Overview of Water Pollution

Structure and Composition of the Hydrosphere
Outline of Topics

1. The Hydrosphere
   - The Hydrologic Cycle
   - Groundwater
   - Water Usage

2. Composition of the Hydrosphere
   - The Dissolution Process
   - Composition of Natural Waters

3. Water Pollution
   - Westhampton Lake
   - Sources and Pollutants
   - US Water Quality Overview
   - Virginia Water Quality
List the major water reservoirs on Earth (the *hydrosphere*) from largest to smallest.

<table>
<thead>
<tr>
<th>Reservoir</th>
<th>Volume, km$^3$</th>
<th>%</th>
<th>Turnover Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oceans</td>
<td>$1.34 \times 10^9$</td>
<td>96.54</td>
<td>2640 y</td>
</tr>
<tr>
<td>Cryosphere</td>
<td>$2.31 \times 10^7$</td>
<td>1.74</td>
<td>8900 y</td>
</tr>
<tr>
<td>Groundwater/permafrost</td>
<td>$2.37 \times 10^7$</td>
<td>1.71</td>
<td>515 y</td>
</tr>
<tr>
<td>Lakes/Rivers</td>
<td>$1.90 \times 10^5$</td>
<td>0.01</td>
<td>4.3 y</td>
</tr>
<tr>
<td>Soil Moisture</td>
<td>$1.65 \times 10^4$</td>
<td>0.0012</td>
<td>52 d</td>
</tr>
<tr>
<td>Atmosphere</td>
<td>$1.29 \times 10^4$</td>
<td>0.0009</td>
<td>8.2 d</td>
</tr>
<tr>
<td>Biomass</td>
<td>$1.12 \times 10^3$</td>
<td>0.0001</td>
<td>5.6 d</td>
</tr>
</tbody>
</table>
The Hydrologic Cycle

What is the hydrologic cycle? Describe the major processes.

Condensation

Precipitation

Evaporation and transpiration

Runoff

Underground flow

Infiltration into soil

Ice

Sublimation

Snow

Evaporation

Condensation

Transport by wind

Precipitation

Ocean
Global Circulation of Water

Why are the oceans salty? Describe the circulation of water on a global scale.

- **Giant distillation:**
  - ocean → air → land → oceans
- **Rivers/lakes get most of their water from groundwater**

### Atmosphere

- 12.9 x 10^3 (8 days)

### Biomass

- 1.12 x 10^3 (6 days)

### Soil Moisture

- 16.5 x 10^3 (50 days)

### Glaciers

- 24.1 x 10^6 (9000 years)

### Rivers and Lakes

- 2.12 x 10^3
- 176 x 10^3
- 11.5 x 10^3 (4.5 years)

### Groundwater

- 23.4 x 10^6
- Permafrost 0.3 x 10^6 (500 years)

### Oceans

- 1.338 x 10^9 (2600 years)

- 71 x 10^3
- 1.0 x 10^3
- 505 x 10^3
- 458 x 10^3
- 44.7 x 10^3
- 2.2 x 10^3
- 2.7 x 10^3
Groundwater

What the heck is groundwater?

- soil moisture
- water table
- aeration zone (vadose water)
- capillary fringe
- saturated zone (groundwater)
- impervious barrier
- well
What might the local water table look like?

- Local water table often follows topography of the land.
- The baseflow is usually the most important input of water into rivers and streams.
- Baseflow usually less important as a water source into lakes due to the low permeability of the sediment (there are exceptions).
Cone of Depression

How might well water become polluted?

- Pumping in an unconfined aquifer creates a *cone of depression* near the well.
- Chemicals dumped on the land within a cone of depression can get into the well water.
- Spills within the *recharge area* of an aquifer can eventually pollute the groundwater.
- Recharge areas do not always lay directly above an aquifer.
Water Use in the US

What are the main uses of water in the US?

2010 withdrawals by category, in million gallons per day

- Public supply: 42,000
- Self-supplied domestic: 3,600
- Irrigation: 115,000
- Livestock: 2,000
- Aquaculture: 9,420
- Self-supplied industrial: 15,900
- Mining: 5,320
- Thermoelectric power: 161,000

Values do not sum to 355,000 Mgal/d because of independent rounding.

1. Thermoelectric: 45%
2. Irrigation: 32%
3. Public supply: 12%
4. All others: 10%

USGS 2010 report: 355,000 million gallons withdrawn per day
- Down 13% from 2005

86% freshwater, 14% saline

78% surface water, 22% groundwater
- Groundwater: irrigation (70%), public supply (20%)
Global Water Use

What is meant by ‘consumptive’ use of water?

- Data from UNEP describing trends/prediction in global water use
- Consumptive use removes water from local re-use
- Grey area represents water that is available for re-use
Urban vs Rural Competition for Water

Is there a connection between water quality and quantity?

Panels below show the effects a developing city have on the local groundwater.
Dissolution of Solids

What is a solution? How is it formed?

Ionic solids exist as 3-d lattices, such as this one for NaCl

Define the following terms:
- solution, solute, solvent
- concentration (including units)
- ionic compound, cation and anion
- electrolyte and non-electrolyte

Composition of Natural Waters

What are the most concentrated solutes in the hydrosphere?

- **Cations:** Na\(^+\), K\(^+\), Ca\(^{2+}\), Mg\(^{2+}\)
- **Anions:** Cl\(^-\), SO\(_4\)^{2-}, HCO\(_3\)^-
- **Neutral:** Si(OH)\(_4\)
Seawater Composition

Describe the composition of seawater, including typical salinity and pH values.

Typical values
- pH: 8.1
- TDS (salinity): 35 g/kg

Concs are mass fractions
- Proportions fairly constant but salinity varies, 33–37 g/kg

- Na\(^+\), 30.67%
- Mg\(^{2+}\), 3.65%
- Ca\(^{2+}\), 1.17%
- K\(^+\), 1.14%
- Cl\(^-\), 55.05%
- SO\(_4^{2-}\), 7.72%
- HCO\(_3^-\), 0.30%
- Br\(^-\), 0.19%
What is the average composition of the world’s rivers?

**Typical values**
- pH: 7.3–8.1
- TDS (salinity): 70–200 mg/L

% Composition:
- HCO₃⁻: 48%
- SO₄²⁻: 10%
- Cl⁻: 8%
- Na⁺: 7%
- Mg²⁺: 3%
- K⁺: 1%
- Ca²⁺: 13%
- Si(OH)₄: 9%

Values from 1980 average of rivers.
Is river composition very variable?

<table>
<thead>
<tr>
<th></th>
<th>Africa</th>
<th>Asia</th>
<th>S. America</th>
<th>N. America</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>conc, mg/L</td>
<td>fraction</td>
<td>conc, mg/L</td>
<td>fraction</td>
</tr>
<tr>
<td>Ca$^{2+}$</td>
<td>5.7</td>
<td>9.4%</td>
<td>17.8</td>
<td>13.3%</td>
</tr>
<tr>
<td>Na$^+$</td>
<td>4.4</td>
<td>7.2%</td>
<td>8.7</td>
<td>6.5%</td>
</tr>
<tr>
<td>Mg$^{2+}$</td>
<td>2.2</td>
<td>3.6%</td>
<td>4.6</td>
<td>3.4%</td>
</tr>
<tr>
<td>K$^+$</td>
<td>1.4</td>
<td>2.3%</td>
<td>1.7</td>
<td>1.3%</td>
</tr>
<tr>
<td>HCO$_3^-$</td>
<td>26.9</td>
<td>44.2%</td>
<td>67.1</td>
<td>50.0%</td>
</tr>
<tr>
<td>SO$_4^{2-}$</td>
<td>4.2</td>
<td>6.9%</td>
<td>13.3</td>
<td>9.9%</td>
</tr>
<tr>
<td>Cl$^-$</td>
<td>4.1</td>
<td>6.7%</td>
<td>10.0</td>
<td>7.5%</td>
</tr>
<tr>
<td>Si(OH)$_4$</td>
<td>12.0</td>
<td>19.7%</td>
<td>11.0</td>
<td>8.2%</td>
</tr>
<tr>
<td>TDS</td>
<td>60.9</td>
<td></td>
<td>134.2</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Europe</th>
<th>Oceania</th>
<th>World Average</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>conc, mg/L</td>
<td>fraction</td>
</tr>
<tr>
<td>Ca$^{2+}$</td>
<td>31.7</td>
<td>15.5%</td>
</tr>
<tr>
<td>Na$^+$</td>
<td>16.5</td>
<td>8.0%</td>
</tr>
<tr>
<td>Mg$^{2+}$</td>
<td>6.7</td>
<td>3.3%</td>
</tr>
<tr>
<td>K$^+$</td>
<td>1.8</td>
<td>0.9%</td>
</tr>
<tr>
<td>HCO$_3^-$</td>
<td>86.0</td>
<td>42.0%</td>
</tr>
<tr>
<td>SO$_4^{2-}$</td>
<td>35.5</td>
<td>17.3%</td>
</tr>
<tr>
<td>Cl$^-$</td>
<td>20.0</td>
<td>9.8%</td>
</tr>
<tr>
<td>Si(OH)$_4$</td>
<td>6.8</td>
<td>3.3%</td>
</tr>
<tr>
<td>TDS</td>
<td>205.0</td>
<td></td>
</tr>
</tbody>
</table>
Why aren’t you allowed to swim in Westhampton Lake? And what is the purpose of the aerators?

- High (human fecal) coliform count.
  Globally, poor sanitation of drinking water is the single worst water pollution problem, mostly affecting less developed countries (but obviously still an issue even in industrialized countries).

- Aerators have two purposes:
  - to oxygenate the lake, countering the effects of eutrophication due to nutrient pollution
  - to mix the lake when it stratifies (summer months), helping keep the bottom layer oxygenated
What are some of the world’s worst water pollution problems?

2.1 million deaths/yr
How is water quality regulated in the US?

Two important laws (there are others): Clean Water Act for natural water bodies, and the Safe Drinking Water Act for drinking water reservoirs and water treatment plants:

- Quantitative **water quality standards** exist for natural water bodies
- Under the CWA, the appropriate standards depend on the intended use of a water body

Classification of water bodies:

- **Good**: water quality is sufficient to meet all designated uses
- **Impaired**: water quality is insufficient to meet at least one designated use. State obliged to develop ‘TMDL’ rules for impaired water bodies

Examples of designated uses of water bodies (varies by state):

- Food supply: fish consumption, shellfish consumption
- Water supply: public drinking water, agricultural (irrigation)
- Recreation: swimming (primary contact), boating (secondary contact)
- Ecosystem health: aquatic life support, wildlife support
Class Exercise: Pollution Sources

What are the major human activities that pollute the hydrosphere?

- **Industrial discharges**: paper and pulp mills, chemical manufacturers, steel plants, textile manufacturers, food processing plants, others

- **Sewage discharges**: discharges of treated sewage from treatment plants; combined sewer overflows (CSOs)

- **Urban runoff**: runoff from impervious surfaces (streets, etc)

- **Agricultural operations**: crop production, livestock operations (esp CAFOS)

- **Silvicultural operations**: forest management, tree harvesting, logging road construction

- **Resource extraction**: mining, petroleum drilling, runoff from mine tailing sites

- **Waste disposal**: landfill leachate, underground injection, incineration (followed by atmospheric deposition of pollutants)

- **Hydrologic modification**: channelization, dredging, dam construction, removal of riparian vegetation, streambank modification, drainage/filling of wetlands
What are the most common activities that cause water quality impairment in the US?

**Leading Pollutant Sources (US EPA 2009)**

<table>
<thead>
<tr>
<th>Rank</th>
<th>Rivers</th>
<th>Lakes</th>
<th>Estuaries</th>
<th>Groundwater*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Agriculture</td>
<td>Atmospheric Deposition</td>
<td>Atmospheric Deposition</td>
<td>Leaky USTs</td>
</tr>
<tr>
<td>2</td>
<td>Hydromodification</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Septic tanks</td>
</tr>
<tr>
<td>3</td>
<td>Unknown</td>
<td>Agriculture</td>
<td>Sewage Discharges</td>
<td>Landfills</td>
</tr>
<tr>
<td>4</td>
<td>Habitat Alteration</td>
<td>Natural/Wildlife</td>
<td>Unspecified nonpoint source</td>
<td>Fertilizer application</td>
</tr>
<tr>
<td>5</td>
<td>Natural/Wildlife</td>
<td>Hydromodification</td>
<td>Other</td>
<td>Industrial</td>
</tr>
<tr>
<td>6</td>
<td>Sewage Discharges</td>
<td>Urban Runoff/Stormwater</td>
<td>Industrial</td>
<td>Hazardous Waste Sites</td>
</tr>
<tr>
<td>7</td>
<td>Unspecified nonpoint source</td>
<td>Sewage Discharges</td>
<td>Natural/Wildlife</td>
<td>Animal feedlots</td>
</tr>
<tr>
<td>8</td>
<td>Atmospheric Deposition</td>
<td>Legacy/Historical Pollutants</td>
<td>Urban Runoff/Stormwater</td>
<td>Pesticides</td>
</tr>
<tr>
<td>9</td>
<td>Resource extraction</td>
<td>Resource extraction</td>
<td>Agriculture</td>
<td>Surface impoundments</td>
</tr>
<tr>
<td>10</td>
<td>Urban Runoff/Stormwater</td>
<td>Unspecified nonpoint source</td>
<td>Hydromodification</td>
<td>Above-ground STs</td>
</tr>
</tbody>
</table>
### US Water Quality Overview

What are the most common pollutants that cause water quality impairment in the US?

#### Leading Pollutants/Stressors (US EPA 2009)

<table>
<thead>
<tr>
<th>Rank</th>
<th>Rivers</th>
<th>Lakes</th>
<th>Estuaries</th>
<th>Groundwater*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pathogens</td>
<td>Mercury</td>
<td>Pathogens</td>
<td>VOCs</td>
</tr>
<tr>
<td>2</td>
<td>Habitat alteration</td>
<td>PCBs</td>
<td>Degradable Organic Pollution</td>
<td>Petroleum products</td>
</tr>
<tr>
<td>3</td>
<td>Degradable Organic Pollution</td>
<td>Nutrients</td>
<td>Mercury</td>
<td>Metals</td>
</tr>
<tr>
<td>4</td>
<td>Impaired Biota</td>
<td>Metals</td>
<td>Toxic Organics</td>
<td>Pesticides</td>
</tr>
<tr>
<td>5</td>
<td>Nutrients</td>
<td>Degradable Organic Pollution</td>
<td>Nutrients</td>
<td>Nitrate</td>
</tr>
<tr>
<td>6</td>
<td>Metals</td>
<td>Nuisance Exotic Species</td>
<td>Pesticides</td>
<td>Pathogens</td>
</tr>
<tr>
<td>7</td>
<td>Sediment</td>
<td>Sediment</td>
<td>Habitat alteration</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Mercury</td>
<td>Pathogens</td>
<td>PCBs</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Flow Alteration</td>
<td>Turbidity</td>
<td>Metals</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Turbidity</td>
<td>Other Causes</td>
<td>Turbidity</td>
<td></td>
</tr>
</tbody>
</table>
What percentage of US rivers and streams are considered impaired?

### Graph
- **Total U.S. Streams**: 3,533,205 Miles
- **Assessed Streams**: 563,955 Miles
- **84% Unassessed**
- **16% Assessed**
- **3% Good but Threatened**: 15,698 Miles
- **53% Good**: 302,255 Miles
- **44% Impaired**: 246,002 Miles

### Table: Designated Use

<table>
<thead>
<tr>
<th>Designated Use</th>
<th>Miles Assessed</th>
<th>Percentage of Total U.S. River Miles</th>
<th>Percentage of Waters Assessed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fish, Shellfish, and Wildlife Protection/Propagation</td>
<td>466,617</td>
<td>13</td>
<td>Good: 61, Threatened: 3, Impaired: 36</td>
</tr>
<tr>
<td>Recreation</td>
<td>303,317</td>
<td>9</td>
<td>Good: 69, Threatened: 3, Impaired: 28</td>
</tr>
<tr>
<td>Agricultural</td>
<td>200,817</td>
<td>6</td>
<td>Good: 90, Threatened: &lt;1, Impaired: 10</td>
</tr>
<tr>
<td>Aquatic Life Harvesting</td>
<td>154,746</td>
<td>4</td>
<td>Good: 56, Threatened: 4, Impaired: 40</td>
</tr>
<tr>
<td>Public Water Supply</td>
<td>144,245</td>
<td>4</td>
<td>Good: 79, Threatened: 3, Impaired: 18</td>
</tr>
</tbody>
</table>
What percentage of US lakes are considered impaired?

- Total U.S. Lakes: 41,666,049 Acres
  - 61% Unassessed
  - 39% Assessed

Assessed Lakes: 16,230,384 Acres
- 64% Impaired
- 35% Good
- 1% Good but Threatened

<table>
<thead>
<tr>
<th>Designated Use</th>
<th>Acres Assessed</th>
<th>Percentage of Total U.S. Lake Acres</th>
<th>Percentage of Waters Assessed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fish, Shellfish, and Wildlife Protection/Propagation</td>
<td>11,770,370</td>
<td>28%</td>
<td>Good: 66% Threatened: 4% Impaired: 30%</td>
</tr>
<tr>
<td>Aquatic Life Harvesting</td>
<td>9,390,396</td>
<td>23%</td>
<td>Good: 26% Threatened: 1% Impaired: 73%</td>
</tr>
<tr>
<td>Recreation</td>
<td>8,069,018</td>
<td>19%</td>
<td>Good: 70% Threatened: 4% Impaired: 26%</td>
</tr>
<tr>
<td>Public Water Supply</td>
<td>6,427,687</td>
<td>15%</td>
<td>Good: 78% Threatened: 1% Impaired: 20%</td>
</tr>
<tr>
<td>Industrial</td>
<td>2,848,335</td>
<td>7%</td>
<td>Good: 82% Threatened: &lt;1% Impaired: 17%</td>
</tr>
</tbody>
</table>
What percentage of US bays/estuaries are considered impaired?

**Overview of Water Pollution**

<table>
<thead>
<tr>
<th>Designated Use</th>
<th>Square Miles Assessed</th>
<th>Percentage of Total U.S. Estuarine Miles</th>
<th>Percentage of Waters Assessed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fish, Shellfish, and Wildlife Protection/Propagation</td>
<td>24,338</td>
<td>28%</td>
<td>73%  &lt;1%  27%</td>
</tr>
<tr>
<td>Aquatic Life Harvesting</td>
<td>11,004</td>
<td>13%</td>
<td>81%  &lt;1%  19%</td>
</tr>
<tr>
<td>Recreation</td>
<td>9,322</td>
<td>11%</td>
<td>87%  &lt;1%  13%</td>
</tr>
</tbody>
</table>
Virginia Water Quality

What about Virginia, are we doing better than the rest of the nation?

Yeah, not so much: data below are from 2014 (draft) report.

<table>
<thead>
<tr>
<th>Waterbody Type</th>
<th>Total</th>
<th>Assessed</th>
<th>Attained Use</th>
<th>Impaired</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rivers (miles)</td>
<td>100,923</td>
<td>22,480</td>
<td>6,441</td>
<td>16,039</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(22% of total)</td>
<td>(29% of assessed)</td>
<td>(71% of assessed)</td>
</tr>
<tr>
<td>Lakes (acres)</td>
<td>117,158</td>
<td>114,191</td>
<td>19,425</td>
<td>94,766</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(97% of total)</td>
<td>(17% of assessed)</td>
<td>(83% of assessed)</td>
</tr>
<tr>
<td>Estuaries (sq. miles)</td>
<td>2,836</td>
<td>2,446</td>
<td>310</td>
<td>2,136</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(86% of total)</td>
<td>(13% of assessed)</td>
<td>(87% of assessed)</td>
</tr>
</tbody>
</table>

1 “Impaired” applies to both EPA Assessment Categories 4 and 5.

Note: Size adjustments using high resolution hydrography data account for discrepancies from prior cycle.
What are the most common causes of water impairment in our fair state?

- **Bacteria**
- **Dissolved Oxygen**
- **Impaired Benthics**
- **pH**
- **Mercury**
- **PCBs**

The bar chart shows the number of sub-watersheds affected by these causes.