Biogeochemical Cycles

- A biogeochemical cycle is the complete path a chemical takes through the four major components of Earth’s system.
  - Atmosphere
  - Hydrosphere
  - Lithosphere
  - Biosphere

Biogeochemical cycles

- The simplest way to think of BGC cycles is a “box and arrow” diagram
- Sometimes useful to consider a global perspective.
  - Global climate change
- Other times may need to viewed at local scale
  - Sella Lake

Environmental Questions

- Hydrologic Questions
  - What determines whether a body of water will be biologically productive?
  - When a body of water becomes polluted, how can we reduce the pollution and its effects?
  - How does land surfaces manage to keep fresh water balance?

The Hydrologic Cycle

- The transfer of water from oceans to the atmosphere to the land and back to the oceans.
  - Involves evaporation of water from oceans
  - Precipitation on land
  - Evaporation from land
  - Runoff from streams, rivers and subsurface groundwater
The Hydrologic Cycle

- Driven by solar energy
- 1.3 billion km³ of water on Earth
  - 97% in oceans
  - 2% in glaciers and ice caps
  - 0.001% in atmosphere
  - The rest in fresh water on land

The Hydrologic Cycle

- At the regional and local level, the fundamental unit of the landscape is the drainage basin.
  - The area that contributes surface runoff to a particular stream or river
  - Vary greatly in size
  - Usually named for main stream or river

Supply of Water Resources

<table>
<thead>
<tr>
<th>Freshwater</th>
<th>Readily accessible freshwater</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundwater 0.392%</td>
<td>Biotas 0.0001%</td>
</tr>
<tr>
<td>Ice caps and glaciers 0.592%</td>
<td>Lakes 0.0007%</td>
</tr>
<tr>
<td>Soil moisture 0.0005%</td>
<td>Rivers 0.0001%</td>
</tr>
<tr>
<td>Atmospheric water vapor 0.014%</td>
<td></td>
</tr>
</tbody>
</table>

Use of Water Resources

- Humans use about 54% of reliable runoff
- Agriculture 38%
- Industry 11%
- Domestic
- Power plants

United States

- Power cooling 38%
- Agriculture 38%
- Industry 11%
- Public 10%
Evaporation and transpiration

- **Evaporation**
- **Stream**
- **Infiltration**
- **Water table**
- **Infiltration**
- **Unconfined aquifer**
- **Confined aquifer**
- **Lake**
- **Well requiring a pump**
- **Flowing artesian well**
- **Runoff**
- **Precipitation**
- **Confined**
- **Recharge Area**
- **Aquifer**

Ground Water

**Water Resources**

- Over the last century
  - Human population has increased 3x
  - Global water withdrawal has increased 7x
  - Per capita water withdrawal has increased 4x
- About one-sixth of the world’s people don’t have easy access to safe water
- Most water resources are owned by governments and are managed as publicly owned resources

**Water Crisis: Part 2**

- **Human water Consumption**
  - Water quality standards
  - Types of pollutants and
  - Source of pollution

**Background**

- Urbanization is a global phenomenon that possess various point and non-point pollution sources of pollution.
- Sustainable water management in order to meet the relentlessly growing drinking water demand of urban population, especially in the developing countries, is among the most indispensable environmental issues after global warming.
- In such a scenario, hydro-geochemical zoning based on prevailing groundwater quality, land-use, soil type, natural topographical surface condition, type of available pollution sources, and water-mineral equilibrium is the first step towards sustainable urban water management.
- Especially because urban area possesses immensely altered hydrology.

**Human Impacted Urban Hydrology**

- Increase of impervious areas (roads and roofs)
- Evapotranspiration
- Runoff
- Infiltration
- Increased urban runoff causes frequent flood

**Groundwater Pollution**

- >70,000 chemicals are used; effects of many are not known
- Each year another 700-800 new chemicals are produced
- 55 million tons of hazardous chemical wastes are produced in the US each year
- The 20 most abundant compounds in groundwater at industrial waste disposal sites include TCE, benzene, vinyl chloride...all are carcinogens, and also affect liver, brain, and nervous system
Kinds of Water Pollution

- Inorganic Pollutants
- Organic Pollutants
- Biologic Pollutants

Inorganic Pollutants

- Examples:
  - Pb in gasoline
  - Radionuclides
  - Phosphorus, nitrogen (Great Lakes)
  - Other heavy metals

Inorganic Pollutants

- 3 groups
  1) Produce no health effects until a threshold concentration is exceeded—e.g., NO\textsubscript{3}−, look at 50 mg/liter; at higher levels: methaemoglobinemia
  2) No threshold—e.g., genotoxic substances: some natural and synthetic organic compounds, microorganic compounds, some pesticides, arsenic
  3) Essential to diets: F, I, Se—absence causes problems, but too much also causes problems

Radionuclides

- Bikini Atoll in South Pacific: > 20 tests, 1946-1958
  - Inhabitants evacuated before 1946 tests; their descendents are still exiled
  - Atmospheric testing of nuclear weapons is now banned
  - National labs…now trying to clean up (Hanford)

Phosphates and Nitrates

- Phosphates—mostly a result of sewage outflow and phosphate detergents
  - Additional phosphate grows excess algae…oxygen depletion, Lake Erie…1972 phosphate management plant…$7.6 billion
  - Nitrates—sewage and fertilizers
How water is used

• In the western US, irrigation makes up 85% of all water use
  --50% to grow food for livestock
  -- 35% to grow crops

Not sustainable...cost of water is heavily subsidized by the federal government

Organic Pollutants

• Three classes of compounds
  ▫ Pesticides and Herbicides
  ▫ Materials for common household and industrial use
  ▫ Materials for industrial use

Pesticides

• Chlorinated hydrocarbons
  ▫ DDT, heptachlor, etc—2-15 years
• Organophosphates
  ▫ Malathion, methyl parathion—1-2 weeks
• Carbamates
  ▫ Carbaryl, maneb, aldicarb—days to weeks
• Pyrethroids
  ▫ Pemethrin, decamethrin—days to weeks

Herbicides

Contact
Triazines—e.g. atrazine, paraquat
(interfere with photosynthesis)
Systemic—phenoxy compounds, N compounds,
Alar, glyphosate
(create excess growth hormones)
Soil sterilants
trifluralin, dalapon
(kill soil microorganisms)

Advantages of Modern Pesticides

• Save human lives (malaria, bubonic plague, typhoid fever)
• Increase food supplies (even now 55% of world’s potential food supply is ‘lost’ to other species)
• Increase profit for farmers ($1 investment $4 increased profit
• They work fast

Disadvantages of Modern Pesticides

• They accelerate the development of genetic resistance to pesticides by pest organisms
  Since 1945, ~1000 species of insects and rodents and 550 species of weeds and plant diseases
• They can put farmers on a financial treadmill
• Some kill natural predators and parasites that control ‘pests’
  ▫ 300 most destructive insects in US: 100 were once minor
• They don’t stay put
  —only 0.1 to 2% of stuff applied reaches target insect, 5% reaches target plant—the rest—into air, water, humans, wildlife
Disadvantages, continued

- Harm wildlife
  - USDA, USFWS: each year pesticides wipe out about 20% of honeybee population, damage another 15%, losing US farmers about $200 million/yr. Kill 6-14 million fish, ~67 million birds/year

- Threaten human health
  --Poison 3.5-5 million workers in developing countries, and at least 300,000 in US; cause about 20000-40000 deaths (about 25 in US) per year. Prob greatly underestimated.
  --In food causes about 4000-20000 cases of cancer/year in US (Nat'l Academy of Sciences); genetic mutations, birth defects, nervous systems disorders, endocrine disorders.

How they’re regulated

- EPA, USDA, FDA
- Fewer than 10% of active ingredients have been evaluated
- 1996—Food Quality Protection Act—Requires EPA to reduce allowed levels of residues on food by a factor of 10 if inadequate info about effects on children
- Poor enforcement; National Academy study: ~98% of potential cancer risk would be eliminated if EPA standards were as strict for pre-1972 chemicals as they are for later ones.
- Big problem—chemicals banned in US can be manufactured here and shipped to other countries

Monitoring water quality

- Number of colonies of fecal coliform bacteria
- Bacterial source tracking (BST)
- Measure biological oxygen demand (BOD)
- Chemical analysis
- Indicator species
- Genetic development of indicator organisms

Biologic Contaminants

- Greater obvious problems than organic and inorganic contaminants in US
- April, 1993, Milwaukee—cryptosporidium (parasite)—source: water plant with a water intake pipe <2mi from a sewage treatment plant; 400,000 ill people, 42 deaths

Scale of Biologic Contaminant Problem

- Major cause of infant deaths in third world
- Diarrhea kills 4-15 million children/year
- Bacteria, viruses, parasites

Types, Effects and Sources of Water Pollution
$23 billion/year for 8-10 years to bring clean drinking water to those who don’t have it

- Consequences of a warmer world
- Pollution of freshwater streams
- Dilution and biodegradation
- Breakdown of pollutants by bacteria—oxygen sag curve

Point source vs non-point source pollution; developed vs non-developed

Developing countries: half of world’s 500 major rivers are heavily polluted

Pollution of Lakes

- Eutrophication

Groundwater Pollution: Causes

- Low flow rates
- Few bacteria
- Low oxygen
- Cold temperatures

Nonpoint Sources

- Reduce runoff
- Buffer zone vegetation
- Reduce soil erosion

Point Sources

- Clean Water Act
- Water Quality Act

Solutions: Preventing and Reducing Surface Water Pollution

Groundwater: Causes

- Low oxygen
- Coal strip mine runoff
- Pumping well
- Waste lagoon
- Accidental spills
- Groundwater flow
- Confined aquifer
- Hazardous waste injection well
- Pesticides
- Gasoline
- Station
- Buried gasoline and solvent tank
- Sewer
- Cesspool
- Septic tank
- De-icing road salt
- Water pumping well
- Landfill
- Leakage from faulty casing
- Microbiocidal waste injection well

Fig. 22-4 p. 494

Fig. 22-7 p. 499
Groundwater Pollution Prevention

- Monitor aquifers
- Find less hazardous substitutes
- Leak detection systems
- Strictly regulating hazardous waste disposal
- Store hazardous materials above ground

One or more organic chemicals contaminate about 45% of municipal groundwater supplies in the US

About 26000 industrial waste ponds in US do not have liners

Leaking underground storage tanks

Nitrates, fluoride, arsenic

Ocean Pollution

![Image of ocean pollution diagram]

Ocean Pollution

- Dumping wastes in the oceans
  - Dumping industrial wastes off US coasts has stopped, but dredge products are legally dumped at 110 sites in Atlantic, Pacific, and Gulf Coasts
  - US has banned dumping sewage sludge in ocean since 1992
  - 50 countries rep ~80% of world’s shipping fleet have agreed not to dump sewage and garbage
  - London Dumping Convention of 1972; 1994

Oil Spills

- Sources: offshore wells, tankers, pipelines and storage tanks
- Effects: death of organisms, loss of animal insulation and buoyancy, smothering
- Significant economic impacts
- Mechanical cleanup methods: skimmers and blotters
- Chemical cleanup methods: coagulants and dispersing agents

Oil Pollution in the Oceans

- Oil Pollution Act of 1990
- Only about 15% of an oil spill can now be recovered
- Crude oil—3 years
- Refined oil—10-20 years
Reducing water pollution

- Non point source
- Septic tanks and sewers
Drinking Water Quality

- Purification of urban drinking water
- Protection from terrorism
- Purification of rural drinking water
- Safe Drinking Water Act
- Maximum contaminant levels (MCLs)
- Bottled water

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<tr>
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<tr>
<td></td>
<td>Disturbance limit (DL)</td>
<td>Maximum permissible limit (PL)</td>
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<tr>
<td>PH</td>
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<tr>
<td>EC (µS/cm)</td>
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</table>

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