CHAPTER 7

GROUNDWATER QUALITY

Groundwater quality is of equal importance to quantity.

SOURCES OF SALINITY

1. **Solution of rock materials**

   Dissolved martials by:

   a. weathering

   b. erosion

   c. Solution

- **Rocks Type:**

  Igneous rocks - small salinity

  Sedimentary rocks - moderate salinity

  Limestone rocks - $CaCO_3$ dissolved

2. Precipitation (Acid Rain)

- SO_2 and NO_2 emitted from industrial areas and CO_2 gas dissolved

- These react with water and produce H_2SO_4, HNO_3, and H_2CO_3 (carbonic acid). These increase solvent action of water.

- This water after infiltrating the GW changes quality.

3. Connate Waters

- **Pockets of residual water entrapped in sedimentary rocks; highly mineralized.**

4. Hot Springs

- **Mineralized water; gases absorbed of magmatic origin contribute to dissolved minerals.**

5. **Seawater Intrusion**

6. **Fertilizers**

- **Movement w/water below root zone**

Measures of Groundwater Quality

1. **Chemical analysis**
   - **concentration of dissolved salt, pH**
2. **Physical analysis**
   - **temperature, color, turbidity, taste, odor**
3. **Bacterial analysis**
   - **coliform organisms**

Methods of Reporting Analysis

1. Dissolved Solids

a. By weight - ppm - one part by weight of ion to a million
parts by weight of water.

b. In irrigation, tons of dissolved solids/acre-feet (taf) used .1 taf = 735 ppm

2. By Chemical Equivalence

a. Cations (+) & Anions (-) combine or dissociate in definite weight ratios.

1 equiv. weight cation $\rightleftarrows$ 1 eq. wt. of anion

$$\text{Eq. wt.} = \frac{\text{atomic weight}}{\text{valence}}$$

Eq. wt. of H = 1

Eq. wt. in grams (or gm eq. wt.) of an ion or compound is that wt. in gm. that replaces one gm. of hydrogen.

$$\frac{1}{1000}\, gm \text{ Eq. wt.}/\ell \rightarrow 1 \text{ m eq}/\ell = 1\, epm$$

or

$$1(me/\ell) \rightarrow \text{milli equiv./lit.} = 1 \text{ equiv. per mil}$$

$$1 \text{ m eq}/\ell = \frac{\text{ppm of ion}}{\text{eq. wt. of ion}}$$

3. By Electrical Conductivity

- **a. TDS - Total dissolved solids**
- **b. mho – conductance**
- **c. ohm – resistance**

$$\text{cond.}\,(\text{moh}) = \frac{1}{\text{res.}(\text{ohm})}$$

Since most natural waters have conductivity

1 mho/cm, use fraction unit.

- **milli mhos → x 10^{-3}**
- **micro mhos → x 10^{-6}**
- **EC - electrical conductivity**

EC = f(Temp.)

- **Standard temp. = 25° C. for Lab reporting**
- **EC for natural water - 100 to 5000 μ mho/cm at 25° C.**

Approximate relationship between EC and concentration of water.

1 ppm = 1.56 EC x 10^6

Major constitutents of GW

(1 - 1000 ppm)

Cations	Anions
Na	(H C_{03})
Ca	S_{04}
Mg	Cl
	Si (silica)

Secondary Constitutents

(0.1 - 1.0 ppm)

Fe	C_{03}
Sr	N_{03}
K	**B (Boron)**

Minor trace constitutents

(.0001 - 0.1 ppm)	(<0.1 ppm)
Antimony	Cadmium
Aluminum	Chromium
Arsenic	Cobalt
Barium	Copper
Bromide	Iodide
Cesium	Lead
	Zinc

4. Total Hardness (TH)

A measure of Ca + Mg content and expressed as equivalent of $CaCO_3$.

$$TH = Ca \times \frac{CaCo_3}{Ca} + Mg \times \frac{CaCo_3}{Mg}$$

ppm ppm m eq/l ppm m eq/l

(const.) (const.)

ratio of eq. wts.

$$TH = 2.497Ca + 4.115\ Mg$$

TYPICAL SEA WATER ANALYSIS

varies -- circulation, depth, etc.

Cations	ppm
Na	10,710*
K	390
Ca	420
Mg	1,300
Anions	ppm
So_4	2,700
Cl	19,350*
Bromide	60
Co_3	70
	35,000

*Na cl makes most of conc. of sea water.

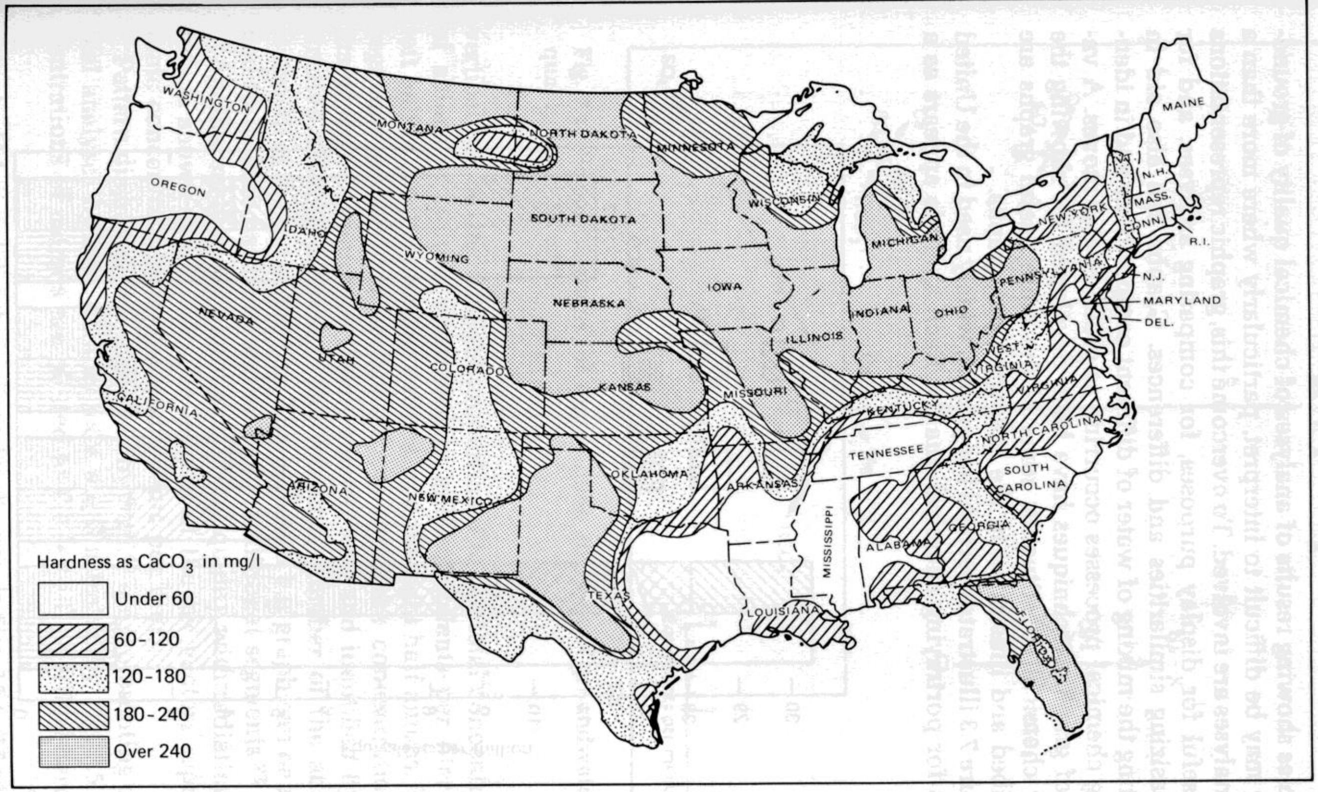


Fig. 7.2 Hardness of groundwater in the United States. Areas delineated represent average conditions on a generalized basis (after Ackerman and Löf, *Technology in American Water Development*, Resources for the Future; copyright © 1959 by The Johns Hopkins University Press).

QUALITY MAPS

1. **Symbols**
2. **Lines of equal cone.**
3. **Shading by categories**

Diagrams of Water Quality

1- Bar Diagram – used by USGS (Ham, 1959)

2- Trilinear Diagram – (Piper, 1953)

$$\frac{Cl}{(CO_3 + HCO_3)}$$

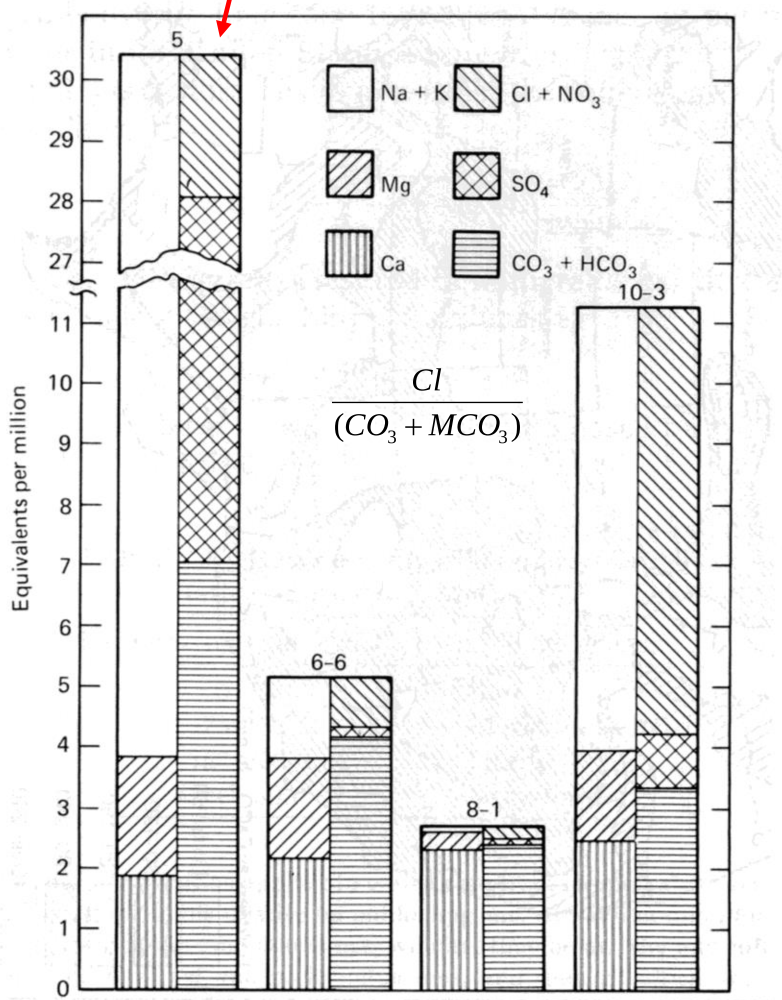


Fig. 7.3 Vertical bar graphs for representing analyses of groundwater quality (after Hem[23]).

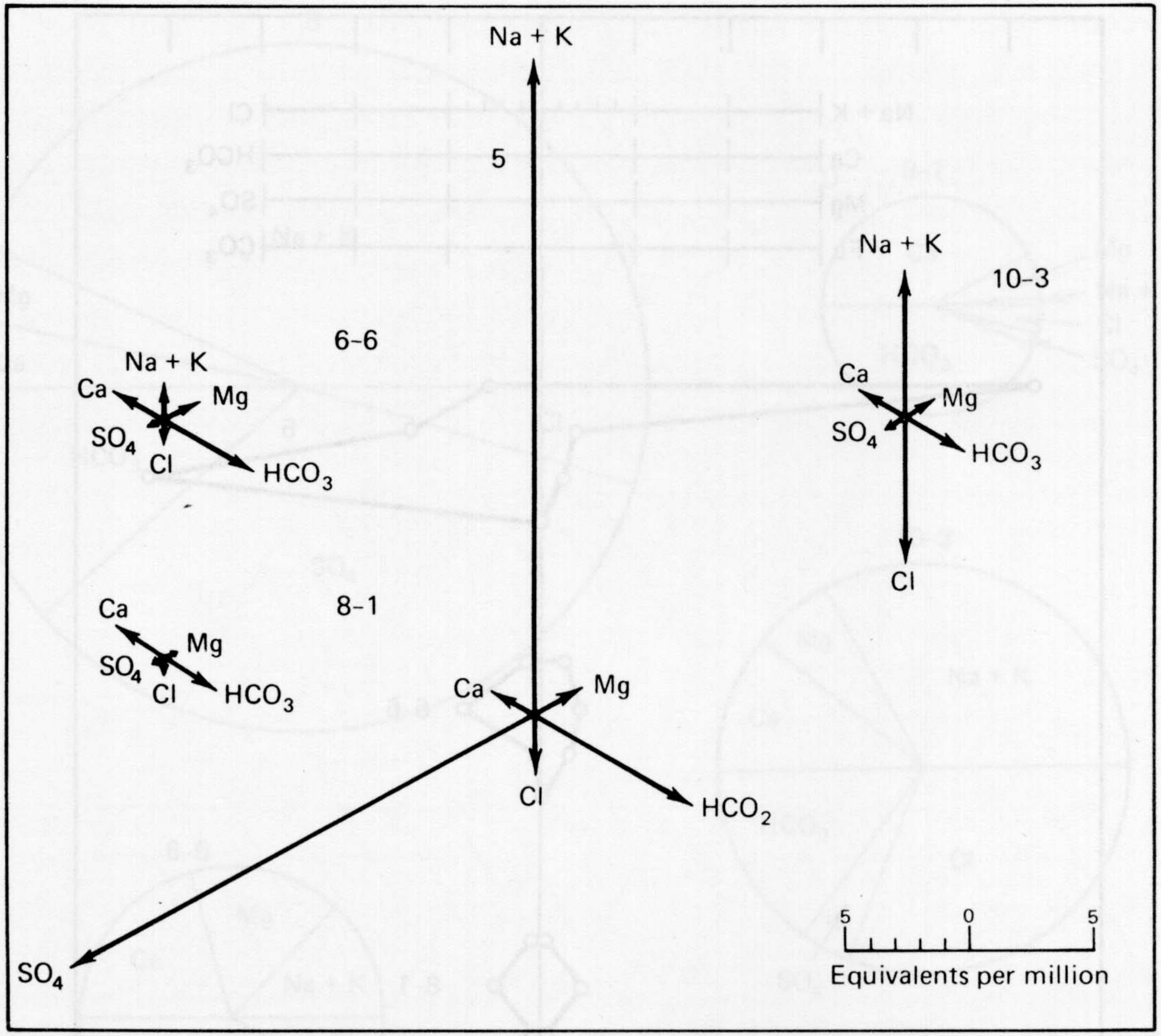


Fig. 7.4 Vector diagrams for representing analyses of groundwater quality (after Hem[23]).

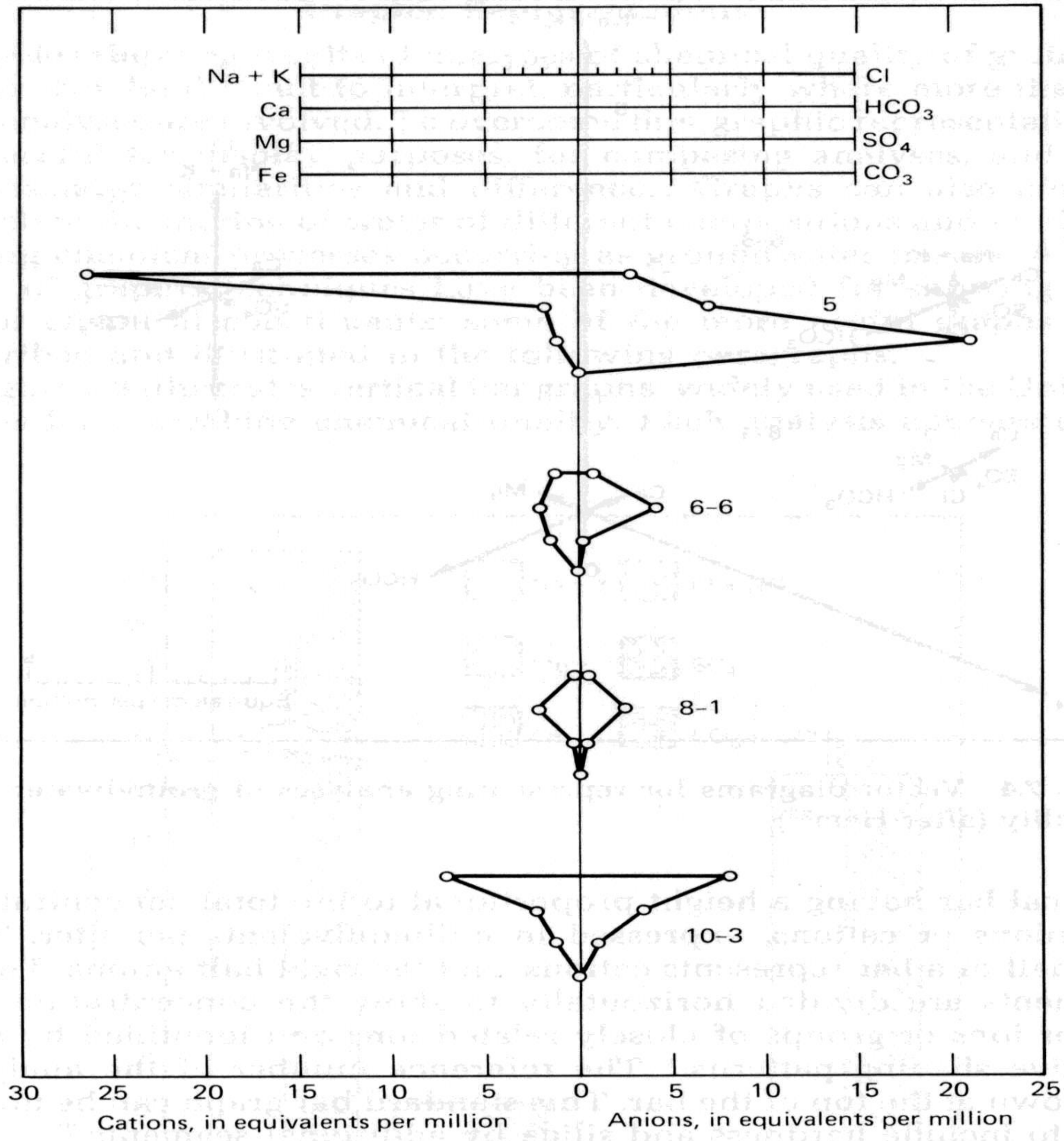


Fig. 7.5 Pattern diagrams for representing analyses of groundwater quality (after Hem[23]).

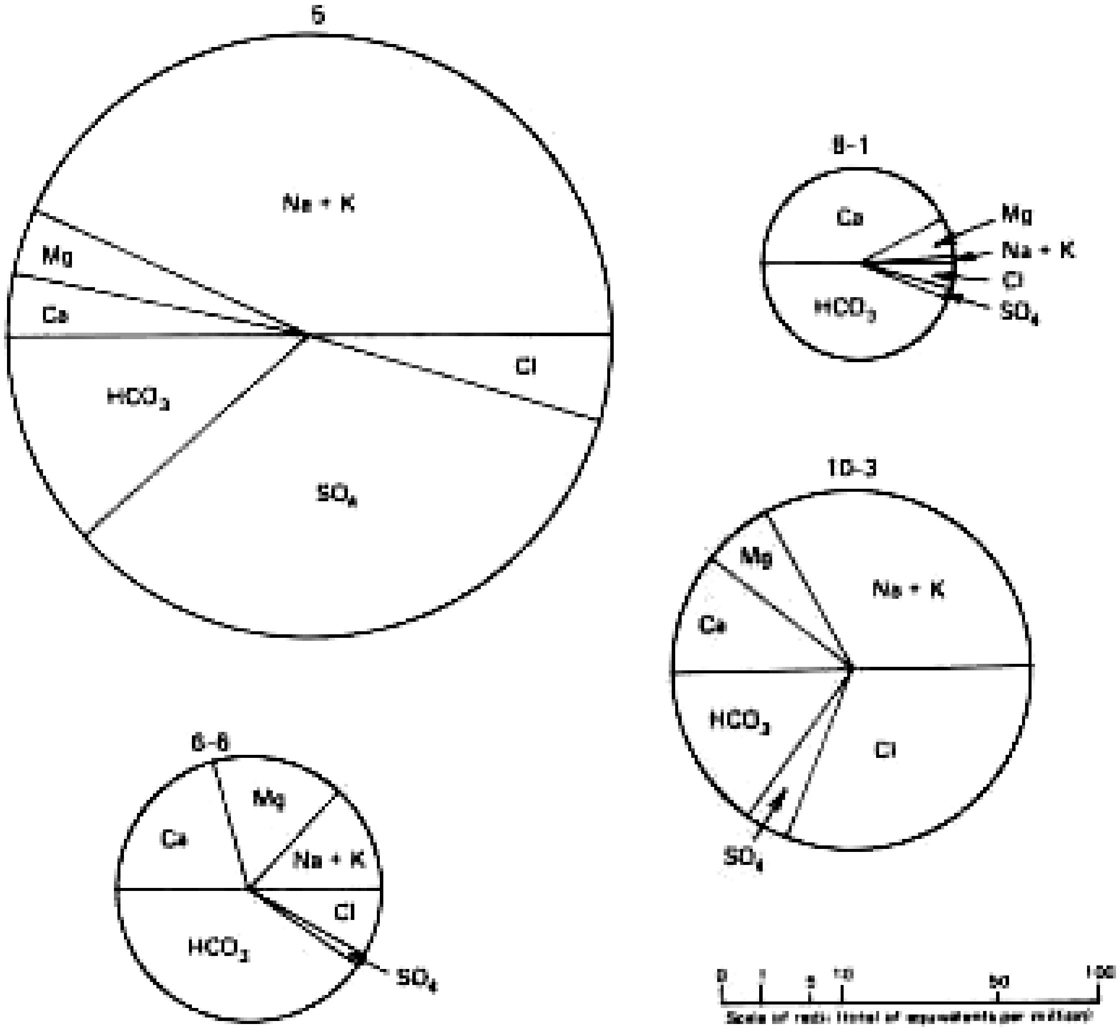


Fig. 7.6 Circular diagrams for representing analyses of groundwater quality (after Hem[21]).

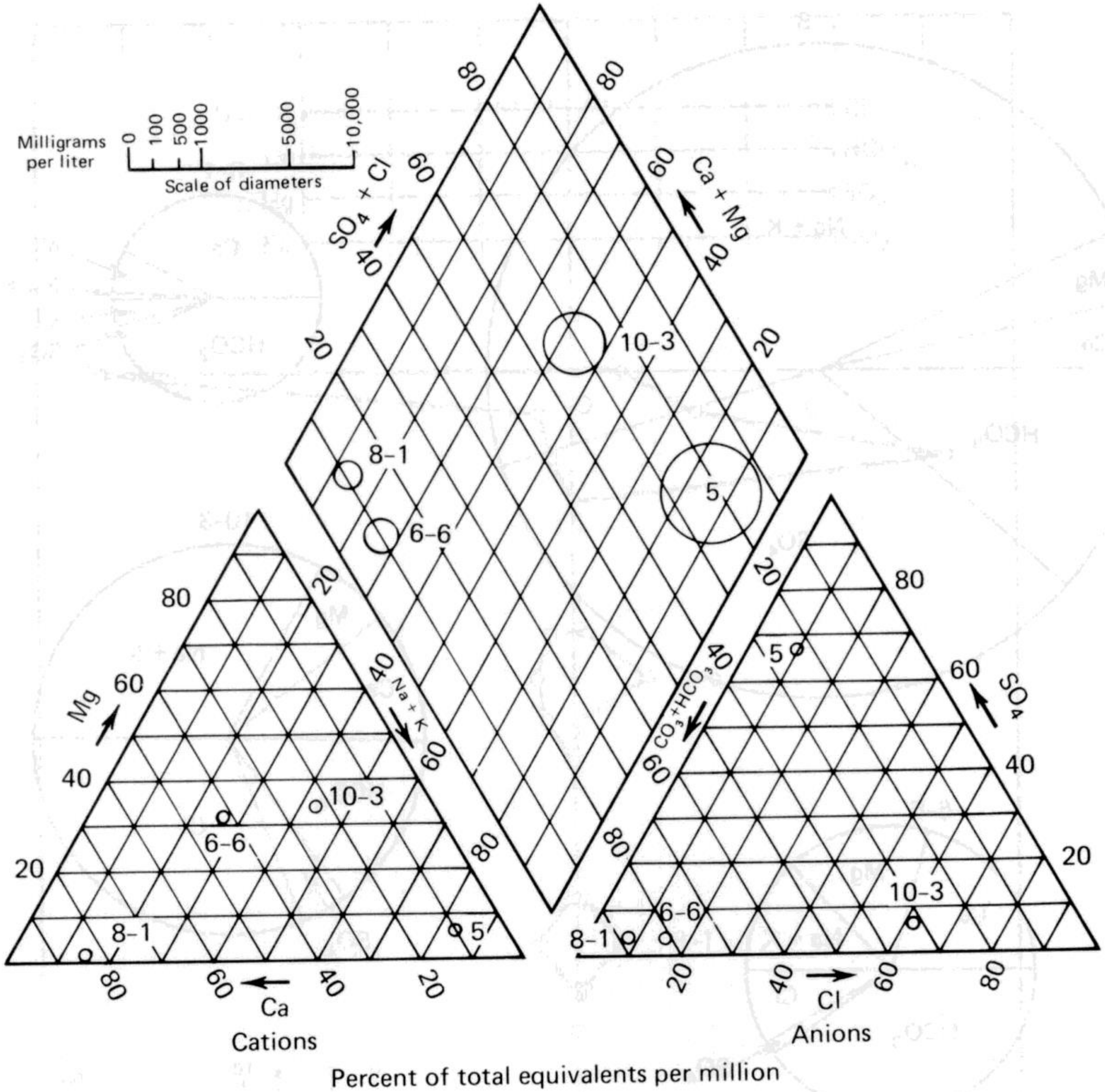


Fig. 7.7 Trilinear diagram for representing analyses of groundwater quality (after Hem[23]).

Trilinear Diagram

a. **Plot Cation and Anion groups in lower triangles by two pointes**

b. **Central diamond field used to show over all character of GW by third point, intersecting rays of the two points**

c. **Central point by circle whose diameter $\propto$ to absolute conc. of water**

IRRIGATION WATER QUALITY

Drinking Standards Table 7.6

Industrial Standards Table 7.7

1. **Water quality based on**

   a. **Total salt conc. of water (TDS)**

   b. **Conc. of toxic ions (Boron)**

   c. **conc. of cations causing defloculation of clay in soil. This results in changes in soil structure, decrease in permeability, and aeration → affecting the plant growth (Na).**

2- Soils containing large Na with carbonate (Co_3) → alkali soils

Soils containing large Na with Cl or S_{04} → saline soils
Criteria –

Percent Na = $$\frac{(Na + K)100}{(Ca + Mg + Na + K)}$$ **(measured in m eq/l)**

3- SAR (Sodium Adsorption Ratio)

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$

(measured in m eq/l)

Water	SAR
Excellent	< 10
Good	10 - 18
Fair	18 - 26
Poor	> 26

Boron	ppm
Sensitive	< .33
Semitolerant	< .67
Tolerant	<1.00

4. **Variables for irrigation water**

   a. **Water quality - TDS, Na, Boron**

   b. **Type of Crop**

   c. **Climate**

   d. **Soil (permeability and drainage)**

5. Tolerance of crops to saline water

Fruits → Vegetables → Forage → Field crop

Low tolerance → High tolerance

IRRIGATION WATER CLASSIFICATION

Water Class	% Na	TDS, EC X10^6	Boron, ppm Sensitive/Semitolerant
Excellent	<20	<250	0.3 - 1.0
Good	20 - 40	250-750	
Permissible	40 - 60	750-2000	
Doubtful	60 - 80	2000 - 3000	
Unsuitable	>80	>3000	1.25 - 3.75

*** Poorest single factor governing criteria of water class:**

a. High Na content - clay defloculation and reduced permeability $\rightarrow$ Scaling of pores with clay.

b. Low Na content - clay floculated; better drainability.

$CaSo_4$ (gypsum) added to soils and Na cations exchanged with Ca. This improves drainability. This exchange process known as *Base Exchange*.

Cl is a major constitutent of sea water.

HC_{03} is a minor constitutent of sea water, but abundant in fresh ground water.

$$\frac{Cl}{(C_{03} + HC_{03})}$$ **– indication of mixing of seawater with F.W.**

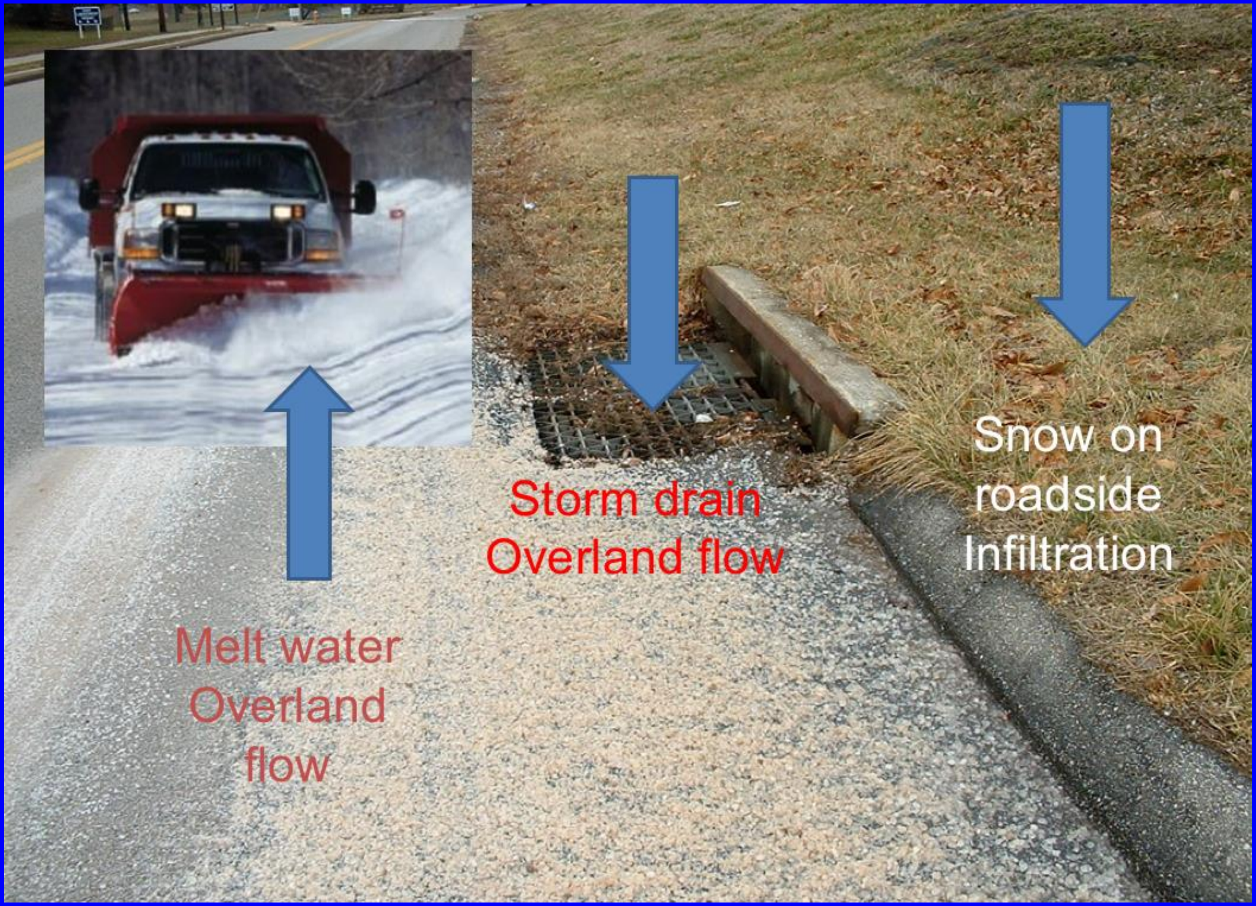
CHAPTER 8

POLLUTION of GROUNDWATER

GROUNDWATER CONTAMINATION

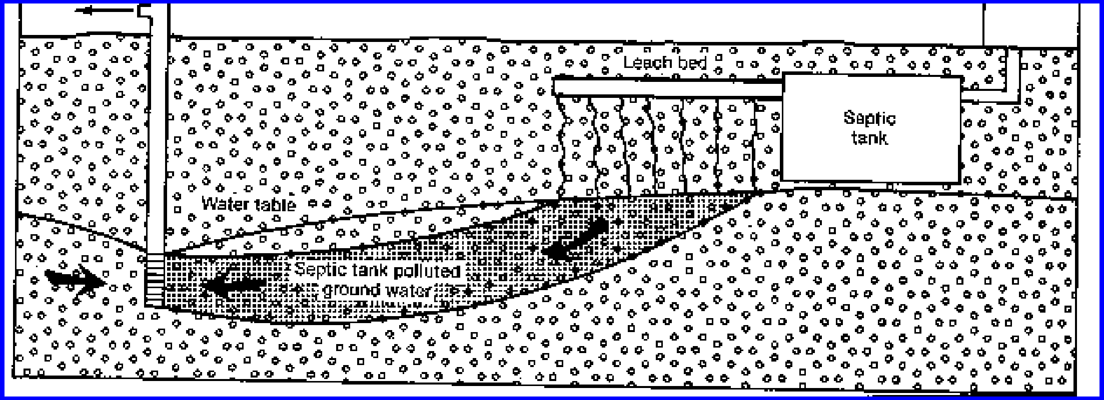
11 Causes of Contamination

1. Road salt



GROUNDWATER CONTAMINATION

2. Sewage and sludge



- septic tanks
- cesspools
- crop irrigation with sewage
- land - treatment system

-- recharge of sewage (secondary effluent)

- sludge

-- dry sewage sludge or sludge slurries

having 5% solids applied to land or soil conditioner or fertilizer

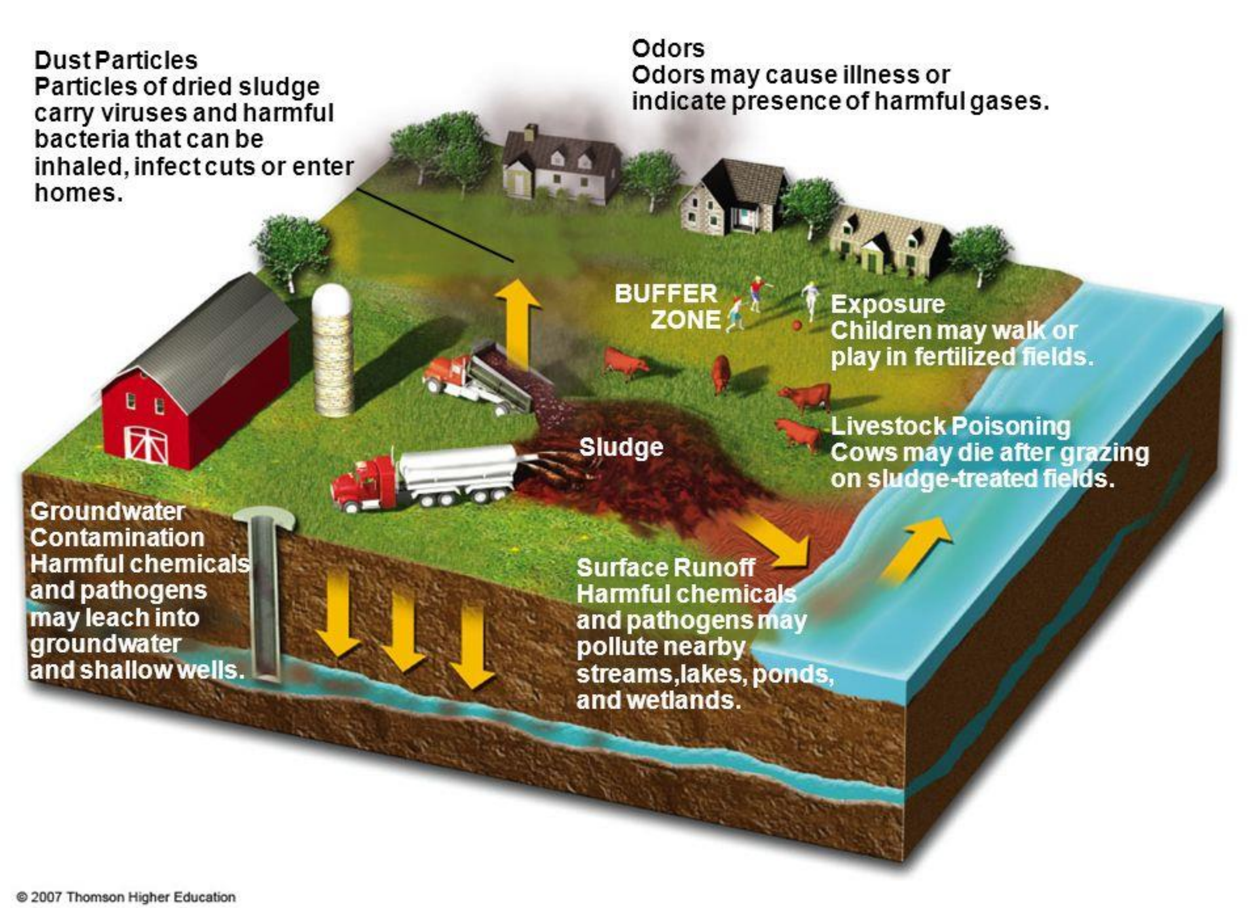
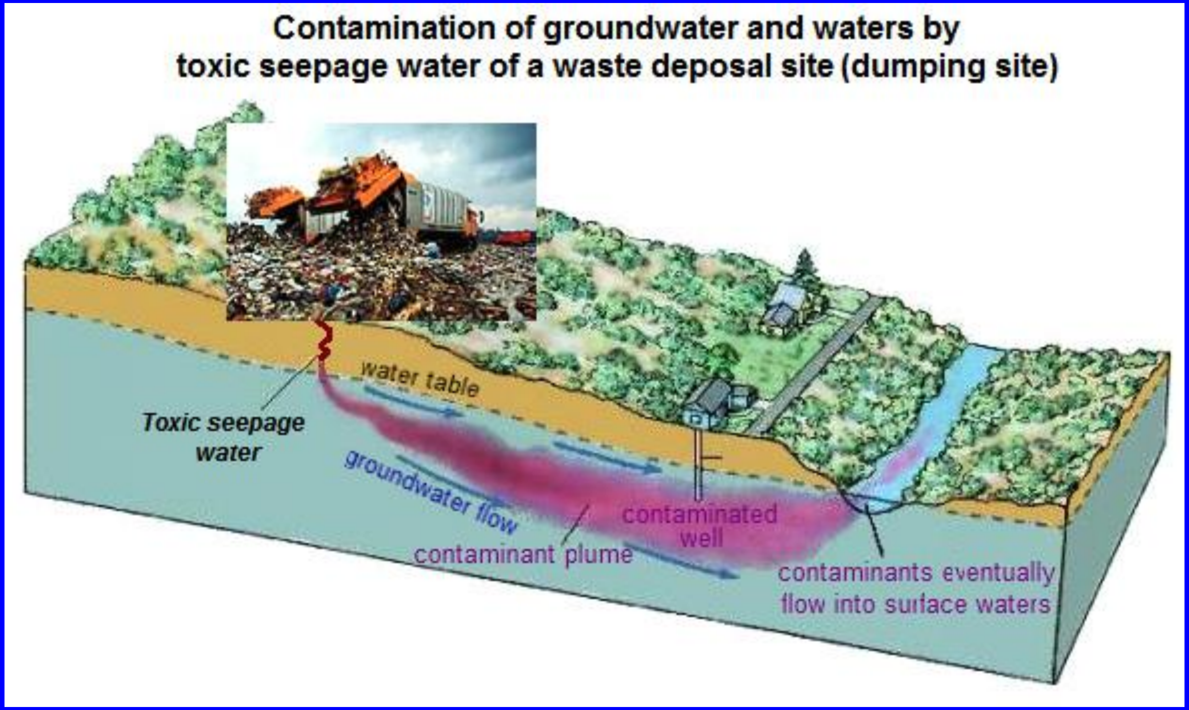


Fig. 21-17, p. 513

4. Cemeteries

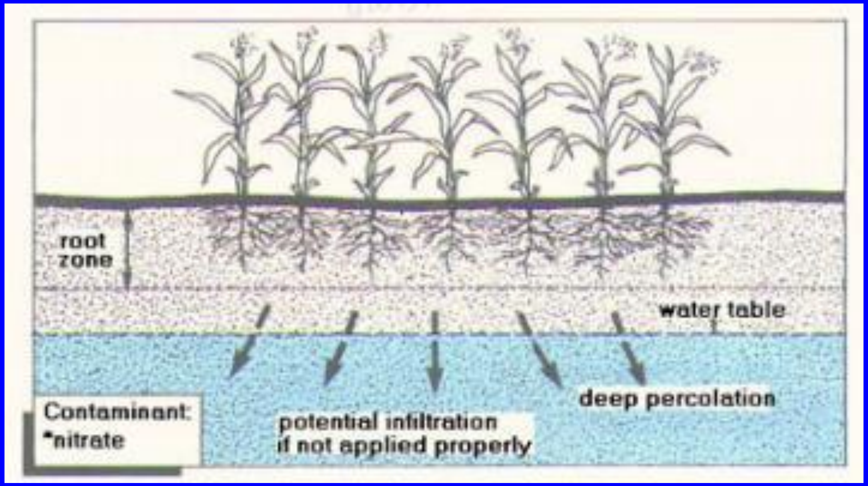
3. Solid waste

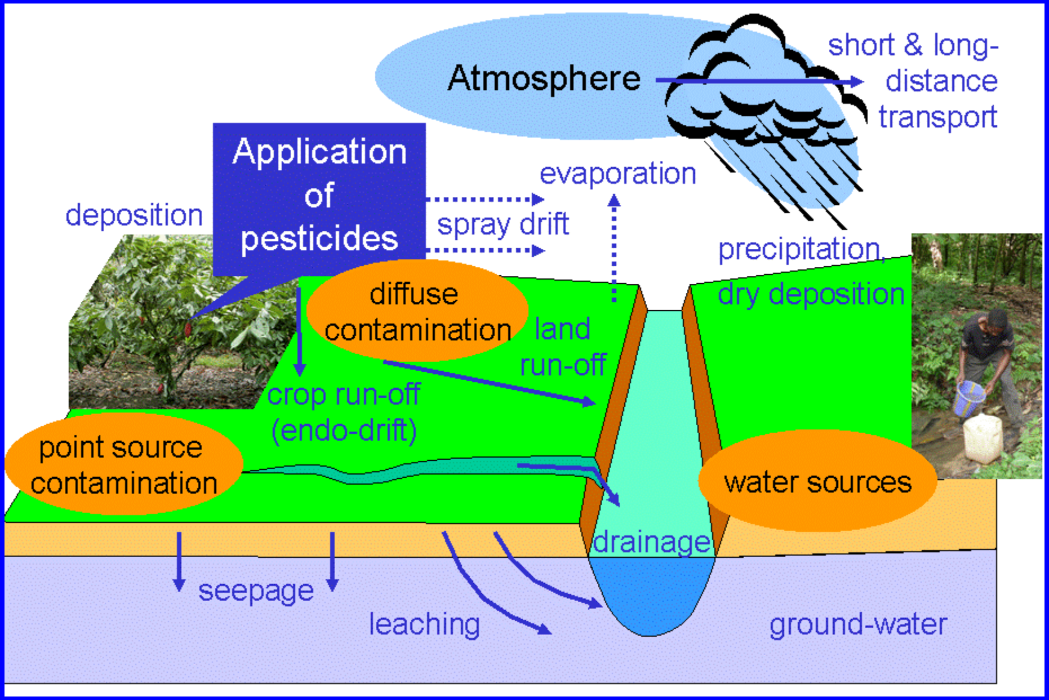
- landfills
  - Garbage & industrial waste disposed in landfills where they decompose and produce leachate



5. Agriculture

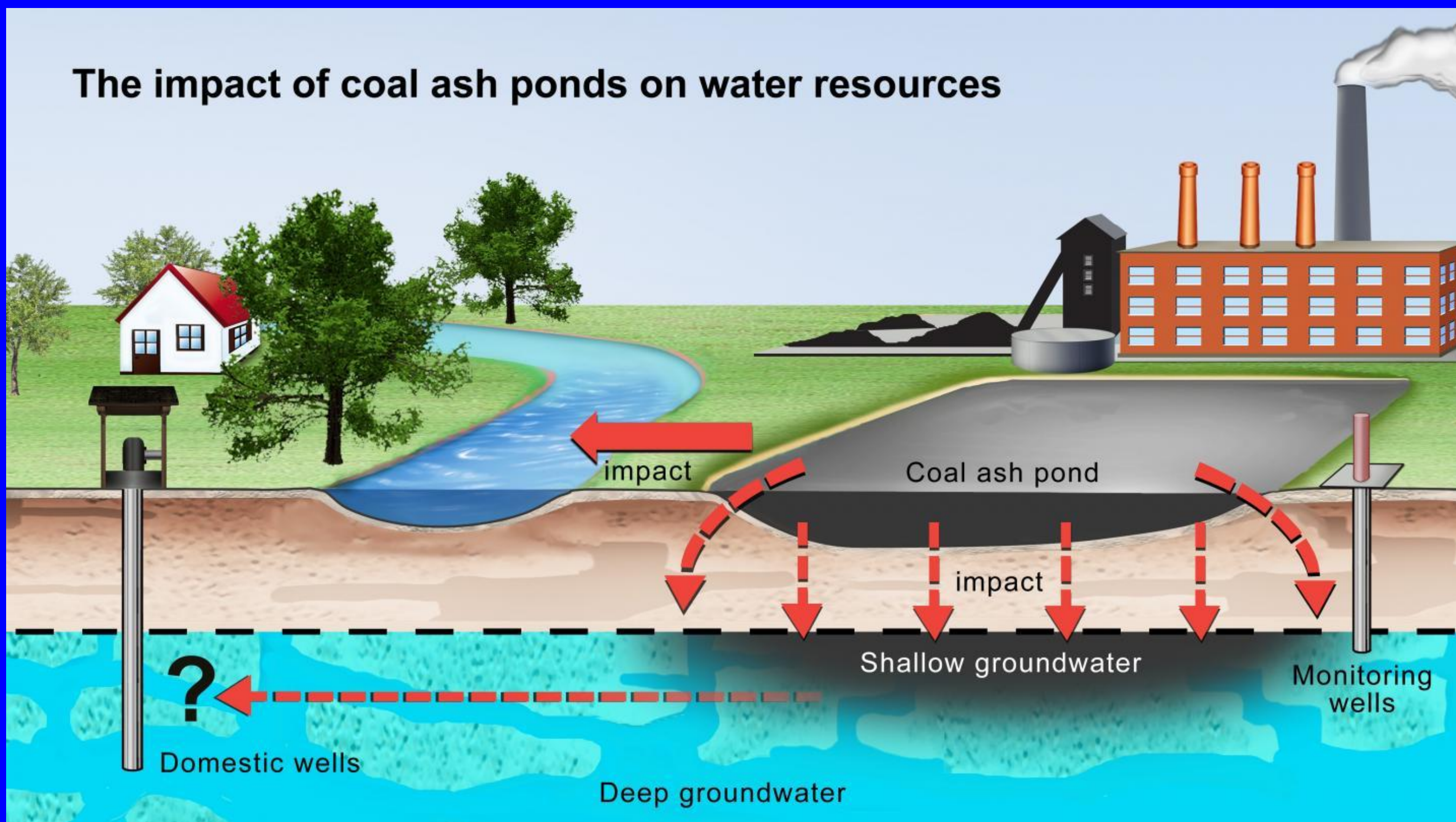
- Fertilizers
- Pesticides





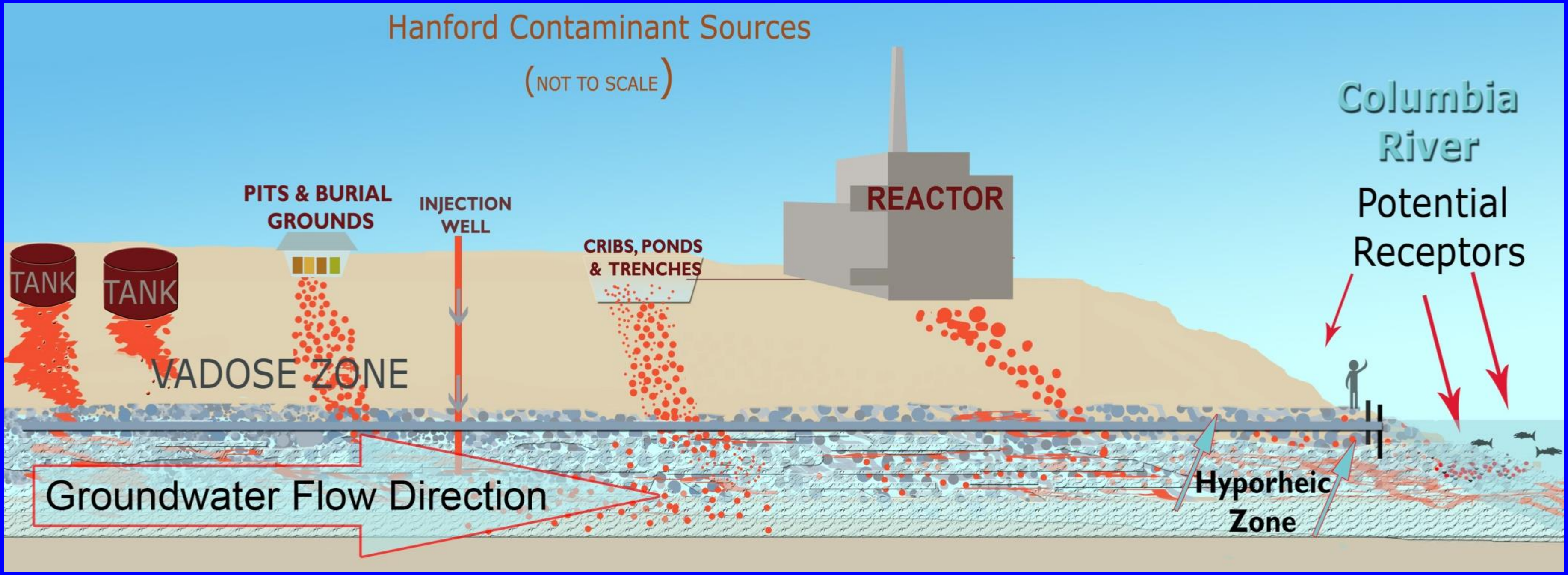
6. Mining

- Coal
- Metals
- Uranium
- Phosphate



7. Disposal of radioactive wastes

- Safe storage of radioactive wastes is a major problem with operation of nuclear reactors for power generation and where radioactive materials produced or used.



- **Radioactive wastes will be disposed in 6 subsurface repositories, to be ready after the year 2000. Waste disposal in salt and salt domes, brine aquifers, thick shale or clay sequences, dry mines in granite or desert hills, and unsaturated zone in arid regions.**

8. Underground storage of liquid wastes

Love cannel (Pollution disaster, 1940, Hooker Electrochemical Company)

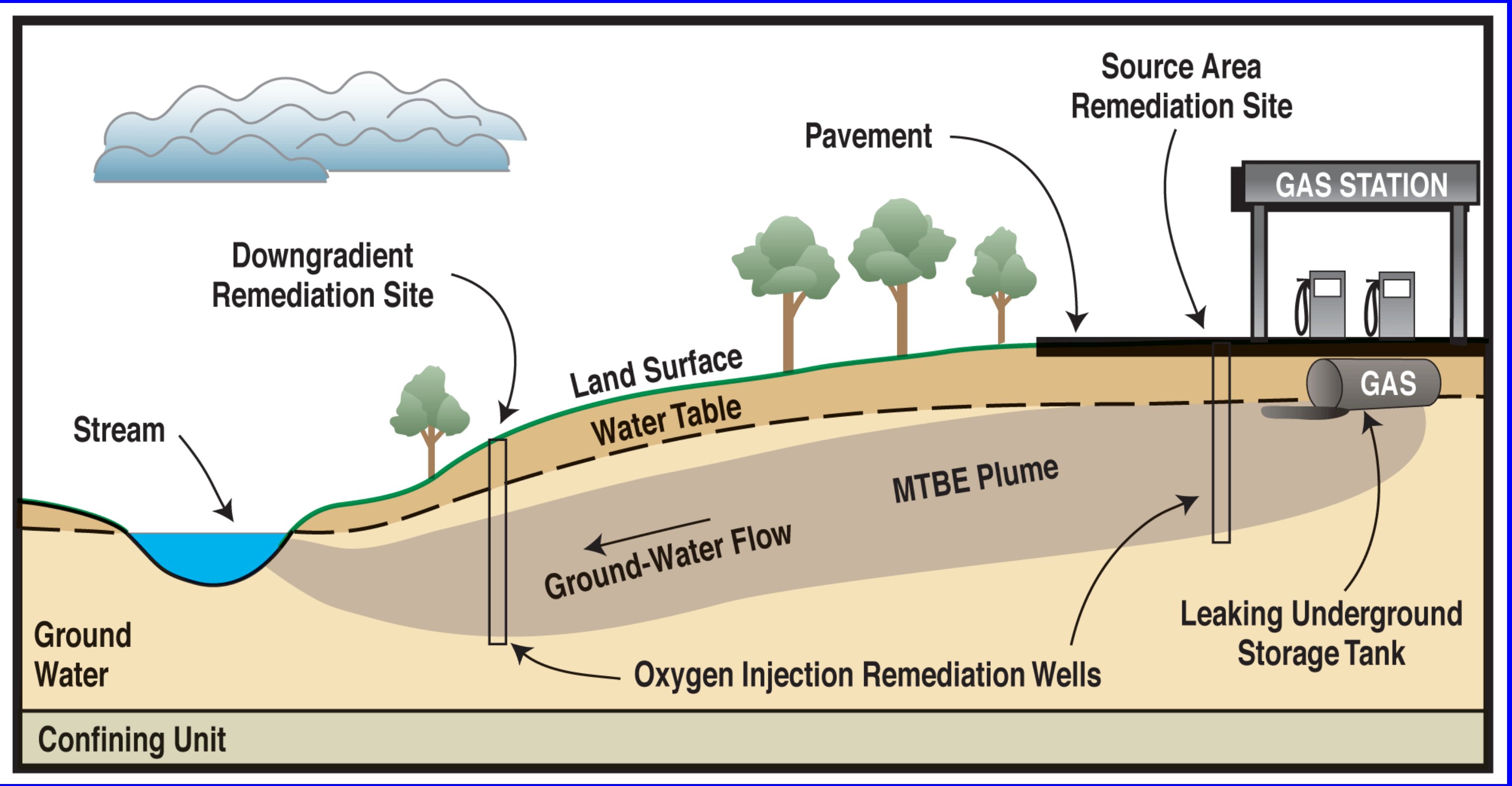
- **By deep-welling injection practiced primarily by chemical petrochemical and pharmaceutical industries, and to a lesser extent by refineries, gas plants, and metal industries. Total # of industrial waste-injection wells = 278, excluding oil-field brine return wells.**

9. **Lagoons and evaporation ponds**

- **Used to treat or dispose industrial wastes**

10. Oil leaks and spills

Gasoline and other petroleum products enter soil and aquifers from leaking pipelines or storage tanks. Most contamination cases from underground tanks at gas stations.



11. Urban runoff and polluted surface water

- Streams receive municipal and industrial wastewater. Seepage of such water into underlying groundwater may adversely affect groundwater quality.