University of Anbar
Department of Applied Geology
Ramadi-Iraq
Mahmood H. D. Al-Kubaisi

Lecture (5)

Darcy's Law

The law was formulated by Henry Darcy based on the results of experiments on the flow of water through beds of sand, forming the basis of hydrogeology, a branch of earth sciences.

Henry Philibert Gaspard Darcy: Was a French engineer who made several important contributions to hydraulics.

Darcy's law states that the rate of flow through a porous medium is proportional to the loss of head and inversely proportional to the length of the flow path.

$$Q \propto dh \qquad , \qquad Q \propto \frac{1}{dl}$$

$$V = K\frac{dh}{dl}$$

Where V = Q/A, which is the specific discharge, also known as the Darcy velocity or Darcy flux (Length/Time), Q = volume rate of flow ($Length^3$/Time), A = cross-sectional area normal to flow direction ($Length^2$), $dh = h_2 - h_1$ which is the head loss, whereby h_1 and h_2 are the hydraulic heads measured at Points 1 and 2 (Length), dl = the distance between points 1 and 2 (Length), dh/dl = i, which is the hydraulic gradient (dimensionless), and K = constant of proportionality known as the hydraulic conductivity (Length/Time).

Alternatively, Darcy's law can be written as:

$$Q = KA\frac{dh}{dl}$$

$Q = -K\ A\ \frac{dh}{dl}$ **(- dh/dl)** represents the hydraulic gradient, with the *negative sign* indicating flow in the direction of decreasing hydraulic head

Darcy's law is valid for laminar flow, but not for turbulent flow, as may happen in cavernous limestone or fractured basalt. In case of doubt, one can use the Reynolds number as a criterion to distinguish between the laminar and turbulent flow. The Reynolds number is expressed as

$$N_R = \rho\frac{Vd}{\mu}$$

Where ρ is the fluid density, V is the specific discharge, μ is the viscosity of the fluid, and d is a representative length dimension of the porous medium, usually taken as a mean grain diameter or a mean pore diameter.

Experiments have shown that Darcy's law is valid for $N_R < 1$ and that no serious errors are created up to $N_R = 10$. This value thus represents an upper limit to the validity of Darcy's law.

Where; (N_R = 1 to 10); (N_R < 10 laminar flow); (N_R >10 turbulent flow)

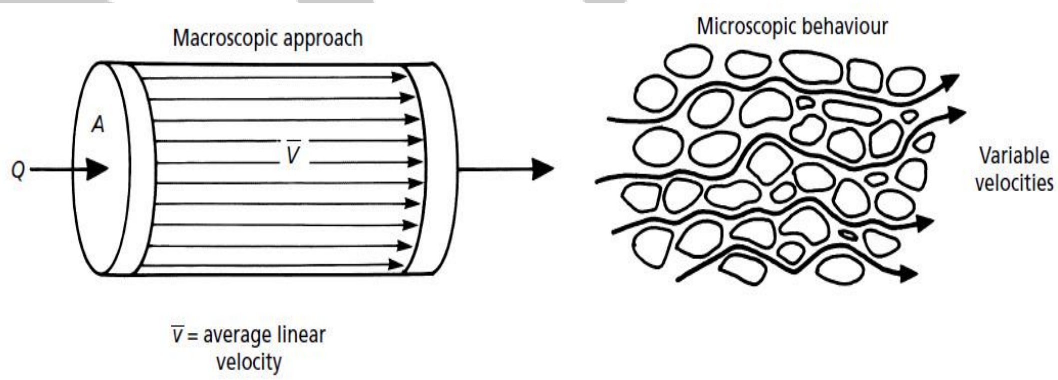


Fig.--: Macroscopic (Darcian) approach to the analysis of groundwater flow contrasted with the true, microscopic behaviour of tortuous flow paths.

Groundwater basin

A general term used to define a groundwater flow system that has defined boundaries and may include permeable materials that are capable of storing a significant water supply. The basin includes both:

(1) the surface area and the permeable materials beneath it.

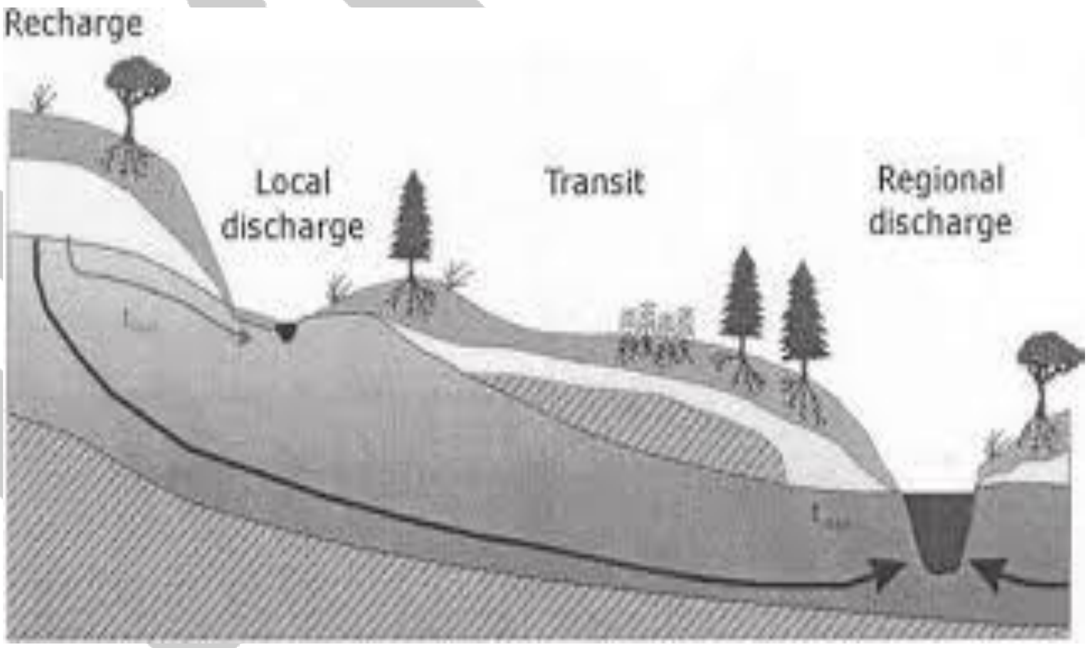
(2) The underground area from which groundwater drains.

Groundwater basin could be separated by geologic or hydrologic boundaries. It contains different patterns of water-bearing layer and includes recharge, transit, and discharge area.

Recharge area: It is the part of the surface of the earth in which water is infiltration into the basin.

Discharge area: It is the part of the surface of the earth where groundwater appears on the surface of the earth.

Transit area: The extended area between the recharge area and the discharge area.



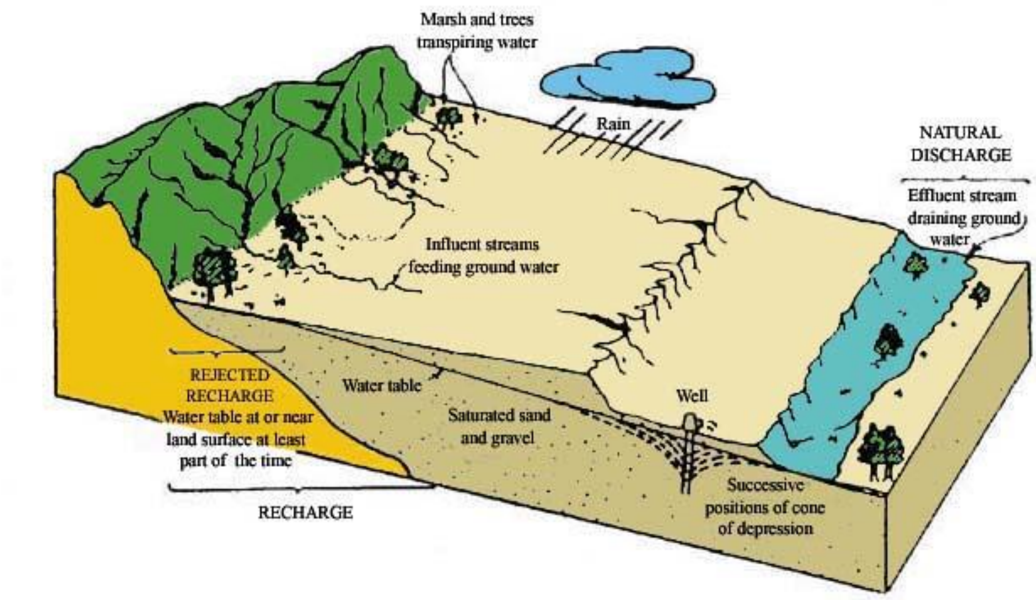


Fig. --: Groundwater basins and recharge, transit, and discharge area.

Bounded aquifers

Another common assumption in well hydraulics is that the pumped aquifer is horizontal and of infinite extent. But, viewed on a regional scale, some aquifers slope, and none of them extend to infinity because complex geological processes cause interfingering of layers and pinchouts of both aquifers and aquitards. At some places, aquifers and aquitards are cut by deeply incised channels, estuaries, or the ocean. In other words, aquifers and aquitards are laterally bounded in one way or another.

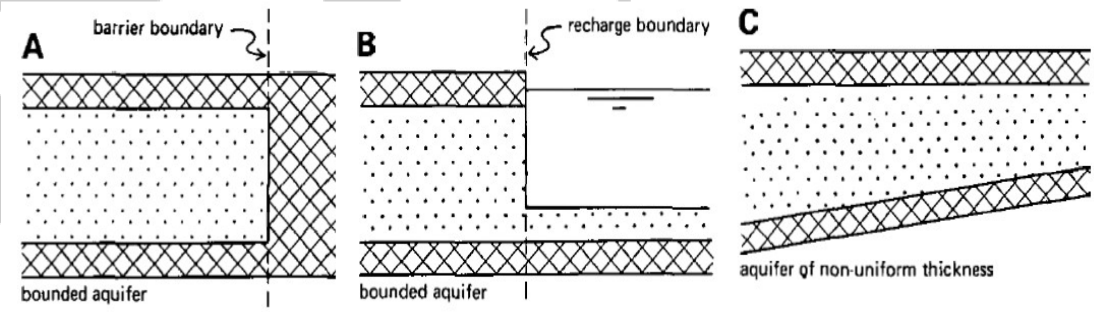
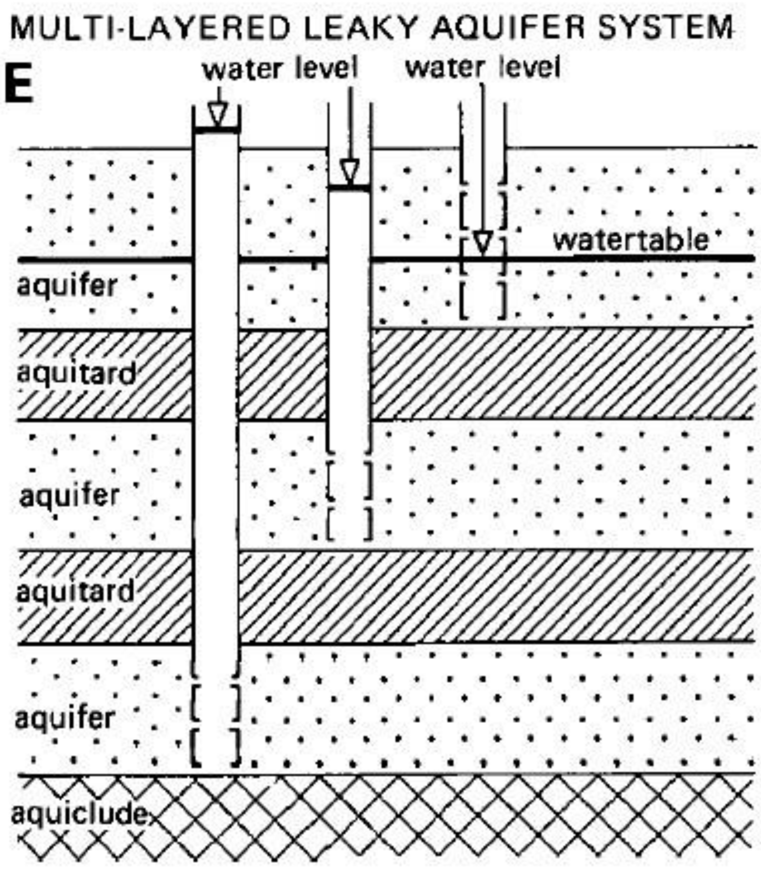


Figure --: Bounded aquifers A, B, and C

The boundaries of the aquifers are of a physiographic nature or structural, lithological, or hydraulic, all these boundaries are called hydrogeological boundaries.

1. *Geological boundaries (lithological, stratification):*

The change in the properties of the lithological or the physical structure of the material is called stratification. The geological boundary is represented by a change in the rocky facies occurring in the aquifer consisting of gravel and sand into a non-permeable clay silty layer and unable to pass water.



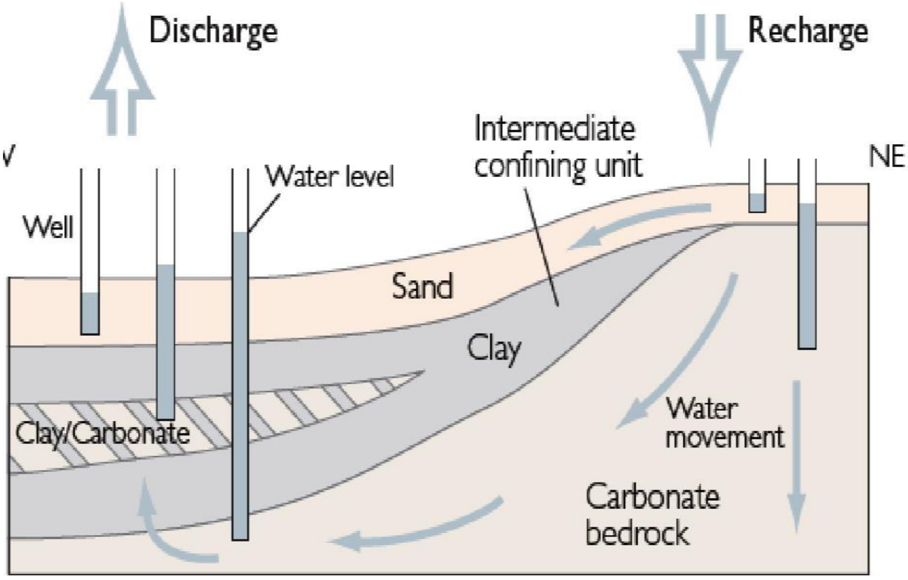
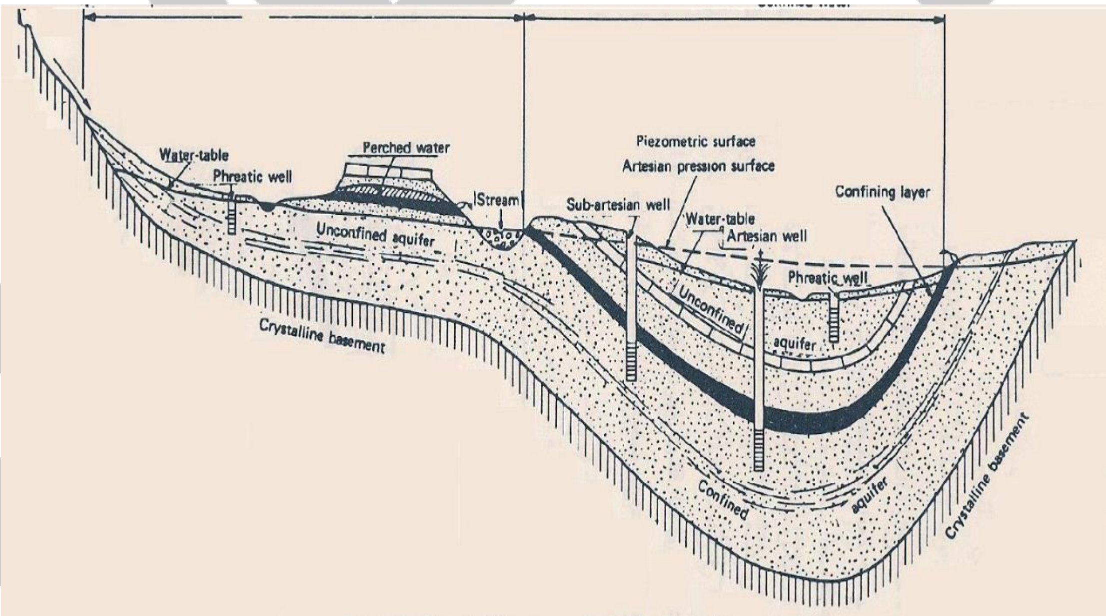


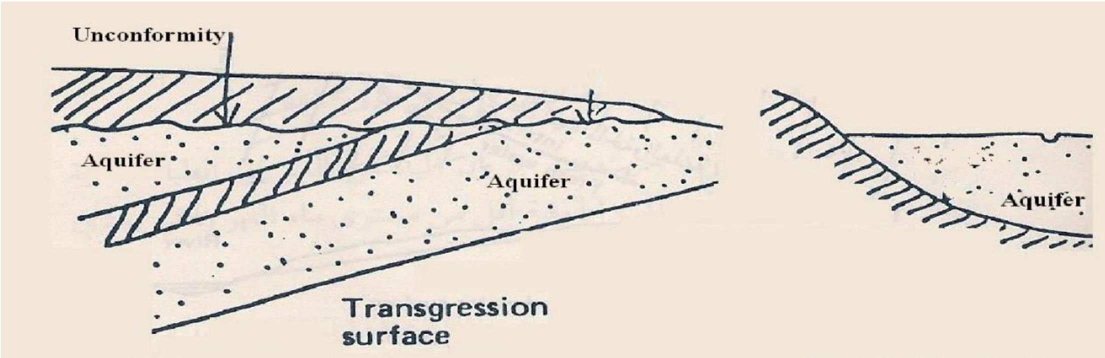
Fig. --: The change in lithology.

2. *Structural boundaries:*

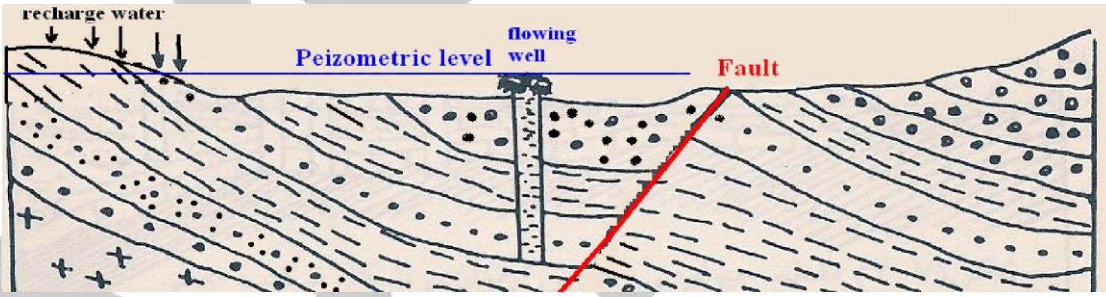
* Synclinorium: It is a curvature in the permeable layers resulting boundaries of the aquifers.



* Monocline structure: slanted layers in a certain direction are leads to boundaries of the aquifers.



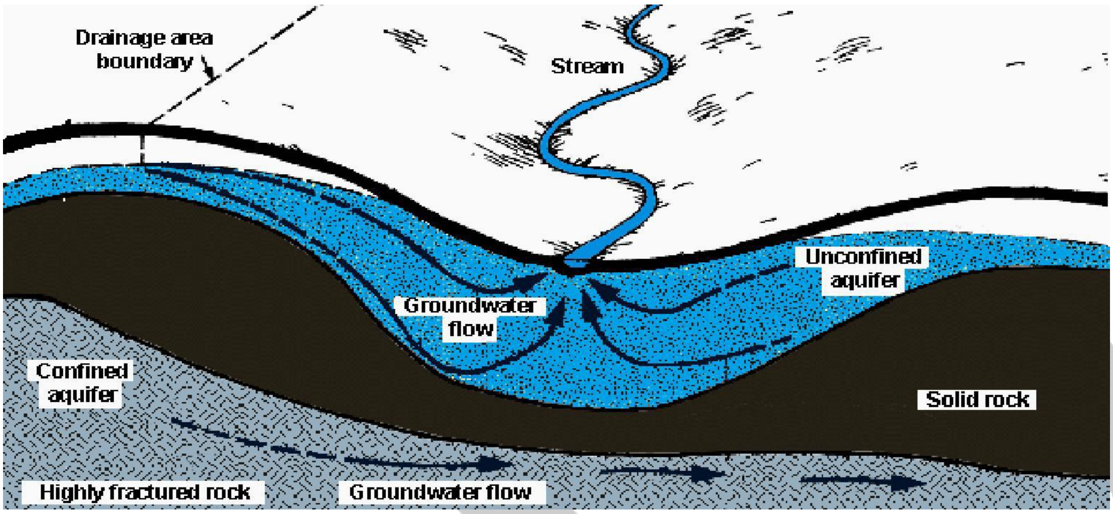
* Fault and Fracture zones: The confined aquifers are formed as a result of the impact of the faults on the slanted layers, forming a non-permeable barrier that collects the water coming from the slanted layers and thus increases its pressure and high levels, and acting as a groundwater storage dam. The fault may be a weak point through which water flows (a drainage gate) causing the mixing of deep and shallow water.



3. *Hydraulic and hydrologic boundaries:*

Hydraulic boundaries considered as prevent limits or move the groundwater flow. These limits can be defined from the structural situation.

Another type of boundary exists within the aquifer that separates between two liquids, different in a specific weight such as the surface separating between freshwater and saltwater.



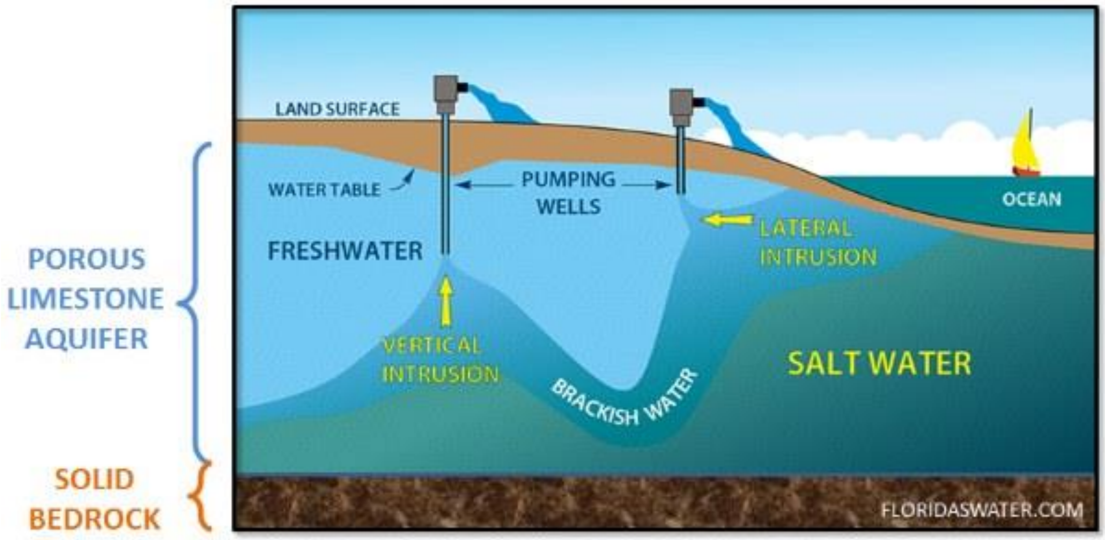


Image --: Saltwater meets freshwater. Gulf of Alaska where two oceans meet but do not mix.

There is a hydraulic relationship between the river and the aquifer, this relationship will be:

1. Free and permanent: When the rivers penetrate the aquifers and the aquifers are at the bottom of the river.
2. Temporary: When the river intersects with the aquifer at a certain depth, where the level of river water rises above the level of the water layer in the season of water surplus.
3. Not available: When the river level is lower than the level of the aquifer permanently.

Generally, the groundwater flow in the aquifer and river occurs in three directions:

1. From the aquifer towards the river: Where the waters of the aquifer are discharged into the river when the groundwater level is higher than the level of river water (the aquifer feeds the river).
2. From the river towards the aquifer: Water flows from the river to the aquifer, when the groundwater level is lower than the level of river water (the river feeds the aquifer).
3. Reciprocal feeding: that happens when the water level in the aquifer and the river is the same level.

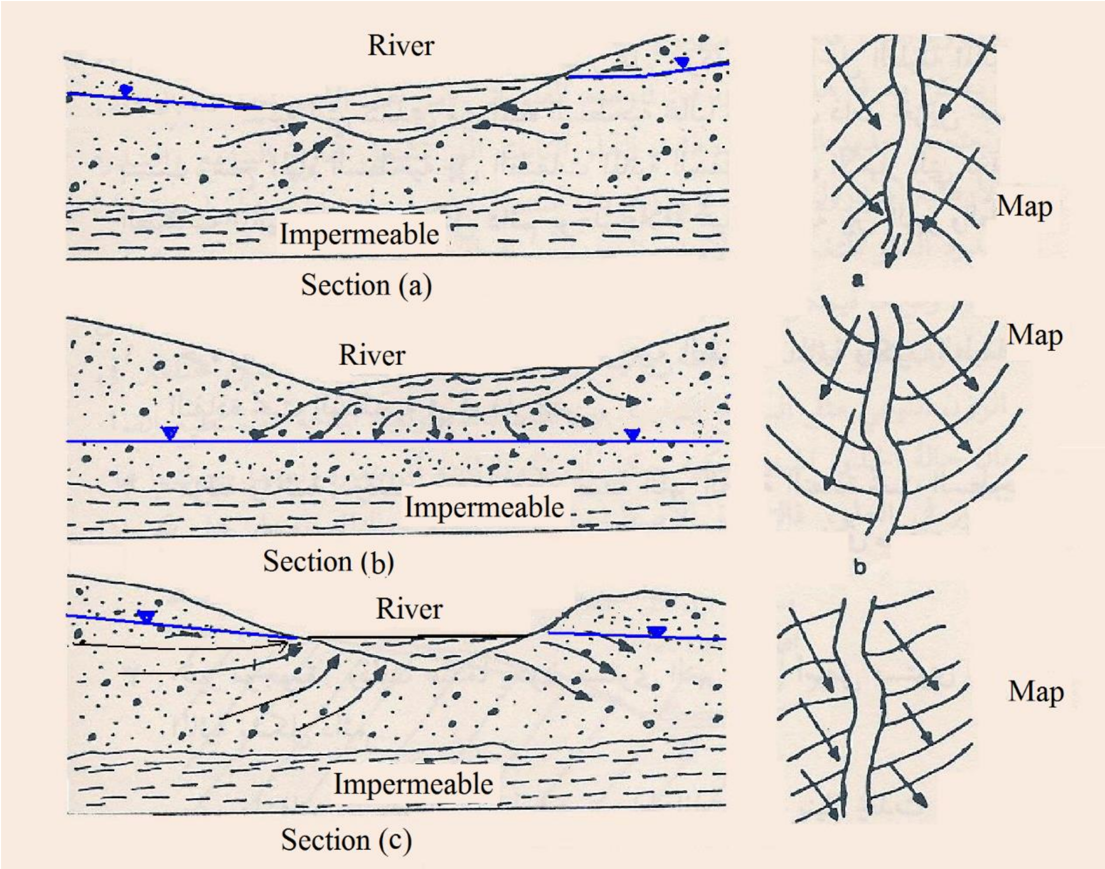


Fig. --: The interrelationships between the level of groundwater and the level of river water.

References:

- **Groundwater hydrology third edition**, Todd, D. K. 2005.
- **Analysis and Evaluation of Pumping Test Data**, Kruseman, G. P., and de Ridder, N. A. 1994.
- **Hydrogeology Principles and Practice**, Second Edition, Kevin M. Hiscock and Victor F. Bense.
- **Watershed management**, Prof. T I Eldho, Department of Civil Engineering, IIT Bombay.
- **Manual on artificial recharge of groundwater**, Central Ground Water Board 2007.
- Getting Up to Speed, for "**Ground Water Contamination**" is adapted from US EPA Seminar Publication.
- **Lectures** by Professor Bayan Muhie Hussien. 2011.