Groundwater Quality

Sources of Groundwater Contaminants

- In the broadest sense, all sources of groundwater contamination and contaminants themselves can be grouped into two major categories:
    - ✓ **naturally occurring** and artificial (**human-made**).

- Although some natural contaminants, such as arsenic and radionuclides, may have significant local or regional impacts on groundwater supplies depending on geology,
    - numerous **human-made sources** and **contaminants** have disproportionately greater negative effects on quality of groundwater resources.
- Arguably, almost **every human activity** has a potential to impact groundwater to some extent.

Sources of Groundwater Contaminants

- An exponential advancement of analytical laboratory techniques in the last decade or so has demonstrated that many **synthetic organic chemicals** are widely distributed in the environment, including in groundwater, and
    - ✓ that a considerable number of them can now be found in human tissue and organs of people living across the world.

- At the same time, a similar advancement in water treatment technologies, understanding of contaminant fate and transport, and groundwater remediation technologies is (arguably) making this fact somewhat **less alarming**.
- Strongly related to the ever-increasing public awareness of the environmental pollution is a very **rapid growth in consumption of bottled drinking water**, also across the world.

Sources of Groundwater Contaminants

- Many consumers are ready to pay premium for brands marketed as "pure spring water" or "water coming from deep pristine aquifers," so that major multinational corporations are frantically looking for groundwater resources that can be marketed as such.

- In general, there is still a lot of truth in the following statement, very much appreciated by many hydrogeologists:
  - groundwater in general is much **less vulnerable to contamination** than surface water, it is of **better quality** and thus requires much **less investment** in water supply development.
- It is, however, also true that, in general, it takes more time and it is more difficult to "cleanup" groundwater than surface water **once it becomes contaminated**.

Sources of Groundwater Contaminants

- For the most part, groundwater contamination results from the following activities, with the note that the list is far from all-inclusive:
  - ✓ Misuse and improper disposal of **liquid and solid wastes** and chemicals at commercial, industrial, agricultural, and governmental facilities, and in households
  - ✓ Illegal **dumping or abandonment** of household, commercial, or industrial chemicals
  - ✓ Accidental **spilling of chemicals** from trucks, railways, aircrafts, handling facilities, and storage tanks

- Use of road salt in winter
- Land application (disposal of wastewater treatment effluent and sludge through infiltration basins, and on land and farmland)
- **Urban runoff** from parking lots, streets, and construction sites

Sources of Groundwater Contaminants

- Improper location, design, construction, operation, or maintenance of **drinking-water wells** around agricultural, residential, municipal, commercial, and industrial and liquid and solid waste disposal facilities
- Application of fertilizers, pesticides, and insecticides in agriculture, on household lawns and gardens, and on golf courses

- Livestock feeding operations
- Atmospheric pollutants, such as airborne sulfur and nitrogen compounds,
  - which are created by smoke, aerosols, and automobile emissions, fall as acid rain, and percolate through the soil

Sources of Groundwater Contaminants

- Contaminants can reach groundwater from activities occurring on the **land surface**, such as industrial waste storage,
    - ✓from sources **below the land surface but above the water table**,
        - ✓such as septic systems,
    - ✓from structures **beneath the water table**,
        - ✓such as wells, and
- from contaminated artificial recharge water.

Point and Non-point Sources

- Probably the most frequently used definition of a point source of groundwater contamination is that it occupies a **small (limited) area at the land surface**, or in the shallow subsurface, as in the case of a leaky underground storage tank (UST).
- Such source, by the same definition, creates contaminant plume of a limited extent.

- In general, nonpoint sources refer to a **widespread** introduction of potential contaminants into the subsurface such as due to application of fertilizers over large agricultural areas.
- Point sources result from both unintentional and intentional hazardous waste disposal practices, spills, leaks, or otherwise limited in extent introduction of contaminants into the subsurface.

Point and Non-point Sources

- It is reported that hospital wastewater is 5 to 15 times more toxic than typical urban outflows.

- The main problems with hospital wastewater are the **large daily volumes produced**, the content of various **microbiological** and **chemical substances** and the fact that this wastewater is often discharged to the **sewer network system without any previous treatment**.

- Potential pollutants and contaminants in hospital wastewater that may result in groundwater pollution are pathogenic microorganisms (including antibiotic resistant bacteria), heavy metals, radioisotopes, organohalogens, pharmaceuticals and drug residues.

Point and Non-point Sources

- Landfills are also considered as an important **pollution point source of groundwater**.
- Contamination of aquifers in landfill sites has been detected in many cases around the world over the last decades.

- Usually, parameters that result in groundwater contamination are
  - ✓ **bad design** or **construction of the landfill**,
  - ✓ inappropriate selection of the installation site or
  - ✓ false characterization of the hydrogeologic regime and soil permeability, among others.

Point and Non-point Sources

- Landfill projects usually include groundwater monitoring programs (frequent samplings and analyses, groundwater elevations measurements), while in cases when there are nearby water bodies, monitoring of surface water is also required.

- Mining waste are produced during the mining of mineral resources in mines and coal mines, and are a mixture of water and powdered mineral and possibly of **heavy metals** as by-products.
- During the **excavations**, protective soil is removed and thus, the possible pollutants reach the aquifer.

Point and Non-point Sources

- Drainage water from mining is rich in metals and is known as acidic mine water.
- The excavated area is often used as **waste deposit area** after the end of mining exploitation, which also results in possible pollution of groundwater.

- **Heavy metal pollution** in groundwater due to mining activities poses a threat to human health, especially when groundwater resources are used as **drinking water supplies**.
- Non-point sources are difficult to be identified and they can cover large, extended geographical areas.

Point and Non-point Sources

- This type of sources includes natural, chemical infiltration and anthropogenic sources, such as **storm water** and **urban runoff**, **highway runoff**, and **agricultural land** (use of fertilizers).
- The use of fertilizers, pesticides, herbicides and animal waste in **agriculture** is a major non-point source of groundwater contamination.

- The water which is **returned from irrigated areas** filtered to the groundwater along with dissolved substances.
- In this way, elements existing in the fertilizers reach the groundwater, especially in cases of permeable soil formations.
- Drainage wells are often used by farmers in order to improve the drainage of agricultural land and increase its productivity.

Point and Non-point Sources

- However, this allows for the direct contamination of groundwater through the washing down of pollutants as agricultural runoff.
- Common pollutants are nitrates, which have a great mobility and can easily move from the unsaturated zone to the aquifer.

- In the unsaturated zone the dissolved substances move vertically towards the underground level and in the saturated zone the hydraulic slope causes the horizontal movement of the groundwater and the pollutants.
- The excessive use of fertilizers results in the increase of nitrate and the respective degradation of the aquifers.
- Natural groundwater contamination also falls within the category of non-point sources.

Point and Non-point Sources

- The presence of various elements and impurities in groundwater may not be originated from anthropogenic sources.
- Seawater intrusion is an issue with global dimensions since it contributes to the degradation of coastal freshwater aquifers.

- Over pumping of groundwater and respective decline in the groundwater level, change in land-use and climate change effect are the main reasons for the incursion of seawater to the coastal groundwater bodies.
- Seawater intrusion results in a decrease of available freshwater storage volume and the contamination of the production wells in the area,
    - while less than 1% of seawater is enough to change the water quality to inappropriate for drinking purposes.

Point and Non-point Sources

- The type and concentration of the natural elements in groundwater also depend on the nature of the geological materials.
- Sedimentary rocks and soils usually indicate the presence of various compounds such as magnesium, calcium and chlorides or even chromium in groundwater.
- Other dissolved constituents such as boron, arsenic and selenium have also been detected in groundwater bodies at relatively high concentrations.
- All of these elements can be found naturally in soils and rocks and can get dissolved in groundwater.
- Local conditions regulate the levels of these constituents in groundwater.

Point and Non-point Sources

- Potential impacts on large public water-supply wells from various contaminant sources are obviously of most concern due to often extensive capture zones of high-yielding wells.
- The screened or open intervals of such wells are commonly from tens to hundreds of feet in length; therefore,
  - water from these wells is generally a mixture of waters of different ages that enter the well at different depths and are associated with different potential sources of contamination, both point and nonpoint.

- For example, Figures below illustrate a case where water entering the well may be coming from two distinct areas:

Point and Non-point Sources

1. water from the urban area may contain contaminants from point sources, such as
   - chlorinated solvents from dry-cleaners and machine shops, and
     - will enter the top portion of the well screens;

2. water that has traveled from the more distant agricultural area,
   - where recharge water may contain contaminants such as agricultural pesticides and fertilizers,
     - will enter the bottom portion of the well screens.

Some common pollutants

- ✓ Fertilizer and pesticides
- ✓ Toxic wastes berried in the ground
- ✓ Accidental spills
- ✓ Farm wastes, Sewage from septic tank,

Point and Non-point Sources

- The water entering the well screens of the public-supply wells is of different ages and from different areas because of their long screened intervals, which commonly make public-supply wells vulnerable to contamination from multiple sources. In this example, sources of contaminants may include those associated with urban and agricultural land-use activities. Aquifer materials may also serve as sources of natural contaminants such as arsenic.

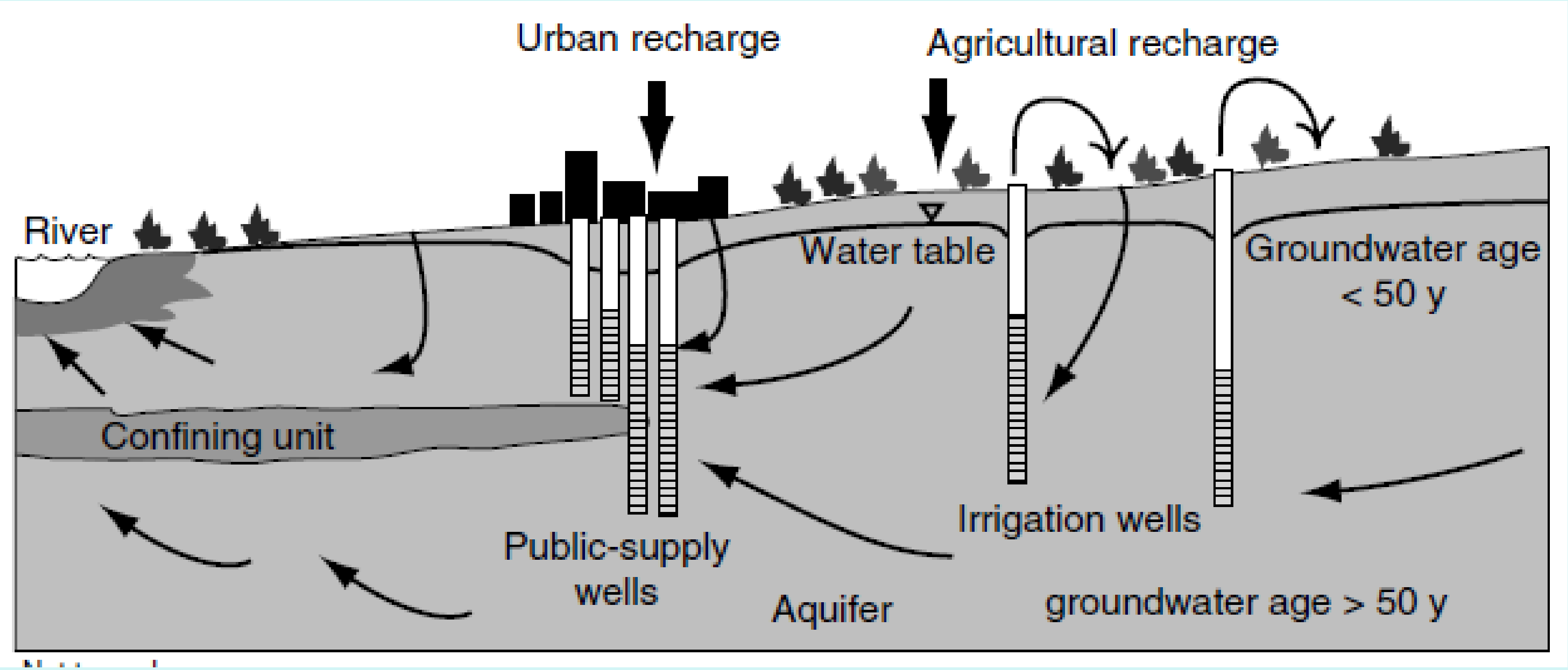
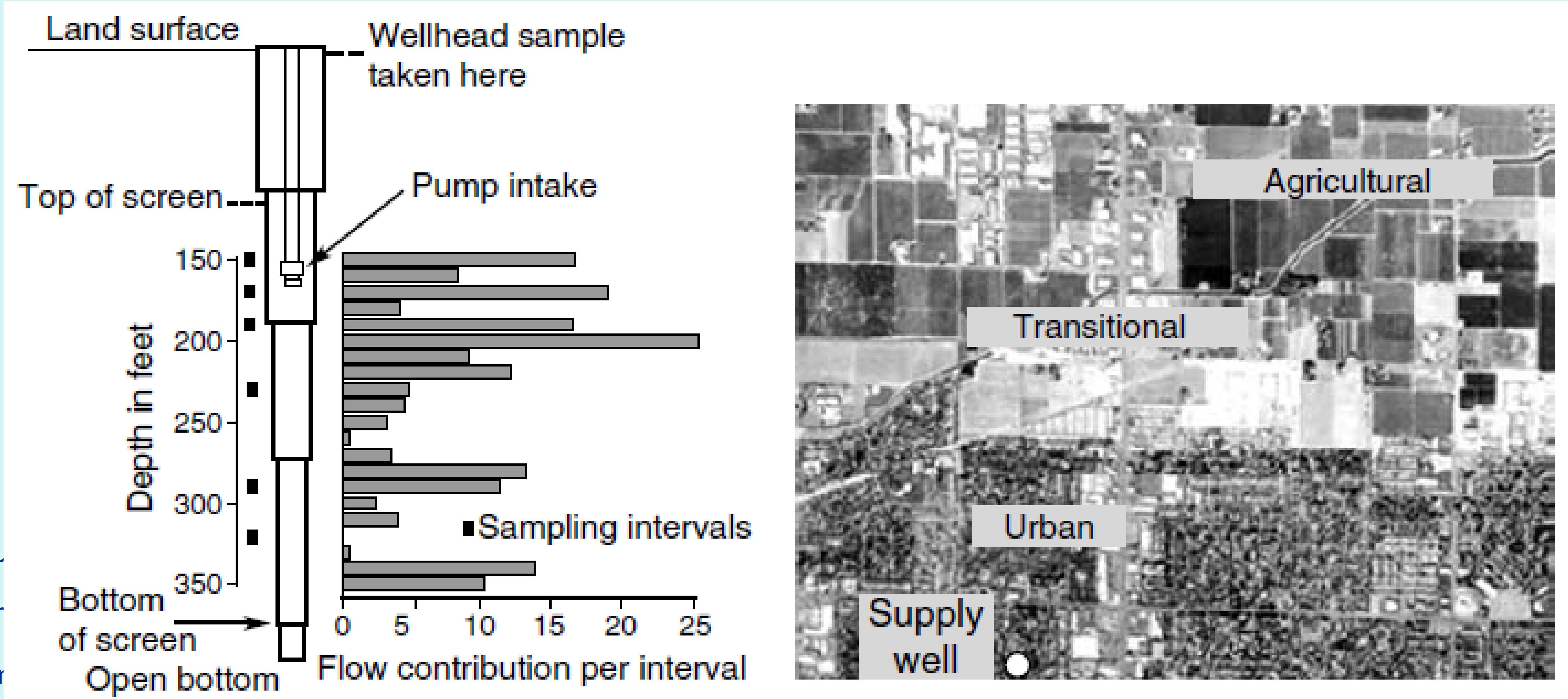


Figure. An aquifer system and public-water system in an urban setting.

Source (Eberts et al., 2005)

Point and Non-point Sources



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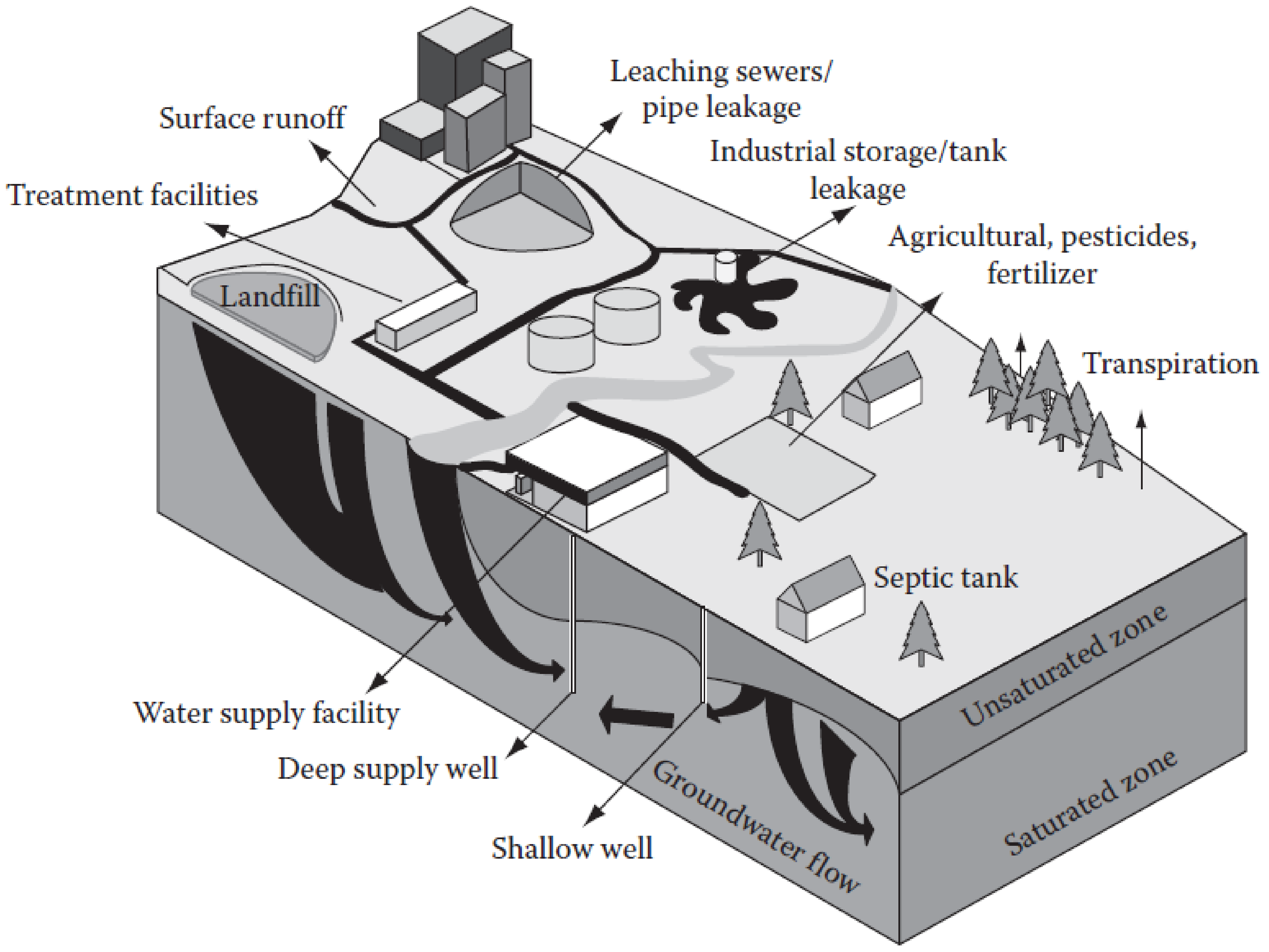


Figure. Threatened hazards of groundwater quality

Domestic Sewage and Animal Wastes

- Compared to domestic sewage, wastes produced by one horse contain twice as much nitrogen as that produced by a family of four during one year.
- However, because the ammonia in animal wastes is exposed to atmospheric effects such as wind and drying, the loss of ammonia through volatilization is undoubtedly much greater from animal wastes than from human wastes,
    - which is disposed of in underground septic systems and is thus isolated from atmospheric effects.

- Therefore, even though domestic animals produce more nitrogen than humans do, probably more animal nitrogen than human nitrogen is lost to the air.

Domestic Sewage and Animal Wastes

- In cattle feeding lots, animal wastes may lose much of the nitrogen by ammonia volatilization, particularly in corrals that are not subject to water application;
  - ✓ water can transport the nitrogen to the subsurface before substantial volatilization has occurred.

The amount of nitrate from animal wastes that percolates to the groundwater depends on

- ✓ the amount of nitrate formed from the wastes,
- ✓ the infiltration rate,
- ✓ the frequency of manure removal,
- ✓ the animal density,
- ✓ the soil texture, and
- ✓ the ambient temperature.

Fertilizers and Natural Sources

- Nitrogen fertilizers are obvious potential sources of groundwater contamination with nitrogen.
- The amount of nitrogen contributed depends on several factors, including
    - ✓ the type and amount of fertilizer applied,
    - ✓ the acidity (pH) of the soil,
    - ✓ the air temperature at the time of application, and
    - ✓ the amount of water applied after fertilization.
- The decay of natural organic material in the ground can contribute substantial amounts of nitrogen to groundwater.
- Dynamite and other explosives contain nitrogen, and breakdown of the explosives can contribute nitrogen to the groundwater.

Microbiological Contaminants

- Microorganisms that can cause disease in humans, animals, and plants are called pathogens.
- They can cause an adverse effect after an acute (short-term) exposure such as ingestion of just one glass of water.
- Pathogens include bacteria, viruses, or parasites and are found in sewage, in runoff from animal farms or rural areas populated with domestic and wild animals, and in water used for drinking and swimming.

- A virus of fecal origin that is infectious to humans by waterborne transmission is of special concern for drinking water regulators.
- Waterborne disease-causing bacteria include *E. coli* and *Shigella*.

Inorganic Contaminants

- Inorganic substances, which are naturally occurring in all groundwaters to some degree, sometimes can have elevated concentrations harmful to human health.
- Such concentrations may be the result of the underlying geology (naturally occurring contaminants) or may be caused by industry, mining, waste disposal, or agricultural activities.
- Inorganic contaminants include radionuclides, metals and metallic elements such as lead, chromium, and arsenic, and inorganic nutrients such as nitrogen and phosphorus in various forms.
- At elevated concentrations inorganic substances can cause a variety of damaging effects to the liver, kidney, nervous system, circulatory system, gastrointestinal system, bones, and skin, depending upon the element and level of exposure.

Organic Contaminants

- Synthetic organic chemicals (SOCs) are human-made compounds that are used for a variety of industrial and agricultural purposes.
- Adverse health effects from exposure to synthetic organic chemicals include damage to the nervous system and kidneys, and cancer risks.
- SOCs can be divided into two groups: nonvolatile (semivolatile) and volatile organic chemicals:

- Nonvolatile and semivolatile organic chemicals include pesticides, insecticides, and herbicides,such as atrazine, aroclor, and DDT.
- Atrazine has the potential to cause weight loss, cardiovascular damage, retinal and some muscular degeneration; and cancer.

Organic Contaminants

- Aroclor can cause eye, liver, kidney, or spleen problems, anemia, and an increased risk of cancer.
- Herbicides can harm aquatic plants.
- VOCs are synthetic compounds used for a variety of industrial and manufacturing purposes.

- Among the most common VOCs are degreasers and solvents such as benzene, toluene, and trichloroethylene (TCE), insulators and conductors such as polychlorinated biphenyls (PCBs), and dry-cleaning agents such as tetrachloroethylene (PCE).
- VOCs have the potential to cause chromosome aberrations, cancer, nervous system disorders, and liver and kidney damage.

Main Sources of Groundwater Pollution with Some of Their Main Characteristics

Pollution Category	Pollution Source	Main Pollutant	Potential Impact
	Dewatering of mine shafts	Salinity, inorganic compounds, metals	May increase concentrations of some compounds to toxic levels
Groundwater development	Saltwater intrusion	Inorganic minerals, dissolved salts	Steady water quality deterioration

Source: Sililo, O.T.N. and Saayman, I.C., *Groundwater Vulnerability to Pollution in Urban Catchments*, The Water Program Division of Water, Environment and Technology CSIR, University of Cape Town, Cape Town, 2001.

Main Sources of Groundwater Pollution with Some of Their Main Characteristics

Pollution Category	Pollution Source	Main Pollutant	Potential Impact
Municipal	Sewer leakage	Nitrates	Health risk to users, eutrophications of water bodies, odor and taste
	Septic tanks, cesspools, privies	Viruses and bacteria	
	Sewage effluent and sludge	Nitrate, minerals, organic compounds, viruses, and bacteria	
	Storm water runoff	Bacteria and viruses	Health risk to users
	Landfills	Inorganic minerals, organic compounds, heavy metals, bacteria and viruses	Health risk to users, eutrophications of water bodies, odor, and taste
	Cemeteries	Nitrate, viruses and bacteria	Health risk to users
	Feedlot wastes	Nitrate-nitrogen-ammonia, viruses and bacteria	Health risk to users (e.g., metahemoglobinemia)
Agricultural	Pesticides and herbicides	Organic compounds	Toxic/carcinogenic
	Fertilizers	Nitrogen, phosphorous	Eutrophications of water bodies
	Leaked salts	Dissolved salts	Increased TDS in groundwater
Industrial	Process water and plant effluent	Organic compounds heavy metals	Carcinogenic and toxic elements (As, Cn)
	Industrial landfills	Inorganic mineral, organic compounds, heavy metals, bacteria and viruses	Health risk to users, eutrophications of water bodies, odor and taste
	Leaking storage tank (e.g., petrol station)	Hydrocarbons, heavy metals	Odor and taste
	Chemical transport	Hydrocarbons, chemical	Carcinogens and toxic compounds
	Pipelines leaks		
Atmospheric deposition	Coal-fired power stations	Acidic precipitation	Acidification of groundwater and toxic leached heavy metals
	Vehicles emissions		
Mining	Mine tailings and stockpiles	Acidic drainage	

Table. Potential pollution sources of groundwater

Category	Types of contaminants	Source of contamination
Residential	Air pollution	Septic tank
	Household waste water	Sewer network
	Household waste	Fuel oil
	Furniture stripping/refinishing	Paints
	Municipal sludge spreading in land	Air pollution
	Salt for street de-icing	Streets and packing lots
Municipal	Municipal incinerators	Municipal landfills
	Sewer lines	Road maintenance depot
	Wastewater treatment plants effluents	Metal plating
	Airports	Medical institutions
	Construction areas	Research laboratories
	Car washes	

Table. Potential pollution sources of groundwater

Category	Types of contaminants	Source of contamination
Commercial	Cemeteries	Rail road tracks
	Dry cleaners	Laundromats
	Gas stations	Scap/junk yards
	Golf courses	Recycling facilities
	Chemical industry/storage	Metal fabricators
Industrial	Electronics manufacture	Petroleum production
	Mining and mine drainage	Pipelines
	Metal working shops	Storage tanks
	Toxic/hazardous spills	Wells
	Animal feeds	Fertilizer storage/use
	Irrigation sites	Manure spreading areas
Agriculture	Sludge reuse	Chemical spills
	Live stocks waste	Pesticides
	Tanks	Wells

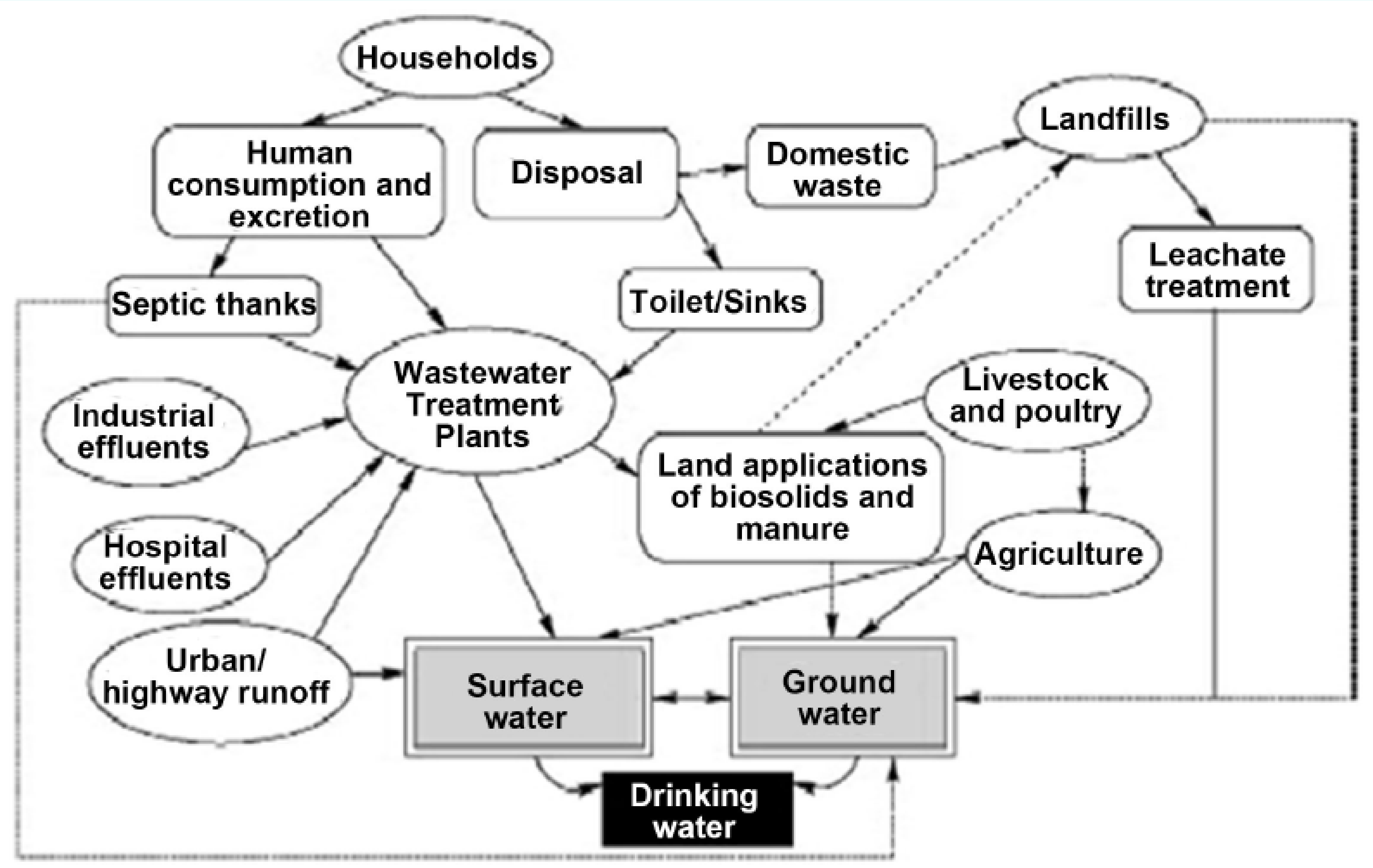


Figure. Possible water pollutant sources

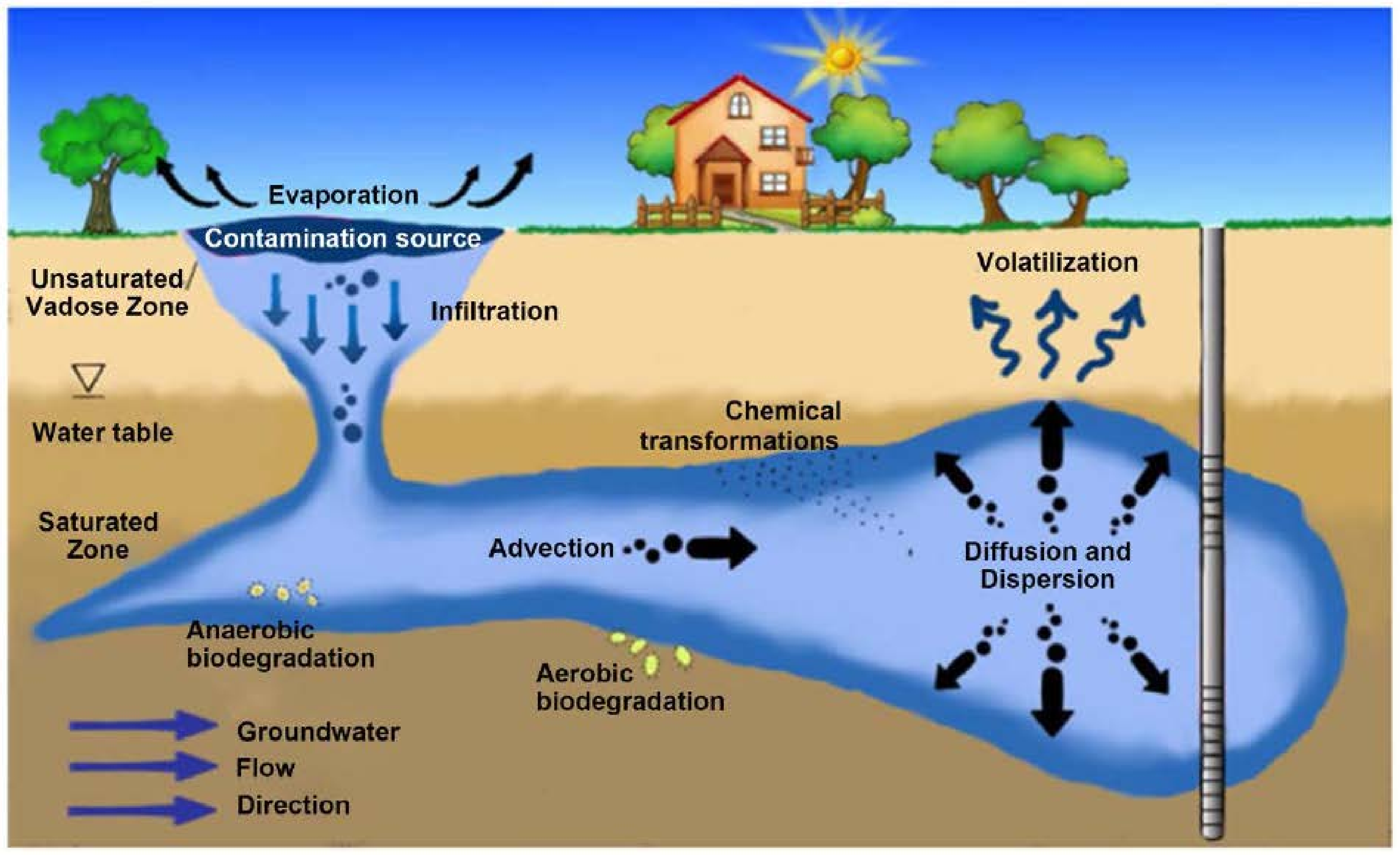


Figure. Main processes involved in contaminant transport in the aquifer.

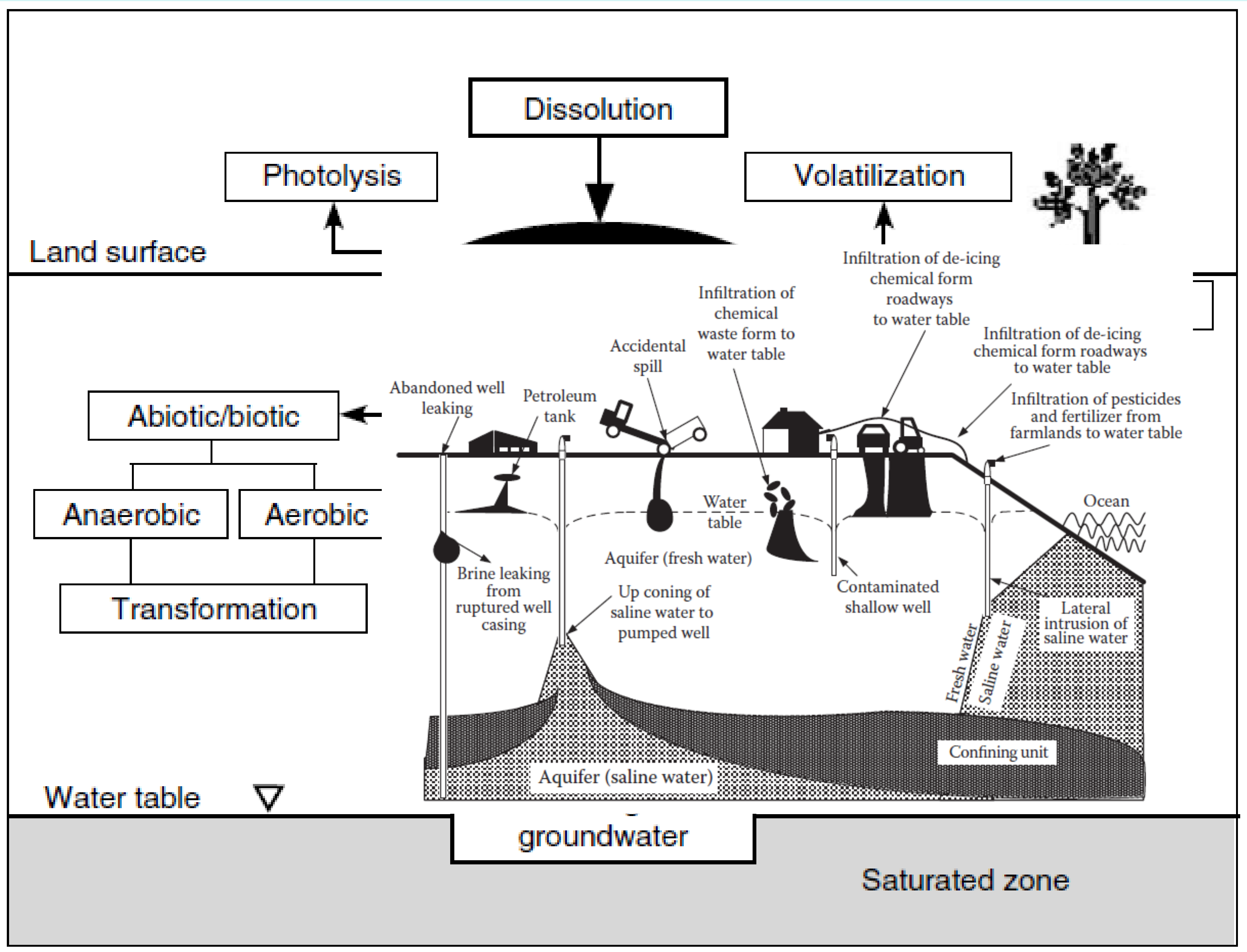


Figure. Physical, chemical, and biological processes affecting contaminant fate and transport in the unsaturated zone.

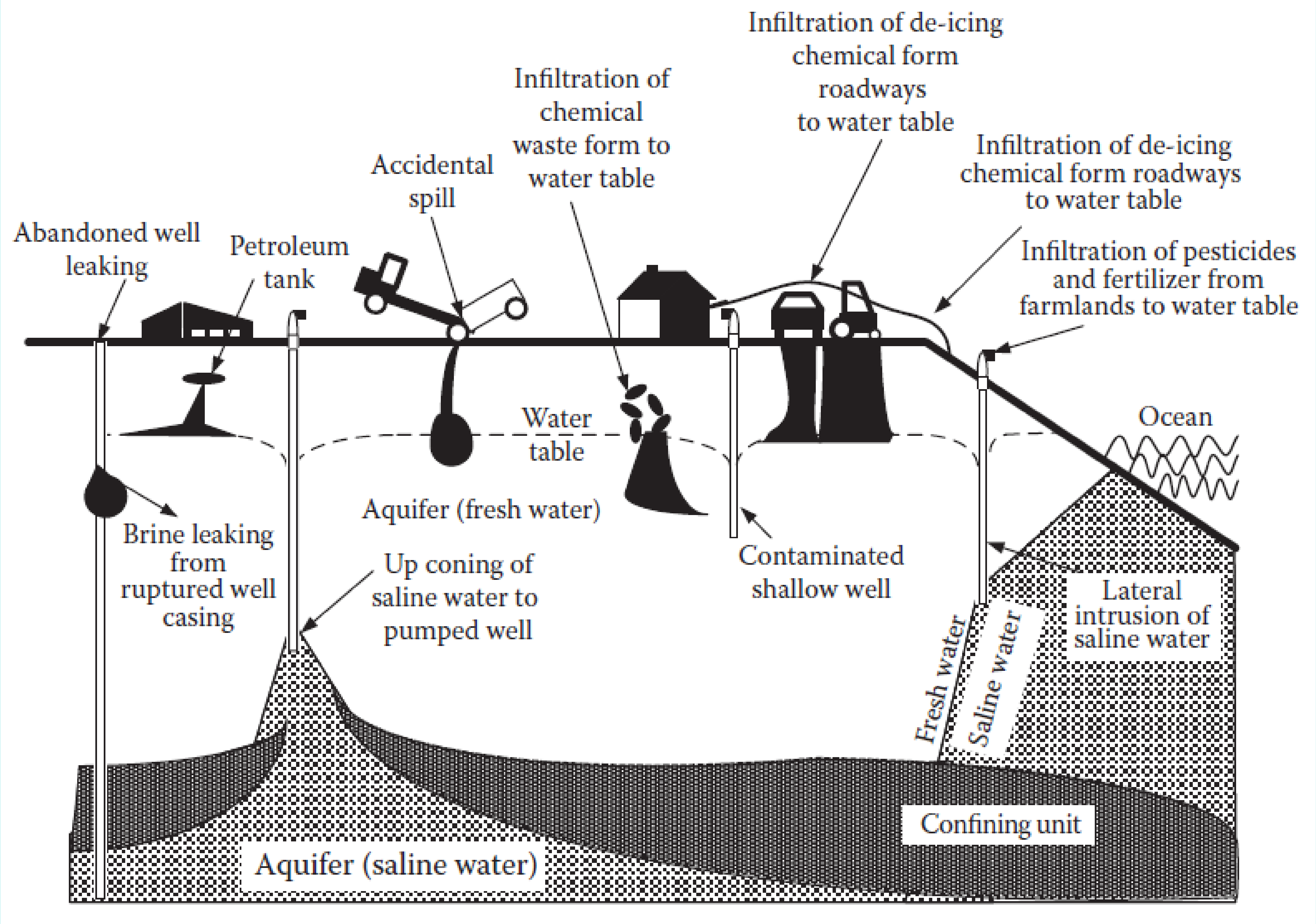


Figure. Sources of groundwater contamination.

Sources of Groundwater Quality Degradation

Groundwater Quality Problems that Originate on the Land Surface

Infiltration of polluted surface water

Land disposal of either solid or liquid wastes Dumps

Disposal of sewage and water-treatment plant sludge Deicing salt usage and storage

Animal feedlots

Fertilizers and pesticides

Accidental spills

Particulate matter from airborne sources

Groundwater Quality Problems that Originate in the Ground above the Water Table

Septic tanks, cesspools, and privies

Holding ponds and lagoons

Sanitary landfills

Waste disposal in excavations

Leakage from underground storage tanks

Leakage from underground pipelines

Artificial recharge

Groundwater Quality Problems that Originate in the Ground below the Water Table

Waste disposal in well excavations

Drainage wells and canals

Well disposal of wastes

Underground storage

Exploratory wells

Groundwater development

TREATMENT OF GROUNDWATER

- The type of treatment required for site specific contaminated groundwaters depends on the contaminants being removed.
- Due to the number of chemicals that potentially exist in groundwater as contaminants; the treatment can be simple or extremely complex.

TREATMENT OF GROUNDWATER

Air Sparging

- In situ air sparging (IAS) is primarily used to remove volatile organic carbons (VOCs) from the saturated subsurface.
- The removal process is done through stripping.
- The basic IAS system strips VOCs by injecting air into the saturated zone to promote contaminant partitioning from the liquid to the vapor phase.

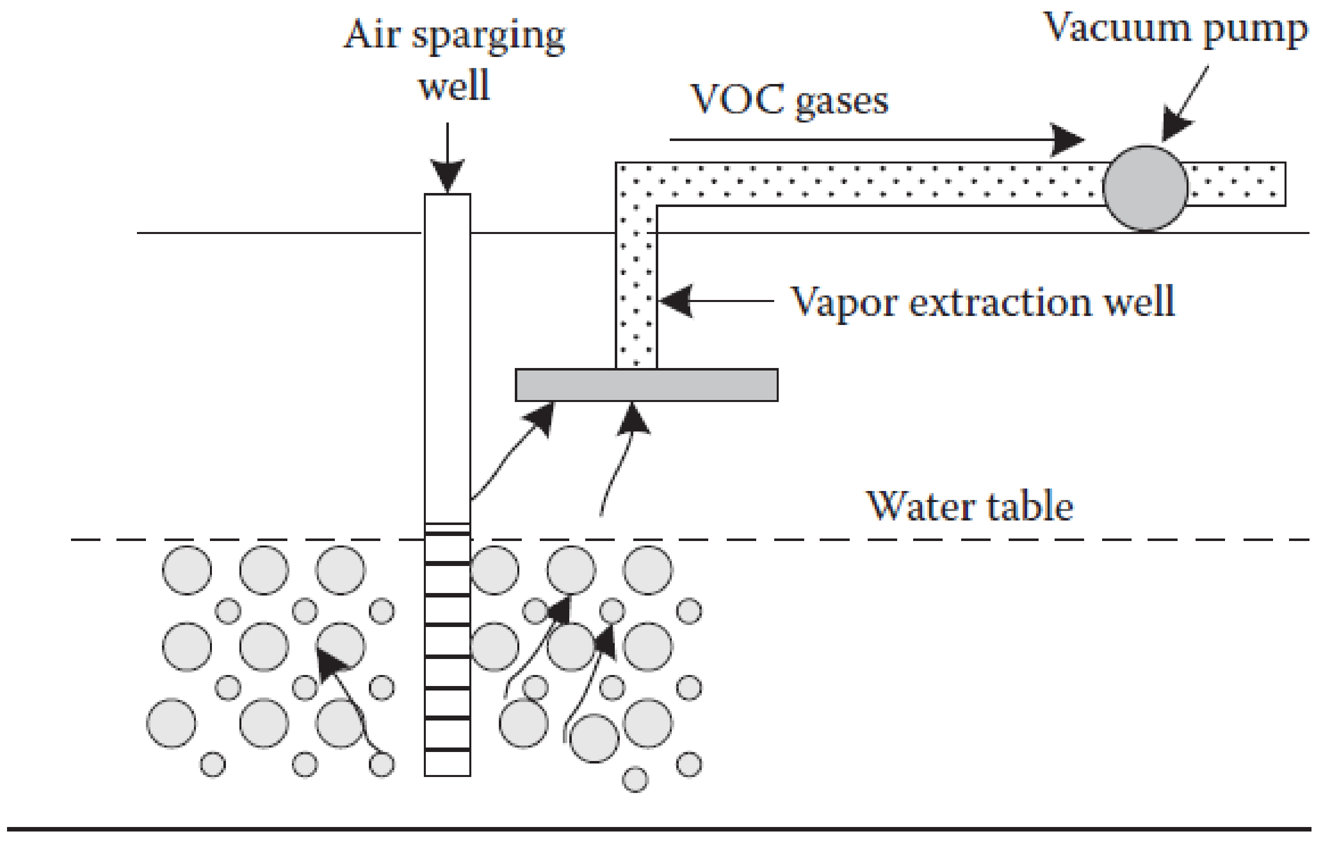


Figure. Typical in situ air sparging system.

Thermal Technologies

- In situ thermal heating methods are generally used for enhanced oil recovery.
- These methods include hot water injection, steam injection, hot air injection, and electric resistive heating (ERH).

- Soil and groundwater zones contaminated by chlorinated solvents can be remediated by these methods.
- Volatile and semi-volatile organic contaminants (SVOCs), such as pesticides, and various fuels, oils, and lubricants can also be treated by in situ thermal technologies.

Thermal Technologies

- A thermal heating system typically consists of a series of injection and extraction wells.
- The injection wells are usually placed in clean areas around the source zone, if possible, to minimize the risk of contaminant spreading.
- Figure below expresses a schematic of thermal heating system.
- In this figure, hot water, steam, or hot air is injected into the subsurface to dissolve, vaporize, and mobilize contaminants that are then recovered.
- Then, mobilized contaminants are extracted from the subsurface using vapor and liquid extraction equipment.
- Extracted vapors and liquids are then treated using conventional aboveground treatment technologies.

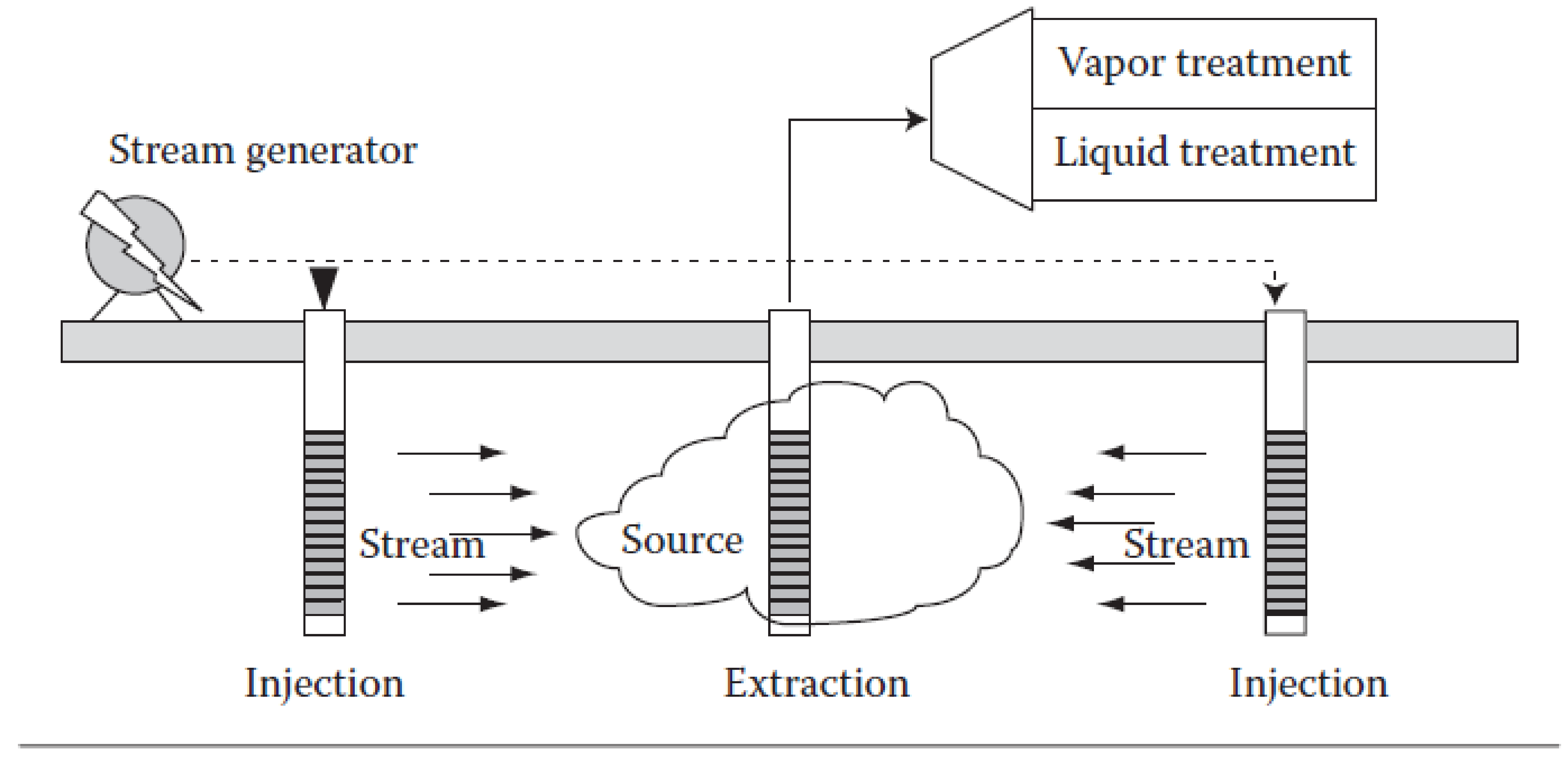


Figure. Schematic of thermal heating systems.

Permeable Reactive Barriers

- Permeable reactive barriers are **not barriers to the water**; they are barriers to the contaminant.
- In this method, reactive materials are placed in the subsurface across the path of a plume of contaminated groundwater to create a passive treatment system.
- When the polluted groundwater passes through these materials, treated water comes out the other side.

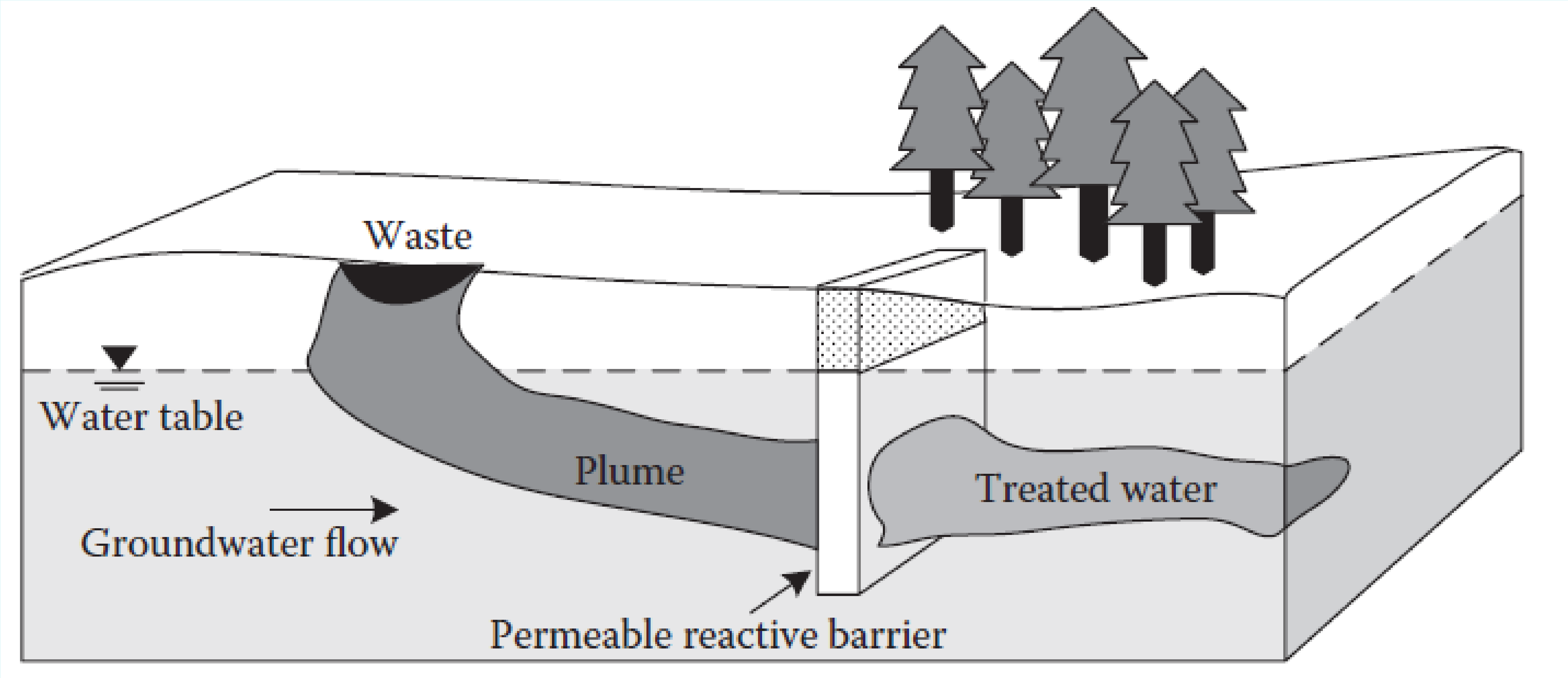


Figure. Plume being treated by a permeable reactive barrier.

- These barriers may contain metal-based catalysts for degrading volatile organics, nutrients, and oxygen for microorganisms to enhance biodegradation or other agents.
- The precipitation wall barrier reacts with the contaminants to form insoluble products, which may remain in the wall and the sorption wall barrier adsorbs contaminants to the wall surface.

Remedial and Preventive Measures

- Once groundwater gets contaminated, it may be difficult and expensive to clean it up.
- The best way to deal with groundwater contamination is not to contaminate it in the first place
- Minimize use of toxic/ Hazardous raw materials

- Implement monitoring programs
  - Leak detection and repair program
- Manage waste materials their transport and disposals properly.
- Install monitoring wells
- Monitor groundwater quality periodically

Remedial and Preventive Measures

- Minimize use of household chemicals containing hazardous substances
- Avoid draining chemicals, motor oil, insecticides in community areas
- Reduce pesticide applications
- Use proper procedure for handling chemicals

- Groundwater remediation is the process that is used to remove pollution from groundwater.
- Pollutants and contaminants can be removed from groundwater by applying various techniques thereby making the groundwater safe for use.
- Groundwater remediation techniques are:
    - Ex-Situ and In-situ technologies

Remedial and Preventive Measures

- Ex-Situ technology involves treatment of groundwater by
  - ✓ dewatering the polluted aquifer (pumping out),
  - ✓ treating the water on surface by physical, chemical and biological technology and
  - ✓ finally re-injecting the treated water in to the aquifer.

- In-Situ technology involves treatment of groundwater within the aquifer (in the sub-surface) by using
  - ✓ thermal,
  - ✓ chemical and
  - ✓ biological treatment technologies.

Remedial and Preventive Measures

Ex-Situ technology

- Extraction is done by pumping groundwater from the well or trench and treat them with a variety of techniques such as:
  - Stream stripping, Oxygen Sparging, Bioremediation, Carbon Adsorption

- There are several treatment techniques used for in-situ groundwater treatment such as:
  - ✓ Air Sparging,
  - ✓ Bioremediation
  - ✓ Chemical oxidation
  - ✓ Thermal treatment
  - ✓ etc

Remedial and Preventive Measures

The selection of the remedial technology depends upon several parameters such as:

Contaminant Profile:

- Type of compounds
- Quantity and solubility
- Toxicity and volatility
- Biodegradability

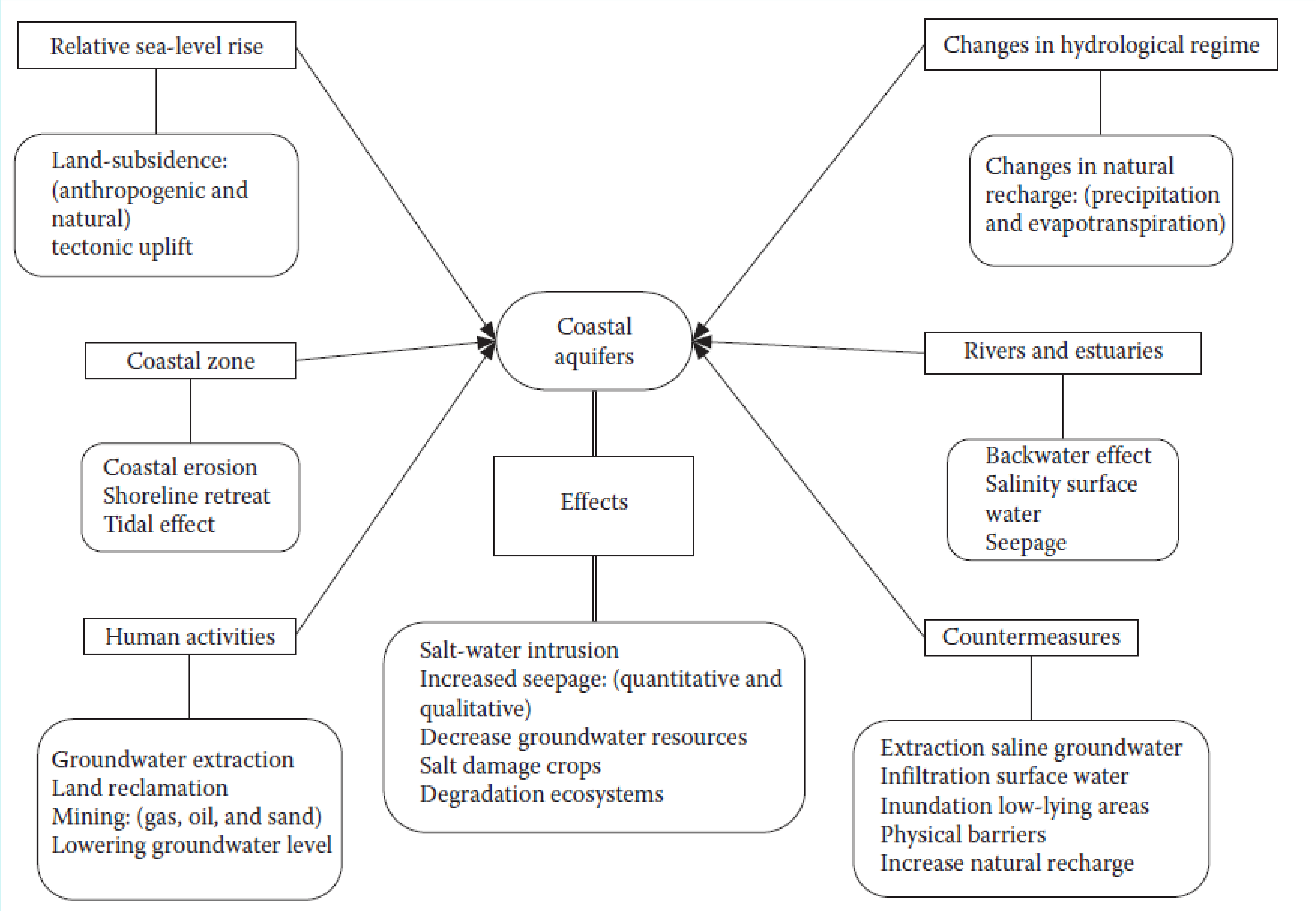
Aquifer Profile:

- Soil type (permeability, chemistry, etc)
- Groundwater flow direction
- Water table location
- Recharge location (seasonal rainfall)

Feasibility Profile:

- Cost of technology
- Time of completion

Features affecting the coastal aquifers.



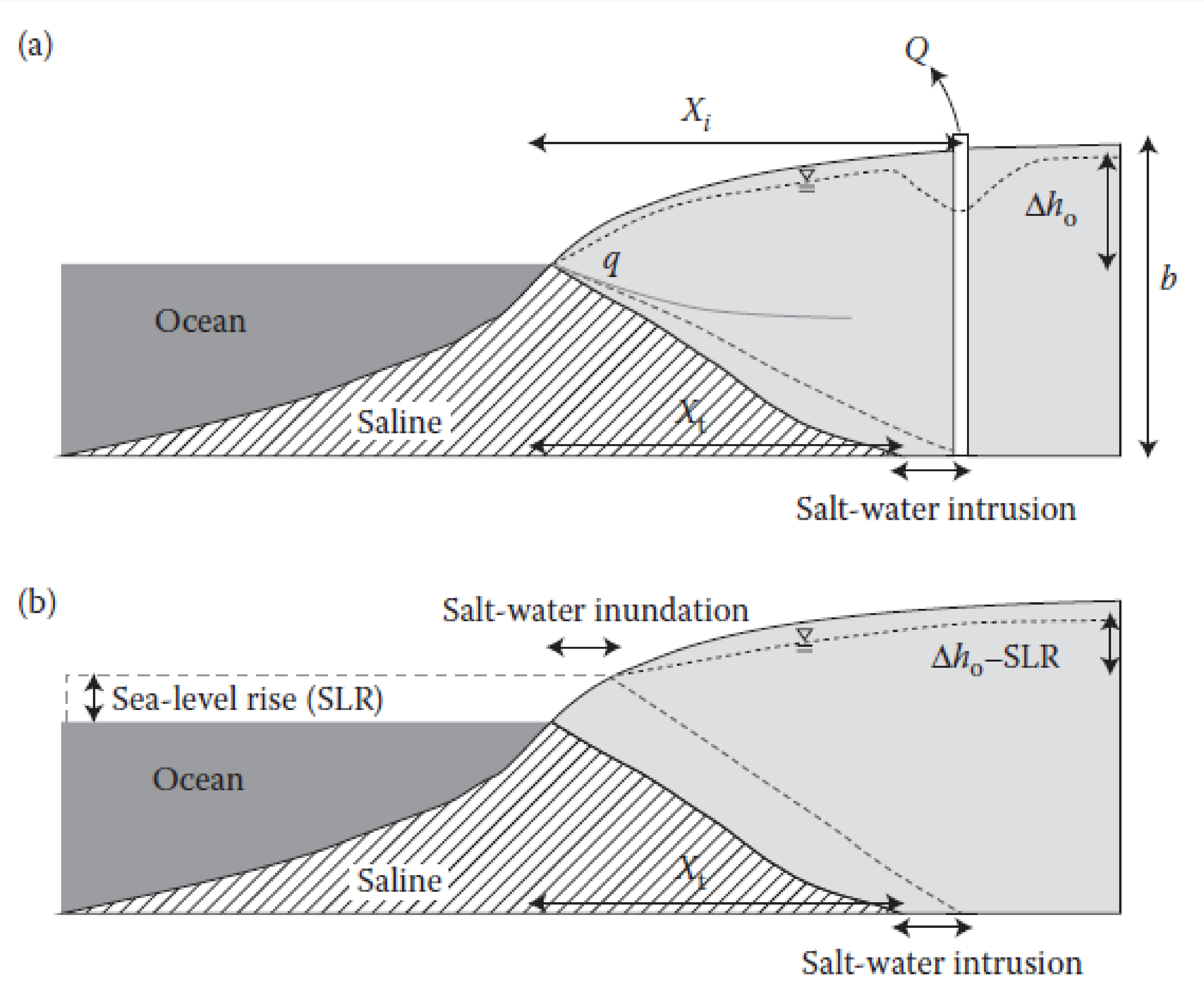


Figure. Coastal aquifers are affected both by (a) groundwater extraction and (b) sea level rise.

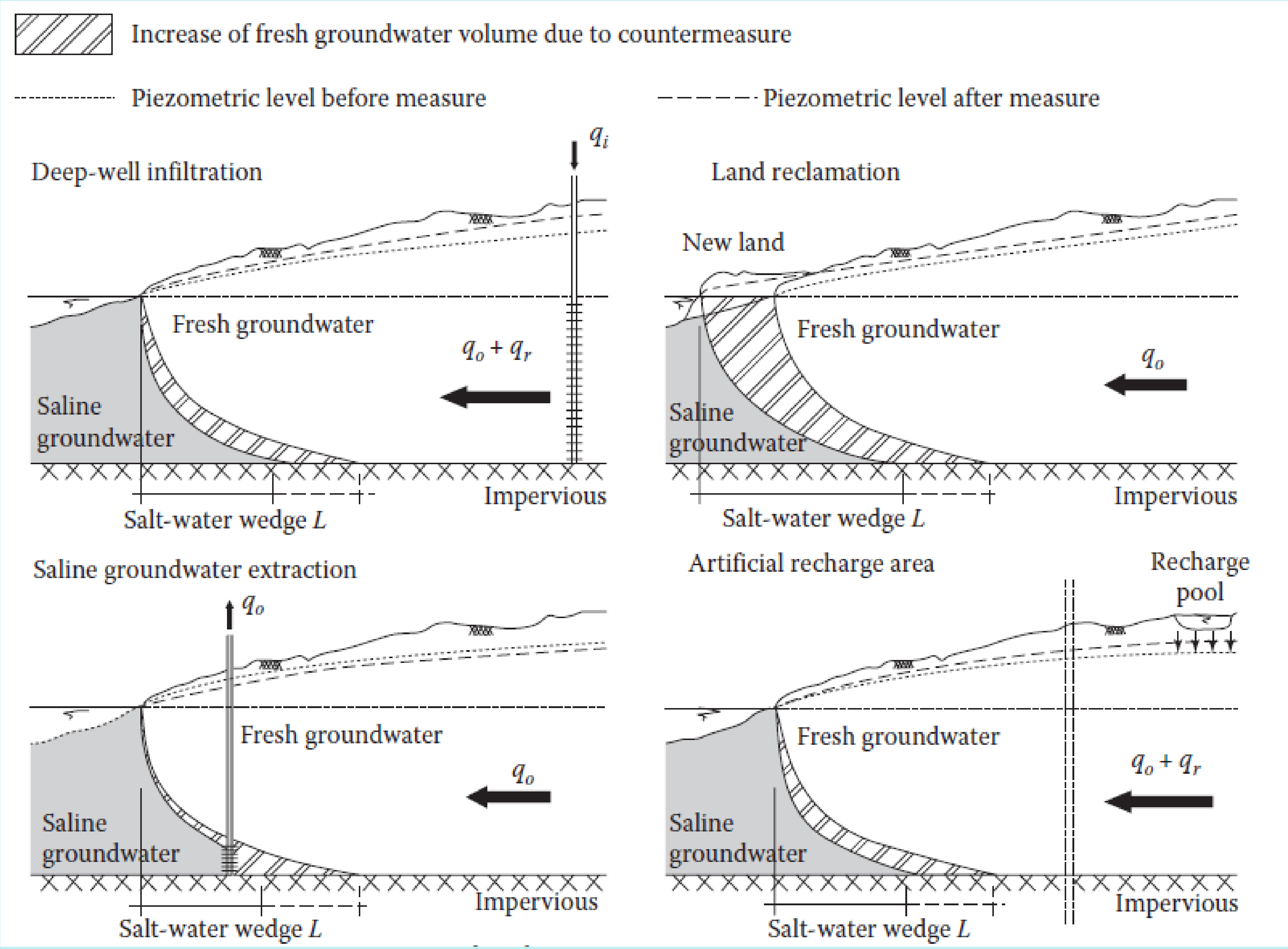


Figure. Counter measures to control saltwater intrusion.

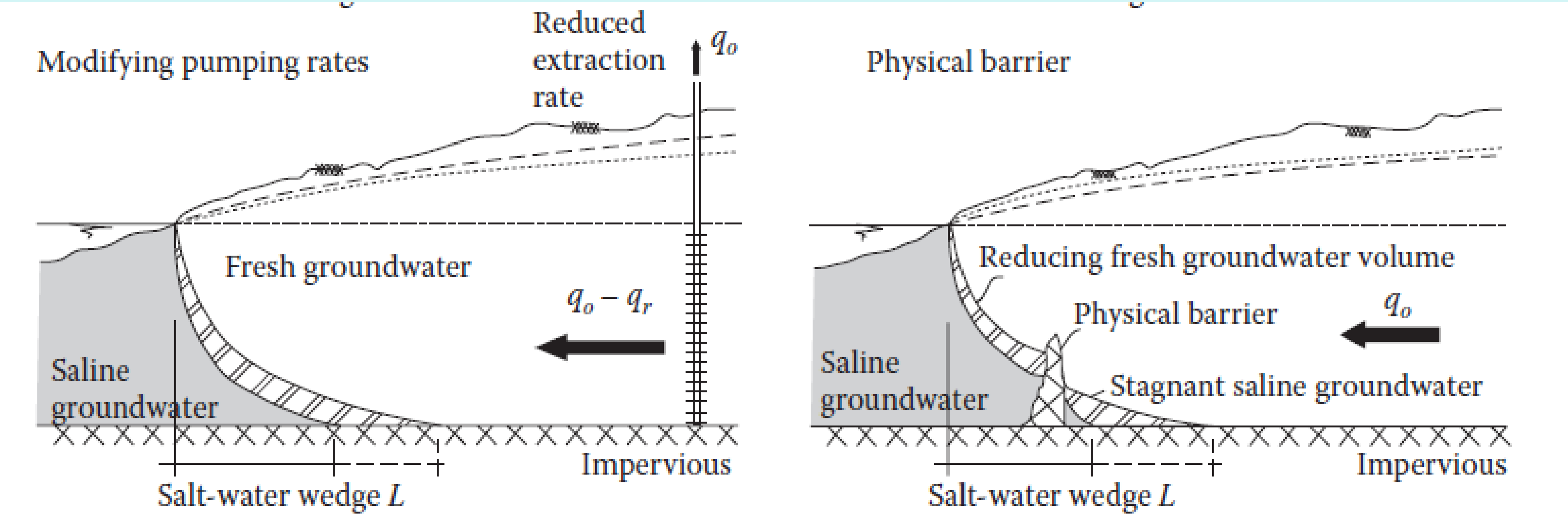


Figure. Counter measures to control saltwater intrusion.