Hazardous waste management

Hazardous waste management

- Introduction to hazardous wastes
- Hazardous waste regulation in the US
- Soil and groundwater remediation techniques
  - In-situ and ex-situ technologies
  - Physical, chemical, and biological processes

Hazardous wastes

- Any waste or combination of wastes that poses a substantial danger, now or in the future, to human, plant, or animal life
- Must be handled or disposed of with special precautions

Hazardous wastes

Consequences of failure to manage hazardous wastes

Some examples of hazardous wastes

- Dioxins
  - Refers to 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (2,3,7,8-TCDD), or to the family of a chemical group called polychlorinated dibenzo-*p*-dioxins (PCDDs)
  - By-product that may be generated during the manufacture and burning of chlorophenols, 2,4,5-T, etc. or from waste incineration

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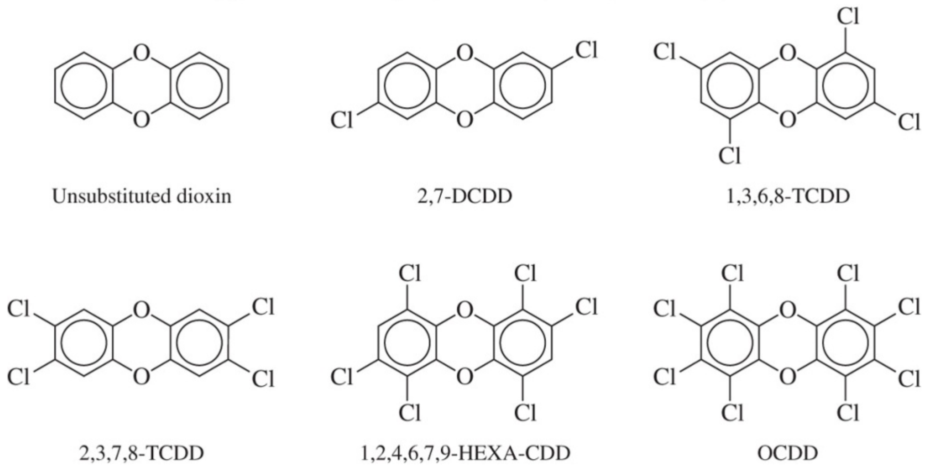

Examples of PCDDs

Toxicity of TCDD and other dioxins

- 2,3,7,8-TCDD is probably the most poisonous of all synthetic chemicals
- 2,3,7,8-TCDD is a “known” human carcinogen, and other dioxins are “likely” human carcinogens

Table. Approximate acute LD_{50}s of some chemical agents

Agent	**LD_{50} (mg/kg)**	**Agent**	**LD_{50} (mg/kg)**
Ethyl alcohol	10000	Hemicholinium-3	0.2
Sodium chloride	4000	Tetrodotoxin	0.1
Morphine sulfate	1500	2,3,7,8-TCDD	0.001
Nicotine	1	Botulinum toxin	0.00001

Some examples of hazardous wastes

- Polychlorinated biphenyls (PCBs)
  - A class of organic chemicals produced by the chlorination of a biphenyl molecule
  - 209 “congeners” exist

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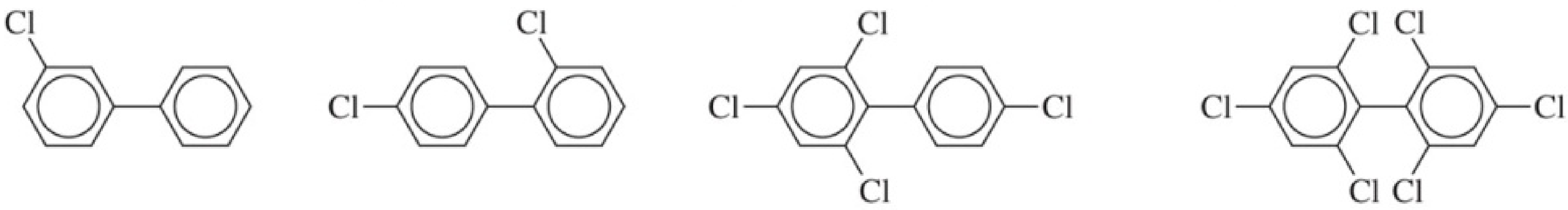


3-Chlorobiphenyl 2,4′-Dichlorobiphenyl 2,4,4′,6-Tetrachlorobiphenyl 2,2′,4,4′,6,6′-Hexachlorobiphenyl

Examples of PCBs

Polychlorinated biphenyls (PCBs)

- Used as coolants, lubricants, and coating materials until the 1970s
- PCB manufacture and use were banned in the 1970s in developed countries
- Chronic exposure could result in hazards to human health and the environment (PCBs are "likely" human carcinogen and endocrine disrupting compound)

Regulation for hazardous wastes (US)

- Resource Conservation and Recovery Act (RCRA)
  - Passed Congress in 1976
  - Amended in 1984 by the Hazardous and Solid Waste Amendments (HSWA)
  - A cradle-to-grave system for the management of hazardous waste: tracks whole life cycle (generation, transportation, treatment, storage, and disposal)
  - Requires permits for the treatment, storage, or disposal
  - Applies mainly to **active facilities** but <u>not for abandoned or closed waste disposal sites or spills</u>

Regulation for hazardous wastes (US)

- Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA; 1980)
  - Enacted in 1980
  - Commonly referred to as “Superfund” act
  - Addresses inactive or abandoned hazardous waste disposal sites
  - Extended in 1986 by the Superfund Amendments and Reauthorization Act (SARA)

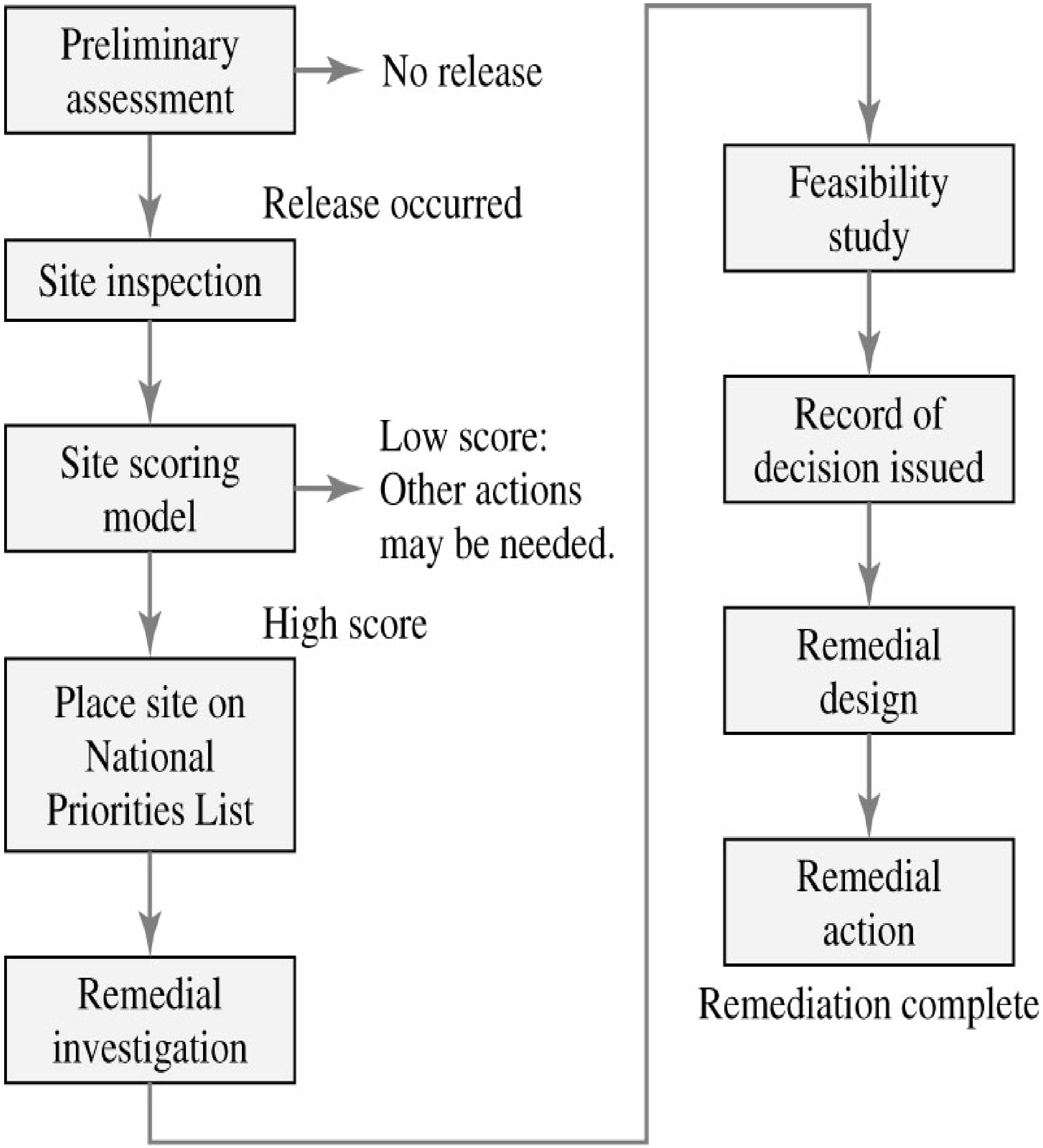
CERCLA

- Major provisions
  - Generate a fund (the “Superfund”) to pay for investigations and remediation at sites where the responsive people cannot be found or will not voluntarily pay
  - A priority list of abandoned or inactive hazardous waste sites for cleanup (“the National Priority List”)
  - The mechanism for action at abandoned or inactive sites (the “National Contingency Plan”)
  - Liability for those responsible for cleaning up

CERCLA - NPL

- National Priority List (NPL)
  - Identify sites that appear to present a significant risk to public health or the environment
  - To wisely use the Superfund money
  - Use “Hazard Ranking System (HRS)” to estimate the potential hazard to a score (added to the list if HRS score $\geq$ 28.50)
  - Updated three times a year: new sites are added to the list and sites are deleted from the list when remediation is completed
  - 1322 sites in the list in October 2014

Superfund cleanup process summary



Soil and groundwater remediation techniques

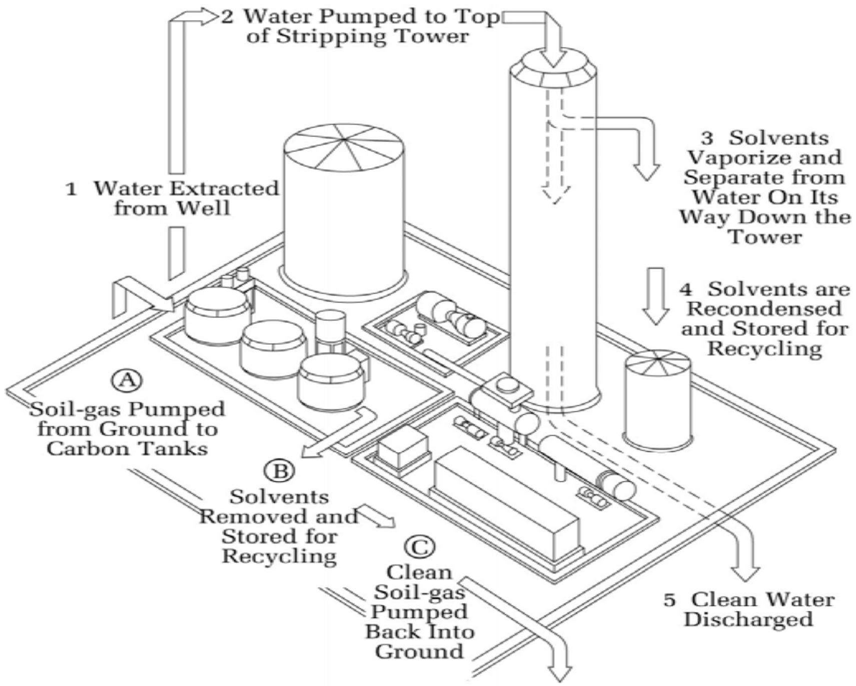
- In-situ vs. ex-situ
  - **In-situ**: does not involve soil excavation; soil is treated at the site of contamination
    - Advantage: generally lower cost, ground surface may be utilized during remediation, treated soil maintains its function at the site after remediation
    - Disadvantage: relatively complicated, monitoring is not easy, efficiency may be limited by material transport and mass transfer

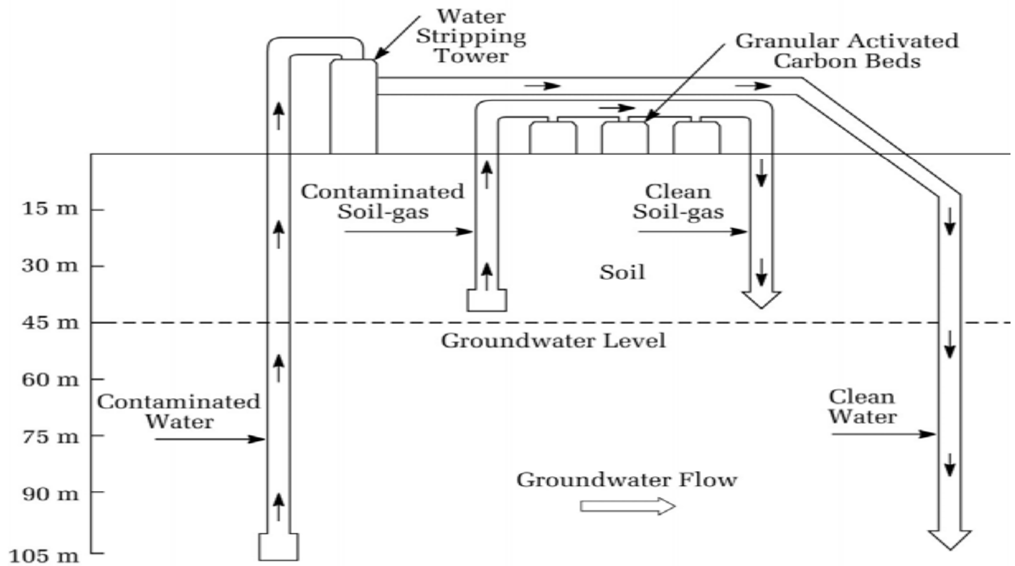
Soil and groundwater remediation techniques

- **Ex-situ**: involves soil excavation; excavated soil is treated on the ground at the site of contamination or transported to treatment facilities
    - Advantage: simpler, people see that contaminants are removed from the site, monitoring is easy, generally better efficiency
    - Disadvantage: generally higher cost, completely changes the soil environment, need to find ways to dispose or recycle the treated soil, ground surface cannot be utilized during remediation

Pump-and-treat systems

1) pump contaminated groundwater to the surface
2) remove the contaminants
3) either recharge the treated water back into the ground or discharge it to a surface water body or municipal wastewater treatment plant





Underground View

Soil vapor extraction (SVE)

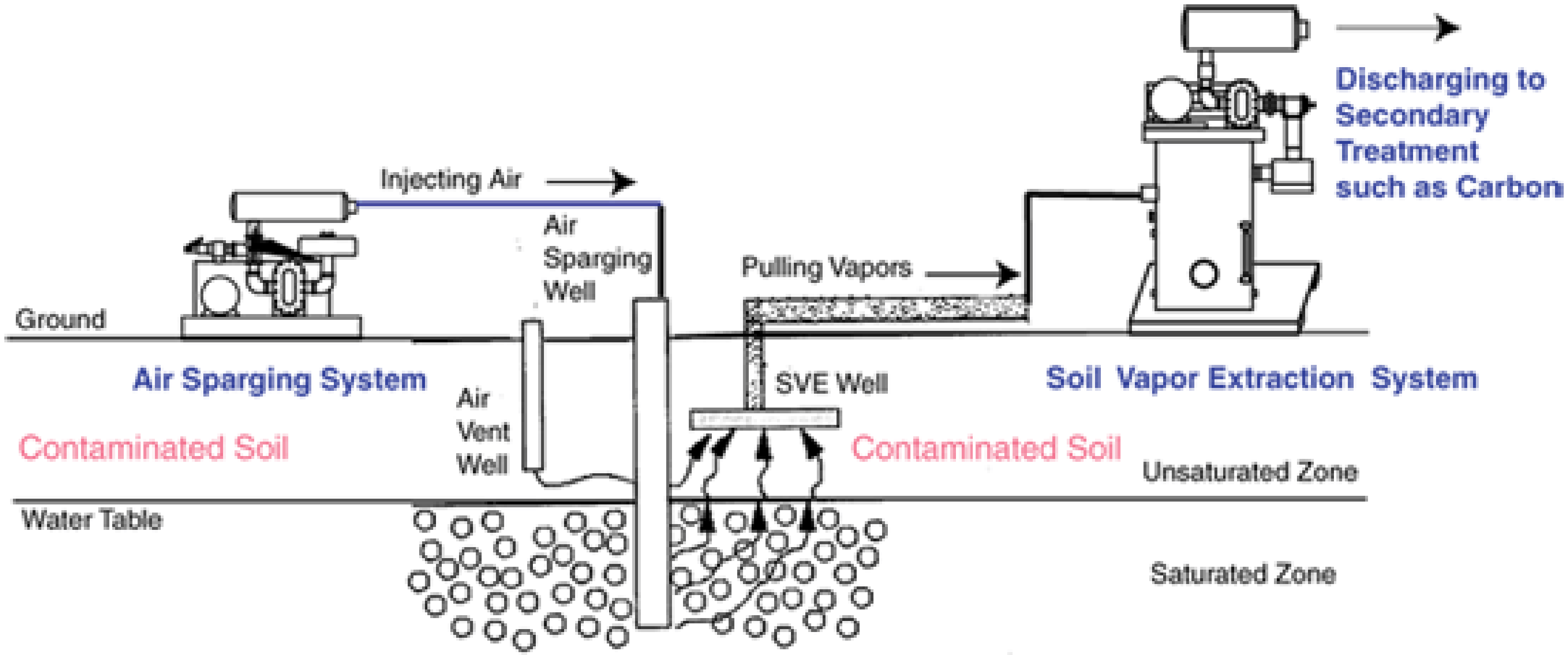
- Applied to unsaturated zone

1) Install vertical extraction wells or horizontal extraction pipes at the contaminated site
2) Apply vacuum
3) Collect volatilized contaminants
4) Treat the air containing contaminants above ground

Air sparging

- Applied to saturated zone
- Usually applied together with soil vapor extraction technique
- Inject contaminant-free air into the saturated zone to convert dissolved contaminants into vapors
- The contaminant vapor moved to the unsaturated zone is collected by the vapor extraction system
- Limitations of soil vapor extraction and air sparging: applicable to volatile compounds in high-permeability zones

SVE & air sparging

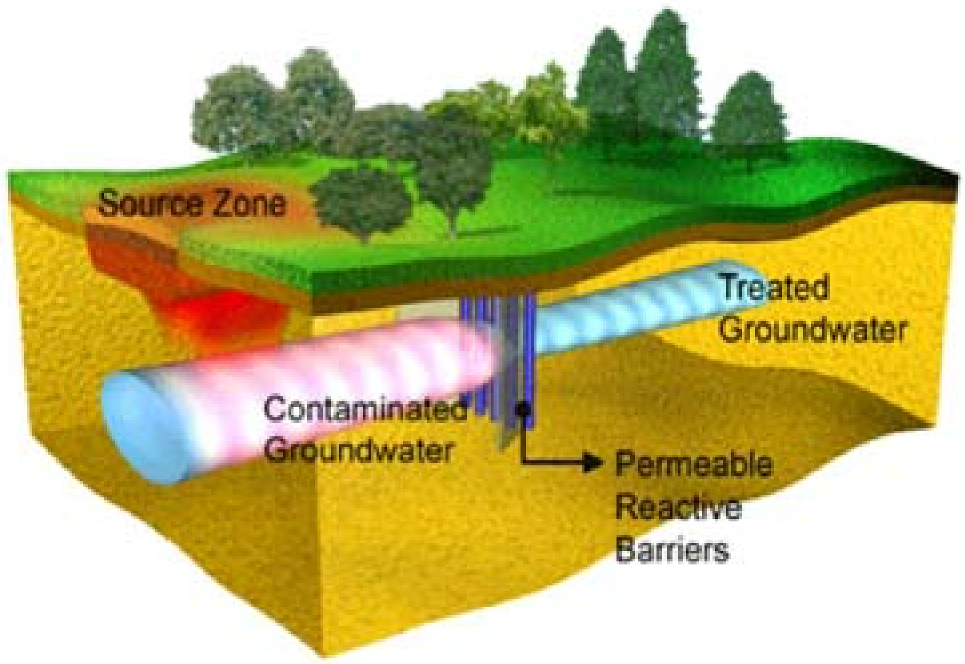


http://www.precisionenvironmentalny.com

* Limitations: applicable only to volatile compounds in high-permeability zones

Permeable reactive barrier (PRB)

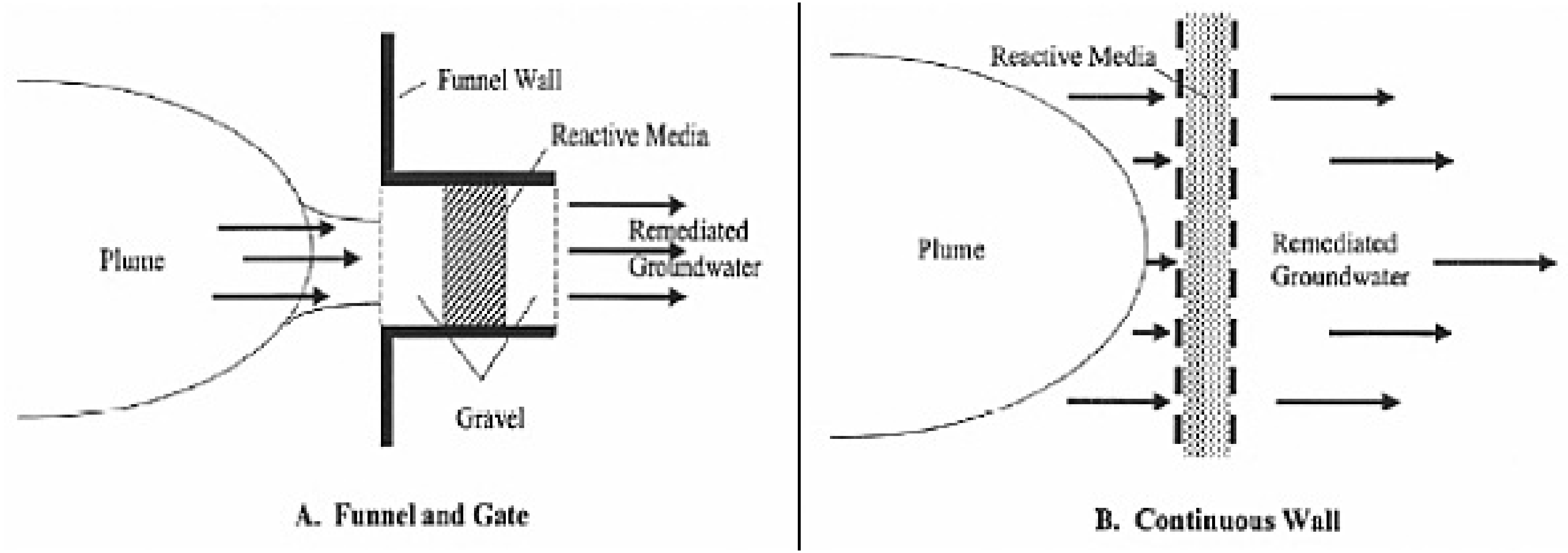
- Place reactive materials in the subsurface at the pathway of contaminated groundwater
- The contaminants in groundwater are transformed into environmentally acceptable forms



Permeable reactive barrier (PRB)

- Reactive materials
  - Zero-valent iron (ZVI; Fe^0): works for PCE, TCE, NO_3^-, and Cr^{6+}
  - Zeolite: works for NH_4^+ and heavy metals
- Advantages
  - No maintenance cost → cost-effective
  - No equipment necessary on the ground → the site can be used during remediation
- Disadvantages
  - Cannot eliminate the contaminant source
  - Do not work if the groundwater flow changes

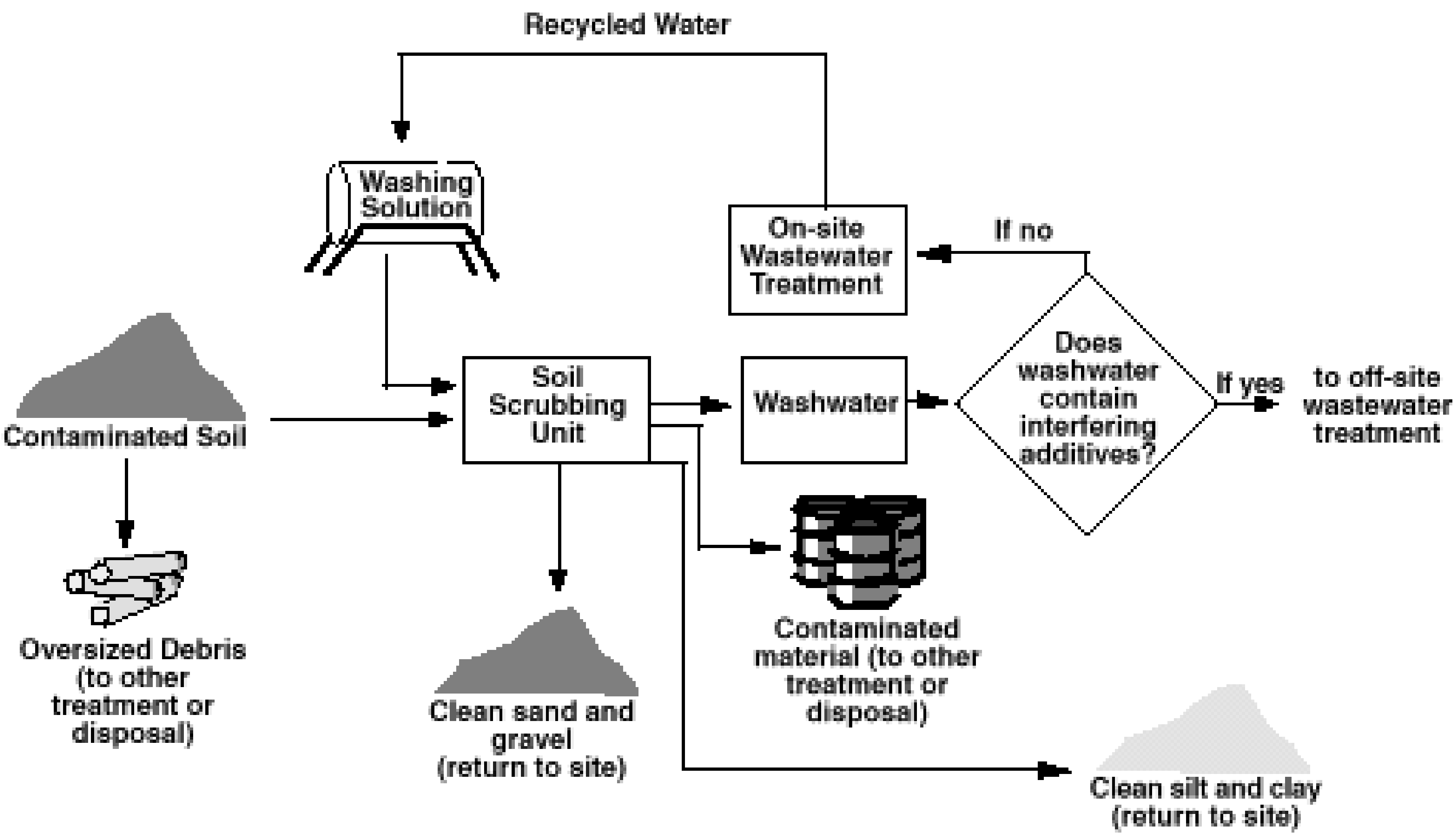
PRB configurations



http://www.geoengineer.org

Soil washing

- A mechanical process that uses liquids, usually water, to remove pollutants from soils
- The pollutants are usually attached to small particles such as silt and clay
- Pollutants are removed by i) separating silt and clay from sand or gravel and ii) transfer of contaminants from soil to water
- The wastewater should be treated; the silt and clay should be treated if contaminants are not sufficiently removed



http://infohouse.p2ric.org

Soil washing – pros and cons

- Advantages
  - Simple technique
  - The unit can be made transportable (a soil washing truck)
  - Can make sure that soil is being cleaned

- Disadvantages
  - High excavation cost
  - Additional treatment may be required for wastewater, and silt & clay

Thermal desorption

- Utilizes heat to increase the volatility of contaminants such that they can be removed from soil
- The produced gas is collected and treated
- Advantages
  - Effective for volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs)
  - Relatively fast
  - Can make sure that soil is being cleaned
- Disadvantages
  - High cost for excavation and treatment
  - Intensive use of energy

http://www.epa.gov/

Landfarming

- A type of a bioremediation treatment process
- Contaminated soils are excavated, spread on the ground, and periodically turned over (tilled) for aeration
- Good for petroleum-contaminated soils

http://www.vertasefli.co.uk/our-solutions/expertise/ex-situ-bioremediation

Landfarming – pros and cons

- Advantages
  - Relatively simple design and operation
  - Relatively rapid and inexpensive

- Disadvantages
  - May not be effective for high removal efficiencies (>95%) and high contaminant concentrations
  - Emission of volatile contaminants and dust during treatment
  - Requires a large land area for treatment

In situ bioremediation

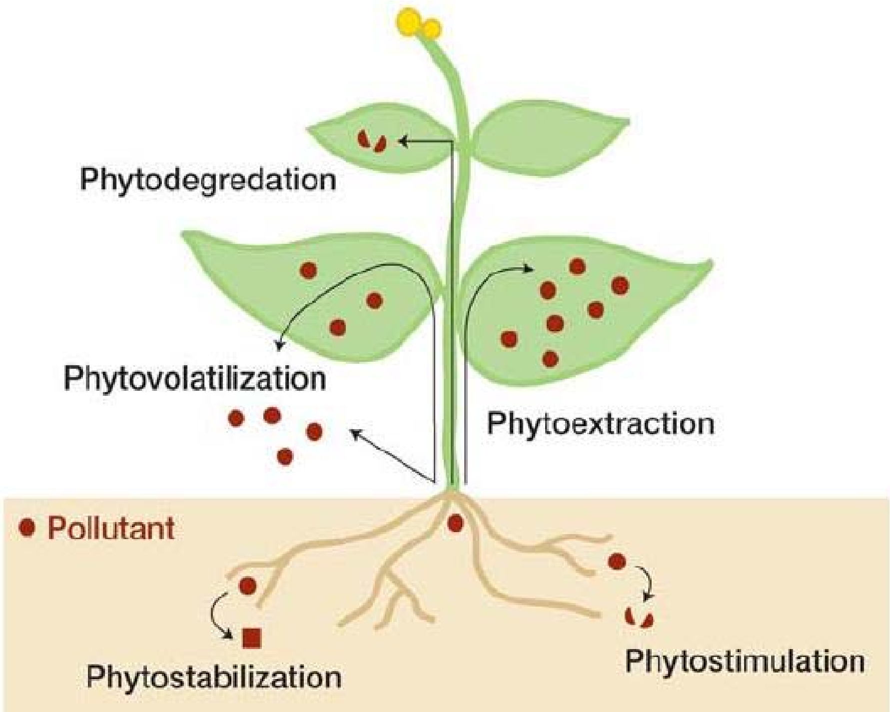
- Application of biological treatment for the in situ cleanup of hazardous chemicals present in the subsurface
- Usually for organic contaminants → needs electron acceptors (usually O_2), nutrients, and microorganisms!

In situ bioremediation approaches

- Biostimulation: providing nutrients, electron acceptors, or other chemical agents to stimulate biodegradation by microorganisms
- Bioaugmentation: injection of microorganisms that have capability of degrading target contaminants
- Bioventing and bio-sparging: application of soil vapor extraction and air sparging technology, but focus more on stimulating biodegradation by providing O_2
- Monitored natural attenuation (MNA): rely on natural processes of biodegradation with a monitoring plan

In situ bioremediation - phytoremediation

- Phytoremediation: use of green plants and their associated microorganisms for the treatment of contaminants



http://systemsbiology.usm.edu

In situ bioremediation – pros and cons

- Advantages
  - Environmentally friendly
  - Low cost, and low energy consumption
  - Toxic compounds are not just separated, but transformed to non-toxic materials
- Disadvantages
  - Slow process
  - Mostly not effective for heavy metals
  - Removal efficiency can be low
  - Knowledge gap exists for biodegradation processes in soils and groundwater

Reading assignment

Textbook Ch 14 p. 692-705