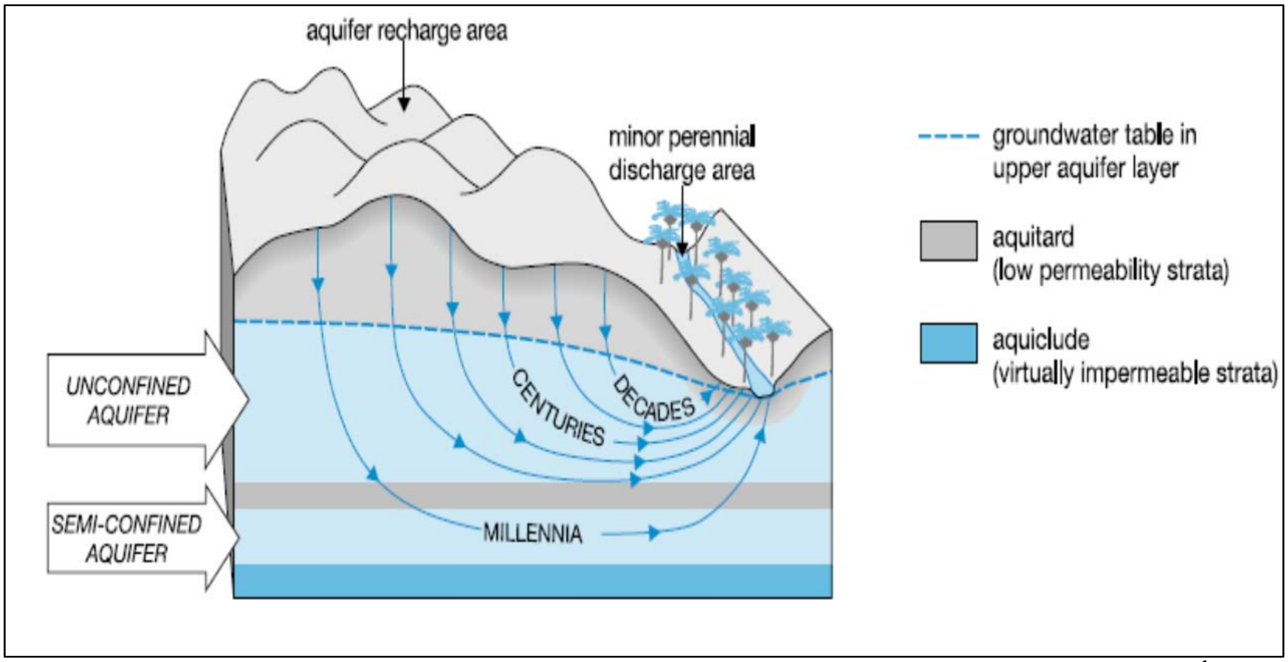
## Why we study the Groundwater

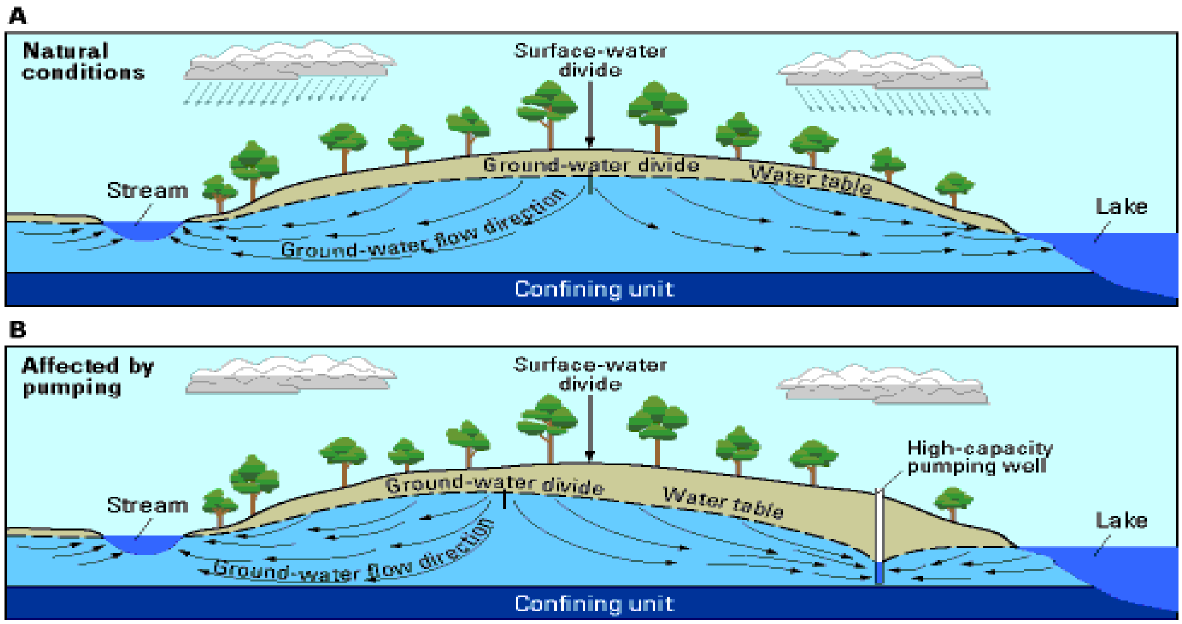
- A readily available source at point needed.
- Its relative low costs compared to surface water.
- Availability in most areas.
- Potable without treatment.
- Employs low cost technologies.
- The frequent drought problems enforce the use of groundwater source as many small intermittent rivers. and streams dry out during the dry season.

## Groundwater flow

- Groundwater moves slowly through interconnected pore/fracture spaces of aquifers materials.
- GW in continuous slow movement from recharge areas (usually upland areas) discharge areas (springs, baseflow, wetlands and coastal zones).
- The flow of groundwater through an aquifer is governed by Darcy's Law.
- Aquifer storage transforms highly variable natural recharge regimes into more stable natural discharge regimes.
- Drawdown induced by pumping from the confined section of an aquifer is often rapidly propagated to the unconfined section.



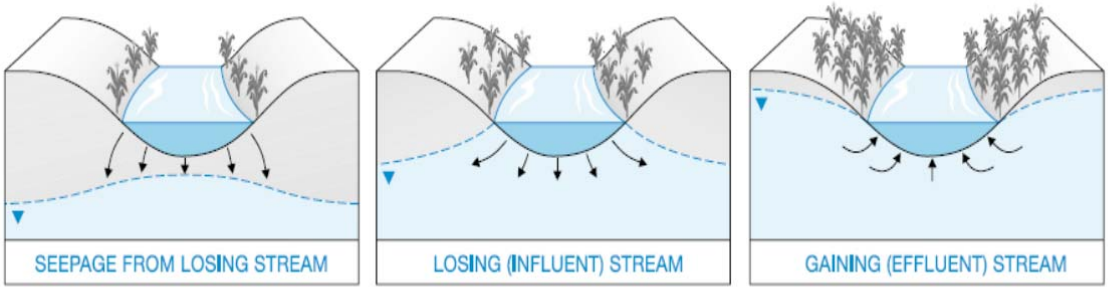

Typical groundwater flow regime and residence times of major aquifers under semi-arid climatic regimes (after GW-Mate2, 2006)




- GW in continuous slow movement from recharge areas (usually upland areas) discharge areas (springs, baseflow, wetlands and coastal zones)

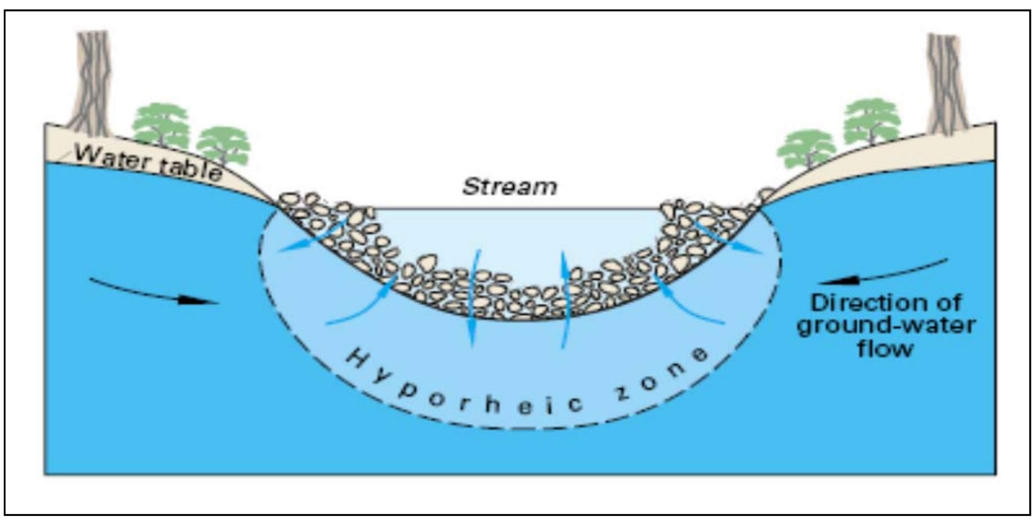
## Relationship between groundwater and surface water

- Diagnosing the relationship surface water / underlying aquifer is an important component of groundwater system characterization.
- It is important to distinguish between:
  - Streams and rivers on which an aquifer is dependent as a significant source of its overall recharge
  - Rivers that in turn depend significantly on aquifer discharge to sustain their dry-weather flow.
  - It should be noted that in some cases rivers may fluctuate seasonally between two of the conditions depicted.




Spectrum of possible relationships between surface watercourses and underlying groundwater systems (after GW-Mate2, 2006)

- Changes to surface water bodies in response to groundwater development can cause significant consequences:
  - Long term reductions in stream flow can affect vegetation along streams
  - Changes in the flow direction to/from streams may affect temperature, oxygen levels, and nutrient concentrations in the stream (affect aquatic life)
  - In gaining and in losing streams, affect hyporheic zones (active sites for aquatic life)




- Lowering of lake diminish lakefront aesthetics, and shoreline structures such as docks, may alter the natural fluxes to lakes of key constituents (nutrients and dissolved oxygen)

- Amplitude and frequency of water-level fluctuations affect wetland characteristics (type of vegetation, nutrient cycling, type of invertebrates, fish, and bird species)
- Lead to reductions in spring flow, changes of springs from perennial to ephemeral, or elimination of springs altogether
- Plant and wildlife communities adapted to coastal areas can be affected by changes in the flow and quality of groundwater discharges

## Groundwater recharge

Recharge may result from:

- Precipitation that percolates through unsaturated zone to water table
- Losses of surface water bodies (steams, lakes, wetlands)

**Recharge rates vary with:**

- river flow diversion or control,
- modifications to surface water irrigation,
- changes in natural vegetation or crop type in recharge areas,
- reduction in leakage from urban water-supply networks and *in-situ* wastewater percolation,
- lowering of water-table, etc.

## Safe yield

Safe yield is the attainment and maintenance of a long-term balance between the amount of annual withdrawal and the amount of annual recharge. This allows water users to abstract groundwater no more than it is replenished naturally. So-called 'safe yield' is clearly bounded by the current long-term average rate of aquifer recharge.

## Critical issues of GW characterization

- Recharge rate quantification
- Recharge area vs land-use (GW protection)
- Interactions (quantity/ quality) with surface water bodies

- Impacts of GW pumping
- Interbasin/interboundary aquifer

## Difficulties and uncertainties

- Groundwater cannot be readily observed;
- GW may occur in large, and complex aquifer systems;
- Aquifers have high spatial variability of its characteristics.

## Assessment of groundwater resources

Different ways to assess groundwater:

- Observation of groundwater levels
- Pumping tests, to test the response of groundwater abstraction
- Hydro geological investigations to built a first concept on groundwater resource;
- Geophysical surveys to find the groundwater resource, to sit borehole
- GW budgeting, modelling for better resource development planning
- Groundwater Quality need to be assessed to protect GW resources:
  - Salinity monitoring, Other field measurements of water quality parameters.
  - Analysis of groundwater samples (in field or in laboratory)

## Recharge and recharge areas

- ***Recharge ensures renewability of GW storage***, input to the system!
- ***Recharge rate estimate***, a critical issue for sustainability of GW development
- ***Recharge area map***, for land-use planning and access to.

## Groundwater discharge

- SW and GW (in many cases) hydraulically connected…all too often ignored in water management considerations and policies
- Useful management information? maps of high risk areas of extensive GW exploitation

- Trend of characteristics as impacted by land-use/change, climate change/variability, water use

**Vertical distribution of groundwater**

The subsurface occurrence of ground water may be divided into zones of aeration and saturation. The zone of aeration consists of interstices occupied partially by water and partially by air. In the zone of saturation, all interstices are filled with water under hydrostatic pressure. On most of the land masses of the earth, a single zone of aeration overlies a single zone of saturation and extends upward to the ground surface as shown in fig (4)

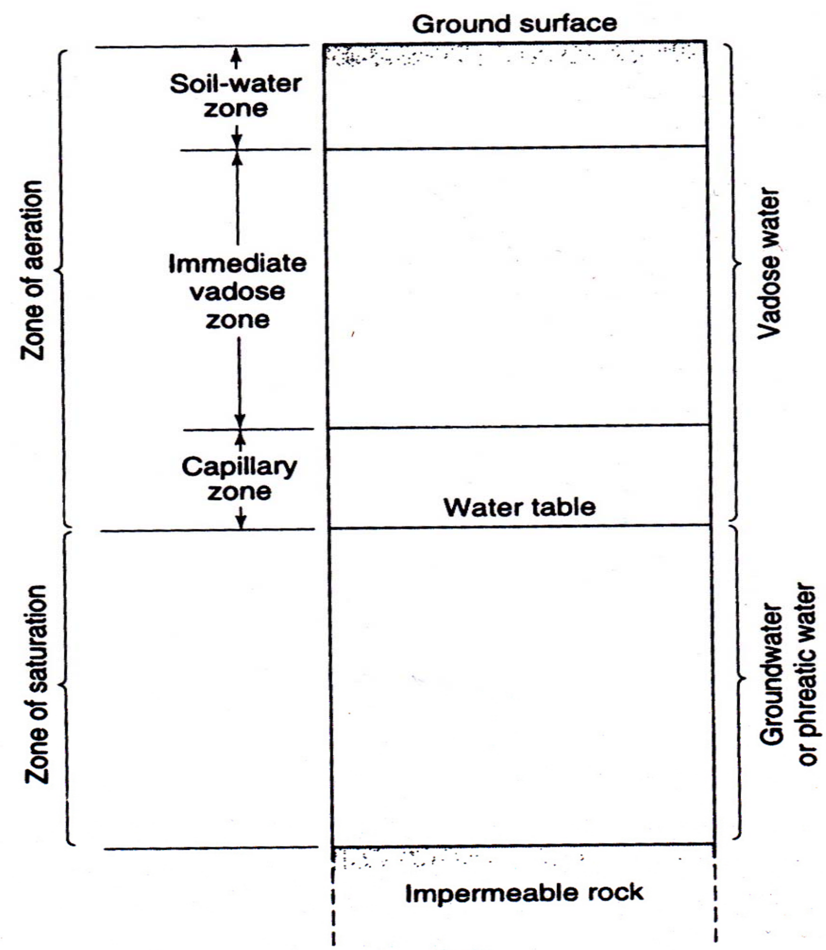



**Figure (4)** Divisions of subsurface water.

In the of aeration, vadose water occurs. This general zone may be further subdivided into the soil water zone, the intermediate vadose zone, and capillary zone.

The saturated zone extends from the upper surface of saturation to underlying impermeable rock.

Specific retention ($S_r$) of soil or rock is the ratio of the volume of water it will retain after saturation against the force of gravity to its own volume.

Thus

$S_r=W_r/V_t$ ………(14)

Where $W_r$ is the volume occupied by retained water and $V_t$ is the bulk volume of the soil rock.

specific yield($S_y$) of a soil or rock is the ratio of the volume of water that , after saturation can be drained by gravity to it's own volume .thus

$S_y=W_y/V_t$ …….(15)

where $W_y$ is the volume of water drained.

volume of $S_r$ and $S_y$ can be expressed as percentage. Because $W_r$ and $W_y$ constitute the total water volume in a saturated material, it's apparent that

$V_v=W_r+W_y$ ……(16)

$\alpha =S_r+S_y$ ………(17)

$\alpha$ is the porosity of the aquifer

***Example:*** Estimate the average drawdown over an area where 25 million m³ of water has been pumped through a number of uniformly distributed wells. The area is 150 km² and the specific yield of the unconfined aquifer is 25 percent.

***Solution:***

the volume of water drained is $W_y=25*10^6$ . Eq. 15 is used to determine the bulk volume,$V_t$ ,of the aquifer to extract this volume of water:

$S_y=W_y/V_t$

$0.25=25*10^6\ m^3/V_t$ $\quad V_t= 1*10^8\ m^3$

thus, the average water level drop over the area is

$\Delta h=V_t/A \quad =1*10^8\ m^3 /150*10^6\ m^2 =0.67\ m$