Introduction to Contaminant Hydrogeology

- Federal Laws Relevant to Groundwater Quality
- Types of Contaminants
- Sources of Contamination
- Extent of Groundwater Contamination
- Controlling Processes
- Groundwater Protection and Remediation
Federal Laws Relevant to Groundwater Quality

• Overview of Federal Environmental Laws
  – Safe Drinking Water Act (SDWA) of 1974
    • set standards for safe drinking water; protect aquifers from contamination resulting from underground injection
  – Resource Conservation and Recovery Act (RCRA) of 1976
    • first major federal effort to regulate hazardous waste; groundwater monitoring systems required for new facilities
  – Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980
    • “Superfund”, national priority list of sites targeted for remedial action; EPA can recover full costs from any responsible parties
  – Superfund Amendments and Reauthorization Act (SARA) of 1986
    • additional mandates from congress to clean up contaminated sites; concept of strict liability;
    • remedial investigations (RI) and feasibility studies (FS)
Safe Drinking Water Act - Protecting America's Public Health

This poster identifies examples of:
1. Surface and groundwater sources of drinking water (in blue).
2. Potential threats to those drinking water sources (in red).
3. The multiple barriers that together protect our nation’s public health (in green).
4. Risk Prevention Barrier
5. Risk Management Barrier
6. Risk Monitoring and Compliance Barrier

Safe Drinking Water Hotline – (800) 426-4771 SafeWater Web Site – www.epa.gov/safewater
USEPA Drinking Water Standards

• **Maximum Contaminant Level (MCL)** - The highest level of a contaminant that is allowed in drinking water. MCLs are enforceable standards.

• **Maximum Contaminant Level Goal (MCLG)** - The level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety and are non-enforceable public health goals.

• **Maximum Residual Disinfectant Level (MRDL)** - The highest level of a disinfectant allowed in drinking water. There is convincing evidence that addition of a disinfectant is necessary for control of microbial contaminants.

• **Maximum Residual Disinfectant Level Goal (MRDLG)** - The level of a drinking water disinfectant below which there is no known or expected risk to health. MRDLGs do not reflect the benefits of the use of disinfectants to control microbial contaminants.
Ground Water & Drinking Water

Current Drinking Water Standards

National Primary Drinking Water Regulations (NPDWRs or primary standards) are legally enforceable standards that apply to public water systems. Primary standards protect public health by limiting the levels of contaminants in drinking water. The table below divides these contaminants into:

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

For more information, see Setting Standards for Safe Drinking Water to learn about EPA’s standard-setting process or look at a timeline that shows the order in which EPA regulated these contaminants. For copies of the complete regulations regarding these contaminants, follow these links:

- National Primary Drinking Water Regulations
- National Secondary Drinking Water Regulations

### National Primary Drinking Water Regulations

<table>
<thead>
<tr>
<th>Microorganism</th>
<th>MCLG (mg/L)</th>
<th>MCL or TT (mg/L)</th>
<th>Potential Health Effects from Ingestion of Water</th>
<th>Sources of Contaminant in Drinking Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cryptosporidium</td>
<td>zero</td>
<td>TT 1</td>
<td>Gastrointestinal illness (e.g., diarrhea, vomiting, cramps)</td>
<td>Human and fecal animal waste</td>
</tr>
<tr>
<td>Giardia lamblia</td>
<td>zero</td>
<td>TT 2</td>
<td>Gastrointestinal illness (e.g., diarrhea, vomiting, cramps)</td>
<td>Human and animal fecal waste</td>
</tr>
<tr>
<td>Heterotrophic plate count</td>
<td>n/a</td>
<td>TT 2</td>
<td>HPC has no health effects; it is an analytic method used to measure the variety of bacteria that are common in water. The lower the number, the cleaner the water.</td>
<td>HPC measures a range of bacteria that are naturally present in the environment</td>
</tr>
</tbody>
</table>
Types of Contaminants

• EPA List of Priority Pollutants
  – risk based, theoretical values
• Radioactive Contaminants
  – major contaminants; much research driven by the needs to find suitable sites for storage of radioactive waste (site sitting)
• Trace Metals
  – aluminium, arsenic, lead, zinc
• Nutrients
  – nitrate, NO₃, NH₄, pesticides
• Other Inorganic Species
  – common anions and cations
• Organic Contaminants
  – most serious problems; hydrocarbons; solvents
• Biological Contaminants
  – bacteria, virus
Table 17.2 Environmental Protection Agency List of Priority Pollutants. Organic Compounds Are Subdivided into Four Categories According to the Method of Analysis

<table>
<thead>
<tr>
<th>BASE-NEUTRAL EXTRACTABLES</th>
<th>VOLATILES</th>
<th>PESTICIDES</th>
<th>INORGANICS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acenaphthene</td>
<td>Diethyl phthalate</td>
<td>Acrolein</td>
<td>1,2-Dichloroethane</td>
</tr>
<tr>
<td>Acenaphthylene</td>
<td>Dimethyl phthalate</td>
<td>Acrylonitrile</td>
<td>1,1-Dichloroethylene</td>
</tr>
<tr>
<td>Anthracene</td>
<td>2,4-Dinitrotoluene</td>
<td>Benzene</td>
<td>trans-1,2-Dichloroethylene</td>
</tr>
<tr>
<td>Benzidine</td>
<td>2,6-Dinitrotoluene</td>
<td>Bis(chloromethyl) ether</td>
<td>1,2-Dichloropropane</td>
</tr>
<tr>
<td>Benzo[a]anthracene</td>
<td>Di-n-octyl phthalate</td>
<td>Bromodichloromethane</td>
<td>cis-1,3-Dichloropropene</td>
</tr>
<tr>
<td>Benzo[b]fluoranthene</td>
<td>1,2-Diphenylhydrazine</td>
<td>Bromoform</td>
<td>trans-1,3-Dichloropropene</td>
</tr>
<tr>
<td>Benzo[k]fluoranthene</td>
<td>Fluoranthene</td>
<td>Bromomethane</td>
<td>Ethylbenzene</td>
</tr>
<tr>
<td>Benzo[g,h,i]perylene</td>
<td>Fluorene</td>
<td>Carbon tetrachloride</td>
<td>Methylene chloride</td>
</tr>
<tr>
<td>Benzo[a]pyrene</td>
<td>Hexachlorobenzene</td>
<td>Chlorobenzene</td>
<td>1,1,2,2-Tetrachloroethane</td>
</tr>
<tr>
<td>Bis(2-chloroethoxy)methane</td>
<td>Hexachlorobutadiene</td>
<td>Chloroethane</td>
<td>Tetrachloroethene</td>
</tr>
<tr>
<td>Bis(2-chloroethyl) ether</td>
<td>Hexachlorocyclopentadiene</td>
<td>2-Chloroethyl vinyl ether</td>
<td>Toluene</td>
</tr>
<tr>
<td>Bis(2-chloroisopropyl) ether</td>
<td>Hexachloroethane</td>
<td>Chloroform</td>
<td>1,1,1-Trichloroethane</td>
</tr>
<tr>
<td>Bis(2-ethylhexyl) phthalate</td>
<td>Indeno[1,2,3-cd] pyrene</td>
<td>Chloromethane</td>
<td>1,1,2-Trichloroethane</td>
</tr>
<tr>
<td>4-Bromophenyl phenyl ether</td>
<td>Isophorone</td>
<td>Dibromochloromethane</td>
<td>Trichloroethylene</td>
</tr>
<tr>
<td>Butyl benzyl phthalate</td>
<td>Naphthalene</td>
<td>Dichlorodifluoromethane</td>
<td>Trichlorofluoromethane</td>
</tr>
<tr>
<td>2-Chloronaphthalene</td>
<td>Nitrobenzene</td>
<td>1,1-Dichloroethane</td>
<td>Vinyl chloride</td>
</tr>
<tr>
<td>4-Chlorophenyl phenyl ether</td>
<td>N-Nitrosodimethylamine</td>
<td>Aldrin</td>
<td>PCB-1016</td>
</tr>
<tr>
<td>Chryscene</td>
<td>N-Nitrosodiphenylamine</td>
<td>Dieldrin</td>
<td>PCB-1221</td>
</tr>
<tr>
<td>Dibenzo[a,h]anthracene</td>
<td>N-Nitrosodi-n-propylamine</td>
<td>α-BHC</td>
<td>PCB-1232</td>
</tr>
<tr>
<td>Di-n-butyl phthalate</td>
<td>Phenanthrene</td>
<td>β-BHC</td>
<td>Endosulfan sulfate</td>
</tr>
<tr>
<td>1,2-Dichlorobenzene</td>
<td>Pyrene</td>
<td>γ-BHC</td>
<td>PCB-1242</td>
</tr>
<tr>
<td>1,3-Dichlorobenzene</td>
<td>2,3,7,8-Tetrachlorodibenzo-p-dioxin</td>
<td>δ-BHC</td>
<td>Endrin</td>
</tr>
<tr>
<td>1,4-Dichlorobenzene</td>
<td>1,2,4-Trichlorobenzene</td>
<td>Chlordane</td>
<td>Endrin aldehyde</td>
</tr>
<tr>
<td>3,3'-Dichlorobenzidine</td>
<td></td>
<td>4,4'-DDD</td>
<td>PCB-1254</td>
</tr>
<tr>
<td>p-Chloro-m-cresol</td>
<td>2-Nitrophenol</td>
<td>4,4'-DDD</td>
<td>Heptachlor</td>
</tr>
<tr>
<td>2-Chlorophenol</td>
<td>4-Nitrophenol</td>
<td>4,4'-DDE</td>
<td>Heptachlor epoxide</td>
</tr>
<tr>
<td>2,4-Dichlorophenol</td>
<td>Pentachlorophenol</td>
<td>*not pesticides</td>
<td></td>
</tr>
<tr>
<td>2,4-Dimethylphenol</td>
<td>Phenol</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4,6-Dinitro-o-cresol</td>
<td>2,4,6-Trichlorophenol</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2,4-Dinitrophenol</td>
<td>Total phenols</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACID EXTRACTABLES</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Antimony</td>
<td>Chromium</td>
<td>Nickel</td>
<td></td>
</tr>
<tr>
<td>Arsenic</td>
<td>Copper</td>
<td>Selenium</td>
<td></td>
</tr>
<tr>
<td>Asbestos</td>
<td>Cyanide</td>
<td>Silver</td>
<td></td>
</tr>
<tr>
<td>Beryllium</td>
<td>Lead</td>
<td>Thallium</td>
<td></td>
</tr>
<tr>
<td>Cadmium</td>
<td>Mercury</td>
<td>Zinc</td>
<td></td>
</tr>
</tbody>
</table>
Sources of Contamination

1. Sources designed to discharge substances: septic tanks; injection wells
2. Sources designed to store, treat, and/or dispose of substances: landfill; UST; waste tailing; waste disposal site
3. Sources designed to retain substances during transport or transmission: pipelines
4. Sources discharging substances as a consequence of other planned activities: pesticides; fertilizers; acid mine drainage
5. Sources providing conduits or inducing discharge through altered flow patterns: production wells; monitoring wells; excavation
6. Naturally occurring sources whose discharge is created and/or exacerbated by human activities: seawater intrusion; groundwater-surface water interaction
Major Pathways of Groundwater Contamination

Pathways of groundwater contamination vary depending on the source. Examples of sources are shown here for each of OTA's six source categories (I-VI) (see the section on Types of Sources and Associated Substances, below).
The causes of groundwater pollution are numerous and are as diverse as human activities…
Extent of Groundwater Contamination

- **Point-Source Contamination**
  - have received most attentions
  - Superfund sites
  - relatively easier to deal with

- **Non-Point Source Contamination**
  - have been pretty much neglected; difficult to deal with
  - potentially much more serious than point-source contamination
  - mostly due to agricultural chemicals

Applying chemicals to cropland in Maryland. (Photograph by David Usher.)
The National Priorities List identifies target sites for remedial action under the Comprehensive Environmental Response, Compensation, and Liability Act. This map shows the number of sites in each State as of September 1984. (Additional sites are located in American Samoa (1), Marianas (1), Guam (1), Puerto Rico (8), and the Pacific Trust Territories (1).)
Superfund sites in Alabama (2002)
Case Study
Groundwater Contamination and Restoration at the Massachusetts Military Reservation (MMR)
MMR: History and Present

- Used by US military since 1930’s
- Heaviest military activity was 1940-46 by US Army; and 1955-72 by US Air Force
- Major contaminants: petroleum products and solvents
- 1978 -- first detection of contaminants at the Town of Falmouth
- 1989 -- the base designated as a Superfund site
- $200 million -- total site investigation and cleanup costs to date
- 78 sites identified as having real or potential problems
Hydrogeology at the MMR

• Base sits atop the recharge area for the sole aquifer for all sounding towns
• Average recharge ranges from 16-34 in/year
• Shallow, unconfined aquifer with water table depth ranging from 30 – 60 ft below surface
• Aquifer consists of glacial outwash with a thickness ranging from < 150 ft to > 400 ft
• Hydraulic conductivity varies from 10 to 300 ft/day for coarse sands with average seepage velocity from 1-4 ft/day
Hydrogeologic Cross Section at MMR
Chemical Spill 10 (CS-10) Site

• 11 potential sources including a former missile site (1960-73) and a training equipment site (since 1978)
• Primary contaminants: TCE, PCE, 1,2-DCE and EDB
• 1996 – source removal (~200 disposal/drainage structures and 700 ft³ soil)
• 1999 -- Record of Decision (ROD) for removal of remaining soil (1700 ft³), and soil vapor extraction for deeper soil, if necessary
• Present -- Pump-and-Treat or ETR (extraction, treatment and reinjection) being implemented for plume containment and cleanup
CS-10 TCE Plume and P&T System
Optimal Steady-State Pumping Strategy

![Graph showing the comparison of pumping rates before and after optimization across different well numbers. The x-axis represents the well number, ranging from 1 to 9, and the y-axis represents the pumping rate in m³/day. The graph uses bars to compare the pumping rates before and after optimization, with purple bars indicating after optimization. The data shows a significant decrease in pumping rates after optimization.]
Calculated TCE Mass Removal

Optimal Strategy 1 (Q=2700 GPM)