Lecture 22: Groundwater Contamination I

Key Questions

1. What causes seawater intrusion?
2. What is the Gyben-Herzberg Relation (z = 40h)
3. Why are islands susceptible to sea-water intrusion?
4. What are some examples of point sources of groundwater contamination?
5. What are some examples of non-point sources of groundwater contamination?
6. Why is nitrate the most common groundwater pollutant?
7. Why is the Abbotsford-Sumas aquifer susceptible to nitrate contamination?
Seawater Intrusion

- Water table
- Fresh water
- Zone of diffusion (interface)
- Saltwater
- Sea level
In a ‘U’ - tube, water seeks its own level
Hydraulic equilibrium between two fluids with contrasting densities

sea water

fresh water

interface between the fresh water and sea water
Sea water is denser so it displaces the fresh water upward.

interface between the fresh water and sea water
Δ = Δh

fresh water

sea water

interface between the fresh water and sea water
\( \rho_s = \text{sea water density} \)

\[ p_A = \rho_s g z \]
\[ \rho_f = \text{fresh water density} \]

\[ P_B = \rho_f g (z + h) \]
hydraulic equilibrium

\[ P_A = \rho_s g z \]

\[ P_B = \rho_f g (z + h) \]

\[ P_A = P_B \]
\[ \Delta = \Delta = h \]

\[ \rho_s g z = \rho_f g (z + h) \]

Solving for “z” yields

\[ z = \left( \frac{\rho_f}{\rho_s - \rho_f} \right) h \]

\[ \rho_s = \text{sea water density} \]

\[ \rho_f = \text{fresh water density} \]
Ghyben – Herzberg relation

\[ z = \left( \frac{\rho_f}{\rho_s - \rho_f} \right) h \]

if

\( \rho_s = 1.025 \text{ g/cm}^3 \)
\( \rho_f = 1.000 \text{ g/cm}^3 \)

then

\[ z = 40h \]
The depth to the freshwater/seawater interface ($z$) is about 40 times the height of the freshwater above sea level ($h$).
Ghyben – Herzberg relation

(static water conditions)

$z = 40 \ h$
Ghyben – Herzberg relation

(static water conditions)

drop in the water table

sea level

rise in the interface

\[ z = 40 \text{ h} \]
Pumping wells create a cone-of-depression in the water table
Seawater Intrusion on Islands

- Water table:
  - Winter (January)
  - Late summer (September)

- Arrows denote direction of ground-water flow

- Not to scale
Chloride Concentrations are an indication of seawater intrusion

Greater than 100 mg/L means intruded

Greater than 250 mg/L means above drinking-water standard
Seawater Intrusion on Islands
Seawater Intrusion on Islands
Lopez Island

Figure 3. Areal distribution of chloride concentrations from wells or spring on Lopez Island measured in the spring of 1997.
Lopez Island

EXPLANATION

WELL OR SPRING SECTION
AND SEQUENCE NUMBER
WITH SPRING 1997 ANALYSIS OF
CHLORIDE CONCENTRATIONS,
IN MILLIGRAMS PER LITER,

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
<th>Number of Wells Sampled</th>
<th>Percent of Wells</th>
</tr>
</thead>
<tbody>
<tr>
<td>02P3</td>
<td>▲ Less than 50</td>
<td>45</td>
<td>24</td>
</tr>
<tr>
<td>11D1</td>
<td>▲ 50 to less than 100</td>
<td>54</td>
<td>29</td>
</tr>
<tr>
<td>12E2</td>
<td>▲ 100 to less than 250</td>
<td>66</td>
<td>36</td>
</tr>
<tr>
<td>01P3</td>
<td>▲ Equal to or greater than 250</td>
<td>19</td>
<td>10</td>
</tr>
</tbody>
</table>

Total 184 99

1 All values rounded to two significant figures; because of rounding percent values do not total one hundred percent.

2 Section and sequence numbers are bolded in table 1.
Seawater Intrusion on Islands
Seawater Intrusion on Islands
Figure 38a. Chloride concentrations, north Lummi Island, Washington, fall 2002
Seawater Intrusion on Islands
Guemes Island

Seawater intrusion problems around the northern coastal region.
More Sources of Groundwater Contamination
Examples of Point Sources

- On-site septic systems
- Leaky tanks or pipelines containing hydrocarbons
- Leaks or spills at manufacturing facilities
- Municipal landfills
- Livestock wastes (manure lagoons)
- Leaky sewer lines
- Spills related to highway or railway accidents

Examples of Non-point Sources

- Fertilizers on agricultural land
- Pesticides on agricultural land and forests
- Contaminants in rain, snow, and atmospheric fallout

Agricultural Pollutants

- Pesticides (organic chemical)
- Herbicides (organic chemical)
- Fertilizers (nutrients)
Nitrate is the most common world-wide groundwater pollutant
Nitrogen fertilizers are major sources of nitrate

Nitrogen inorganic commercial and organic manure fertilizers are added to the soil to supplement nutrients for crops
Liquid manure spreading in Whatcom County
Mineralization and Nitrification

Excess nitrogen in the soil is converted to nitrate by the help of bacteria.
Non-Point Nitrate Contamination

Nitrate derived from fertilized fields is called a “non-point” source contaminant because it covers large surface areas on the aquifer.
Nitrate Leaching

Rainfall (or irrigation water) percolating into the soil transports nitrate in the soil to the surface of the aquifer (water table).
Nitrate is transported through an aquifer by groundwater
Why is nitrate in drinking water a problem?

Nitrate can affect red blood cells and reduce their ability to carry oxygen to the body. In most adults and children these affected blood cells rapidly return back to normal.

However the blood cells of infants can take much longer to return to normal. As a result, infants who are given water with high levels of nitrate (or foods made with nitrate contaminated water) may develop a serious health condition due to the lack of oxygen. This condition is called methemoglobinemia or “blue baby syndrome.”

The above information was extracted from a State of Washington Department of Health Fact Sheet (DOH PUB. # 331-214).
http://www.doh.wa.gov/ehp/dw/Publications/nitrate_english_spanish.htm
How is nitrate in drinking water regulated?

• The U.S. EPA has established a Maximum Contaminant Level (MCL) of 10 milligrams per liter (mg/L) for nitrate.

• Public water systems are required to sample for nitrate on a regular basis.

• There is no required sampling of private individual wells.

The above information was extracted from a State of Washington Department of Health Fact Sheet (DOH PUB. # 331-214).
http://www.doh.wa.gov/ehp/dw/Publications/nitrate_english_spanish.htm
Groundwater is vulnerable to nitrate contamination where there is a combination of:

- rainfall (or irrigation)
- agricultural land use
- permeable soils
- shallow water table
Nitrate Vulnerability Map

The red areas on this map indicate regions that are highly susceptible to groundwater nitrate contamination.

Vulnerability map. Probability (in percent) of detecting nitrate at concentrations of 3 milligrams per liter or greater in wells that are 50 feet deep in the Puget Sound Basin.
Abbotsford-Sumas Aquifer

Vulnerability map. Probability (in percent) of detecting nitrate at concentrations of 3 milligrams per liter or greater in wells that are 50 feet deep in the Puget Sound Basin.
The lowlands over the aquifer are agriculturally productive.

Whatcom County’s Raspberry Industry is #1 in the Nation.
Whatcom County’s Dairy Industry is #2 in the State (~60,000 cows)
Southern British Columbia is dominated by poultry industries and raspberry.
Groundwater flows south from BC into Whatcom County
Elevated nitrate concentrations in the aquifer are due to agricultural practices on both sides of the border.

The concentrations can exceed the US-EPA maximum contaminant level (MCL) of 10 mg-N/L.

Well water with nitrate greater than 10 mg-N/L is not safe to drink.
Nutrient management in Whatcom County is difficult to assess because of nitrate transport from BC.
International Mitigation Strategy

In 1992 the Abbotsford-Sumas International Task Force was formed to coordinate groundwater protection efforts in the aquifer.

Members represent government agencies, tribes, cities and counties on both side of the border. Their goals are to

- Collect and Coordination Scientific Data
- Manage Activities Threatening the Aquifer
- Assist with Legislation and Policy Advice