ENGINEERING HYDROLOGY

Prof. Rajesh Bhagat
Asst. Professor
Civil Engineering Department
Yeshwantrao Chavan College Of Engineering
Nagpur

B. E. (Civil Engg.)
GCOE, Amravati

M. Tech. (Enviro. Engg.)
VNIT, Nagpur

Mobile No.:- 8483003474 / 8483002277
Email ID:- rajeysh7bhagat@gmail.com
Website: www.rajeysh7bhagat.wordpress.com

UNIT-V

Geohydrology:

1) Introduction, occurrence and distribution of groundwater, aquifers, specific yield, specific retention, porosity, permeability, water table, types and properties of aquifer, Darcy's law.
2) Introduction to hydraulics of wells, Open wells safe yield test, Pumping Tests.
3) Groundwater quality, geomorphic and geological control on ground storage and movement.

Basin Hydrologic Cycle

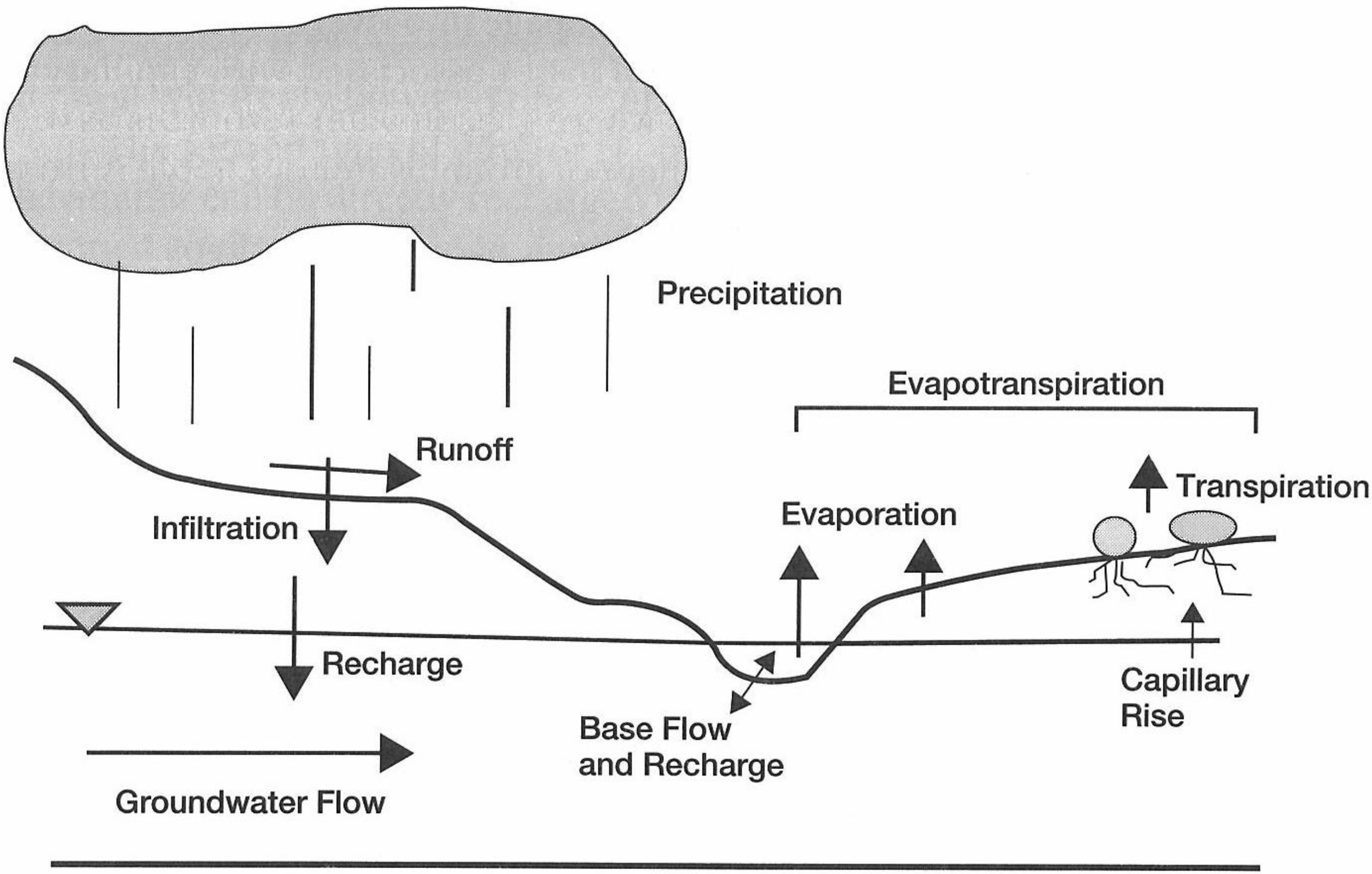
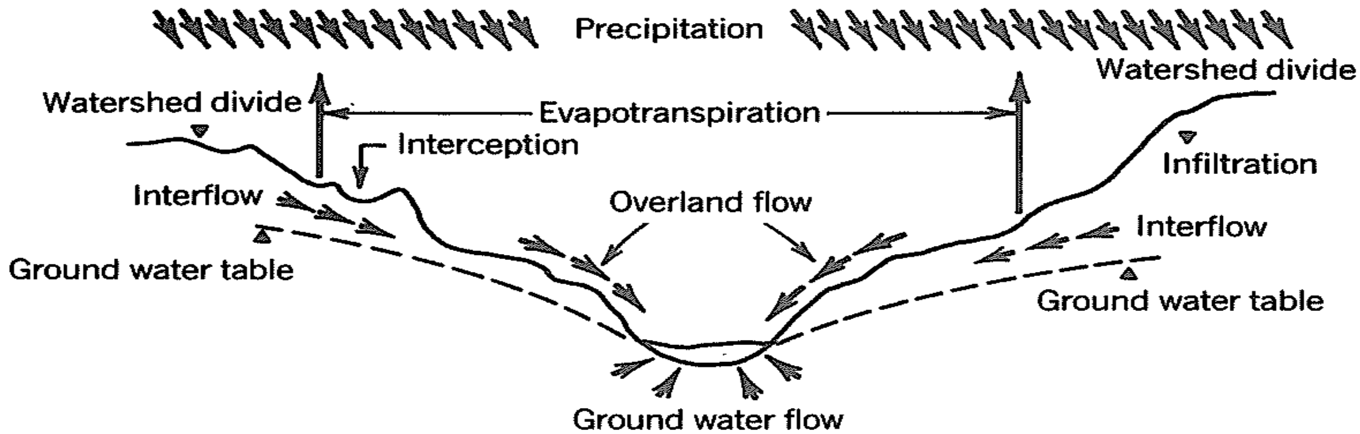
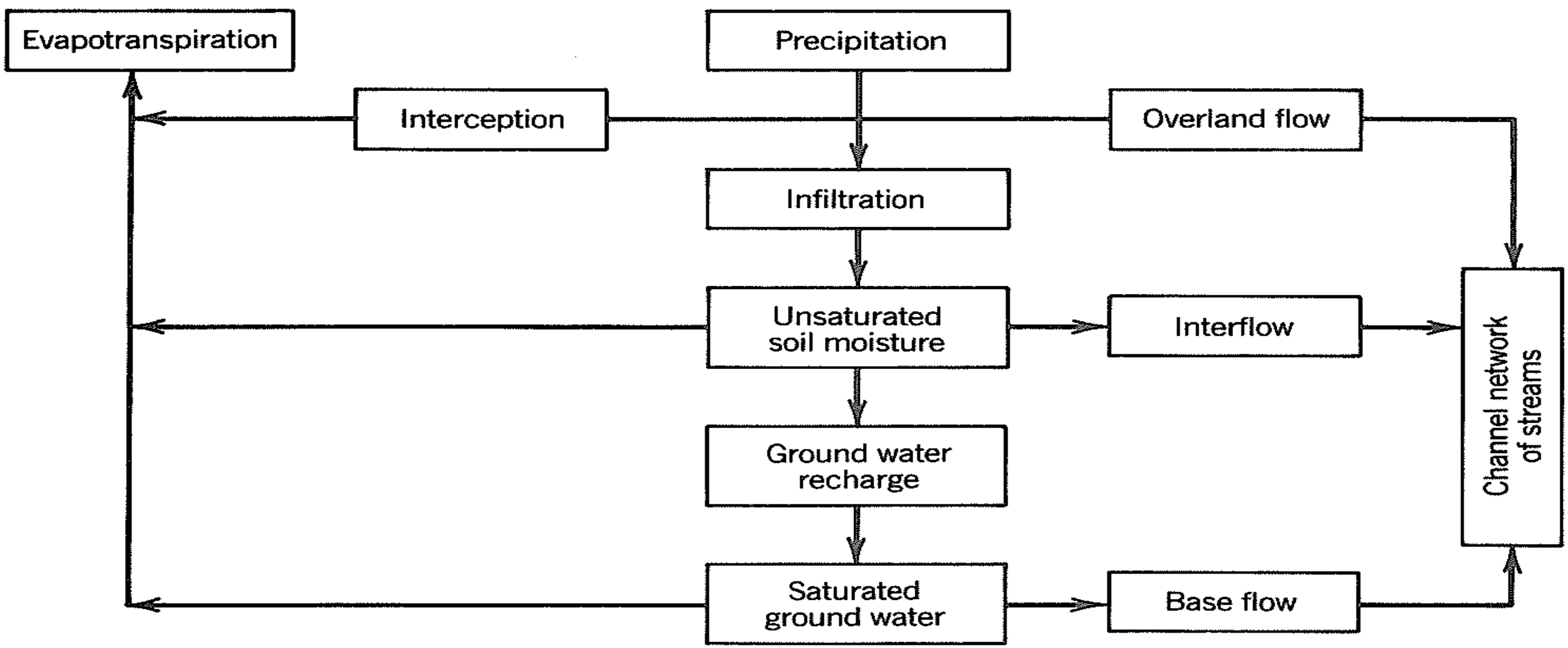


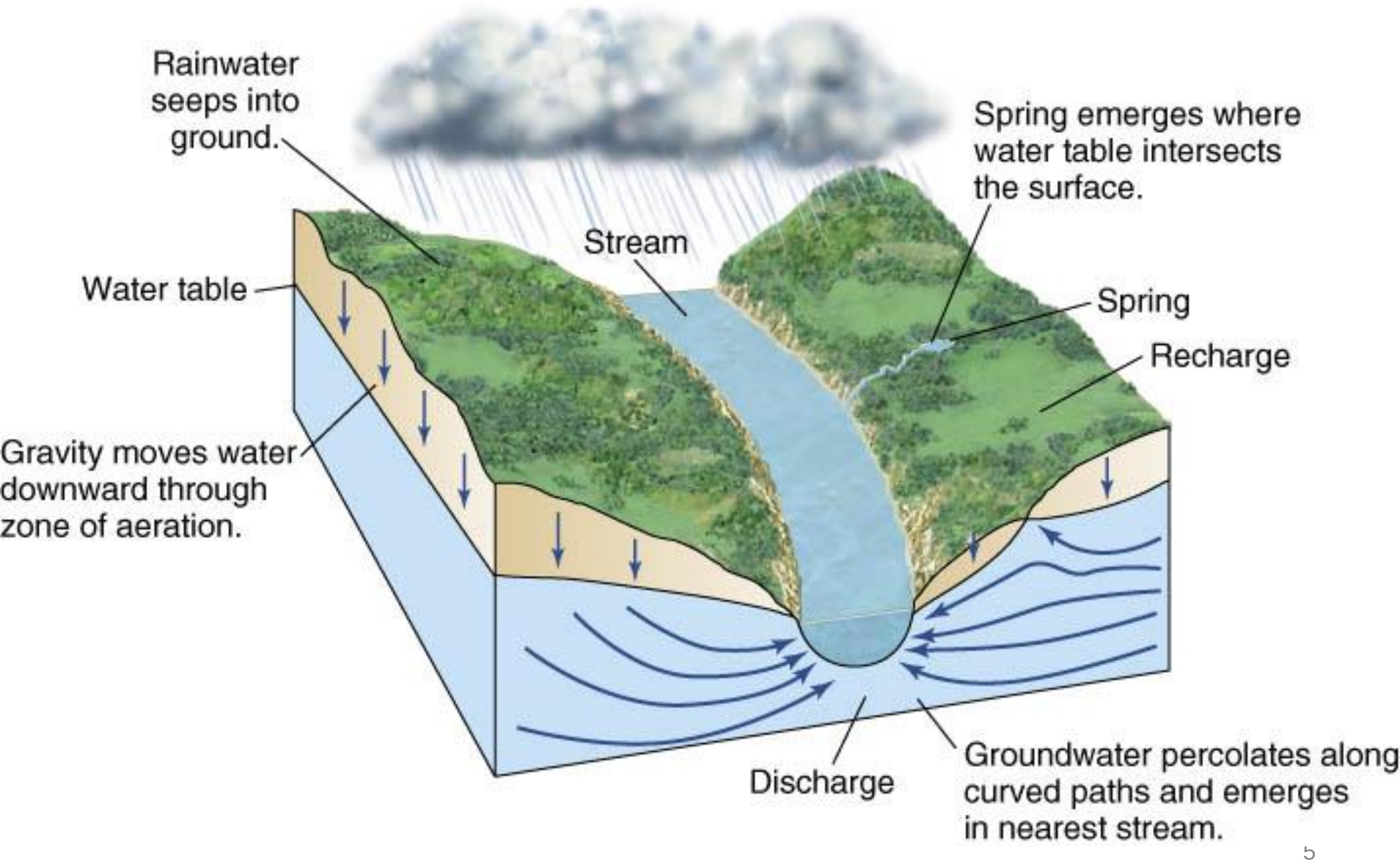
FIGURE 1.4.1 Schematic view of the hydrologic cycle


Precipitation
Watershed divide
Watershed divide
Evapotranspiration
Interception
Infiltration
Interflow
Overland flow
Interflow
Ground water table
Ground water table
Ground water flow

(a)


Evapotranspiration
Precipitation
Interception
Overland flow
Infiltration
Unsaturated soil moisture
Interflow
Channel network of streams
Ground water recharge
Saturated ground water
Base flow

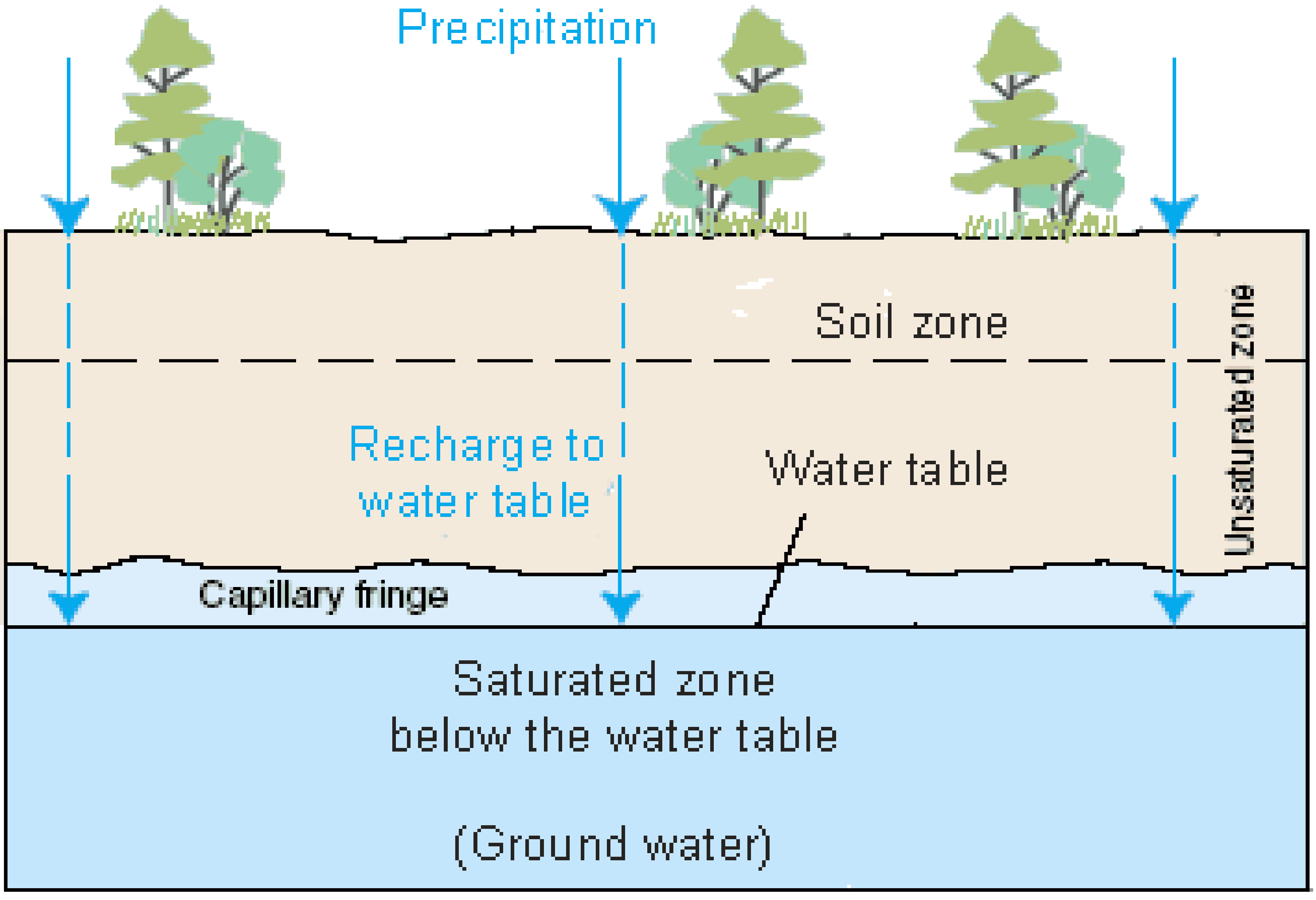
Ground water Surface water Interaction



Ground water:

1) The water that lies beneath the ground surface, filling the pore space between grains in bodies of sediment and sedimentary rock, and filling cracks and crevices in all types of rock.

2) Ground water is rain and snow which percolates down into the ground.


Precipitation
Soil zone
Unsaturated zone
Recharge to water table
Water table
Capillary fringe
Saturated zone
below the water table
(Ground water)

Distribution of Sub-surface Water :

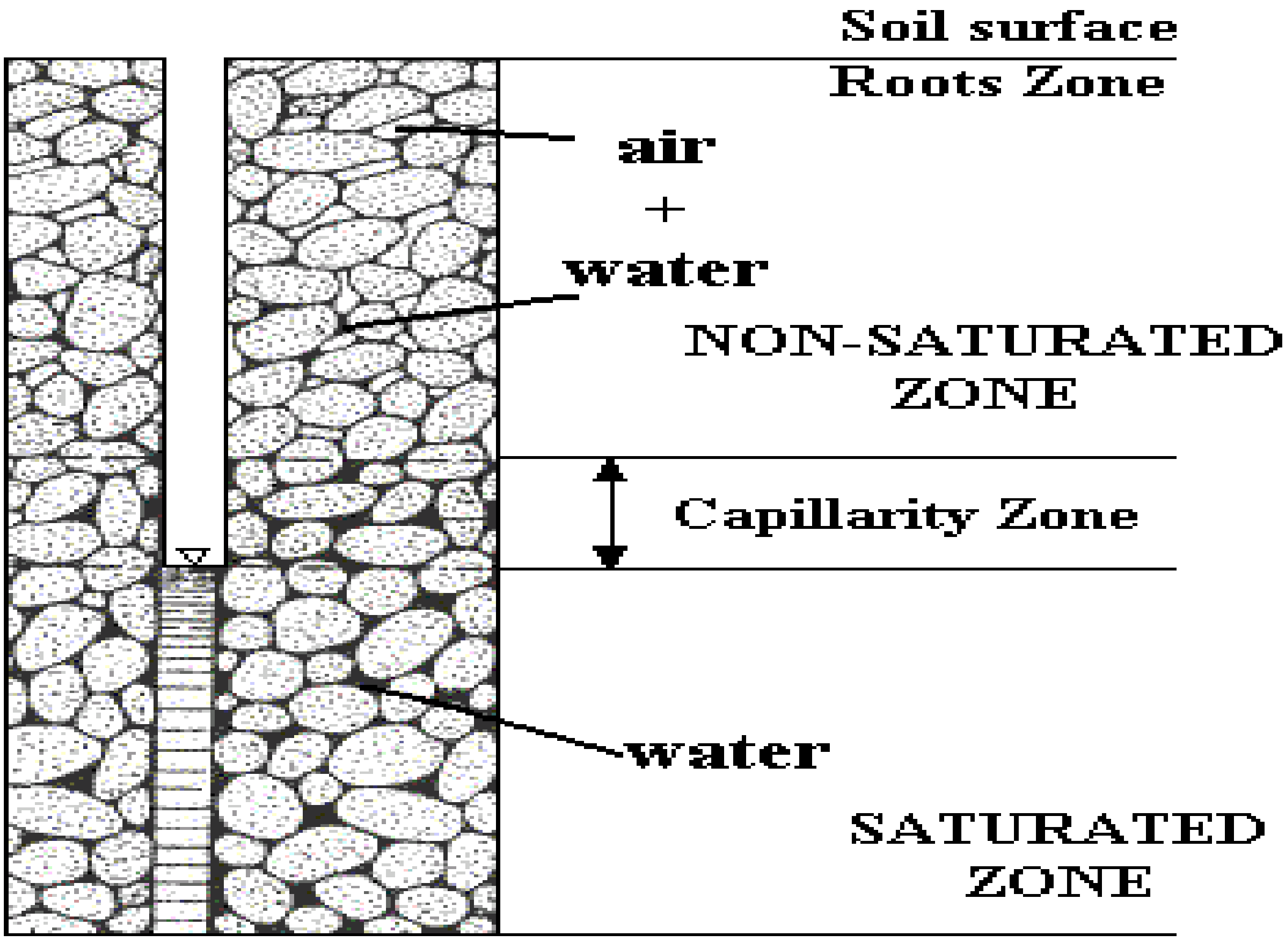
1) Sub-surface water (i.e. all forms of ground water) can be broadly classified as:

    1) The portion in unsaturated zone (Aeration Zone)
    2) The portion in saturated zone (Ground water zone)

- Region above ground water table is called as the unsaturated zone & it comprises of three sub-surface zones:

    1) Soil water zone (Root zone depth)
    2) Intermediate zone
    3) Capillary zone

- **Soil water zone:** zone of soil through which water can be taken by roots of plants is called root zone depth. It also called soil moisture belt. This zone remains unsaturated except during period of heavy infiltration.



Soil surface
Roots Zone
air
+
water
NON-SATURATED
ZONE
Capillarity Zone
water
SATURATED
ZONE

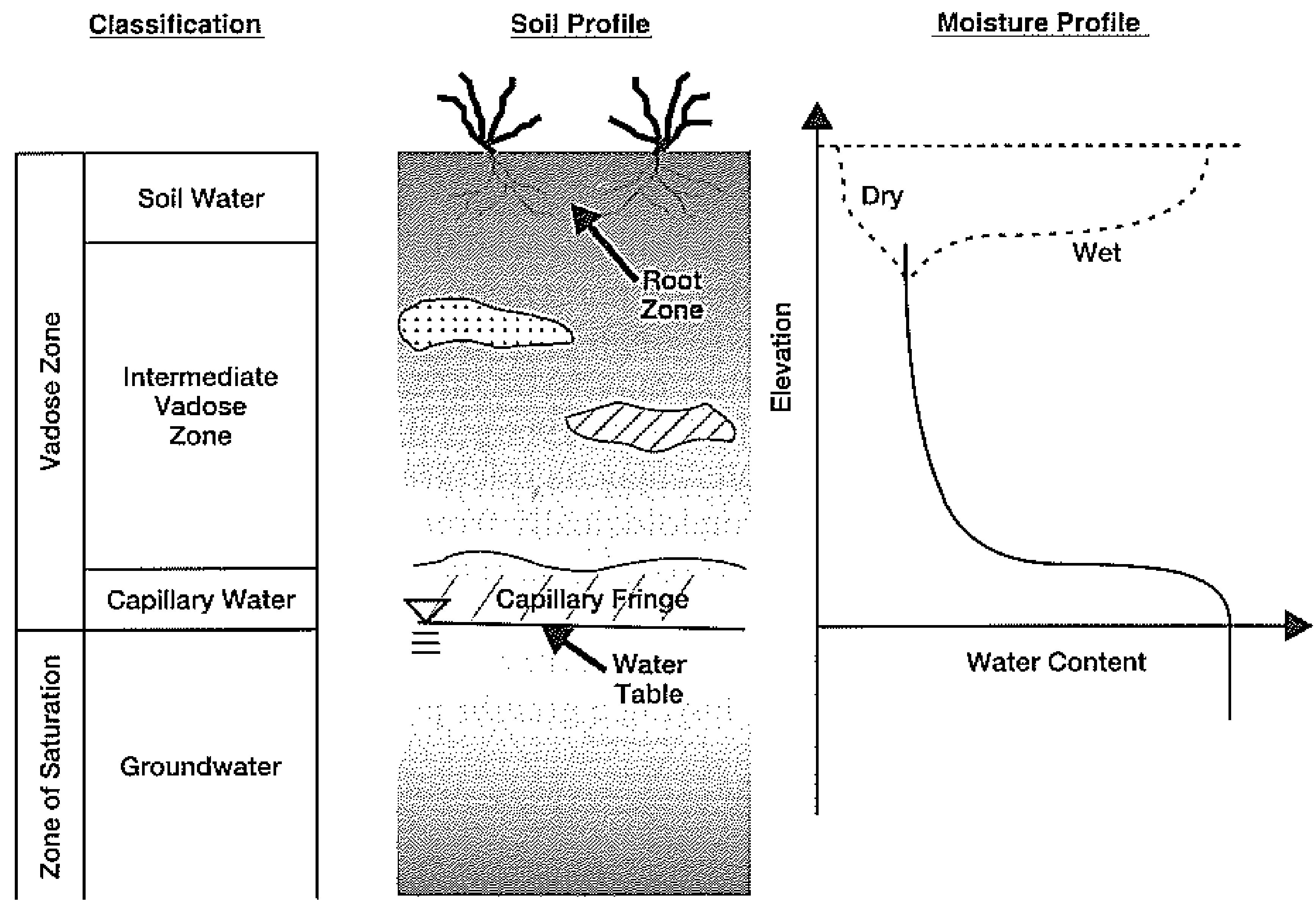
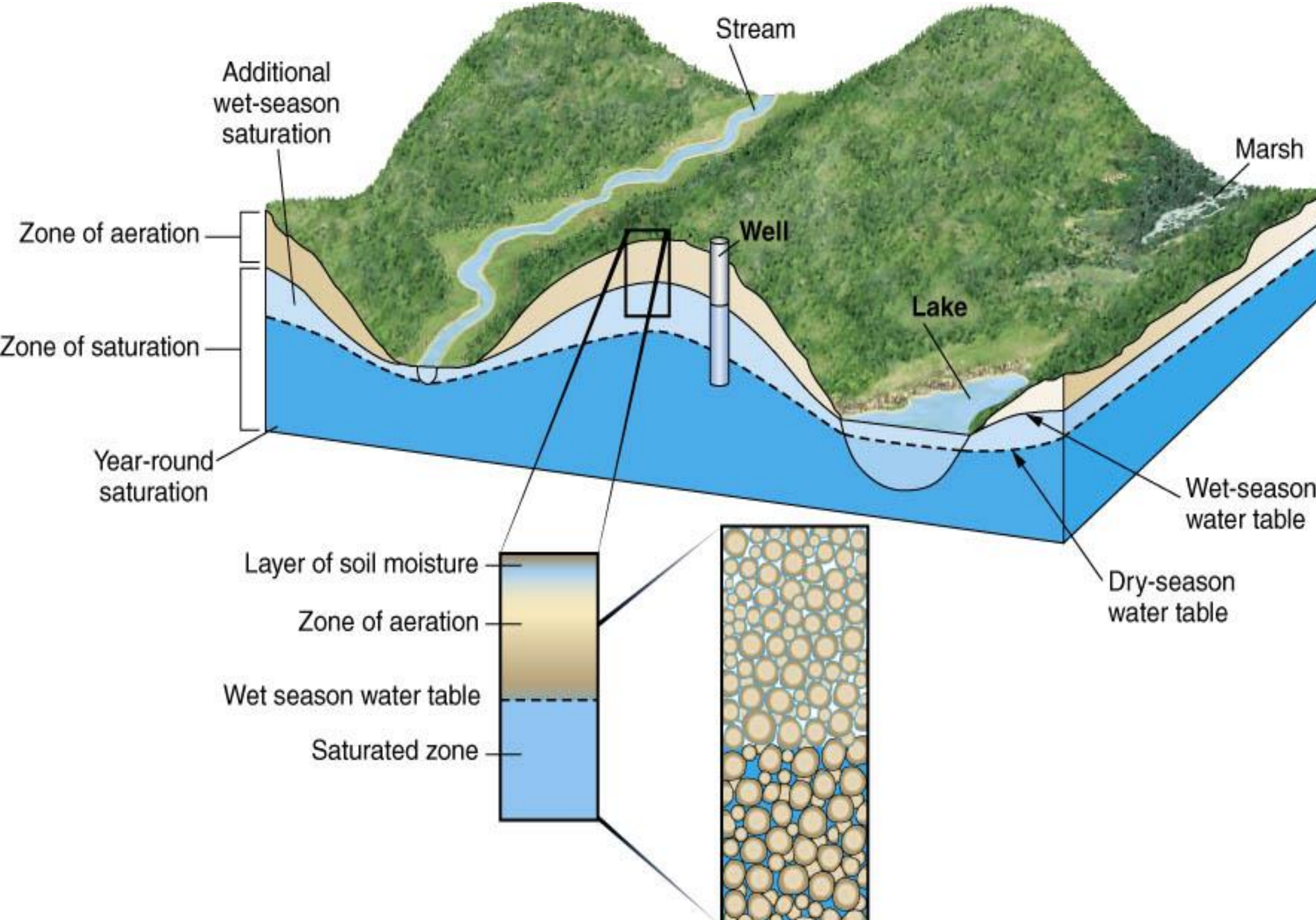


FIGURE 1.2.1 Vertical distribution of water content and classification system


Stream
Additional wet-season saturation
Marsh
Zone of aeration
Well
Lake
Zone of saturation
Year-round saturation
Wet-season water table
Dry-season water table
Layer of soil moisture
Zone of aeration
Wet season water table
Saturated zone

Distribution of Sub-surface Water :

1) Sub-surface water (i.e. all forms of ground water) can be broadly classified as:
   1) The portion in unsaturated zone (Aeration Zone)
   2) The portion in saturated zone (Ground water zone)

- The unsaturated zone comprises of three sub-surface zones:
  1) Soil water zone (Root zone depth)
  2) Intermediate zone
  3) Capillary zone

- **Intermediate zone:** It extends from bottom of soil water zone to top of capillary fringe. It greatly varies in thickness from no thickness to several hundred meters. All infiltration water must pass through this region.

Distribution of Sub-surface Water :

1) Sub-surface water (i.e. all forms of ground water) can be broadly classified as:

   1) The portion in unsaturated zone (Aeration Zone)
   2) The portion in saturated zone (Ground water zone)

- The unsaturated zone comprises of three sub-surface zones:

   1) Soil water zone (Root zone depth)
   2) Intermediate zone
   3) Capillary zone

- **Capillary zone:** It is the zone of soil commencing from the top of water table.

  Capillary rise depends on the size of pores.

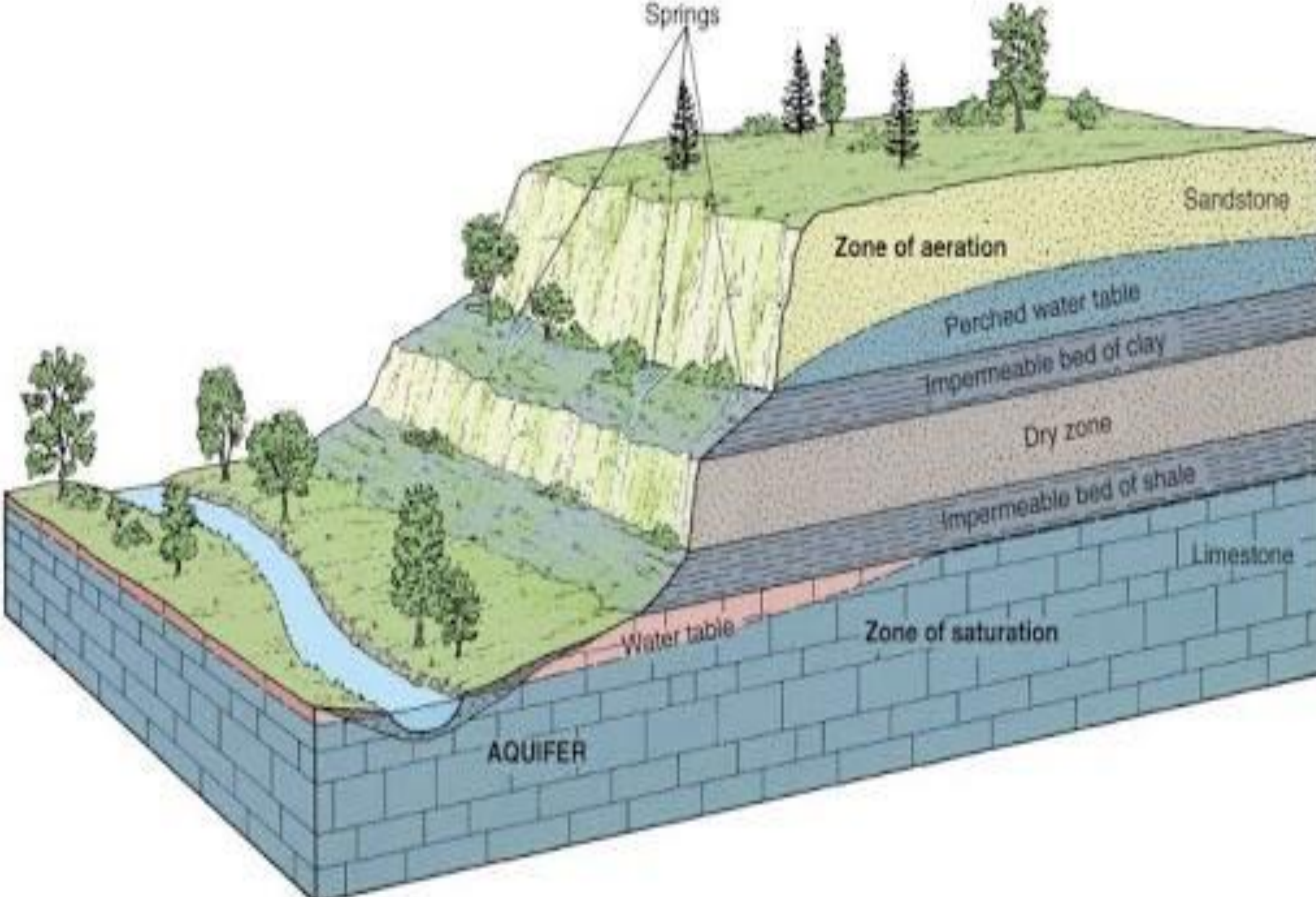
Distribution of Sub-surface Water :

1) Sub-surface water (i.e. all forms of ground water)
2) can be broadly classified as:
    1) The portion in unsaturated zone (Aeration Zone)
    2) The portion in saturated zone (Ground water zone)

- **Saturated Zone:**
- In this zone, ground water fill the pores completely.
- The atmospheric pressure assumed to be exist at the water table
- The Saturated zone comprises of four categories:
    1) Aquifer
    2) Aquitard
    3) Aquiclude
    4) Aquifuge

Aquifer:

- A geological unit which can store and supply significant quantities of water.
- It is a saturated formation of earth material which not only stores the water but yields it in sufficient quantity relatively easily due to its high permeability.
- Deposits of sands and gravel form good aquifers.


Springs
Sandstone
Zone of aeration
Perched water table
Impermeable bed of clay
Dry zone
Impermeable bed of shale
Limestone
Water table
Zone of saturation
AQUIFER

Aquitard:

- It is a formation through which only seepage is possible and thus the yield is insignificant compared to aquifer.
- A sandy layer is example of aquitard.

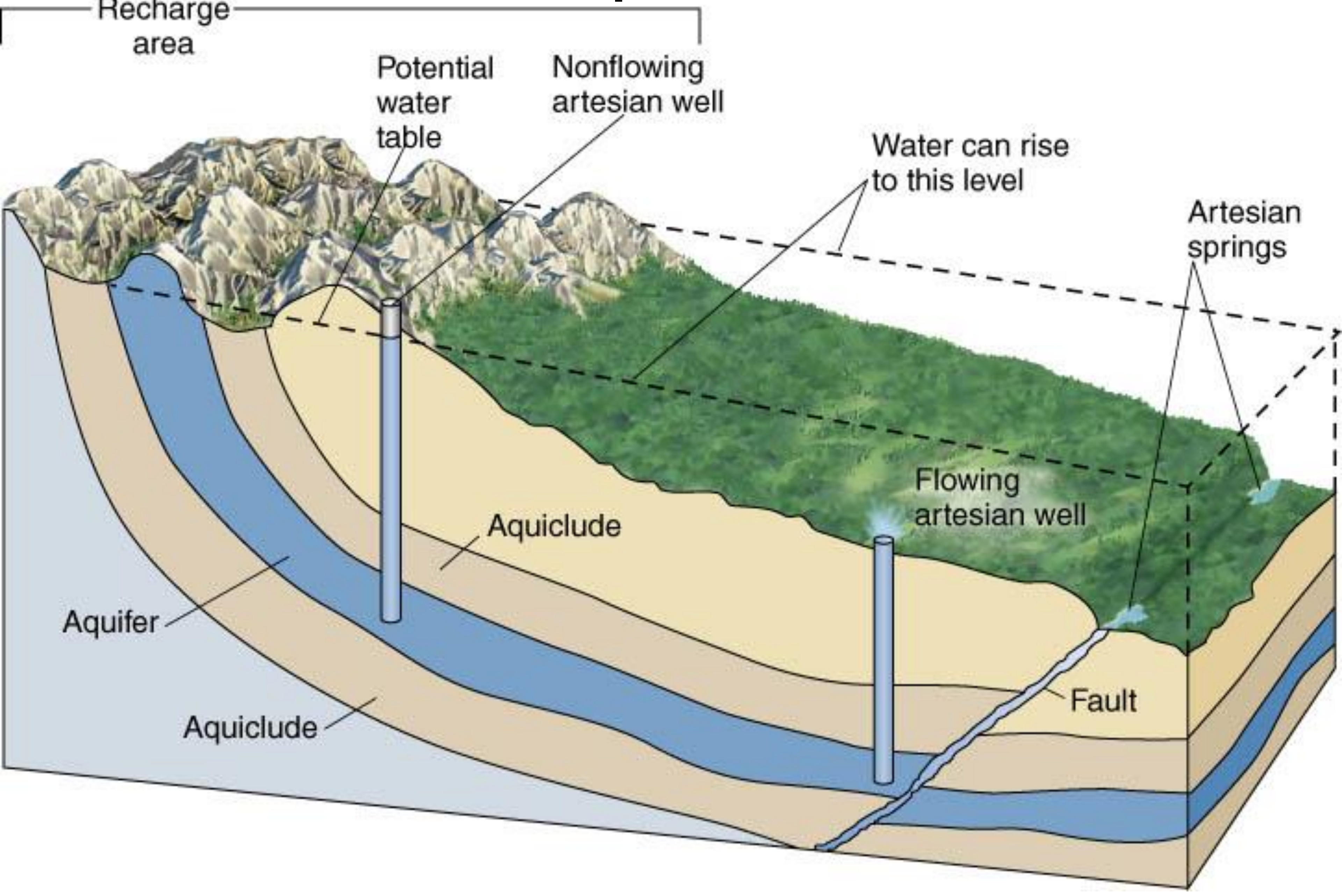
Aquiclude:

- Formation like clay which is highly porous but not permeable due to very small size of pores.
- A clay layer is example of aquiclude.

Aquifuge:

- It is geological formation which is neither porous nor permeable.
- Massive compact rock without any fractures.
- A rock layer.

Other Aquifer Features



Aquifer:

- A geological unit which can store and supply significant quantities of water.
- It is a saturated formation of earth material which not only stores the water but yields it in sufficient quantity relatively easily due to its high permeability.
- Deposits of sands and gravel form good aquifers.

- **Types of Aquifer:**

1) Unconfined Aquifer
2) Confined Aquifer

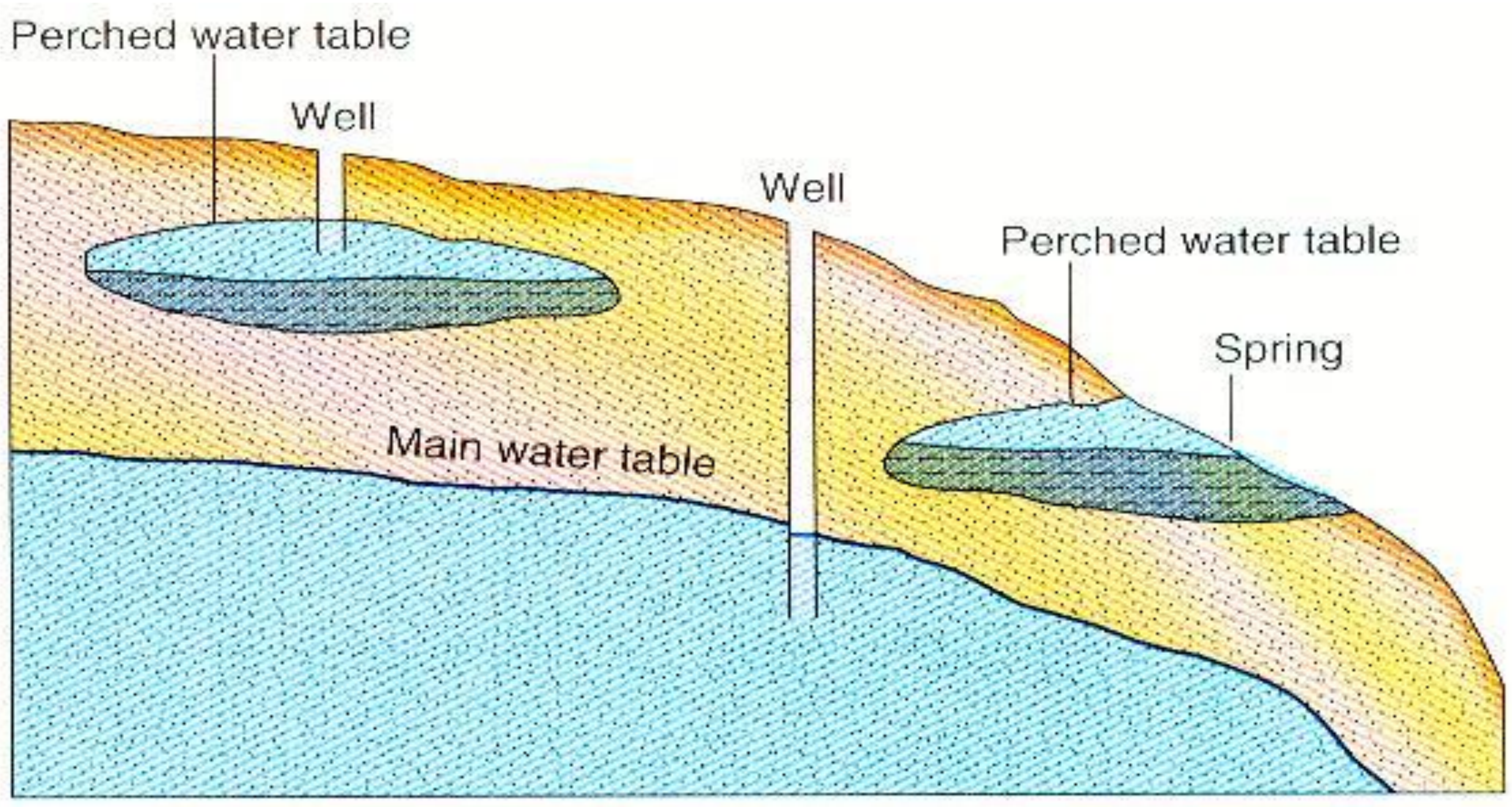
Types of Aquifer:

1) Unconfined Aquifer:-

- The aquifer which has no containment from the top is called as unconfined aquifer.
- Water level of unconfined aqufier changes by addition or depletion of water.
- The water level in a large diameter dug wells tapping unconfined aquifer represents water table.
- This aquifer is also known as water table aquifer or phreatic aquifer.

- A special case of unconfined aquifer is known as **perched aquifer.** A perched aquifer is formed when the infiltrated rain water is intercepted within the zone of aeration by an impermeable layer and local zone of saturation is formed.

- Perched water table: The top of a body of ground water separated from the main water table beneath it by a zone that is not saturated



Horizontal and Vertical Head Gradients

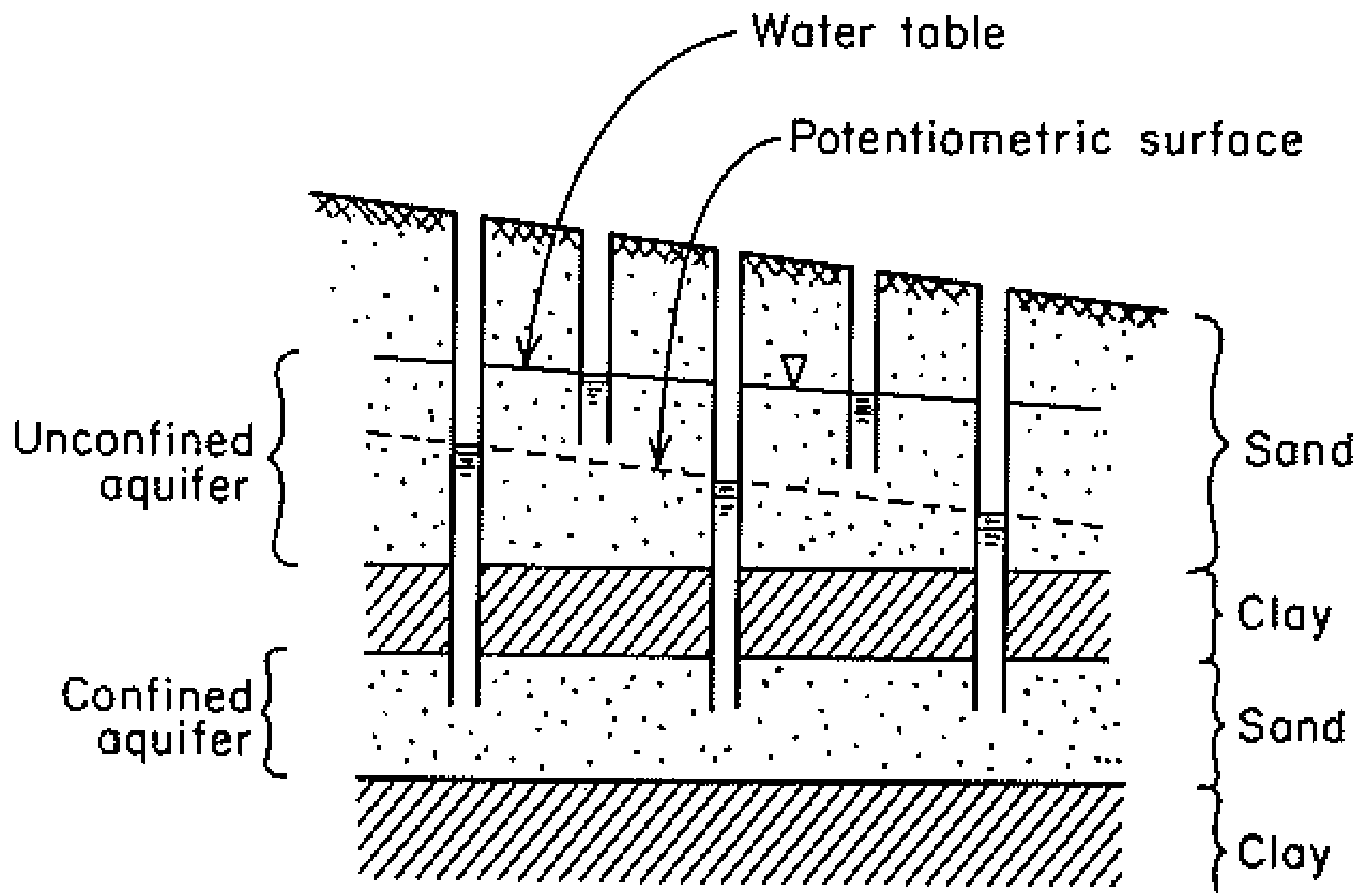


Figure 2.16 Unconfined aquifer and its water table; confined aquifer and its potentiometric surface.

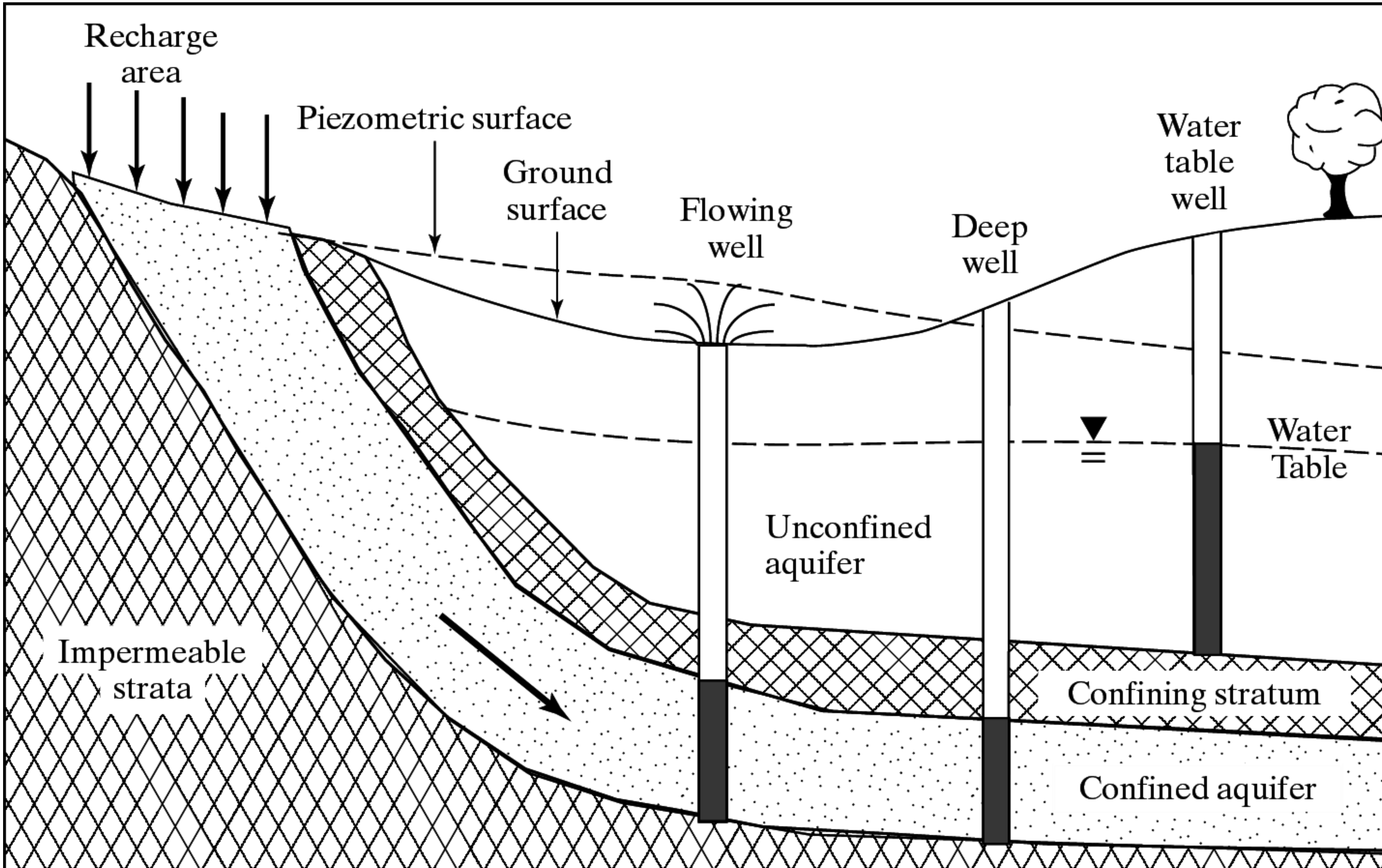
Freeze and Cherry, 1979.

Types of Aquifer:

1) Confined Aquifer:-

- The confined aquifer is also called artesian aquifer.
- It is the one which is overlain and underlain by a impermeable layers or aquiclude.
- Unlike the unconfined aquifer, the water in the confined aquifer is not in direct contact with the atmosphere.
- Water within confined aquifer occurs under pressure greater than atmospheric pressure.
- The level up-to which water will rise in well is kwon as potentiometric level.

Example Layered Aquifer System



Bedient et al., 1999.

Aquifer Properties:

- **A aquifer perform two functions:**

1) Storage of water.
2) Transmission of stored water.

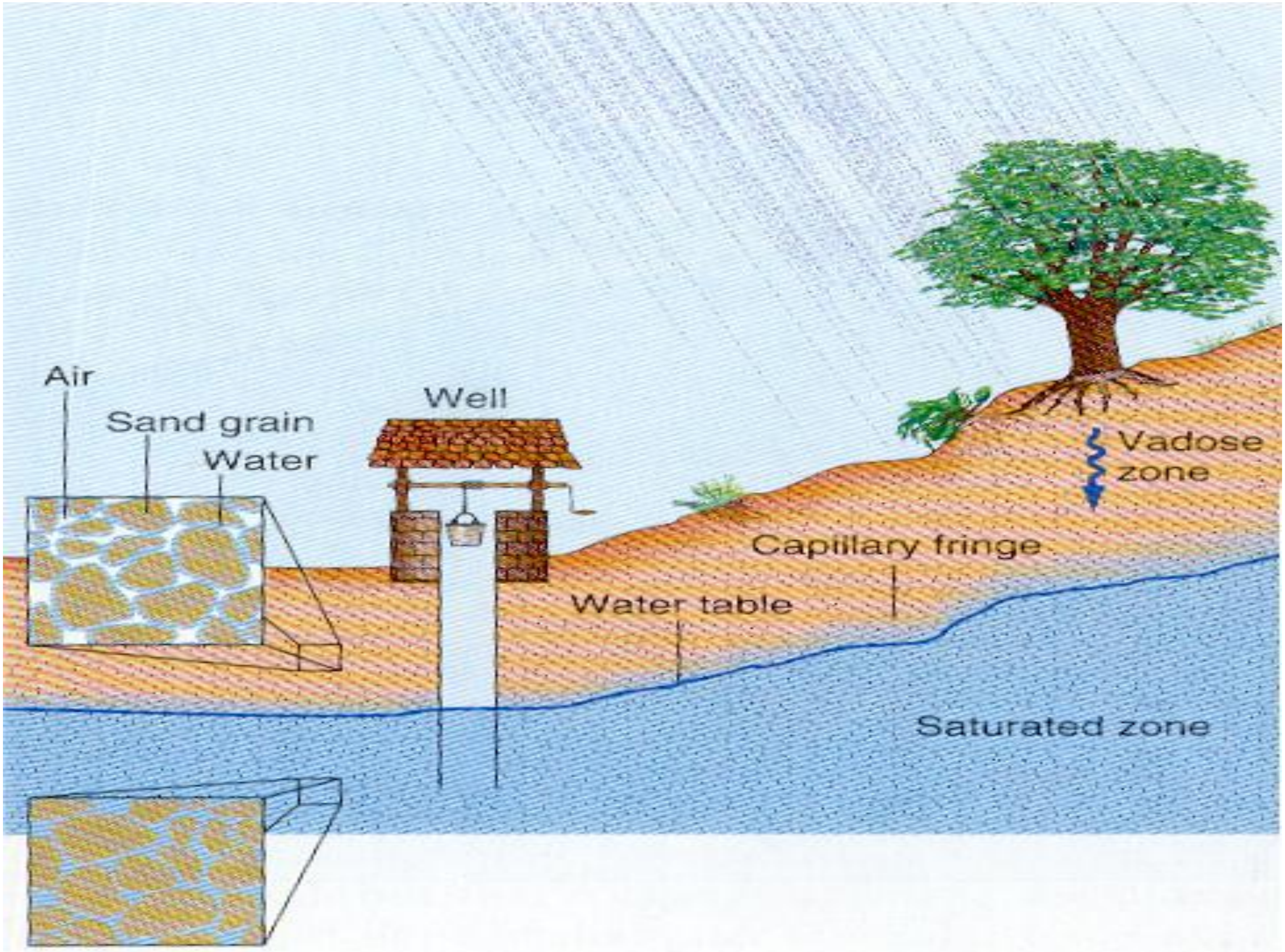
- The porosity and hydraulic conductivity (permeability) explain the storage & transport of water.

- Porous: that holds much water.
- Permeable: that allows water to flow easily through it.
- Impermeable: that does not allow water to flow through it easily.

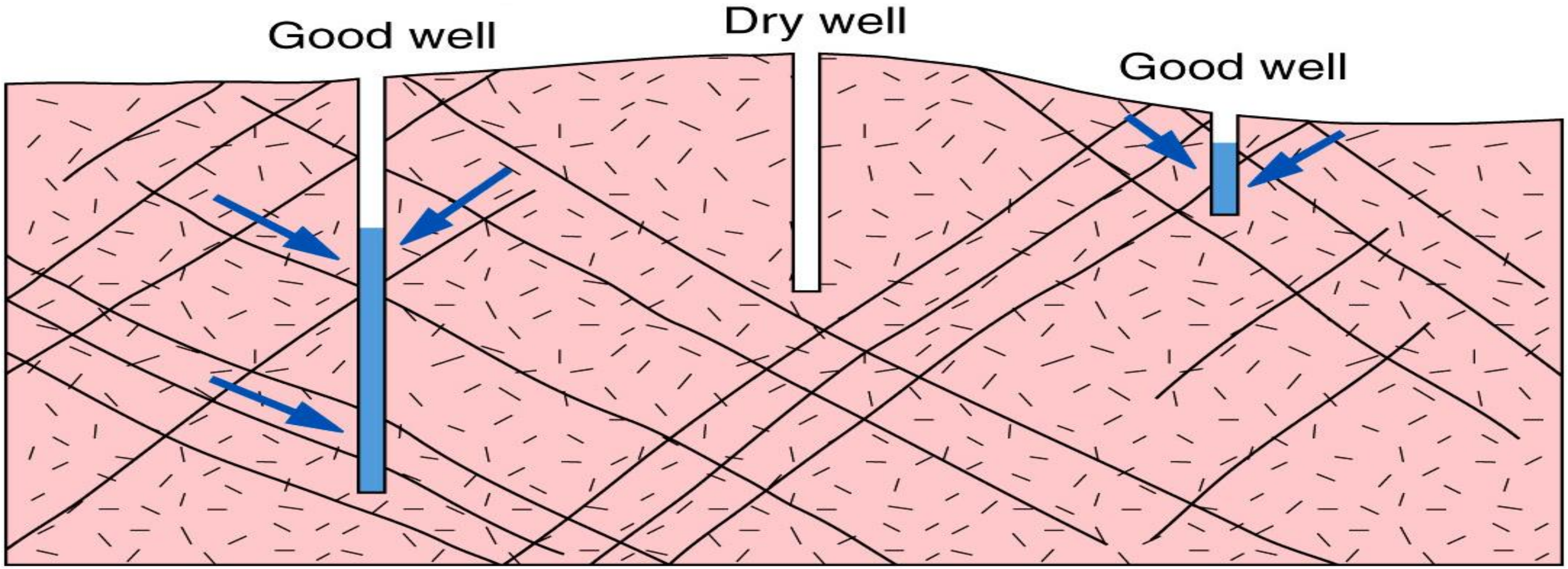
1) Porosity:

- The amount of pore space per unit volume of aquifer material is called porosity. (30 to 60 %)
- n = (Vv / Vo) = Volume of voids / volume of porous medium.
- It represents water storage.
- The percentage of rock or sediment that consists of voids or openings.

- **Specific yield:** the actual volume of water that can be extracted or drained under gravity per unit volume of soil mass is called specific yield.
- **Specific Retention:** volume of water that can not be drained under force of gravity and which are strongly bonded with soil particles is called specific retention or field capacity.
- $n = S_y + S_r$


Air
Sand grain
Water
Well
Vadose
zone
Capillary fringe
Water table
Saturated zone

2) **Permeability:** The capacity of a rock or soil to transmit a fluid such as water or petroleum through pores and fractures.



Hydraulic Conductivity of bedrock is controlled by:

–Size of fracture openings

–Spacing of fractures

–Interconnection of fractures.

1) **When 3.68 million m^3 of water was pumped out from an unconfined aquifer of 6.2 km^2 area extent, the water table was observed to go down by 2.6 m what is the specific yield of the aquifer? During a monsoon season if water table of the same aquifer goes up by 10.8m what is the volume of recharge?**

Water released from the aquifer = (area extent) x (water table go down) x (Sy)

= (6.2 x 1000000) x 2.6 x Sy

Water pumped out = 3.68 x 1000000 m3

Equating these two quantities:

(6.2 x 1000000) x 2.6 x **Sy** = 3.68 x 1000000

Sy = (3.68) / (6.2 x 2.6) = 0.2283

Specific yield of the aquifer = 0.2283 or 22.83 %

Volume of recharge = (area extent) x (water table goes up) x (Sy)

= 6.2 x 1000000 x 10.8 x 0.2283

= 15.287 million m3

2) In a certain alluvial basin of 100 km^2, 90 Million m^3 of ground water was pumped in a year and the ground water table dropped by about 5 m during the year. Assuming no replenishment, estimates the specific yield of the aquifer. If the specific retention is 12%, what is the porosity of the soil?

Water released from the aquifer = (area extent) x (water table dropped by) x (Sy)

= (100 x 1000000) x 5 x Sy

Water pumped out = 90 x 1000000 m3

Equating these two quantities:

(100 x 1000000) x 5 x **Sy** = 90 x 1000000

Sy = (90) / (100 x 5) = 0.18

Specific yield of the aquifer = 18 %

Porosity, n = Sy + Sr

n = 0.18 + 0.12

n = 0.30 or 30 %

Darcy's law:-

V = K x i

Q = K x i x A

Where, V = velocity of seepage

Q = Discharge

K = Coefficient of permeability

A = cross sectional area of porous media

i = hydraulic gradient

Darcy's law is valid for laminar flow only when Re < 1

Re = (V x Da) / v

Ground-Water Flow

Depends upon

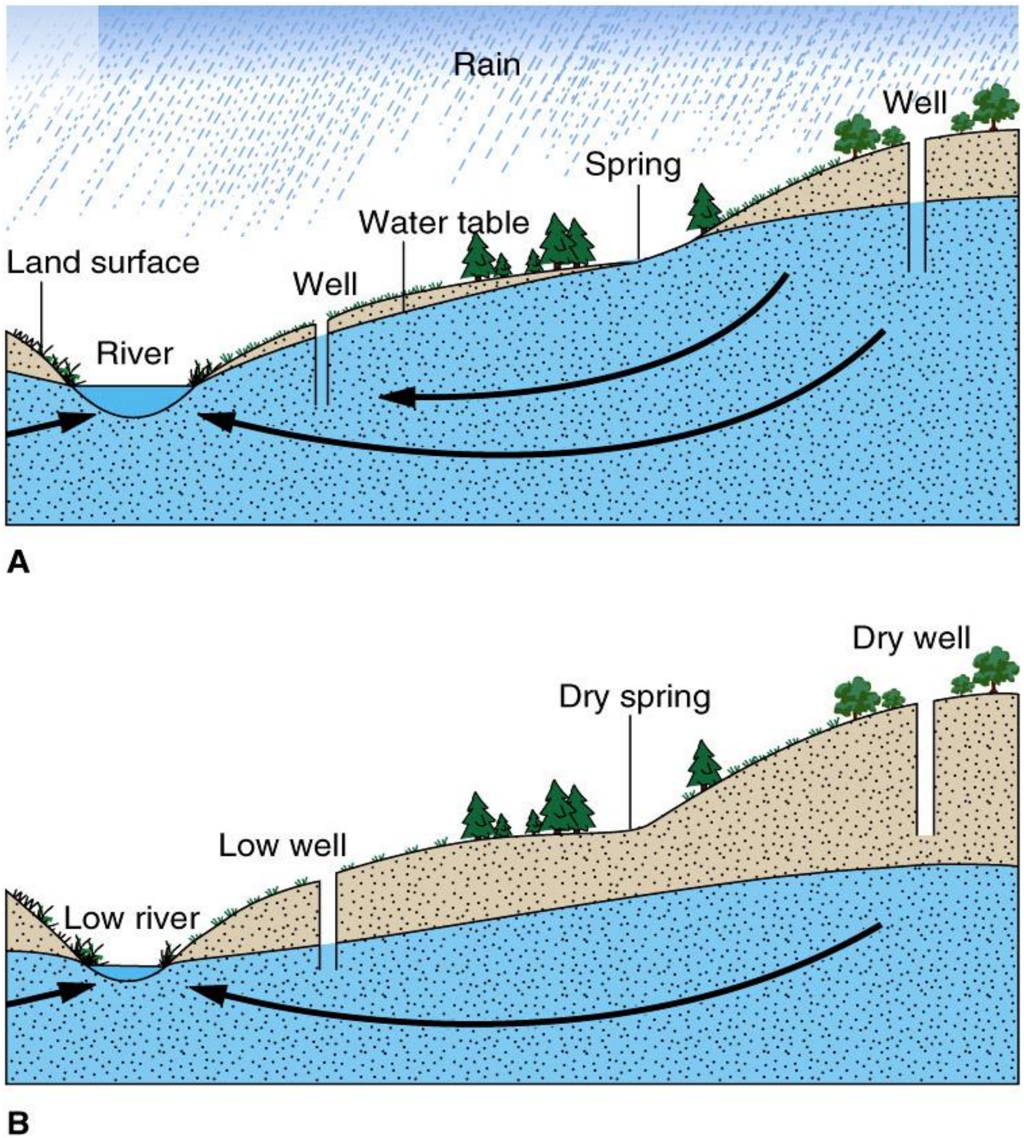
Precipitation

Infiltration

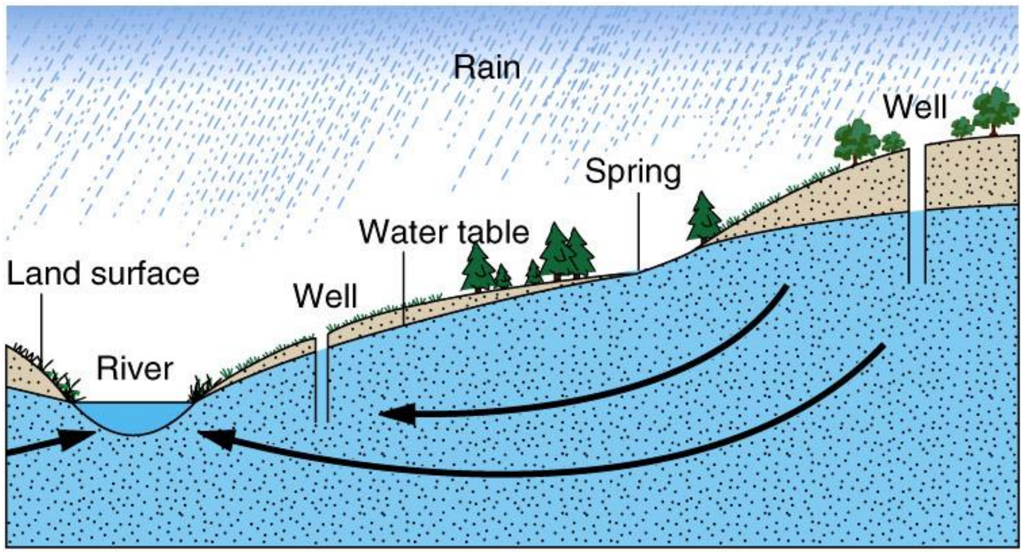
Ground-water recharge

Ground-water discharge to

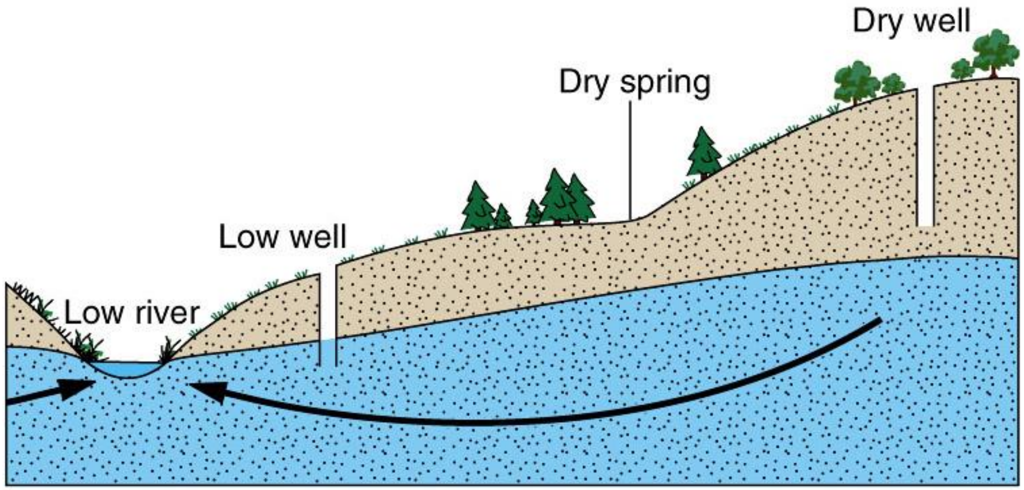
- Springs
- Streams and
- Wells



- Velocity is proportional to
  - –Permeability
  - –Slope of the water table

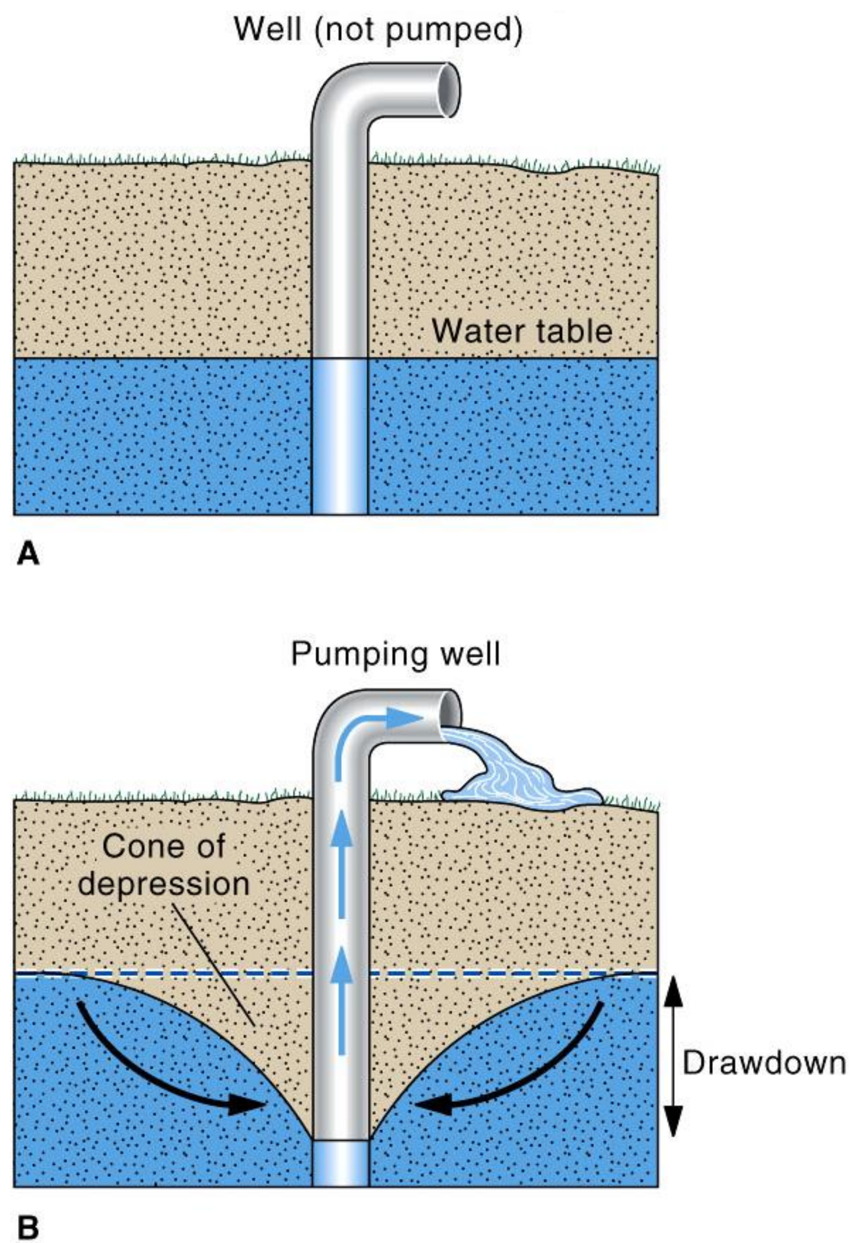


A



B

- **Effects of Pumping wells:-**
  1) Accelerates flow near well
  2) May reverse ground-water flow
  3) Causes water table drawdown
  4) Forms a cone of depression
  5) May dry up springs. Wetlands, river and wells



Wells:

- Wells form the most important mode of groundwater extraction from an aquifer.
- Wells are used in a number of different applications, they find extensive use in water supply & irrigation engg.
- Lowering of water table takes place on pumping in well.
- Due to radial flow into the well through the aquifer, the water table assumes a conical shape called cone of depression.
- The drop in water table elevation at any point from its previous static level is called drawdown.
- Areal extent of cone of depression is called area of influence and its radial extent is called radius of influence.

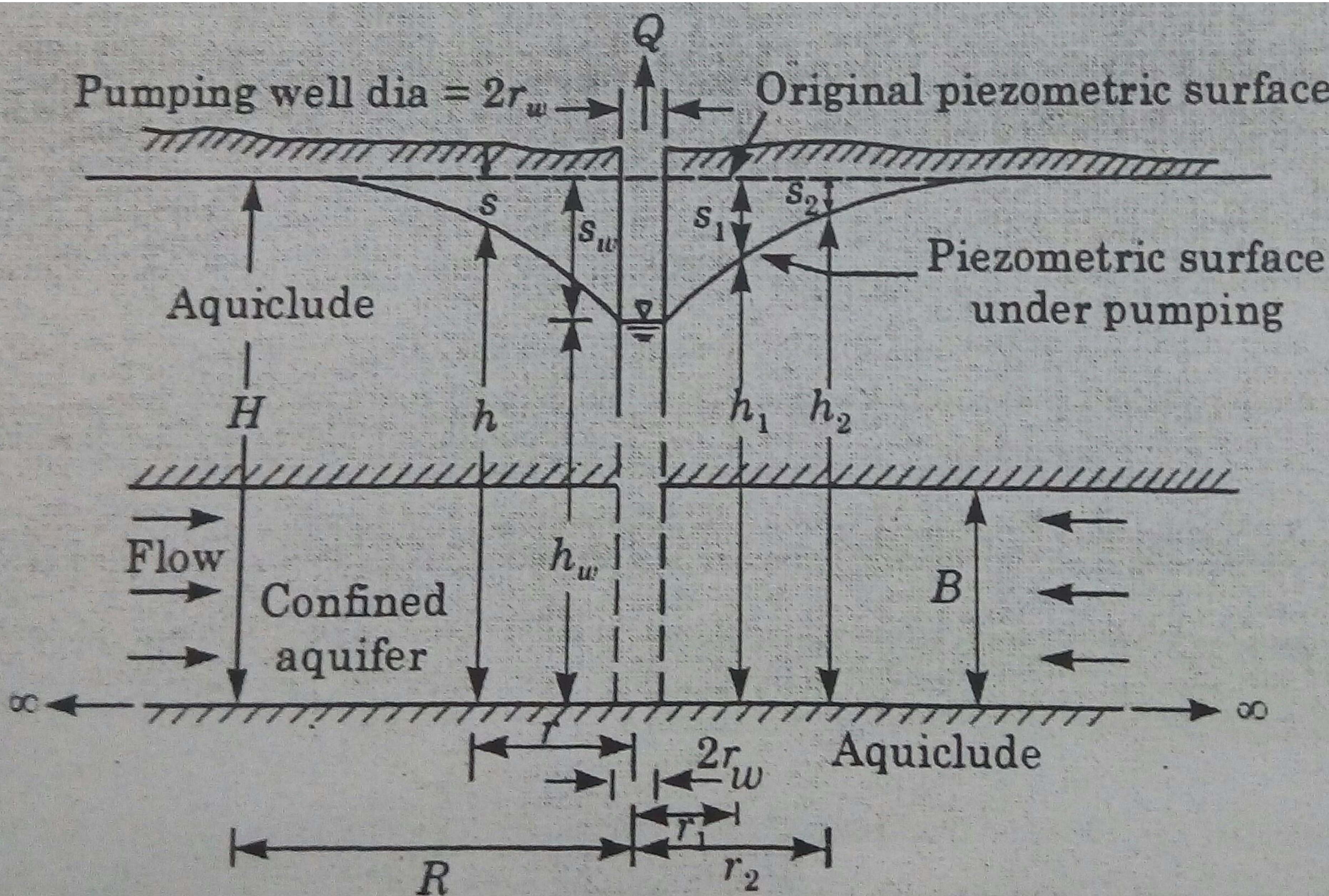


Fig. 9.14: Well operating in an confined aquifer.

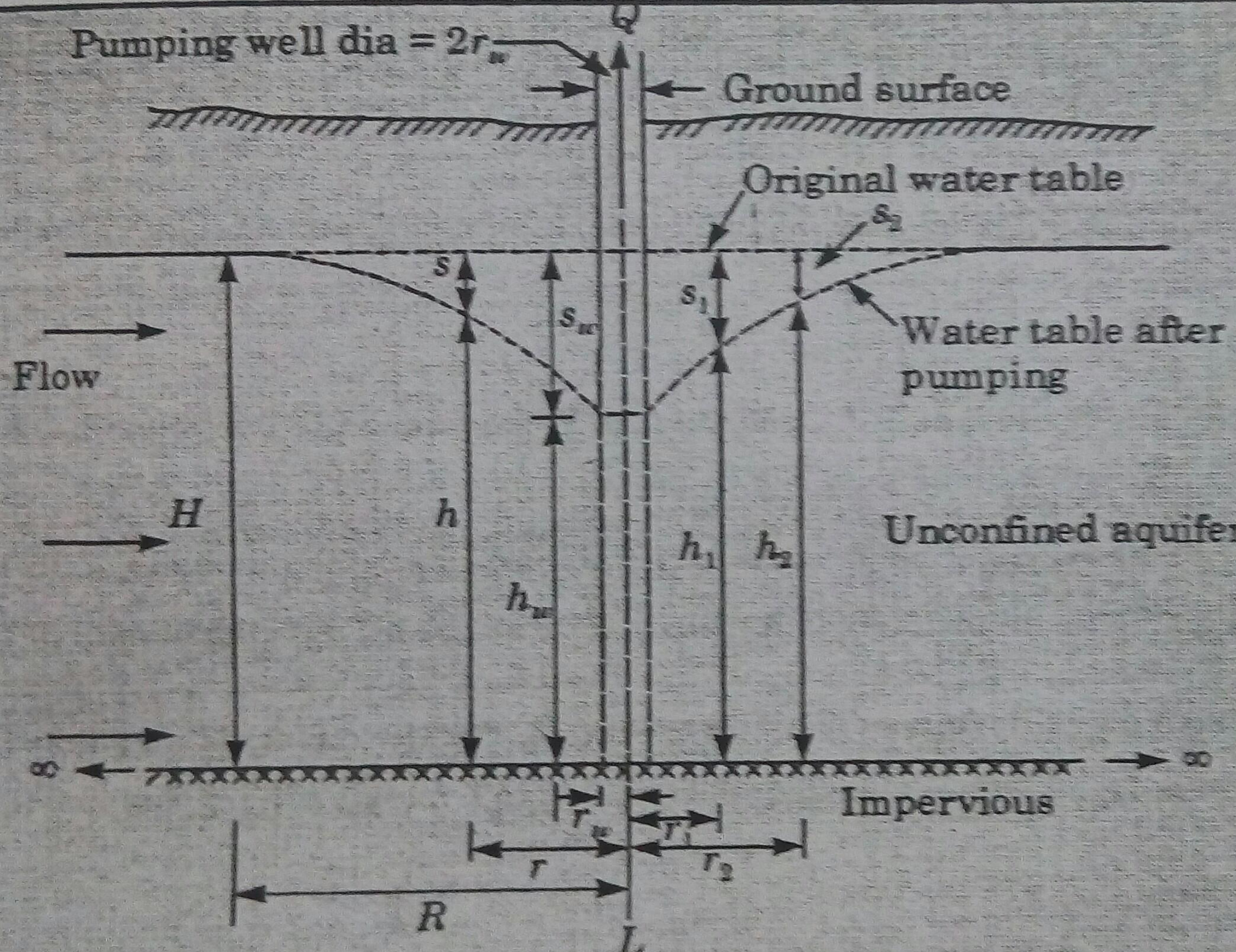


Fig. 9.12.: Well operating in a unconfined aquifer.

Wells:

- At constant rate of pumping, the drawdown curve develops gradually with the time due to the withdrawal of water from storage. This phase is called unsteady flow as the water table elevation at a given location near the well changes with the time.
- As soon as pumping is stopped, the depleted storage in the cone of depression is made good by ground water inflow into the zone of influence. There is gradual accumulation of storage till the original (static) level is reached. This stage is called **recuperation or recovery** & is unsteady phenomenon.
- Changes similar to above take place due to pumping of a well in a confined aquifer, but with the difference that, it is the piezometric surface instead of the water table that undergoes drawdown with the developments of the cone of depression.
- In confined aquifer, the recovery into the well takes place at a very rapid rate.

Equilibrium Equation for steady flow:

- $Q = ((2 \times \prod \times K \times B)(h_2 - h_1)) / (\ln (r_2 / r_1))$
- Thiem's equation (Confined)

K – coefficient of permeability

B – surface through which velocity occurs

r1 & r2 is radius corresponding piezometric heads h1 & h2

Thiem's formula for Unconfined aquifer:

$Q = ((\prod \times K)(H^2 - h^2_w)) / (\ln (R / r_w))$

H = saturated thickness of aquifer.

Dupit's Formula (Unconfined):

- $Q = ((2 \times \prod \times K \times B \times S_w) / (\ln (R/r_w))$
- At the edge of zone of influence, $s = 0$, $r_2 = R$ & $h_2 = H$.
- At the well wall, $s_1 = s_w$, $r_1 = r_w$, & $h_1 = h_w$

Non-Equilibrium Formula For Confined Aquifer (Unsteady Flow):

- The drawbacks of equilibrium formulae given by Thiem & Dupit was the problem to attain equilibrium condition.
- The pumping has to be continued at a uniform rate for a very long time, so as to achieve steady flow conditions.
- Hence we adopt non-equilibrium formula:
- $s = (Q / (4 \times \prod \times T)) (\log_e ((4 \times T \times t) / (r^2 \times S)) – 0.5772)$

s = drawdown in the observation well after a time t.

T = coefficient of transmissibility

Q = constant discharge

S = coeff. Of storage of measured drawdown.

r = radial distance of the observation well from the main pumped well.

3) In an artesian aquifer, the drawdown is 1.2m at a radial distance of 10m from a pumped well after two hours of pumping. On the basis of non-equilibrium equation, determine its pumping time for the same withdrawn ie 1.2m at a radial distance of 30m from this well.

The non-equilibrium equation is

$s = (Q / (4 \times \prod \times T)) (\log_e ((4 \times T \times t) / (r^2 \times S)) – 0.5772)$

Drawdown is the same in both the observation wells, therefore, $s_1 = s_2 = 1.2$m

Well (1) : $r_1 = 10$m , $t_1 = 2$ hrs

Well (2) : $r_2 = 30$m, $t_2 = ?$

$s_1 = (Q / (4 \times \prod \times T)) (\log_e ((4 \times T \times t_1) / (r_1^2 \times S)) – 0.5772)$

$s_2 = (Q / (4 \times \prod \times T)) (\log_e ((4 \times T \times t_2) / (r_2^2 \times S)) – 0.5772)$

But $s_1 = s_2$

By equating we get, $(t_1 / r_1^2) = (t_2 / r_2^2)$

2 hrs / $10^2 = t_2 / 30^2$

t_2 = 18 hrs.

Well Loss:-

- S_w is the total draw down at the well. ($S_w = C_1 Q + C_2 Q^2$)
- S_{wl} is the formation loss ie head drop caused in laminar porous media.
- S_{wt} is drop of piezometric head to sustain turbulent flow
- S_{wc} is head loss through the well screen & casing.

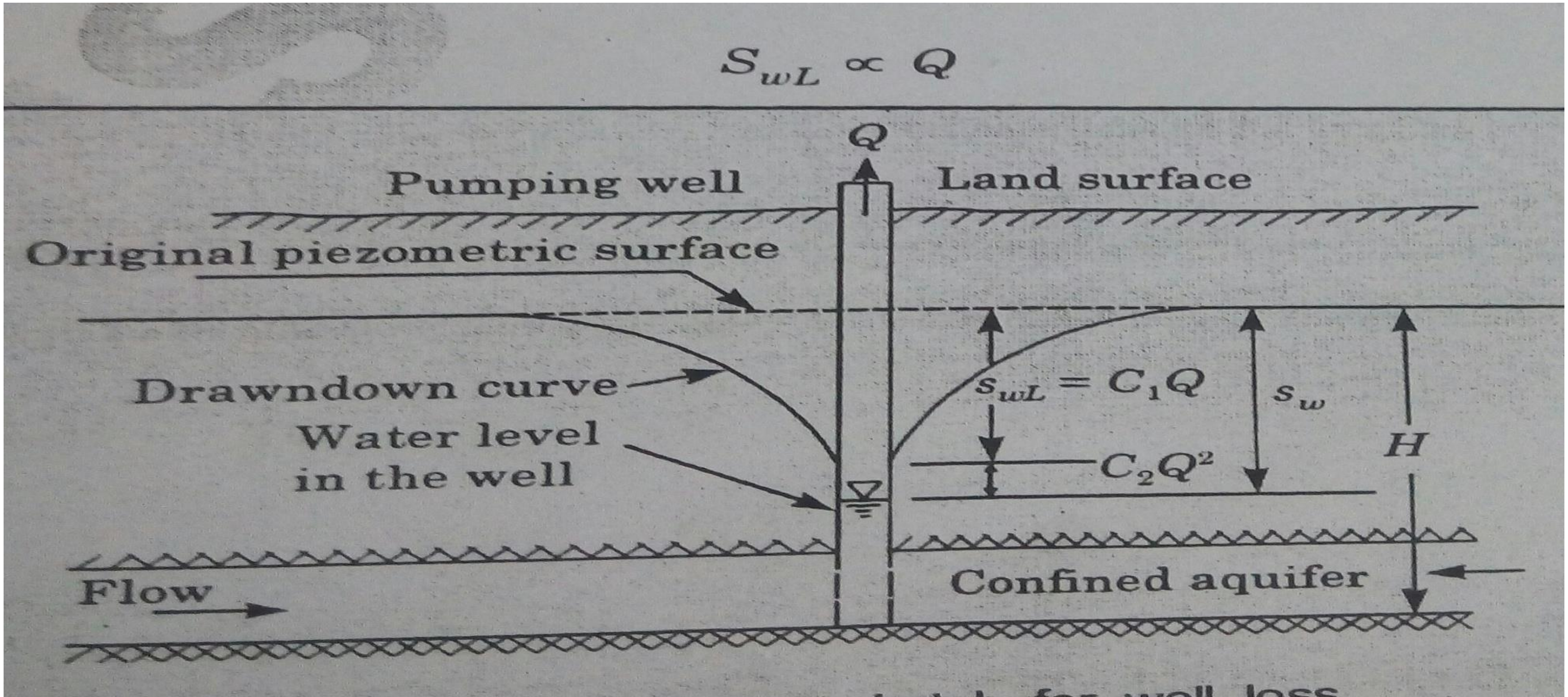


Fig. 9.17. Definition sketch for well loss.

Specific Capacity:-

- It is defined as the well yield per unit of drawdown.

$$\text{Specific Capacity} = (\text{ Discharge of well / Drawdown })$$

$$\text{Specific Capacity} = (Q / (C_1 Q + C_2 Q^2)) = (1 / (C_1 + C_2 Q))$$

- The equation clearly shows that the specific capacity of the well is not constant but decreases as the discharge increases.

Safe Yield:-

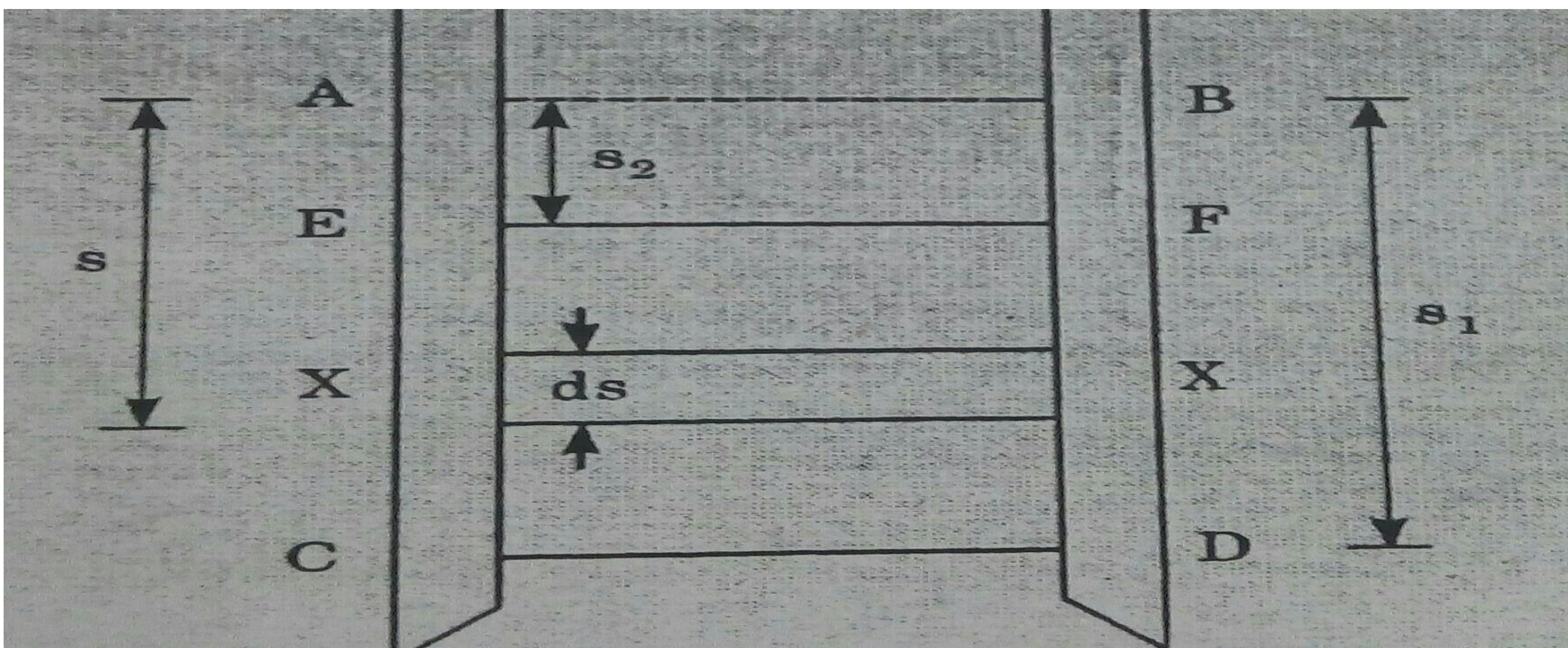
- The maximum rate at which the withdrawal of ground water in a basin can be carried without producing undesirable results is termed safe yield.
- Undesirable result includes permanent lowering of the ground water table or piezometric head, maximum drawdown exceeding a preset limit leading to inefficient operation of wells and salt water encroachment in a coastal aquifer.
- Depending upon what undesirable effect is to be avoided, a safe yield for a basin can be identified

Recuperating Test:-

- Although the pumping test gives accurate value of safe yield, it sometimes becomes very difficult to adjust the rate of pumping, so as to keep the well water level constant.
- In such circumstances, recuperation test is adopted.
- The water is first of all drained from the well at a fast rate so as to cause sufficient drawdown.
- The pumping is then stopped.
- The water level in the well will start rising.
- The time taken by the water to come back to its normal level or some other measured level is then noted.

Recuperating Test:-

- AB = Static water level in the well before the pumping was started.
- CD = Water level in the well when the pumping was stopped.
- S_1 = Depression head in the well at the time the pumping stopped
- EF = Water level in the well at the noted time T from when pumping stopped.
- S_2 = Depression head in the well at time T after the pumping is stopped.



Recuperating Test:-

$$(C' / A) = (2.3 / T) \text{Log}_{10} (s_1 / s_2)$$

$$Q = ((2.3 / T) \text{Log}_{10} (s_1 / s_2)) A s$$

C' is specific capacity.

S_1 is initial drawdown in m.

S_2 is final drawdown in m.

T is time in hours.

Q is yield in m^3/Hr.

A is area of well in m^2.

S is depression head in m.

4) During a recuperation test, the water level in an open well was depressed by pumping by 2.5 meters and is recuperated by an amount of 1.6 m in 70 minutes. A) determine the yield from a well of 3m diameter under a depression head of 3.5m. B) also determine the diameter of the well to yield 10 liters/second under a depression head of 2.5m.

$$(C' / A) = (2.3 / T) \text{Log}_{10} (s_1 / s_2)$$

$$(C' / A) = (2.3 / 1.167) \text{Log}_{10} (2.5 / 0.9)$$

$$= 0.875 \text{ m}^3 / \text{hr} / \text{m}^2 / \text{m of depression head}$$

A) Yield from well of 3m under depression head of 3.5m:

$$Q = ((2.3 / T) \text{Log}_{10} (s_1 / s_2)) A \times s$$

$$Q = ((2.3 / 1.167) \text{Log}_{10} (2.5 / 0.9)) ((\Pi / 4) 3^2) 3.5$$

$$= 21.65 \text{ m}^3 / \text{hr} = 6.02 \text{ litres / sec}$$

B) When depression head = 2.5m & Q = 10 liters / sec = 36 m^3 / hr

$$Q = ((2.3 / T) \text{Log}_{10} (s_1 / s_2)) A \times s$$

$$36 = ((2.3 / 1.167) \text{Log}_{10} (2.5 / 0.9)) ((\Pi / 4) D^2) 2.5$$

$$D = 4.58 \text{ say } 4.6\text{m}$$

Hence the diameter of the required well = 4.6m