Water Resources and Irrigation Engineering
Ground Water Engineering(WRIE2095)

BY Asmare B.

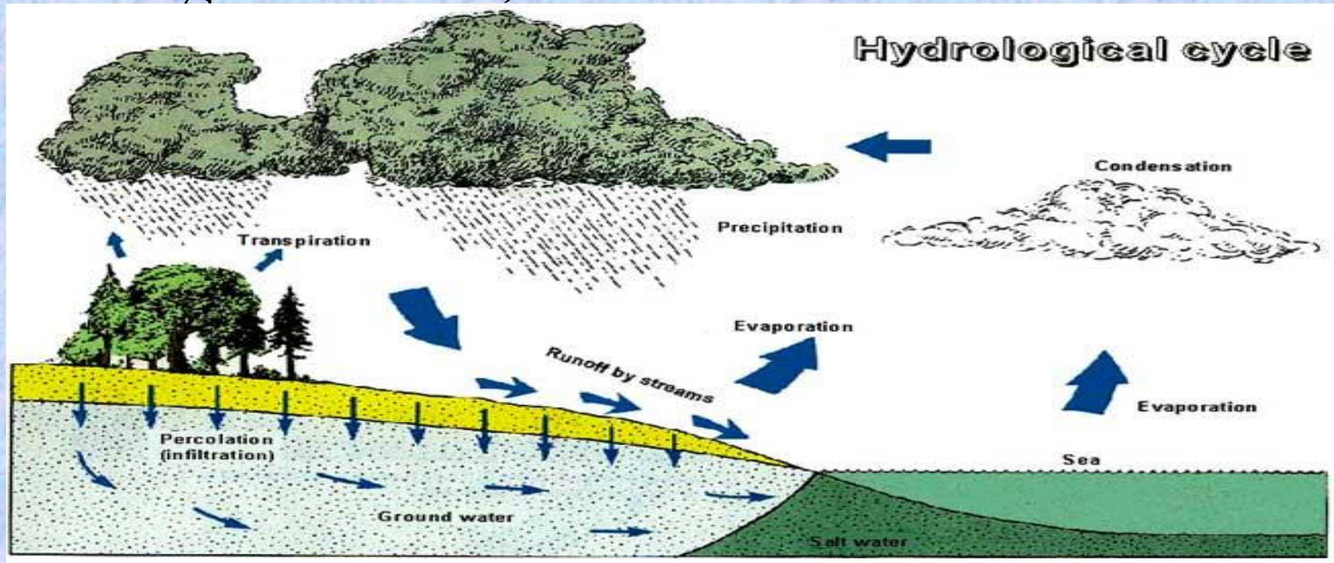
Chapter One
Occurrence of Groundwater

1.1. GROUNDWATER RESOURCES

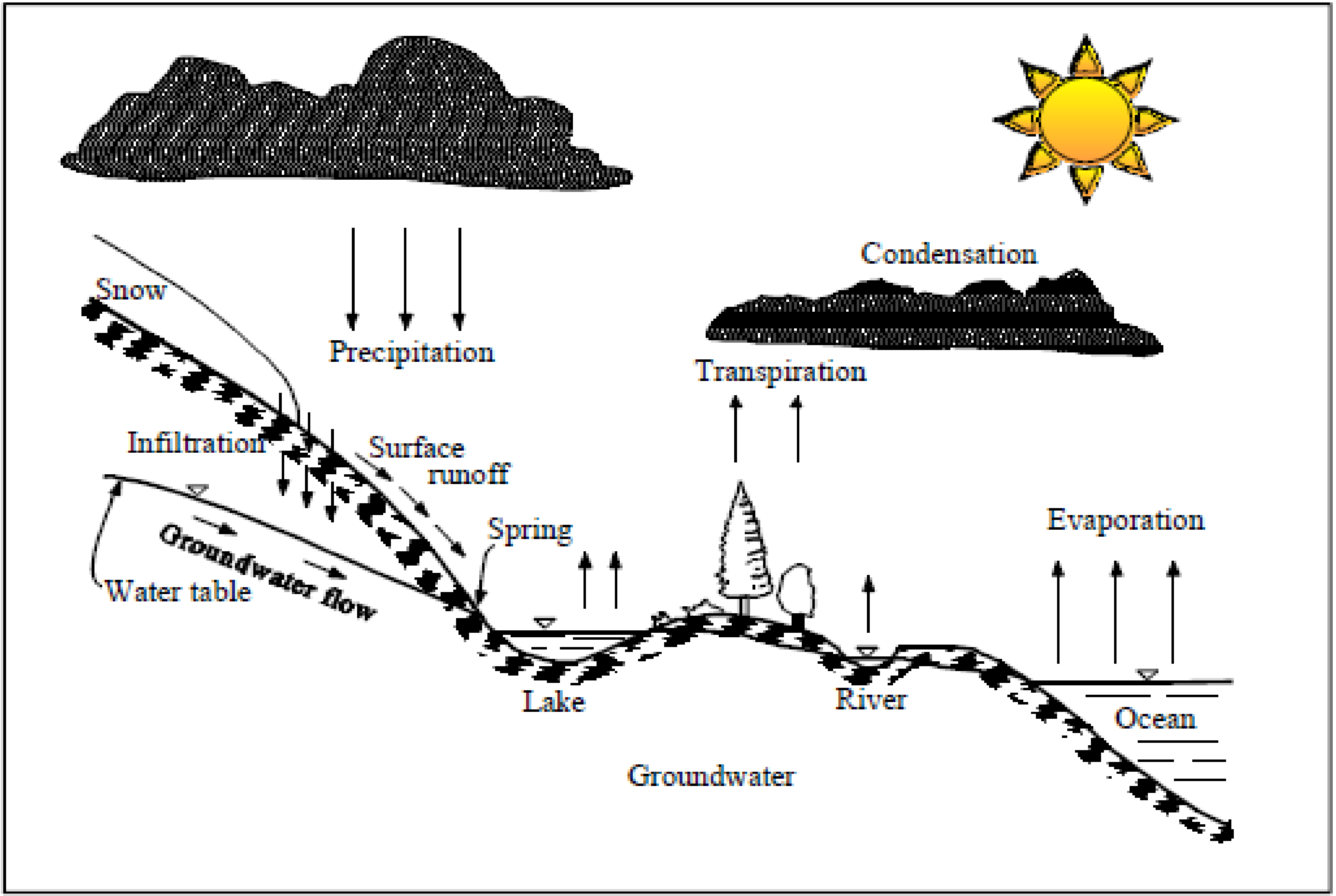
- Subsurface openings large enough to yield water in a usable quantity to wells and springs underlie nearly every place on the land surface and thus make ground water one of the most widely available natural resources .
- When this fact and the fact that ground water also represents the largest reservoir of freshwater readily available to man are considered together.
- Groundwater is water that exists in the pore spaces and fractures in rocks and sediments beneath the Earth's surface.
- The total water resources on earth account 97.5% water(1,365,000,000 km3) of salty water and 2.5% (35,000,000km3)of fresh water from this 30.8% of Ground water.
- Therefore, groundwater is very important in terms of quantity and water use for drinking and for irrigation.
- Groundwater is a part of total water resources is the most important in estimating perspectives of fresh groundwater use.
- To understand the occurrence and distribution of water in a given system (global, basin, catchment, well field) one has to start from the basic understanding of the hydrologic cycle.

cont....

- The term hydrologic cycle refers to the constant movement of water above, on, and below the Earth's surface .
- The concept of the hydrologic cycle is central to an understanding of the occurrence of water and the development and management of water supplies.
- ✓ Groundwater flow is one part of the complex dynamic hydrologic cycle. Saturated formations below the surface act as mediums for the transmission of groundwater, and as reservoirs for the storage of water.



Cont…


Condensation
Precipitation
Snow
Transpiration
Infiltration
Surface
runoff
Spring
Evaporation
Groundwater flow
Water table
Lake
River
Ocean
Groundwater

Cont…

Generally the most favorable areas to groundwater are:

- Existence of favorable geological structures (folds and faults)
- Permeable rock zones
- Topographically depressed areas
- With good groundwater recharge possibilities
- Presence of localizing structures or boundary conditions
- For shallow aquifers areas close to major surface water bodies

1.2. Occurrence of Groundwater

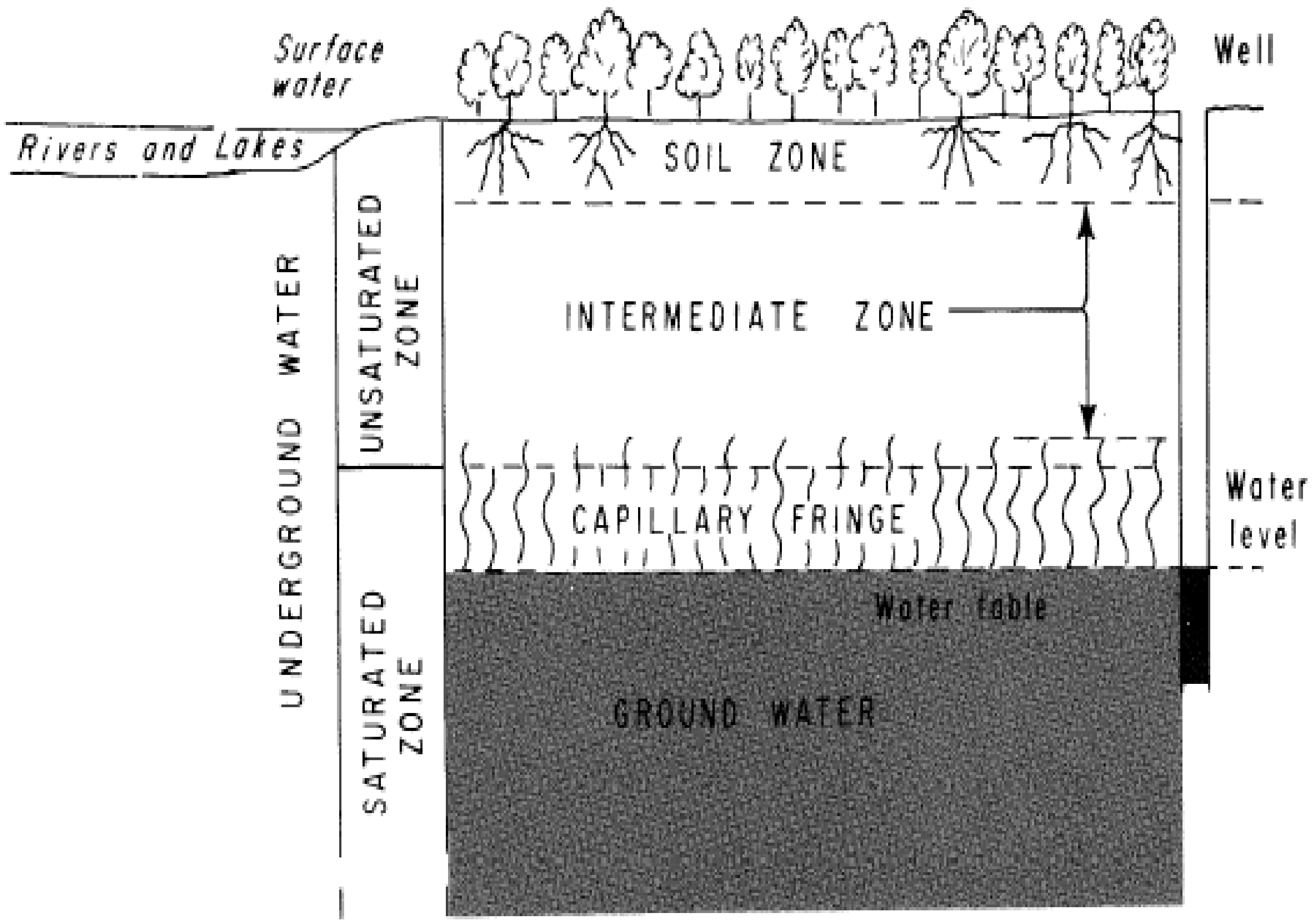
- Groundwater system is the zone in the earth's crust where the open space in the rock is completely filled with water at a pressure greater than atmospheric.

Two zones can be distinguished in which water occurs in the ground:

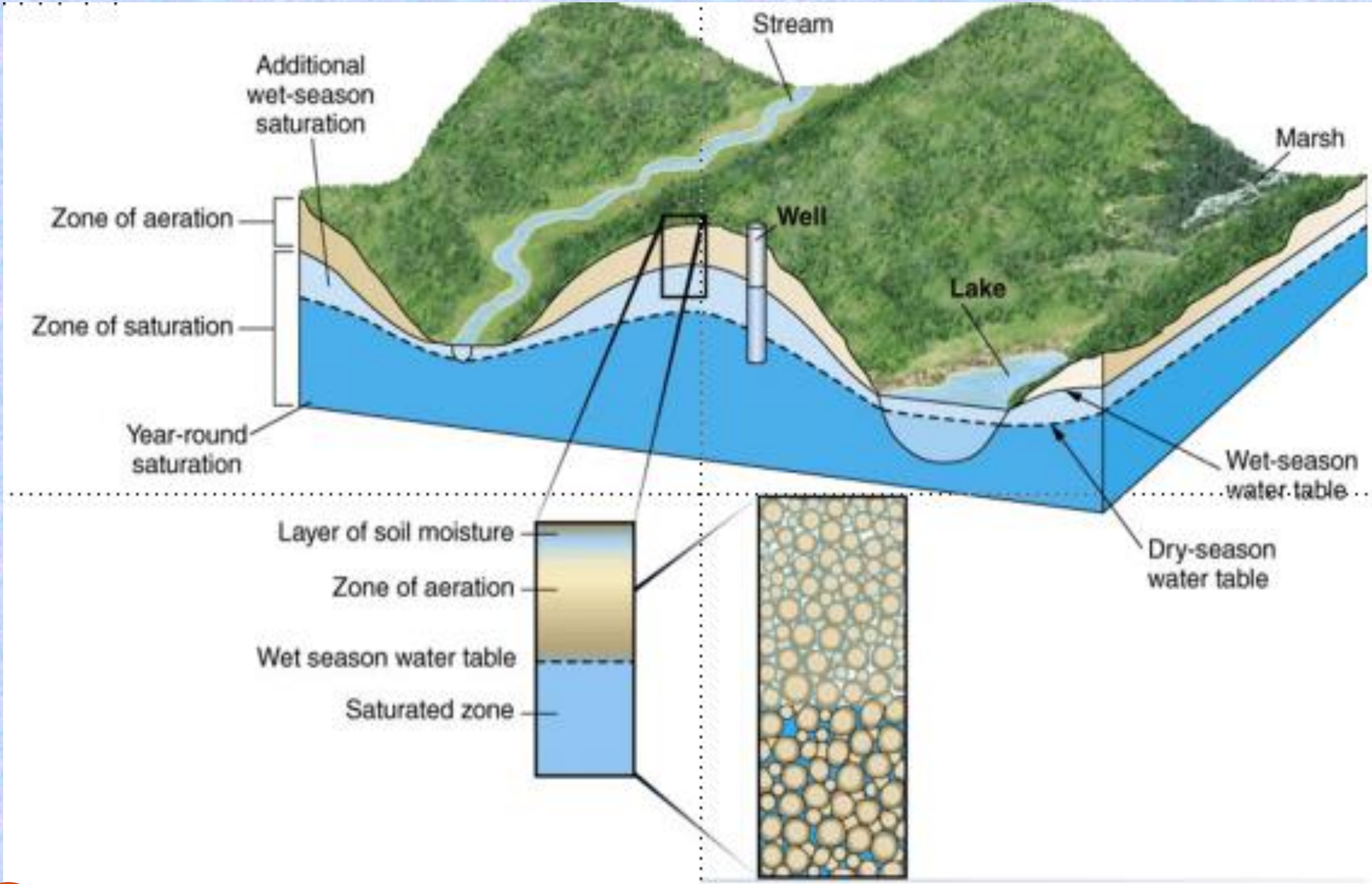
- The unsaturated zone/ Zone of aeration
- The saturated zone

- The process of water entering into the ground is called infiltration.
- Downward transport of water in the unsaturated zone is called percolation,
- whereas the upward transport in the unsaturated zone is called capillary rise.
- The flow of water through saturated porous media is called groundwater flow.

Saturated and unsaturated zone



Cont…



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

Cont…

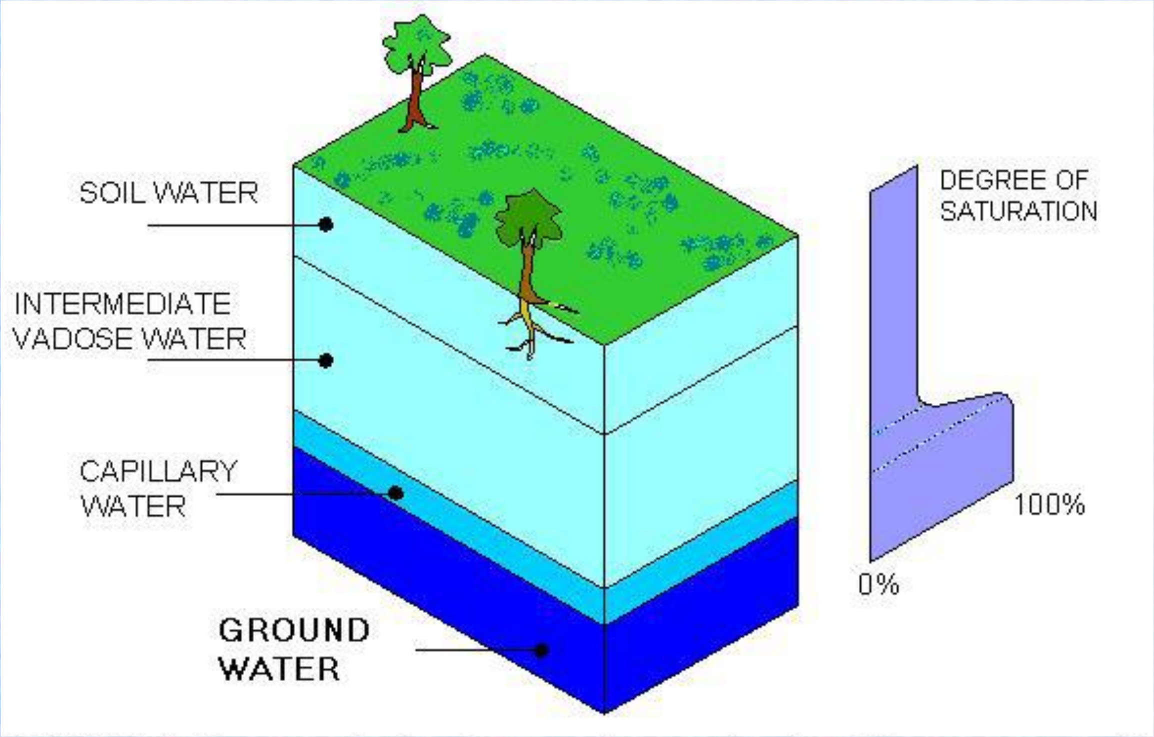
1.2.1. Unsaturated Zone/ Zone of aeration

In this zone the soil pores are only partially saturated with water.

Further, the zone of aeration has three sub zones: *soil water zone*, *capillary fringe* and *intermediate zone*.

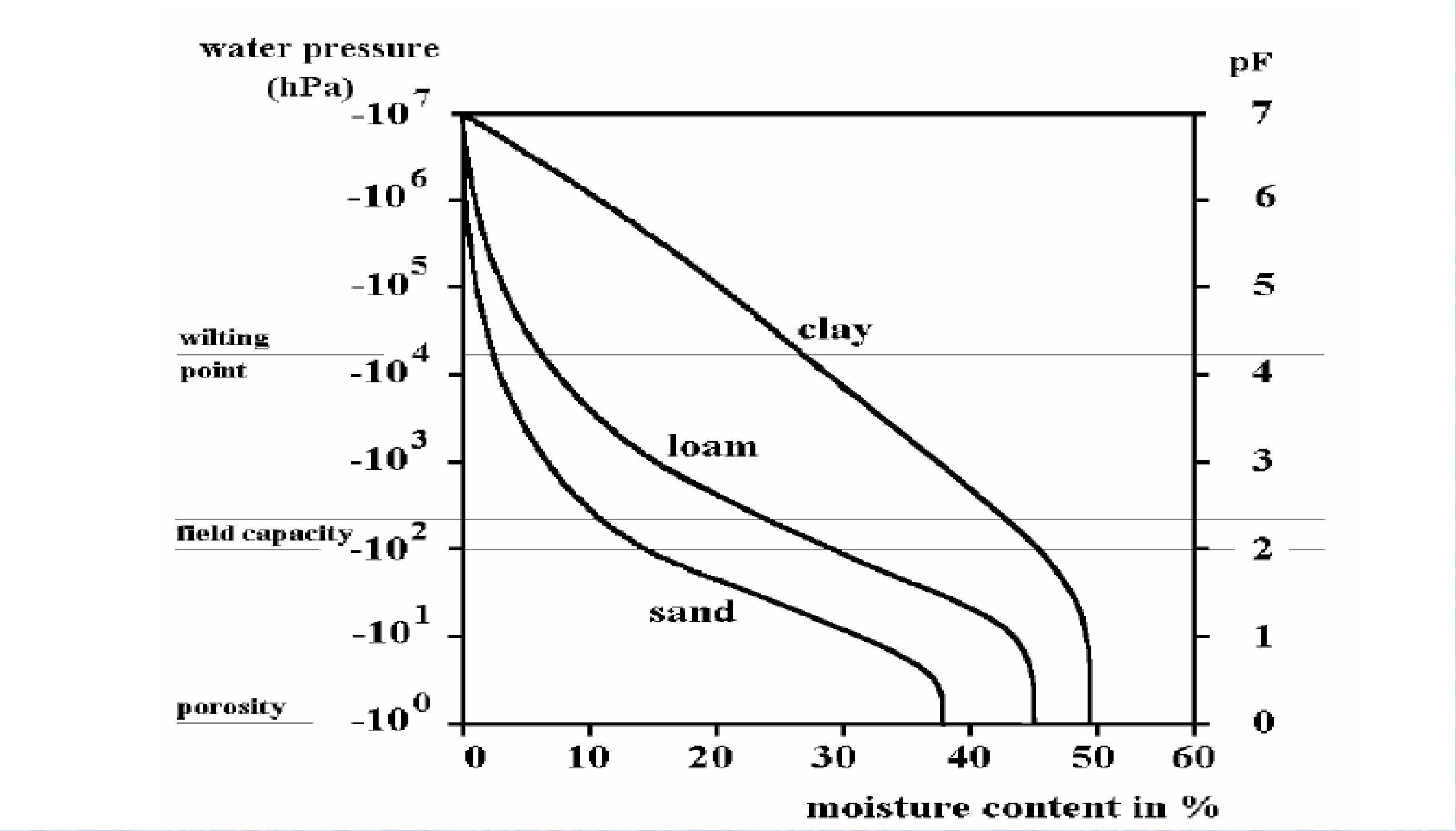
- The soil water zone lies close to the ground surface in the major root band of the vegetation from which the water is lost to the atmosphere by evapotranspiration.
- Capillary fringe on the other hand hold water by capillary action. This zone extends from the water table upwards to the limit of the capillary rise.
- The intermediate zone lies between the soil water zone and the capillary fringe.

Cont…



Important conditions in the unsaturated zone are the ***wilting point*** and the ***field capacity***.

Cont…



Often the soil water pressure is given as a pF value, which is the 10base logarithm of the pressure in centimeters of water column h, i.e. pF = log10 (-h).

Cont…

1.2.2. Saturated Zone

- All earth materials, from soils to rocks have pore spaces although these pores are completely saturated with water below the groundwater table or phreatic surface (GWT).
- Natural variations in permeability and ease of transmission of groundwater in different saturated geological formations lead to the recognition of aquifer, Aquitard, Aquiclude and Aquifuge.
- **Aquifer***:* This is a water-bearing layer for which the porosity and pore size are sufficiently large that which not only stores water but yields it in sufficient quantity due to its high permeability.
- **Aquitard***: It* is less permeable geological formation which may be capable of transmitting water (e.g. sandy clay layer). It may transmit quantities of water that are significant in terms of regional groundwater flow.

Cont…

- **Aquiclude**: is a geological formation which is essentially impermeable to the flow of water. It may be considered as closed to water movement even though it may contain large amount of groundwater due to its high porosity (e.g. clay).
- **Aquifuge**: is a geological formation, which is neither porous nor permeable. There are no interconnected openings and hence it cannot transmit water. Massive compact rock without any fractures is an aquifuge.

1. 2.3 Aquifers and their characteristics

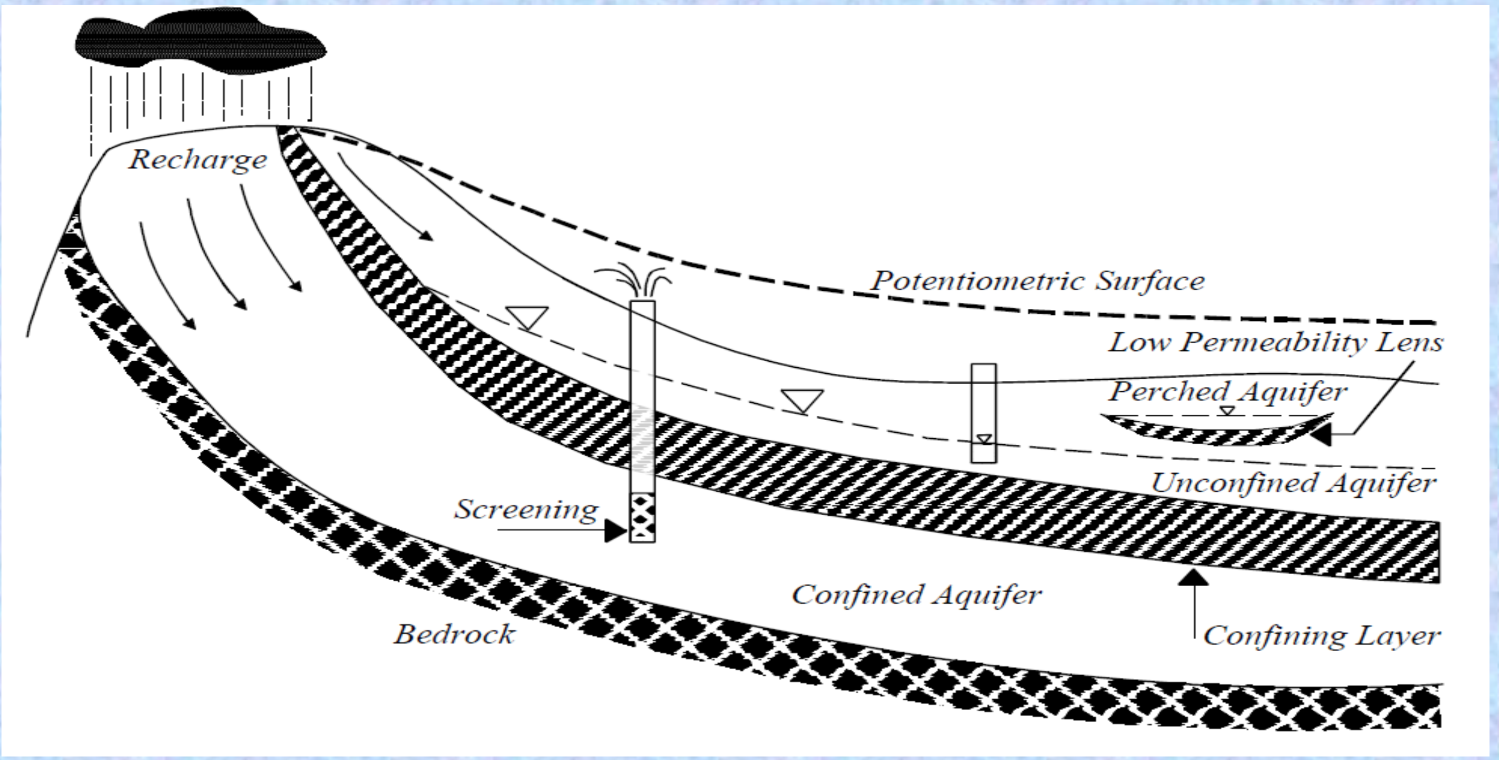
The aquifers are simplified into one of the following types

Unconfined aquifer (also called phreatic or water table aquife*r*): Such type of aquifer consists of a pervious layer underlain by a (semi-) impervious layer.

Cont…

- The upper boundary is formed by a free water-table (phreatic surface) that is in direct contact with the atmosphere.
- **Confined aquifer**: Such an aquifer consists of a completely saturated pervious layer bounded by impervious layers. There is no direct contact with the atmosphere.
- **Semi-confined or Leaky aquifers**: consists of a completely saturated pervious layer, but the upper and/or lower boundaries are semi-pervious. They are overlain by aquitard that may have inflow and outflow through them.
- **Perched aquifers**: These are unconfined aquifers of isolated in nature. They are not connected with other aquifers.

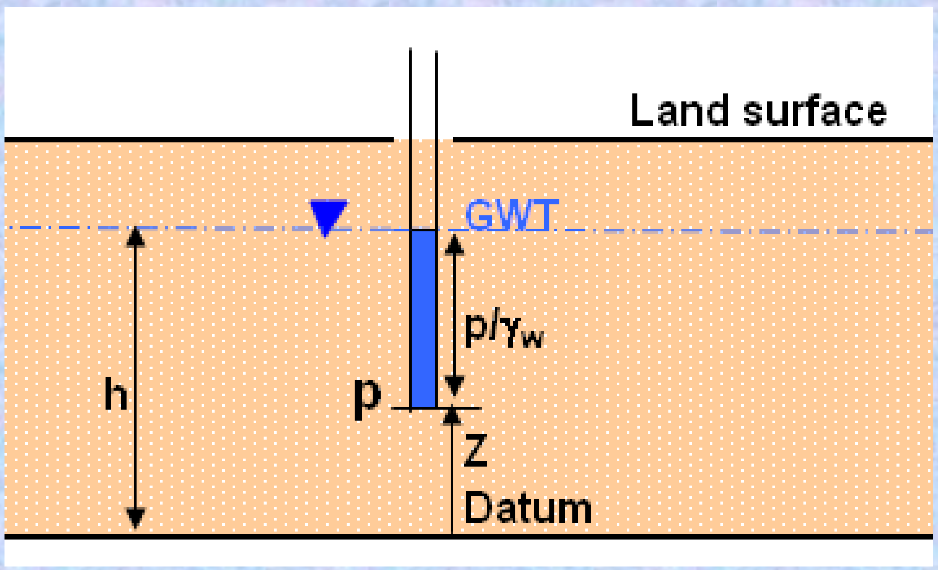
Cont…



- The pressure of the water in an aquifer is measured with a **piezometer**, which is an open ended pipe with a diameter of 3-10 cm. The height to which the water rises with respect to a certain reference level (e.g. the impervious base, mean sea level, etc.) is called the **hydraulic head**.

Cont…

- Generally the head can be written as $h = z + p/\gamma_w$ whereby the z is the gravitational elevation head and the p/γ_w the pressure head.



1. 2.4 Determination of groundwater flow parameters

1 . Porosity(n) and void ratio (e)

- The porosity, **n** is the ratio of volume of the open space in the rock or soil to the total volume of soil or rock.

$$n = \left(\frac{Vv}{V_T}\right) * 100$$

By Asmare Belay

Cont…

- Porosity is also the measure of water holding capacity of the geological formation.
- The greater the porosity means the larger is the water holding capacity. Porosity depends up on the shape, size, and packing of soil particles. Porosity greater than 20% is considered large; 5-20% medium and less than 5% is small.

Type of rock	Range of porosity	Type of rock	Range of porosity
Unconsolidated		**Consolidated**	
Gravel	0.2-0.4	Basalt	0.05-0.5
Sand	0.2-0.5	Lime stone	0.05-0.5
Silt	0.3-0.5	Sand stone	0.05-0.3
Clay	0.3-0.7	Shale	0.0-0.1

Cont…

Void ratio (e)

- The void ratio is an index of the fractional volume of soil pores, but it relates that volume to the volume of solids rather than to the total volume of soil.

$$e = \frac{(V_a + V_w)}{V_s} = \frac{V_f}{(V_t - V_f)}$$

Cont…

2 Soil Texture

- The relative proportion of sand, silt and clay in a soil mass determines the soil texture.
- According to textural classification, soils may be broadly classified as **light, medium** and **heavy textured soils.**
- The ***light textured soils*** contain very low content of silt and clay and hence these soils are coarse or sandy.
- The ***medium textured soils*** contain sand silt and clay in sizable proportions
- The ***heavy textured soils*** contain high content of clay.

Cont…

3 Degree of saturation (s)

- This index expresses the volume of water present in soil relative to the volume of pores.

$$s = \frac{V_w}{V_f} = \frac{V_w}{(V_a + V_w)}$$

4 Volume Wetness (θ)

- The volume wetness (often termed volumetric water content or volume fraction of soil water) is generally computed as a percentage of the total volume of the soil rather than on the basis of the volume of particles alone.

$$\theta = \frac{V_w}{V_t} = \frac{V_w}{(V_s + V_f)}$$

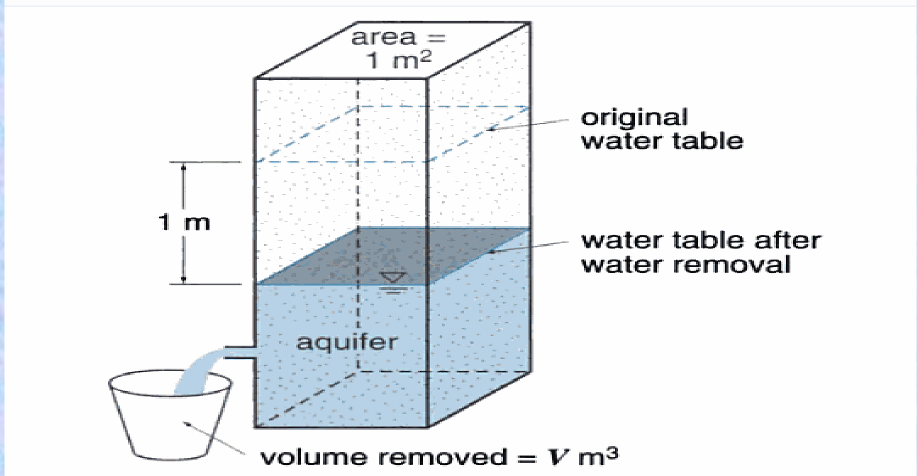
Cont…

5. Specific yield (Sy)

- ✓ The actual volume of water that can be extracted by the force of gravity from a unit volume of **aquifer** material is known as the specific yield, S_y.

$$S_y = \left(\frac{V_w}{V_T}\right) * 100$$

- ➢ For unconfined aquifers the *specific yield* (S_y) is defined as the amount of water stored or released in an aquifer column with a cross-sectional area of $1 m^2$ as a result of a 1m increase or decrease in hydraulic head.



Cont…

6 Specific retention (Sr)

- The water which is not drained or the ratio of volume of water that can not be drained (V_r) to the total volume (V_T) of a saturated aquifer is called *specific retention* (S_r).

$$S_r = \left(\frac{V_r}{V_T}\right) * 100$$

7 . Storage Coefficient (S)

- The amount of water stored or released in an aquifer column with a cross sectional area of 1m^2 for a 1m increase or drop in head is known as **storage coefficient**. Storage coefficient of unconfined aquifer is equal to the specific yield

Cont…

- In confined or semi-confined aquifers water is stored or released from the whole aquifer column mainly as a result of elastic changes in **porosity and groundwater density**.
- The volume of water drained from an aquifer, Vw may be found from the following equation.

$$Vw = SA\Delta h$$

Where: A is horizontal area and Δh is fall in head and **s** is storage coefficient

8. Specific Storage (Ss)

In a unit of saturated porous matrix, the volume of water that will be taken in to storage under a unit increase in head, or the volume that will be released under a unit decrease in head is called specific storage. It is also the storage coefficient per unit saturated thickness of an aquifer.

Cont…

- For confined aquifer, the relation between the ***specific storage*** and the ***storage coefficient*** is as follows:
- $S = S_s * b$

Where:

S = Storage coefficient (dimensionless),

b = aquifer thickness (m)

Specific Storage is also called elastic storage coefficient and is given by the following expression.

$Ss = \rho g (\alpha + n\beta)$

Where: ρ=fluid (water) density,

g=gravitational acceleration

Cont…

α=aquifer compressibility,

n= porosity,

β=water compressibility.

- Elastic storage is the only storage occurring in semi-confined and confined aquifers

chapter Two

2.0 GROUNDWATER MOVEMENT

2.1. Darcy's Law

- The flow through aquifers, most of which are natural porous media, can be expressed by what is known as Darcy's law.
- The law is stated as "the flow through a porous media is proportional to the area of normal to the flow direction (A) and the head loss (h_L) and inversely proportional to the length (L) of the flow path."

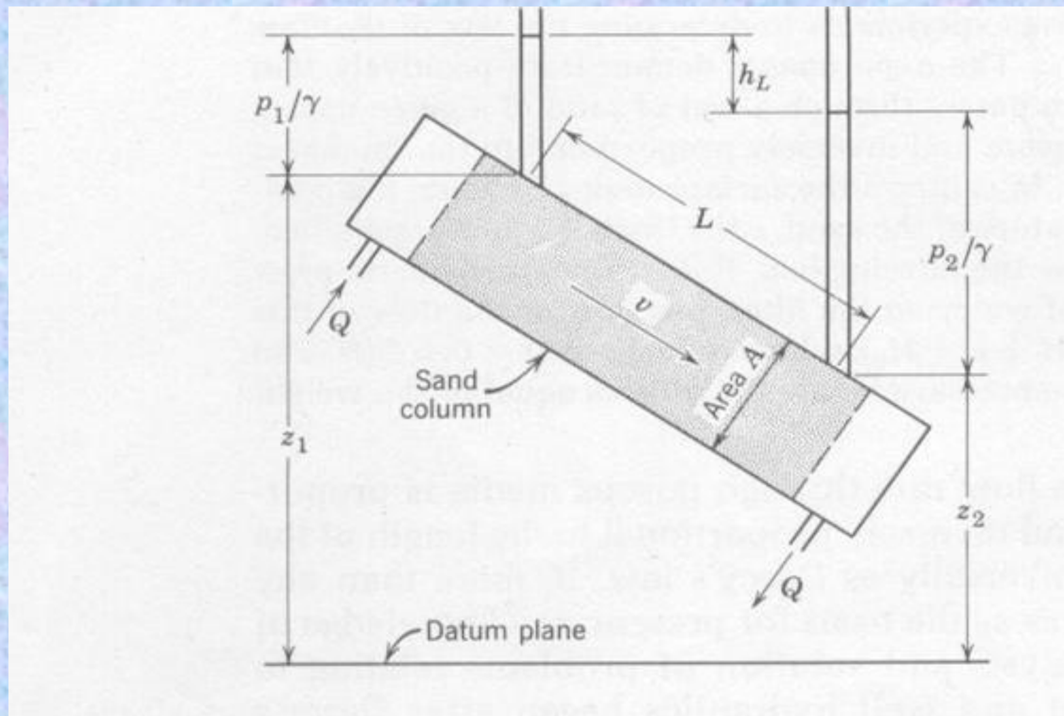
Introducing the proportionality constant K, $\mathbf{Q = -K.h_L/L.A}$

$Q = KAdh/dl$

Formulation of Darcy's Law

The experimental verification of Darcy's law can be performed with water flowing at a rate Q through a cylinder of cross-sectional area A packed with sand and having a piezometric distance L apart (as shown in fig below).

Cont…



- Total Energy head, or fluid potentials, above the datum plane may be expressed by Bernoulli equation as:

$$\frac{p_1}{\gamma_w} + \frac{v_1^{\,2}}{2g} + z_1 = \frac{p_2}{\gamma_w} + \frac{v_2^{\,2}}{2g} + z_2 + hL$$

Cont…

- Since the velocity of flow in porous media is very ver small, the velocity head can be neglected ($v^2/2g \approx 0$) and thus the head loss can be obtained as:

$$hL = \left(\frac{p_1}{\gamma_w} + z_1\right) - \left(\frac{p_2}{\gamma_w} + z_2\right)$$

- **Specific Discharge**

Specific discharge is also called as the Darcy Velocity. It is the discharge Q per cross-section area, A.

Form Darcy's equation,

$$q = {Q}/{A} = -k\frac{\Delta h}{\Delta \ell}$$

Cont…

- Taking the limit as 0 i.e. $\lim_{\Delta\ell \to 0} it \; -K\frac{\Delta h}{\Delta \ell} = -k\frac{dh}{dl}$ $$q = -k\frac{dh}{dl}$$
- Where: q = specific discharge or flow rate per unit area (m/day),

  K = coefficient of permeability or hydraulic conductivity of rock (m/day),

  Δh = hydraulic head (m),

  Δl = distance measured in flow direction (m).

For the three dimensions, the following equations are then valid for flow in isotropic porous medium and Darcy's law will be written as:

$$q_x = -K_x\left(\frac{\partial h}{\partial X}\right), q_y = -K_y\left(\frac{\partial h}{\partial Y}\right), q_z = -K_z\left(\frac{\partial h}{\partial Z}\right)$$

Cont…

Validity of Darcy's law

In general the Darcy's law holds well for

i) Saturated & unsaturated flow.

ii) Steady & unsteady flow condition

iii) Flow in aquifers and aquitards.

iv) Flow in homogenous & heterogeneous media

v) Flow in isotropic & an isotropic media. vi) Flow in rocks and granular media.

- Darcy's law is valid for laminar flow condition as it is governed by the linter law.

$$v = -k\left(\frac{dh}{d\ell}\right)^m, m = 1.0$$

Cont…

$$N_R = \frac{Inertial\ force}{visouse\ force} = \frac{\rho v D}{\mu}$$

- For the flow in porous media, v is the Darcy velocity and D is the effective grain size (d_{10}) of a formation/media.
- Experiments show that Darcy's law is valid for $N_R < 1$ and does not go beyond seriously up to $N_R = 10$. This is the upper limit to the validity of Darcy's laws.
- Fortunately, natural underground flow occurs with $N_R < 1$. So Darcy's law is applicable.

2.2 HYDRALIC CONDUCTIVITY

Generally, hydraulic conductivity is a coefficient of proportionality describing the rate at which water can move through a permeable medium.

Cont…

$$V = K\frac{\Delta h}{L}$$

Where $\Delta h/L$ is the hydraulic gradient & Δh is the head loss along the distance L.

Intrinsic Permeability

- It is dependent only on the physical properties of the porous medium: grain size, grain shape and arrangement, pore interconnections etc…
- On the other hand hydraulic conductivity is dependent on the properties of both porous media and the fluid.
- The relationship between intrinsic permeability (K_i) and hydraulic conductivity (K) is expressed through the following formula.

Cont…

$K = k_i . k_w$ (1.5)

Where: K = Coefficient of permeability,

k_i = Intrinsic permeability; depending on rock properties (such as grain size & packing),

k_W = Permeability depending on fluid properties (such as density and viscosity of water)

- Further for unconsolidated rocks, from an analogy of laminar flow through a conduit the coefficient of permeability K can be expressed as:

$$K = C\, d_m^{\,2}\,(\gamma / \mu) = C\, d_m^{\,2}\,(\rho g / \mu)$$

Where: d_m = Mean pore size of the porous medium (m),

γ = unit weight of the fluid (kg/m^2s^2),

ρ = density of the fluid (kg/m^3),

Cont…

g = acceleration due to gravity (m/s^2),

μ = dynamic viscosity of the fluid (kg/ms),

C = a shape factor which depends on the porosity, packing, shape of grains and grain-size distribution of the porous medium.

- can be split into two components: intrinsic permeability (k_i) and permeability due to fluid properties (k_w). ⇒ $k_i = C\, d_m^{\,2}$ and $k_w = \gamma/\mu = g/\nu$.
- According to Kozeny-Carman's formula

$$K_i = C d_m^{\,2} \left(\frac{n^3}{(1-n)^2} \right)$$

Cont…

2.3 flow in anisotropic Aquifer and Transmissivity

Aquifer flow

Aquifer flow can be one dimensional, two dimensional or more. Darcy's equation can be used to calculate one dimensional flow in aquifers.

To obtain the volume rate of flow in aquifer, Darcy's velocity is multiplied by cross sectional area of an aquifer normal to the flow.

$Q = Av = -AKdh/dl = -Aki$ i is the hydraulic gradient (slop of water table or piezometric surface)

Cont….

Transmissivity (T) and Vertical Resistance (C):

Transmissivity is the product of horizontal coefficient of permeability and saturated thickness of the aquifer. For an isotropic aquifer ($K_x = K_y = K$):

$T = KB$

Where: T = aquifer Transmissivity (m^2 / day),

B = aquifer thickness (m).

- Where B is the saturated thickness of an aquifer. Therefore, the flow rate in Darcy's equation can be given as
- $Q = -WBKi = Q = -WTi$

The vertical resistance of an aquitard is defined as the ratio of the thickness of the aquitard and its permeability in the vertical direction (k_z):

$C = D / K_Z$

Where: C = vertical resistance (days),

D = thickness of the aquitard (m).

Cont…

- Two main kinds of stratifications (flow situations in stratified aquifers) are possible in aquifers; **horizontal and vertical stratifications**.
- **Horizontal stratification**

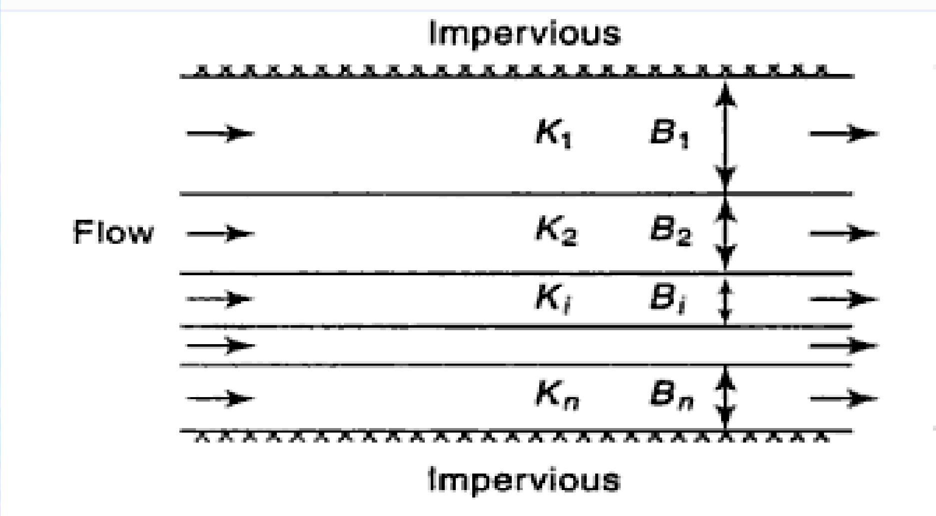
When the flow is parallel to the stratification as in Figure below equivalent permeability K_e of the entire aquifer of thickness $b = \sum b_i$ is:

$$K_e = \frac{\sum_{i=1}^{n} K_i B_i}{\sum_{i=1}^{n} B_i}$$

Transmissivity of an aquifer formation will therefore be given as follows:

$$T = K_e \sum_{i=1}^{n} B_i = \sum_{i=1}^{n} K_i B_i$$

Cont…

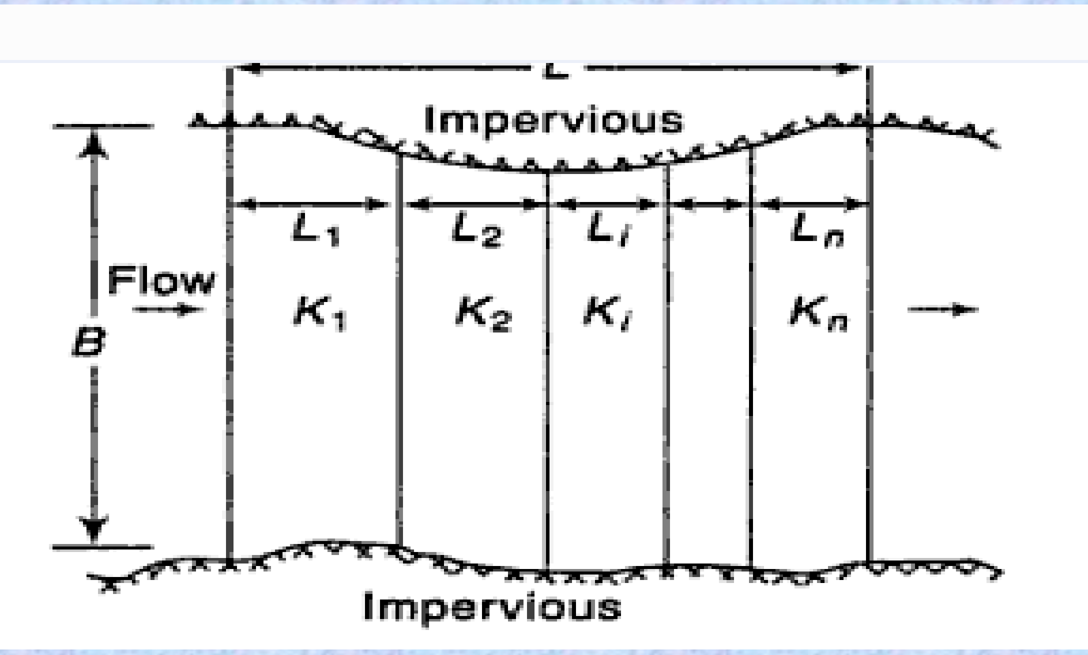


- **Vertical Stratification**

When the flow is vertical and normal to the stratification as in figure below the equivalent permeability K_e of the aquifer length $L = \sum_{i=1}^{n} L_i$ is

$$K_e = \frac{\sum_{i=1}^{n} L_i}{\sum_{i=1}^{n} \left(\frac{L_i}{K_i} \right)}$$

Cont…



- Transmissivity of the aquifer, T = Ke.B

Cont…

- **Average Hydraulic Conductivity**
- The hydraulic conductivity in horizontal direction (Kx) and in the vertical direction (Kz) defined previously were the average hydraulic conductivities in their respective directions.
- The overall average hydraulic conductivity is computed from the geometric mean or the arithmetic mean of the logarithm of the average horizontal and vertical hydraulic conductivities.

$$K_{av} = \sqrt{K_x . K_z}$$

- or $\log K_{av} = (\log K_x + \log K_z)/2$

Cont…

2.4 Determination of hydraulic conductivity

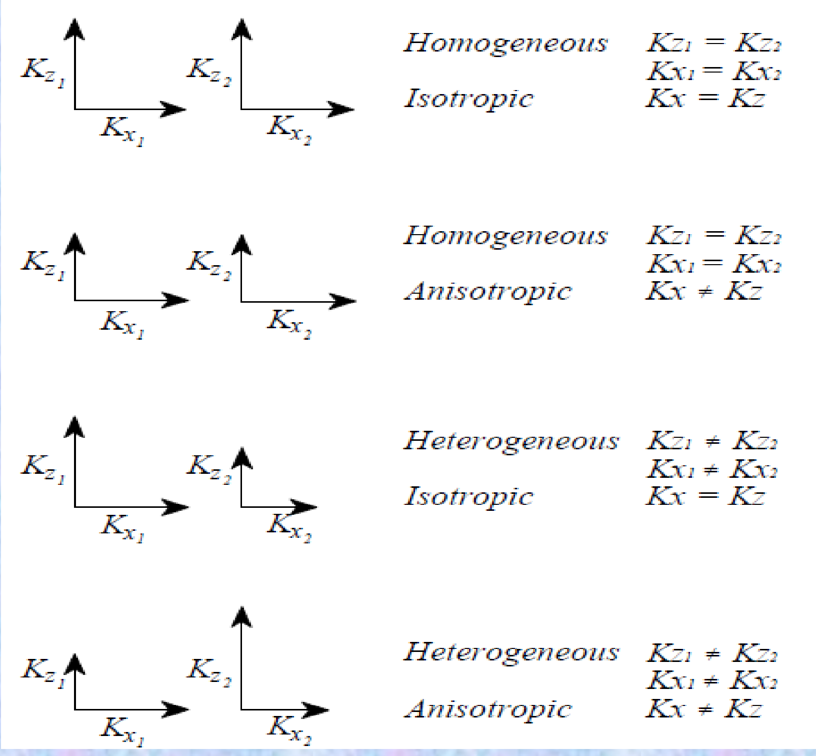
Hydraulic conductivity in saturated zones can be determined by variety of techniques. These include, analytical or empirical methods, laboratory methods, tracer tests, augur hole tests and pumping tests of wells.

a. Laboratory determination of hydraulic conductivity

- If hydraulic conductivity is consistent throughout a formation, regardless of position, the formation is **homogeneous**.
- If hydraulic conductivity within a formation is dependent on location, the formation is **heterogeneous**.
- When hydraulic conductivity is independent of the direction of measurement at a point within a formation, the formation is **isotropic** at that point.

Cont…

- If the hydraulic conductivity varies with the direction of measurement at a point within a formation, the formation is **anisotropic** at that point.
- Consequently, flow is generally less restricted in the horizontal direction than the vertical and K_x is greater than K_z for most situations.



Cont…

- Permeability could be determined by direct method in either the laboratory or the field. Direct and indirect methods are also applied for the determination of Permeability.

1. Constant head permeameters

The principle in this setup is that the hydraulic head causing flow is maintained constant; the quantity of water flowing through a soil specimen of known cross sectional area and length in a given time is measured by graduated cylinder. In highly impervious soils the quantity of water that can be collected will be small and accurate measurements are difficult to make. Therefore constant head permeameters are mainly applicable in relatively pervious soils.

$$K = \frac{Q * dl}{A * dh}$$

Cont…

2. Falling head permeameters

Falling head permeameter is used for relatively less permeable soils where the discharge is small. Observations should be taken after a steady state of flow has reached. If the head of water level in the stand pipe above that in the constant head chamber falls from h_0 to h_1, corresponding to elapsed time t_0 and t_1, the coefficient of permeability, k is determined as follows.

$$K = \frac{a}{A} * \frac{L}{t_1 - t_0} \ln \frac{h_0}{h_1}$$

Where:

a= Cross sectional area of stand pipe,

A= Cross sectional area of soil sample,

L= Length of the soil sample,

Cont…

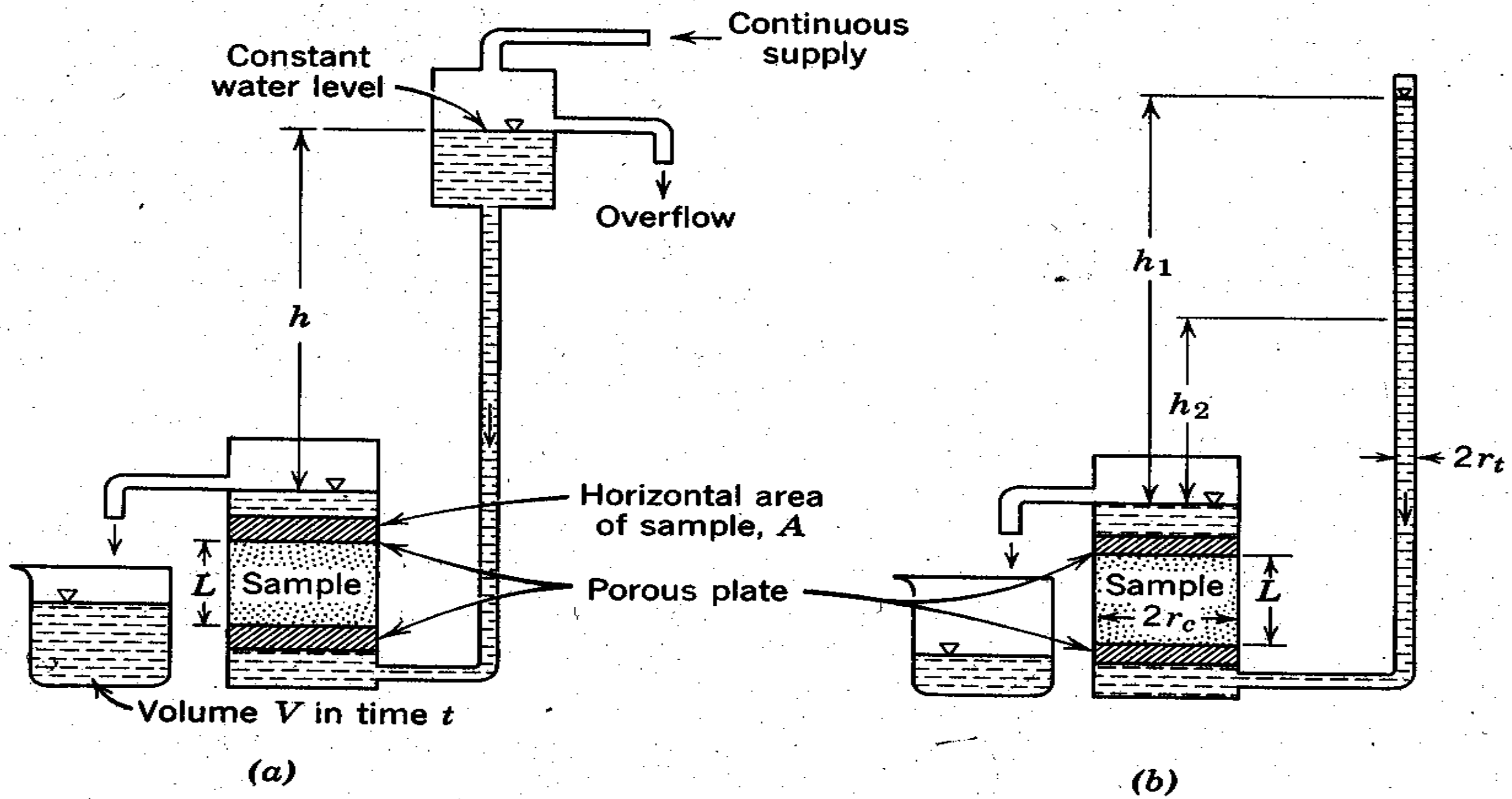


Fig. 3.4 Permeameters for measuring hydraulic conductivity of geologic samples. (a) Constant head. (b) Falling head.

Cont…

b. Field Methods

The average permeability of a soil in the field may be different form values obtained in the laboratory. Some of the field methods are:

- **using auger hole**
- Pumping test
- Tracer test's
- - Double Ring Infiltrometer tests

2.5 Groundwater flow directions

2.5.1. Flow nets

- Flow net is a net work flow lines and equipotential lines intersecting at right angles to each other.
- The imaginary path which a particle of water follows in its course of seepage through a saturated soil mass is called flow line. An equipotential line is the line which joins points with equal potential head.
- For specified boundary conditions, flow lines and equipotential lines can be mapped in to two dimensions to form a flow net.
- The hydraulic gradient is given by: $i = -dh/ds$
- and the constant flow rate , between two adjacent lines is given by

$q = -K.dm.dh/ds$ for unit thickness. But for the squares of the flow net, the approximation $ds \sim dm$ can be made. Therefore, the above equation reduces to

- $q = Kdh$
- Applying this to an entire flow net, where the total head loss h is divided in to n squares b/n two adjacent flow lines, then

$dh = h/n_d$

Cont…

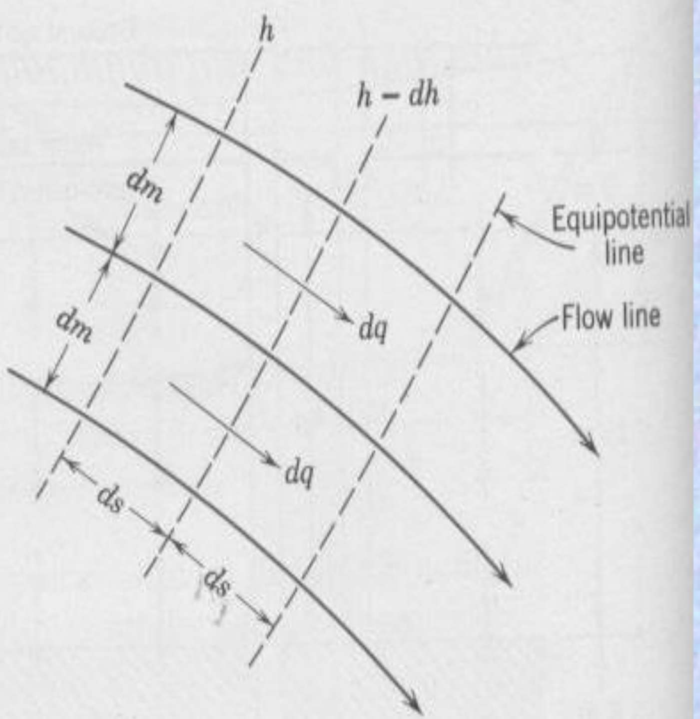


Fig. 3.10 Portion of an orthogonal flow net formed by flow and equipotential lines.

- If the flow field is divided in to n_f channels by flow lines, then the total flow rate is:

$$Q = n_f q = K n_f h / n_d$$

Cont…

The properties of a flow net can be expressed as given below.

- Flow and equipotential lines are smooth curves.
- Flow and equipotential lines meet at right angles to each other.
- No two flow lines cross each other
- No flow or equipotential lines start at the same point.

The three common types of boundaries of GW flow are:

- Impermeable (No flow boundary)
- Constant head boundary(head not varies)
- Water table (Variable head boundary)

Cont…

a. Impermeable(No flow boundary)

- There is no flow through such a boundary. Flow lines run parallel to the boundary and GW head contour lines (equipotential lines) are perpendicular to this boundary.

b. Constant head boundary

- This could be the boundary with open water bodies such as perennial rivers, lakes or seas. The flow lines are perpendicular to this open water bodies.

c. Water table (variable head) boundary

- It is the boundary which may be influenced by recharge or discharge from an aquifer. Water table may be served as constant head boundary if there is no recharge/discharge and not influenced by other phenomena in which water table is fairly constant.

Cont...

2.5.2. Flow in relation to GW Contours

- Contour maps of water levels (both unconfined and confined aquifers) are made in the majority of hydro geologic investigations and, when properly drawn, represent a very powerful tool in aquifer studies.
- At least several data sets collected in different hydrologic season should be used to draw GW contour maps for the area of interest.
- In addition to recordings from piezometers, monitoring and other wells, every effort should be made to record elevations of water surface in the nearby surface streams, lakes, seas, ponds and other bodies including cases when these bodies seem "too far" to influence GW flow pattern.

cont….

Determination of groundwater flow direction

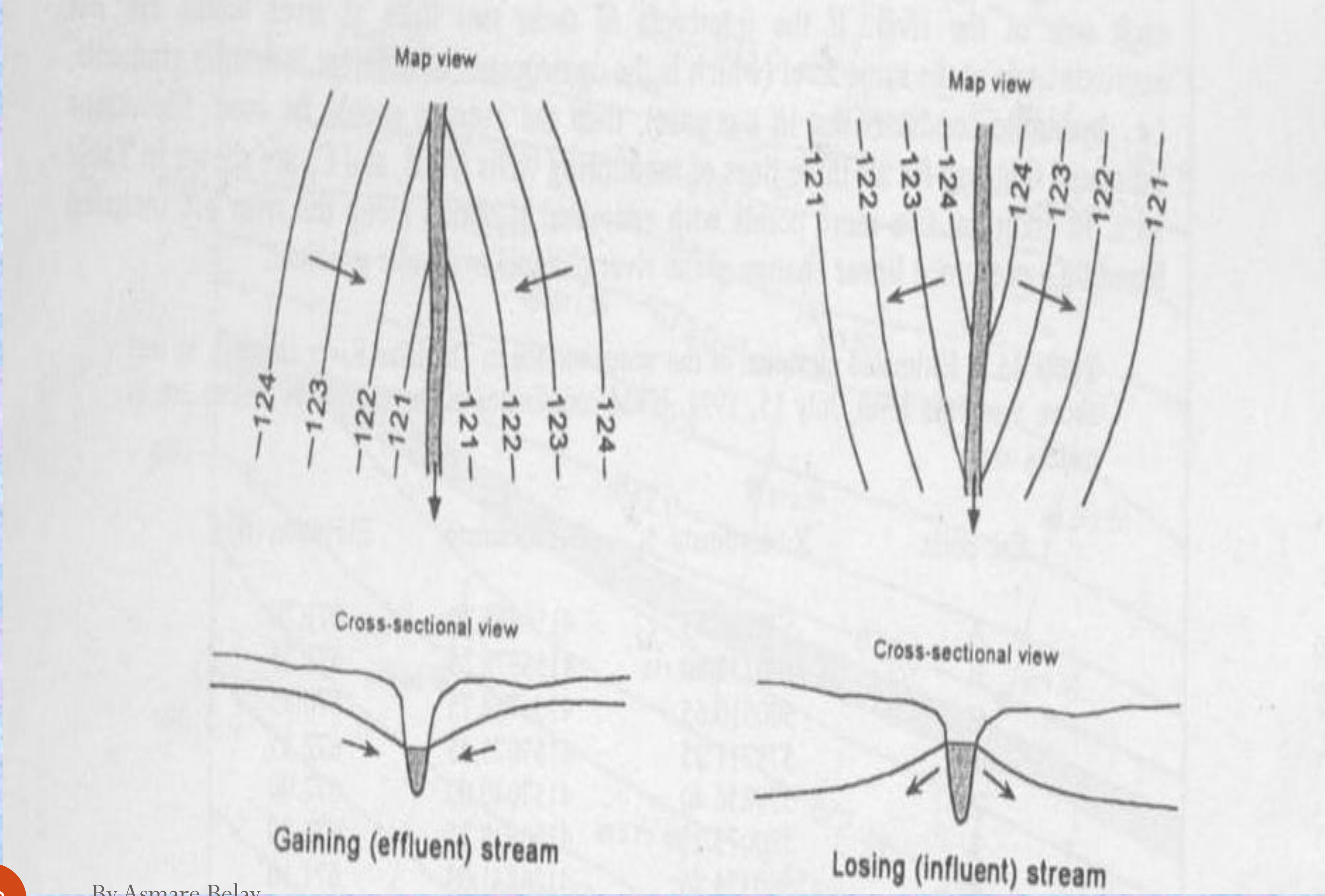
The direction of GW flow in a localized area of an aquifer can be determined if at least three recordings of water table (piezoelectric surface) elevations are available.

- Contouring Methods

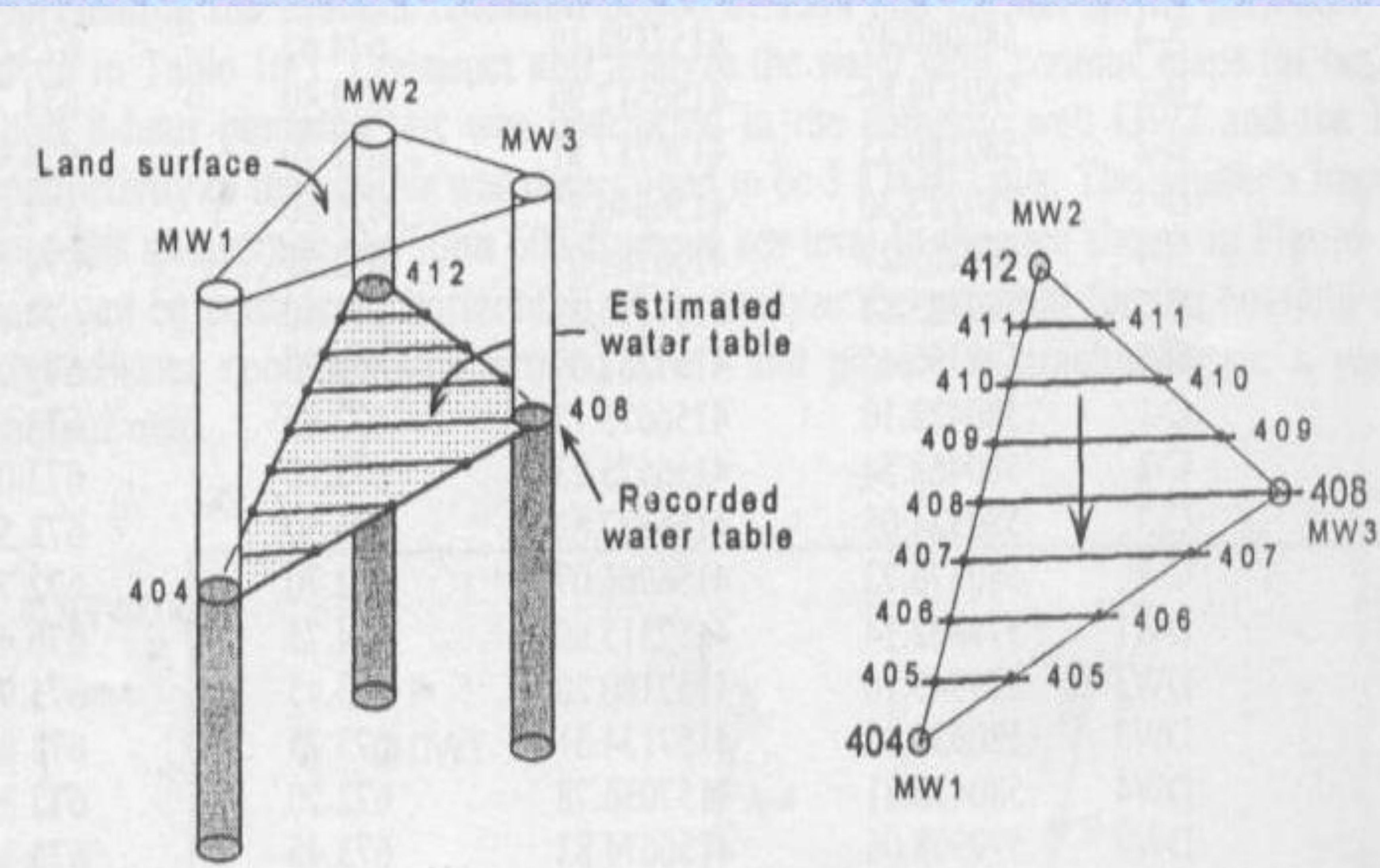
1.Manaul contouring 2. Contouring with computer programs

- **Manual contouring**
- Manual contouring is practically always used in GW studies
- Manual contouring is essentially based on triangular linear interpolation combined with the hydro geologic experience of the interpreter.

Cont…


Map view
124
123
122
121
121
122
123
124
Map view
121
122
123
124
124
123
122
121
Cross-sectional view
Gaining (effluent) stream
Cross-sectional view
Losing (influent) stream

Cont…



MW2
MW3
Land surface
MW1
412
Estimated water table
408
Recorded water table
404
MW2
412
411
411
410
410
409
409
408
408
MW3
407
407
406
406
405
405
404
MW1

Cont…

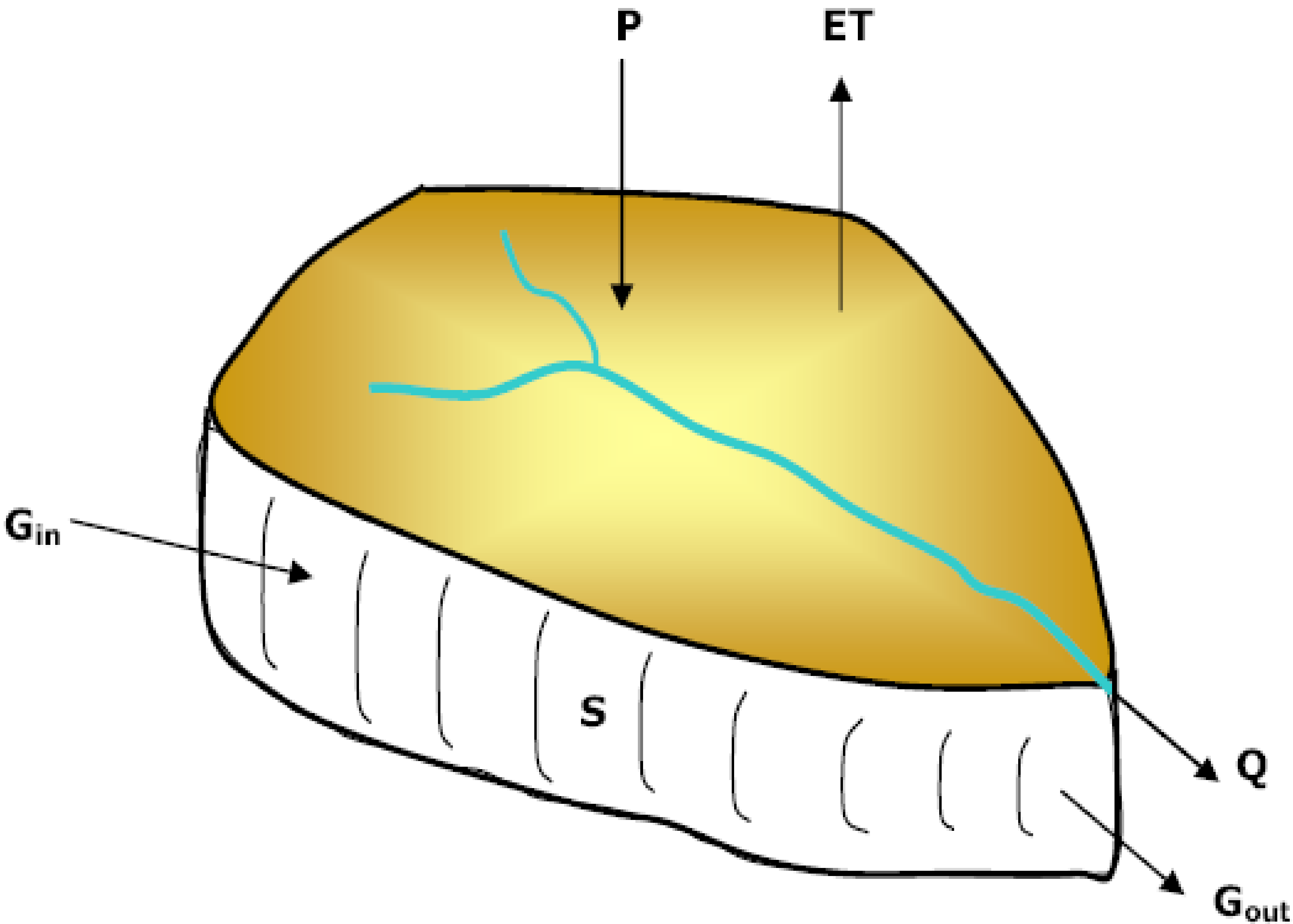
Contouring with computer programs

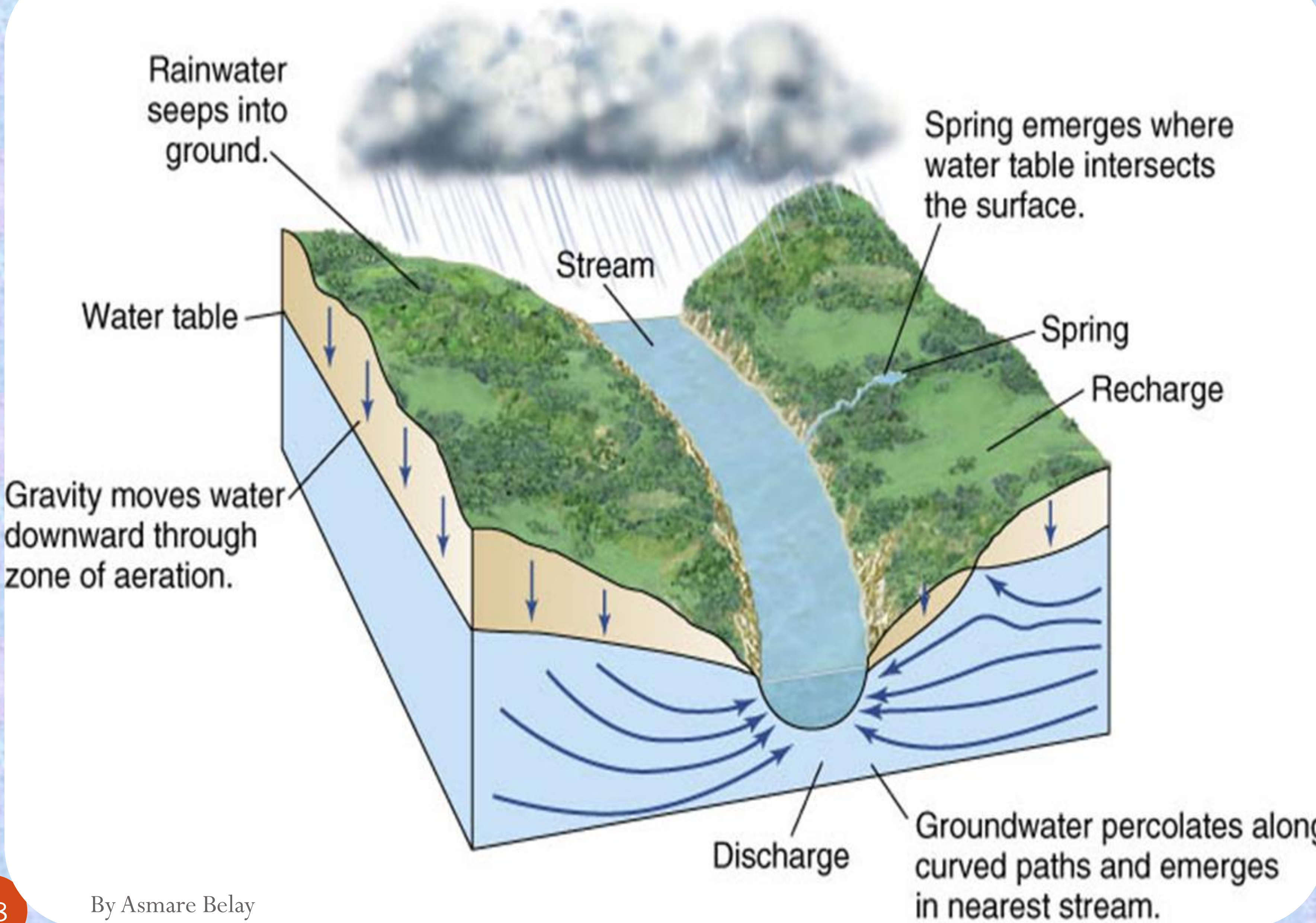
- Some of them may be ArcView GIS, Surfer Golden software, AutoCAD and so on…
- Most of them need elevation of GW levels as an input.

2.6. Ground water flow equations

Watershed Hydrologic Budgets

- Delineation of a watershed (drainage basin, river basin, catchment)
- Area that topographically appears to contribute all the water that flows through a given cross section of a stream. In other words, the area over which water flowing along the surface will eventually reach the stream, upstream of the cross-section.
- Horizontal projection of this area is the drainage area.
- The boundaries of a watershed are called a divide, and can be traced on a topographic map by starting at the location of the stream cross-section then drawing a line away from the stream that intersects all contour lines at right angles. If you do this right, the lines drawn from both sides of the stream should intersect. Moving to either side


P
ET
G_{in}
S
Q
G_{out}



Rainwater seeps into ground.
Spring emerges where water table intersects the surface.
Stream
Water table
Spring
Recharge
Gravity moves water downward through zone of aeration.
Discharge
Groundwater percolates along curved paths and emerges in nearest stream.

1.Water or mass balance Equation

- $\frac{\partial S}{\partial t} = P + G_{in} - (Q + ET + G_{out})$
- At steady-state: $\frac{\partial S}{\partial t} = 0$

$$There\ fore,\ P + G_{in} - (Q + ET + G_{out}) = 0$$

From an engineering point of view, we are interested in what controls the over all discharges (Q),

$$Q = P + (G_{in} - G_{out}) - ET$$

Cont……

2.Diffusion equation (transient flow)

3. Laplace equation (steady state flow)

4. Two Dimensional ground water flow

Thank you!!!!