Water Pollution and Water Quality
(with additional materials)

Water is a basic necessity of nature and humans. We use water for:
- drinking
- food preparation
- washing
- growing crops
- industrial processes
- recreation
... and in many more activities.

Different uses require different level of purity.

In addition, we have to make sure that natural water bodies such as rivers, lakes and estuaries remain healthy habitats for the ecosystems they contain.

How much water is there on the planet?

<table>
<thead>
<tr>
<th>Location</th>
<th>Volume (km³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oceans</td>
<td>1,350,000,000</td>
</tr>
<tr>
<td>Polar ice caps and glaciers</td>
<td>29,000,000</td>
</tr>
<tr>
<td>Groundwater</td>
<td>8,300,000</td>
</tr>
<tr>
<td>Freshwater lakes</td>
<td>125,000</td>
</tr>
<tr>
<td>Saline lakes and inland seas</td>
<td>104,000</td>
</tr>
<tr>
<td>Soil and subsoil</td>
<td>67,000</td>
</tr>
<tr>
<td>Atmospheric moisture</td>
<td>13,000</td>
</tr>
<tr>
<td>Stream channels</td>
<td>3,000</td>
</tr>
<tr>
<td>Living organisms and biomass</td>
<td>1,000</td>
</tr>
</tbody>
</table>

Residence time of water molecules by water type
(Nazaroff & Alvarez-Cohen, Table 2.A.1)

<table>
<thead>
<tr>
<th>Type</th>
<th>Average residence time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmosphere</td>
<td>9 days</td>
</tr>
<tr>
<td>Rivers</td>
<td>2 weeks</td>
</tr>
<tr>
<td>Soil moisture</td>
<td>months</td>
</tr>
<tr>
<td>Large lakes</td>
<td>decades to centuries</td>
</tr>
<tr>
<td>Shallow groundwater</td>
<td>10s to 100s years</td>
</tr>
<tr>
<td>Upper ocean</td>
<td>120 years</td>
</tr>
<tr>
<td>Oceanic abyss</td>
<td>3,000 years</td>
</tr>
<tr>
<td>Deep groundwater</td>
<td>up to 10,000 years</td>
</tr>
<tr>
<td>Antarctic ice cap</td>
<td>&gt; 10,000 years</td>
</tr>
</tbody>
</table>

Distribution of fresh and saline water on Earth
(Nazaroff & Alvarez-Cohen, Table 6.A.1)
And how does water move naturally to become available to us?

(Source: Mihelcic & Zimmerman, Fig. 9.1)

Units of $10^{12}$ m$^3$/year for the entire planet

Source and use of freshwater in the United States, 2005

Numbers in million gallons per day
Major pollution sources for fresh and saline waters  
(Nazaroff & Alvarez-Cohen, Table 6.A.2, page 282)

<table>
<thead>
<tr>
<th>Pollutant class</th>
<th>Point sources</th>
<th>Non-point sources</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Municipal sewage</td>
<td>Industrial waste</td>
</tr>
<tr>
<td>BOD</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Nutrients</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Pathogens</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Suspended solids</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Salts</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Toxic metals</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Toxic organics</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Heat</td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>

BOD = Biochemical Oxygen Demand

The problems that these pollutants cause are:

**Oxygen-depleting substances (BOD)**
- asphyxiation of fish

**Nutrients**
- eutrophication (= excessive feeding), that is, promotion of undesirable forms of life → brown, slimy waters

**Pathogens**
- disease (diarrhea, cholera) or even death

**Suspended solids** (siltation)
- murkiness
- clogging of bed → altered bottom habitats and spawning grounds

**Toxic metals**
- poisoning of both human and non-human lives

**Toxic organics**
- poisoning of both human and non-human lives
- disruption of metabolism and reproduction

**Heat**
- lowering of dissolved oxygen level, impairing fish habitats
- formation of fog
Often, pollution in surface waters is not measured in terms of the concentrations of the individual contaminants but is measured in terms of their aggregate potential for oxygen depletion. This is called the **Biochemical Oxygen Demand (BOD)**.

Substances contributing to BOD are food for bacteria, and the more the bacteria feed on these, the more they also take oxygen (like us humans, who both eat and breathe).

\[ \text{Organic matter } + \text{ O}_2 \rightarrow \text{new cells } + \text{ CO}_2 + \text{ H}_2\text{O} + \text{ etc.} \]

The **definition** is:

1 mg/L of BOD will, after uptake by bacteria, decrease the DO level by 1 mg/L.

**Note**: 1 mg/L of BOD may correspond to more or less than 1 mg/L of the offensive substance.

BOD is determined in the laboratory by measuring the depletion of dissolved oxygen in the contaminated water placed in a closed container, over the course of several days (usually 5 days).

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**Ensuring water quality**

Two components to water quality:

1. Safe drinking → treatment of surface or subsurface water for consumption
2. Safe release → treatment of municipal sewage and industrial wastewater

Historically, the design and operation of treatment systems for both drinking water and wastewater were activities conducted as a branch of civil engineering, because it involves some hydraulics. It was called **Sanitary Engineering**.

**Environmental Engineering** grew out of sanitary engineering as additional issues arose, including air quality, solid-waste disposal, hazardous waste, etc.

(See Nazaroff & Alvarez-Cohen, Section 6.B)
Regulations in the US
(Nazaroff & Alvarez-Cohen, Section 6.B.1)

Triple concern

- Health of people who drink the water
  avoidance of cholera, typhoid fever, gastroenteritis, etc.
- Aesthetics
  water color, hardness, taste, odor
- Quality of water in the environment
  dissolved oxygen, salt content, habitat

1969: Cuyahoga River in Ohio catches on fire; other highly visible problems
1970: Establishment of the Environmental Protection Agency (EPA)
1972: Clean Water Act (CWA)
1974: Safe Drinking Water Act (SDWA)

CWA regulates discharges in rivers, lakes, estuaries and wetlands by means of discharge permits and effluent standards.
The concern is to keep outdoor waters “swimmable and fishable”.

SDWA establishes water quality standards for all public water distribution systems that serve an average of 25 or more people daily.
• Primary standards are enforceable maximum contaminant levels for the protection of human health.
• Secondary standards are non-enforceable guidelines for aesthetic effects.

Water and wastewater systems in settled areas.
In older cities, storm and sanitary sewers may still be combined, leading to untreated but diluted wastewater releases after heavy rain.

(See Nazaroff & Alvarez-Cohen, pages 302-303)
Water treatment in a nutshell

Incoming water, with its actual properties

Engineer’s job & responsibility

Outgoing water, with desired properties

Water taken from the environment:
suspended solids, bacteria, hardness, odor

Drinking water:
safe, clear, soft, no smell

Wastewater:
elevated BOD, nutrients, pathogens, grease, suspended solids

Discharge back to environment:
low BOD, low nutrients, no pathogens, no grease, low in suspended solids

QUESTION: What technology must go in the box?

Schematic of a typical municipal drinking-water treatment system
(Nazaroff & Alvarez-Cohen, Figure 6.B.1)
Schematic of a municipal wastewater treatment plant
(Nazaroff & Alvarez-Cohen, Figure 6.B.2)

Contaminant | Concentration in wastewater | Desired concentration after treatment | (*): depends on permit, based on receiving water body
--- | --- | --- | ---
Total solids (TS) | average 720 mg/L | | |
Total dissolved solids (TDS) | 200 – 1000 mg/L | | |
Total suspended solids (TSS) | 100 – 350 mg/L | 30 mg/L | |
Volatile suspended solids (VSS) | 165 mg/L | 0 mg/L | |
BOD (5-day, 20°C) | 100 – 300 mg/L | 30 mg/L | |
Nitrogen | 20 – 80 mg/L | 10 mg/L(*) | |
Phosphorus | 5 – 20 mg/L | 2 mg/L(*) | |
Chlorides | 50 mg/L | varies by type | |
Sulfates | 30 mg/L | | |
Alkalinity | 2 meq/L | | |
Toxic chemicals | varies | zero | |
Pathogens | $10^7$ – $10^8$ per 100 mL | < 200 counts/mL | |
Volatile organic compounds (VOCs) | 0.1 – 0.4 | minimal | |

Typical composition of municipal wastewater and the desired level of treatment
(Nazaroff & Alvarez-Cohen, Table 6.B.2)
(Mihelcic & Zimmerman, Table 11.3)
What does it look like?

For drinking water treatment …

Drinking water treatment plant in Saskatoon, Saskatchewan

Reverse osmosis filter

… and for wastewater treatment

Wastewater treatment plant in Saskatoon, Saskatchewan

Bioreactor in Manchester, Iowa