FACTORS CONTROLLING MOVEMENT OF GROUND WATER

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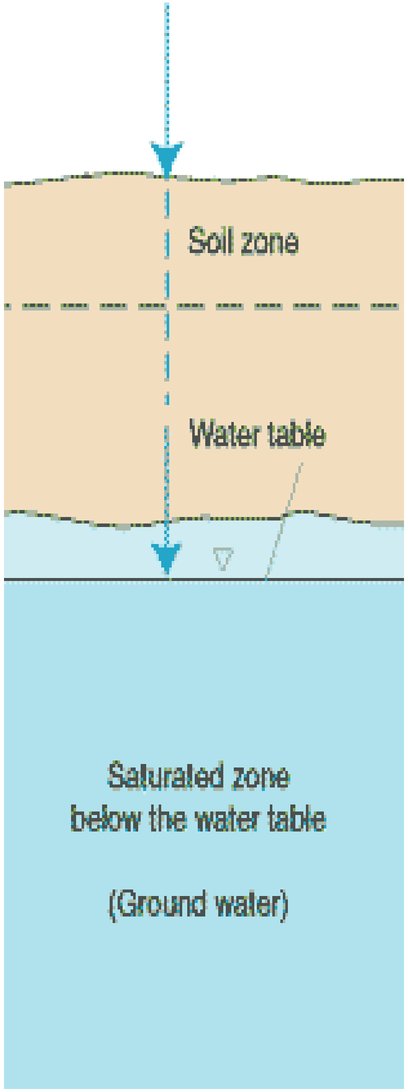
WHAT IS GROUND WATER ?

All subsurface water that fills the pores, fractures, and other spaces in rock strata in the saturated zone of geologic formations.

PROCESSES AND PRINCIPLES



Infiltration

Percolation

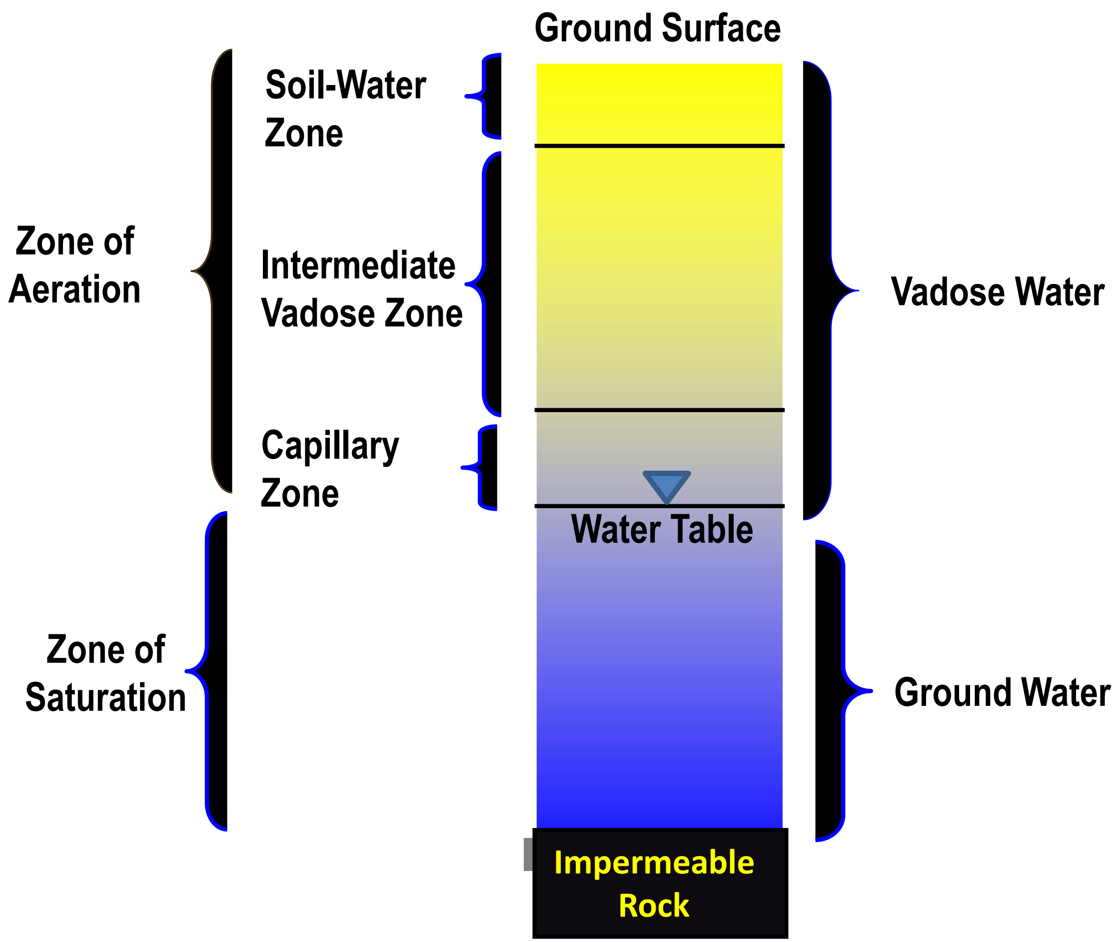
Formation of recharge mound

INFILTRATION & PERCOLATION

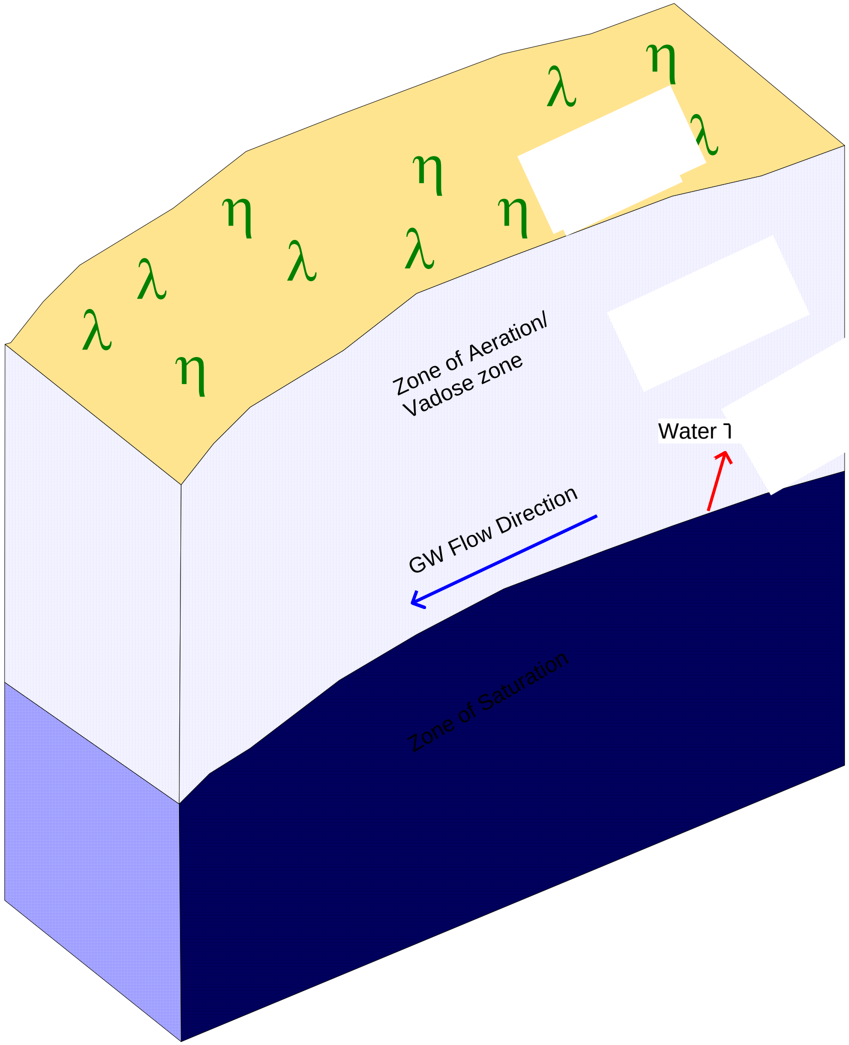
- Infiltration is the process of absorption of water from rainfall or other surface water bodies into the ground.

- The term percolation is used to denote the transit of in filtered water through the unsaturated zone.

Vertical distribution of ground water



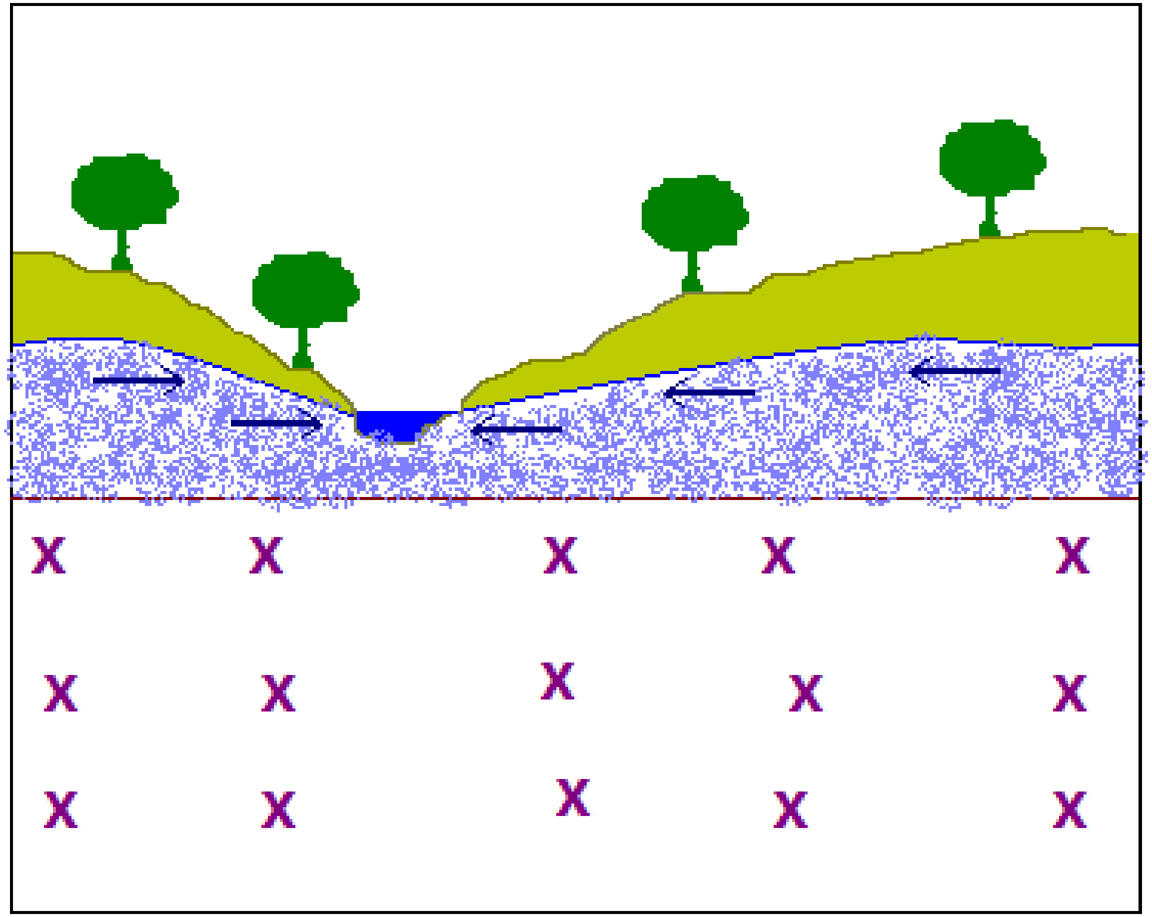
ZONE OF AERATION AND ZONE OF SATURATION



WATER TABLE & WATER LEVEL

- Top level of 'ZONE OF SATURATION'

GROUND WATER MOVEMENT



DRY SEASON FLOW IN THE RIVER IS FROM GROUND WATER

WATER BEARING FORMATIONS

- Aquifer
- Aquitard
- Aquiclude
- Aquifuse

AQUIFER

An aquifer is a geological formation that is saturated and permeable enough to yield sufficient amount of water to wells and springs.

Ex. Sand, Gravels.

AQUITARD

Aquitard is a saturated geological formation of low permeability that can store ground water and also transmit it slowly from one aquifer to another.

Ex: Sandy clay.

AQUICLUDE

Aquiclude is a saturated but relatively impermeable geological formation that does not yield appreciable quantities of water to wells.

Ex: Clay

AQUIFUSE

A relatively impermeable geological formation neither containing nor transmitting water.

Ex.: Solid Granite

TYPES OF AQUIFERS

- Unconfined Aquifer
- Confined Aquifer
- Semi-Confined Aquifer

UNCONFINED AQUIFER

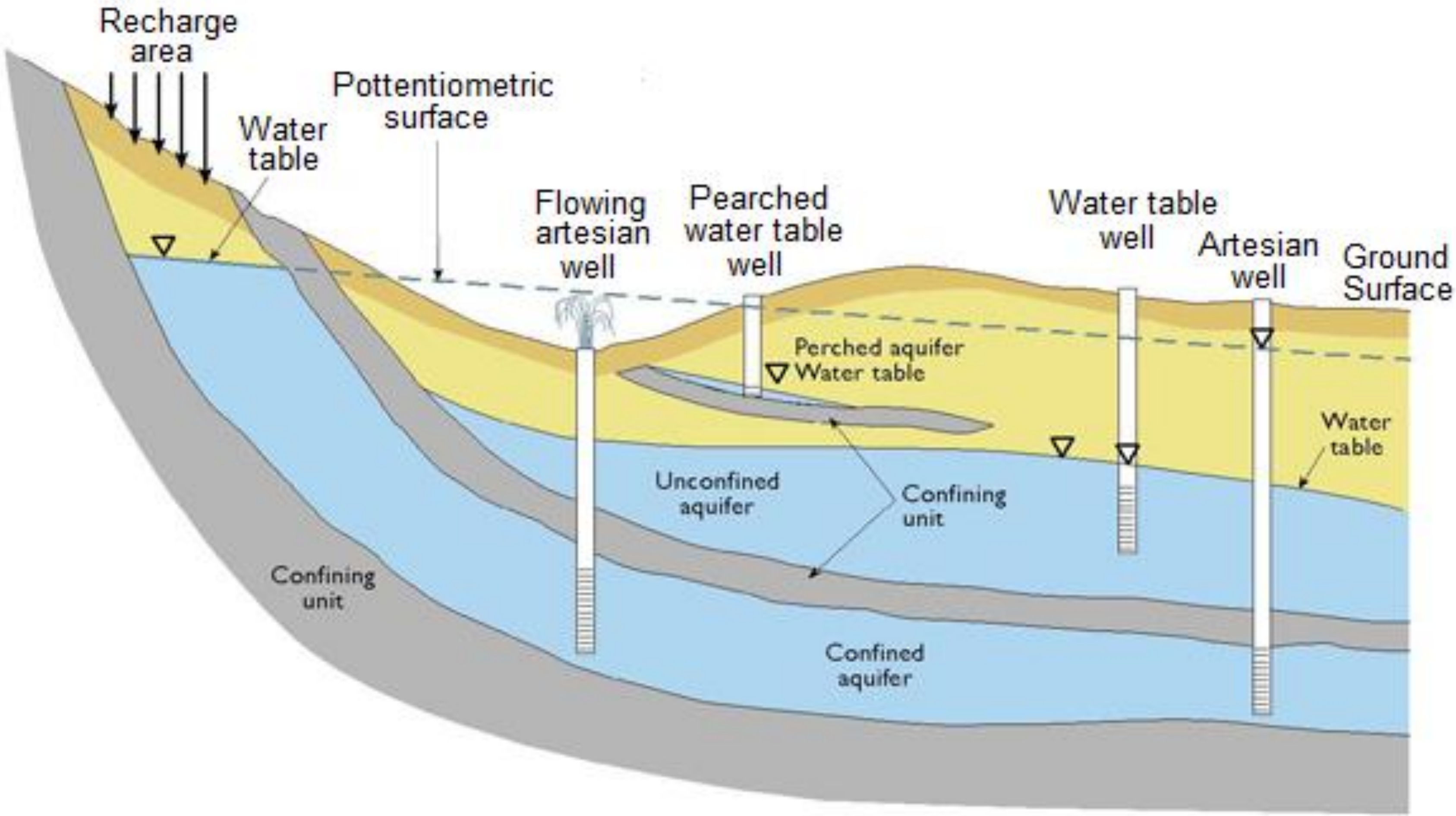
An unconfined aquifer is one in which a water table varies in undulating form and in slope, depending on areas of recharge and discharge, pumping from wells, and permeability.

CONFINED AQUIFER

Confined aquifer is one in which ground water is confined under pressure greater than the atmospheric by overlying impermeable strata.

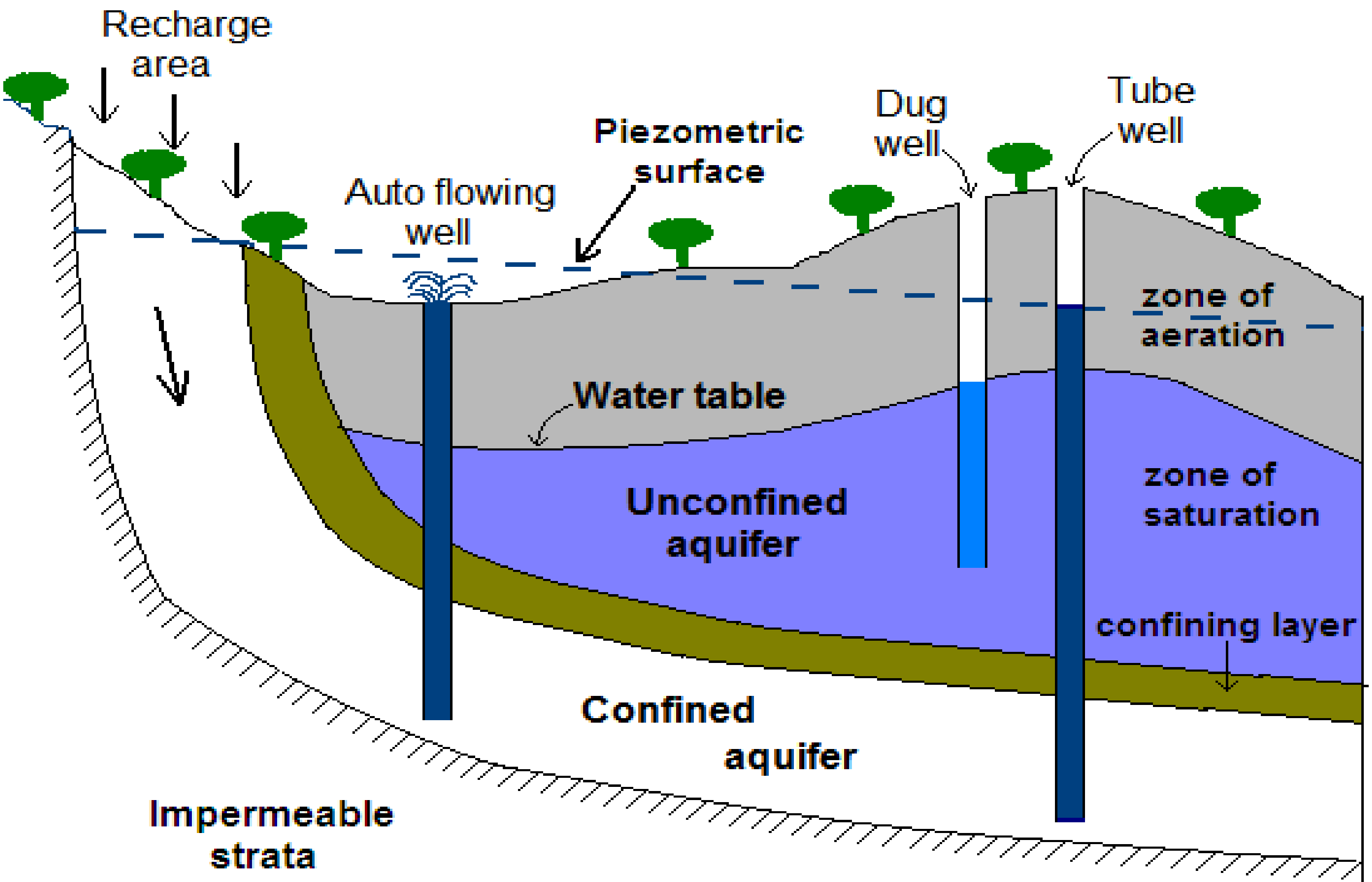
SEMI-CONFINED AQUIFER

Semi-confined aquifer is a permeable stratum which is overlain or underlain by a semi-pervious aquitard or semi-confining layer.

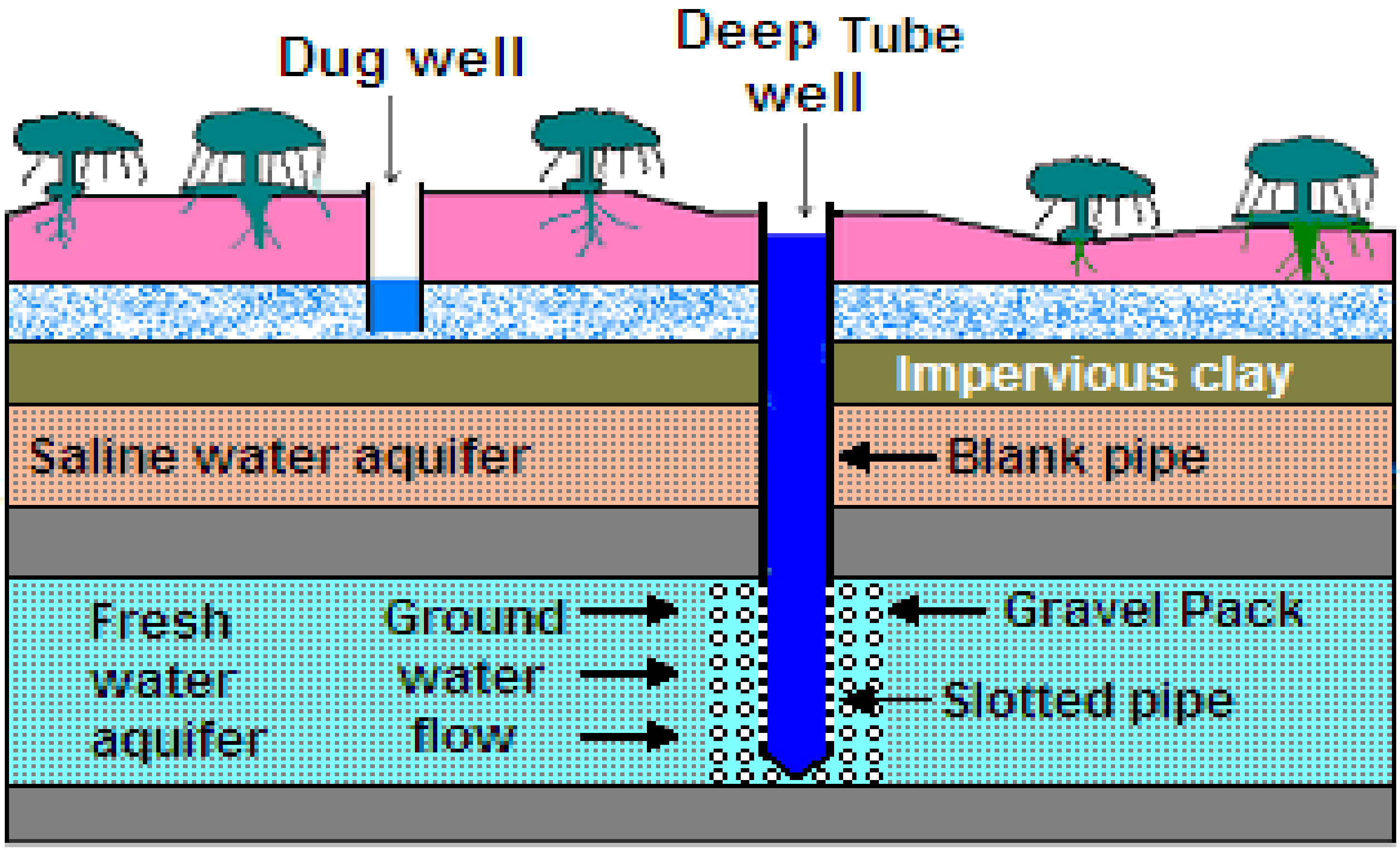


Schematic Cross-sections of Aquifer Types

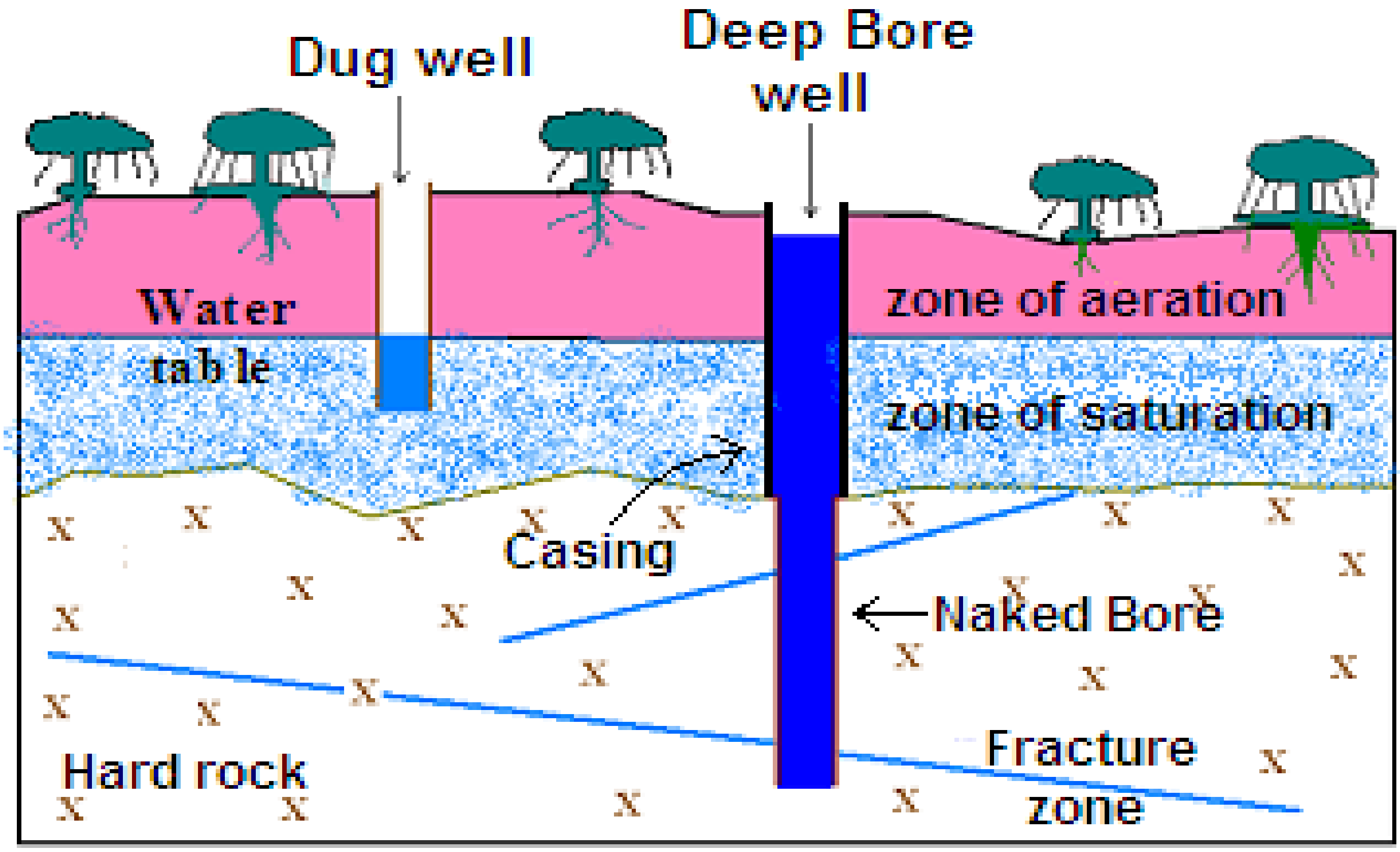
Vertical distribution of ground water



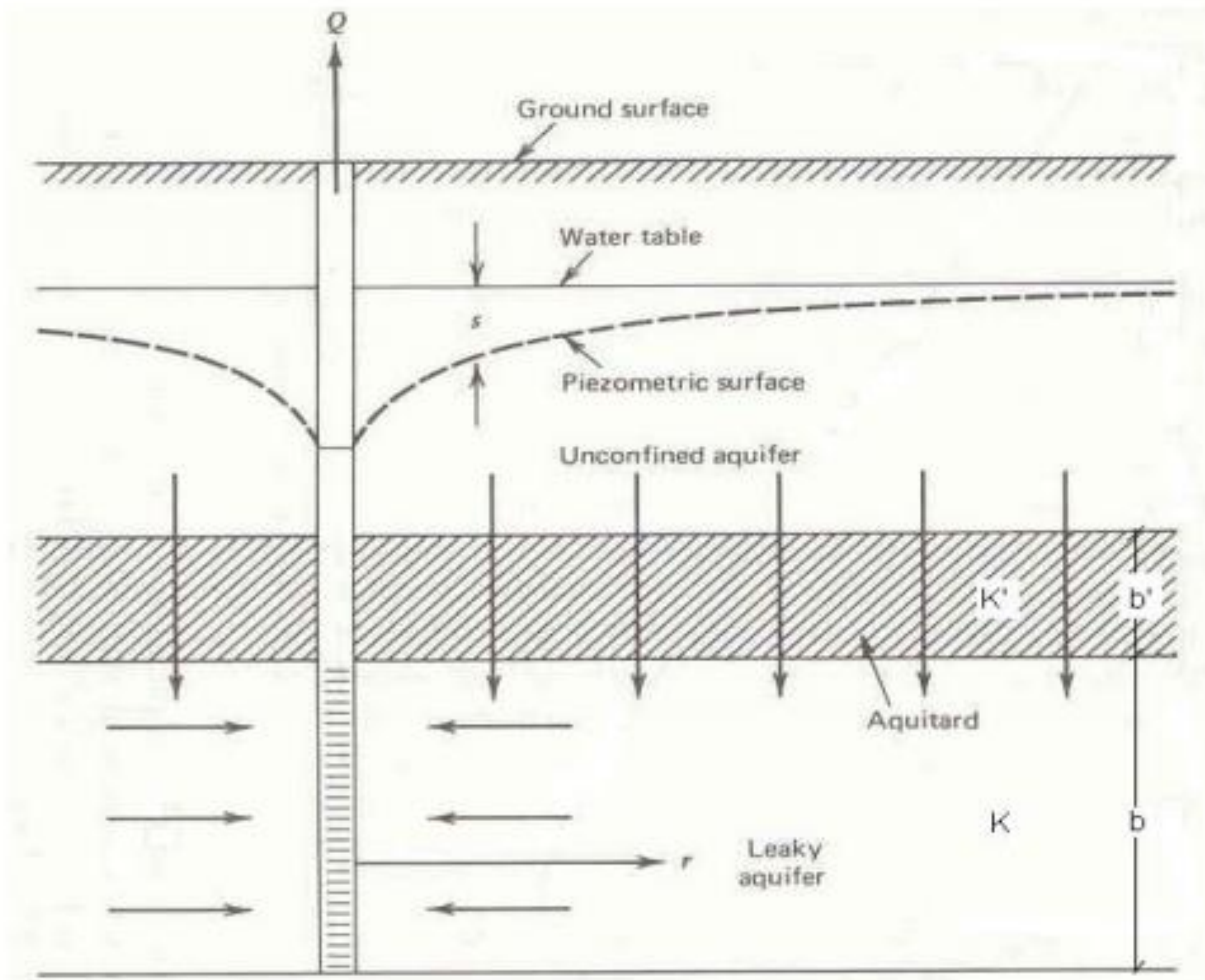
Disposition of aquifers in soft rock terrain



Disposition of aquifers in hard rock terrain



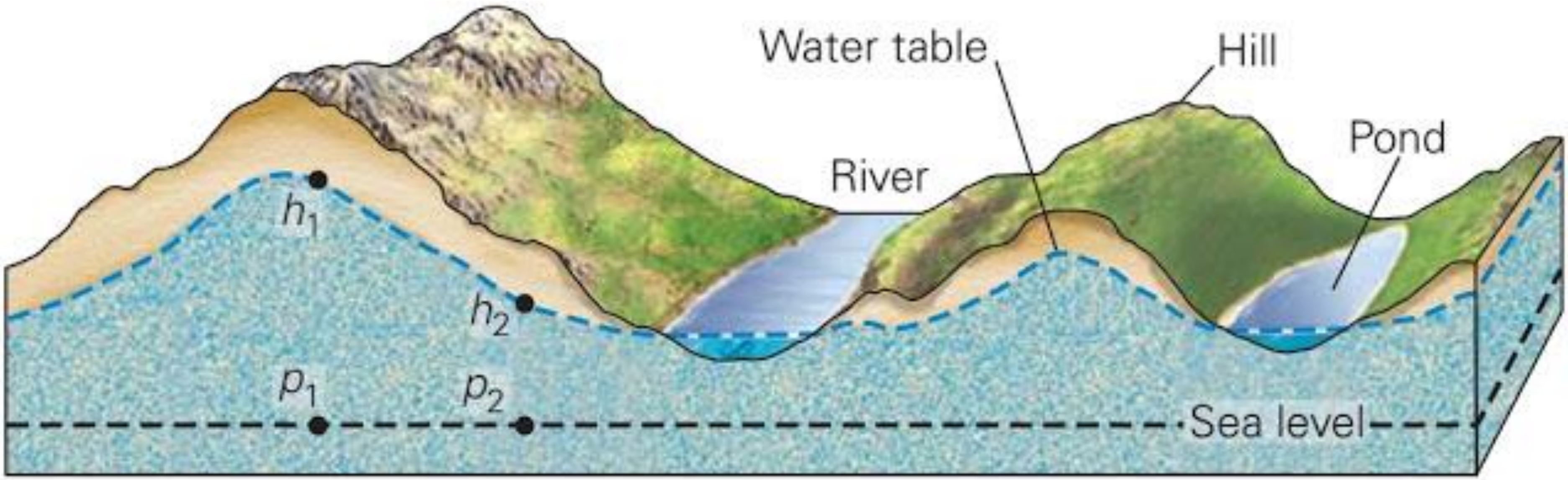
LEAKY AQUIFER



FACTORS CONTROLLING GW MOVEMENT

- Gravity
- Topography
- Aquifer Material: consolidation of material
- Aquifer Properties: porosity, permeability
- Aquifer Parameters: K, T, S, Sy
- Hydraulic Gradient: change in head/unit distance
- Recharge and Discharge Areas
- External boundaries
- Location of Wells
- Rate of Pumping

SLOPE CONTROLLING GROUND WATER MOVEMENT



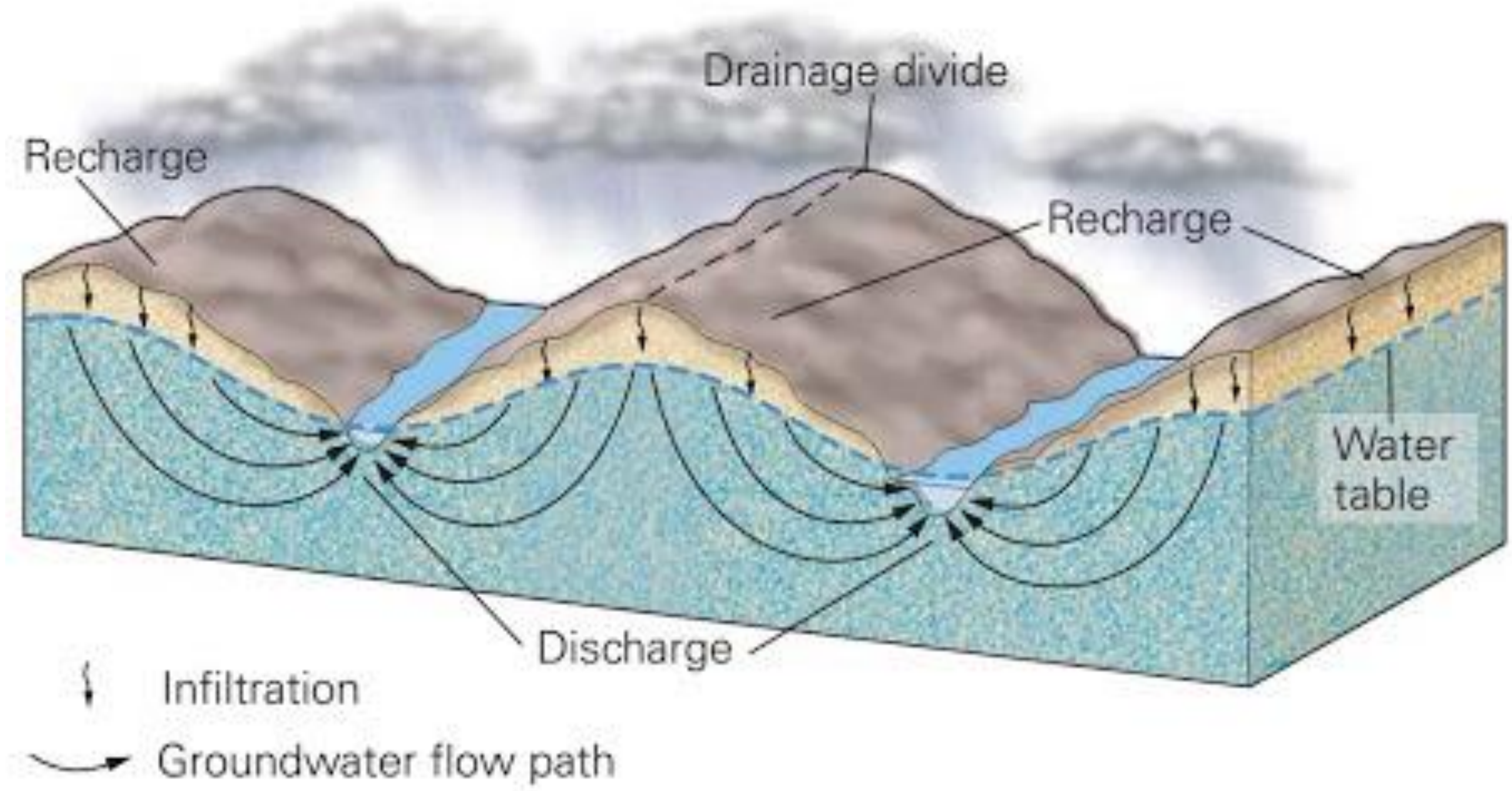
AQUIFER PARAMETERS

- Permeability
- Conductivity or Coefficient of Permeability
- Transmissivity
- Specific Yield
- Storativity or Coeffcient of Storage

WELL PARAMETERS

- Diameter
- Depth
- Parapet
- Depth of Lining, etc.
- Yield
- Specific Capacity

RECHARGE AND DISCHARGE AREAS



POROSITY

The porosity of a geological formation is a measure of its interstitial space.

Properties of the Medium

- ***Primary porosity*** is the inherent character of a rock which is developed during the formation of the rock itself.
- ***Secondary porosity*** is the induced character and is developed subsequent to the formation of rocks.

Properties of the Medium

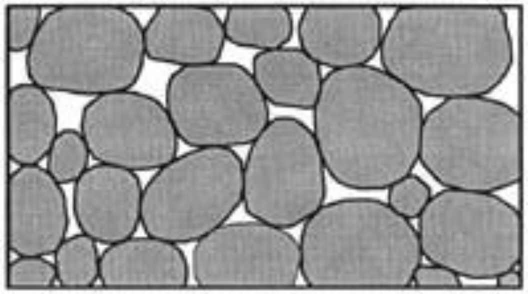
Porosity in sedimentary formations is controlled by:

- Shape and arrangements of constituent grains
- Degree of sorting
- Degree of compaction and cementation
- Packing of particles.

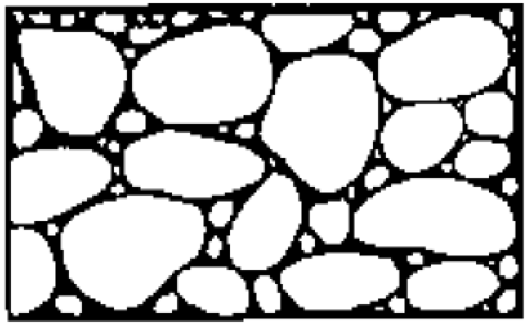
Properties of the Medium

- Shape: Angularity tends to increase porosity.
- Sorting:
  - ***Well sorted*** clastic material has high porosity irrespective of grain size.
  - ***Poorly sorted*** material has less porosity (small-size grains occupy pore spaces between bigger grains).
- Compaction and cementation: reduces porosity.
  - Porosity at deeper levels is less due to compaction, e.g. shales have lower porosity than clays.

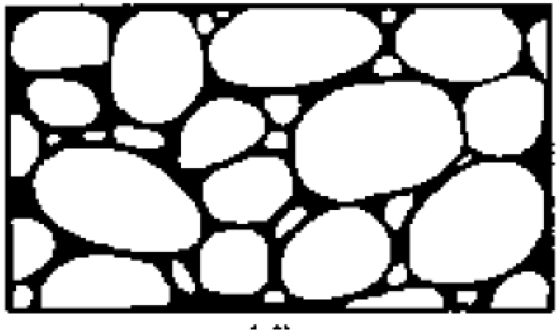
Rock texture and porosity



Well sorted sedimentary deposit with high porosity



Poorly sorted sedimentary deposit with low porosity



Porosity reduced by cementation

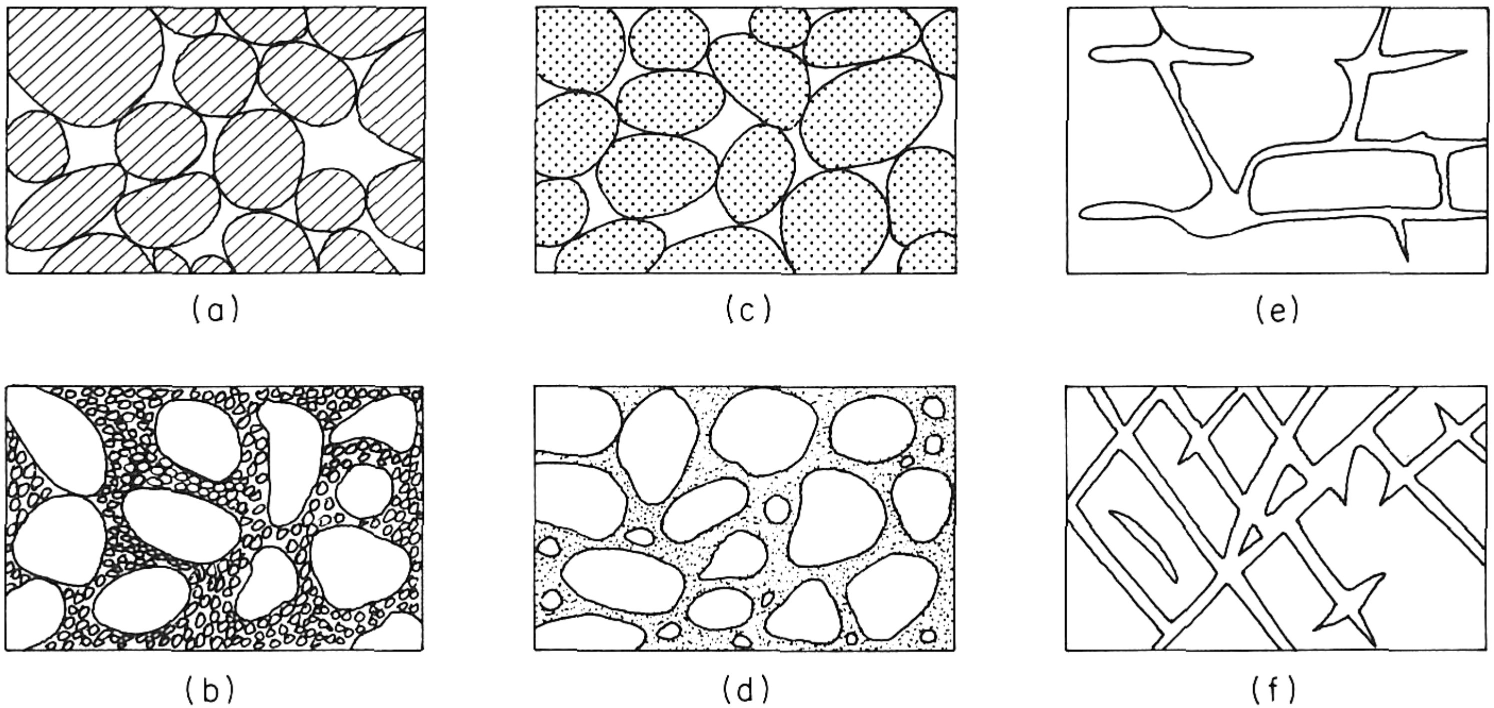
Relation between Packing & Porosity

The geometrical arrangement of constituent grains (packing) and sorting have important influence on porosity.

(a) Square packing ($n = 47.6\%$) (Loosest state of packing)

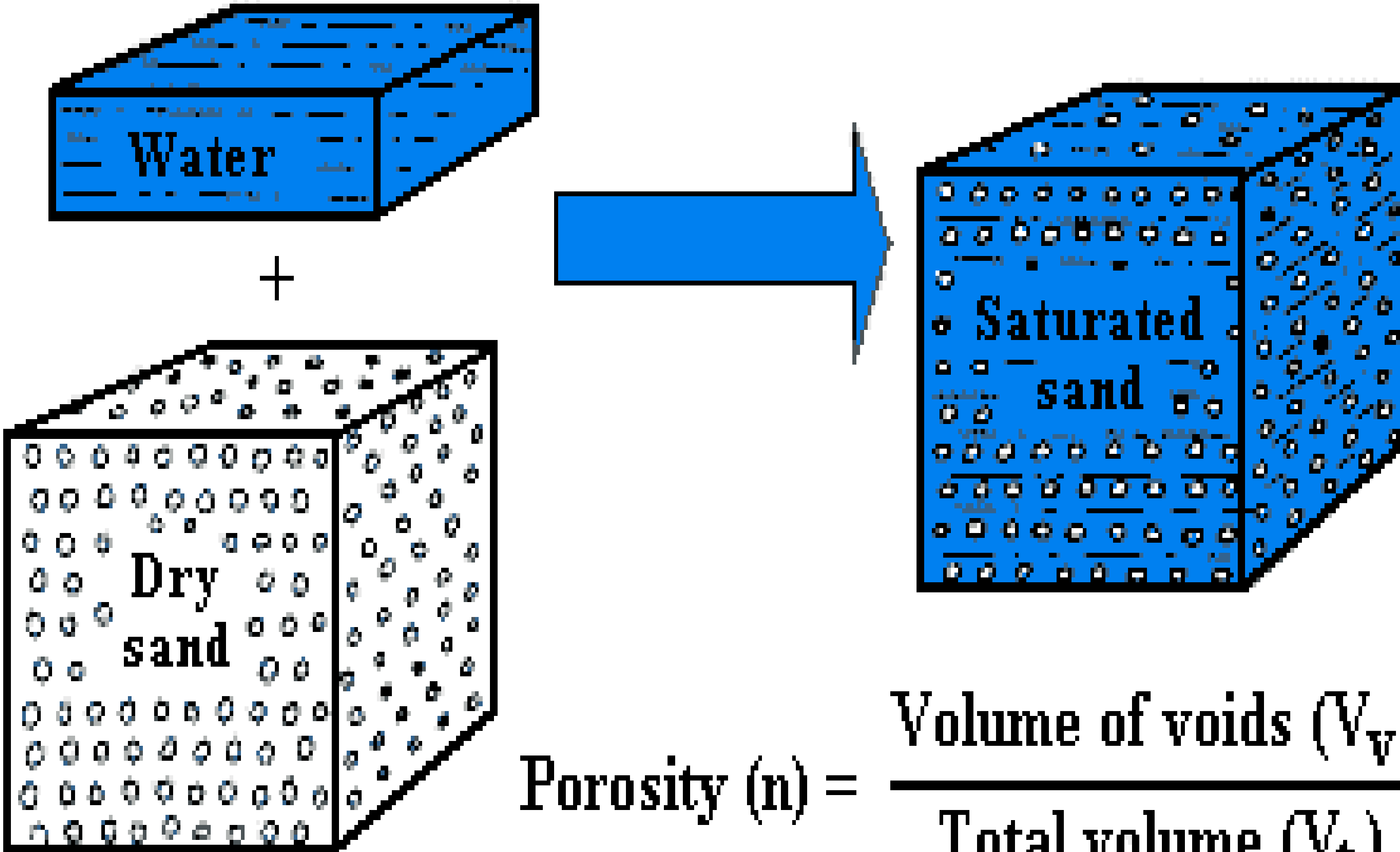
(b) Rhombic packing ($n = 26\%$)

Types of Porous Media

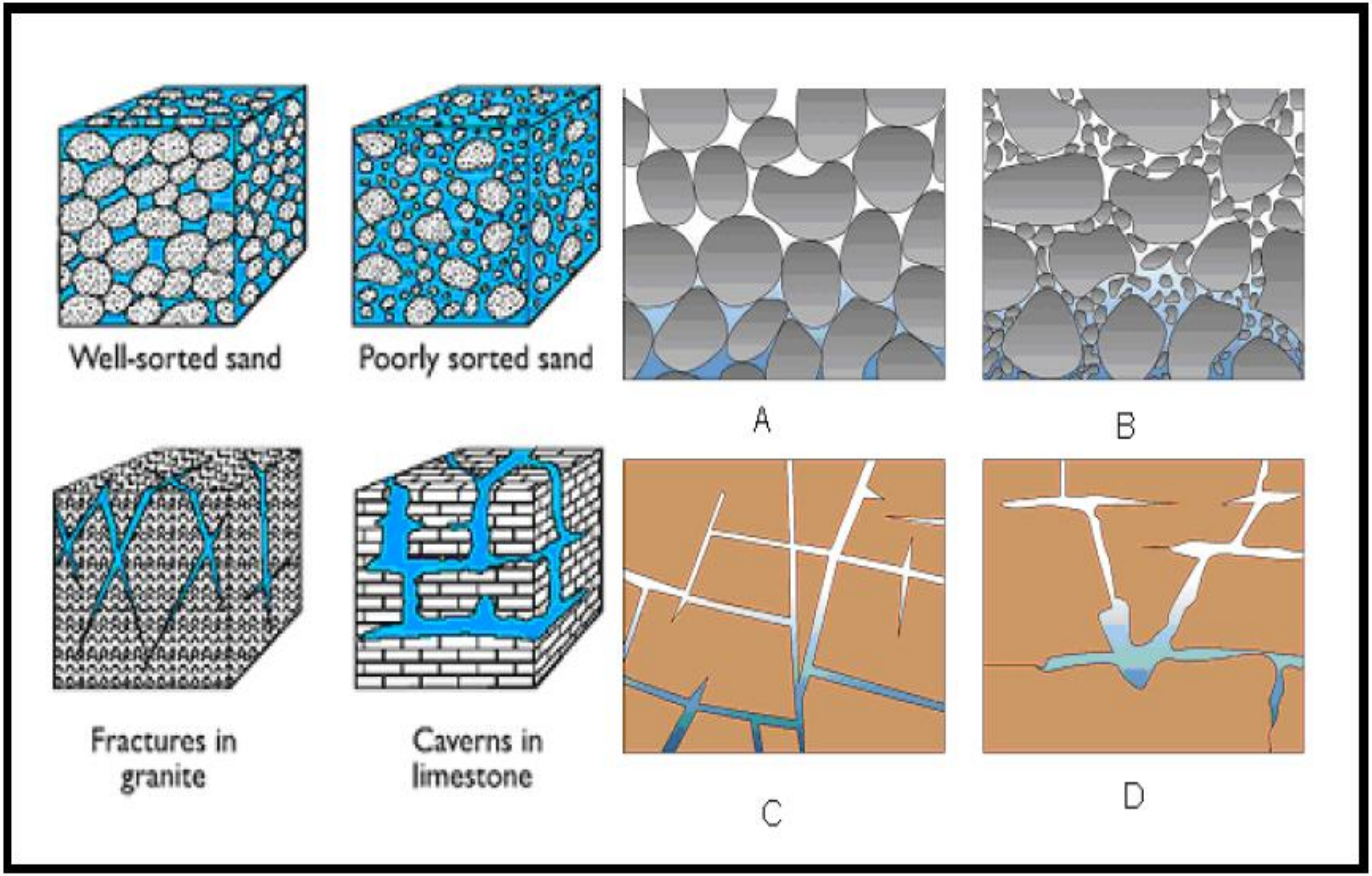


$$n = V_V / V_T = \text{Vol. of Voids / Total Vol.}$$

Freeze and Cherry, 1979.



$$\text{Porosity } (n) = \frac{\text{Volume of voids } (V_v)}{\text{Total volume } (V_t)}$$



Relations Between Texture and Porosity A. Well - Sorted Sand Having High Porosity; B. Poorly - Sorted Sand Having Low Porosity; C. Fractured Crystalline Rocks (Granite); D. Soluble Rock-Forming Material (Limestone).

Formation	*n* (%)
Unconsolidated deposits	
Gravel	25 - 40
Sand	25 - 50
Silt	35 - 50
Clay	40 - 70
Rocks	
Fractured basalt	5 - 50
Karst limestone	5 - 50
Sandstone	5 - 30
Limestone, dolomite	0 - 20
Shale	0 – 10
Fractured crystalline rock	0 - 10
Dense crystalline rock	0 – 5

Range of Values of Porosity (after Freeze & Cherry, 1979)

SPECIFIC RETENTION

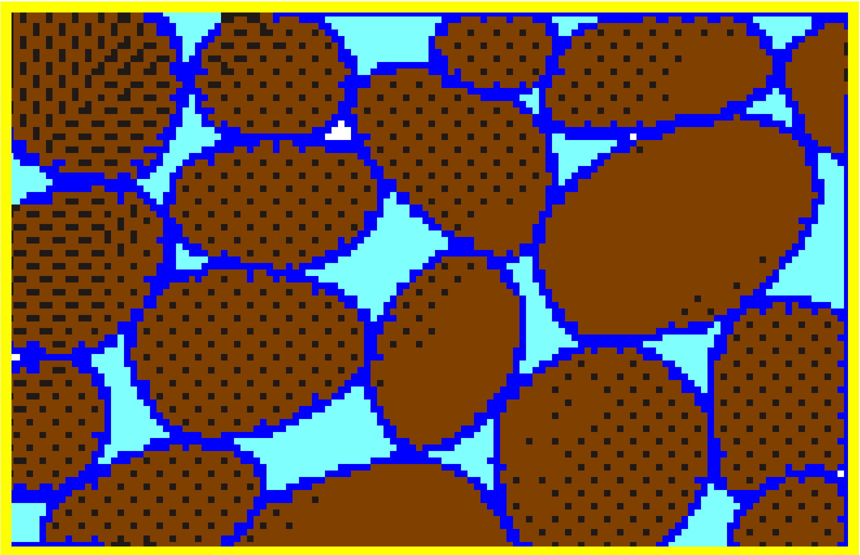
Specific Retention (Sr) of a soil or rock is the ratio of the volume of water it will retain after saturation against the force of gravity to its own volume.

$$Sr = Wr/V$$

SPECIFIC YIELD

Specific Yield (Sy) of a soil or rock is the ratio of the volume of water that can be drained by gravity to its own volume.

$$Sy = Wy/V$$

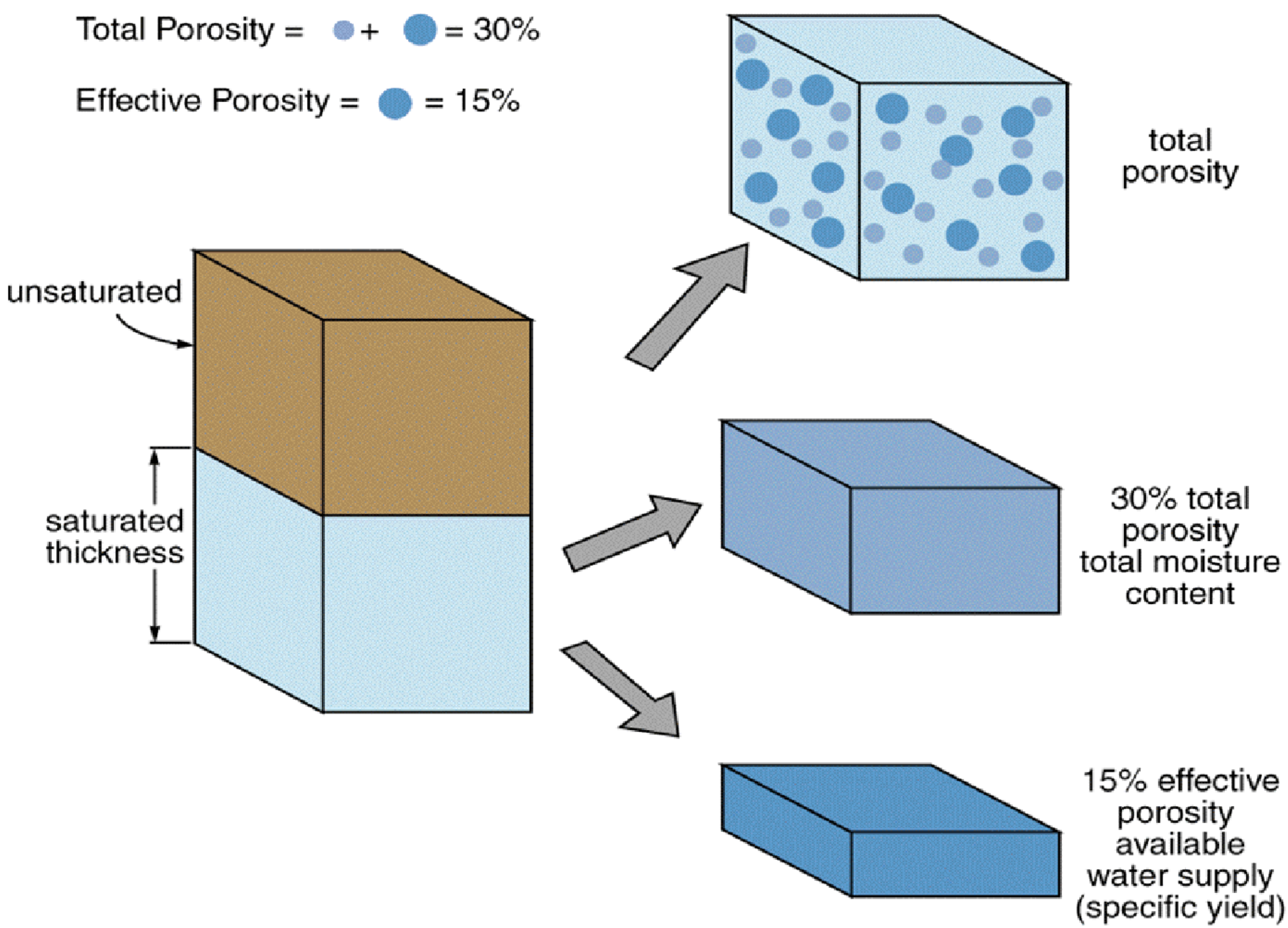


Porosity =

Specific Retention + Specific Yield

$$P = Sr + Sy$$

POROSITY AND EFFECTIVE POROSITY



DARCY'S LAW

Velocity of Flow through a porous media is proportional to the head loss and inversely proportional to the length of the flow path.

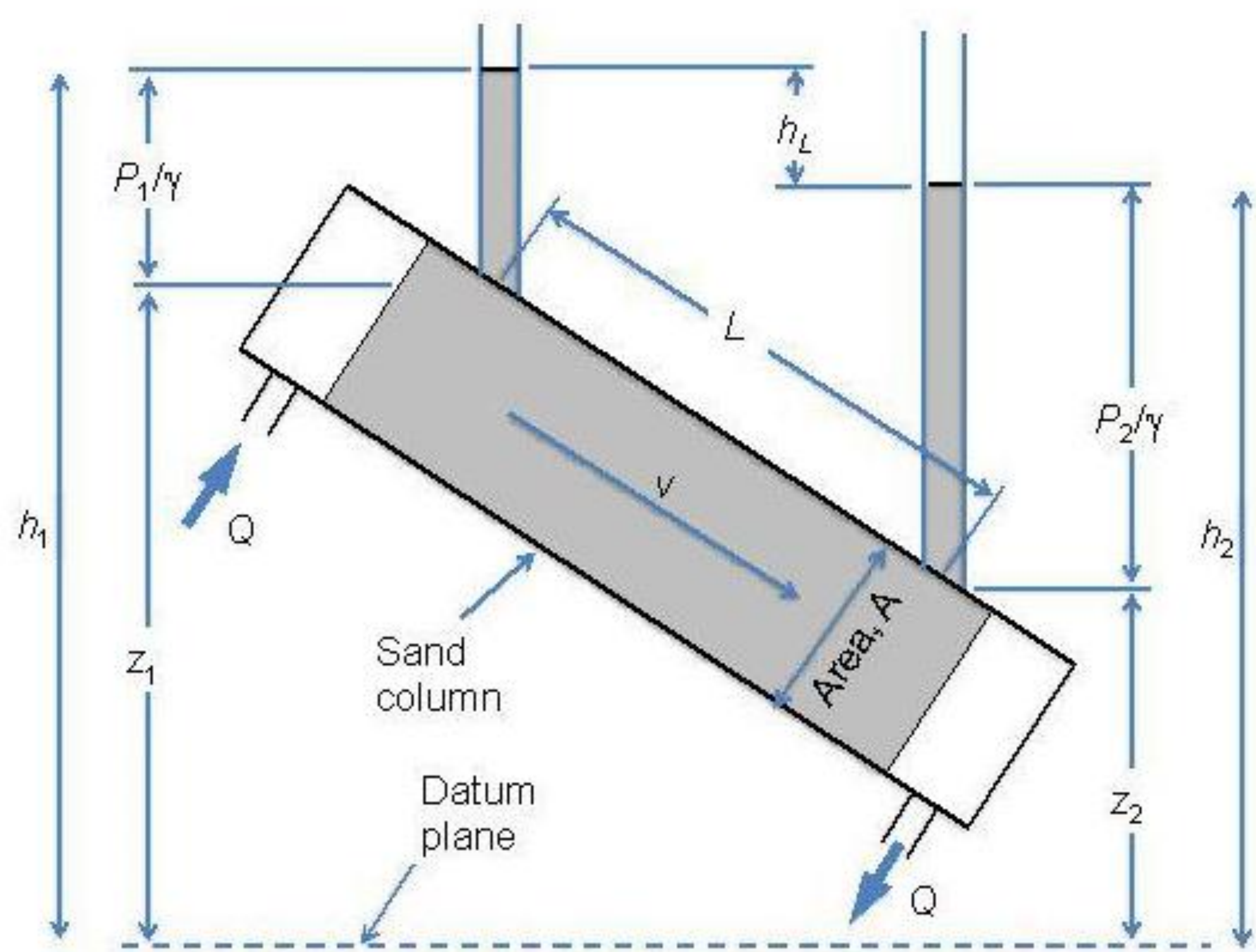
$$v \sim h_L$$

&

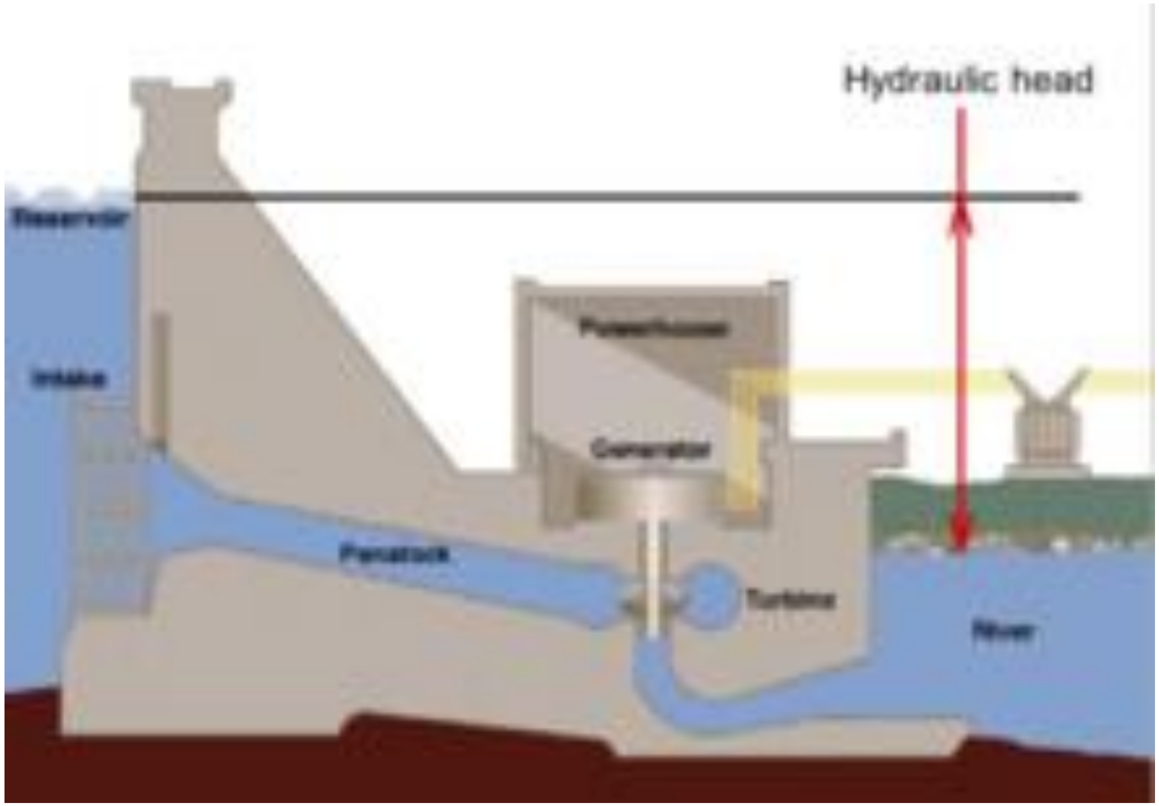
$$v \sim \frac{1}{L}$$

HENRY PHILIBERT GASPARD DARCY
(10 June 1803 – 3 January 1858)

DARCY'S EXPERIMENT



HYDRAULIC HEAD



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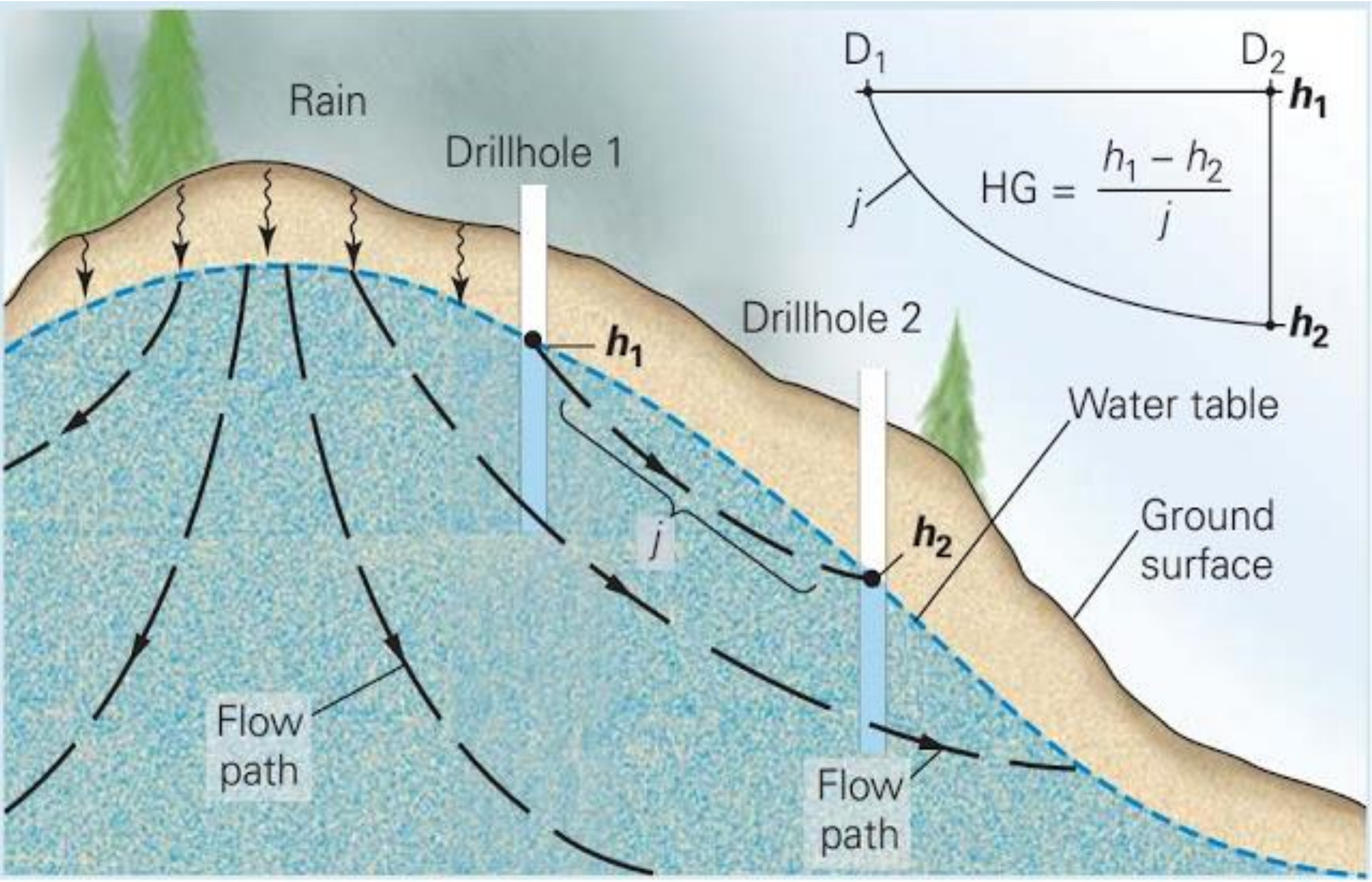

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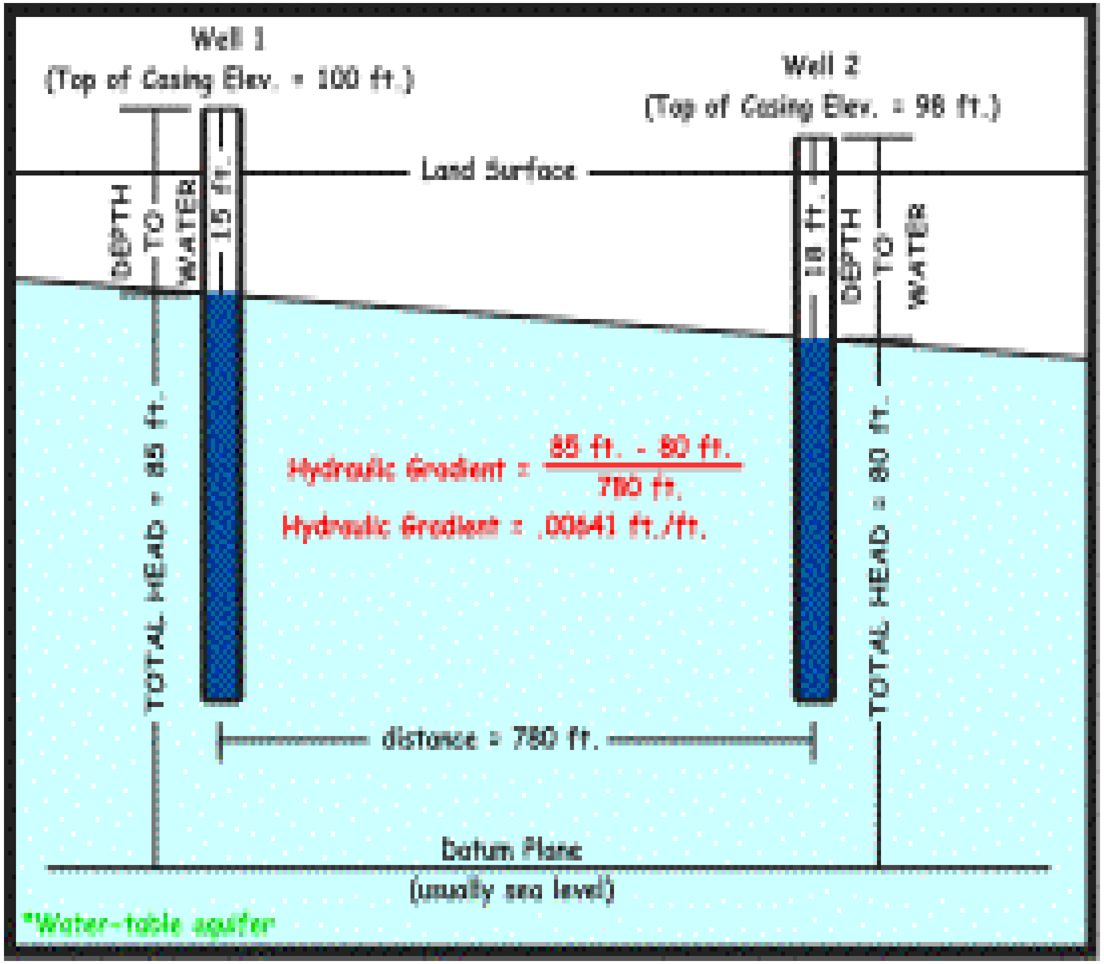
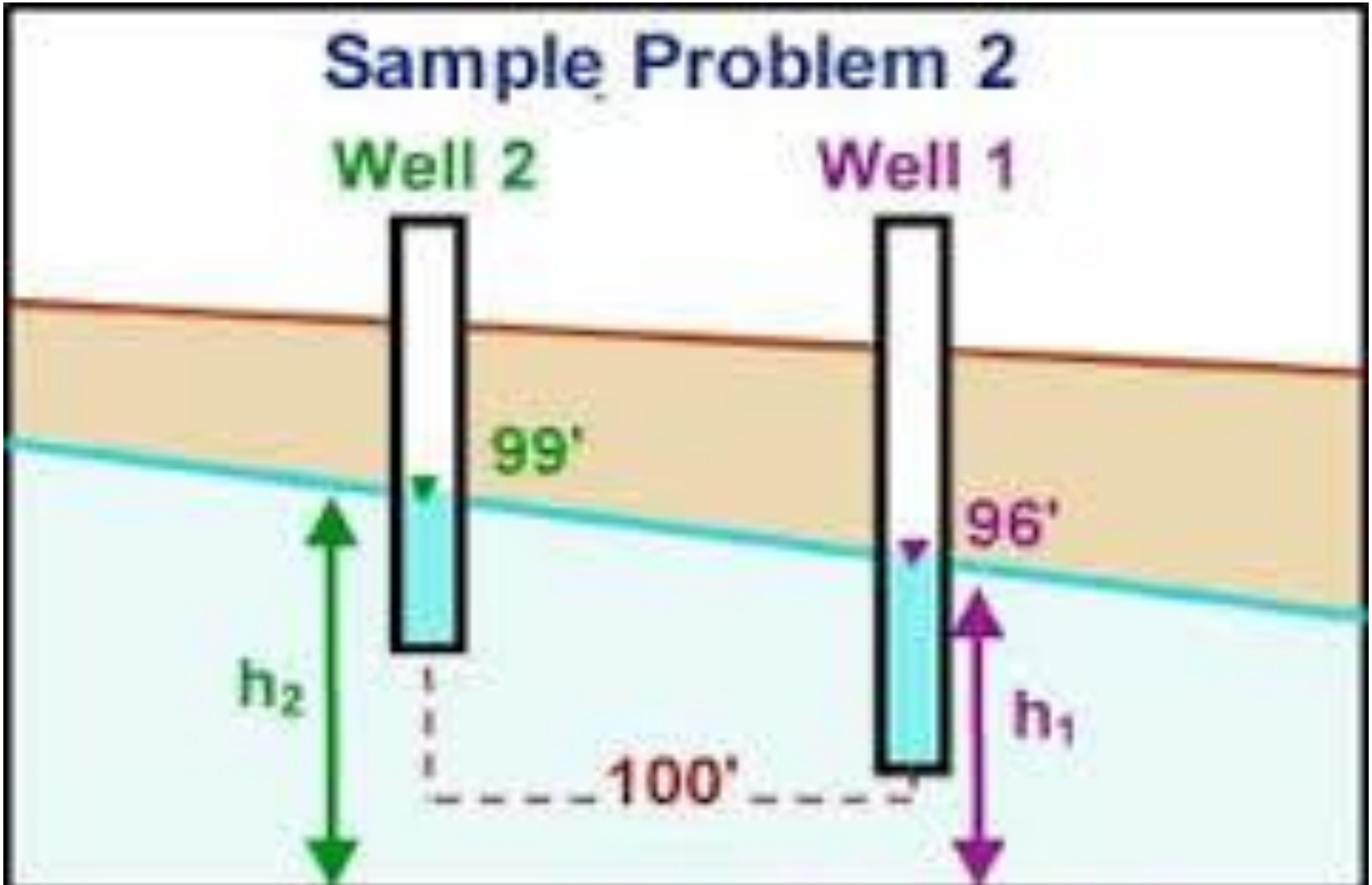
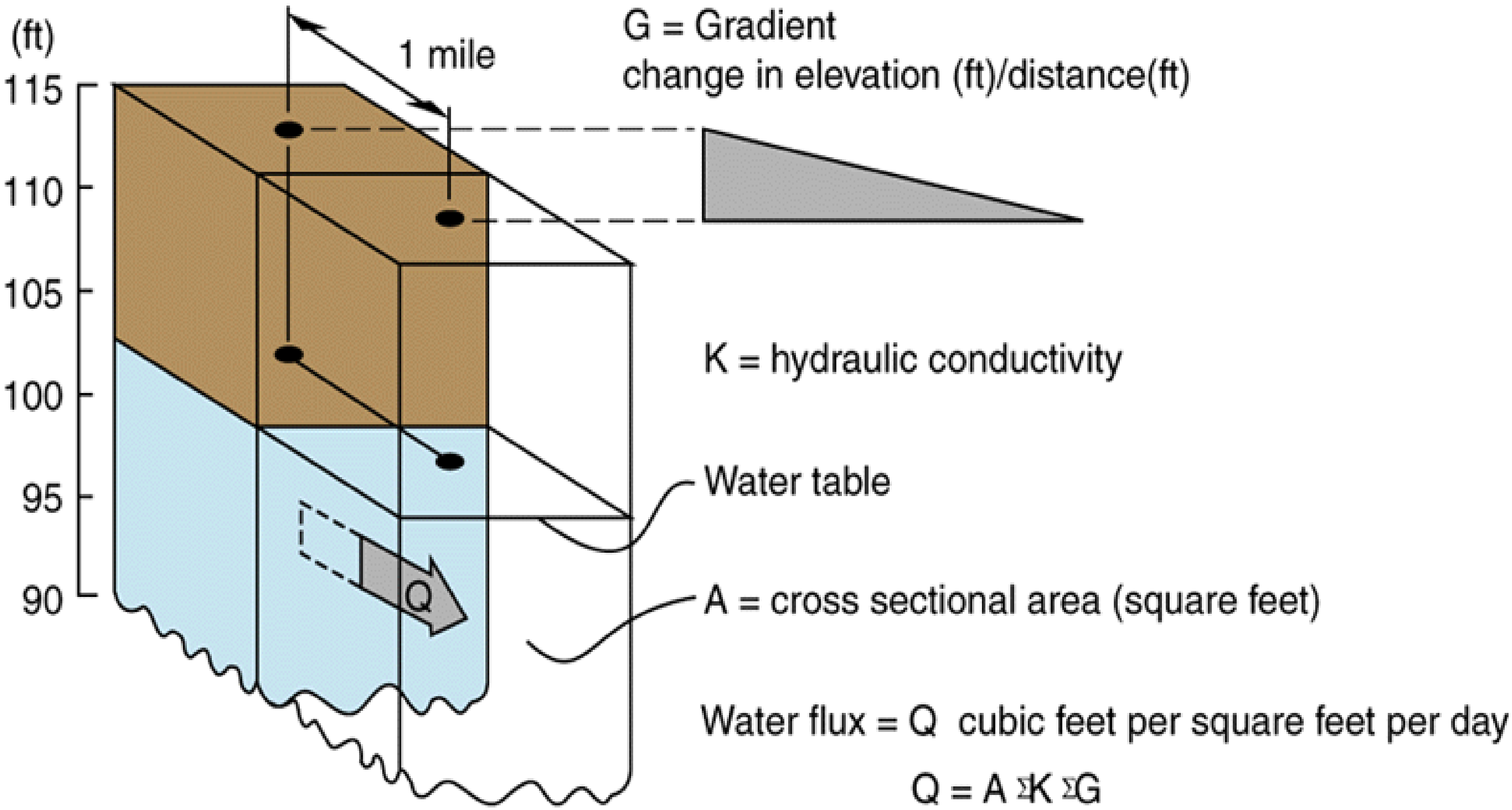


HYDRAULIC HEAD



ROLE OF HYDRAULIC GRADIENT



BERNOULLI’S PRINCIPLE

The total energy at a given point in a fluid is (1) the energy associated with the movement of the fluid, plus (2) energy from static pressure in the fluid, plus (3) energy from the height of the fluid relative to an arbitrary datum.

BERNOULLI'S EQUATION

Where p = pressure, Y = specific weight,

v = velocity of flow, g = acceleration of gravity,

z = elevation, h_L= headloss

$$\frac{p_1}{\gamma} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\gamma} + \frac{v_2^2}{2g} + z_2 + h_L$$

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

HYDRAULIC RESISTANCE

- Friction resistance
  - hydraulic resistance is due to momentum transfer to the solid walls
- Local resistance
  - Local resistance is caused by dissipation of mechanical energy when the configuration or the direction of flow is sharply changed, by the formation of vortices and secondary flows as a result of the flow breaking away, by the centrifugal forces, etc.

DARCY'S EQUATIONS

- $v \sim \frac{h_L}{L}$
- $v = K\frac{h_L}{L}$
- $v = \frac{Q}{A}$
- $Q = v\,A$
- $Q = -K\frac{h_L}{L}A$
- $Q = -KA\frac{dh}{dl}$ or $-KAI$

DARCY VELOCITY

$$v_a = \frac{Q}{\alpha A}$$

v_a = average interstitial velocity

$\boldsymbol{\alpha}$ = porosity

When $\boldsymbol{\alpha}$ = 33%, $v_a = 3\ v$

VALIDITY OF DARCY LAW

- Reynolds No. $(N_R) = \frac{\rho v D}{\mu}$

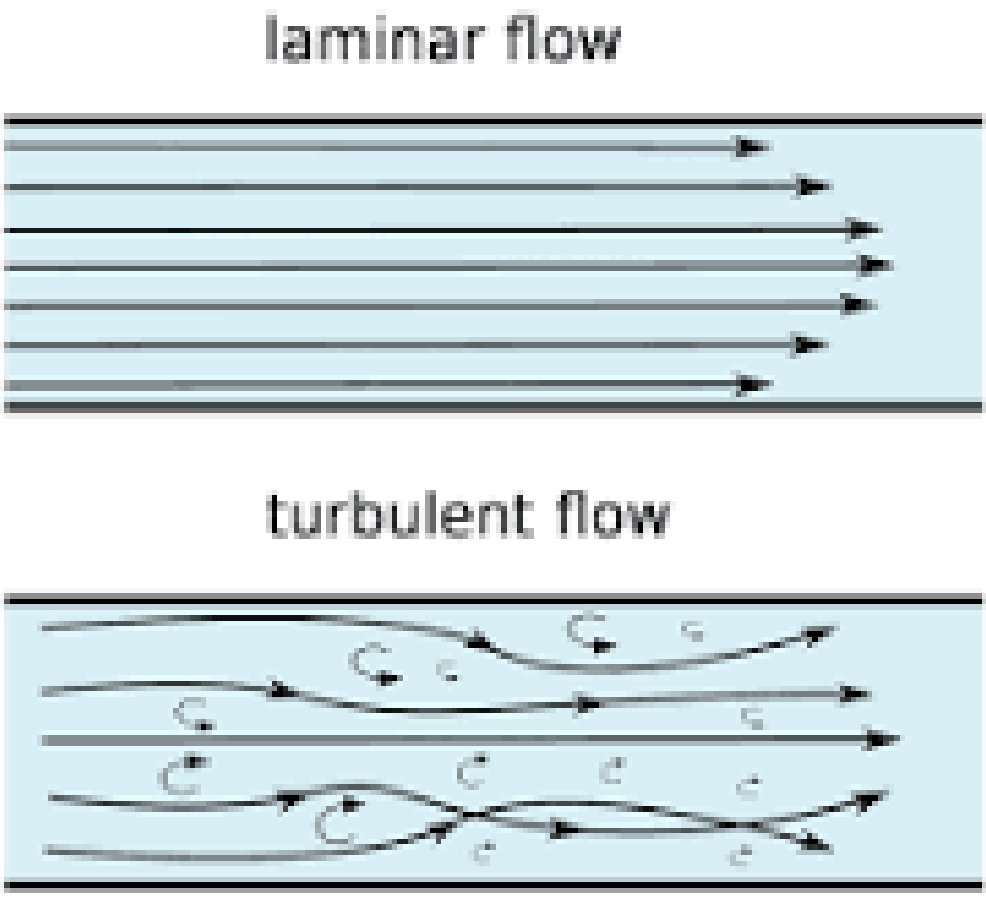
Where ρ = fluid density, v = velocity,

D = diameter (of a pipe), μ = viscosity of fluid.

- Darcy's Law is valid for $N_R < 1$ and

  does not depart seriously up to $N_R = 10.$

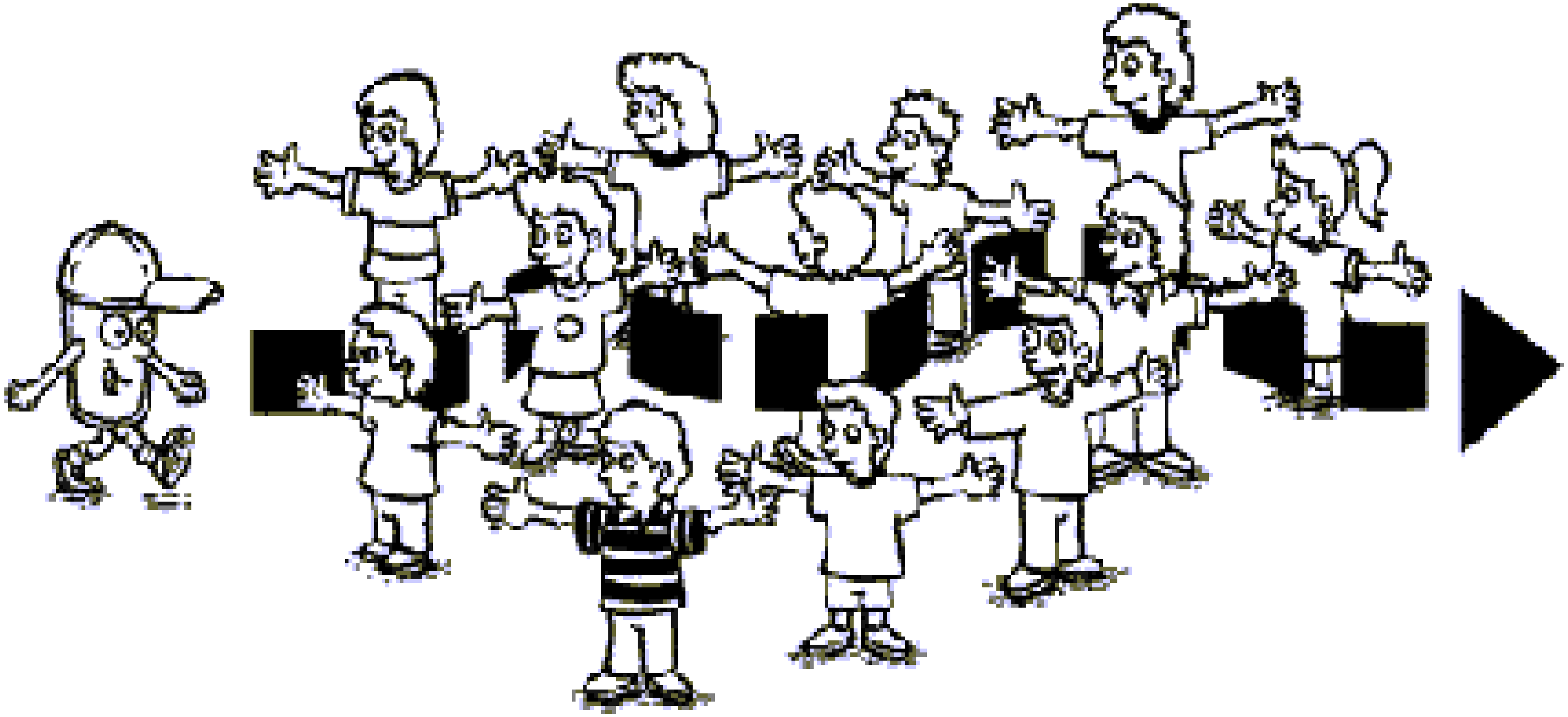
TYPES OF FLOW



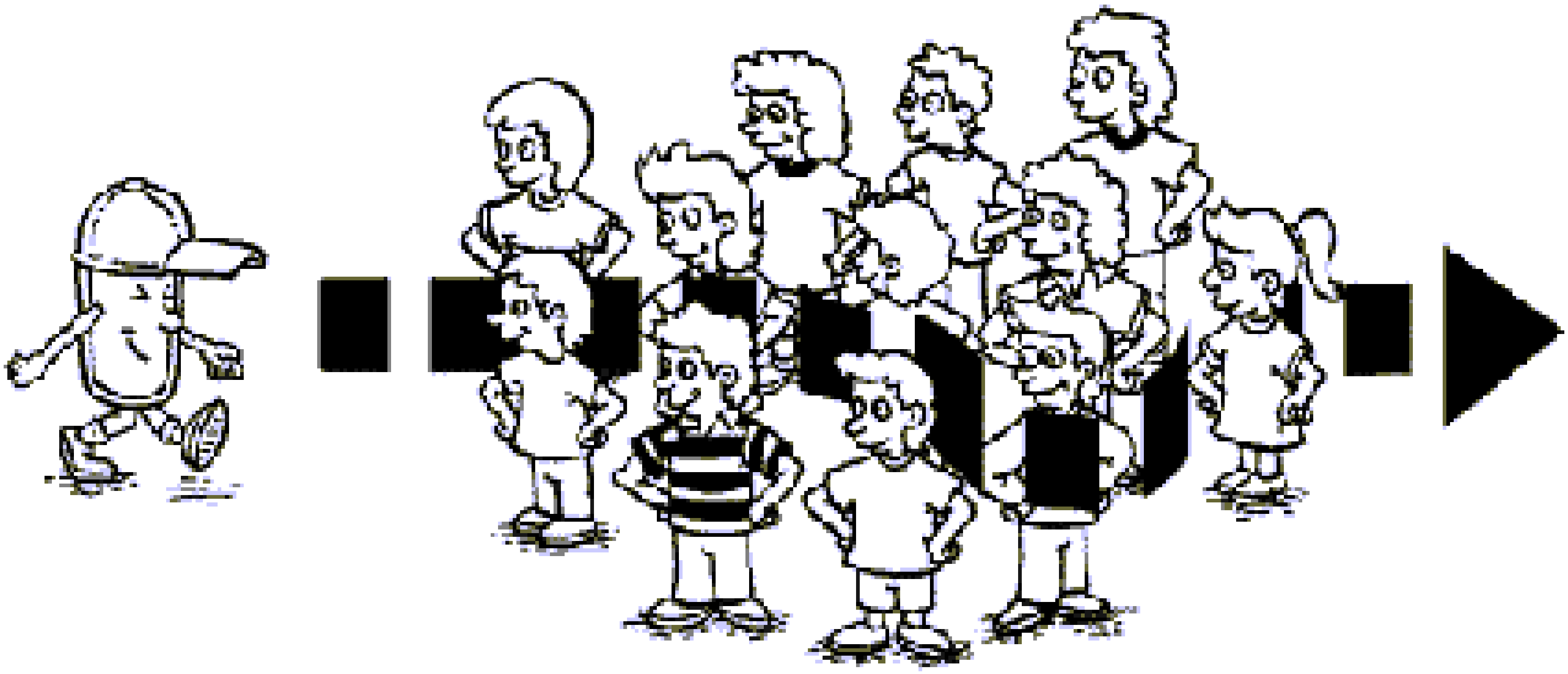
PERMEABILITY

Permeability is the ability of a rock or soil to transmit a fluid.

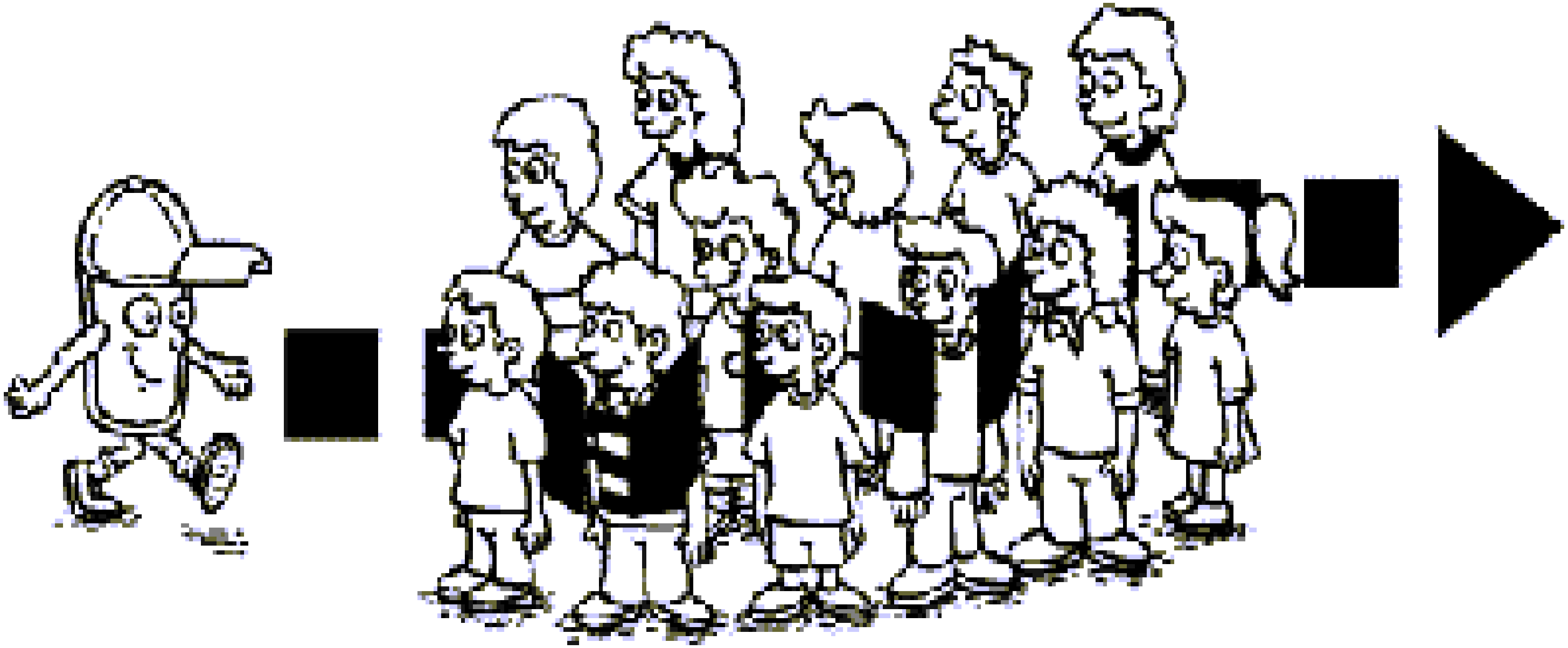
This is a property of the medium and independent of fluid properties.



Ground Water Movement through Gravel



Ground Water Movement through Sand



Ground Water Movement through Clay

HYDRAULIC CONDUCTIVITY

- Hydraulic Conductivity is the ease with which a fluid (usually water) can move through pore spaces or fractures.
- Hydraulic conductivity is also commonly known as coefficient of permeability.

HYDRAULIC CONDUCTIVITY

The coefficient of permeability / hydraulic conductivity can be defined as the rate of flow per unit cross sectional area of the formation, measured at right angles to the direction of flow, when subjected to unit hydraulic gradient.

HYDRAULIC CONDUCTIVITY

A medium has a unit hydraulic conductivity if it will transmit in unit time a unit volume of ground water at the prevailing kinematic viscosity through a cross-section of unit area.

HYDRAULIC CONDUCTIVITY

- From Darcy's Law:
  $v = Q/A = -K(dh/dl)$

- $K = -v / (dh/dl)$

- $K = (m/day) / m/m$
  $= m/day$

RELATIONSHIP BETWEEN K & n_e

- $v = \frac{K\,i}{n_e}$

  v = linear velocity

  K = hydraulic conductivity

  i = hydraulic gradient

  n_e = effective porosity

- $n = \frac{V_v}{V_t} = \frac{Volume\ of\ voids}{Total\ Volume\ of\ voids + aquifer\ material}$
- $n_e = \frac{V_{vi}}{V_t} = \frac{Interconnected\ Volume\ of\ voids}{Total\ Volume\ of\ voids + aquifer\ material}$

ISOTROPIC AND ANISOTROPIC

- Isotropy: parameters do not vary with direction.

- Anisotropy: parameters vary with direction.

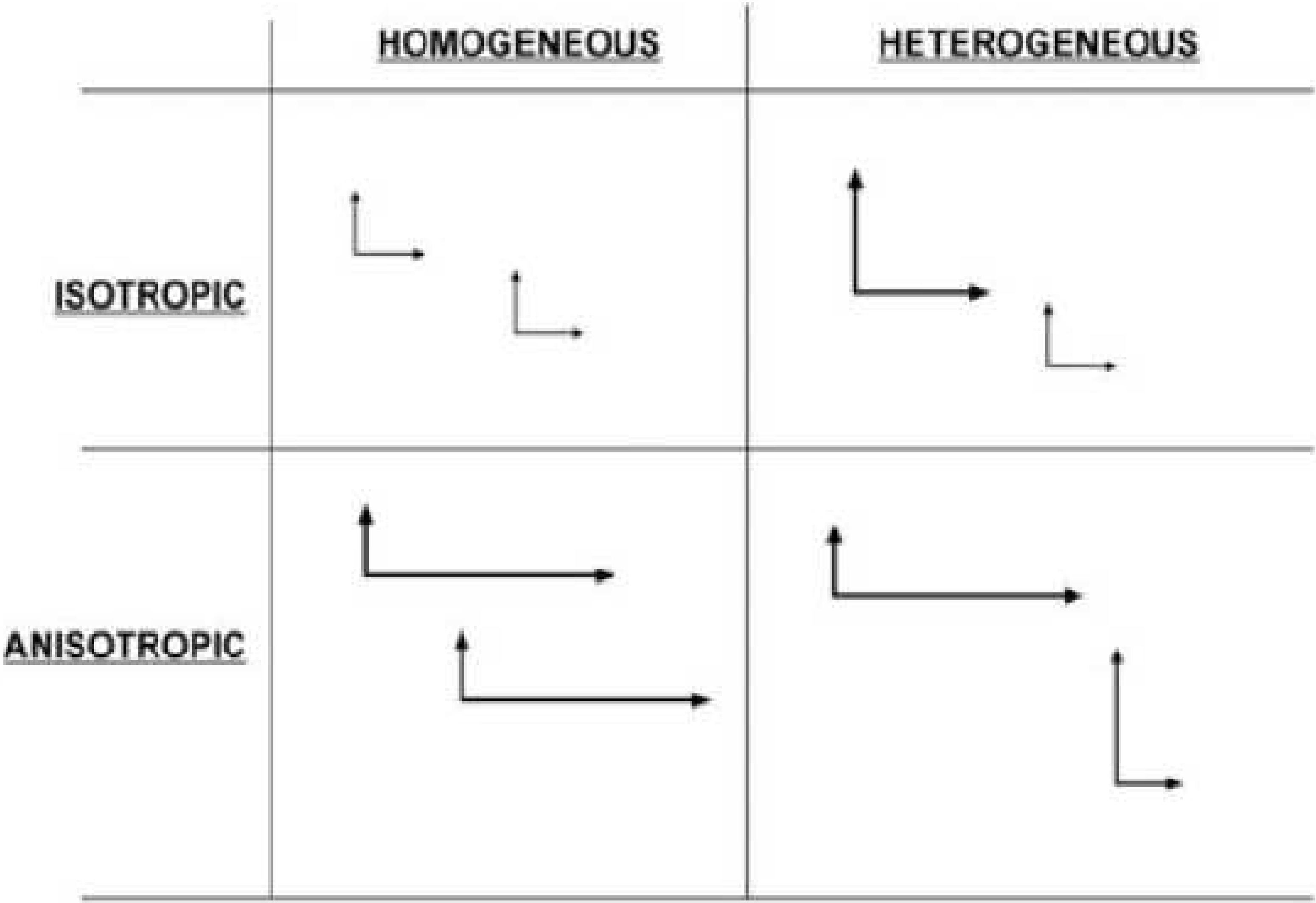
(Parameter = Hydraulic Conductivity).

HOMOGENEOUS AND HETEROGENEOUS

Homogeneity: parameters don’t vary with location.

Heterogeneity: parameters vary with location.

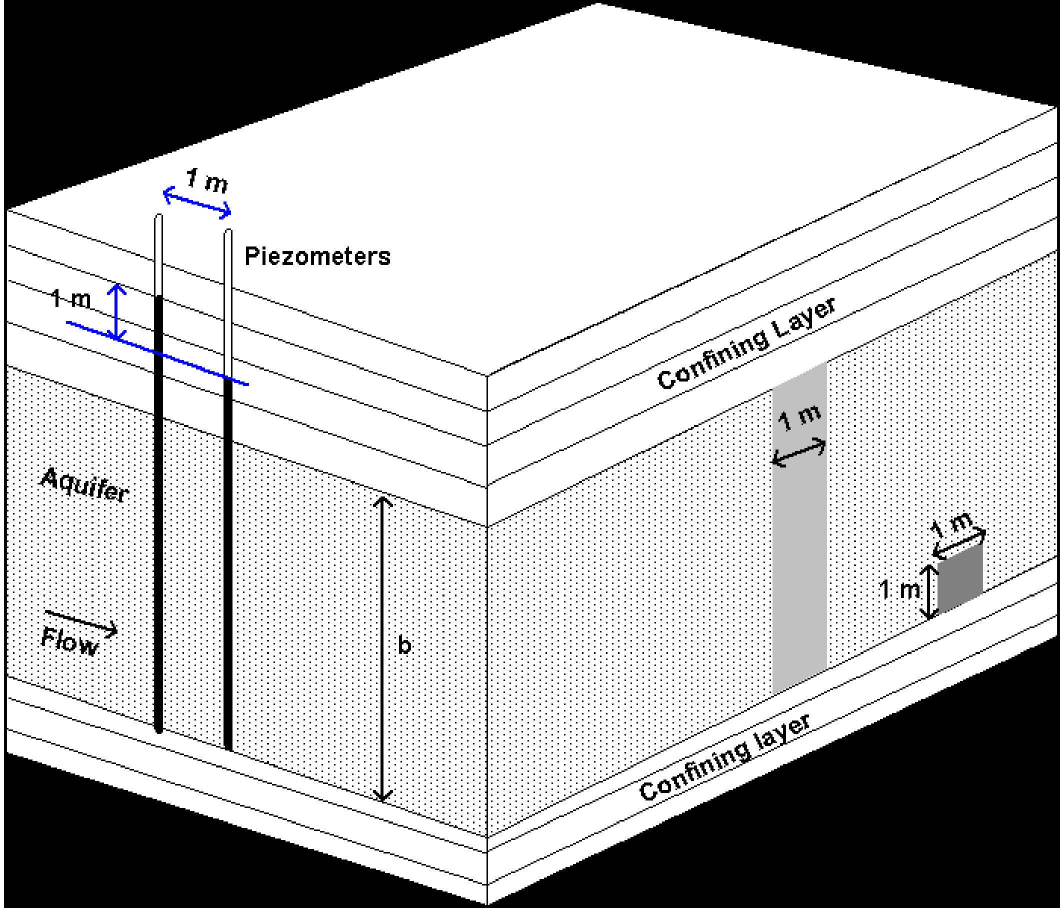
(Parameter = Hydraulic Conductivity)


HOMOGENEOUS
HETEROGENEOUS
ISOTROPIC
ANISOTROPIC

TRANSMISSIVITY

Rate at which water of prevailing kinematic viscosity is transmitted through a unit width of aquifer under a unit hydraulic gradient.

T = Kb = (m/day)(m) = m^2/day



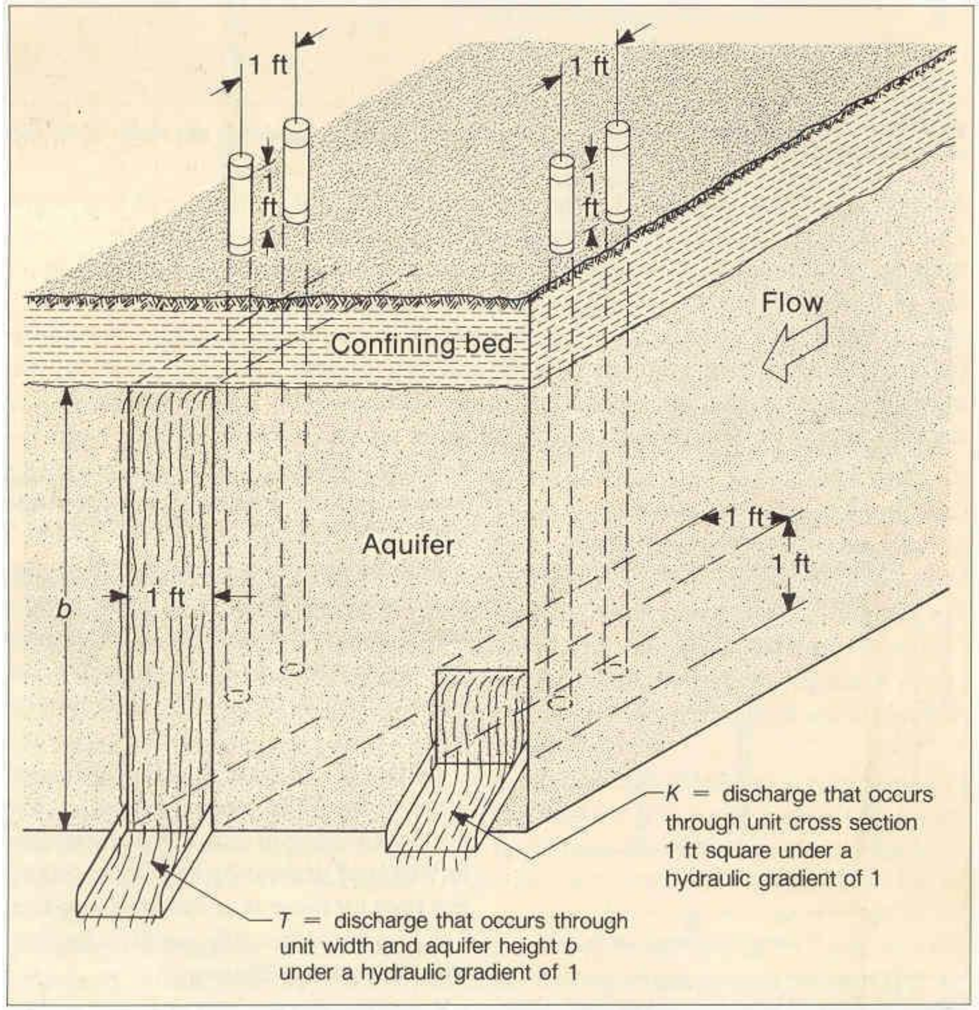
The rate of flow of water under a unit hydraulic gradient through a vertical strip of the aquifer of unit width and extending through the entire saturated thickness of the aquifer.

T= Kb

Where T= Transmissivity (m^2/d)

K= Hydraulic Conductivity (m/d)

b= Thickness of the aquifer (m)



Hydraulic Conductivity and Transmissivity

Formation	*K (m/day)*
Unconsolidated deposits	
Clay	$10^{-8} – 10^{-2}$
Fine sand	1 - 5
Medium sand	5 - 20
Coarse sand	$20 - 10^{2}$
Gravel	$10^{2} - 10^{3}$
Sand and gravel mixes	$5 - 10^{2}$
Clay, sand, gravel mixes (e.g. till)	$10^{-3} – 10^{-1}$
Hard Rocks	
Chalk (very variable according to fissures if not soft)	30.0
Sandstone	3.1
Limestone	0.94
Dolomite	0.001
Granite, weathered	1.4
Schist	0.2

Hydraulic Conductivity for Unconsolidated and Consolidated Rocks

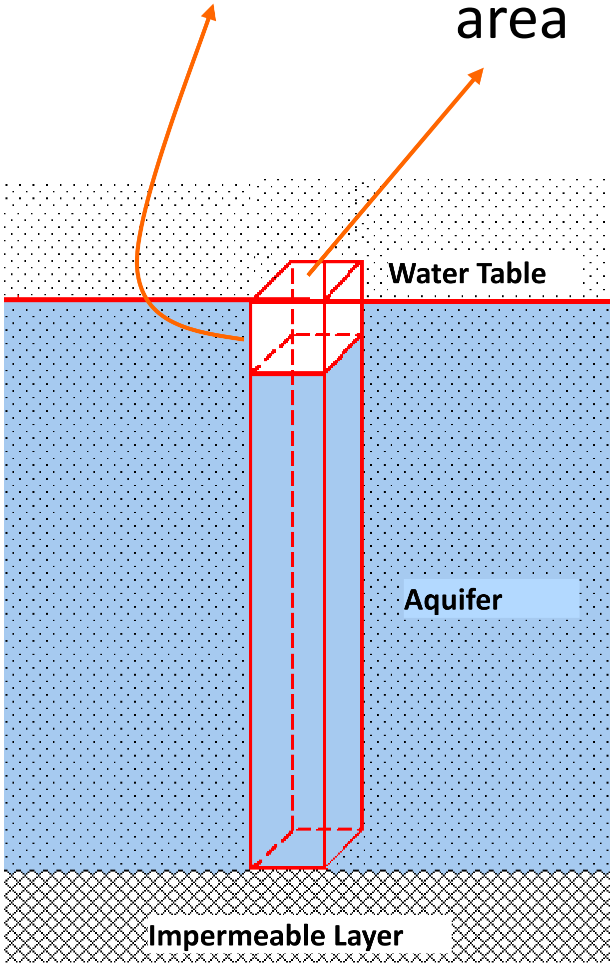
STORATIVITY
(STORAGE COEFFICIENT)

Volume of water that an aquifer releases or takes into storage per unit surface area of aquifer per unit change in the component of head normal to that surface.

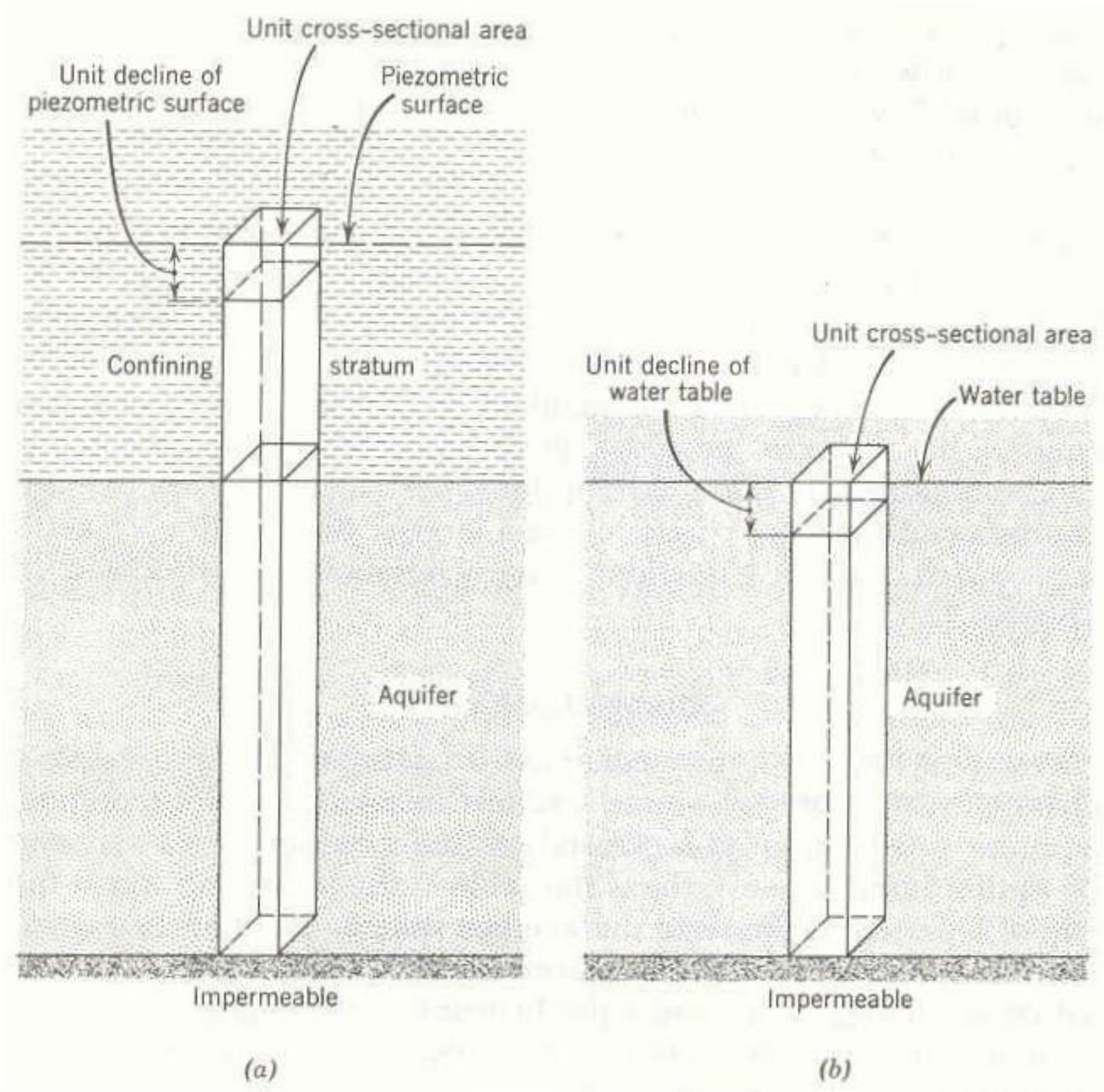
Storativity

Unit decline in water table

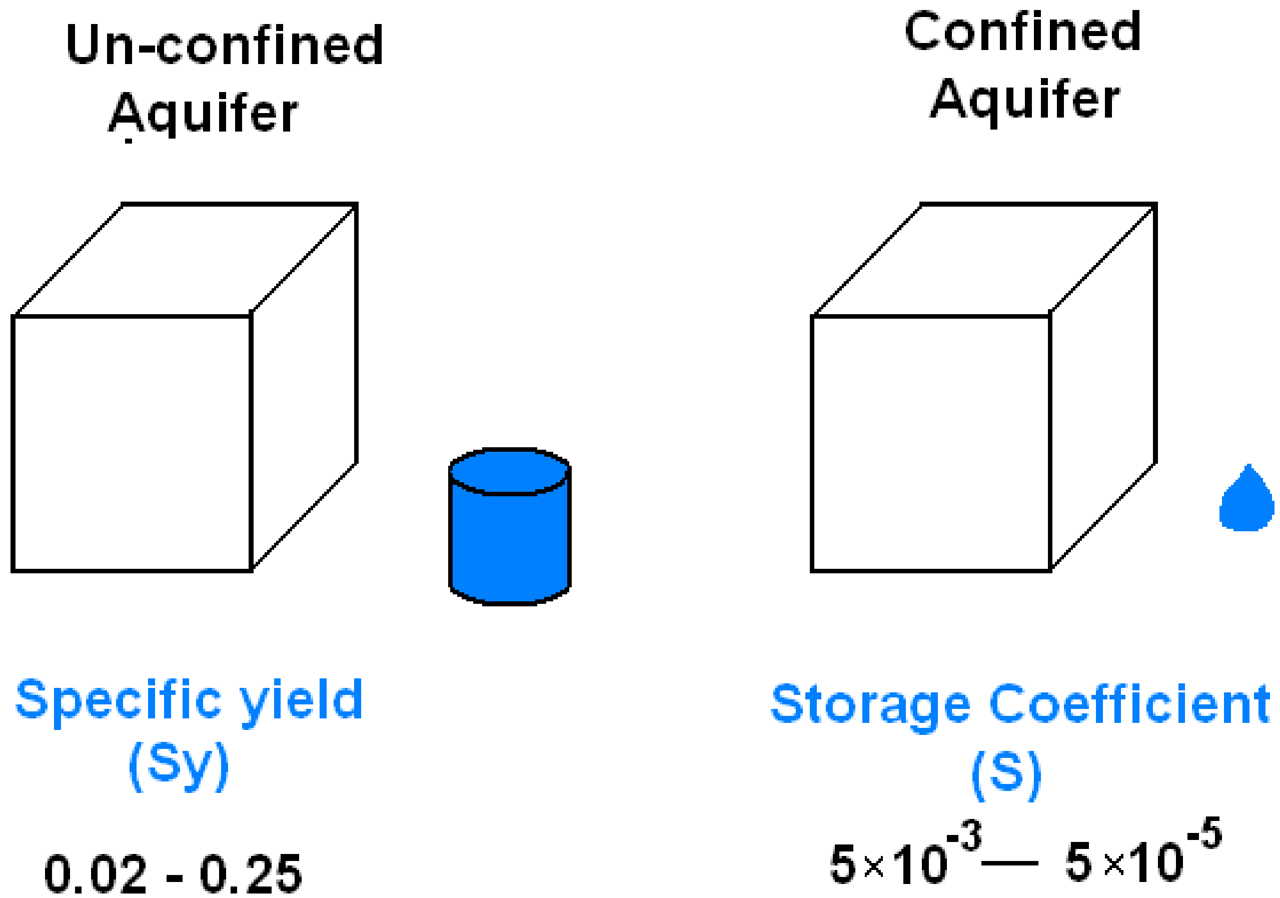
Unit cross-sectional area



Volume of water that an aquifer releases or takes into storage per unit surface area of aquifer per unit change in the component of head normal to that surface.



Storage Coefficient of (a) confined and (b) unconfined aquifers



Comparison of Specific Yield (S_y) with Storage Coefficient (S)

S.No	Formation	Recommended Value (%)	Minimum (%)	Maximum (%)
(a)	Alluvial areas			
	Sandy alluvium	**16.0**	12.0	20.0
	Silty alluvium	**10.0**	8.0	12.0
	Clayey alluvium	**6.0**	4.0	8.0
(b)	Hard rock areas			
	Weathered granite, gneiss and schist with low clay content	**3.0**	2.0	4.0
	Weathered granite, gneiss and schist with significant clay content	**1.5**	1.0	2.0
	Weathered or vesicular, jointed basalt	**2.0**	1.0	3.0
	Laterite	**2.5**	2.0	3.0
	Sandstone	**3.0**	1.0	5.0
	Quartzite	**1.5**	1.0	2.0
	Limestone	**2.0**	1.0	3.0
	Karstified limestone	**8.0**	5.0	15.0
	Phyllites, Shales	**1.5**	1.0	2.0
	Massive poorly fractured rock	**0.3**	0.2	0.5

S_y values recommended by GEC-1997

STORAGE COEFFICIENT AND SPECIFIC STORAGE

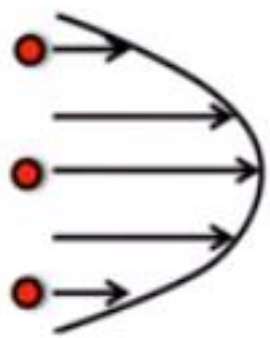
- **Specific storage** (S_{s}) is the volume of water released from one unit volume of the aquifer under one unit decline in head.
- $S = S_s$ X b

  where b = thickness of the confined aquifer

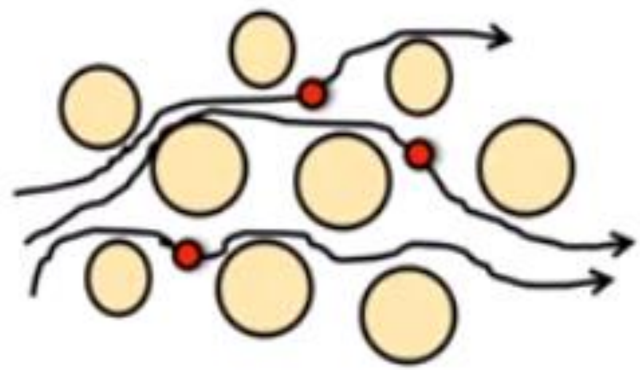
MECHANICAL DISPERSION

Mechanical Dispersion

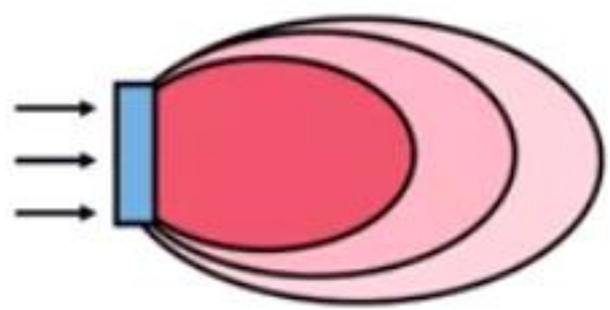
1. Variations in flow velocity



2. Different solute flow paths

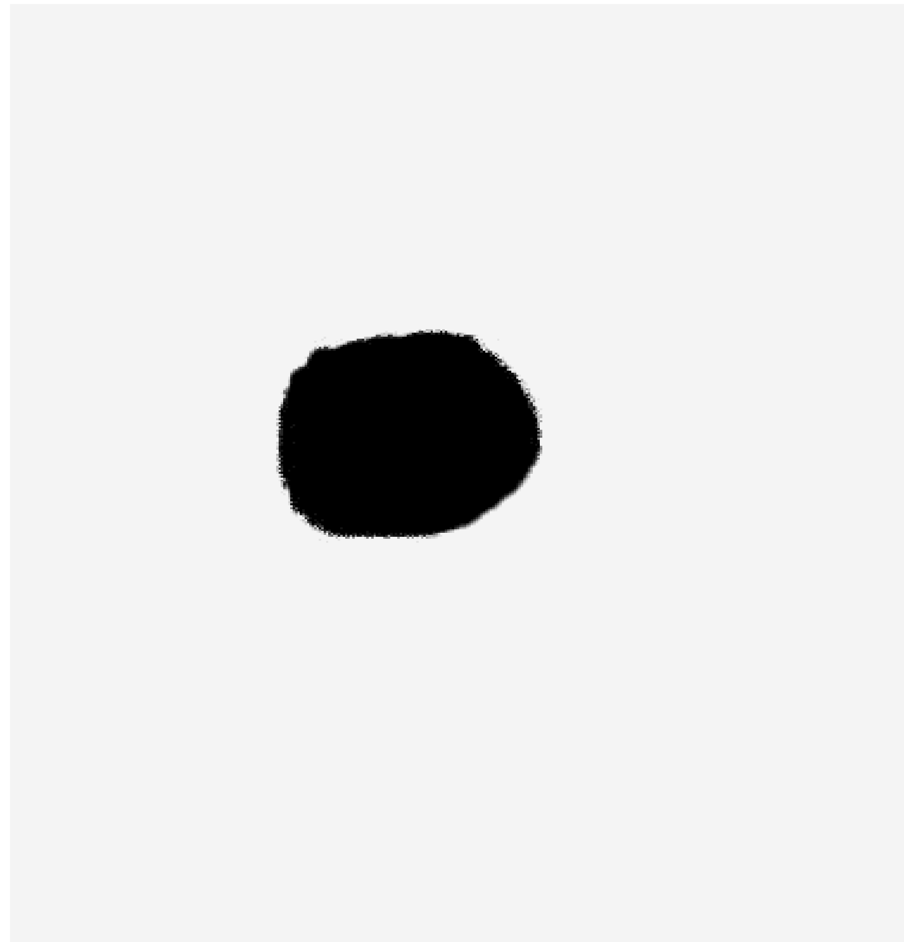


3. Causes the plume to spread



DIFFUSION

Spread of particles through random motion from regions of higher concentration to regions of lower concentration.



THANK YOU FOR LISTENING