CE 331: Water Supply Engineering

Lecture 4

Overview

Ground Water:

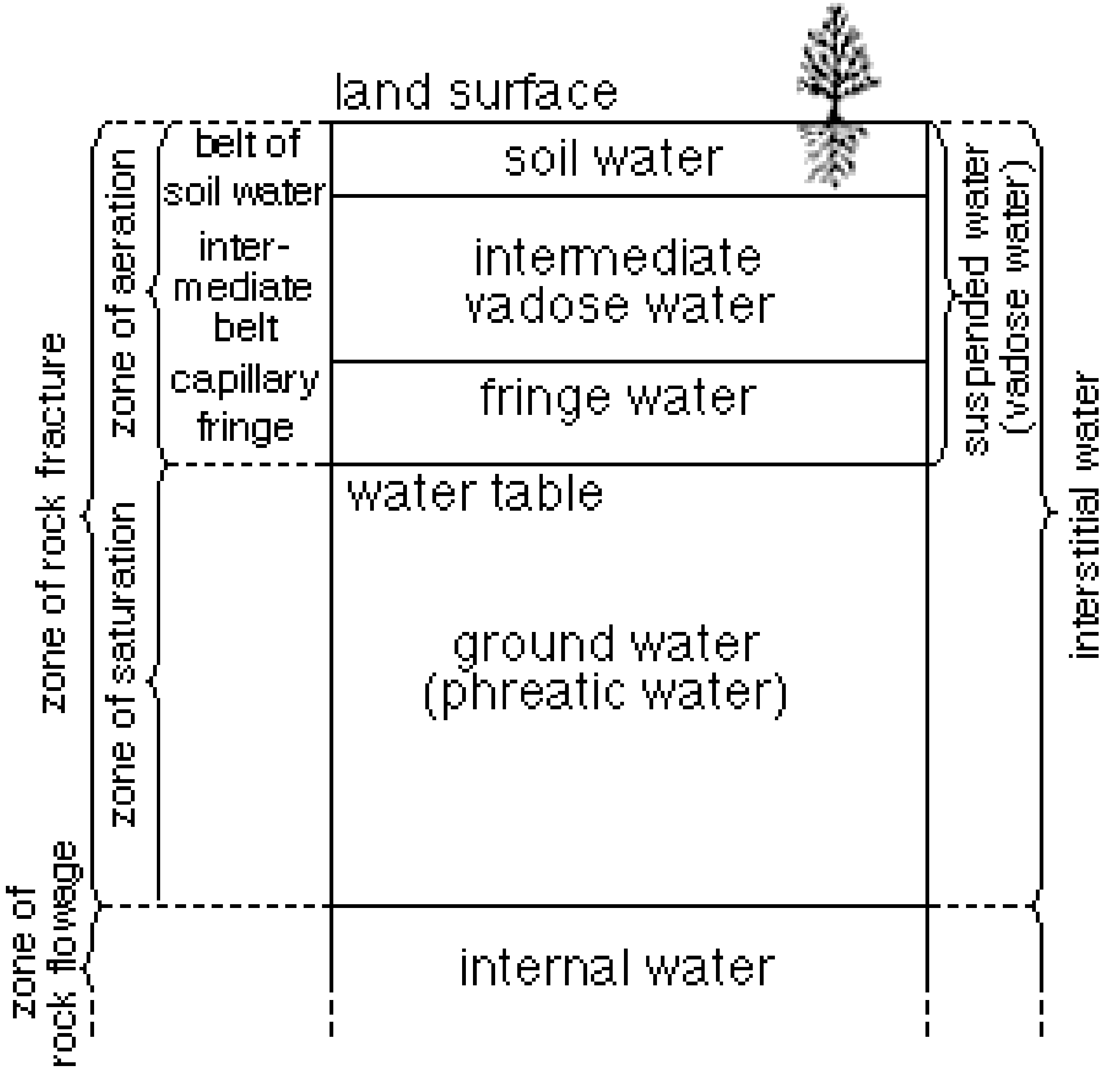
- Groundwater Exploration
- Aquifer Properties and Groundwater Flow
- Groundwater hydraulics
- Well hydraulics
- Recharge of Ground Water.

Groundwater

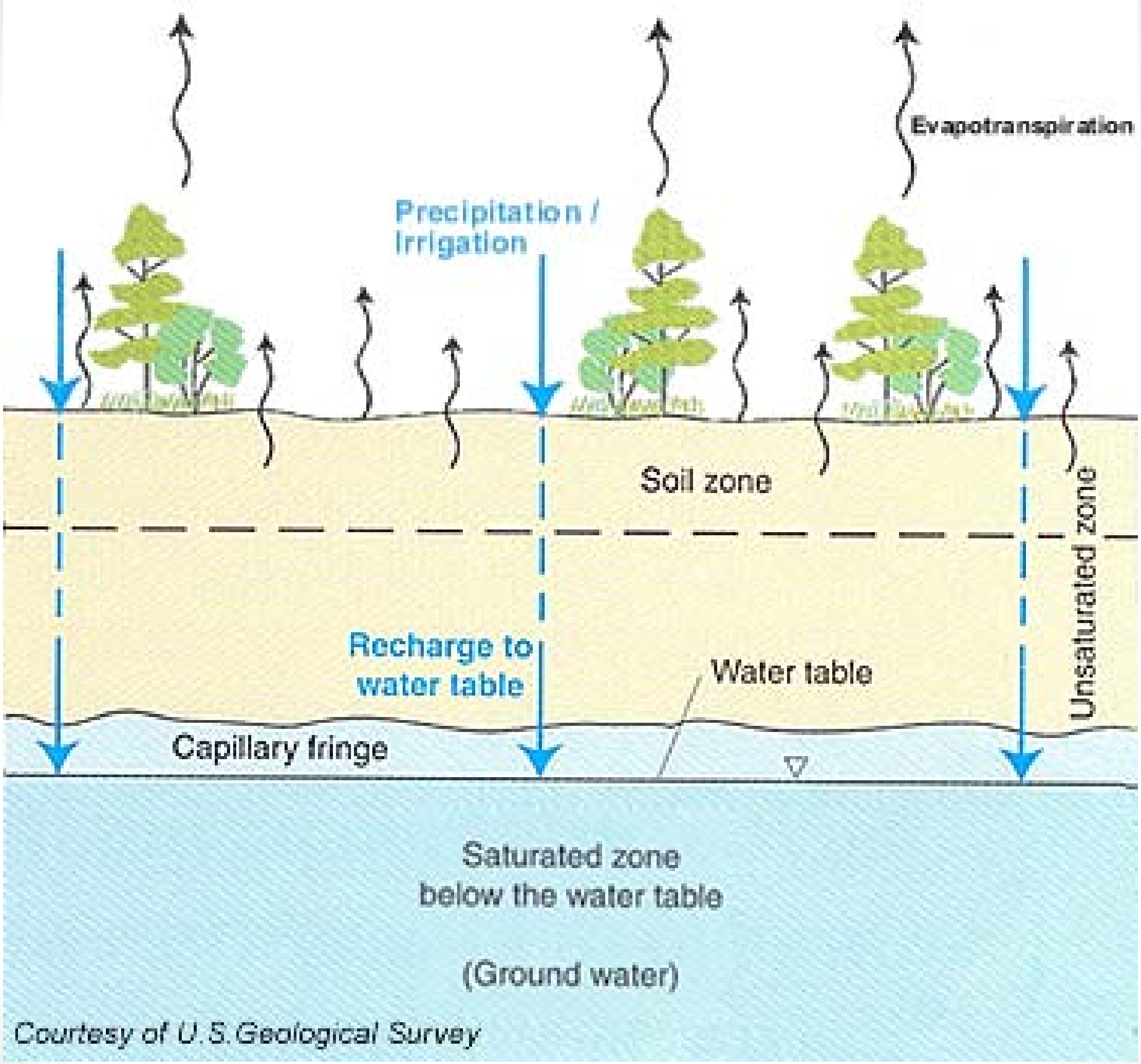
- Water available in the saturation zone is known as groundwater.
- Constitute the most important source of fresh water supply.
- Amount of groundwater which can be obtained from an area depends on the characteristics of the underlying aquifer and the extent and frequency of recharge.

Groundwater

- Zone of aeration – both air and water in pores
- Zone of saturation – pores completely filled with water
- Water table – upper limit of zone of saturation

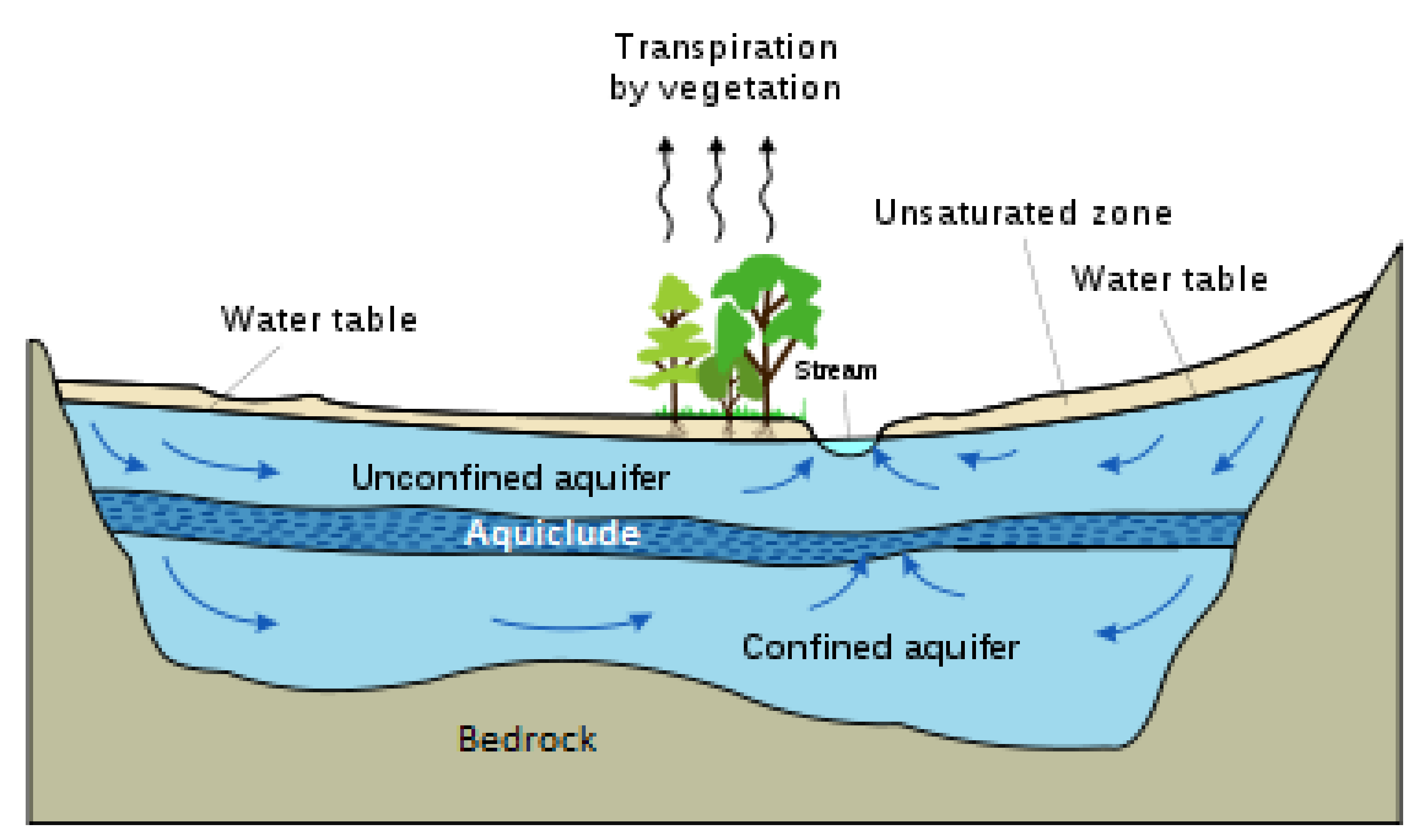


http://www.kgs.ku.edu/General/Geology/Ford/05_gw2.html


Evapotranspiration
Precipitation / Irrigation
Soil zone
Unsaturated zone
Recharge to water table
Water table
Capillary fringe
Saturated zone below the water table
(Ground water)
Courtesy of U.S.Geological Survey

Aquifer and Aquiclude

- The soil strata which contain groundwater and will readily yield it to wells are called aquifers
- The impervious formations or strata containing very little groundwater are termed aquicludes
- An aquifer has interconnected pores filled with water
- Interconnected pores provide both storage and flow functions in an aquifer



http://sciblogs.co.nz/waiology/tag/aquiclude/

Factors governing the occurrence of groundwater

- Porosity of soil

Porosity={(total volume of voids in the soil or the volume of water required to saturate the dry sample(Vv))/ total volume of soil aggregate (V)}x 100

therefore, □ = Vv/ V x 100

Soil type	Porosity (%)	Specific yield (%)
Clay	45	3
Gravel and sand	20	16
Sand	35	25
Gravel	25	22

Factors governing the occurrence of groundwater

- Permeability of soil

Permeability = A measure of the capacity of an aquifer to transmit water which is related to the pressure difference and velocity of flow between two points

Darcy's law:

$$V = K^* (h_1 - h_2)/l$$

The equation can be modified as

$$V = KS; \; S = (h_1 - h_2)/l$$

and is called the hydraulic gradient.

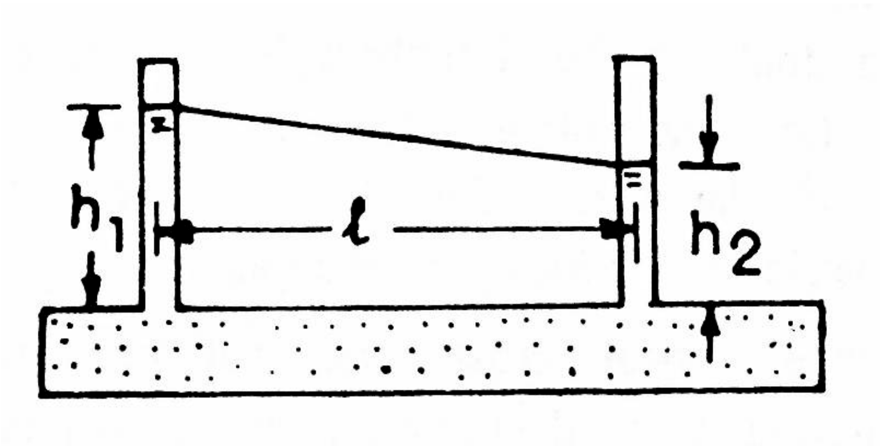
Where, V= the velocity of flow(ft/ day)

h_1 = the pressure at the point of entrance to the section of pipe under consideration in ft of water.

- h_2 = the pressure at the point of exit of the same section in ft of water

l= the length of the section of the pipe inft,

K = a constant known as the coefficient of permeability but often referred to simply as the permeability



Factors governing the occurrence of groundwater

- Specific Yield

Sp. Yield= {(volume of water obtained by gravity drainage)/(total volume of the total material drained or dewatered)}x 100

$$Sy = Wy/ V$$

- Specific Retention

Specific retention or field capacity= {(volume of water held against the gravity drainage)/ total volume of the material drained} x100

$$Sr = Wr/ V$$

- It is evident that the sum of the specific yield and the specific retention is equal to its porosity.

Therefore, $\eta = Sr + Sy$

Factors governing the occurrence of groundwater

- Hydrostatic pressure

Pressure coming from the weight of the liquid and is proportional to the height of the liquid column (h) and to the density of the liquid (ρ).

- It can be calculated as: $p = h*\rho*g$

  ($g=10 m/s^2$)

Ground water Hydraulics

- Darcy's law

$V \propto h_L \propto 1/l$

or, $V \propto h_L / l$

or, $V \propto I$

i,e. $V = Ki$

K is called the coefficient of permeability

- The value of K can be determined experimentally or can be estimated by empirical formula.

$K = c\, d_{10}^2$

where, d = effective grain size and

c =constant, values vary from 100- 120

Important terms

- Coefficient of permeability or hydraulic conductivity

defined from Darcy's law, as the rate of flow of water through a unit cross-sectional area of the water bearing material under a unit hydraulic gradient and at temperature of 20^0 C.

- Drainage of groundwater

generally means extracting the water from below the water table through wells, infiltration galleries, springs etc. The water drained under a natural phenomenon (like- spring) or it can be drained artificially by constructing wells and lifting the water from them.

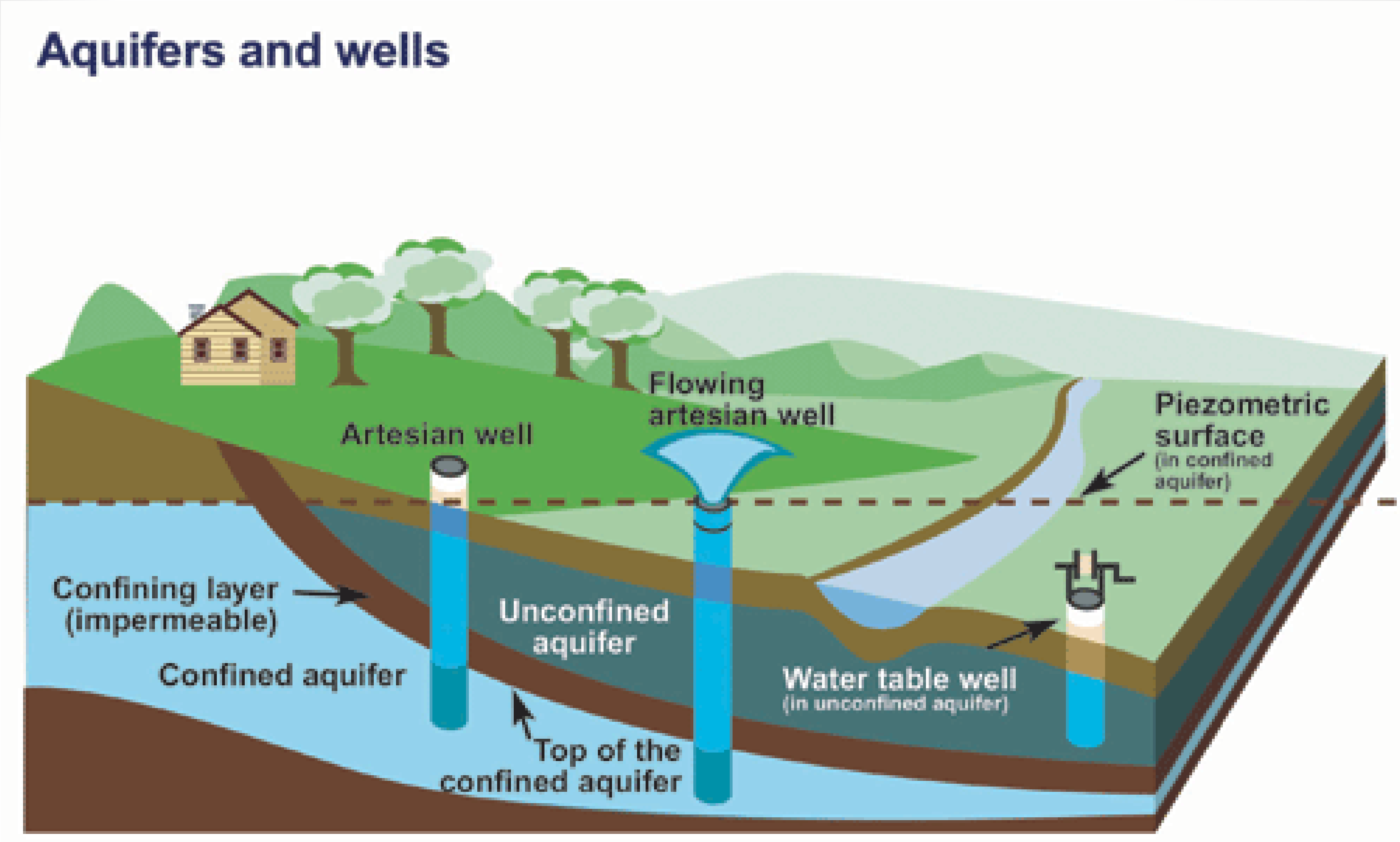
- Water table

is the surface at which water pressure is equal to atmospheric pressure. It is depicted on maps as a line across an aquifer.

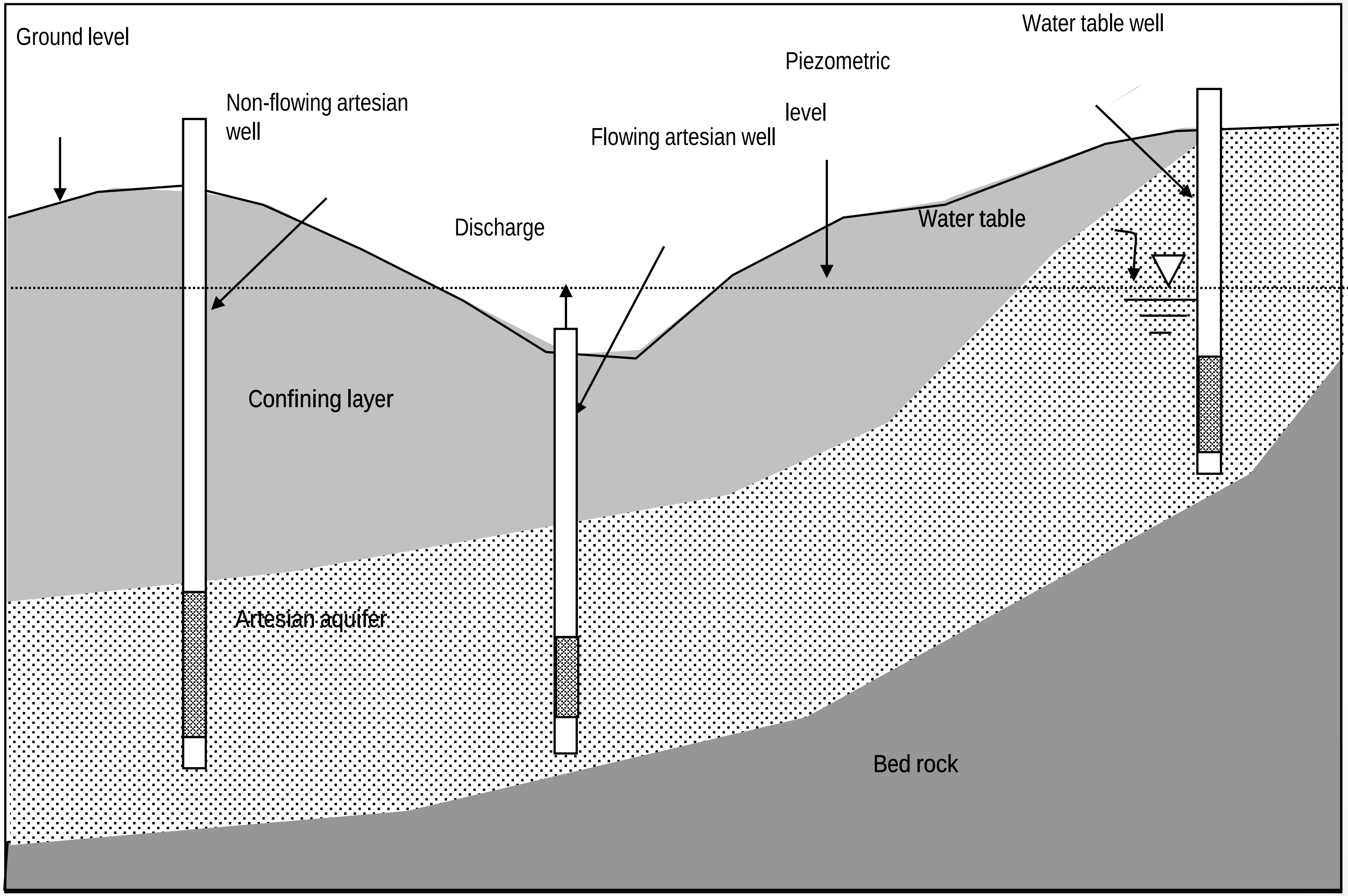
- Piezometric surface

Piezometric Surface

- The imaginary surface to which water will rise to wells located throughout an confined or artesian aquifer is called the piezometric surface (the imaginary surface that everywhere coincides with the piezometric head of the water in the aquifer).
- This surface is may be either above and below the ground surface at different parts of the same aquifer.
  - Where the piezometric surface lies above the ground level and is referred to as flowing artesian wells.
  - Where the piezometric surface is below the ground surface a non-flowing artesian wells results, such as a pump must be provided to obtain water from the well.



https://www.ec.gc.ca/eau-water/default.asp?lang=En&n=300688DC-1


Ground level
Non-flowing artesian well
Piezometric level
Water table well
Flowing artesian well
Discharge
Water table
Confining layer
Artesian aquifer
Bed rock

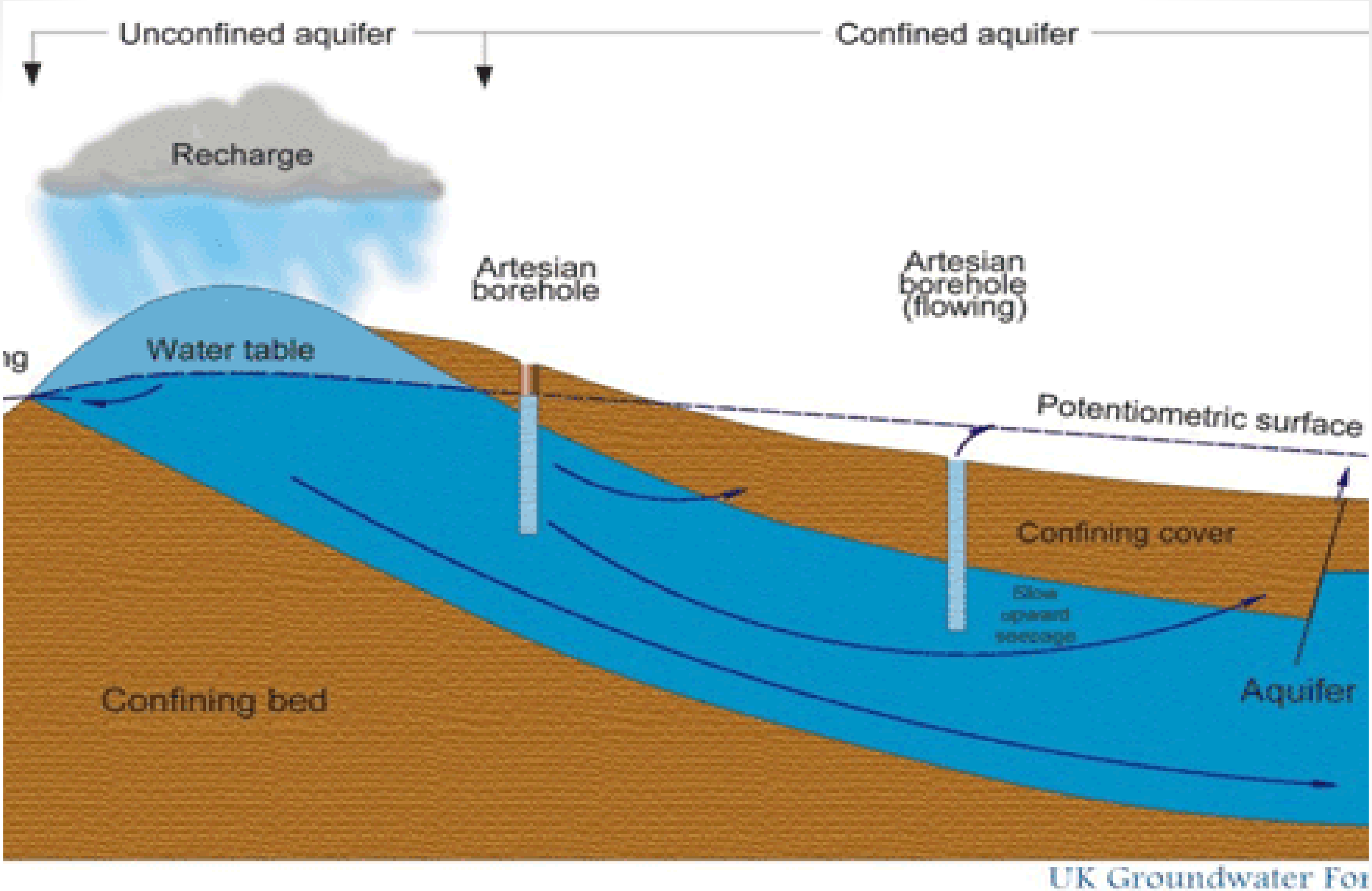


Fig: confined and unconfined aquifer

Recharge of Groundwater

- General hydrologic equation

- $\Sigma R = \Sigma D + \Delta S$

Where ΣR = hydrologic factors contributing to recharge

ΣD = hydrologic factors contributing to discharge

ΔS = Associated change in storage volume

Recharge of Groundwater

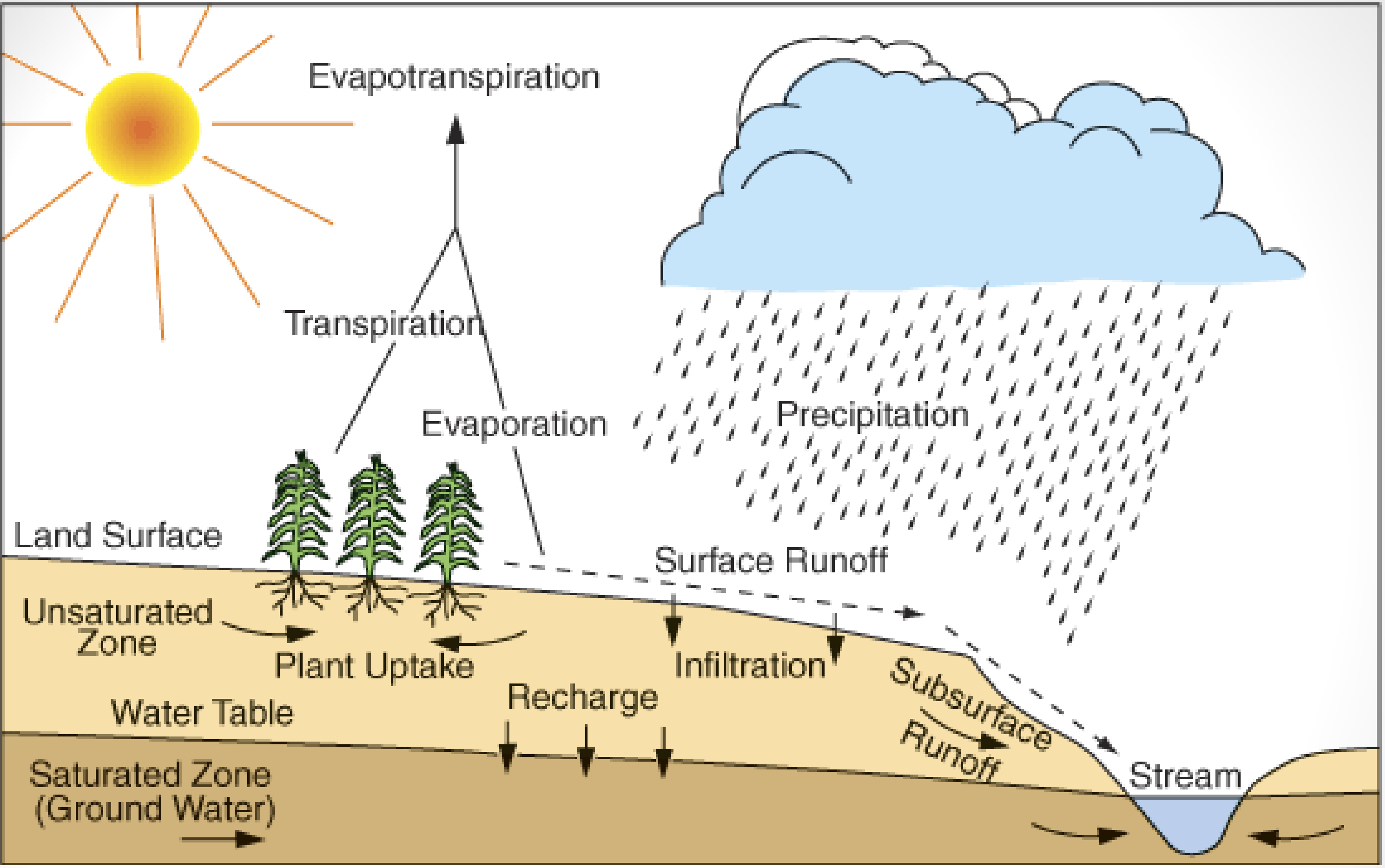
- Recharge is composed of:

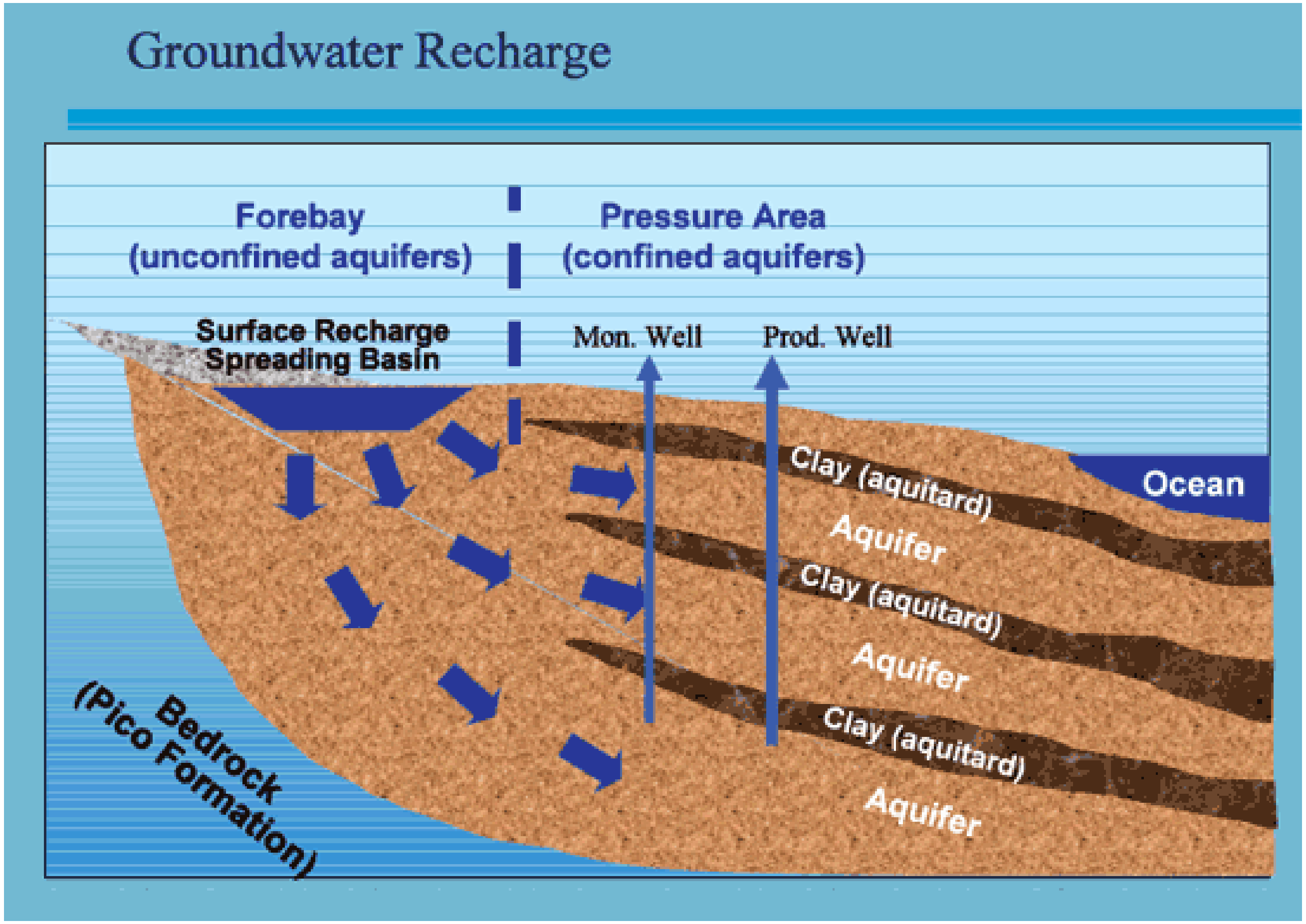
1. Natural infiltration derived from rainfall and snowmelt
2. Infiltration from surface bodies of water
3. Underflow
4. Leakage through confining layers or water displaced from them by compression
5. Water derived from diffusion, charging and water spreading operation

Recharge of Groundwater

- Conversely discharge includes:

1. Evaporation and transpiration
2. Seepage into surface bodies of water
3. Underflow
4. Leakage through confining layers or absorbed by them through the reduction of compression
5. Water withdrawn through wells and infiltration galleries


Evapotranspiration
Transpiration
Evaporation
Precipitation
Land Surface
Surface Runoff
Unsaturated Zone
Plant Uptake
Infiltration
Recharge
Water Table
Subsurface Runoff
Saturated Zone (Ground Water)
Stream


Groundwater Recharge
Forebay
(unconfined aquifers)
Pressure Area
(confined aquifers)
Surface Recharge
Spreading Basin
Mon. Well
Prod. Well
Ocean
Clay (aquitard)
Aquifer
Clay (aquitard)
Aquifer
Clay (aquitard)
Aquifer
Bedrock
(Pico Formation)

Well Hydraulics

- Specific capacity
- Drawdown

Sp. Capacity= Discharge of well / Drawdown

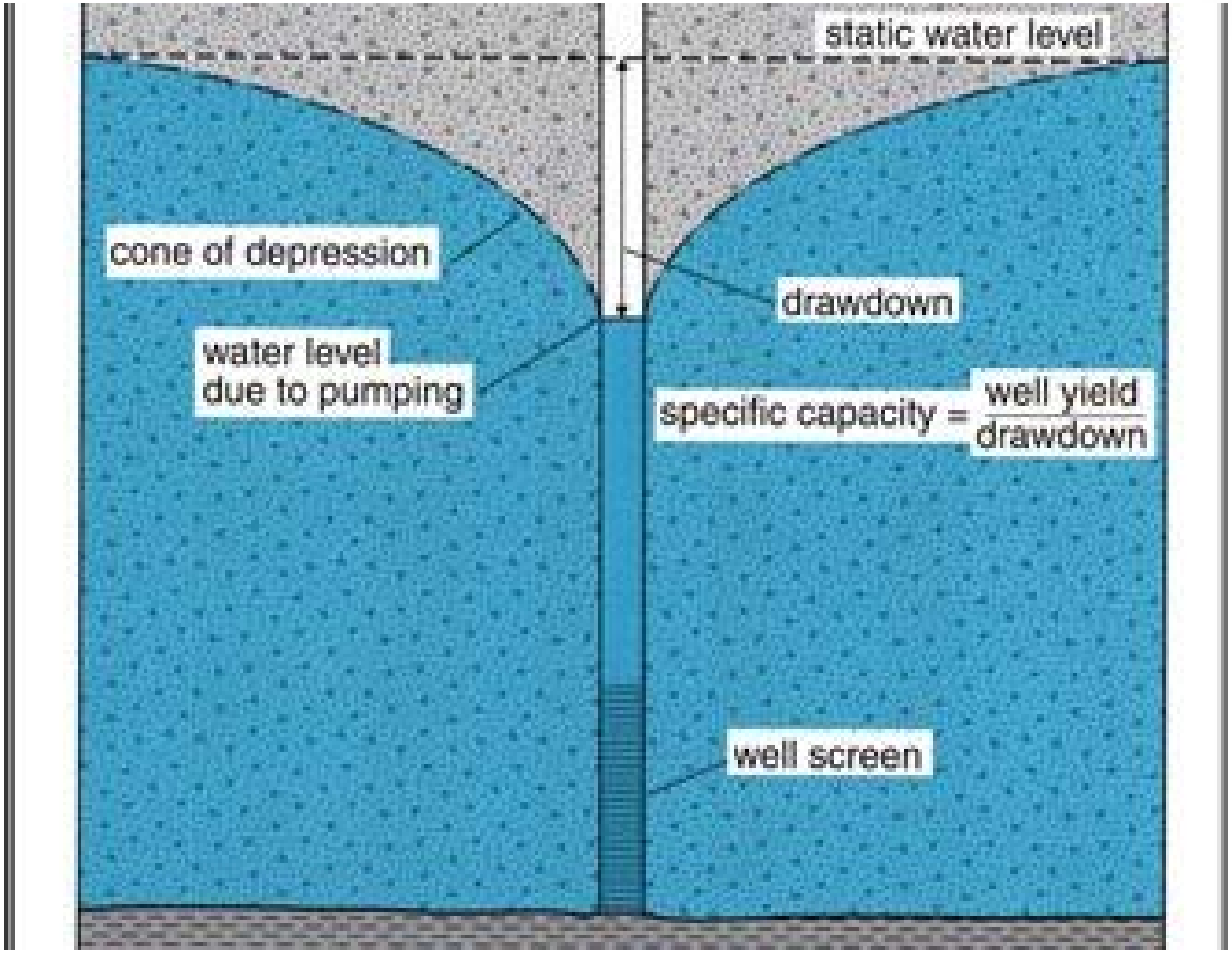


Fig-Specific capacity & drawdown

Types of aquifers

- Unconfined or non-artesian or water table aquifers
- Confined or artesian aquifers

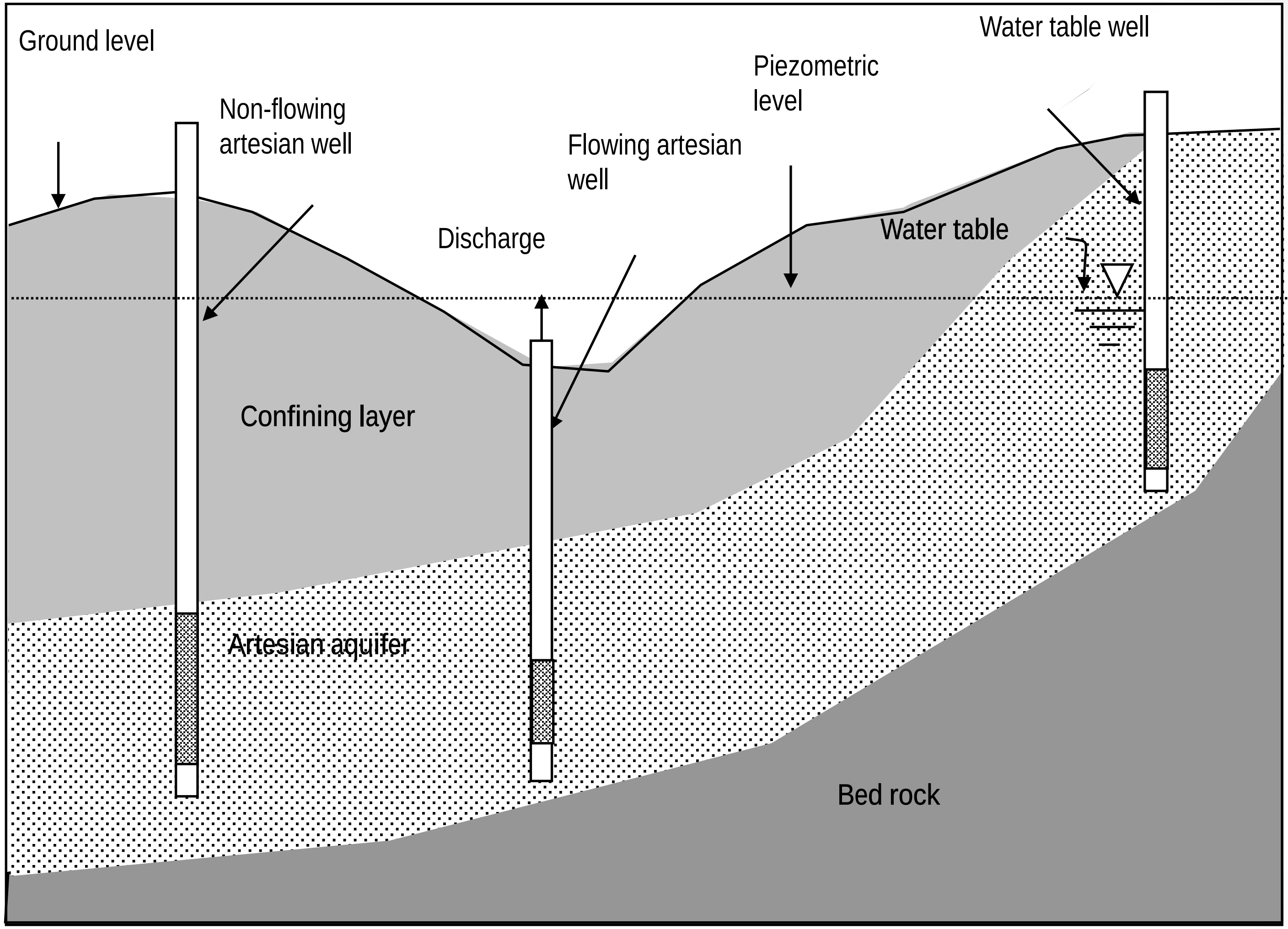


Fig-Types of aquifers

Flow towards wells

- When well is at rest → static water level
- Pumping → converging flow

$Q = AV = KAi$

[Where, Q= quantity of flow per unit of time

A = cross-sectional area

K = coefficient of permeability

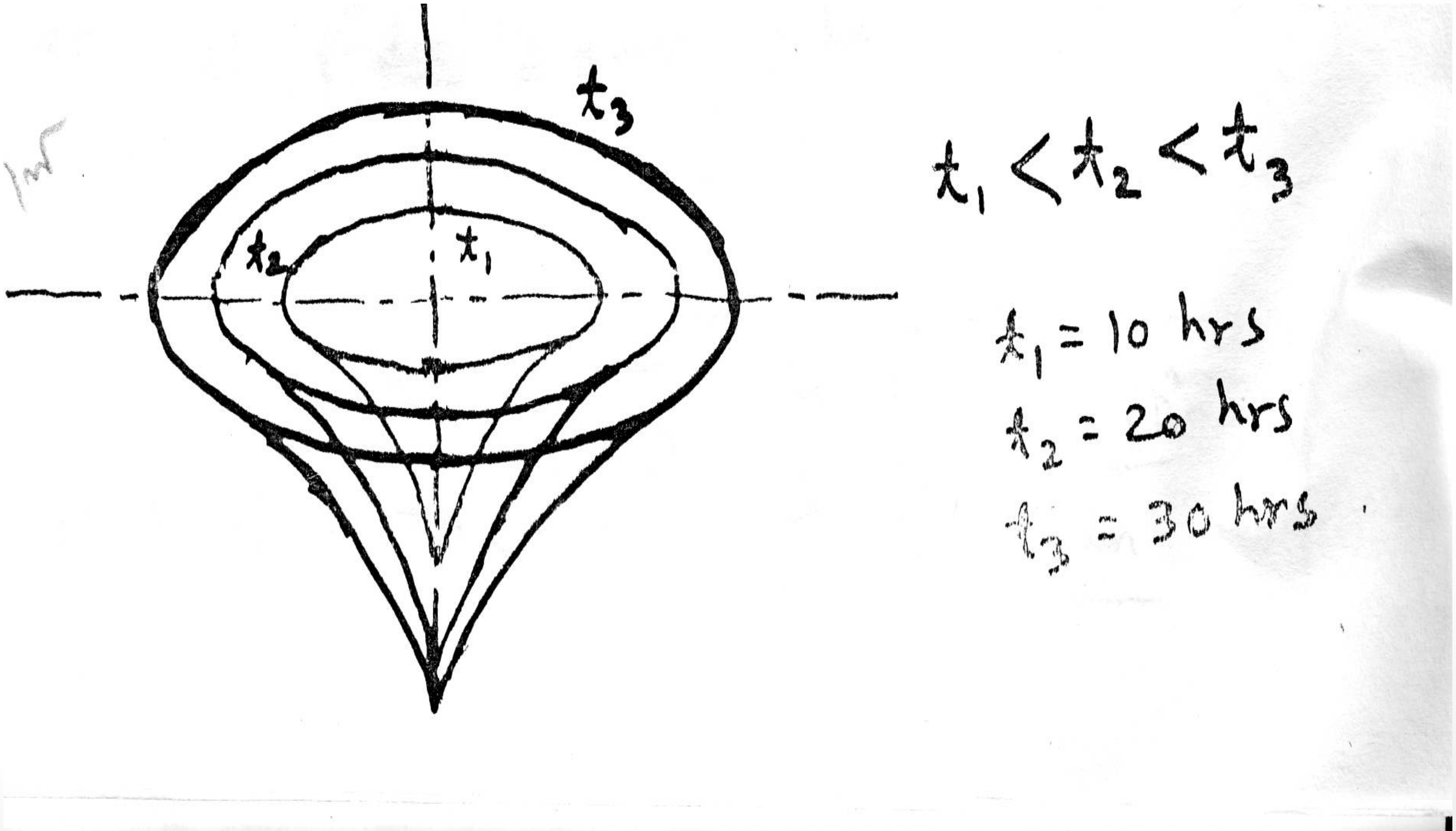
i= hydraulic gradient]

- The velocity close to the well is higher than the velocity at a greater distance from the well.

Flow towards wells

- According to Darcy's law , the hydraulic gradient varies directly with the velocity.
- The increasing velocity towards well is therefore accompanied by an increasing hydraulic gradient.
- The water table or piezometric surface develops a steeper slope towards the well and takes the form of an inverted cone called the cone of depression , has its apex at the water level in the well during pumping is known as pumping water level.
- Drawdown, therefore increases from zero at the outer limits of the cone of depression to a maximum in the pumped well.
- The radius of influence is the distance from the centre of the well to the outer limit of the cone of depression.
- As pumping continues, the cone expands and deepens more slowly with time and equilibrium may occur.

Fig- Flowing towards well



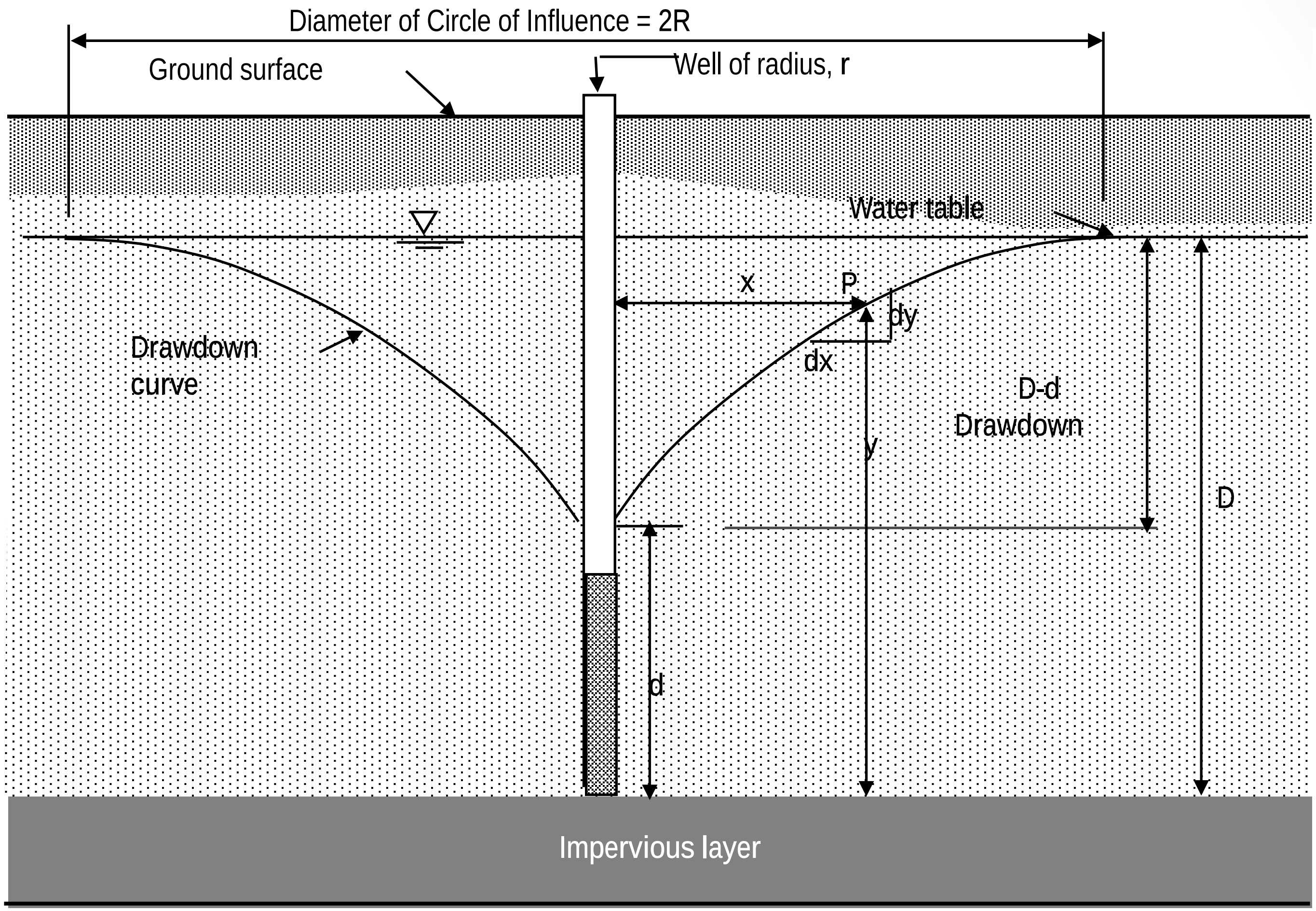


Fig-Hydraulics of flow in a well through unconfined aquifer

Unconfined steady flow

$$Q = \{\pi\, k(D^2 - d^2)\} / \{\ln(R/r)\}$$

Where, Q = well discharge, m^3/d

K = coefficient of permeability, m/d

D = depth of aquifer, m

d = static head, m

R = radius of circle of influence, m

r = radius of the well, m

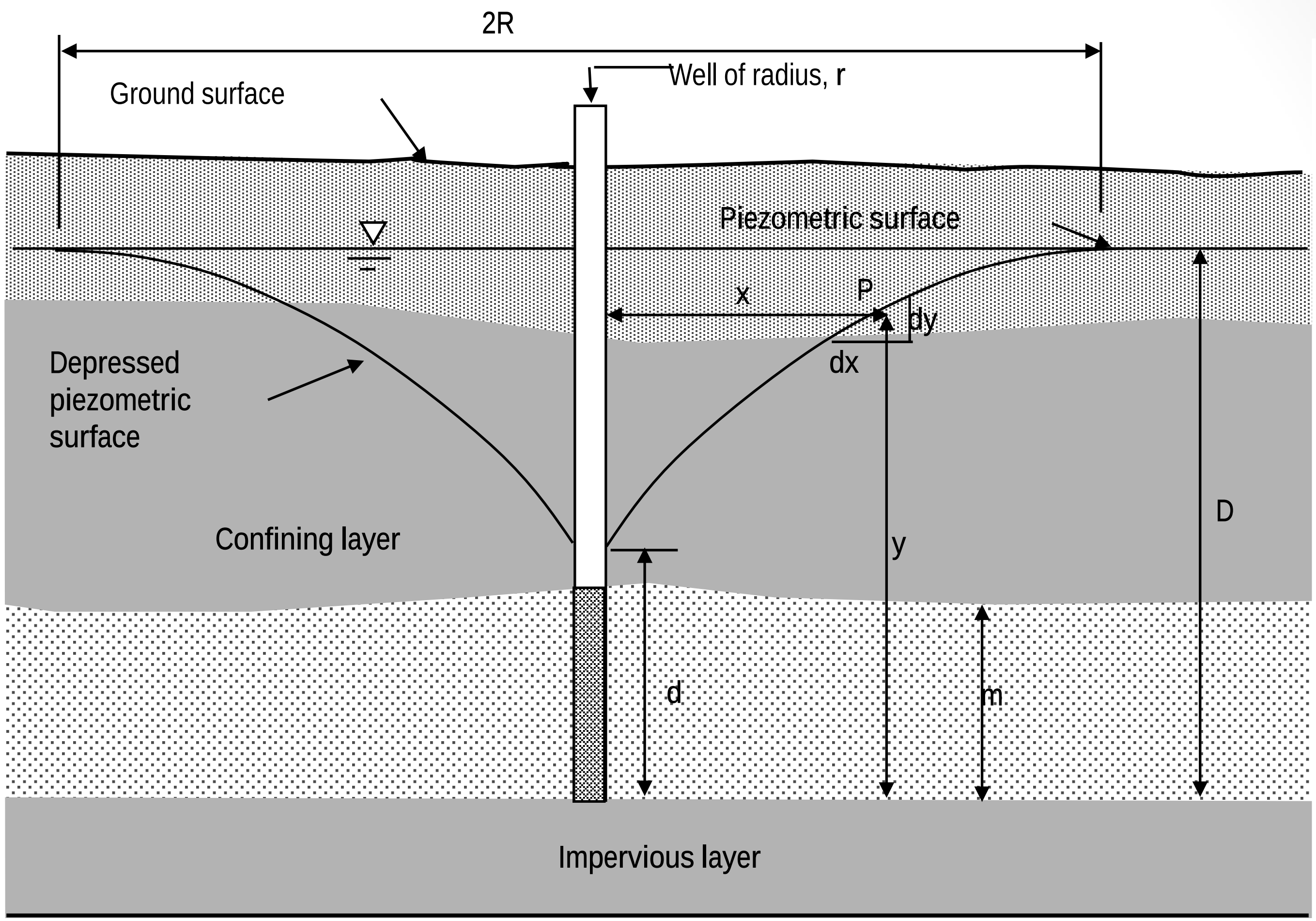


Fig-Hydraulics of flow in a well through confined aquifer

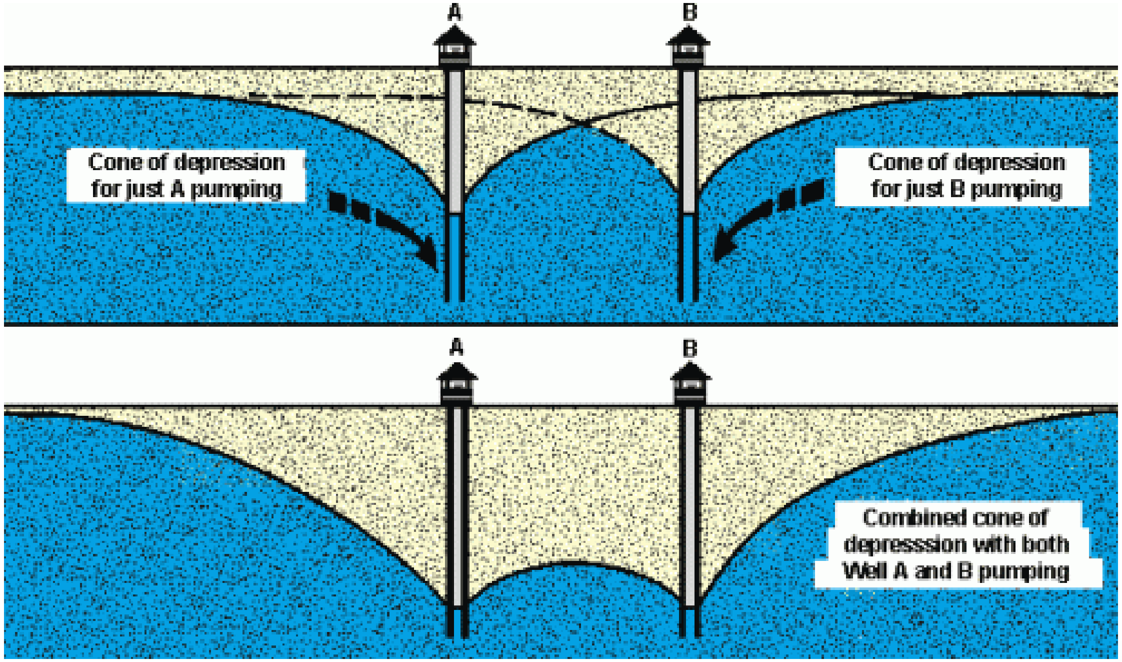
Confined steady flow

$$Q = \{\pi\, km(D - d)\} / \{\ln(R/r)\}$$

- In an artesian tubewell, the drawdown occurs in the piezometric surface and the depth of flow remains constant and equal to the thickness of the aquifer, m.

Interference of wells

- Cones of depression between wells overlap
- Interference reduces the discharges of the interfering tubewells.
- Tubewells should be spaced enough to avoid interference.
- Small diameter tubewells installed in find sand will produce too little drawdown to cause interference.



Aquifer characteristics in Bangladesh

Two types

- Shallow aquifers – Lies within 100 m
- Deep aquifers- Occurs at depths between 300 and 2500 m

MAIN AQUIFERS – Shallow Aquifers

- GW gradient varies from 1:1000 in NW to 1:13000 in central to 1:20000 in coastal
- Permeability vary from 10 to 200 m/d
- Transmissibility range from 100 to 10000 m^2/d – average being 2000
- Specific yield varies from 0.02 to 0.25.

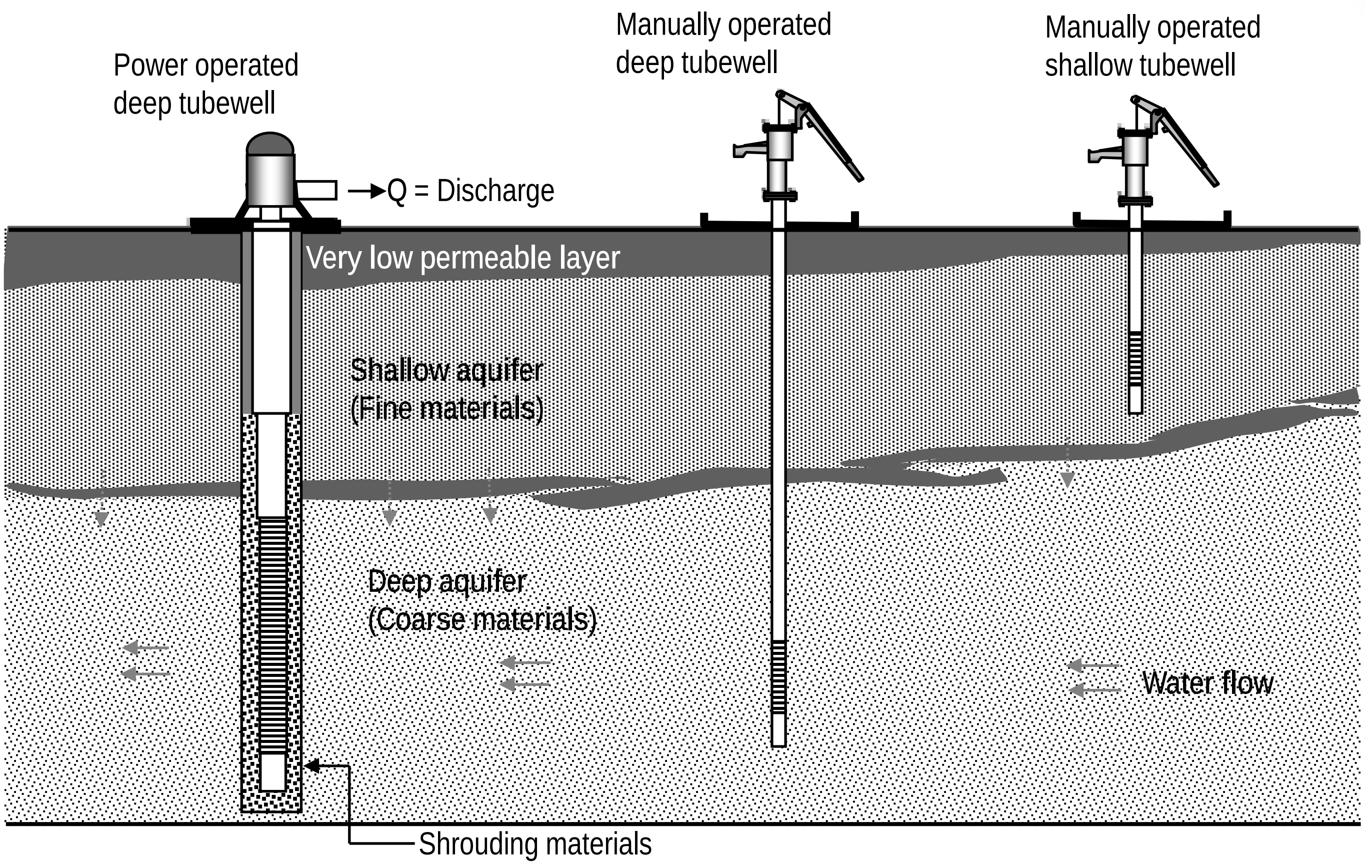


Fig-The main aquifers and the wells for water supply

Groundwater situation in Bangladesh

Groundwater depletion situation in the capital

Year	Bellow the surface
1996	26.60m
1997	28.15m
1998	30.45m
1999	31.86m
2000	34.18m
2001	37.78m
2002	42.00m
2003	46.24m
2004	50.6m
2005	57.42m
2006	59.72m
2007	61.18m

Source: Groundwater monitoring survey project, BADC

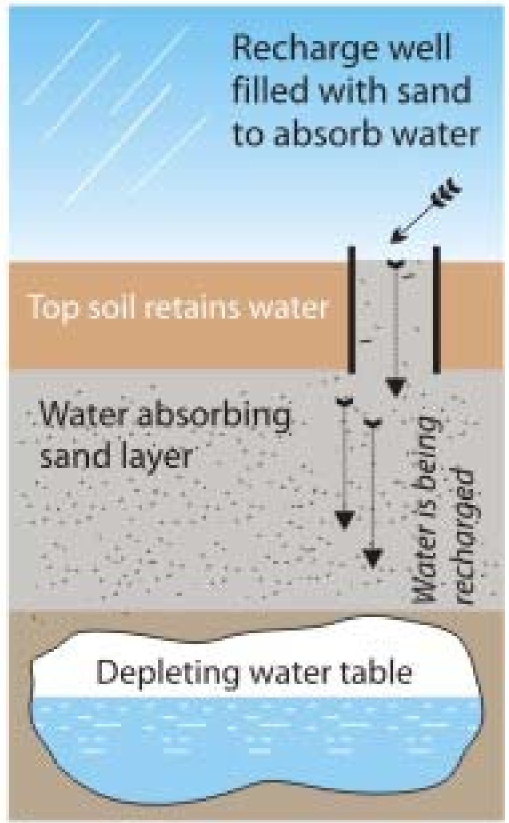
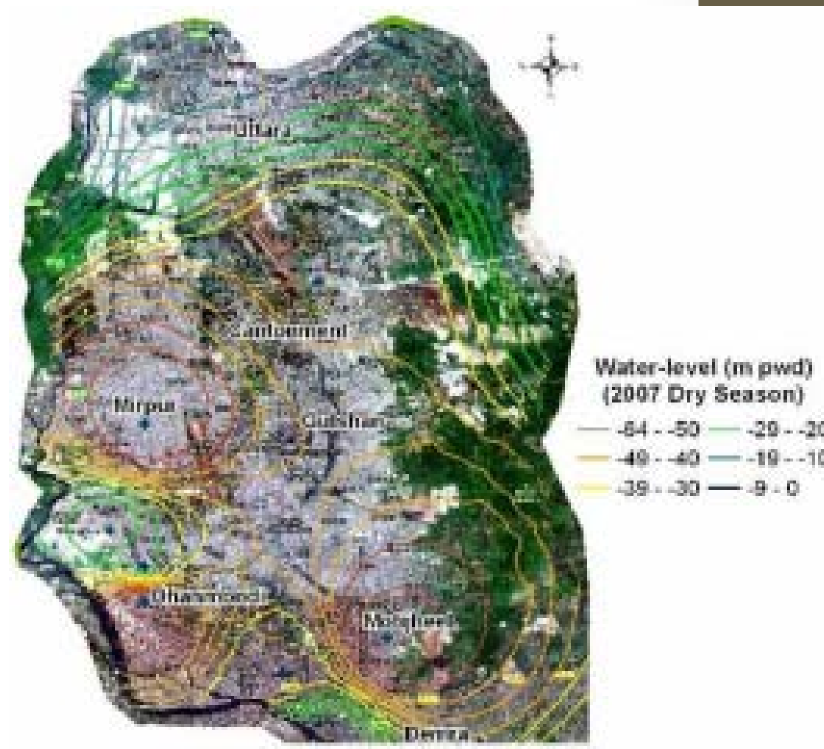


Diagram by Sharier

http://sos-arsenic.net/english/groundwater/index.html



http://geodesh.weebly.com/research.html