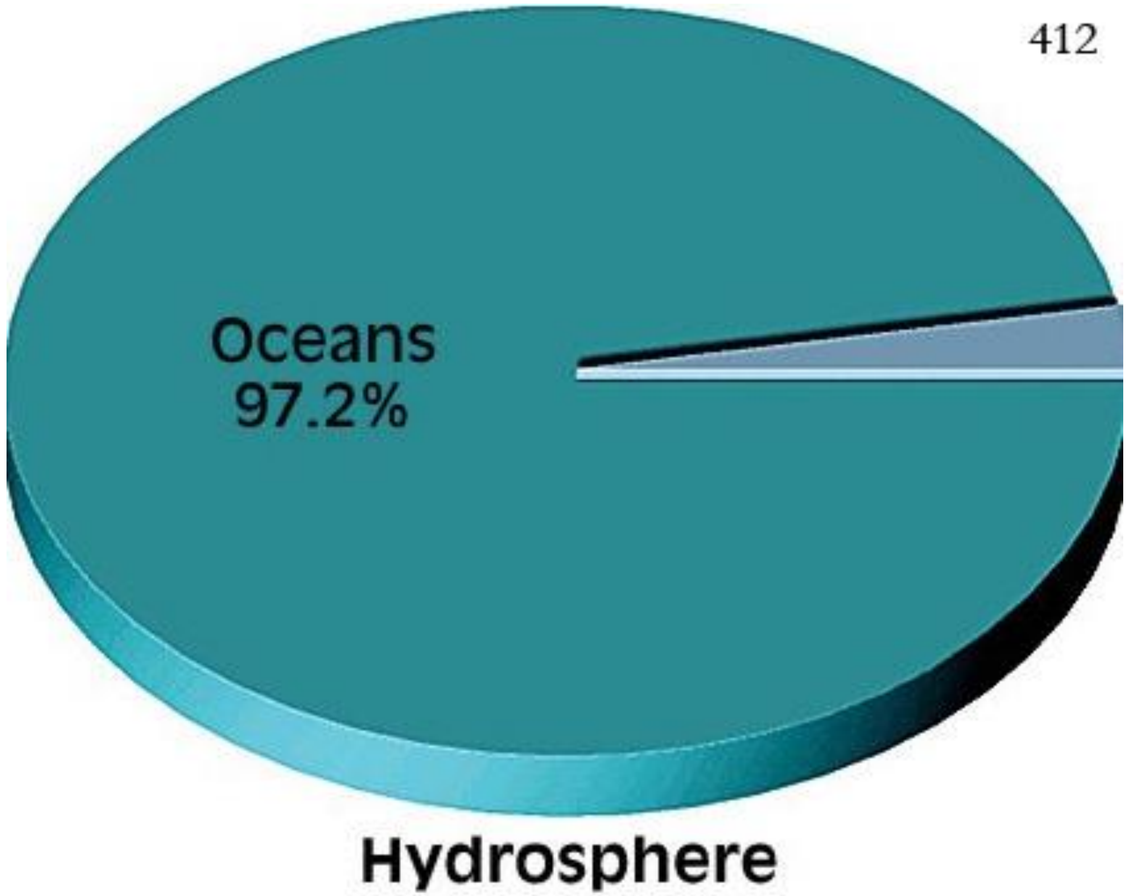
INTRODUCTION TO WATER RESOURCES

Earth's Water

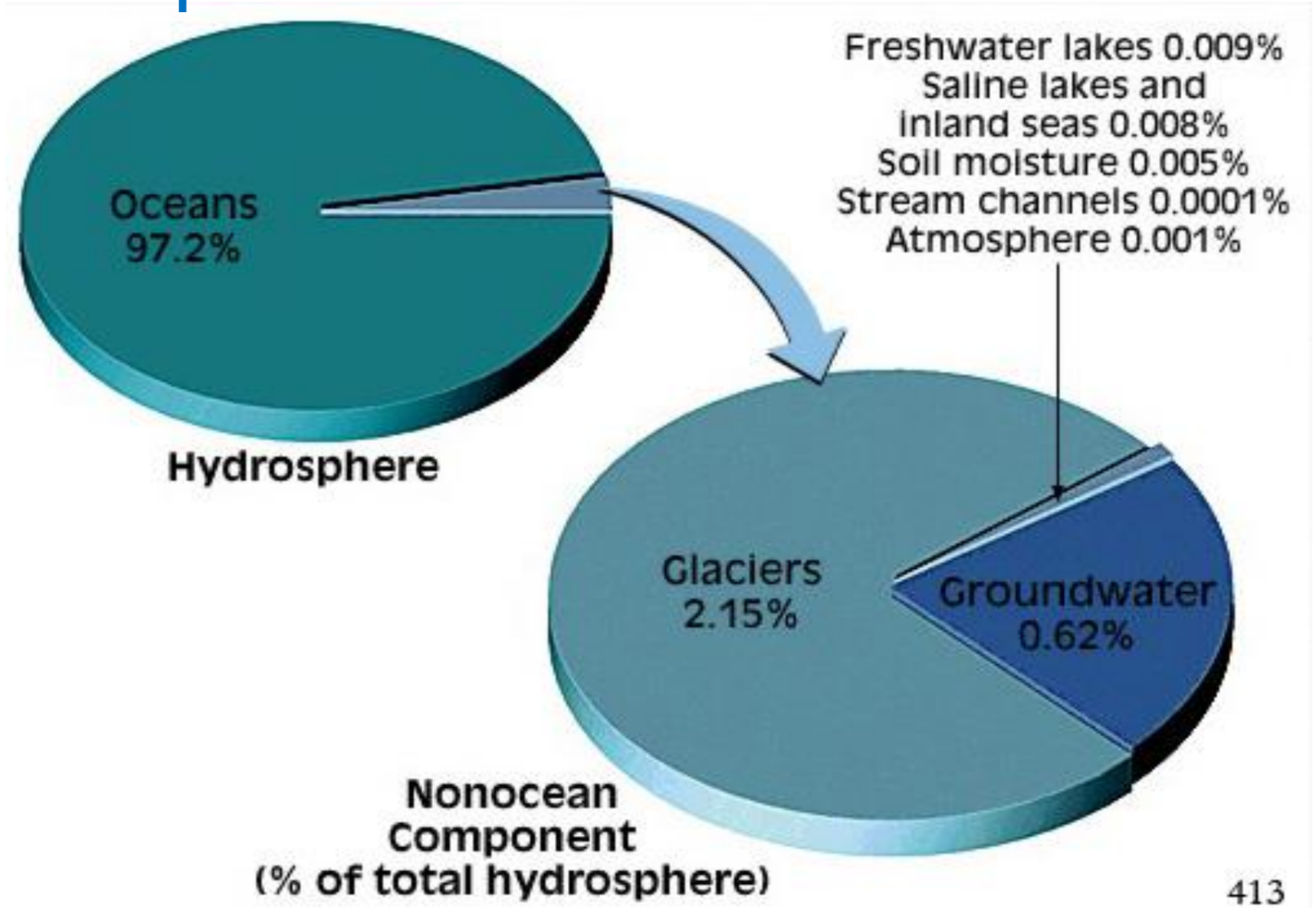
The amount of water on Earth is immense – an estimated **1.36 billion** cubic kilometres.

- Most of it is in oceans.



Earth's Water.....(2)

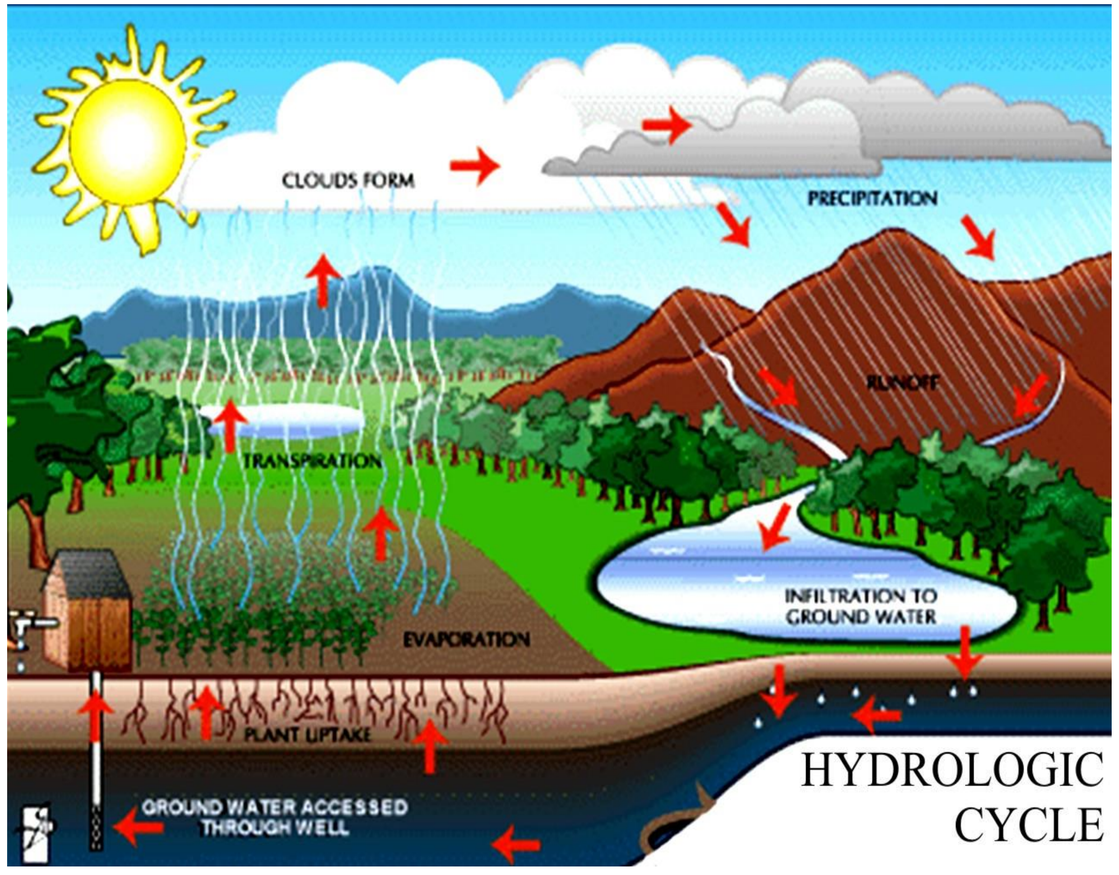
- The remainder is distributed among ice sheets & glaciers, groundwater, lakes, streams & atmosphere.



The Hydrologic Cycle

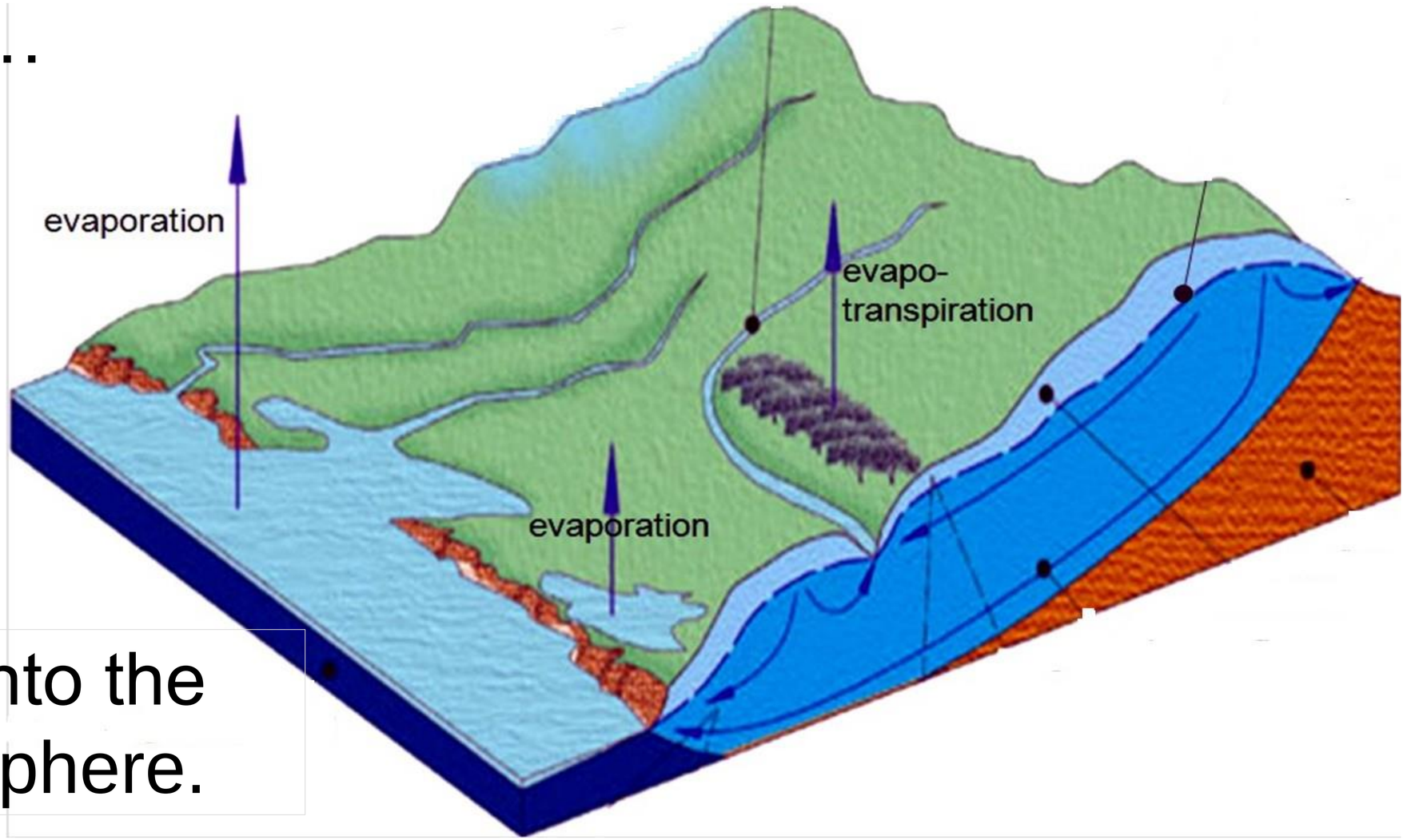
Water on earth moves in a continuous cycle – the WATER or HYDROLOGIC CYCLE.

- It is a continuous process of water transportation from OCEANS to ATMOSPHERE to LAND and back to OCEANS.



The Hydrologic Cycle.....(2)

Lifting of water vapour by wind & sun's energy (EVAPO(TRANSPI)RATION from oceans, over land, & vegetation…



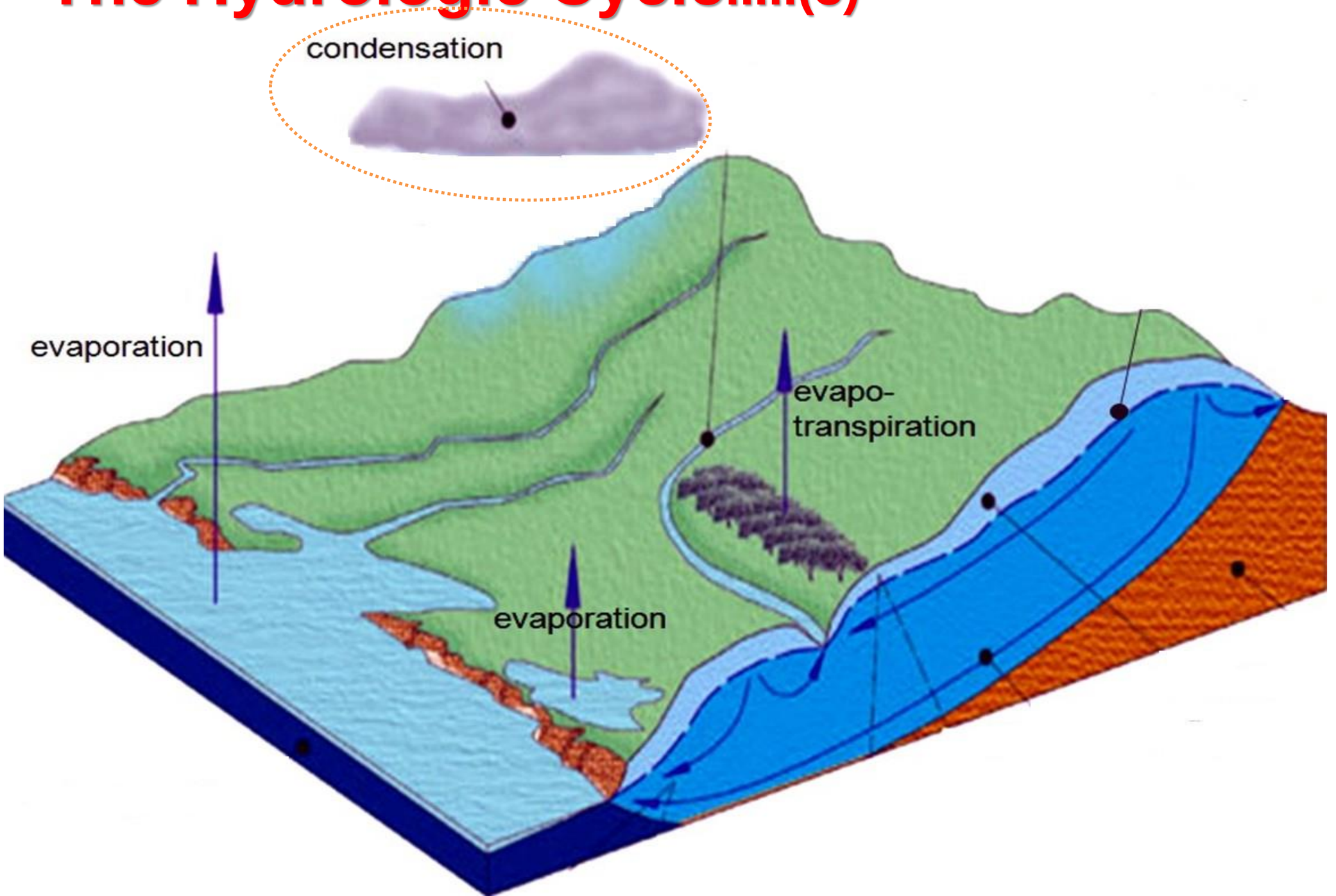
…….into the atmosphere.

The Hydrologic Cycle.....(3)

Evapotranspiration

- Combined net effect of two processes: evaporation & transpiration.
- Evaporation – process of returning moisture (on any surface, especially surfaces of ponds, streams, rivers, lakes, & oceans) to atmosphere thru water vapour.
- Transpiration – process by which plants return moisture to atmosphere.

The Hydrologic Cycle.....(3)

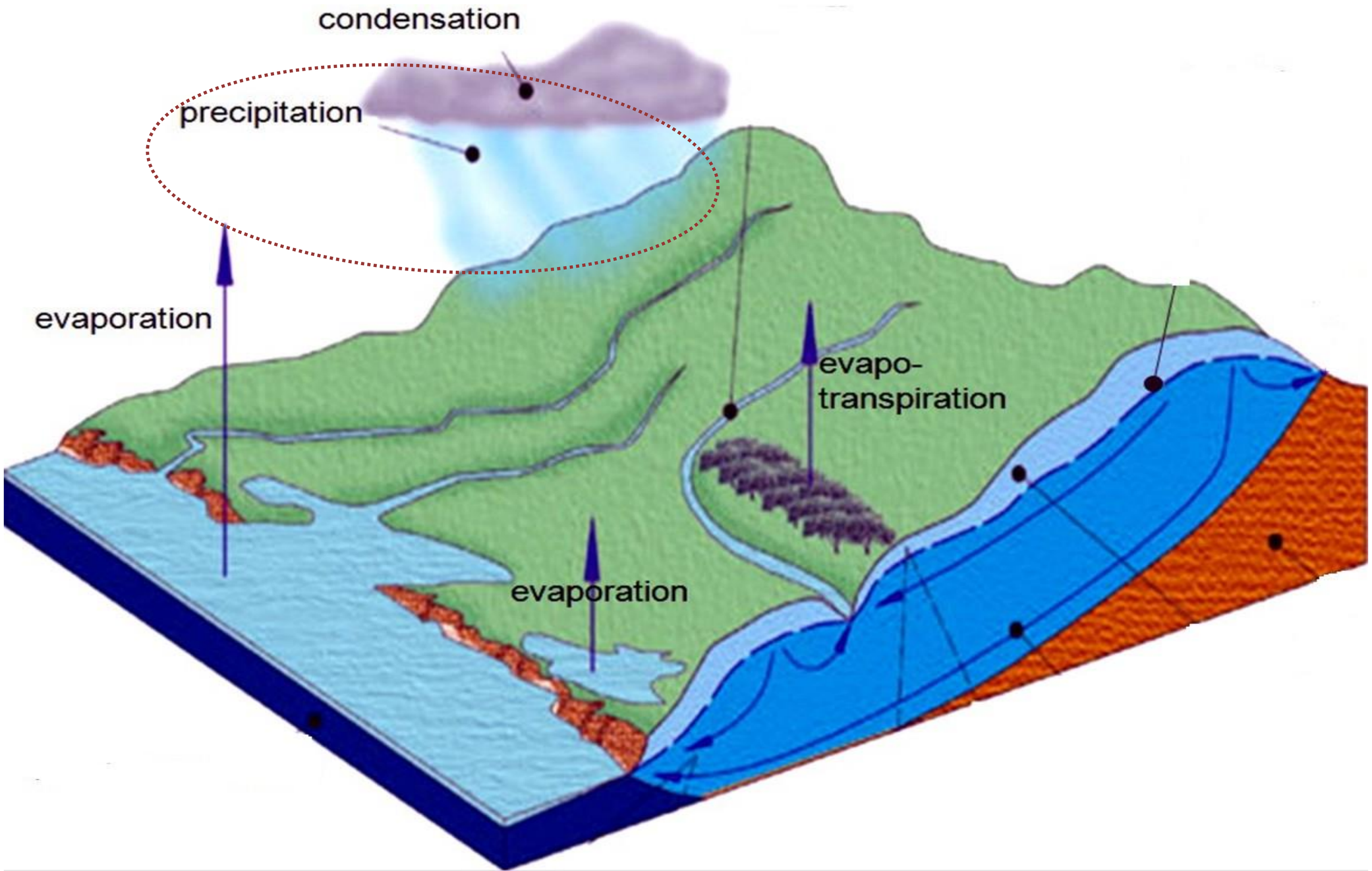


The Hydrologic Cycle.....(4)

Condensation

- **Cooling of water vapour until it becomes liquid:**
  - As dew-point is reached, water vapour forms tiny visible water droplets.
  - When droplets form in sky, and other atmospheric conditions are present, clouds will form.
  - As the droplets collide, they merge and form larger droplets resulting in precipitation.

The Hydrologic Cycle.....(5)

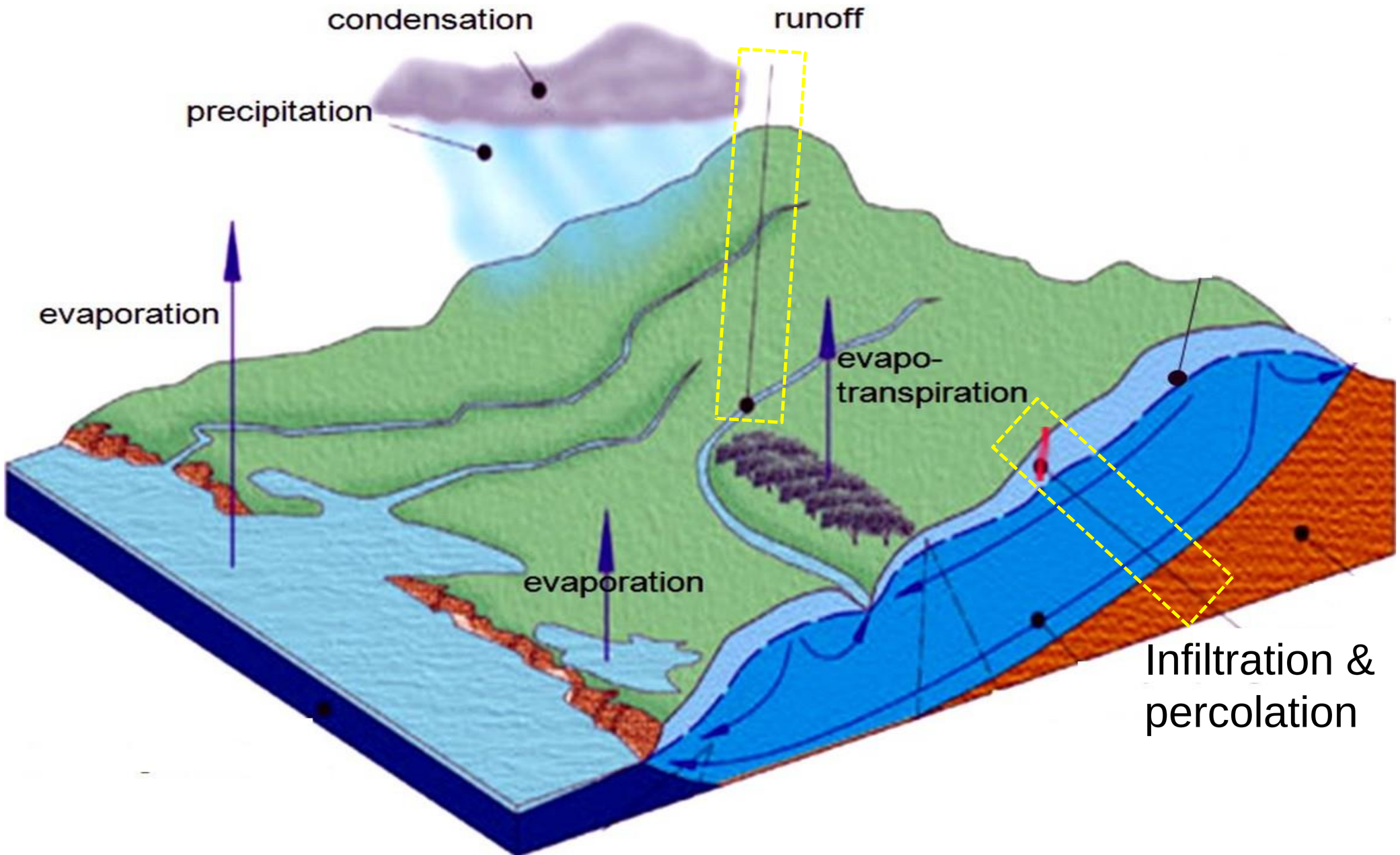


The Hydrologic Cycle.....(6)

Precipitation

- Moisture that falls from **atmosphere** as rain, snow, or hail.
- Varies in **amount**, **intensity**, and **form** by season and geographic location.
- **Recorded** as amount of rainfall – vital info for:
  - determination of **average** rainfalls for **a location** & for classifying rain-storms...
  - engineering **design of water control structures** & flood control.

The Hydrologic Cycle.....(7)



The Hydrologic Cycle.....(8)

Runoff

- **Movement** of water, usually from precipitation, across earth's surface towards depressions & low-points in earth's surface – *stream channels, lakes, oceans.*
- It is **affected** by
  - rainfall duration & intensity
  - soil type
  - ground cover
  - slope of ground

The Hydrologic Cycle.....(9)

Infiltration

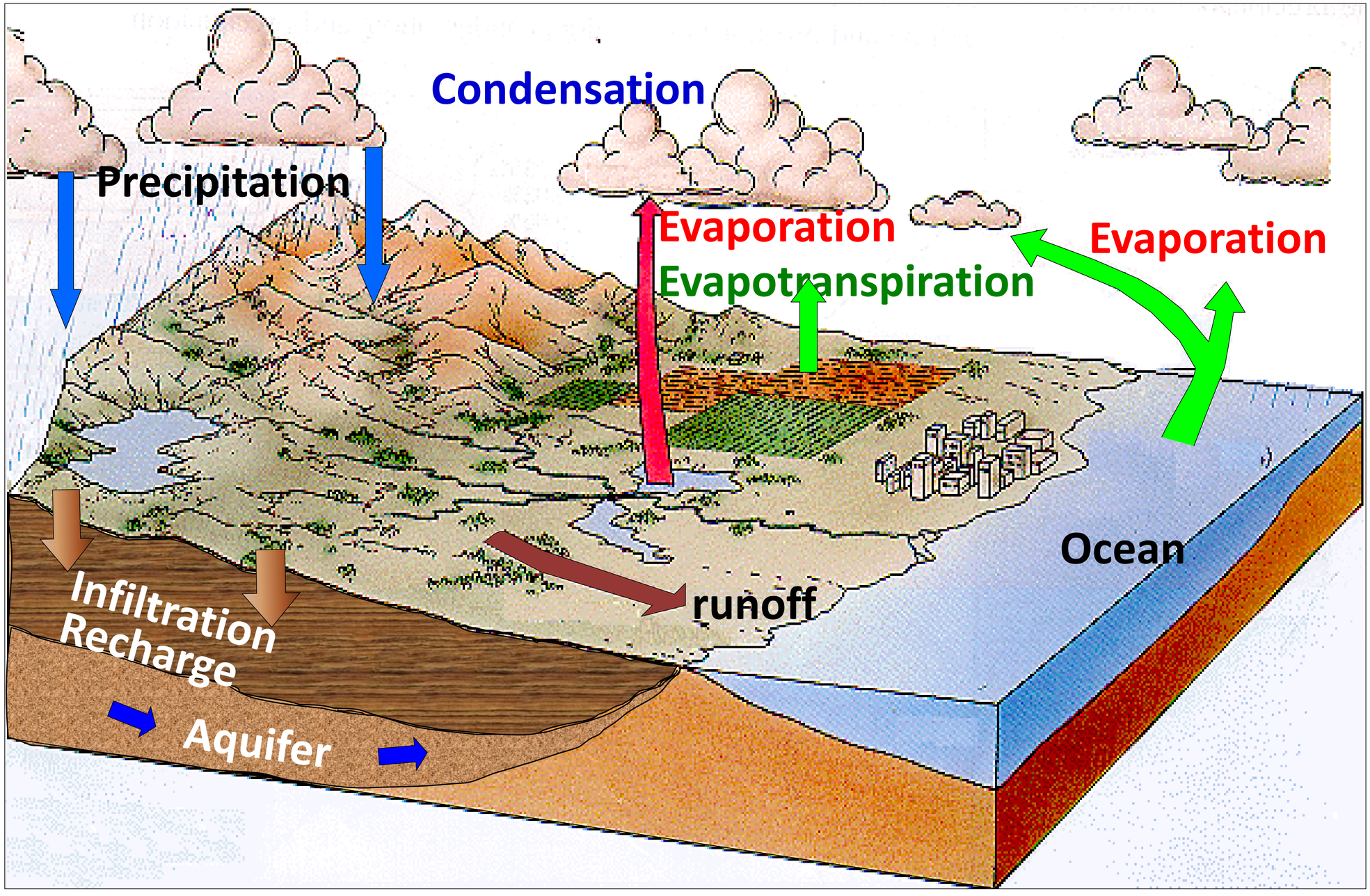
- **Entry of water into soil** – sole source of water to sustain growth of vegetation
- **Sustains groundwater supply** to wells, springs and streams.
- Its rate is usually influenced by *physical characteristics of soil, soil cover, water content of the soil, soil temperature & rainfall intensity.*

The Hydrologic Cycle.....(10)

Percolation

- **Is Downward** movement of water **through soil** & **rock** to **groundwater store** (aquifer)
  - Water moves from space to space along fractures in rock, through sand and gravel, or through channels in formations such as cavernous limestone.
- Occurs beneath root zone, after **plant water requirements have been met**.

Summary


Condensation
Precipitation
Evaporation
Evapotranspiration
Evaporation
Ocean
runoff
Infiltration
Recharge
Aquifer

Summary.....(2)

- **Evaporation / transpiration** – *transformation of water into vapour from a combination of surface water bodies and plants.*
- **Condensation** – *saturation/cooling of air masses/vapour to liquid as dew point is reached.*
- **Precipitation** – *falling of moisture on Earth's surface from atmosphere.*
- **Runoff** – *movement of water from ppt across Earth's surface towards streams, lakes, oceans,…*
- **Infiltration** – *Entry of water into the soil.*
- **Percolation** – *downward movement of water thru soil/rock (below root zone) to grounbwater store.*

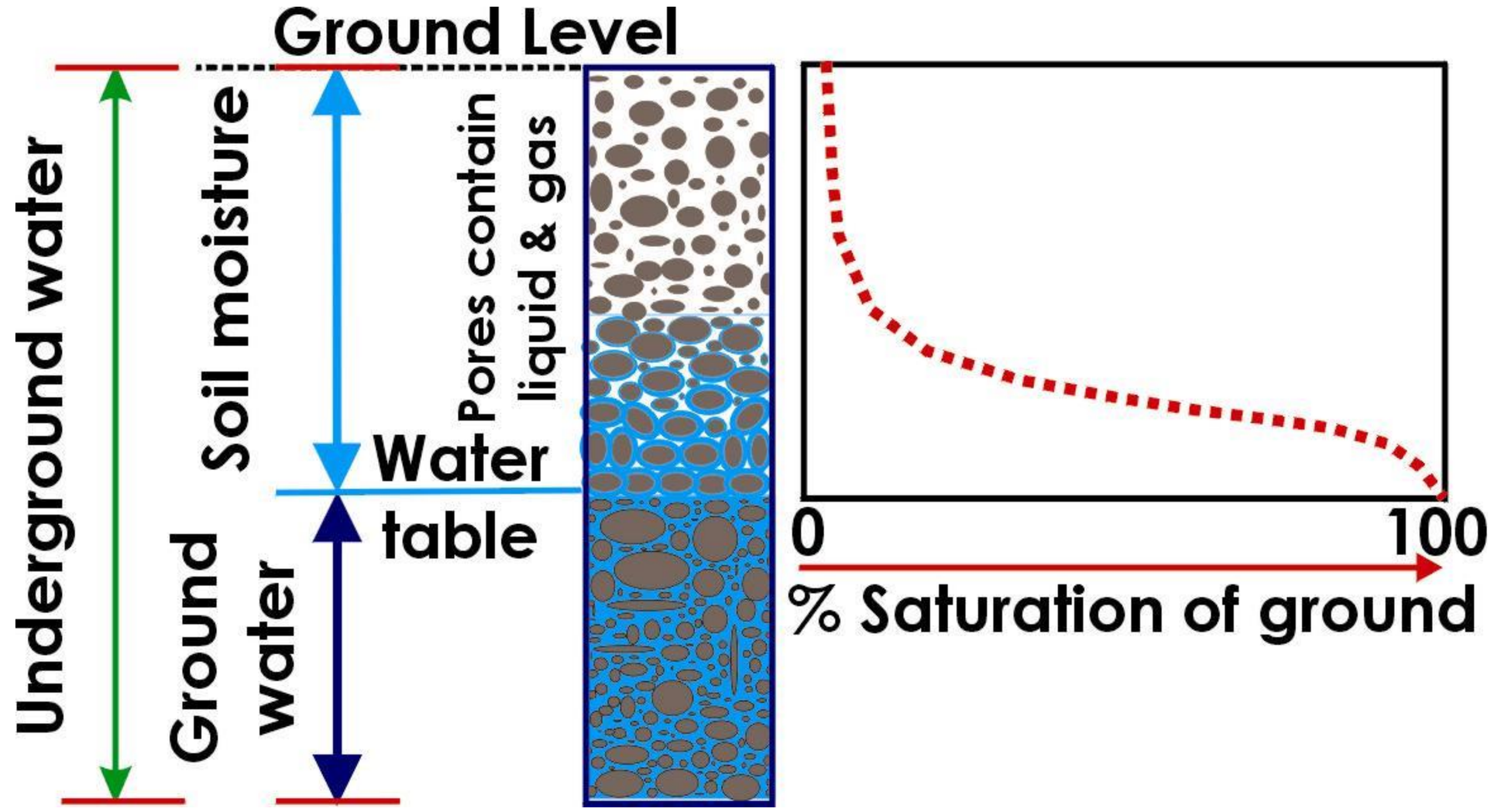
GROUNDWATER

What is groundwater?

- It is **rainfall that soaks** into the **ground** and **moves downwards** into soil pore spaces and cracks in rocks.

- The study of geological formations that store groundwater is essential for a **comprehensive understanding of groundwater.**

Groundwater vs Underground Water

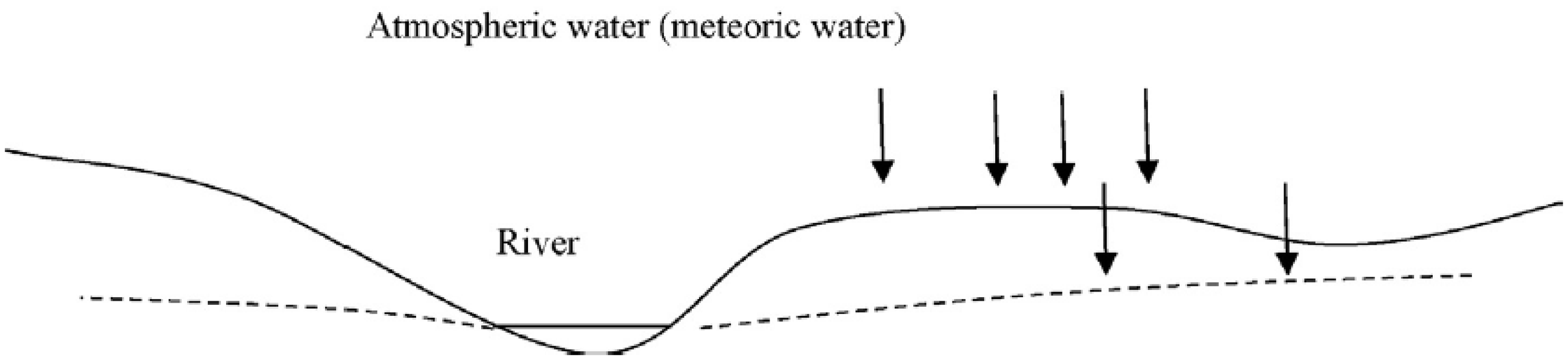


Water table – level at which porewater rests at atmospheric pressure.

Components of groundwater

- Water that exists in the **atmosphere**, in **clouds** and **air,** is known as **meteoric water**.
- Surface water could be **fresh water** or **oceanic water**.
- Groundwater is a part of the water cycle.
- **Groundwater** would seep into streams and **then get evaporated**.
- The **evaporated** water falls back on earth and seeps back into the ground

Components of groundwater cont'd

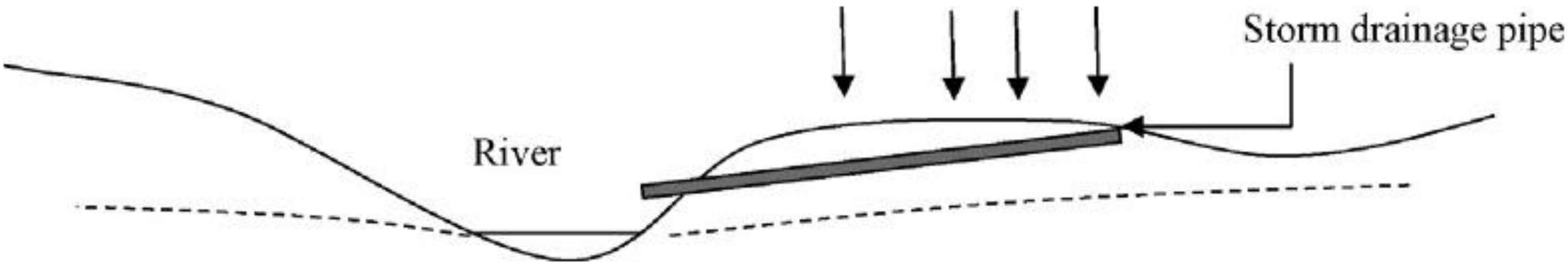


Ground water as part of water cycle

Components of groundwater cont'd

- **Man-made** parking lots and **cities** prevent the infiltration of water into ground.
- The water falling on a big city would be transported to drains and then it flows to the ocean or large rivers through storm pipes.
- This would **bypass the groundwater**

Components of groundwater cont'd



Storm drainage

Components of groundwater cont'd

Magmatic water:

- When volcanoes erupt, magma would flow. The water in magma gets released to the atmosphere and to the ground.
- Magmatic water can be identified from its mineral content.

Components of groundwater cont'd

Connate water:

- During the formation of sedimentary rocks, **water gets trapped i**nside the rocks.
- This water has not been in contact with the atmosphere for a **long period** of time.

Components of groundwater cont'd

Metamorphic water:

- metamorphic rocks are formed due to **high pressure** and **high temperature**.
- During the **formation of metamorphic rocks**, water gets trapped inside metamorphic rocks.
- The **chemical composition of metamorphic** water is different from connate water.

Components of groundwater cont'd

Juvenile water:

- Magmatic water, connate water, or metamorphic water **newly entering** into the **water cycle** is known as juvenile water

Formation of Groundwater

GW is formed from:

- **Infiltration** component – Entry of water into the soil
- **Percolation** of infiltrated water – downward movement of water thru soil/rock (and occurs below root zone).

Formation of Groundwater…..(2)

Both **infiltration** & **percolation** depend upon:

- Size of pores in soil / rock
- Total porosity of soil / rock
- Interconnectivity of soil / rock pores

  - ✓ Smaller pores have smaller hydraulic radius, & greater friction between water & pores.
  - ✓ Well-graded soils have smaller pores than uniform graded soils.
  - ✓ Dense soils are less permeable than loose soils

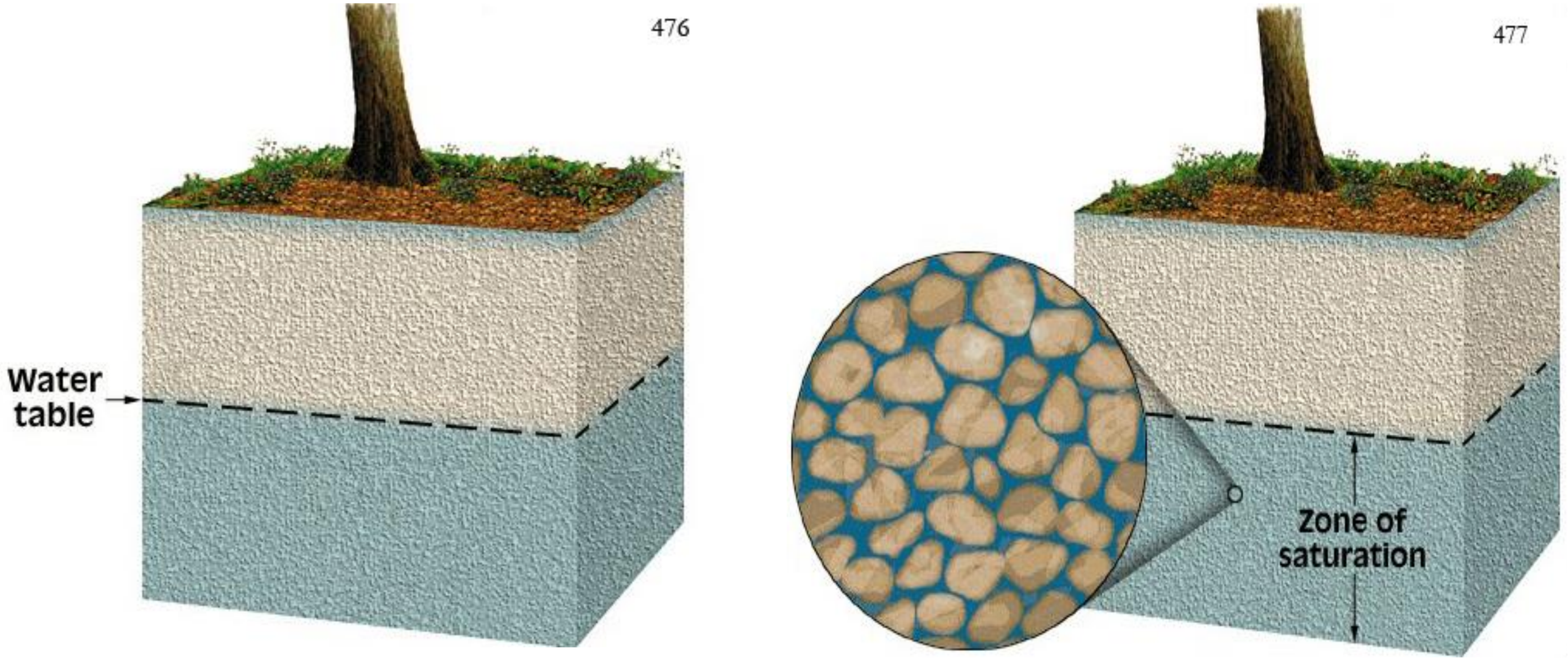
Groundwater Occurrence

GW occurs below surface in **voids, spaces and cracks**

between particles of soil and rock

Groundwater Occurrence.....(2)

Ppt percolates downwards to the **water table.**



- Below the water table, all pore spaces in sediment & rocks are *filled* with water.
- This is the **zone of saturation**

Groundwater occurrence cont'd

- The zone above the groundwater level is known as **vadose zone.**
- The vadose zone is also known as the zone of aeration. The vadose zone is divided into soil-water zone, intermediate-vadose zone, and capillary zone.

Ground water occurrence cont'd

- *Soil-water zone*: this zone is exposed to the atmosphere. During rains, this zone gets saturated. Other times, this zone is semi-saturated.
- *Intermediate vadose zone*: water in this zone depends on the soil type. Some soils would be able to store a significant amount of water.
- *Capillary zone*: due to capillary action, the groundwater rises up. The amount of water in the capillary zone depends on the soil type.

Groundwater occurrence

Aquifers, aquicludes, aquifuges, and aquitards:

- ***Aquifer*:** Water-bearing soil and rock formations are known as aquifers.
- The aquifers are capable of absorbing water and also transmitting water.
- Typically, sandy soils and sedimentary rock formations are considered to be aquifers.
- Aquifers are of two types: confined aquifers and unconfined aquifers.

Groundwater occurrence

- Confined aquifers are **not open to the atmosphere**. Confined aquifers sometimes may be **under pressure**.
- When a confined aquifer is **under pressure**, it is known as an *artesian aquifer*.

Groundwater occurence

- ***Aquiclude*:** Aquicludes can absorb water but would not yield an appreciable quantity of water.
- *Aquitard*: Aquitards, as in the case of aquicludes, can absorb water; however, they would not yield an appreciable quantity of water.
- **But unlike aquicludes,** the aquitards can transmit water from adjacent aquifers.

Groudwater occurence

According to USGS et al:

Aquiclude *– is a hydrogeologic unit which, although porous and capable of storing water,* ***does not transmit*** *it at rates sufficient to furnish an appreciable supply for a well or spring.*

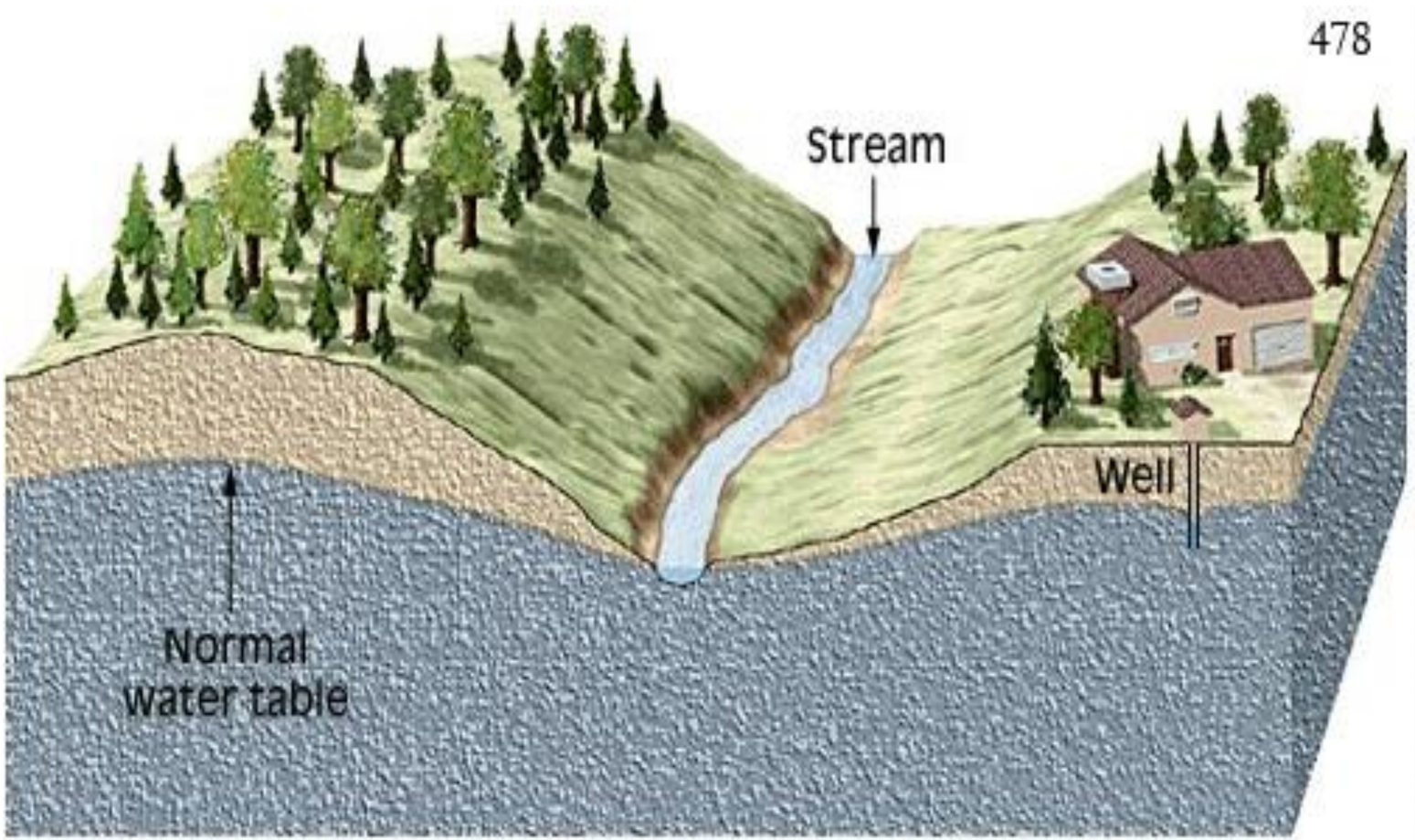
Aquitard *– A confining bed that retards but does not prevent the flow of water to or from an adjacent aquifer; a leaky confining bed. It does not readily yield water to wells or springs, but may serve as a storage unit for ground water.*

Groundwater occurence

- Although, aquitards do not have much water in store, they can transmit water from nearby aquifers.
- However, aquicludes are unable to do so.
- USGS prefers to use the term “**confining unit**” for aquicludes, aquitards, and aquifuges.

Groundwater Occurrence.....(3)

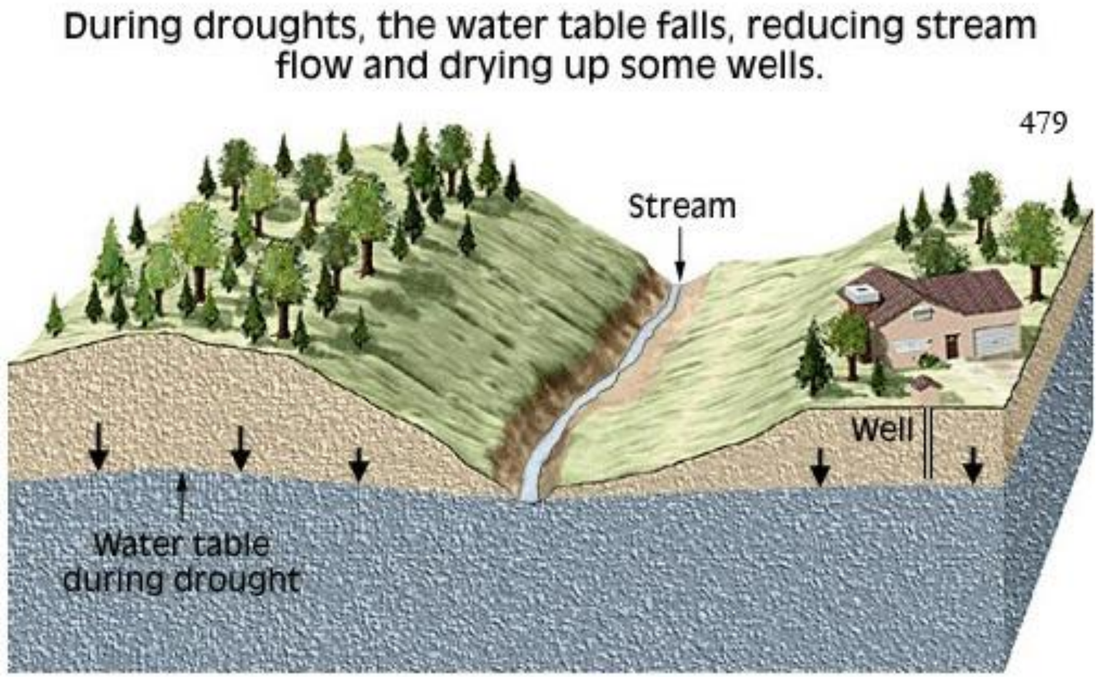
The water table is **rarely level**. Instead, its shape is a subdued replica of surface topography.

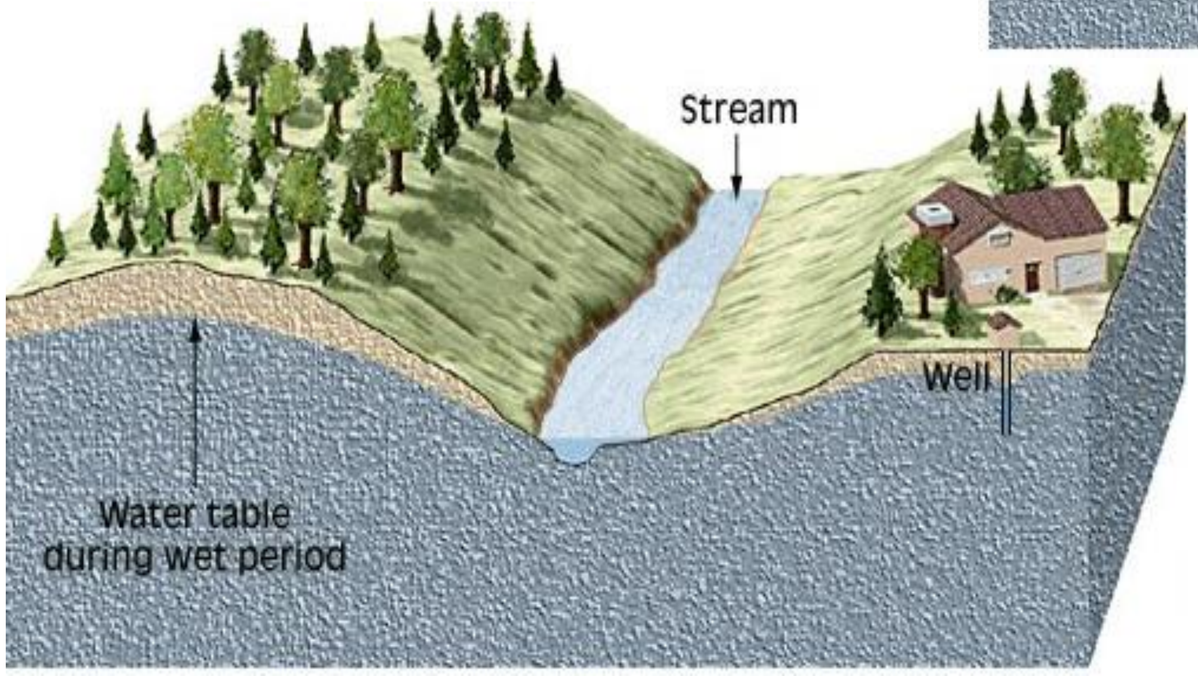


Groundwater Occurrence.....(4)

The height of the water table fluctuates:

During droughts, it drops….

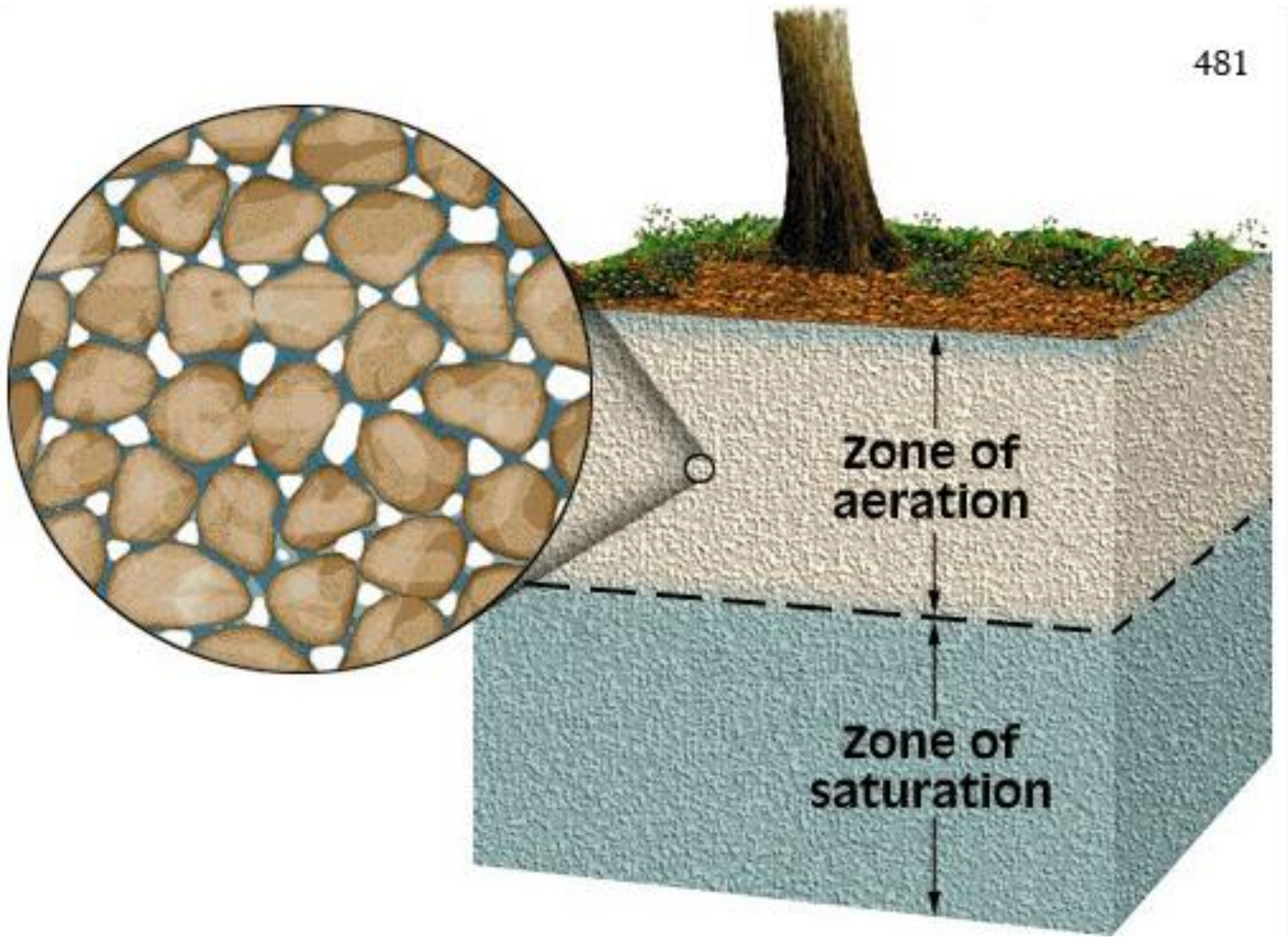




…and rises during wet periods

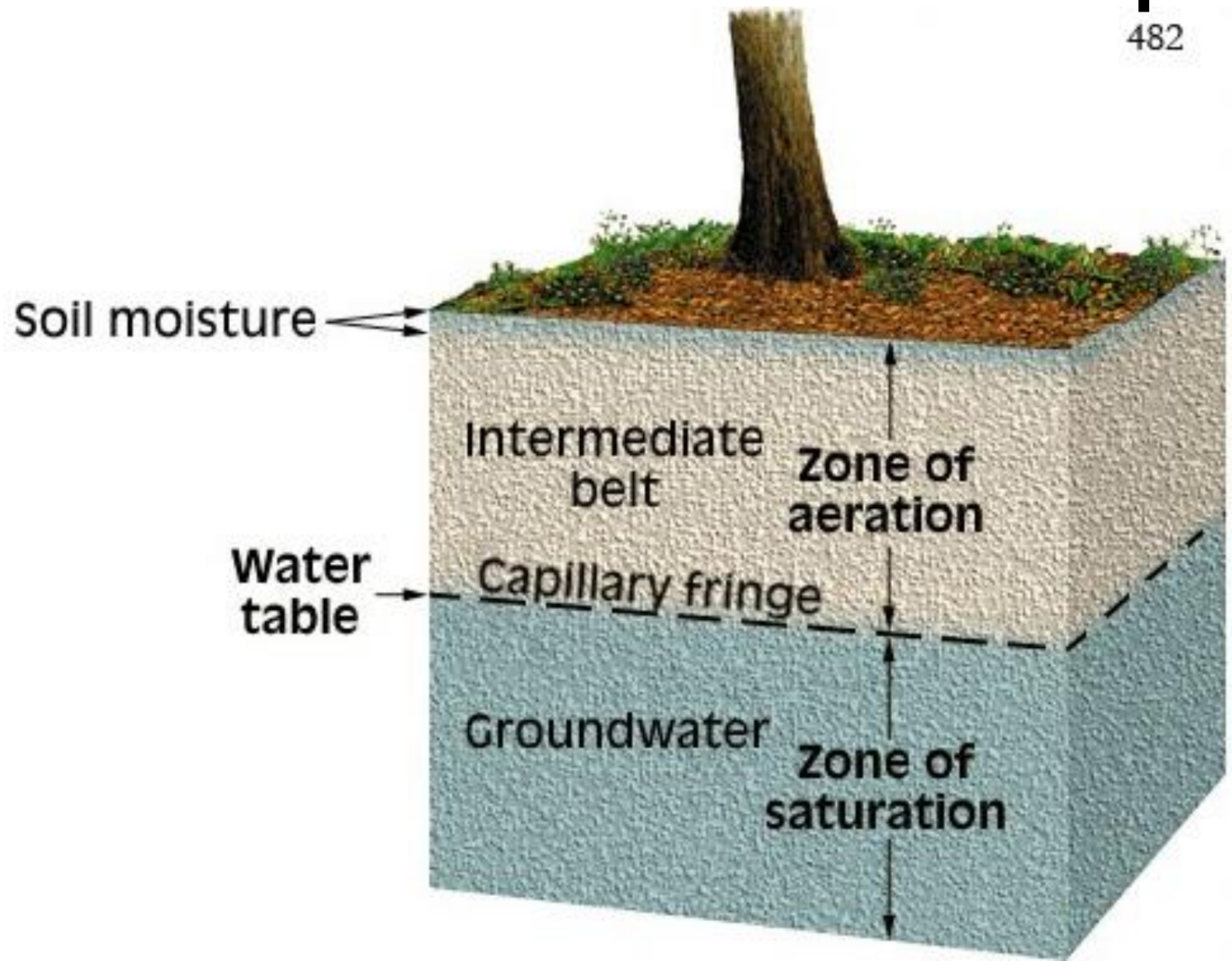
Groundwater Occurrence.....(5)

Above the watertable, pore spaces are unsaturated and filled mainly with air. This is called the **zone of aeration.**



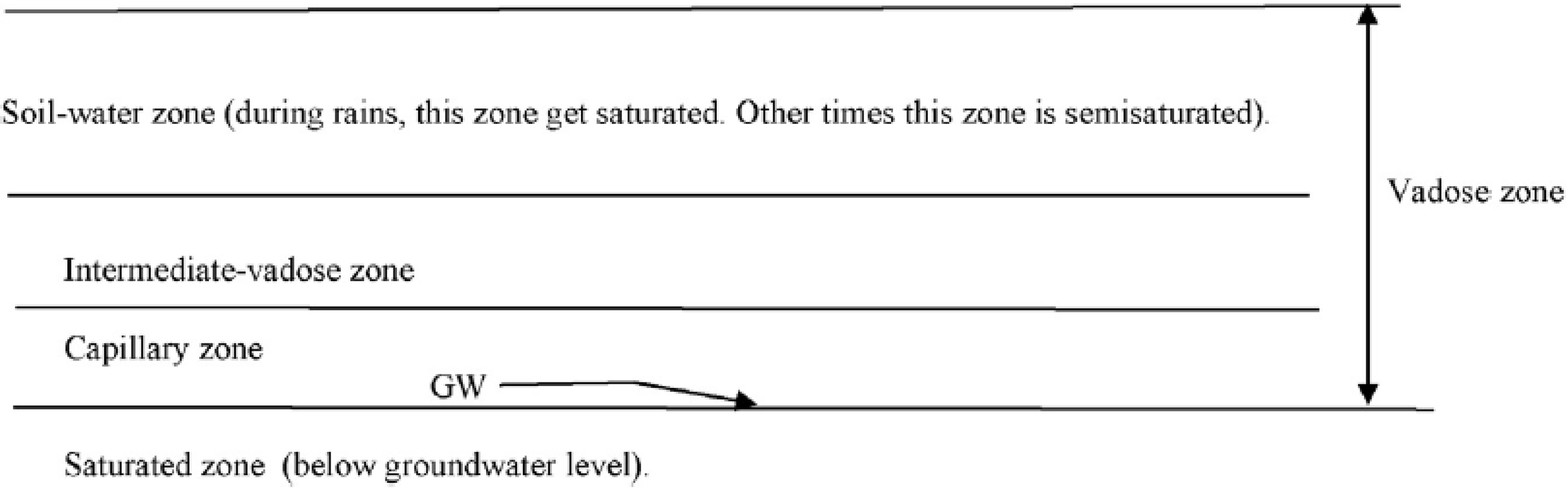
Groundwater Occurrence.....(6)

The **zone of aeration** can be further divided into the **zone of soil moisture**, the **intermediate belt** and the **capillary fringe**



Groundwater Occurrence…..(6) cont'd

Vertical distribution of GW [Zones]:

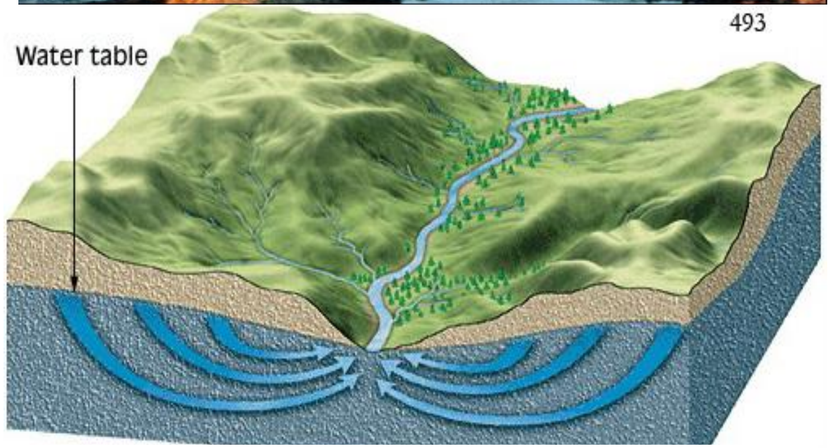


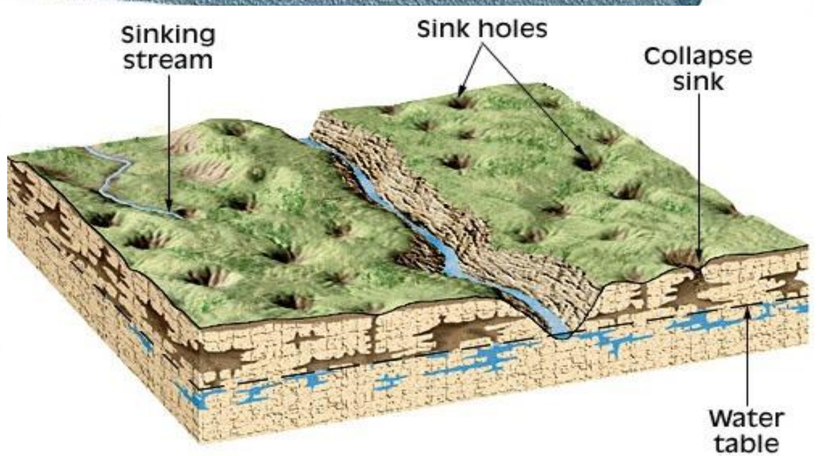
Groundwater Occurrence.....(7)

Parts of the Hydrosphere	Volume of Freshwater (km^3)	Share of Total Volume of Freshwater (percent)
Ice sheets and glaciers	24,000,000	84.945
Groundwater	4,000,000	14.158
Lakes and reservoirs	155,000	0.549
Soil moisture	83,000	0.294
Water vapor in the atmosphere	14,000	0.049
River water	1,200	0.004
Total	28,253,200	100.000

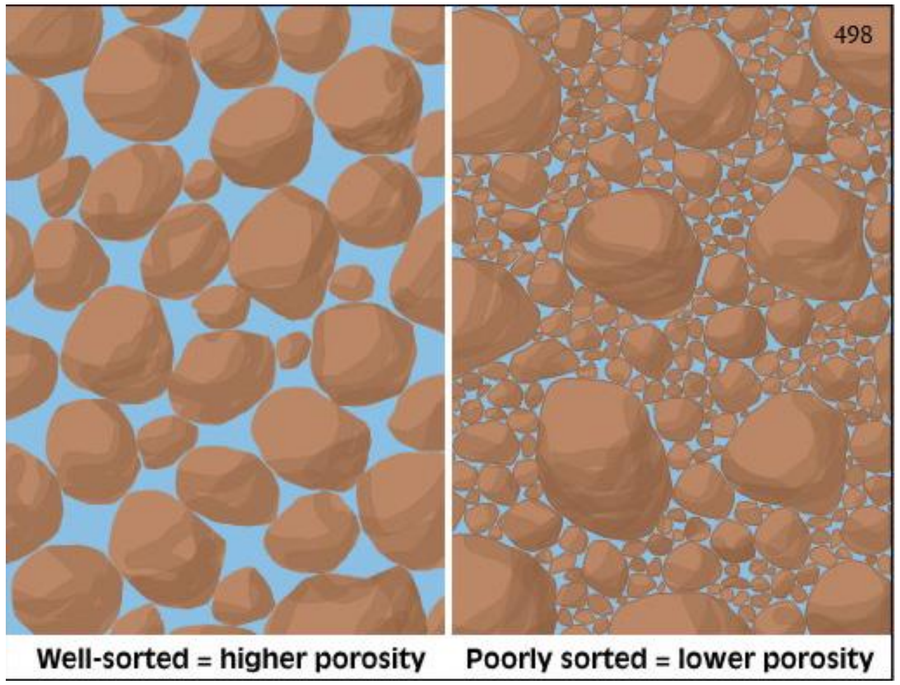
Role of Groundwater

- GW is very important **source of drinking water,** & for irrigation.
- GW has **important geologic roles.**
- In **humid regions**, it **contributes** significantly to flow of streams
- In regions underlain by soluble rocks e.g. in limestone, dissolving action of gw creates sinkholes…..





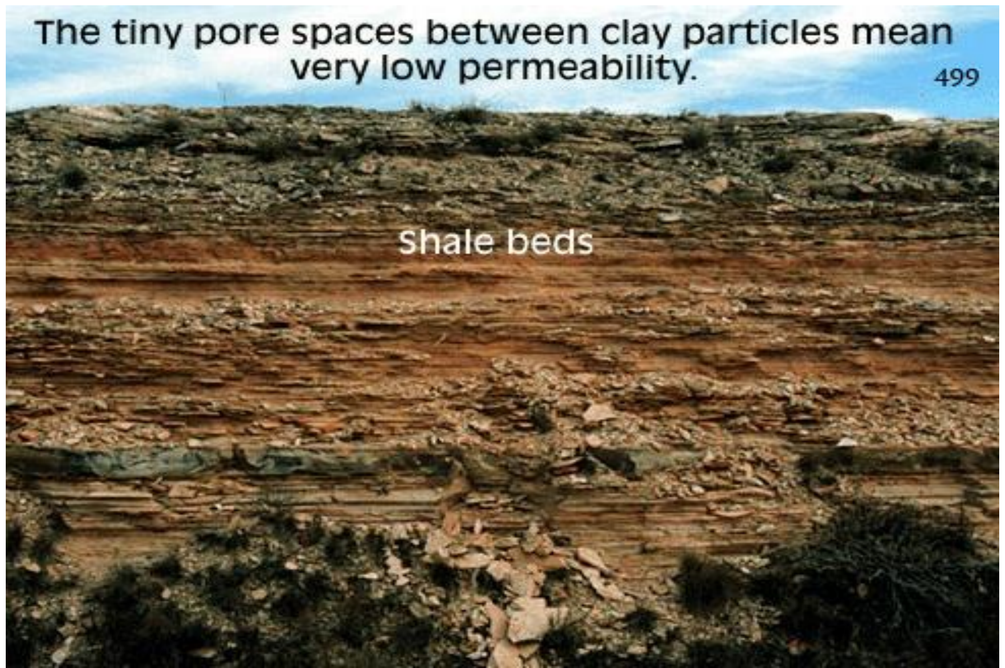
Parameters governing groundwater flow



Quantity of grdwater that can be stored depends on *porosity* of material.

***Porosity* =** *% age of total volm of rock/sediment that consists of pore spaces.*

Permeability = ability of a material to transmit a fluid. If pore spaces are too small, surface tension keeps the water from moving.



Parameters governing groundwater flow…..(2)

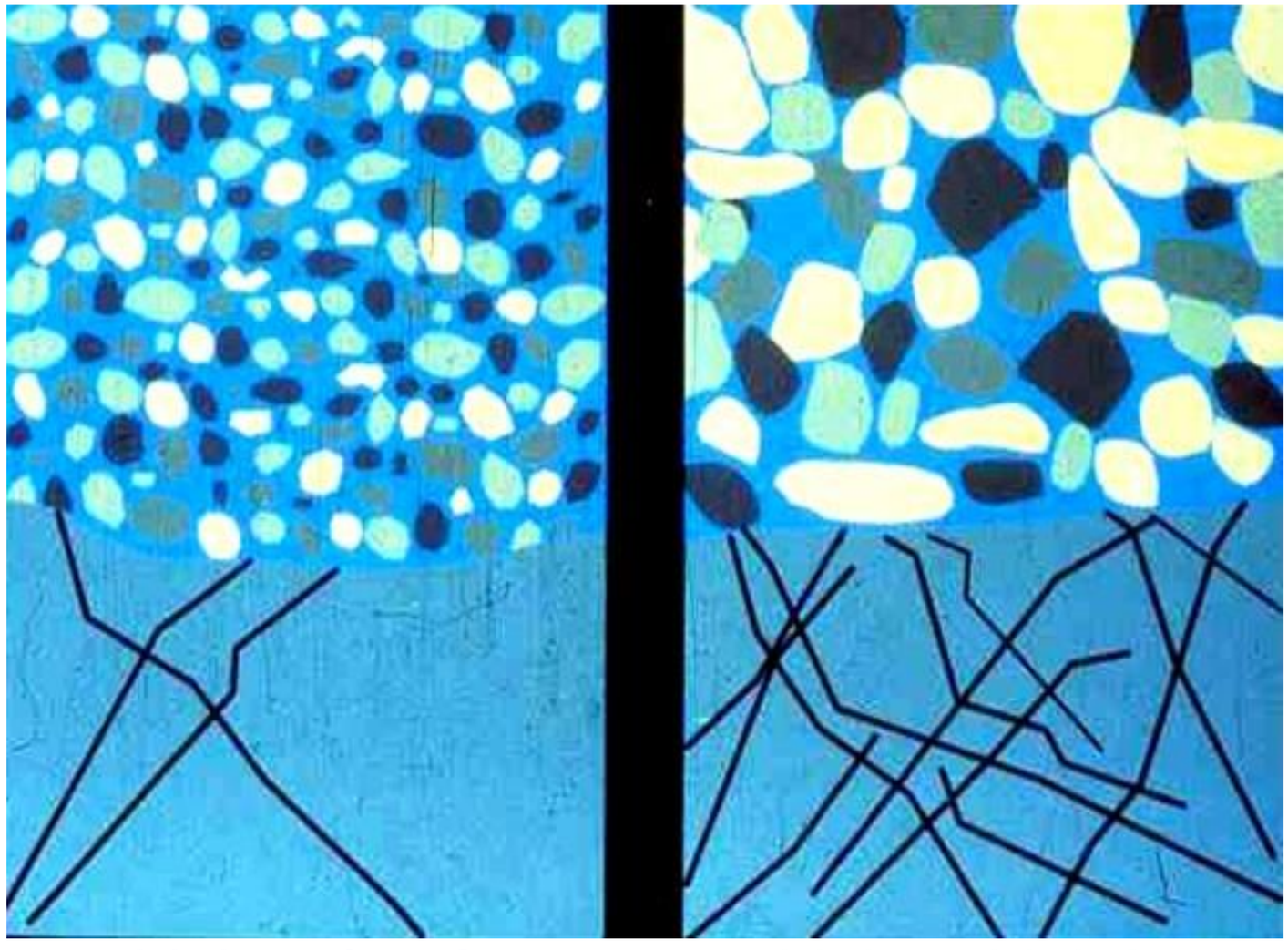
- **Porosity** (stores) **η** and **Permeability** (transmits) k

Sediments:

- granular rocks from detrital material
- Primary porosity with matrix flow
- Fine grained &Coarse grained – shale, sst.

Crystalline rocks:

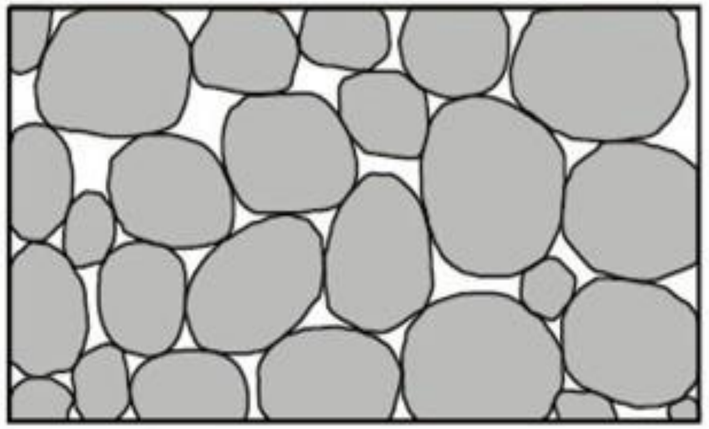
- fractures
- Secondary porosity with water flow only in fractures
- Fracture density controls yield – granite, basalt



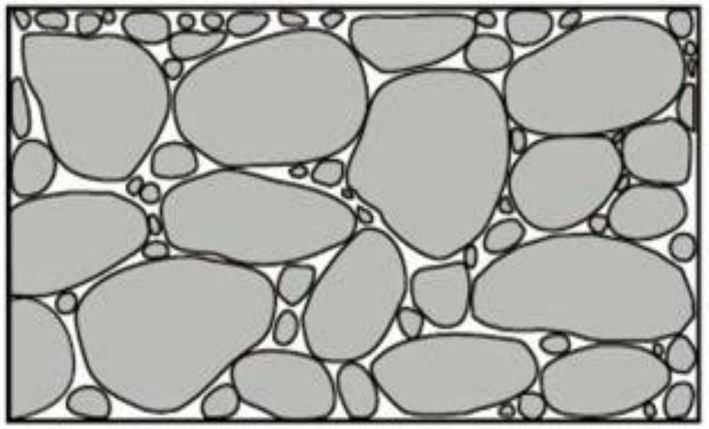
high **η**, low **k**
low **η**, low **k**

high **η**, high **k**
low **η** high **k**

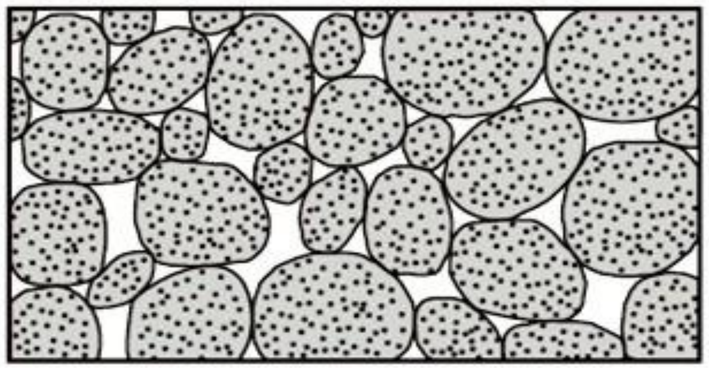
Parameters governing gw flow.....(3)



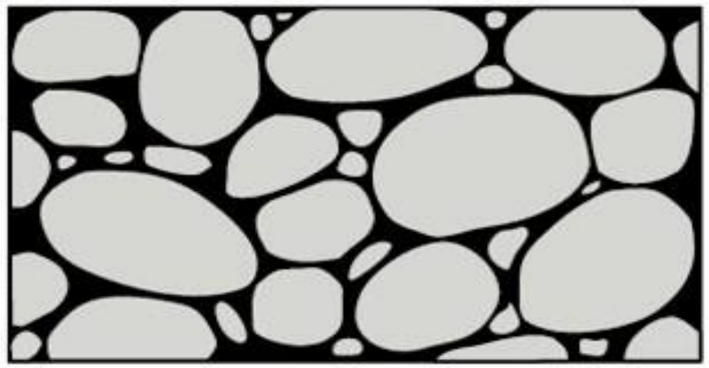
(A) Well-sorted, unconsolidated sedimentary deposit having high porosity



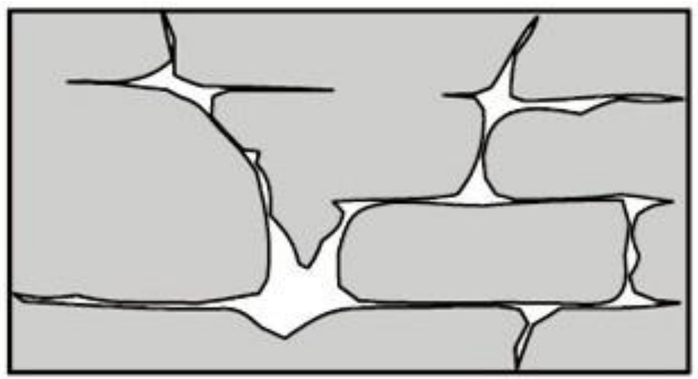
(B) Poorly sorted sedimentary deposit having low porosity



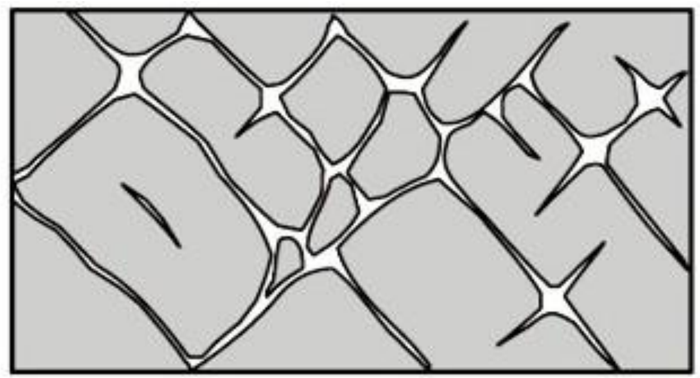
(C) Well-sorted sedimentary deposit consisting of pebbles that are themselves porous, so the deposit as a whole has high porosity



(D) Sedimentary deposit whose porosity has been diminished by the deposition of mineral matter between the grains



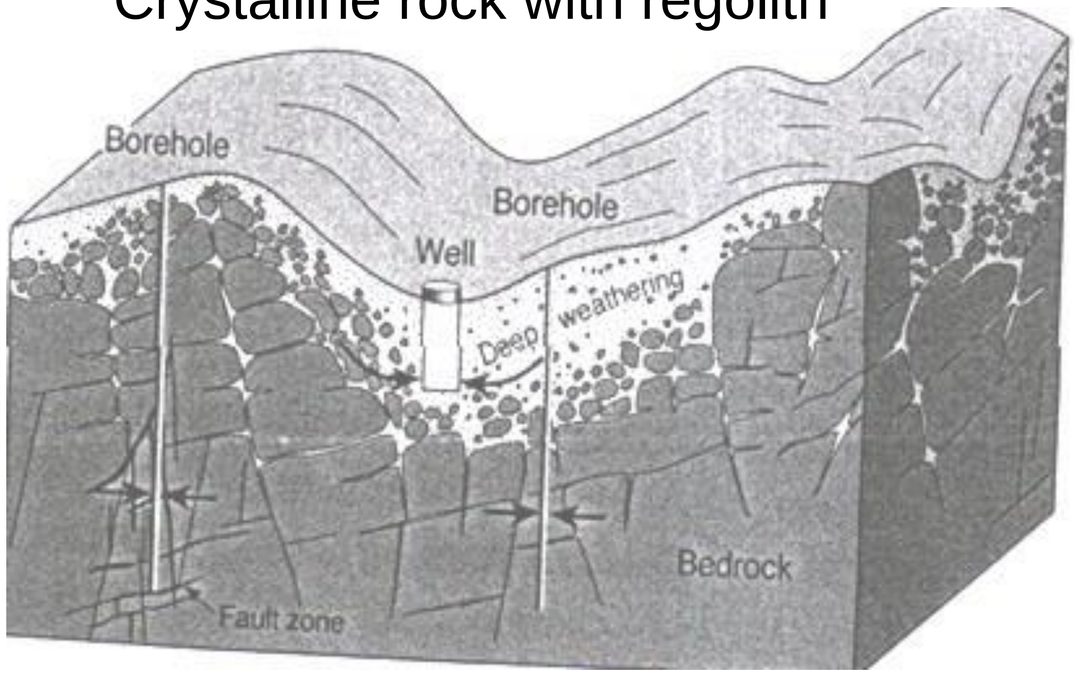
(E) Rock with porosity increased by solution

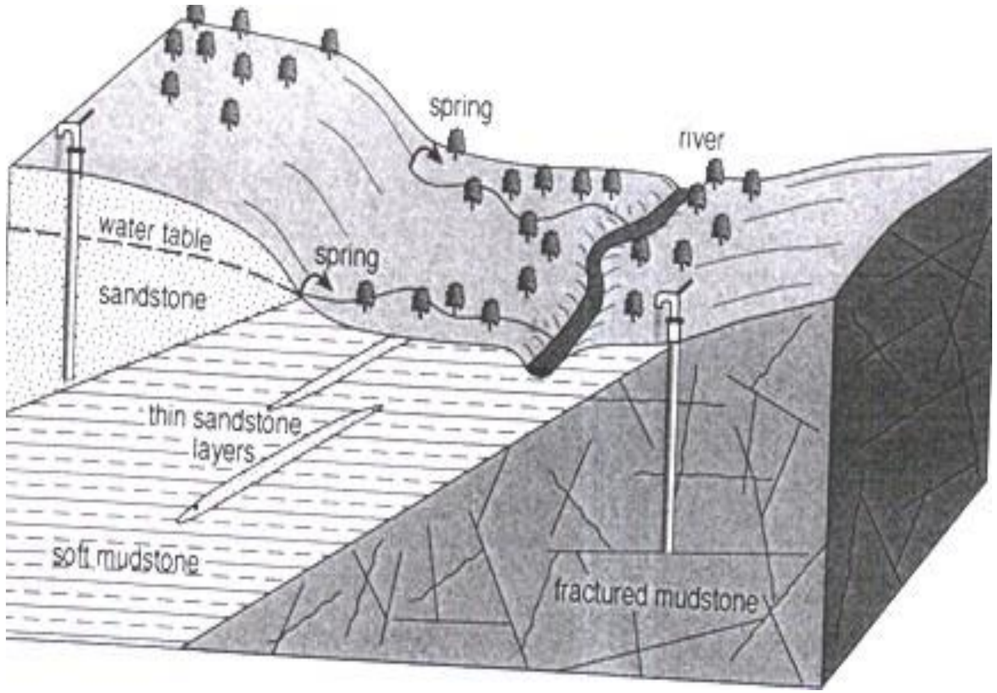


(F) Rock with porosity increased by fracturing

Parameters governing groundwater flow

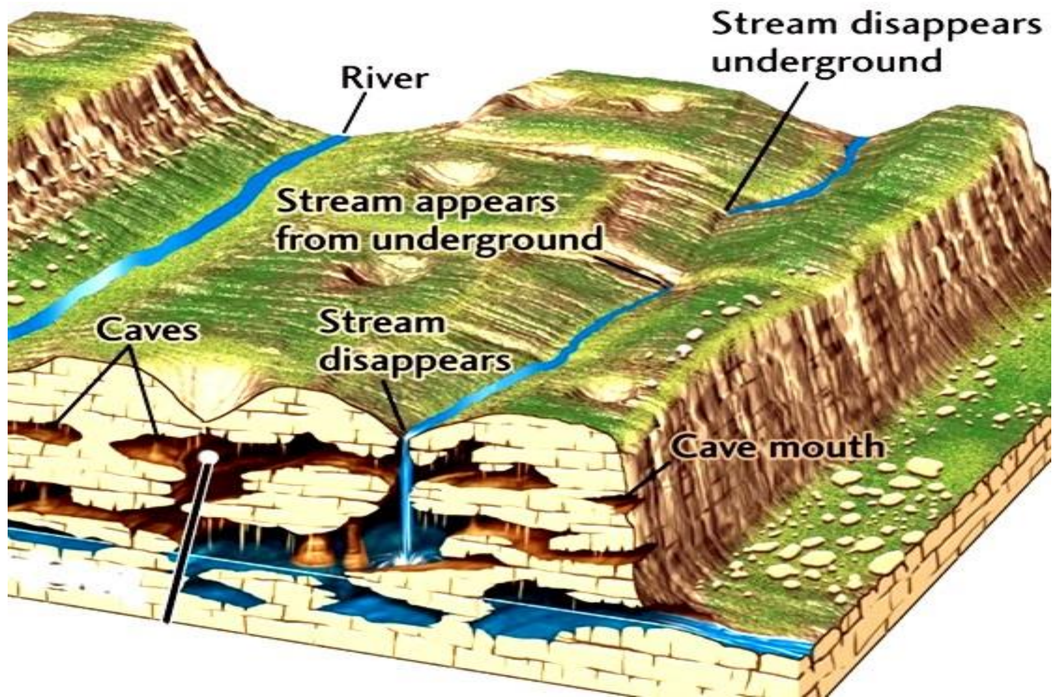
Crystalline rock with regolith



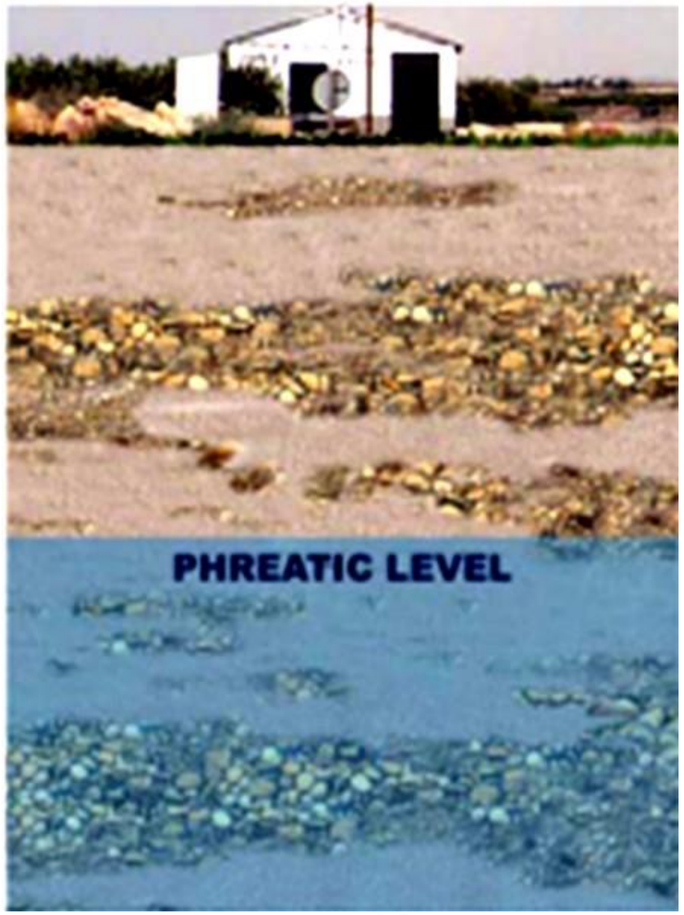


Sedimentary rocks of different types

Karst marble



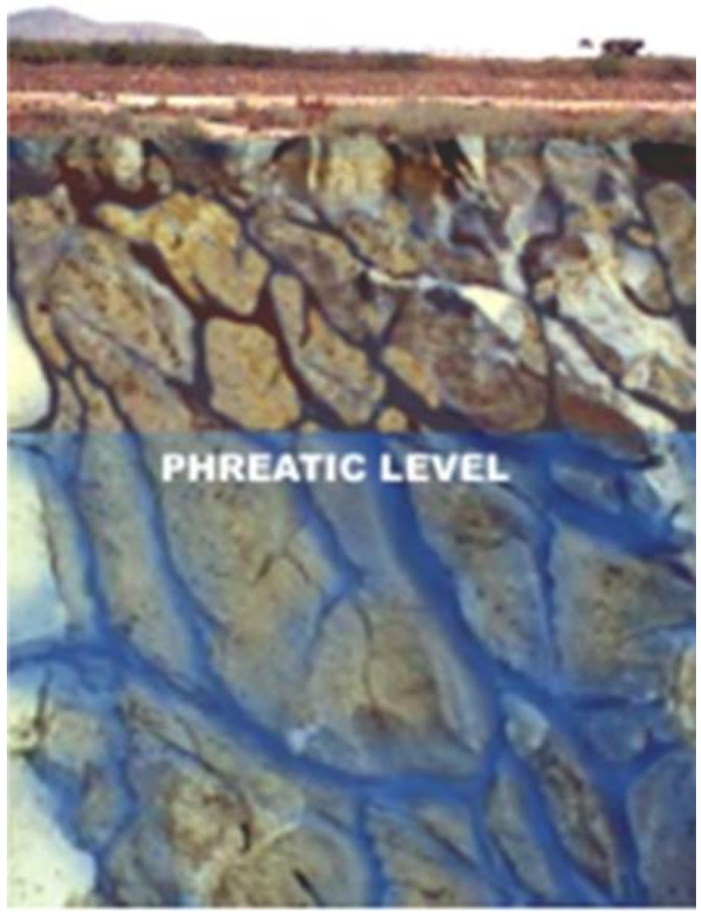
Hydrogeological diversity



Detritic aquifer

Unconsolidated rocks:

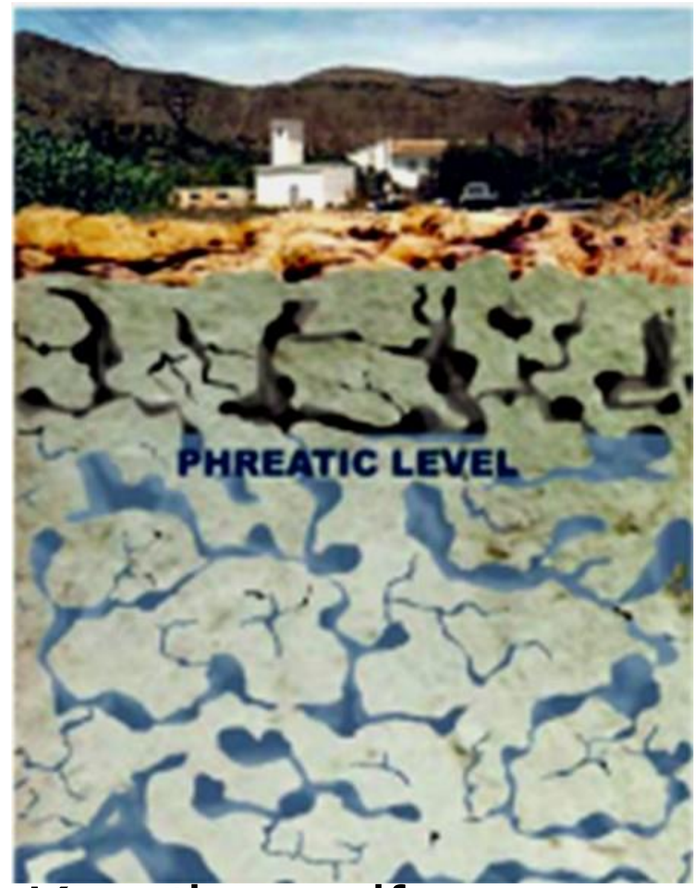
- Primary Porosity
- Large storage
- Locally high permeability



Fissured aquifer

Consolidated rocks:

- 2ndary fracture porosity
- Small storage
- Low permeability



Karstic aquifer

Consolidated rocks:

- Karsts (enlarged fractures)
- Moderate storage
- High permeability

GROUNDWATER SUPPLIES & ITS QUALITY ASPECTS

Special characteristics of Groundwater

- Is a **vital resource to most of the people**, who depend on it for their water supplies.
- It provides low-cost, drought-reliable & high-quality water supplies for both urban + rural populations
- Therefore gw will be vital for achieving water MDGs.
- GW replenishment is finite & limited to shallower aquifers, & whose quality **can seriously be degraded by pollution**.

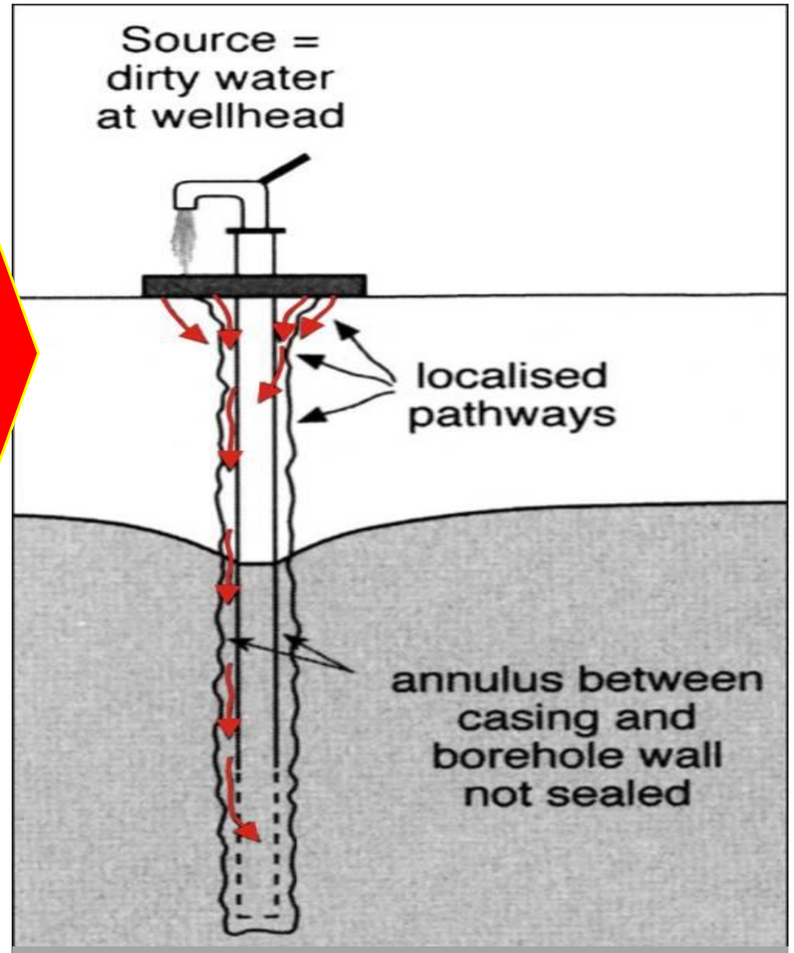
Groundwater – A source of rural water supply

- Currently supplies about **47% of Africa‘s rural population** [while 53% still remains without access to safe water (AfDB 2009)]
- Is a predominant source of ***Safe drinking water*** through hand-dug-wells and drilled wells with hand pumps.
  - Frequent reports (in literature) indicate elevated nitrate levels and bacterial contamination.

Contamination sources for rural water supplies

dirty water at well head recirculating into the well

Nkhuwa, 2009



McDonold et. al. (2005)

Contamination sources for rural water supplies (2)

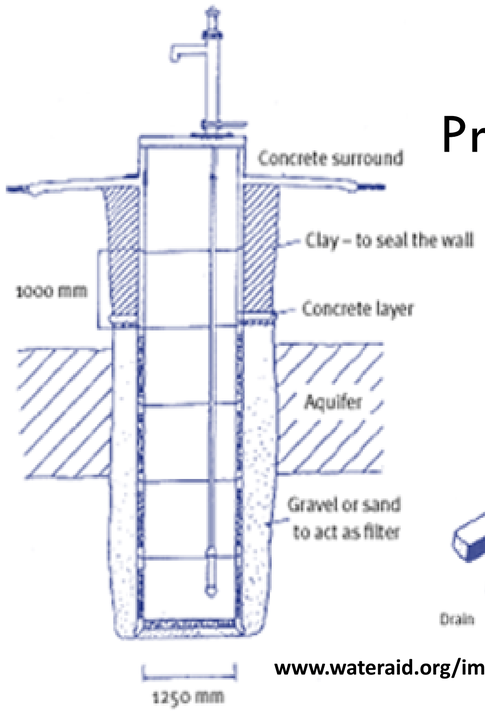
Nkhuwa, 2006 Pollution from animal-faeces

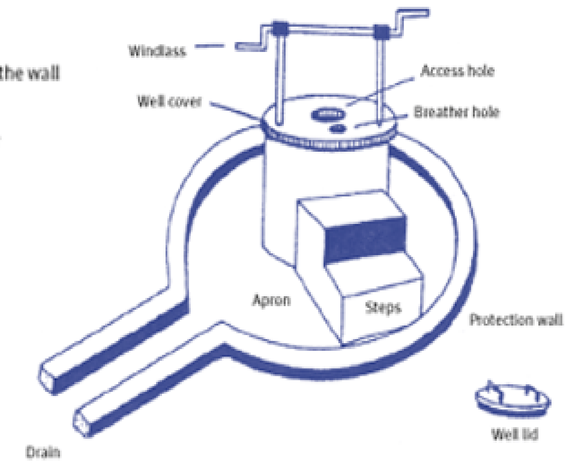
Remedial measures for rural water sources

- Proper well construction can significantly improve water quality
- Well location upstream / away from **pollution sources** – *pit latrines, waste dumps, cemeteries, etc.*
- Installation of concrete platforms around well, & with proper drainage
- **Animals** must be kept away by a fence.

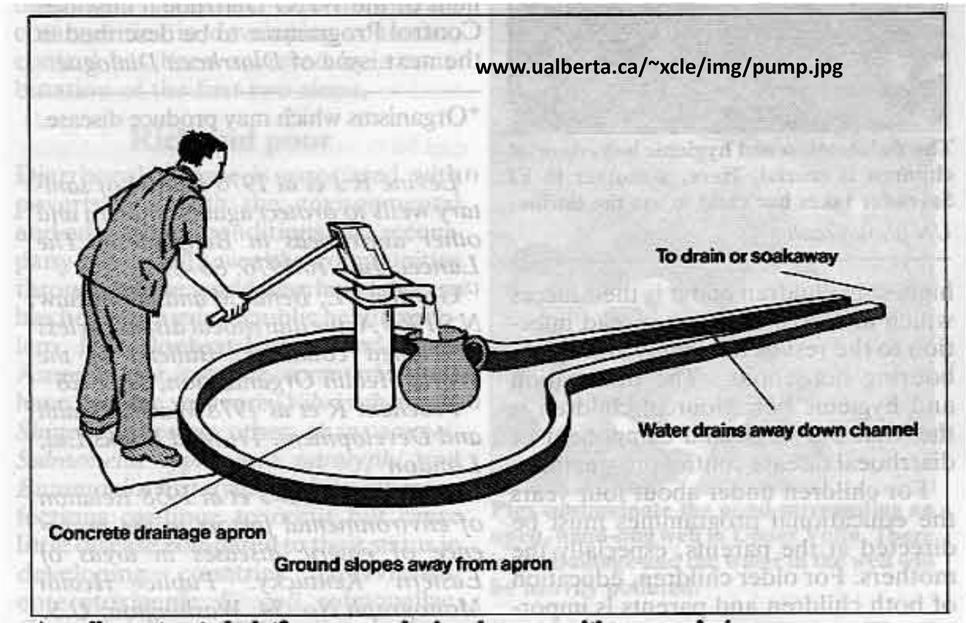
Protection measures…..(2)

Proper well construction





www.wateraid.org/images/cm_images/pump-web.jpg



A well constructed platform around a hand pump, with proper drainage.

Concrete platforms around the well

Fencing to keep away animals

Wells must be located upstream/away from pollution sources – *pit latrines, waste dumps, cemeteries, etc.*

Peri-urban settlements

Present situation in Peri-urban settlements in Africa:

- Uncontrolled settlement
- Predominant use of on-site sanitation
- Uncontrolled waste dumping
- Water supply predominantly from dug wells or water ponds

❖ Extensive contamination by **nitrate**, **nitrite**, **ammonia**, and **faecal bacteria**

❖ Frequent outbreaks of **water-borne diseases** (cholera).

Contamination sources in Peril-urban settlements…..(2)

- Choice of **location of pit latrines** in high-density settlements

Strategies to improve water pollution in peri-urban areas

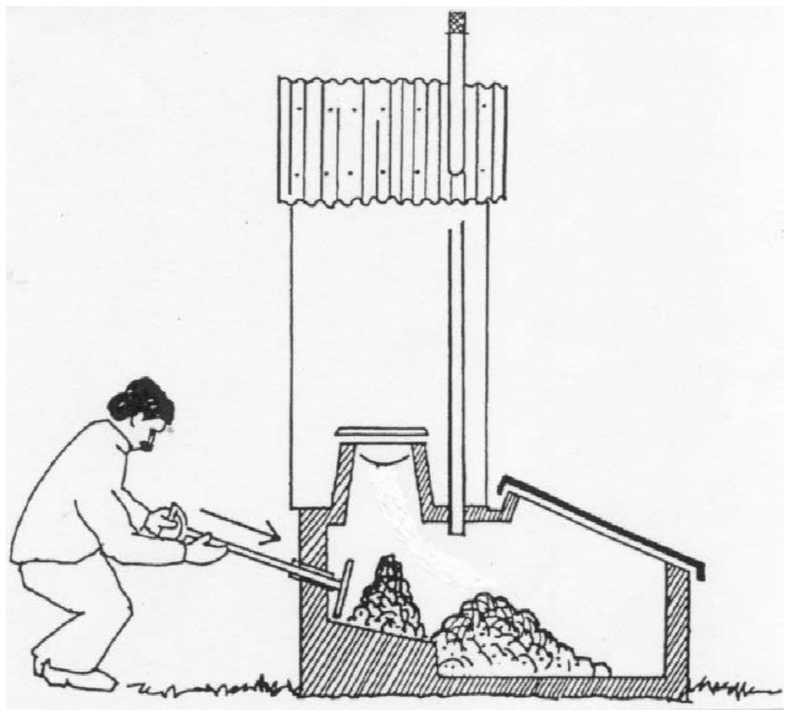
- Connection to public water supply (**piped water system)**
- Connection to sewerage system

  - Both these options are very expensive
  - Therefore, Ecosan Toilets would provide alternative systems

Strategies to improve water pollution in peri-urban areas

- Improvement of on-site sanitation through reuse of faecal matter (dry toilets – ecosan).

Dehydrating toilets

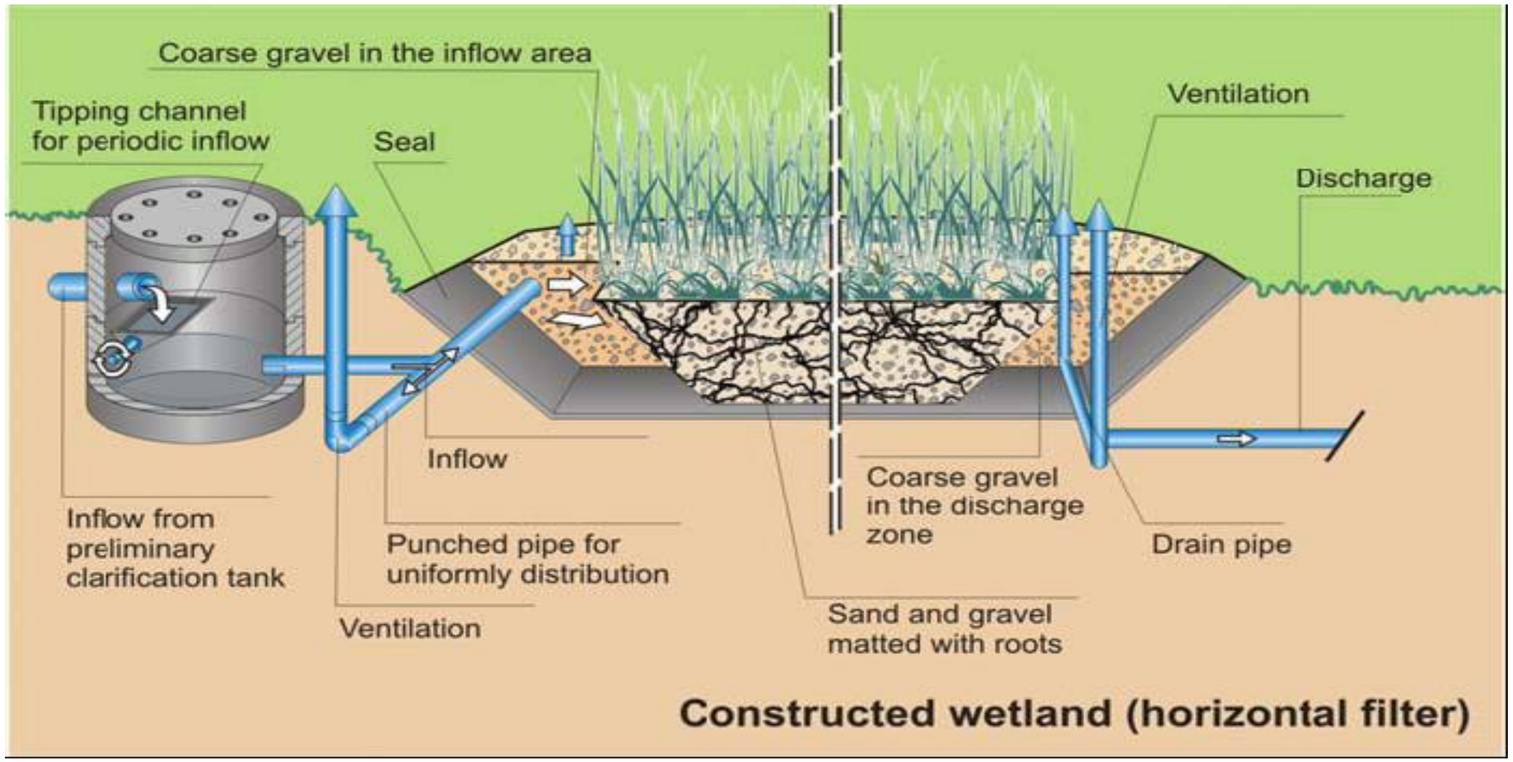


Source: CSIR 2004

Strategies to improve water pollution in peri-urban areas

- Improvement of on-site sanitation through use of low cost wastewater treatment.

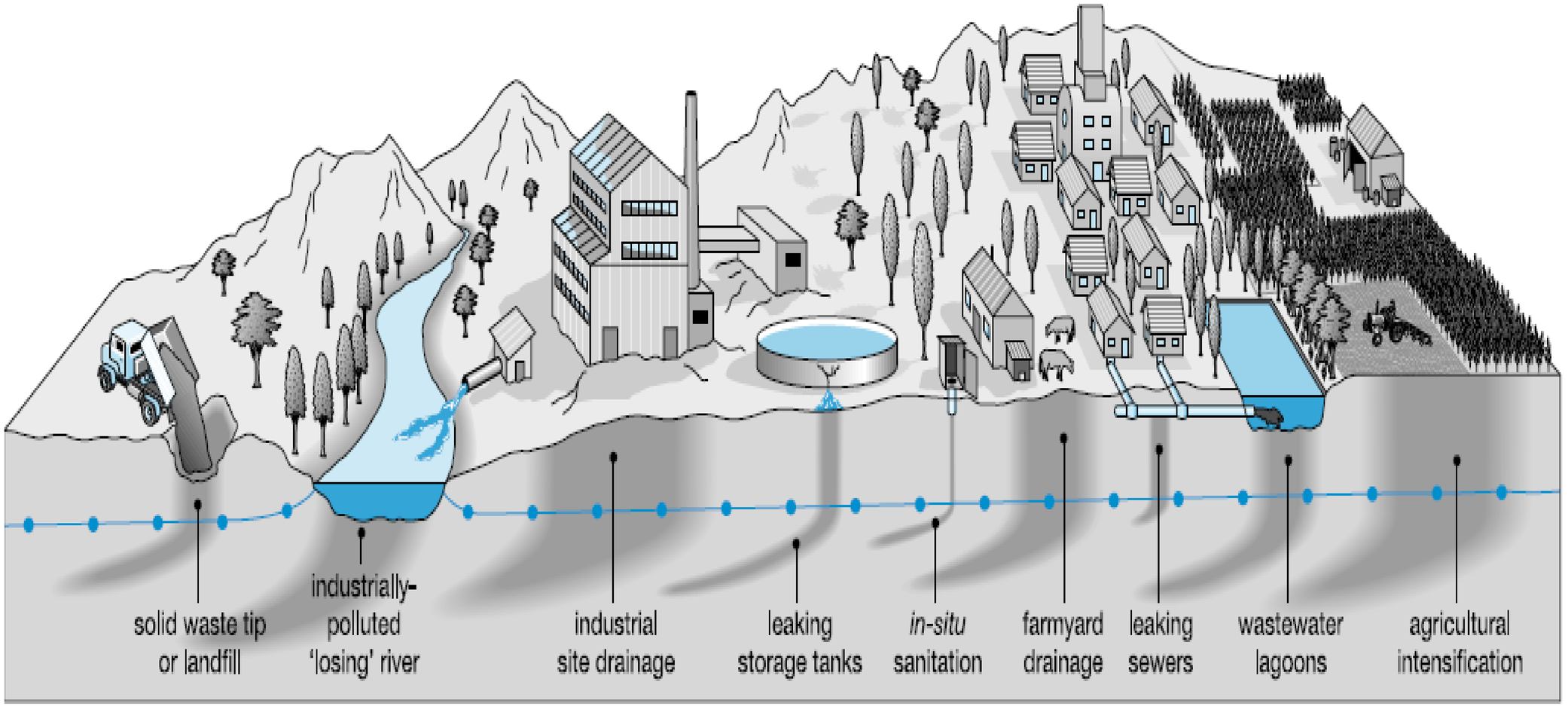
Wastewater treatment



Source: BGR 2008

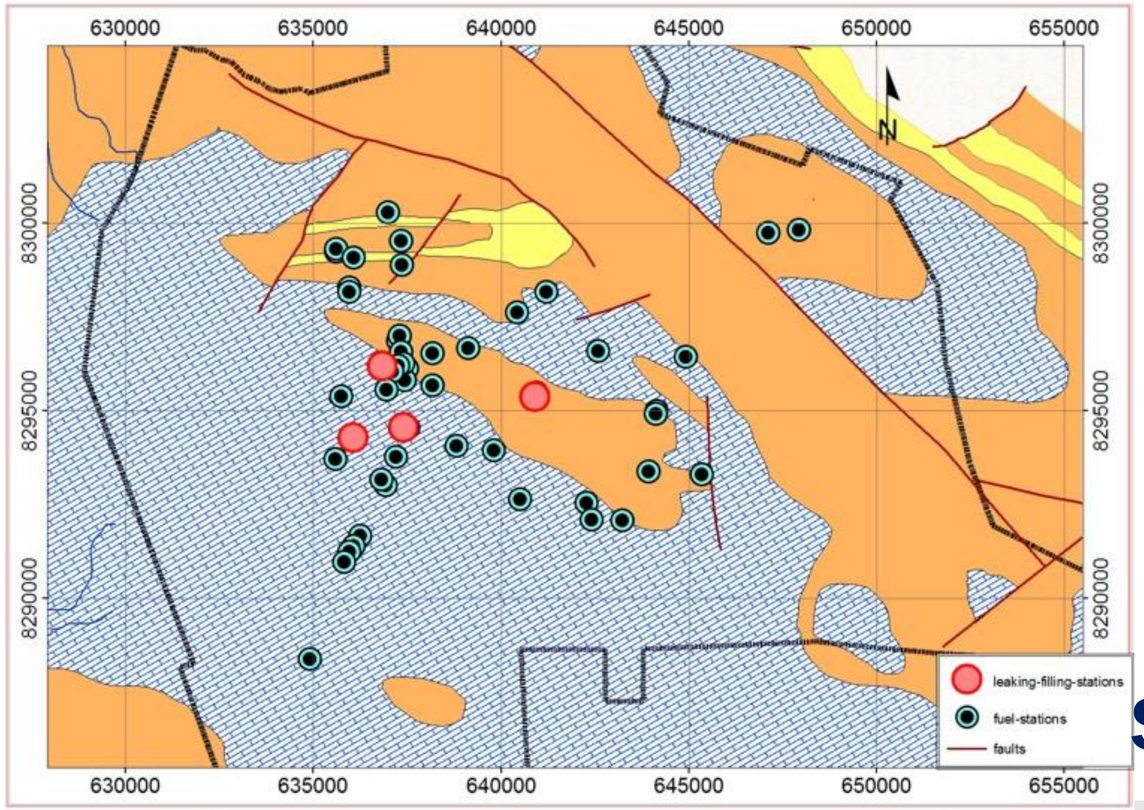
The Urban Environment

Some land-use activities commonly responsible for groundwater pollution in the Urban areas include:

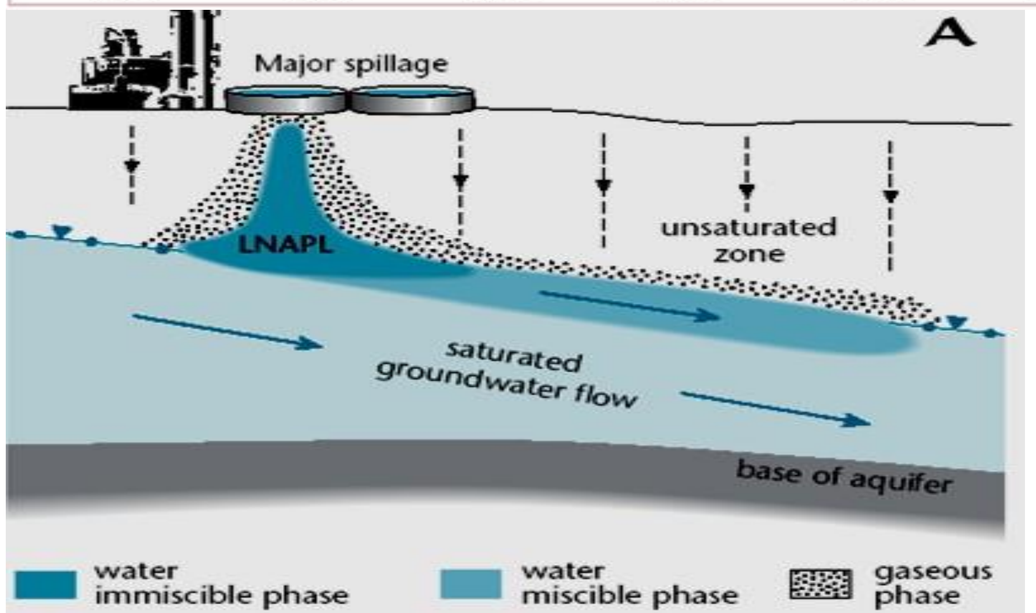


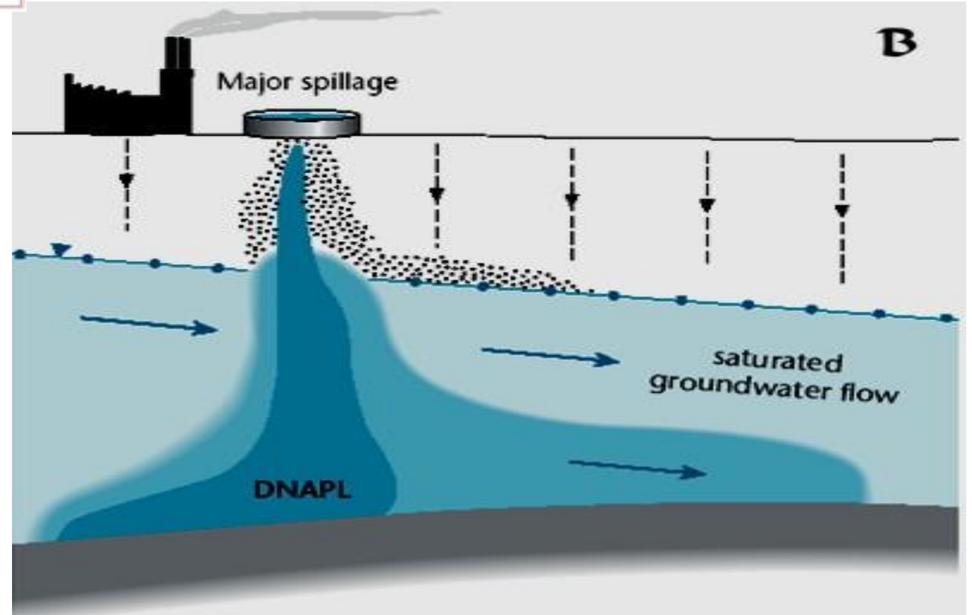
Source: GW-Mate

Contamination sources in urban settlements



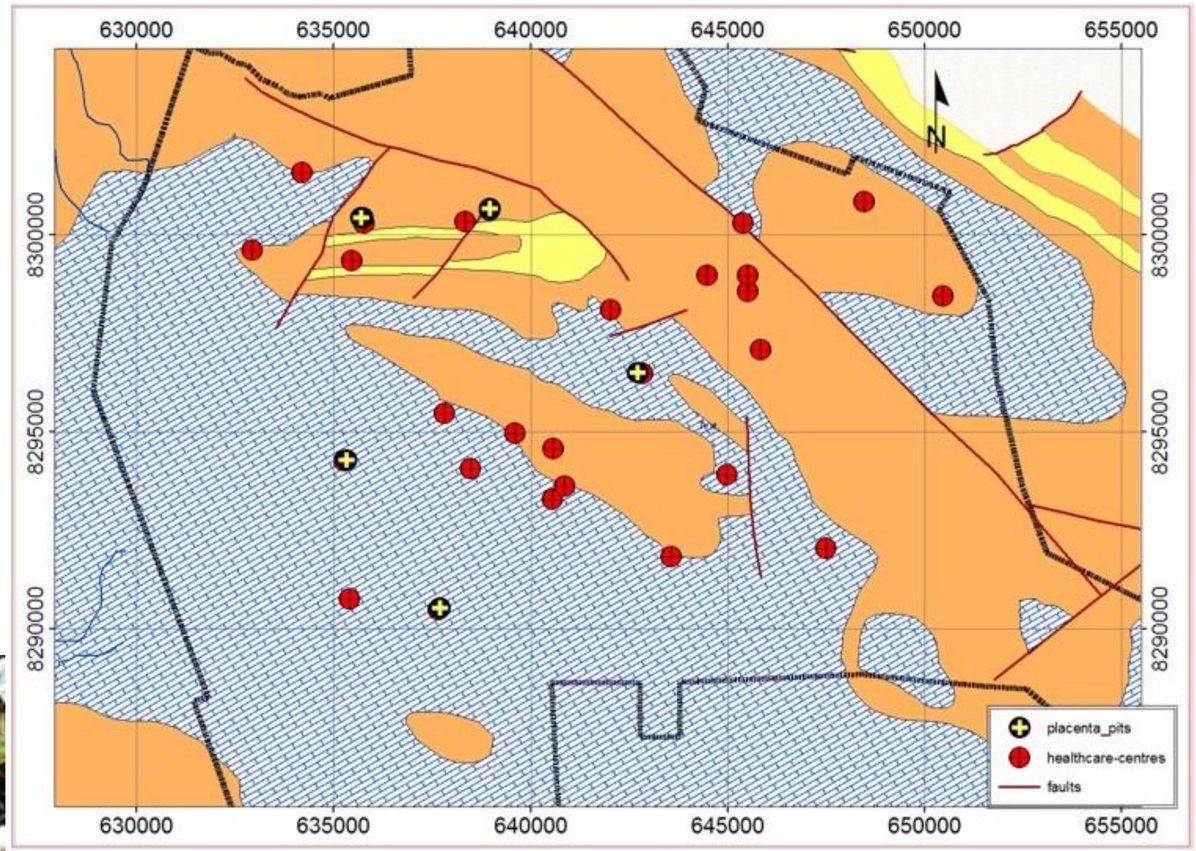
Spread of filling stations





Contamination sources in urban settlements.....(2)

Spread of filling stations...



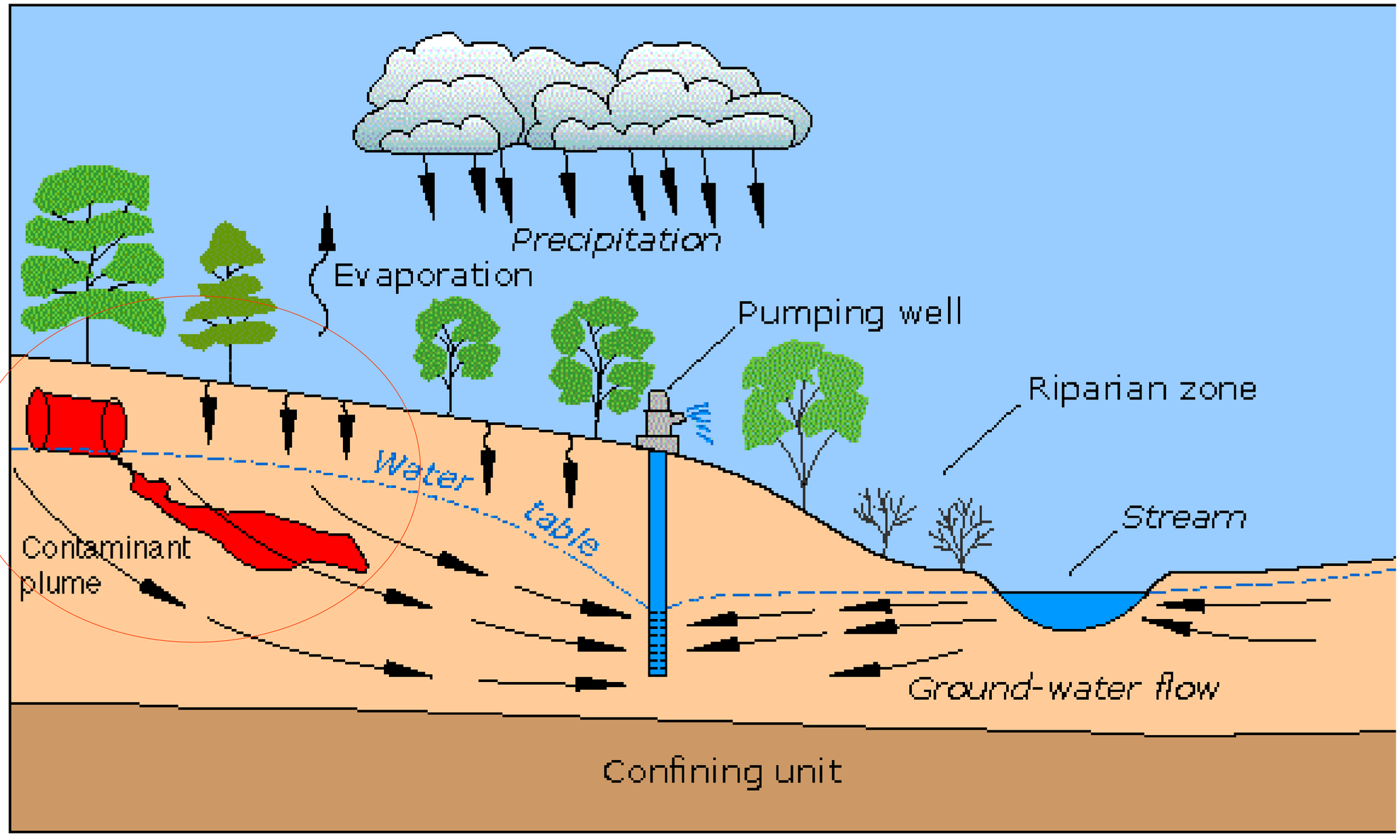
Contamination sources in urban settlements.....(3)

Contamination sources in urban settlements…..(4)

Disposal of
Incinerated material

Contamination sources in urban settlements.....(4)

Contamination sources in urban settlements.....(5)



Remedial measures

Protection of the Resource:

- Common approach worldwide:
  - Protection of water resources by Groundwater Protection Zones (GPZ).

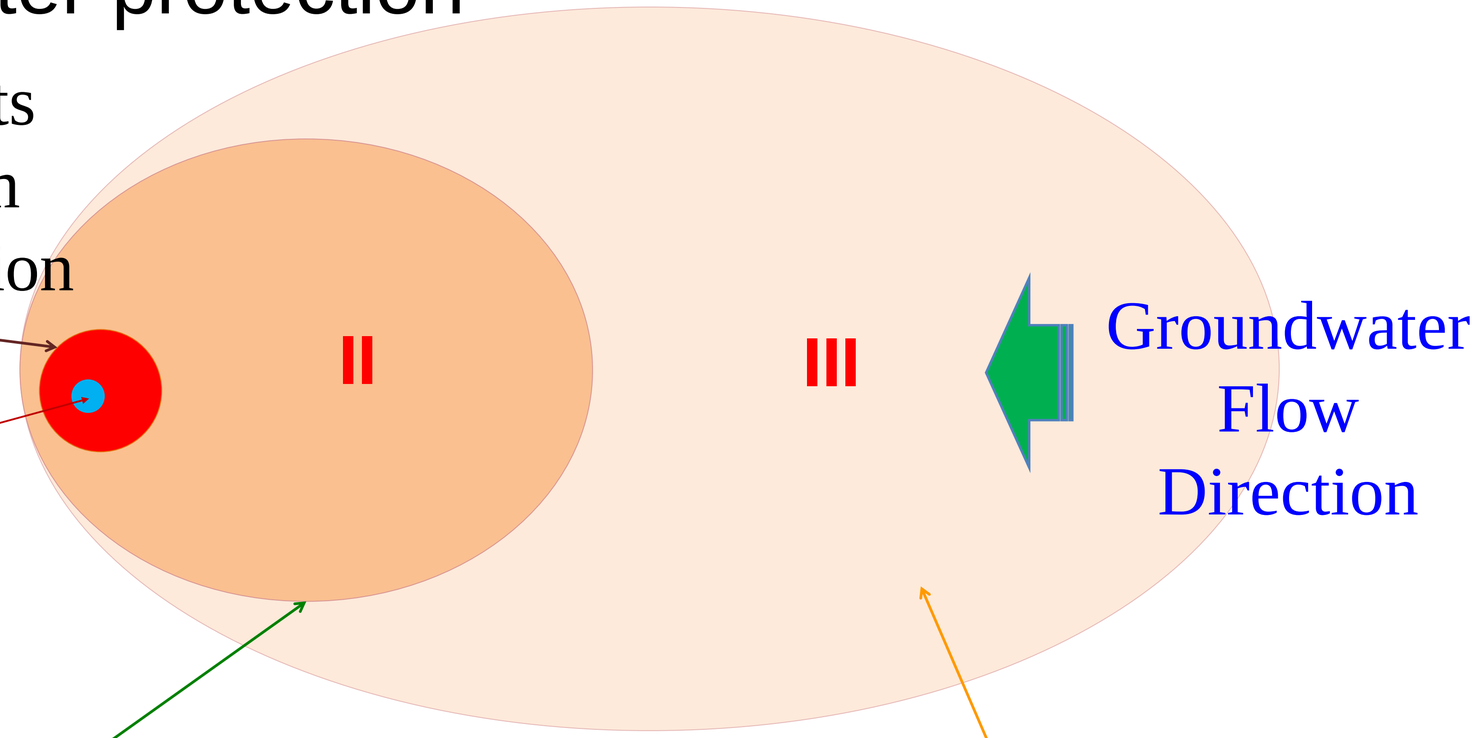
General aim:

- To Protect drinking GROUNDWATER resources, upstream of a well or spring, from pollution.

Remedial measures.....(2)

....Groundwater protection

Zone 1 – Protects well/spring from direct contamination



Zone II – Protects drinking water source against pathogenic micro-biological constituents *bacteria*, *viruses*, *parasites*.

Zone III – Protects against contamination affecting drinking water source over long distances (for chemical substances, which are non- or hardly degradable)

End of Lecture