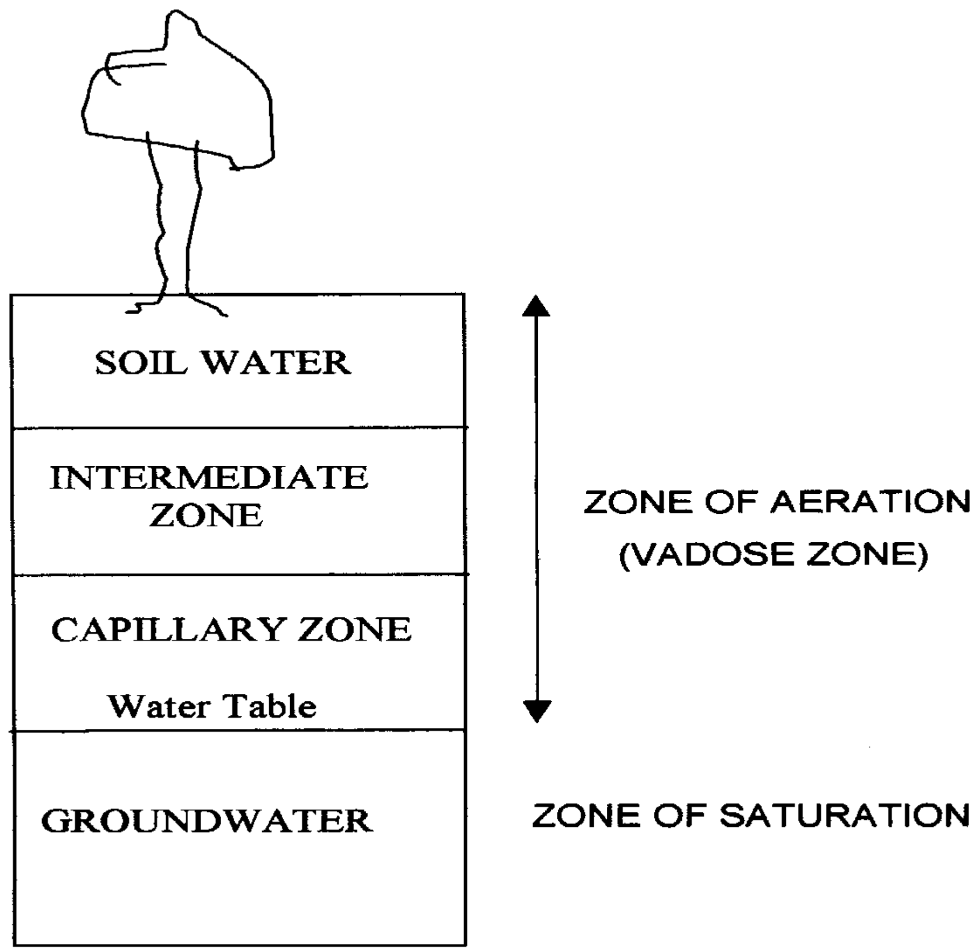
INTRODUCTORY WELL HYDROLOGY

GROUNDWATER OCCURRENCE

7.1 GROUNDWATER OCCURRENCE



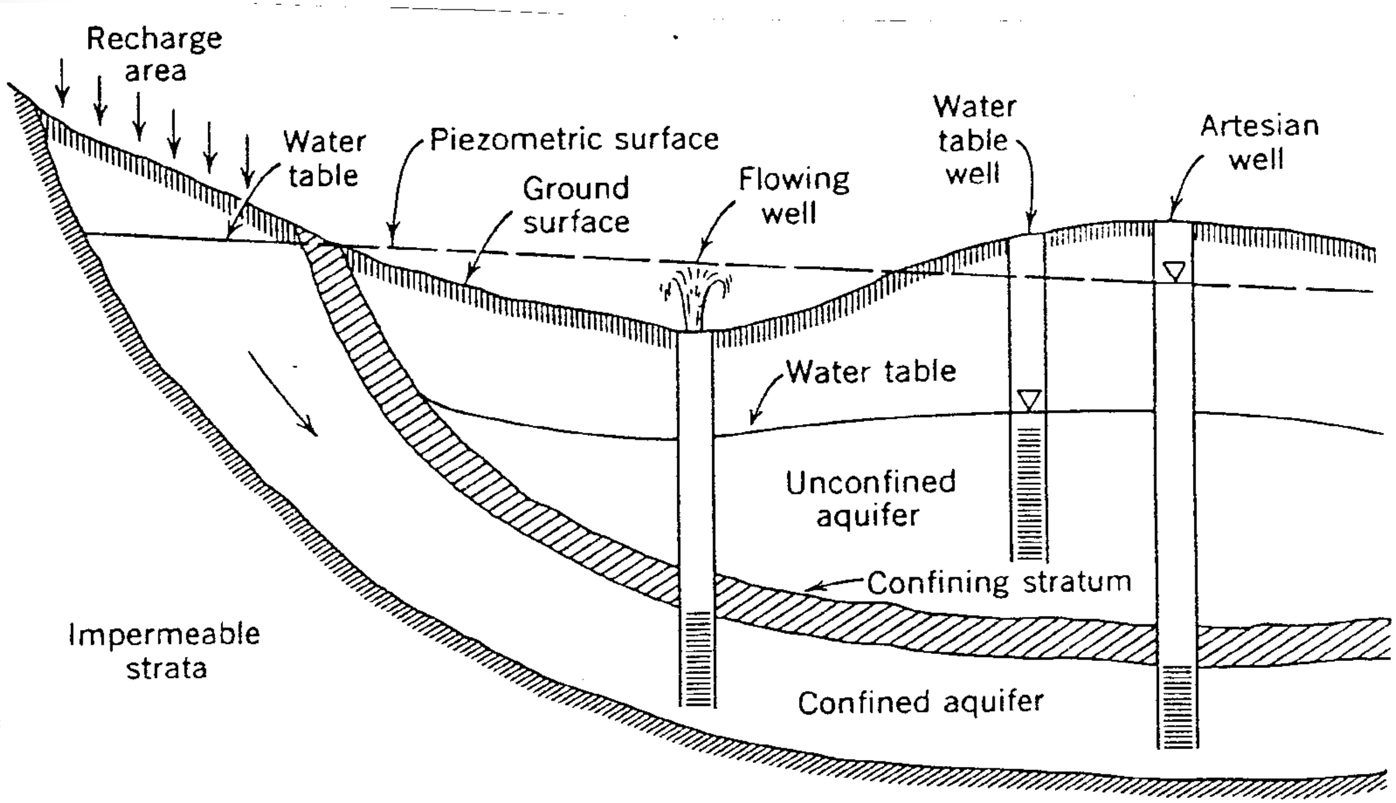
ZONES OF AERATION AND SATURATION

- In the zone of saturation, all interstices or pores are filled with water under hydrostatic pressure.
- The zone of aeration consists of interstices occupied partly by air and water.
- The capillary zone has variable thickness and separates the zones of aeration and saturation.
- This zone extends from the water table (top of the groundwater) to the limit of capillary rise.
- We are interested in the zone of saturation below the water table.

SOME HYDRO-GEOLOGIC TERMS

- **a) Aquifer:** A geologic formation or stratum containing water in its voids or pores that may be extracted economically and used as a source of water supply.
- An aquifer may be confined or unconfined (see diagram).

AQUIFER



Schematic cross section illustrating unconfined and confined aquifers.

d) Flowing Artesian Well: Exists when the piezometric surface lies above the ground

AQUIFER CONTD.

- b) **Confined Aquifer**: One in which groundwater is confined under pressure greater than atmospheric by overlying impermeable strata. It is also known as artesian or pressure aquifer.
- c) **Unconfined Aquifer:** One in which a water table serves as the upper surface of the zone of saturation. It is also known as a free, phreatic or non-artesian aquifer.

HYDRO-GEOLOGIC TERMS CONTD

- d) **Flowing Artesian Well:** Exists when the piezometric surface lies above the ground surface.
- e) **Aquiclude:** A geologic formation so impervious that for all practical purposes it completely obstructs the flow of groundwater (although it may itself be saturated with water).
- f) **Aquitard:** A geologic formation of rather impervious and semi-confined nature which transmits water at a very slow rate compared to an aquifer.

HYDRO-GEOLOGIC TERMS CONTD

- **g) Spring**: Abrupt intersection of the ground by the groundwater table. Unlike swamps, the point of intersection is usually followed by a steep slope causing the water to flow by gravity.
- **h) Ephemeral Stream:** Flows seasonally in response to groundwater fluctuations.
- **i) Intermittent Stream:** Flows only after a rain and is fed totally by surface water.

HYDRO-GEOLOGIC TERMS CONTD

- j) **Porosity:** Groundwater occurs in voids, or pores of geologic formations. Porosity term is defined as : = W/V where W is the volume of water required to saturate all voids or volume of all pores and V is the total volume of the rock (soil).

HYDRO-GEOLOGIC TERMS CONTD

- k) **Specific Retention (Sr):** When groundwater is pumped or drained, some water is retained by molecular and surface tension forces. Specific retention is therefore expressed as: $Sr = Wr/V$ (usually expressed in %).
- Wr is the volume of water retained and V is the total volume of rock (soil).

HYDRO-GEOLOGIC TERMS CONTD

- I) **Specific Yield (Sy):** The water removed by the force of gravity is the specific yield or effective porosity. It is defined as: Sy = Wy/V (usually expressed in %).
- Wy is the volume of water drained while V is the total volume of rock(soil).
- Since total volume, W = Wy + Wr
- Porosity, : = Sr + Sy.

HYDRO-GEOLOGIC TERMS CONTD

- **m) Storage Coefficient (Storativity, S):** It is the volume of water which an aquifer releases from or takes into storage per unit surface area per unit change in head.
- Units = L^3 = [ ] ie. dimensionless ie. has no units.
- $(L^2)(L)$
- For the unconfined aquifer, S = Sr

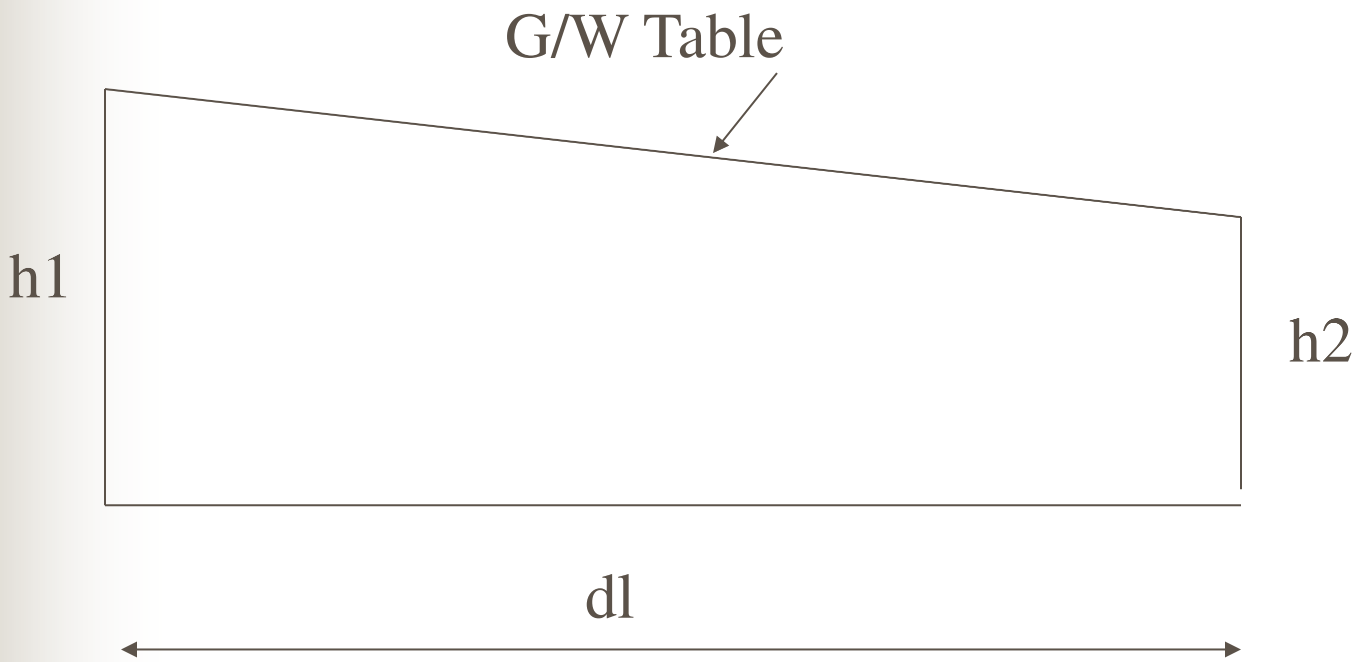
HYDRO-GEOLOGIC TERMS CONTD

- **n) Transmissivity (T):** It is a measure of the ease of water movement in the soil.
- It is the hydraulic conductivity (K) multiplied by aquifer thickness (b).
- ie. $T = K \times b$
- $m^2/d \quad m/d \times m$

GROUNDWATER HYDRAULICS

- There are two considerations:
- a) Steady or unsteady flow conditions
- (b) Confined and unconfined aquifers
- These flows are different and considered separately. Two basic equations are used in groundwater hydraulics:
- i) Laminar flow in porous media - Use Darcy's law.
- ii) Conservation of mass - Continuity(Water cannot be created or destroyed)

Darcy's Law



$$Q = -K A \, dh/dl$$

Darcy’s Law Contd.

- dh/dl is hydraulic gradient in the direction of decreasing head.
- The negative means that flow is in the direction of the decreasing head.
- Darcy's law is applicable only to laminar flow i.e non-turbulent flow.

Reynold's Number

$$Re = \frac{V\, d_e}{\upsilon}$$

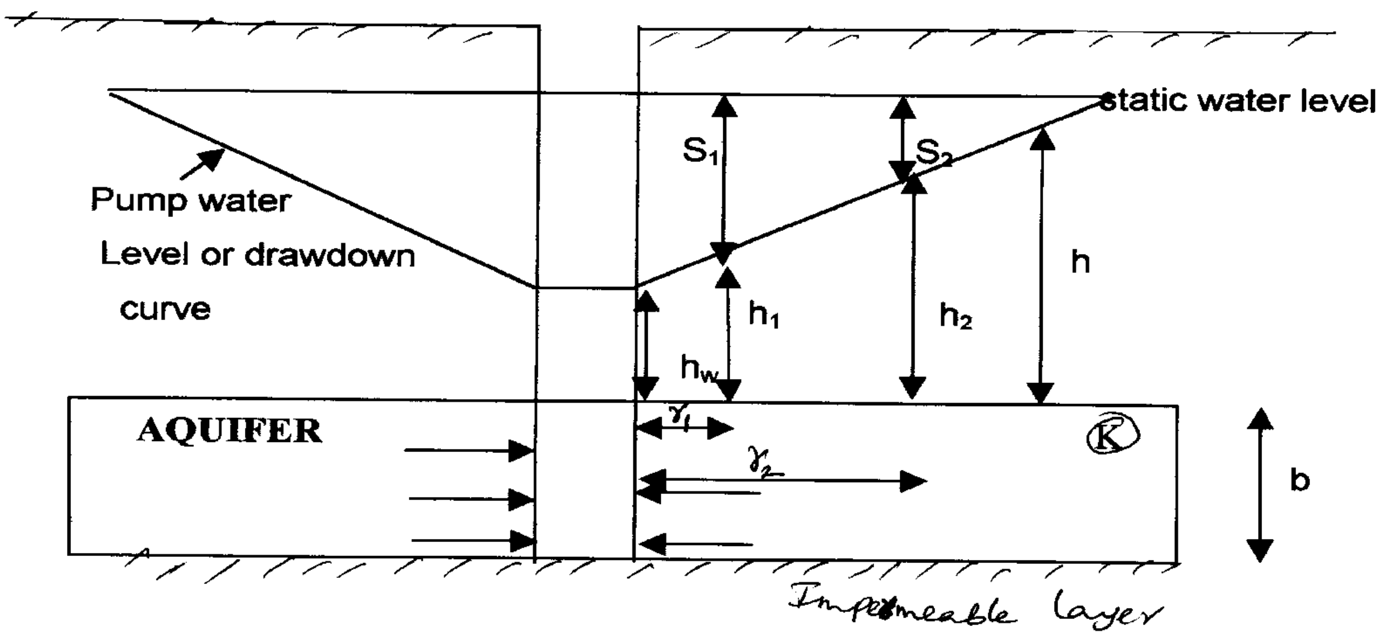
- where V is mean velocity, d_e is effective diameter (90% is larger than). is kinematic viscosity = 1.14 mm^2/s at 15 ° C
- When Re is less than 2000, flow is laminar and when it is more than 2000, flow is turbulent.
- All groundwater flows are laminar except:
- a) Fissured rocks: limestones (b) As water approaches wall of well.

Steady Radial Flow to a Well

7.3.2 Steady Radial Flow to a Well

When a well is pumped, water is removed from the aquifer surrounding the well and the water table or piezometric surface, depending on the type of aquifer is lowered.

a) Confined Aquifer (Steady State Radial Flow)



Steady Flow to a Well Contd.

- s_1 and s_2 are drawdowns.
- This is the difference in level between the static water level and the pumping water level at a specified point.
- Assumptions: (i) There is radial symmetry in wells.
- (ii) If any annulus is considered, the total quantity of water is same with other annuli i.e. for continuity, the flow across any annulus is constant. As water approaches a well, the flow rate increases.

Assumptions of Derivation Contd.

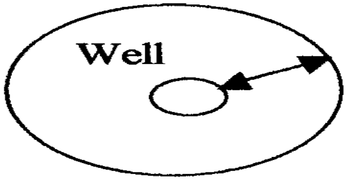
- iii) The groundwater flow is horizontal
- (iv) The flow is steady, the drawdown is not increased further.

Derivation of Steady State Equation

Consider annulus (cylindrical element) at radius, r

Darcy: Q = - K A dh/dr

ie. Q = - K . 2 r b dh/dr



$$\frac{dr}{r} = \frac{-2\,\pi\,K\,b\,dh}{Q}$$

Integrating: $\int \frac{dr}{r} = \frac{-2\,\pi\,K\,b}{Q} \int dh$

or $\ln r = \frac{-2\,\pi\,K\,b}{Q}[h]$

Recall that T = K b

Limits: $r = r_1$, $h = h_1$

$r = r_2$, $h = h_2$

So : $\ln \frac{r_1}{r_2} = \frac{-2\,\pi\,T}{Q}[h_1 - h_2]$

But $(h_1 - h_2) = -(s_1 - s_2)$

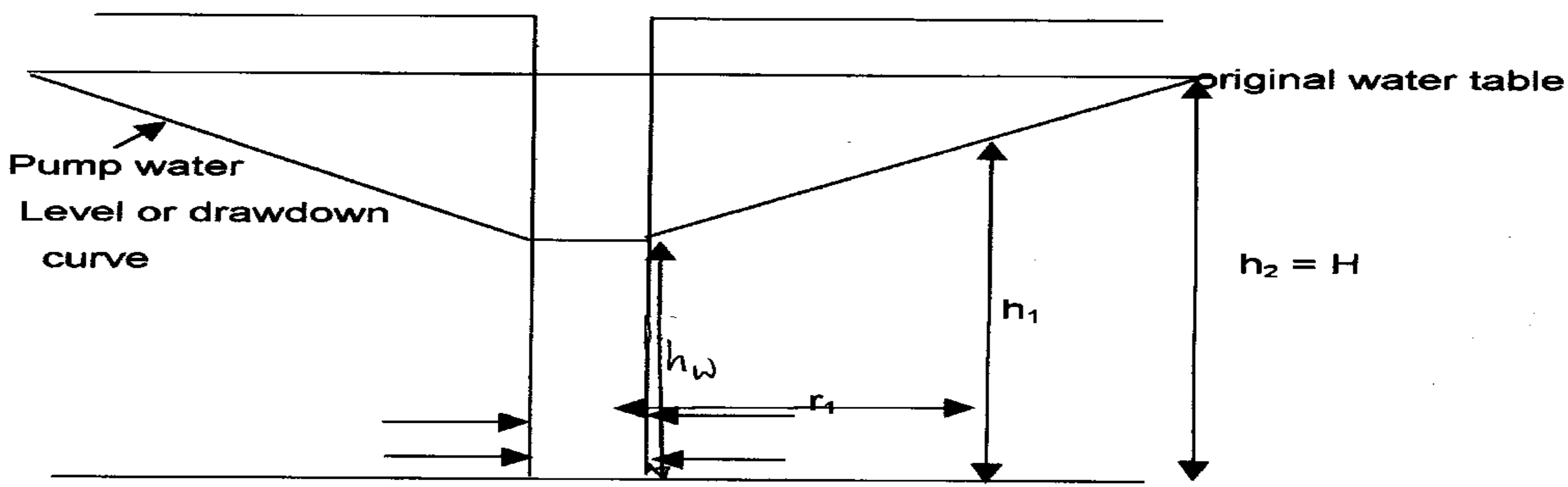
So : $T = \frac{Q}{2\,\pi\,(s_1 - s_2)} \ln \frac{r_2}{r_1}$

This is the Thiem or Equilibrium (Steady state) equation.

Derivation of Steady State Equation Contd.

- **Note:** The replacement of the head, h with drawdown, s is because the drawdown rather than the head is normally measured during pumping tests.
- Given s_1 and s_2 (drawdowns) at r_1 and r_2, and knowing pumping rate, Q, Transmissivity, T can be derived

b) Unconfined Aquifer(Steady State Radial Flow)



Note that an unconfined aquifer has infinite thickness.

From Darcy, $Q = 2\pi r\ h\ K\ dh/dr$

$$\int_{r_1}^{r_2} \frac{dr}{r} = \frac{-2\pi K}{Q} \int_{h_1}^{h_2} h\, dh$$

Limits: $r = r_1$, $h = h_1$ and $r = r_2$, $h = h_2$

Integrating between the limits:

$$\ln \frac{r_2}{r_1} = \frac{-\pi K}{Q}\left[h_2^2 - h_1^2\right]$$

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