available data, ranging from 1980 to 1998
Water surplus

Figure 8.2 Global Water Surplus and Deficiency

(millimeters per year)

World Resources 1987

Note: a. Defined as difference between annual precipitation and evapotranspiration. Evapotranspiration corresponds to the water demand from a potential crop not suffering from water deficiency.

# Freshwater availability

## Trends in access to improved water sources and sanitation facilities, 1990–2000 (% of population)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>East Asia and Pacific</td>
<td></td>
<td>70</td>
<td>75</td>
<td></td>
<td>38</td>
<td>48</td>
</tr>
<tr>
<td>Eastern Europe and Central Asia</td>
<td></td>
<td>N/A</td>
<td>90</td>
<td></td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Latin America and Caribbean</td>
<td></td>
<td>81</td>
<td>85</td>
<td></td>
<td>72</td>
<td>78</td>
</tr>
<tr>
<td>Middle East and North Africa</td>
<td></td>
<td>85</td>
<td>89</td>
<td></td>
<td>78</td>
<td>83</td>
</tr>
<tr>
<td>South Asia</td>
<td></td>
<td>79</td>
<td>87</td>
<td></td>
<td>31</td>
<td>36</td>
</tr>
<tr>
<td>Sub-saharan Africa</td>
<td></td>
<td>49</td>
<td>55</td>
<td></td>
<td>55</td>
<td>55</td>
</tr>
<tr>
<td>Developing Countries</td>
<td></td>
<td>73</td>
<td>79</td>
<td></td>
<td>44</td>
<td>52</td>
</tr>
</tbody>
</table>
Resource management

Overall there is plenty of water, but it isn’t always where it is needed

Possible strategies:

- build dams (capture and store runoff)
- well drilling
- transfer water (reallocation)
- improve resource management (conserve)
- other (desalination, icebergs, relocate people)
Simplified hydrologic cycle

**FIGURE 5.3** The hydrologic cycle. Units are $10^3$ km$^3$/yr.
(Source: Based on Shiklomanov, 1993.)
• These two processes use 1/2 of the Sun’s energy that strikes the Earth

→ Evaporation of ocean waters (88%)—desalination process

→ Evapotranspiration (12%)—evaporation of water and transpiration of water from leaves
• Over oceans—less precipitation than evaporation
• Over land—more precipitation than evaporation
• About 1 m³ falls on every m² of land surface each year
• Water that doesn’t evaporate (a rapid process) is available for use by people

• Renewable runoff is \( \sim 46 \times 10^{12} \text{ m}^3/\text{year} \), order of magnitude more than the current consumption rate

• We actually only use (primarily due to costs) 9 to \( 14 \times 10^{12} \text{ m}^3/\text{year} \)

• To maintain balance, there must be runoff water returned to oceans via stream and groundwater flow
## Water pollutants

- **Nine water pollutants of interest**

<table>
<thead>
<tr>
<th>Oxygen demanding wastes</th>
<th>Heavy metals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pathogens</td>
<td>Pesticides</td>
</tr>
<tr>
<td>Nutrients</td>
<td>Volatile organic compounds (VOCs)</td>
</tr>
<tr>
<td>Salts</td>
<td>Acidity</td>
</tr>
<tr>
<td>Thermal pollution</td>
<td></td>
</tr>
</tbody>
</table>
1) Oxygen demanding wastes

- Dissolved oxygen (DO) is important for many forms of aquatic life

- From Henry’s Law we can find the DO concentration in air-saturated water is 8–15 mg/L depending on T and salinity

- Higher T, less DO; Lower T, more DO
• Fish need 3 mg to 5–8 mg (#s are for carp and trout)

• The biodegradation of organic wastes from wastewaters (sewage) and industrial effluents create an oxygen demand, as do natural organics and animal wastes.

• As DO falls, odors, tastes, colors make water less acceptable

• Chemical oxygen demand (COD): oxygen required for chemical oxidation (= TOD)

• Biochemical oxygen demand (BOD): oxygen required by microorganisms to biologically degrade wastes.
2) Pathogens

- Disease producing organisms that grow and multiply within a host
  - Bacteria: cholera, dysentery, typhoid
  - Viruses: infectious hepatitis, poliomyelitis
  - Protozoa: amebic dysentery, giardiasis
  - Helminths (parasitic worms): schistosomiasis, hookworm
• If sewage contaminates drinking water these diseases spread to many.
   → e.g., cholera epidemic of London 1840’s

• Typhoid/cholera epidemic of Chicago 1885: 90,000 people died when untreated sewage was drawn into the public water supply during a storm.

• Chlorination of water supplies in US virtually eliminated these problems, but they are severe in many other parts of the world.
Two types of infection:

WATER BORNE

Acquired by ingesting pathogens by drinking water or contact through utensils, food, etc.

Contamination from open water handling system

— in US giardia is problematic: cysts survive a long time not easily destroyed by chlorination

(ex., Cryptosporidium in Milwaukee, 1993)
WATER CONTACT

Don’t need to drink the water, just be in it.

*Schistosomiasis*: eggs develop in snails and attach to human skin, enter blood and mature in liver; snails must have standing water.

Water breeding insects spread malaria, yellow fever, and the lack of water for hygiene allows skin diseases to develop: leprosy, trachoma.
3) Nutrients

- Chemicals essential for life
  - Problematic when high concentrations allow for excessive growth of aquatic plants, especially algae.

- 3 important nutrients: Carbon, Nitrogen, Phosphorus

- The one that limits plant growth is called the limiting nutrient

- Carbon is available from the atmosphere (CO₂). Seawater is generally limited by nitrogen, fresh water by phosphorus.
Nitrogen and phosphorus are in wastewater, feedlot runoff, agricultural chemicals.

Nitrate (NO$_3$) can be converted to nitrite (NO$_2$) in infants younger than 6 months (in hemoglobin, called methemoglobinemia).

Most of the phosphorus in wastewater is from household detergents (!)

\[
\text{Na}_2\text{P}_3\text{O}_{10} \rightarrow \text{P}_3\text{O}^{5-}_{10} + \text{H}_2\text{O} \rightarrow 3\text{PO}_4^{3-} + 4\text{H}^+
\]

tripolyphosphate orthophosphate

Orthophosphate is immediately usable by plants.
4) Salts

Many salts naturally accumulate in water:

\[ \text{Na}^+, \text{Ca}^{2+}, \text{Mg}^+, \text{K}^+, \text{Cl}^-, \text{SO}_4^{2-}, \text{HCO}_3^- \]

Rough measurement of salt content: total dissolved solids (TDS)

Fresh water has TDS of < 1500 mg/L

- Brackish water up to 5000 mg/L
- Saline water > 5000 mg/L
- Seawater 30,000 to 34,000 mg/L TDS
- Drinking water < 500 mg/L (higher: laxative)

Animals can tolerate more than 500 mg/L

Irrigation requires < 500–2000 mg/L, but plants would prefer < 500 mg/L.
• Irrigation (how?), as well as evaporation from ponds can increase salt concentrations.

• As water flows downstream, there is water added from drainage, further increasing salt concentration.
“The collapse of ancient civilizations, such as those that once flourished in the Fertile Crescent in what is now Iraq, is thought to have been precipitated by the demise of irrigated agriculture caused by accumulating salt.”

### SALT IN THE RIO GRANDE RIVER

<table>
<thead>
<tr>
<th>Station</th>
<th>Flow ($10^6$ m$^3$/year)</th>
<th>Dissolved Solids (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Otowi Bridge, NM</td>
<td>1.33</td>
<td>221</td>
</tr>
<tr>
<td>San Marcial, NM</td>
<td>1.05</td>
<td>449</td>
</tr>
<tr>
<td>Elephant Butte, NM</td>
<td>0.97</td>
<td>478</td>
</tr>
<tr>
<td>Caballo Dam, NM</td>
<td>0.96</td>
<td>515</td>
</tr>
<tr>
<td>Leasburg, NM</td>
<td>0.92</td>
<td>551</td>
</tr>
<tr>
<td>El Paso, TX</td>
<td>0.65</td>
<td>787</td>
</tr>
<tr>
<td>Ft. Quitman, TX</td>
<td>0.25</td>
<td>1691</td>
</tr>
</tbody>
</table>
5) Thermal pollution

- What are the effects of using water in a cooling system where the discharges are warmer than the input?
- This can cause stress on aquatic life, which may acclimate to a somewhat different ecosystem—but then the plant turns off....
- DO is a function of temperature
At the same time, microorganism growth increases
6) Heavy Metals

- Metals, as a rule, form cations in solution. Heavy metals have high densities (> 4 or 5 g/cm³).

  → Most of them are toxic.

- Common Toxics: lead (Pb), cadmium (Cd), mercury (Hg) and arsenic (As).

  → Toxicity is strongly dependent on the oxidation state of the metal.
• High doses of essential minerals, chromium (Cr$^{6+}$), iron (Fe), etc. are also toxic.

→ Damages the brain, kidneys or nervous system.

→ Inhaled chromium (Cr$^{6+}$) clearly causes lung cancer, with very high potency.

→ Cr$^{6+}$ orally appears to be less toxic because some Cr$^{6+}$ is reduced to Cr$^{3+}$ in the stomach, however it appears that stomach and bladder cancer and liver toxicity rates are elevated in people exposed to Cr$^{6+}$ in drinking water.
• Lead

→ Causes: sterility, kidney and neurological damage, spontaneous abortions and stillbirths, and more.

→ Lead was used to sweeten wine in ancient Rome, and this combined with lead pipes may have been part of the fall of the roman empire.

→ Lead is still in aviation fuel and in fuel in Africa.
→ Blood lead in the US population is 2.8 µg/dL (1990), down from 14 in 1972.

→ Blood lead is inversely related to IQ, and the correlation is especially strong at levels between 1 and 10; 10 is the current cut off. A major source of lead in our world now is batteries.

And . . . metals are not in any way biodegradable.
7) Pesticides

- Pesticides include insecticides, herbicides, rodenticides & fungicides.
  - Problem is their persistence in the environment
  - Many are lipophilic (soluble in fat) — accumulate in animal’s fatty tissue through food chain.

- Organochlorines
  - DDT (paradichlorodiphenyltrichloroethane) is still widely used in the developing world to control malaria.
• Acoustic profiling clearly showed a 20- to 60-cm thick low-density sediment layer extending over much of the 3 km by 10 km continental shelf.

• Physical property testing of cores confirmed the presence of a 20- to 60-cm thick low-density sediment layer on the shelf and also showed that the layer extended well down the 3 km by 10 km continental slope.
• Chemical analyses confirmed that virtually the entire sediment is contaminated with DDT and PCBs.

• Results indicate that at least 100 tons of DDT are present on the Palos Verdes margin, and that significant amounts of DDT and PCBs will remain near the sediment surface and thus remain biologically available well into the next century.
• The effluent-affected deposit covers an area greater than 40 square kilometers. The volume of the contaminated sediment exceeds 9 million cubic meters.

• Acute human toxicities vary, and long-term chronic exposure can cause cancer or neurological effects.

• Many organochlorines have since been replaced with organophosphates and carbamates. The replacement has been motivated by human health concerns, but also developing insect resistance.
• Organophosphates are not as persistent, but have more acute toxicity to humans. They are absorbed through the skin, lungs, intestines.

→ Malathion was sprayed around Los Angeles during the late ‘80’s...led to confusion, slurred speech...

• Carbamates are derived from carbamic acid, H₂NCOOH. Examples are these two herbicides: Mix these two together and you have agent orange:

![Chemical structures of 2,4-Dichlorophenoxyacetic acid and 2,4,5-Trichlorophenoxyacetic acid](image)
8) Volatile Organic Compounds (VOCs)

- Most common groundwater pollutant
  - Mainly solvents
  - Toxicity varies; some are carcinogens.
    - Mutagen: causes biological mutations
    - Carcinogen: causes cancer
    - Teratogen: causes fetal malformations
- EPA standard: 1/million excess cancers for 70 year lifetime
- OSHA: 1/1000 excess cancers
Vinyl chloride (chloroethylene)—making PVC resins, carcinogen

TCE (trichloroethylene)—solvent to clean from jet engines to septic tanks and CFC production. Suspected carcinogen.

1,2-dichloroethane (DCA)—metal degreasing; high exposure causes kidney, liver, CNS damage; very soluble
Carbon tetrachloride (CT)—household cleaning?! Fungicide, very toxic; a few mLs can kill.

Perchloroethylene (“Perc”)—most widely used dry cleaning solvent. Possible human carcinogen, may cause miscarriages.

Tetrachloroethylene (PCE)—solvent, causes tumors in animals.

Methyl tertiary butyl ether (MTBE)—formerly used as gasoline oxygenation additive; currently banned in California

Drinking tap water during the first trimester in Los Angeles (and other places) is associated with increased miscarriage rates.
On April 21, 2001, an F4 tornado passed through Hoisington, Kansas - a small town in south-central Kansas of about 31,000 people. The tornado severely impacted a nine-block by nine-block area, damaging over 500 homes, 200 of which were totally destroyed. The area's hospital was significantly damaged and required evacuation. The town's high school also was significantly damaged and alternate education sites were used for the remainder of the school year. The Tornado devastated everything in its path, including aboveground utilities. It was Hoisington's damaged electrical utilities that presented the town with some difficult environmental issues. During FEMA's Public Assistance process, the Agency's Region VII Environmental Officer helped Hoisington address these problems with some unique approaches and solutions.

**Damaged Electrical Transformers**

Hoisington's tornado was so severe that all of the town's pole-mounted electrical equipment was damaged, including 76 electrical transformers. Electrical transformers are used to convert high-voltage power of overhead electrical distribution lines into low-voltage power that can be used in residential structures. These transformers generate a lot of heat; therefore, dielectric fluid is placed inside the transformers to keep the equipment cool. In the 1960's and 1970's, dielectric fluid was based on polychlorinated biphenyls (PCBs). PCBs are quite stable, even at high temperatures, and do not break down for many years. Unfortunately, the properties that make PCBs so useful as heat transfer agents and dielectrics are the same properties that cause problems when PCBs are released into the environment.

**PCBs and the Environment**

PCBs are endocrine inhibitors (they mimic natural hormones), which can cause a host of problems for wildlife and humans. Among wildlife, PCB exposure can cause reproductive failure, deformities, weakened immune systems, and the failure of certain fish species to differentiate between males and females. In humans, the PCB exposure can cause infertility, genital deformities, liver problems, skin deformities, breast and prostate cancers, and neurological problems such as hyperactivity and attention deficit disorder. Additionally, since PCBs are so stable, they don't break down when released into the environment. Finally, PCBs bio-accumulate or build-up in the fatty tissues of animals and their concentration can be magnified thousands of times as they move up the food chain.

**PCB Cleanup and the Toxic Substances Control Act**

In 1976, Congress passed the Toxic Substances Control Act (TSCA), which phased-out PCB use and banned its manufacture. TSCA requires electric transformers to be appropriately labeled, and that transport and disposal standards for the equipment be specifically outlined. Clean-up standards for PCB contaminated material are based on PCB concentrations at the source of the spill. For example, if a transformer's dielectric fluid containing greater than 50 ppm PCBs spills on a lawn, TSCA requires any soil in the spill area with PCB concentrations of 10 parts per million (ppm) or higher to be removed and handled as PCB waste. In an area of highly porous soils such as south-central Kansas, relatively large areas can quickly become contaminated with low concentrations of contaminant, resulting in a lengthy and expensive cleanup of what may be low concentrations of PCBs. Contaminated materials from transformers with dielectric fluid containing less than 50 ppm PCBs may be handled as "special waste" and disposed in many municipal solid waste landfills. Disposing of non-PCB material will cost a municipality considerably less than disposing of PCB material.
Environmental Issues Arise in Aftermath of Hoisington Tornado

What does this information have to do with Hoisington? Many of town's damaged electrical transformers fell to the ground during the April 2001 tornado, and 29 of them broke open and spilled dielectric fluid. Since TSCA clean-up standards are source-based, the damaged transformers presented Hoisington with some serious environmental issues that the town needed to quickly address. Four of the transformers contained enough PCB-contamination to be regulated under TSCA.

http://www.fema.gov/ehp/hoisington.shtm

Recent findings indicate that susceptible populations (e.g., certain ethnic groups, sport anglers, the elderly, pregnant women, children, fetuses, and nursing infants) continue to be exposed to PCBs via fish and wildlife consumption. Human health studies discussed in this summary indicate that 1) reproductive function may be disrupted by exposure to PCBs; 2) neurobehavioral and developmental deficits occur in newborns and continue through school-aged children who had in utero exposure to PCBs; 3) other systemic effects (e.g., self-reported liver disease and diabetes, and effects on the thyroid and immune systems) are associated with elevated serum levels of PCBs; and 4) increased cancer risks, e.g., non-Hodgkin's lymphoma, are associated with PCB exposures.