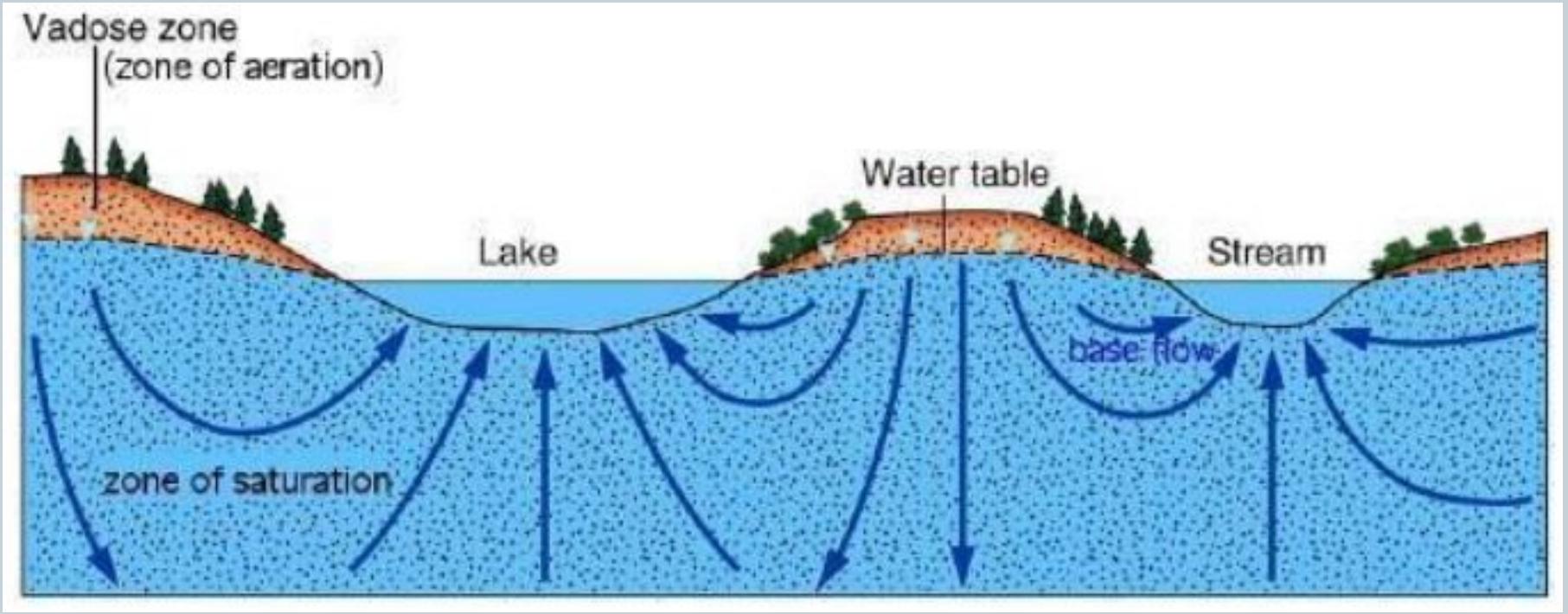
# EWCE 331

# GROUNDWATER

# Groundwater

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

# Groundwater



# Forms of Subsurface Water

***Zone of Saturation***

This zone, also known as *groundwater zone,* is the space in which all the pores of the soil are filled with water. The water table forms its upper limit and marks a free surface, *i.e.* surface having atmospheric pressure.

***Zone of Aeration***

In this zone the soil pores are only partially saturated with water. The space between the land surface and the water table marks the extent of this zone.

# Forms of Subsurface Water

The zone of aeration has three subzones:

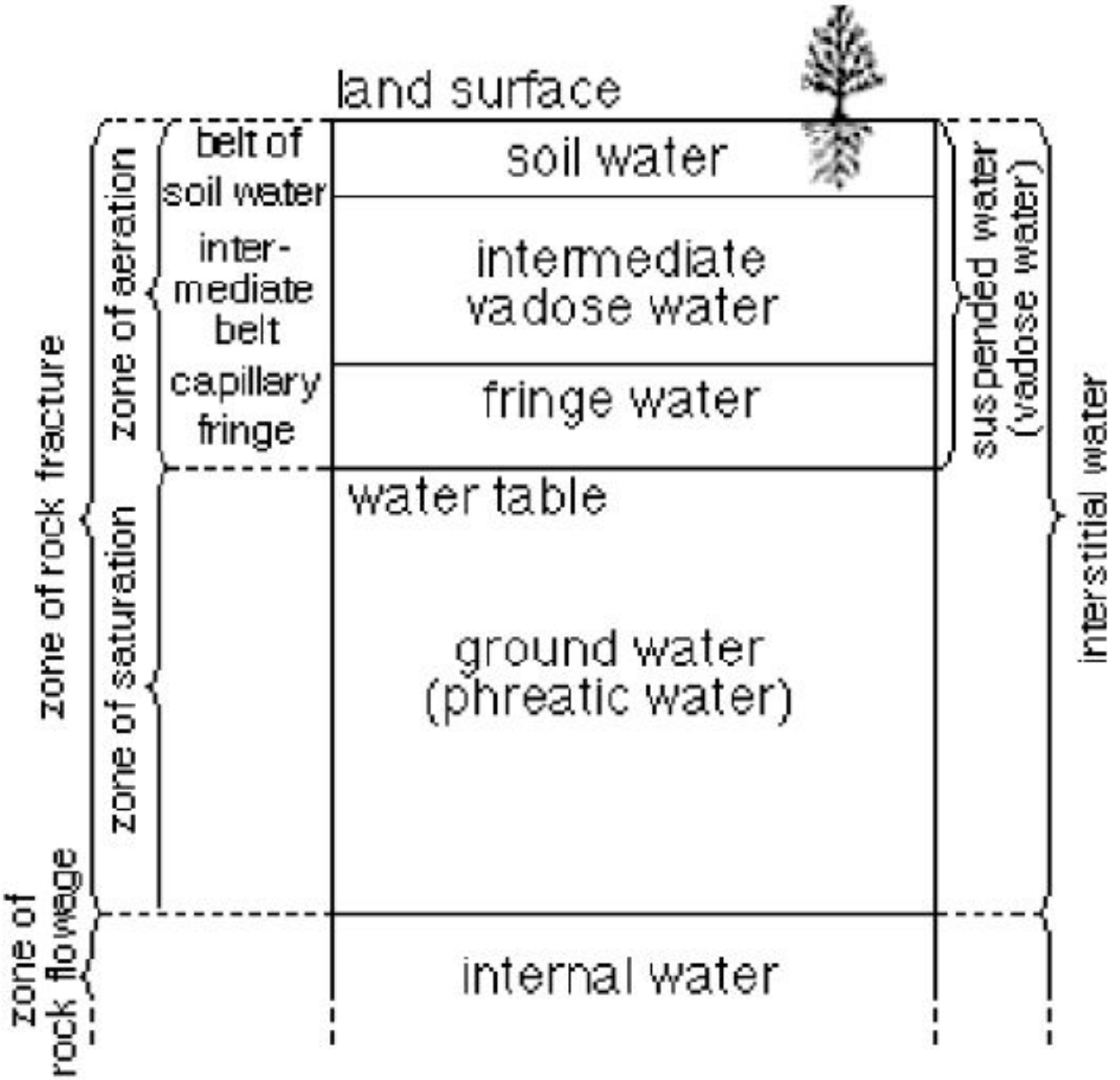
***i) Soil water zone*** : This lies close to the ground surface in the major root band of the vegetation from which the water is lost to the atmosphere by evapotranspiration.

***ii) Capillary fringe***: In this the water is held by capillary action. This zone extends from the water table upwards to the limit of the capillary rise.

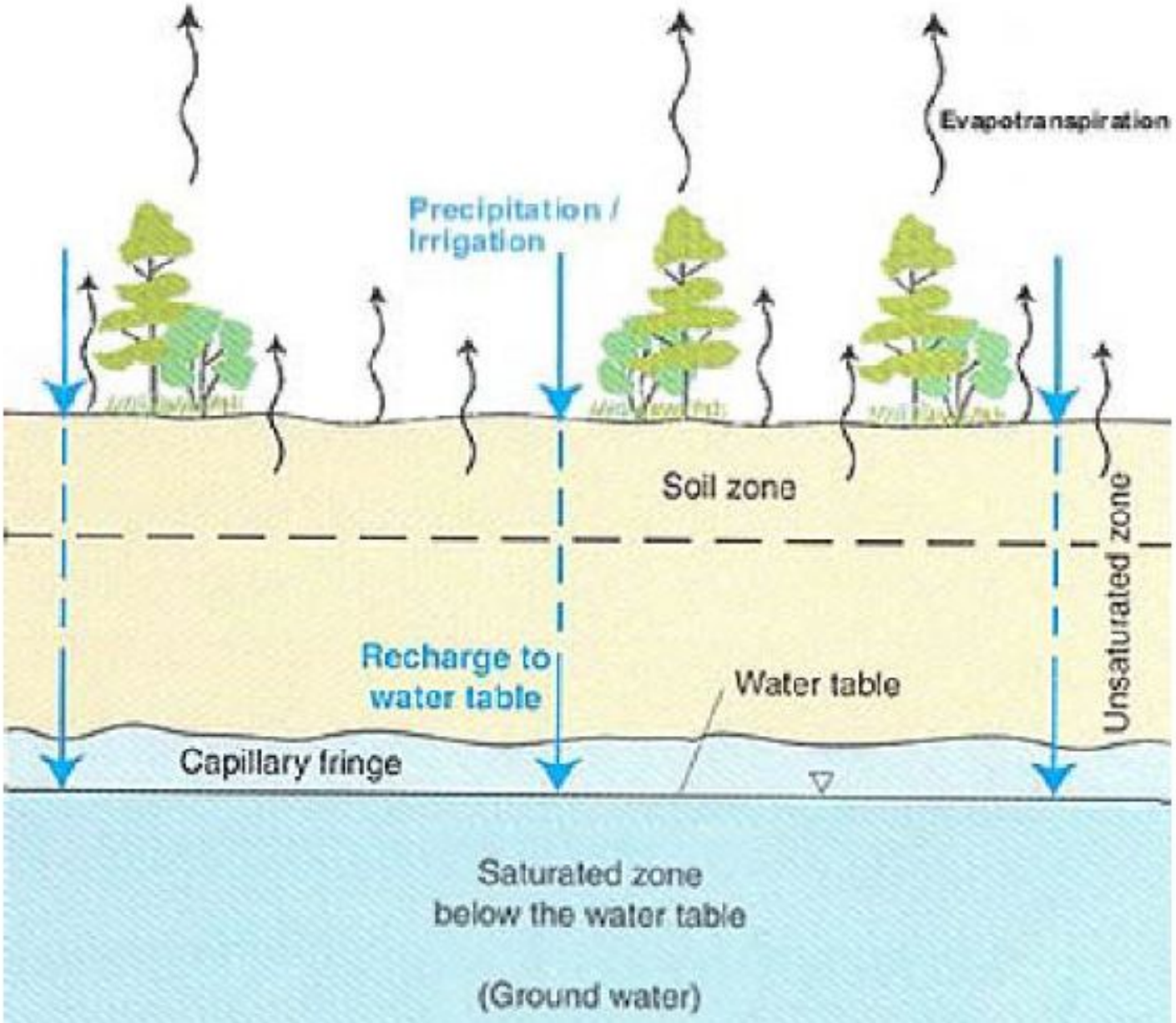
***iii) Intermediate zone*** *:* This lies between the soil water zone and the capillary fringe.

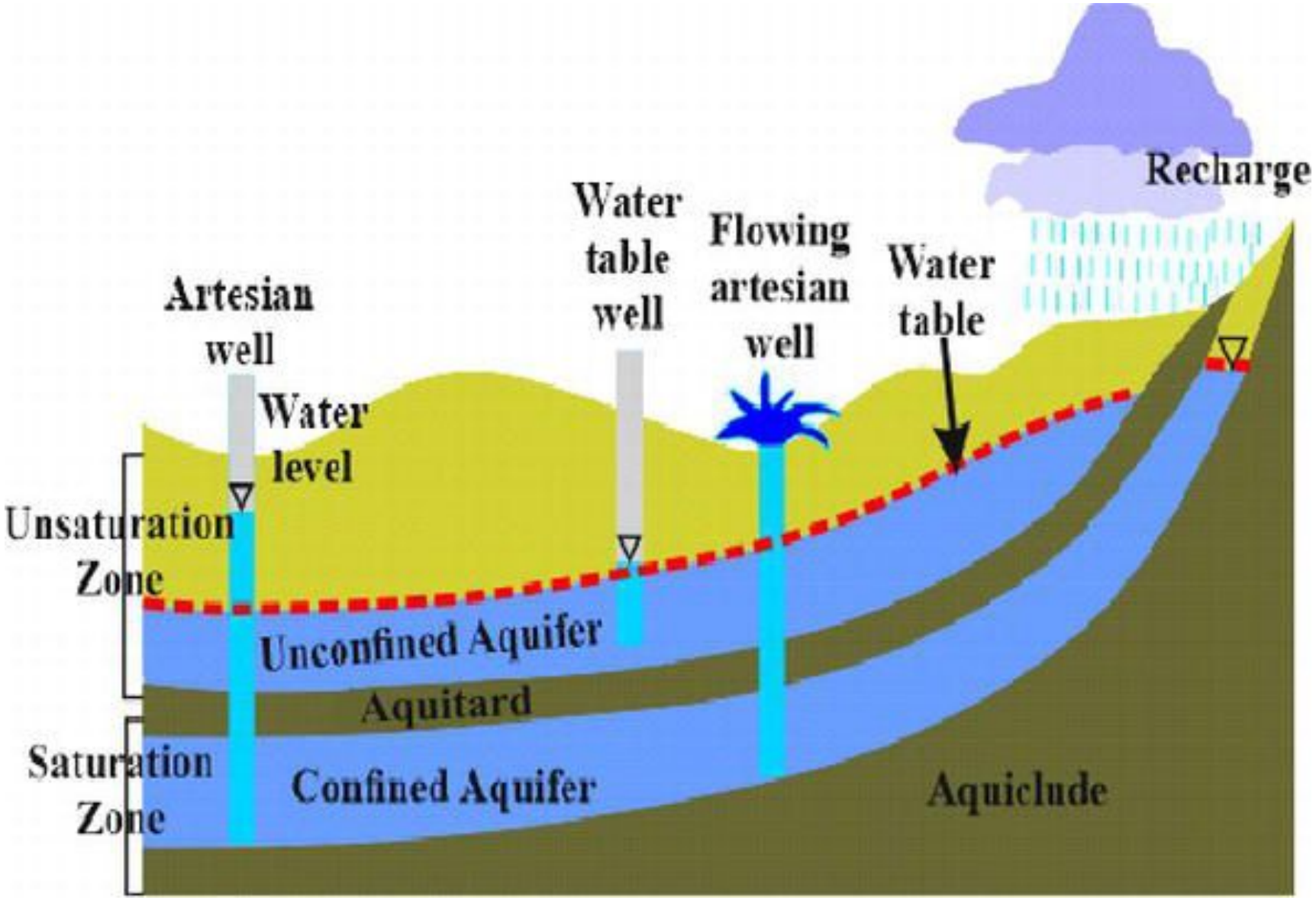
The thickness and its constituent subzones depend upon the soil texture and moisture content and vary from region to region. The soil moisture in the zone of aeration is of importance in agricultural practice and irrigation engineering.

# Groundwater



# Groundwater




Recharge
Water table well
Flowing artesian well
Water table
Artesian well
Water level
Unsaturation Zone
Unconfined Aquifer
Aquitard
Saturation Zone
Confined Aquifer
Aquiclude

# Aquifer

- An underground layer of rock that holds groundwater which is rain or melted snow that has seeped into the ground and is held there.
- Filled slowly and can dry up when people drain them faster than they can be refilled—a process called aquifer depletion.
- Drained by man-made wells or they can flow out naturally in springs.
- The impervious formation or strata containing very little groundwater are termed Aquiclude.

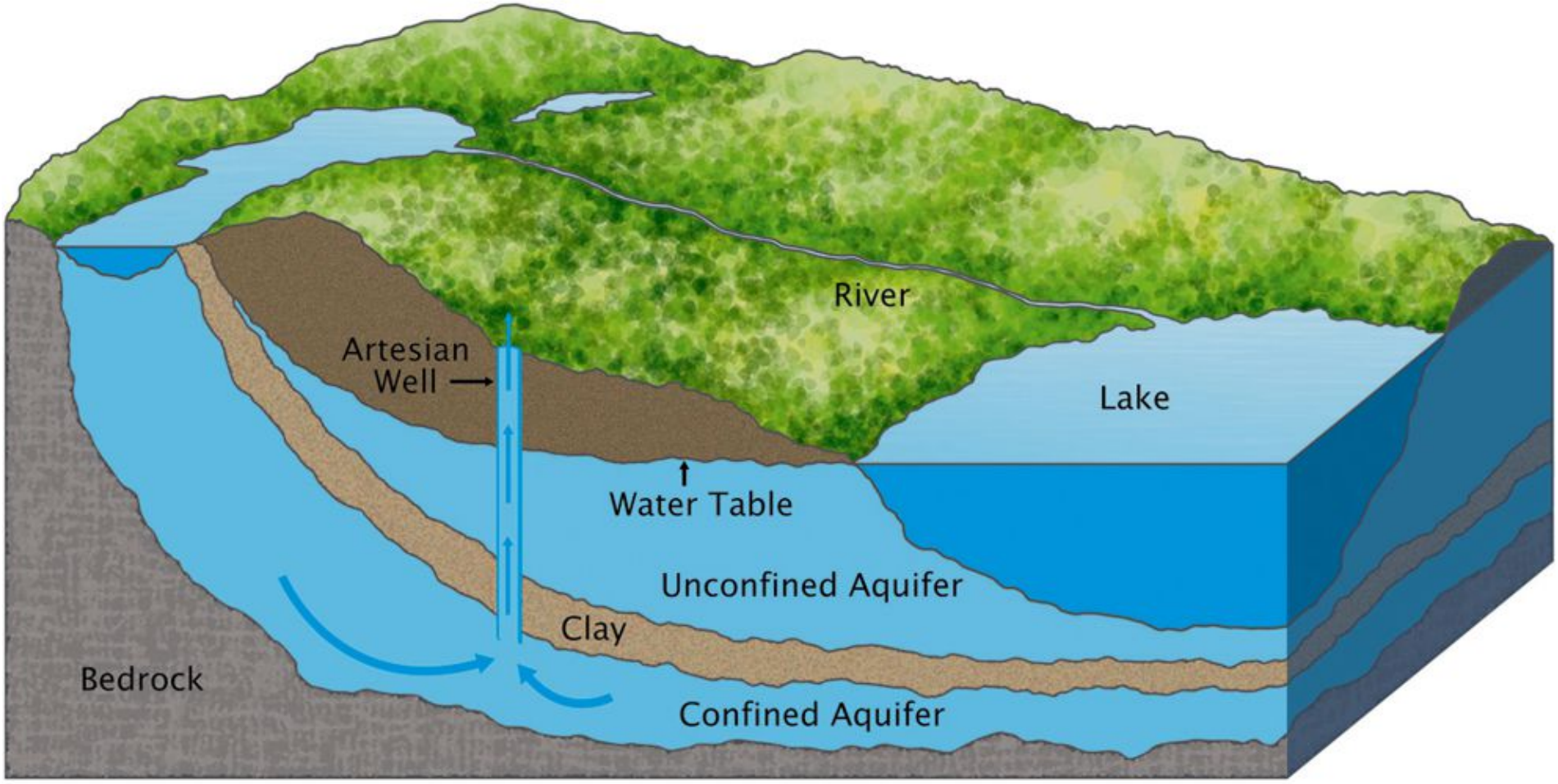
# Aquifer

- An aquifer has interconnected pores filled with water. Interconnected pores provide both storage and flow functions in an aquifer.
- Capacity of an aquifer to contain water is measured by porosity of the formation.
- But high porosity does not indicate that it will yield large volume of water and only the water which flow by gravity can be obtained from the aquifer.

# Types of Aquifer

- An unconfined aquifer can receive water directly from the surface, while a confined aquifer is trapped between two layers of rock.
- Water-table or unconfined aquifer is one which is not confined by an upper impermeable layer and is at under atmospheric pressure. Water seeps into it directly from the ground surface.
- Artesian or confined aquifer is one which is confined under a pressure greater than atmospheric and overlay by an impermeable layer that prevents water seeping into it from the ground surface.

# Aquifer


River
Artesian Well
Lake
Water Table
Unconfined Aquifer
Clay
Bedrock
Confined Aquifer

# Factors governing the occurrence of groundwater

- **Aquifer functions** : aquifer has an interconnected pores filled with water and it works as a network of pipes through which water flows at a very slow rate.
- Two functions are considered in an aquifer:
  - Storage function
  - Conduit function

# Factors governing the occurrence of groundwater

**Storage function:** porosity and specific yield are important properties of storage function.

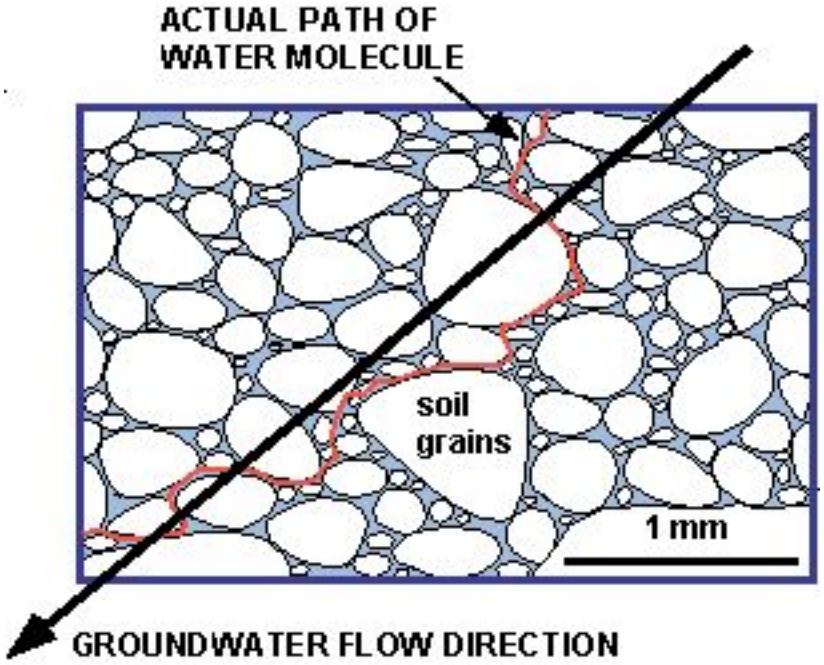
- **Porosity of soil** ={(total volume of voids in the soil or the volume of water required to saturate the dry sample ($V_v$))/total volume of soil aggregate (V)} x 100

$$\eta = V_v/V \times 100$$

- **Specific yield** is the volume of water released freely or by gravity from a unit volume of aquifer.

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

$$S_y = W_y/V$$




| 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

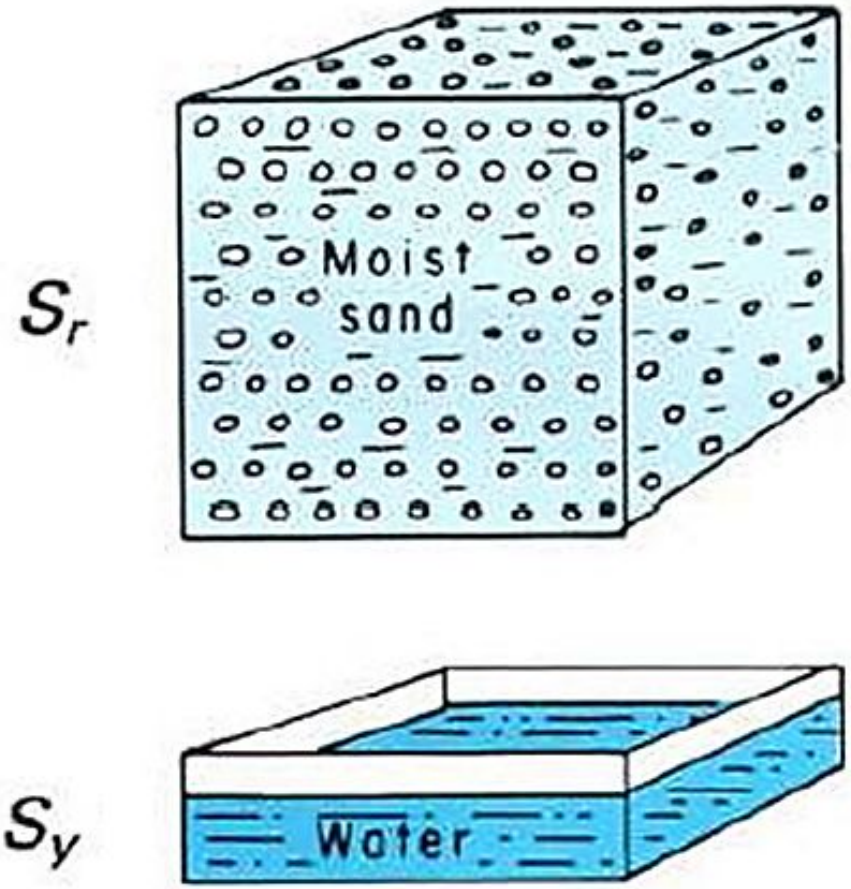
- **Specific retention** is the volume of water held up by capillary or other attraction forces.

Sp. retention or field capacity={(volume of water held against the gravity drainage)/total volume of the material drained} x 100

$$S_r = W_r / V$$

- Sum of the specific yield and the specific retention is equal to its porosity.

$$\eta = S_r + S_y$$




$$n = S_y + S_r$$

The table below shows the properties of four types of soil. Mention which type of soil is capable of retaining most of the water and which one is capable of discharging most of the water. Also calculate the maximum amounts retained and discharged respectively if the aquifer bearing the soil layer has a total volume of 1000 $m^3$.

| 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

- **Conduit function**: permeability is a property of conduit function. It is the measure of the capacity of an aquifer to transmit water.
- Velocity of flow is related to the slope of the hydraulic gradient by Darcy's law equation:

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

  The equation can be modified as $V=Ki$

  $i=(h_1-h_2)/l$ and is called the hydraulic gradient
- Quantity of flow per unit time Q, through a given cross-sectional area A is $Q=AV=K\ A\ i$
- The flow per unit width of the aquifer having thickness of m is

  $q=K\ m\ i$

# Factors governing the occurrence of groundwater

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

$$K = cd_{10}^{2}$$

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.
- **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.
- **Drainage of groundwater** 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.

# Important terms

## Transmissivity (T)

- ✓ Rate at which water is transmitted through its unit width under a unit hydraulic gradient.
- ✓ Co-efficient of transmissivity or transmissibility.
- ✓ Characterizes the ability of aquifer to transmit the water.

$$T = K \times b \times i$$

Where,

K=hydraulic conductivity(m/day),

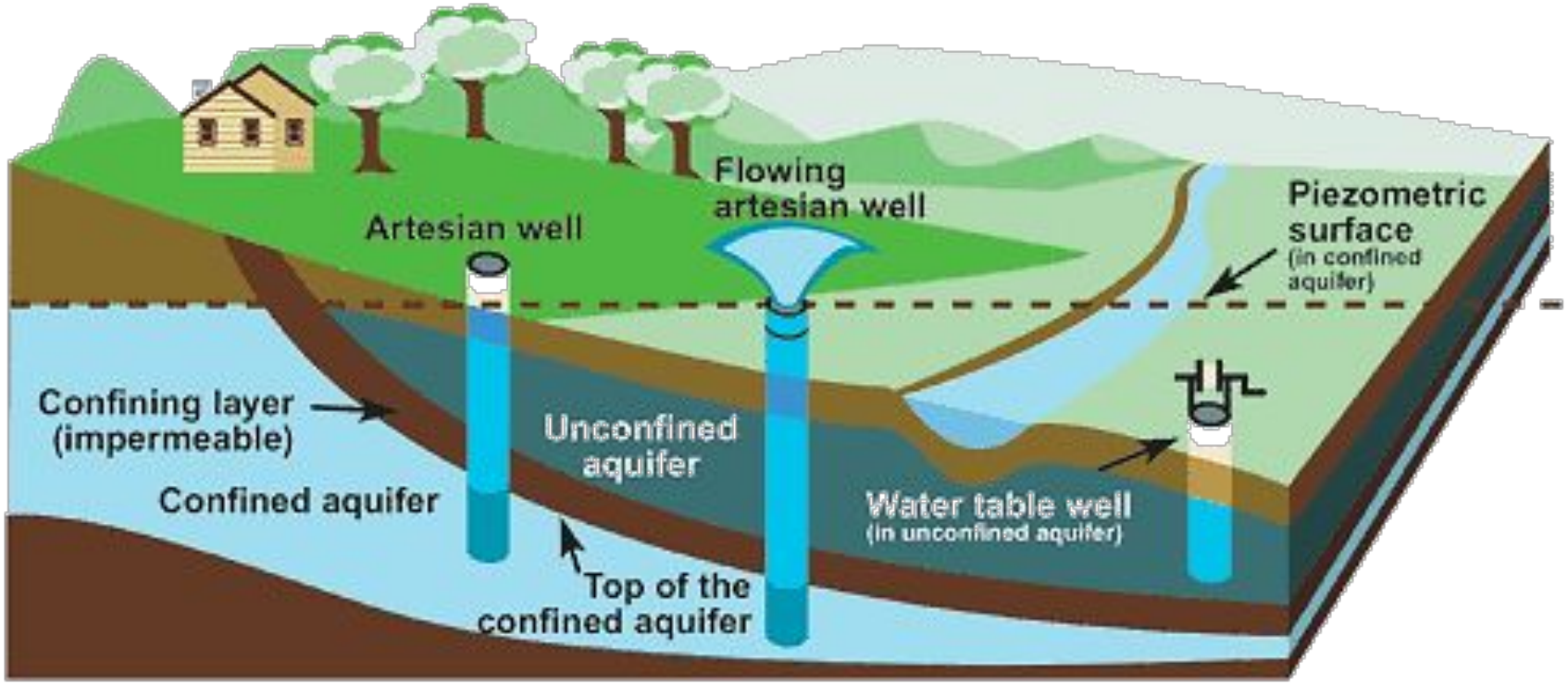
b=thickness(m),

i=hydraulic gradient.

# Piezometric Surface

- Imaginary surface to which water will rise to wells located throughout a confined or artesian aquifer is Piezometric surface (the surface coincides with the piezometric head of the water in the aquifer).
- May be either above and below the ground surface at different parts of the same aquifer.
  - If piezometric surface lies above the ground level is referred as flowing artesian wells.
  - If piezometric surface is below the ground surface a non-flowing artesian wells results, pump must be provided to obtain water.

# Aquifers and wells



# Groundwater Situation in Dhaka

**Depth of Groundwater in Different Areas of Dhaka City (in feet)**

| Year | Mirpur | Mohammadpur | Dhanmondi | Gulshan | Cantonment | Lalbag | Sabujbag | Sutrapur |
|---|---|---|---|---|---|---|---|---|
| 1980 | 8.36 | 9.3 | 10.12 | 9.91 | - | 1.67 | 3.13 | 5.88 |
| 1985 | 13.57 | 13.5 | 12.76 | 9.95 | - | 16.06 | 13.63 | 8.93 |
| 1990 | 15.3 | 14.52 | 15.4 | 10 | - | 17.71 | 21.49 | 11.08 |
| 1995 | 20.76 | 20.48 | 24.27 | 24.25 | 18.46 | 19.78 | 26.43 | 15.67 |
| 2000 | 35.2 | 20.87 | 40.12 | 27.59 | 27.88 | 36.57 | 46.45 | 18.79 |
| 2005 | 63 | 32.21 | 60.85 | 37.3 | 27.8 | 44.77 | 54.4 | 20.12 |
| 2010 | 65.97 | 31.24 | 66.32 | 42.66 | 27.81 | 44.77 | 54.4 | 21.1 |

***Source:*** *Bangladesh Water Development Board, 2014*

# Recharge of Groundwater

General hydrologic equation

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

Where $\Sigma R$=hydrologic factors contributing to recharge

$\Sigma D$=hydrologic factors contributing to discharge

$\Delta S$=Associated change in storage volume

# Recharge of Groundwater

**Recharge is composed of:**

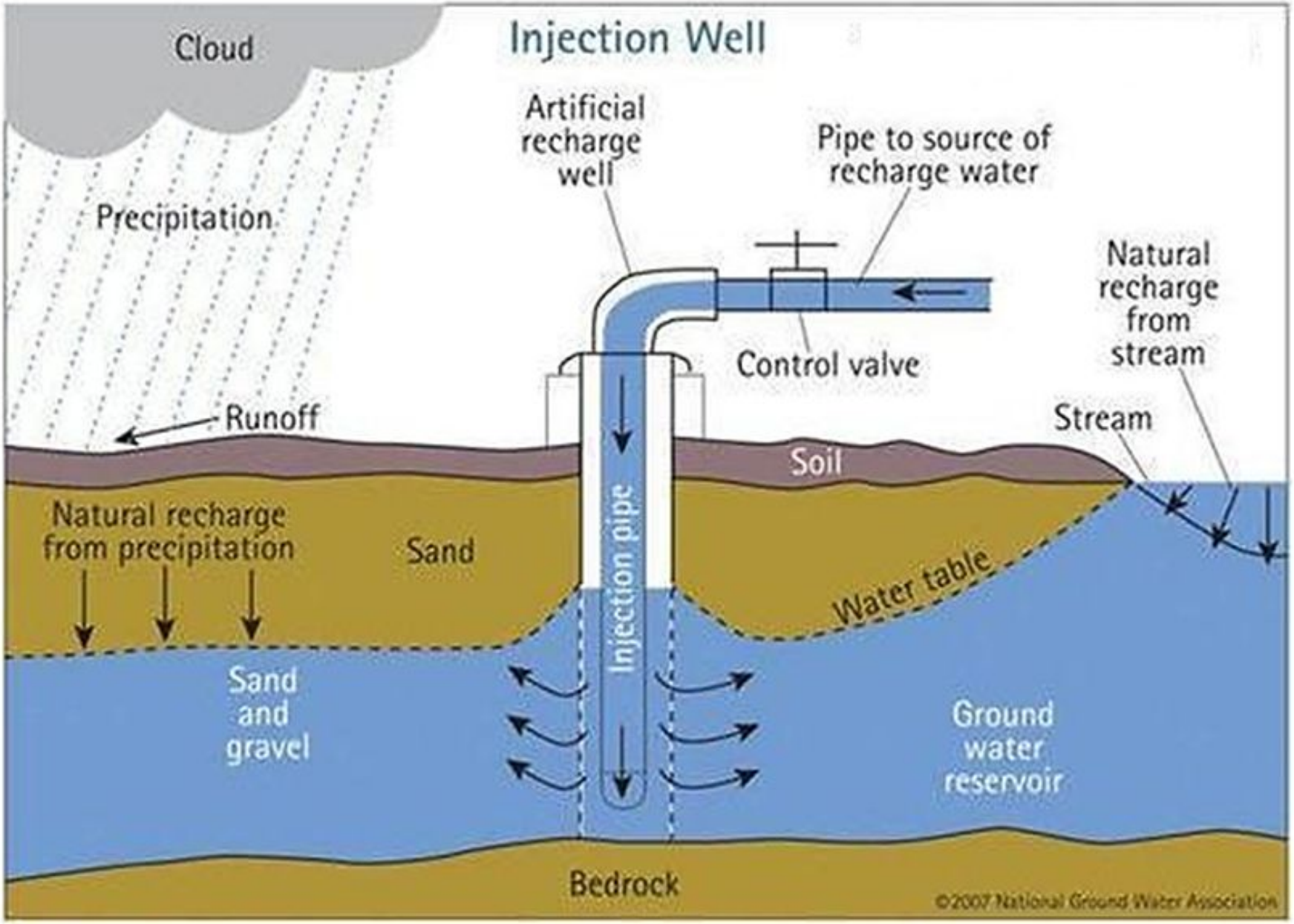
- Natural infiltration derived from rainfall and snowmelt
- Infiltration from surface bodies of water
- Underflow — Subsurface inflow of groundwater from one region to another
- Leakage through confining layers or water displaced from them by compression
- Water derived from diffusion, charging and water spreading operation

Artificial replenishment of aquifer by methods like injection wells, recharge pits, etc.

# Recharge of Groundwater

**Conversely discharge includes:**

- Evaporation and transpiration
- Seepage in to surface bodies of water
- Underflow
- Leakage through confining layers or absorbed by them through the reduction of compression
- Water withdrawn through wells and infiltration galleries


Injection Well
Cloud
Artificial recharge well
Pipe to source of recharge water
Precipitation
Natural recharge from stream
Control valve
Runoff
Stream
Soil
Natural recharge from precipitation
Sand
Injection pipe
Water table
Sand and gravel
Ground water reservoir
Bedrock
©2007 National Ground Water Association

# Aquifer Characteristics in Bangladesh

- A shallow aquifer (main aquifer) lies between 100m from the surface with an overlying clay/silt blanket (2m thick) in northwest and increases southward to more than 50m.
- Deep aquifers occur at depths between 300 and 2500m.
- Groundwater (GW) of shallow aquifer flows from north to south without flow into the major rivers.
- Gradient of GW varies from 1:1,000 in the northwest to 1:13,000 in central Bangladesh and less than 1:20,000 in the coastal area.

# Aquifer Characteristics in Bangladesh

- Permeabilities are very high and vary from 10 to 200m/day.
- Transmissibilty of the main aquifer has an average value of 2000 $m^2$/day.
- Horizontal flow of groundwater is very low because of the low hydraulic gradient.
- Storage capacity of the aquifer increases with depth because of increase in the size of aquifer materials.
- The specific yield varies from 0.02 to 0.25.

# Aquifers and Water supply Wells

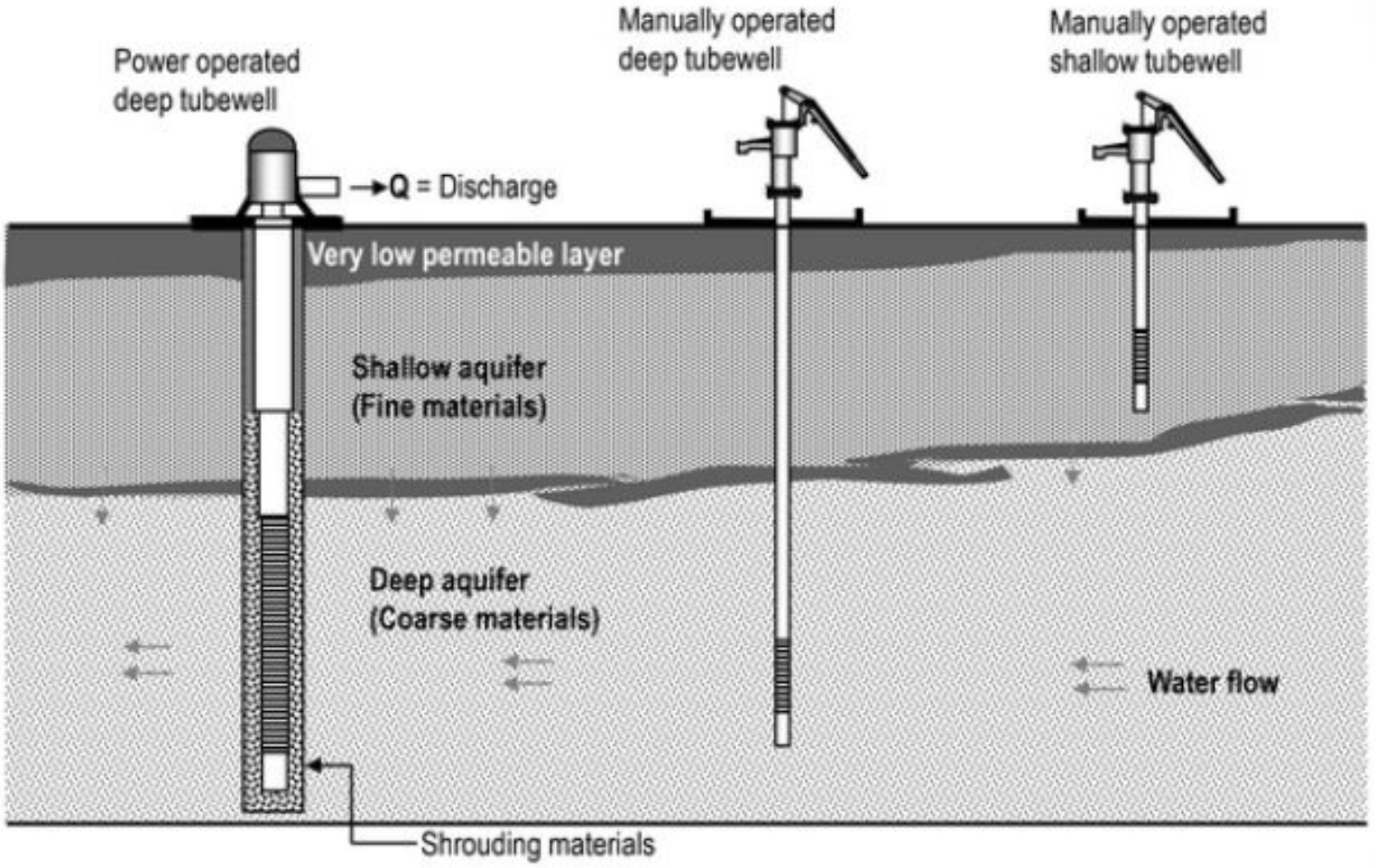
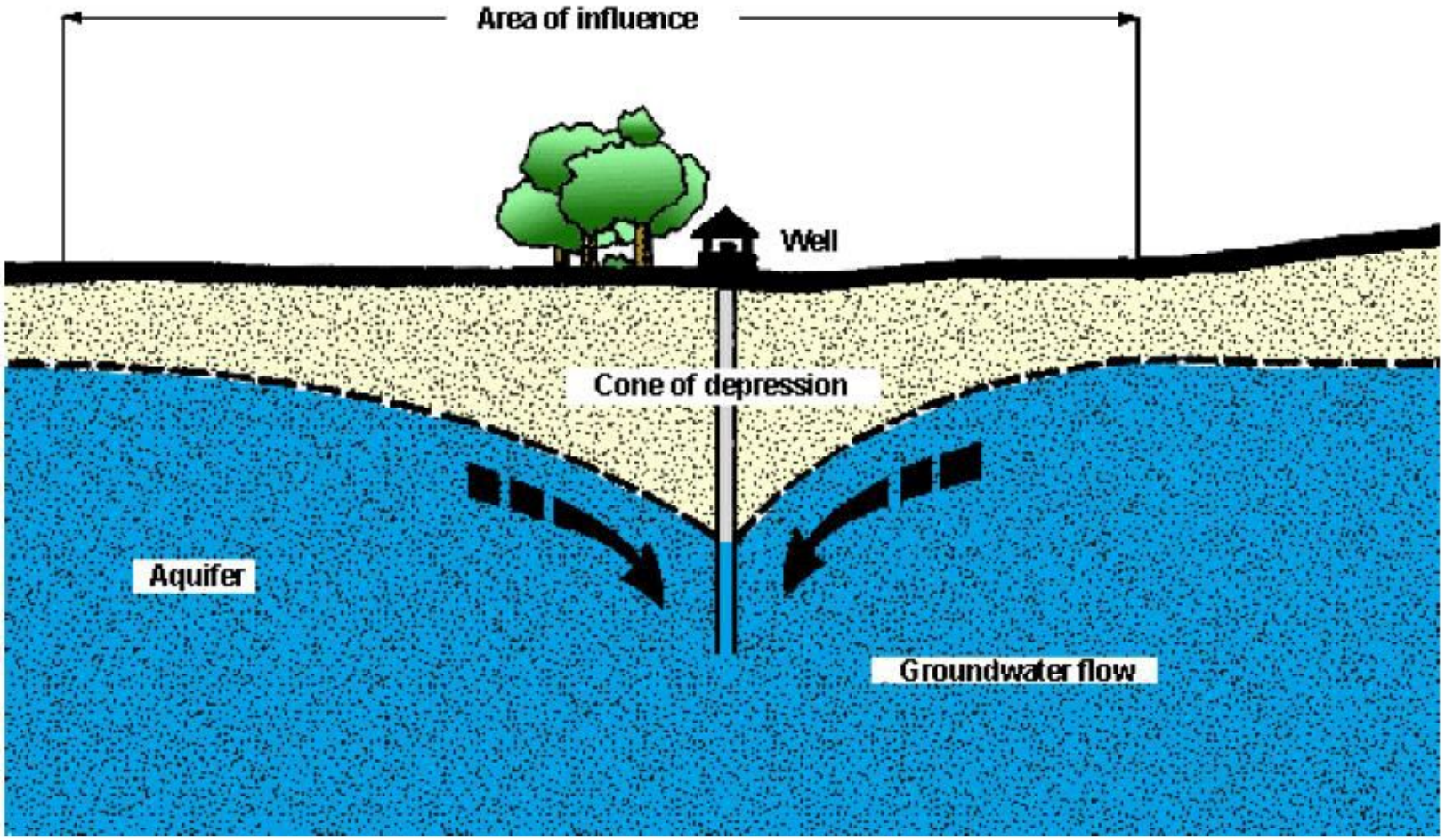



Fig-The main aquifers and the wells for water supply

# Well Hydraulics




Pumping a well lowers the fluid pressure at that point. The resulting lower hydraulic head causes water flow towards the well from all directions. A cone of depression is formed.

# 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.

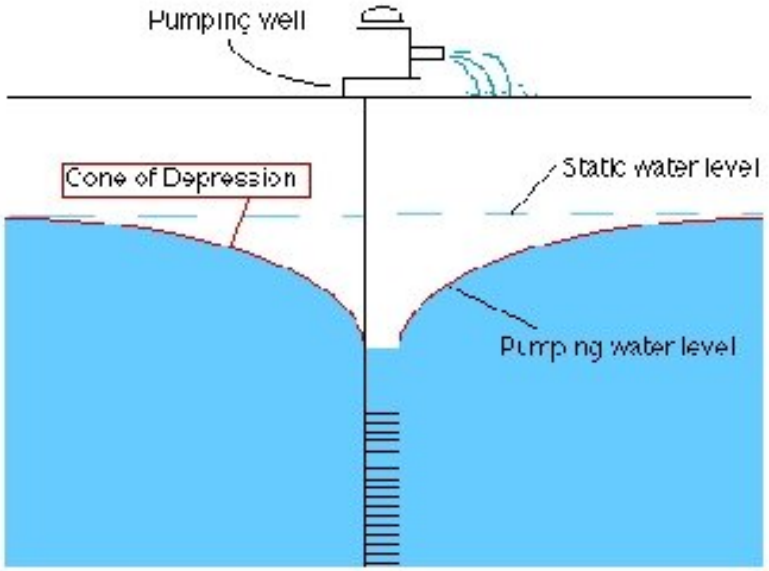
# Flow Towards Wells

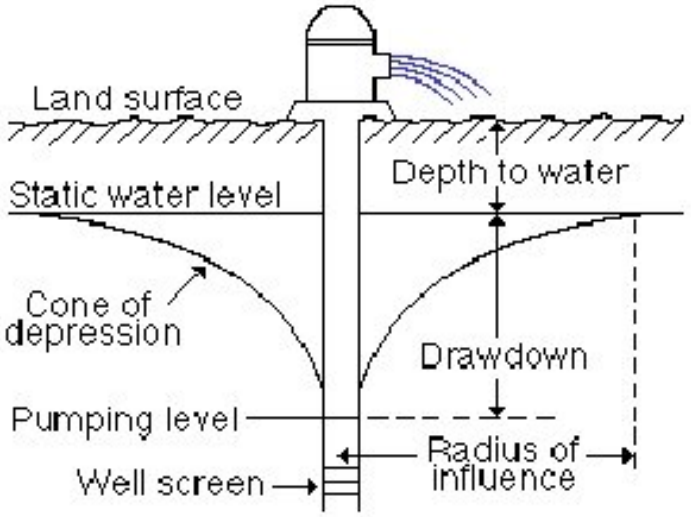
- Static water level (when well at rest) coincides with the water table of the aquifer and the Piezometric surface.
- Pumping causes lowering of the pressure and induces flow from all directions into the well which is known as converging flow.
- In a converging flow velocity close to the tube well is higher than the velocity at a distance from the tube well.
- Darcy's law explains that the hydraulic gradient varies directly with the velocity. So, the increasing velocity towards well is accompanied by an increasing hydraulic gradient.

The hydraulic gradient is the slope of the water table or potentiometric surface, that is, the change in water level per unit of distance along the direction of maximum head decrease.

# Flow Towards Wells

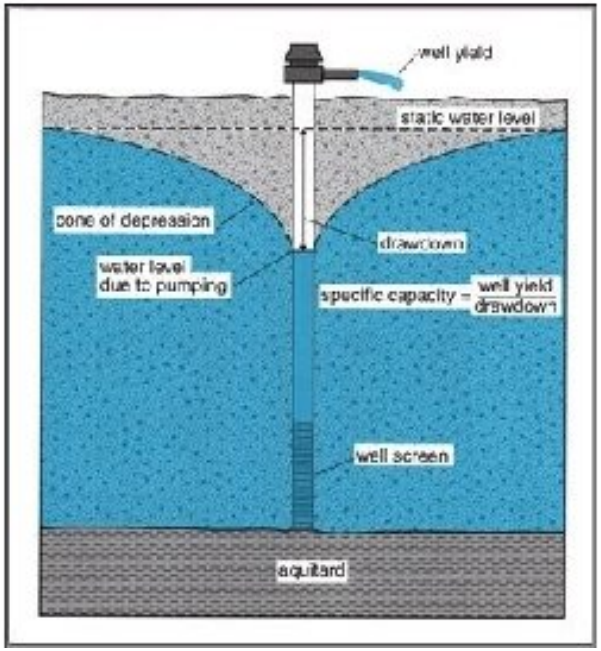
- The water surface develops a steeper slope towards the well and takes the form of an inverted cone called cone of depression.
- The difference between the static water level and the surface of the cone of depression is called the drawdown.



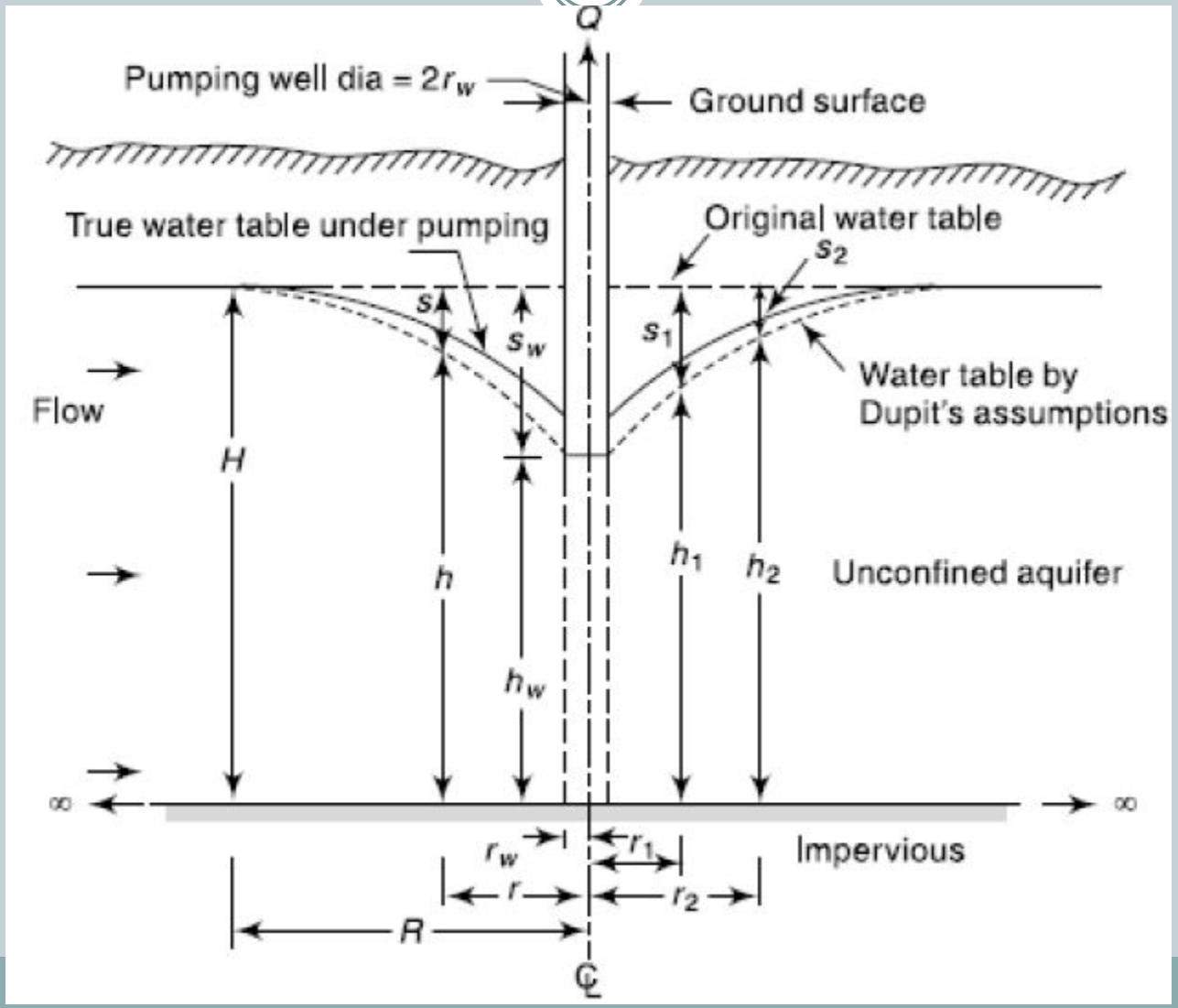




Some useful terms to know:

- ✓ Cone of depression
- ✓ Drawdown
- ✓ Radius of influence
- ✓ Specific capacity



# Unconfined Steady Flow



# Unconfined Steady Flow

Consider the well of radius $r_w$ penetrating completely an extensive unconfined horizontal aquifer as shown in Fig. The well is pumping a discharge $Q$. At any radial distance $r$, the velocity of radial flow into the well is; $V_r = K\left(\frac{dh}{dr}\right)$, where $h$ is the height of the water table above the aquifer bed at that location.

For steady flow, by continuity:

$$Q = (2\pi rh)V_r = (2\pi rh)K\left(\frac{dh}{dr}\right) \quad or; \quad \frac{Q}{2\pi K}\frac{dr}{r} = h\,dh$$

Integrating between limits $r_1$ and $r_2$ where the water-table depths are $h_1$ and $h_2$, respectively and on rearranging:

$$Q = \frac{\pi K(h_2^2 - h_1^2)}{ln\frac{r_2}{r_1}}$$

This is the equilibrium equation for a well in an unconfined aquifer. As at the edge of the zone of influence of radius $R$. $H$= saturated thickness of the aquifer, Eq.can be written as:

$$Q = \frac{\pi K(H^2 - h_w^2)}{ln\frac{R}{r_w}}$$

where $h_w$ = depth of water in the pumping well of radius $r_w$.

**Example-1**

A 100 mm diameter tubewell is sunk 35 m below static groundwater level. The depth of water in the tubewell while pumping is 33 m. The radius of drawdown is 30 m and the coefficient of permeability of the aquifer is 0.5 l/s/m$^2$. Calculate the probable discharge of the well.

**Solution:** $$Q = \frac{\pi K(D^2 - d^2)}{\text{Log}_e(\frac{R}{r})}$$

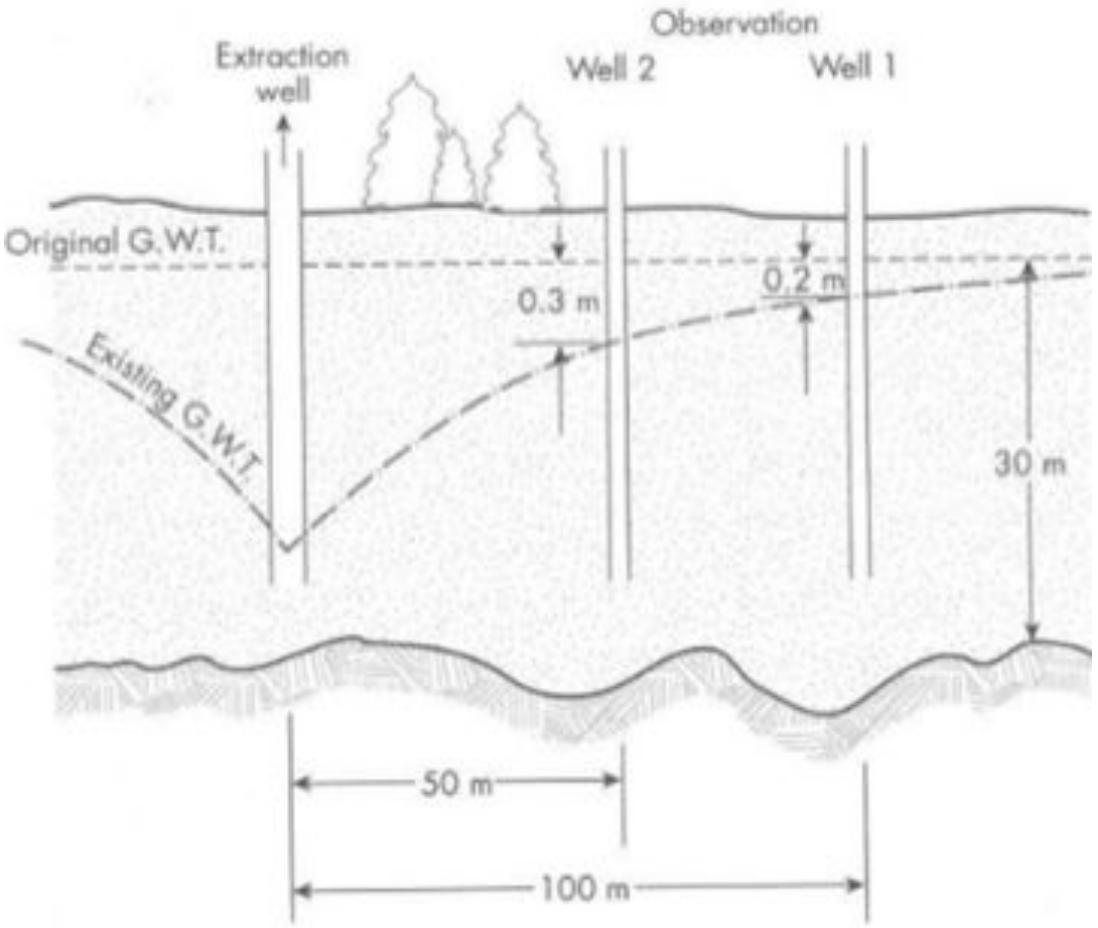
$K = 0.5$ lps/m$^2$; $D = 35$m; $d = 33$m; $R = 30$m; $r = 0.05$m

Substituting the values in the above equation:

$Q = 3.14 \times 0.5 \times (35^2 - 33^2) / \text{Log}_e (30/0.05)$

$Q = 3.14 \times 0.5 \times 136/6.3969 = 33.4$ lps

A well is 0.2 m in diameter and pumps from an unconfined aquifer 30 m deep at an equilibrium rate of 1000 $m^3$/day. Two observation wells are located at distances of 50 and 100 m and have drawdowns of 0.3 and 0.2 m, respectively. What is the coefficient of permeability (hydraulic conductivity, K)



A 30-cm well completely penetrates an unconfined aquifer of saturated depth 40 m. After a long period of pumping at a steady rate of 1500 *Lpm*, the drawdown in two observation wells 25 and 75 m from the pumping well were found to be 3.5 and 2.0 m, respectively. Determine the transmissivity of the aquifer. What is the drawdown at the pumping well?

**Solution:**

***(a)***

$$Q = \frac{1500 \times 10^{-3}}{60} = 0.025 m^2/S$$

$h_2 = 40.0 - 2.0 = 38.0$ $\quad r_2 = 75\ m$

$h_1 = 40.0 - 3.5 = 36.5\ m$ $\quad r_1 = 25\ m$

From Eq. (28),

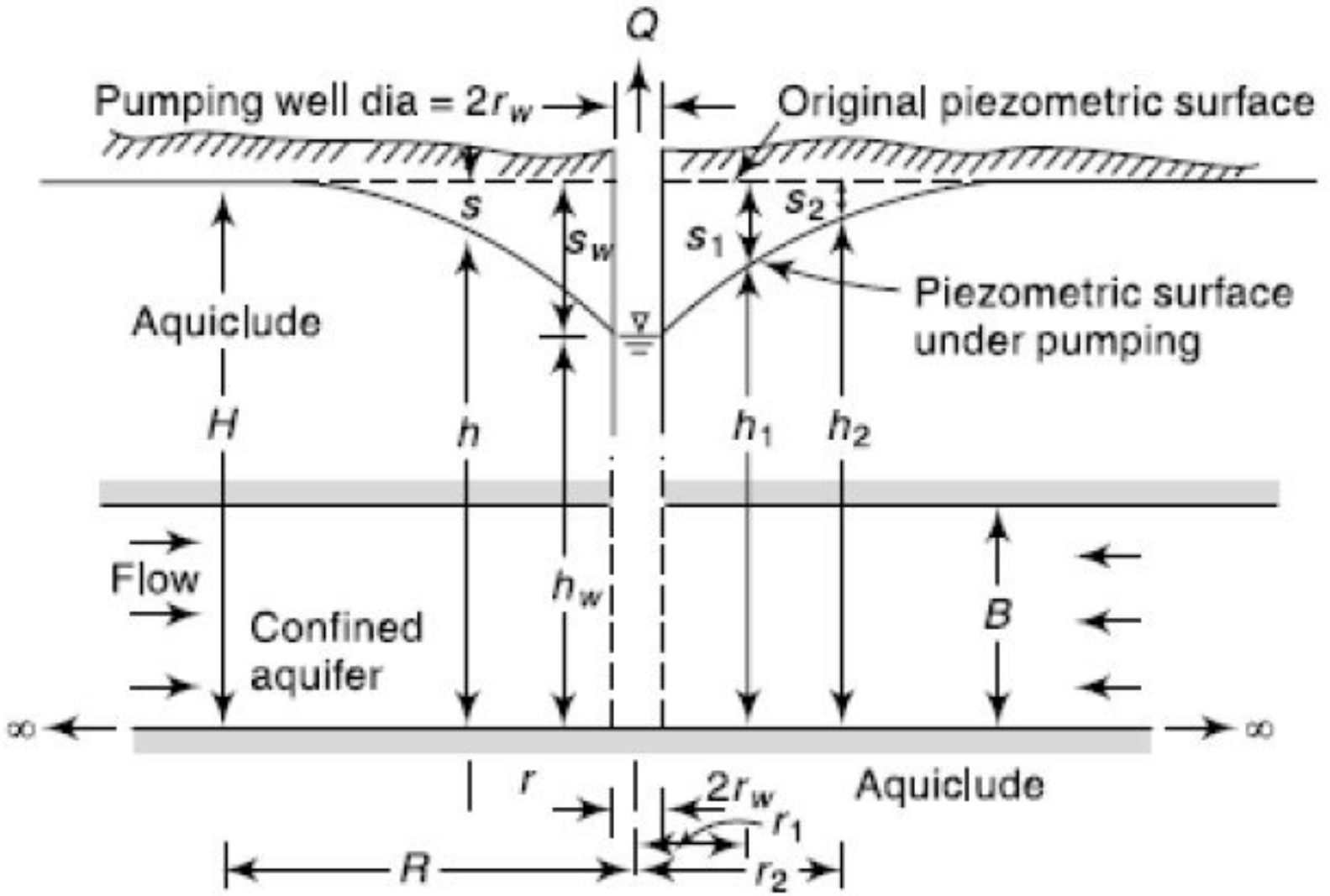
$$Q = \frac{\pi K(h_2^2 - h_1^2)}{ln\frac{r_2}{r_1}} = \frac{\pi K(38^2 - 36.5^2)}{ln\frac{75}{25}} = 0.025 \quad ; \quad K = 7.823 \times 10^{-5}\ m/s$$

$T = KH = 7.823 \times 10^{-5} \times 40 = 3.13 \times 10^{-2}\ m^2/s$

$$Q = \frac{\pi K(H^2 - h_w^2)}{ln\frac{R}{r_w}}$$

At the well,( $r_1 = r_w$; $h_1 = h_w$)

# Confined Steady Flow



# Confined Steady Flow

Figure shows a well completely penetrating a horizontal confined aquifer of thickness *B*. Consider the well to be discharging a steady flow, *Q*. The original piezometric head (static head) was H and the drawdown due to pumping is indicated in Fig The piezometric head at the pumping well is hw and the drawdown $s_w$.

At a radial distance r from the well, if h is the piezometric head, the velocity of flow by Darcy's law is:

$$V_r = K\left(\frac{dh}{dr}\right)$$

The cylindrical surface through which this velocity occurs is $2\pi$ r B . Hence by equating the discharge entering this surface to the well discharge, yields:

$$Q = V_r A_s = 2\pi r B\, K\left(\frac{dh}{dr}\right) \qquad or\ ; \qquad \frac{Q}{2\pi KB}\frac{dr}{r} = dh$$

Integrating between limits $r_1$ and $r_2$ with the corresponding piezometric heads being $h_1$ and $h_2$ , respectively,

$$\frac{Q}{2\pi KB}\ln\frac{r_2}{r_1} = (h_2 - h_1) \qquad or;$$

$$Q = \frac{2\pi KB(h_2 - h_1)}{\ln\frac{r_2}{r_1}}$$

**Example - 2**

A 100 mm diameter tubewell is sunk to withdraw water from a 10 m thick confined aquifer having coefficient of permeability equal to 0.75 lps/m². The depth of water below the piezometric level is 30 m and it falls 2 m in the tubewell while pumping. Calculate the discharge of the tubewell when the radius of the circle of influence is 30 m.

**Solution:** $$Q = \frac{2\pi Km(D-d)}{\log_e(\frac{R}{r})}$$

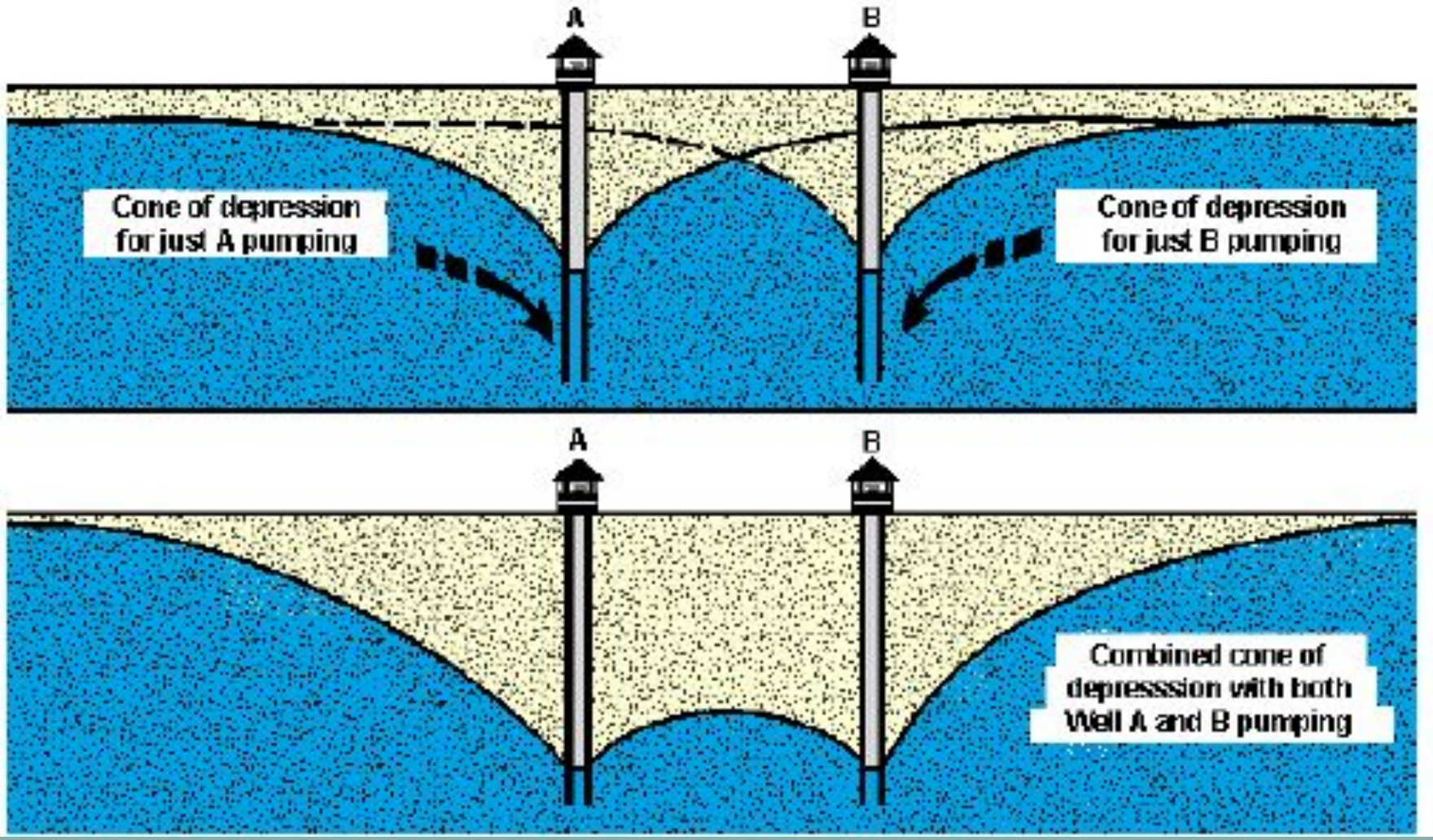
$K = 0.75$ lps/m²; $m = 10$m; $D = 30$m; $d = (30\text{-}2)$m $= 28$m; $R = 30$m; $r = 0.05$m

$Q = 2 \times 3.14 \times 0.75 \times 10\ (\ 30 - 28\ ) / (\ \log_e\ 30/0.05)$

$Q = 94.2 / 6.3969 = 14.73$ lps

A 150 mm diameter tubewell produces 100 lps with a drawdown of 3 m and a circle of influence of 120 m in diameter. The static depth of water in the well is 40 m. Calculate the coefficient of permeability of the aquifer in which the tubewell is sunk.

# Interference of Well



# Interference of Well

- Occurs when the pumping of one well lowers the water level in another nearby well, reducing the amount of water available to the affected well.
- Cones of depression between wells overlap.
- Tubewells should be spaced enough to avoid interference. Spacing of 250 to 500 ft is found to be satisfactory.
- Small diameter tubewells installed in fine sand will produce too little drawdown to cause interference.

# Interference of Well

For two similar wells drawing water from the same aquifer situated at w ft apart, their rate of discharge shall be

$$Q_1 = Q_2 = \frac{\pi K (D^2 - d^2)}{log_e \left(\frac{R^2}{rw}\right)}$$

# Interference of Well

**Example:** At what rate could water be pumped from the two wells 24 inch diameter each, static depth of water 200 ft and drawdown 30ft, if both wells were being pumped together at a distance of 24ft?

Assume: R=1025ft, K=0.099 gpm/sft.

Solution: from the equation above

Given, D=200ft, d=200-30=170ft, r=1ft, w=24 ft

So, $Q_1 = Q_2 = \frac{\pi(0.099)(200^2-170^2)}{log_e\left(\frac{1025^2}{1x24}\right)}$=323 gpm

Combined rate of flow from two wells=2x323=646 gpm.