GROUND WATER AND WELL IRRIGATION
UNIT - V

INTRODUCTION

Ground water hydrology is the science of occurance, distribution and movement of water below the surface of earth. The largest available source of fresh water lies underground. The total ground water potential is estimated to be one third the capacity of oceans.

Aquifer: Aquifers are the permeable formations having structures which permit appreciable quantity of water to move through them under ordinary field conditions Thus these are the geologic formations in which ground water occurs (i.e sands and gravels)

Aquiclude: Aquicludes are the impermeable formations which contain water but are not capable of transmitting and supplying a significant quantity (eg. clays)

Aquifuge: Aquifuge is an impermeable formation which neither contains water nor transmits any water
Ex: Granite, shale.

Aquitard: Saturated geological formation poorly permeable and hence does not yield water freely into the well It may transmit vertically appreciable quantity of water to/from adjacent aquifer
Ex: Sandy clay.

Occurance of ground water:

The ground water strata formation possesses

i) Porosity
ii) Permeability

Porosity: Porosity (n) is defined as the ratio of the volume of openings or pores (or voids) V_u in the material to its total volume V and is expressed as percentage

$$n = \frac{V_u}{V} \times 100$$

$n > 20$	large	Mere porosity
$5 < n < 20$	Medium	alone cannot
$n < 5$	low	given G.W.

Permeability: Capacity to permit water through soil

Permeability of unconsolidated sedimentation is to transmit water through it

Transmissibility: Which represents the same physical meaning and differ mathematically

Def: Capability of entire soil formation of full depth and unit width is known as transmissibil

Specific Yield: The specific yield of an aquifer is defined as the ratio expressed as percentage, of the volume of water which after being saturated, can be drained by gravity to its own volume

$$\text{Specific yield} = \frac{\text{Volume of water drained by gravity}}{\text{Total volume}}$$

(or)

$$S_y = \frac{w_y}{V} \times 100$$

Specific Retention: The specific retention (S_r) of an aquifer is the ratio, expressed as a percentage, of the volume of water it will retain after saturation against the force of gravity to its own volume.

$$S_r = \frac{w_r}{V} \times 100$$

w_r = volume of water retained

$$\text{Porosity } n = \frac{V_v}{V} \times 100 = \frac{w}{V} \times 100$$

w = volume of water = V_v in a saturated aquifer

$= w_y + w_r$

$$n = S_y + S_r$$

Divisions of Subsurface water:

a) Zone of Aeration

b) Zone of Saturation

Zone of aeration:

consisting of :

i) Soil water zone : Soil water

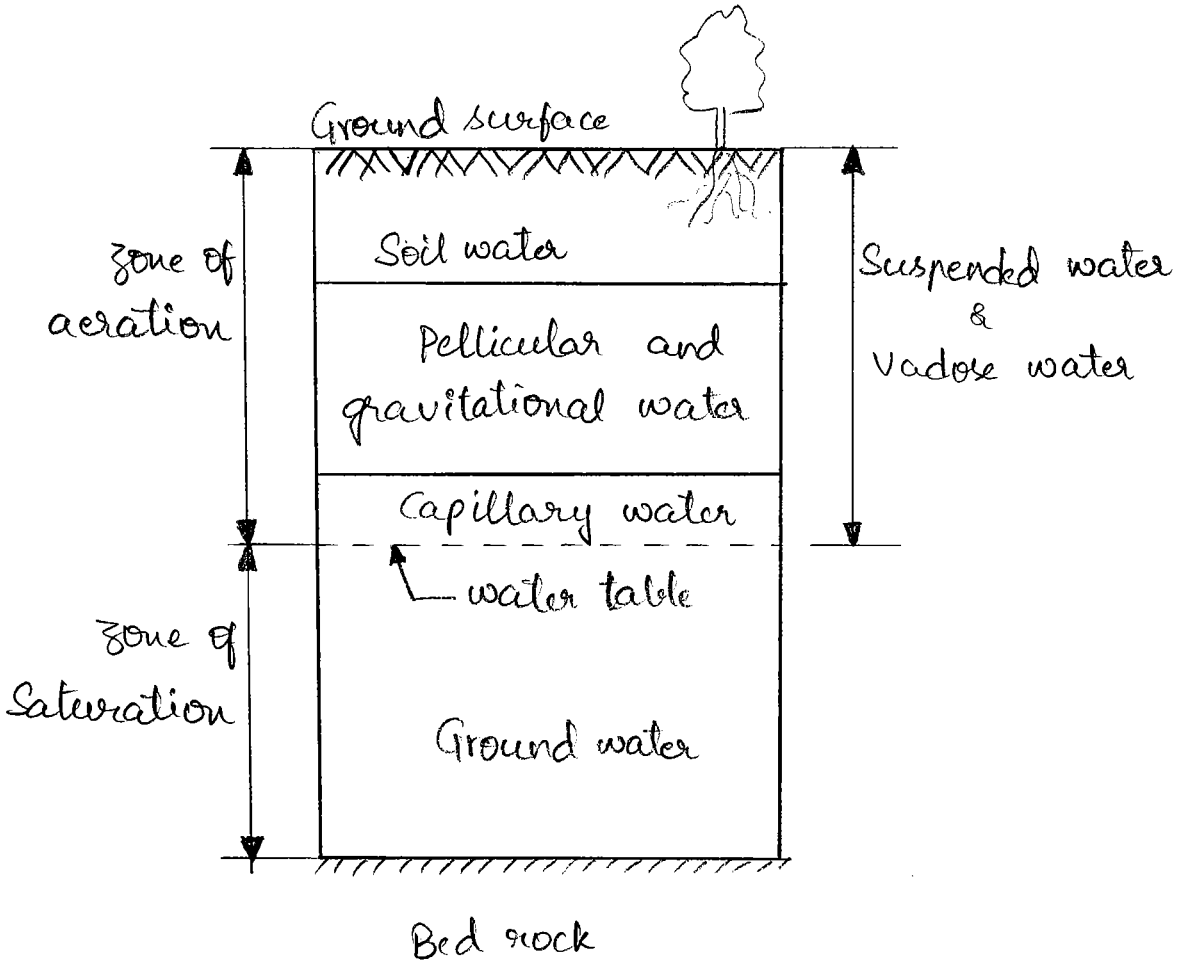
ii) Intermediate zone : Pellicular and gravitational water

iii) Capillary zone : capillary water

Zone of Saturation :

Ground water fills all the interstices in the saturated zone

Water table : In the absense of the confining impermeable layer, the static level of water in wells penetrating the zone of saturation is called the water table



DIVISIONS OF SUBSURFACE WATER

Aquifer: An aquifer is an underground body of rock or sediment that serves as a storage reservoir for ground water

Types Of Aquifers:

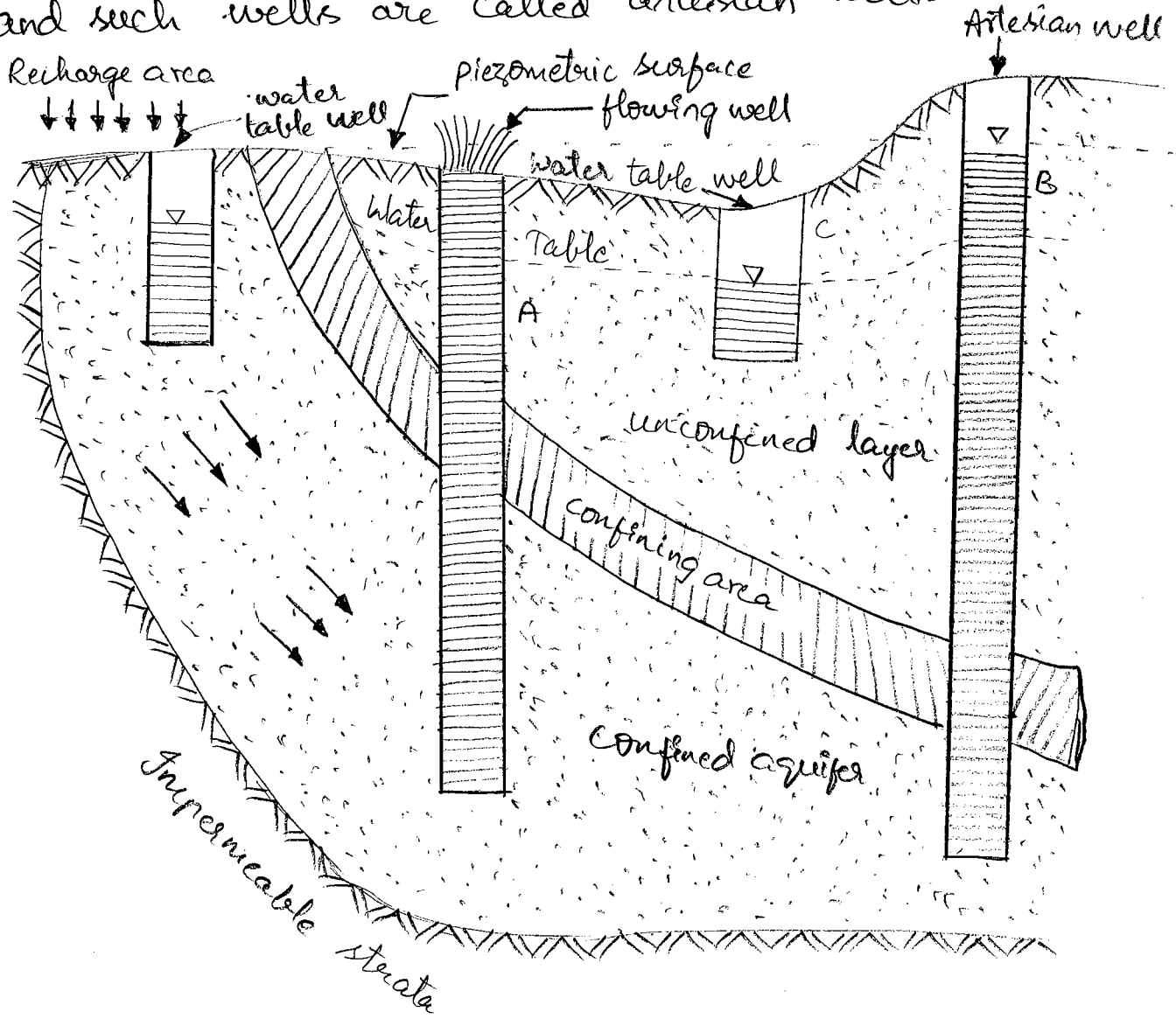
Aquifers are mainly of two types:

1. Unconfined aquifer
2. Confined aquifer (artesian aquifer)

Unconfined aquifer: Unconfined aquifer or water table aquifer is the one in which a water table serves as the upper surface of the zone of saturation. It is also sometimes known as the free, phreatic or non-artesian aquifer. In such an aquifer, the water table varies in undulating form and in slope. Rises and falls in the water table corresponds to changes in the volume of water in storage within unconfined aquifer

Confined aquifer: A second common type of aquifer is a confined aquifer which is isolated from pressure communication with overlying or underlying geologic formations and with the land surface and atmosphere by one or more confining layers or confining units. Confined aquifers differ from unconfined aquifers in two

fundamental and important ways. First, confined aquifers are typically under considerable pressure which may be derived from recharge at higher elevation or from the weight of the overlying rock and soil (known as the over burden). In some cases the pressure is high enough that wells drilled into the aquifer are free flowing. This condition requires that the water pressure in the aquifer is sufficient to drive water up the well bore and above the land surface and such wells are called artesian wells.



CONFINED AND UNCONFINED AQUIFERS

Perched aquifer : It is a special type of aquifer) unconfined aquifer, and occurs where a ground water body is seperated from the main ground water by a relatively impermeable stratum of small aerial extent and by the zone of aeration above the main body of ground water

Storage coefficient :

The water yielding capacity of a confined aquifer can be expressed in terms of its storage coefficient. Storage coefficient is defined as the volume of water that an aquifer releases from or takes into storage per unit surface area of aquifer per unit change in the component of head normal to that surface.

Acquifer parameters:

coefficient of permeability (K):

It is defined as the velocity of flow which will occur through the total c/s area of the soil (or) acquifer under a unit Hydraulic gradient.

$$K = \frac{Q}{A}$$

Coefficient of Transmissibility (T):

It is defined as the rate of flow in (m^3/day) through a vertical strip of acquifer of width 1m, extending full saturation height under unit hydraulic gradient.

$$T = K \times b$$

Specific yield and specific Retention:

Specific yield (S_y): volume of water drained from acquifer by gravity force divided by total volume of acquifer drained.

Specific Retention (S_r): volume of water held by acquifer against gravity force divided by total volume of acquifer drained.

$$S_r + S_y = n$$

Specific capacity: specific capacity of well is defined as rate of flow from a well per unit of draw down.

Coefficient of storage (A):

→ Defined for confined acquifer's only.

It is defined as the volume of water that a confined acquifer releases (or) stores per unit surface area of acquifer

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er unit change in the component of head perpendicular to the surface.

→ Range varies from 0.00005 to 0.005

formulae:

I. confined aquifer:

$$\longrightarrow Q = \frac{2.72T(H-h)}{\log_{10}\left(\frac{R}{r}\right)} \qquad [T = Kb]$$

$$\longrightarrow Q = \frac{2.72TS}{\log_{10}\left(\frac{R}{r}\right)}$$

for observation wells by thiem's equation:

$$\longrightarrow Q = \frac{2.72T(h_2-h_1)}{\log_{10}\left(\frac{r_2}{r_1}\right)} \Rightarrow \frac{2.72T(s_1-s_2)}{\log_{10}\left(\frac{r_2}{r_1}\right)}$$

for strainer length:

$\boxed{L=r}$

$$\longrightarrow Q = \frac{2.72Kbs}{\log_{10}\left(\frac{r_2}{r_1}\right)} \Rightarrow \frac{2.72Kbs}{\log_{10}\left(\frac{R}{r}\right)}$$

Coefficient of Transmissibility:

$$T = \frac{Q\log_{10}\left(\frac{r_2}{r_1}\right)}{2.72(s_1-s_2)}$$

for 1 log cycle:

$$T = \frac{Q}{2.72\Delta s}$$

II. Unconfined aquifer:

$$\longrightarrow Q = \frac{1.36\ K\ (H^2 - h^2)}{\log_{10}\left(\frac{R}{r}\right)}$$ (Dupit's equation)

$$\longrightarrow Q = \frac{1.36\ KS\ (S + 2h)}{\log_{10}\left(\frac{R}{r}\right)}$$

$$\longrightarrow Q = \frac{2.72\ KS\left(h + \frac{S}{2}\right)}{\log_{10}\left(\frac{R}{r}\right)} \Rightarrow \frac{2.72\ KS\left(L + \frac{S}{2}\right)}{\log_{10}\left(\frac{R}{r}\right)}$$

[$L \rightarrow$ strainer length, $L = h$]

For observation wells by Thiem's equation:

$$\longrightarrow Q = \frac{1.36\ K\ (h_2^2 - h_1^2)}{\log_{10}\left(\frac{R}{r}\right)}$$

Coefficient of Transmissibility:

$$T = \frac{Q \log_{10}\left(\frac{R}{r}\right)}{2.72\ \Delta s'}$$

For 1 log cycle:

$$T = \frac{Q}{2.72\ \Delta s'}$$

Well hydraulics:

Darcy's law: The percolation of water through soil was first studied by darcy (1856) who demonstrated experimentally that for laminar flow conditions in a saturated soil the rate of flow, (Q) the discharge per unit time is proportional to the hydraulic gradient, and it could be expressed as follows:

$$Q = KiA$$

(or)

$$v = \frac{Q}{A} \Rightarrow Ki$$

where Q = rate of flow

i = hydraulic gradient

K = Darcy's coefficient of permeability

A = Total cross-sectional area of soil mass perpendicular to the direction of flow.

v = flow velocity

Darcy's law is valid only for laminar flow. Because of very small pore dimensions in fine grained soils, a laminar flow should exist, but in course grained soils turbulent flow may be expected under certain conditions. It has been borne out by experiments that the limits of validity of Darcy's law may be fixed with respect to particle size, velocity of flow and hydraulic gradient.

Steady radial flow to a well : Dupit's theory :

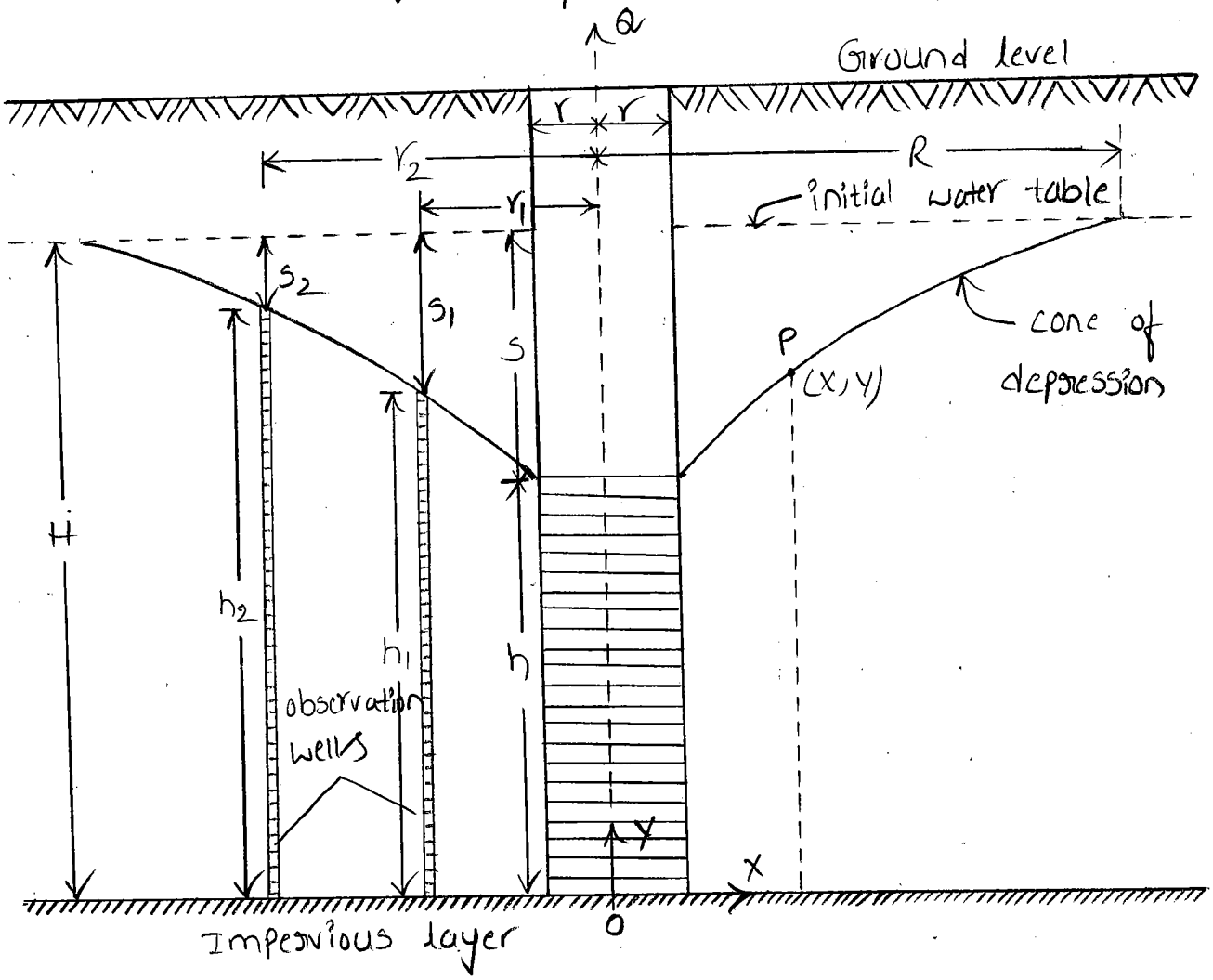
When a well is penetrated into an extensive homogeneous aquifer, the water table initially remains horizontal in the well. When the well is pumped, water is removed from the aquifer and the water table (or) piezometric surface, depending upon the type of the aquifer, is lowered resulting in a circular depression in the water table (or) the piezometric surface. This depression is called the cone of depression (or) the draw down curve. At any point, away from the well, the drawdown is the vertical distance by which the water table (or) the piezometric surface is lowered. The analysis of such radial flow towards a well was originally proposed by Dupit in 1863 and later modified by Thiem (1906). for the sake of analysis, we shall take 2 cases.

1) well in unconfined aquifer, and
2) well fully penetrating a confined aquifer.

1) unconfined aquifer :

following fig shows a well penetrating an unconfined (or) free aquifer to it's full depth.

Unconfined aquifer



Where R = Radius of influence

s = Draw down

h = depth of water in main well

H = Total depth of water

r_1 = Radius of observation well (1)

r_2 = Radius of observation well (2)

h_1 = Height / depth of water in observation well (1)

h_2 = Height/depth of water in observation well (2)

s_1 = Draw down of well (1)

s_2 = Draw down of well (2)

$$Q = \frac{1.36K(H^2 - h^2)}{\log_{10}\left(\frac{R}{r}\right)}$$

$$Q = \frac{1.36\,K(h_2^2 - h_1^2)}{\log_{10}\left(\frac{r_2}{r_1}\right)}$$

$$Q = \frac{2.72\,KS\left(L + \frac{S}{2}\right)}{\log_{10}\left(\frac{R}{r}\right)}$$

Assumptions and limitations of Dupit's theory:

Dupit's theory of flow for unconfined aquifer is based on the following assumptions:

→ The velocity of flow is proportional to the tangent of the hydraulic gradient instead of sine.

→ The flow is horizontal and uniform everywhere in the vertical section.

→ Aquifer is homogeneous, isotropic and of infinite aerial extent.

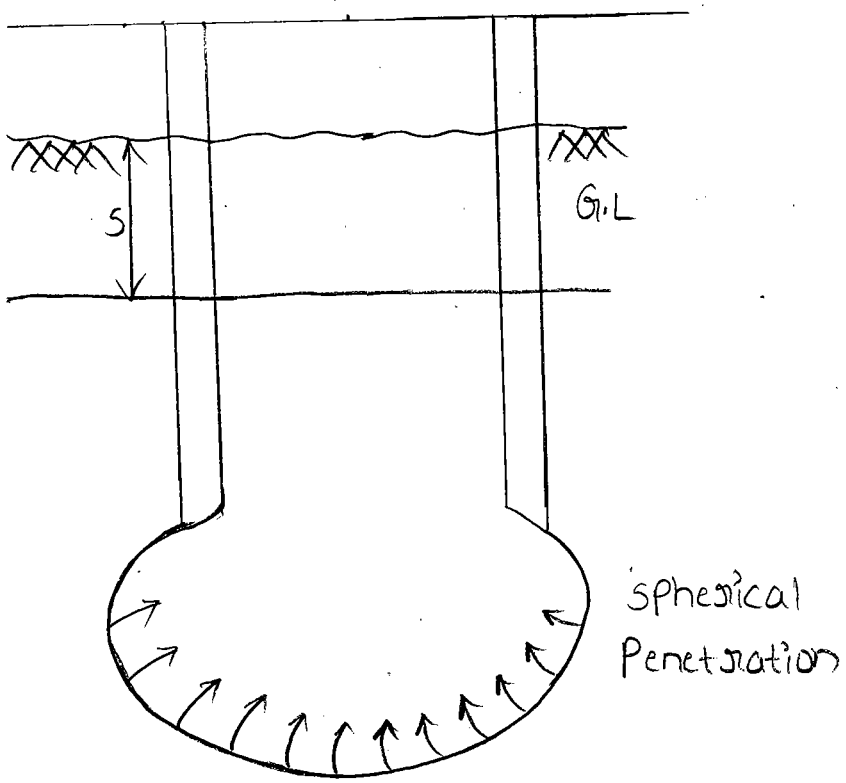
→ The well penetrates and receives water from the entire thickness of the aquifer.

→ The coefficient of transmissibility is constant at all places and at all times.

→ Natural ground water regime affecting an aquifer remains constant with time.

→ flow is laminar and Darcy's law is applicable.

Constant level pumping test:



→ using pump, heavy discharge is taken out to create depression head (S).

→ The discharge to be such that outward discharge should be same as inward discharge. (spherical penetration).

from Darcy's equation

$$AV = Q = KiA$$

$$= K \cdot \frac{S}{L} \cdot A$$

$$= \frac{K}{L} \cdot S \cdot A$$

$$\boxed{Q = CSA}$$

$i = \frac{S}{L}$

C → depends on soil formation.

C → Percolation intensity coefficient

$Q \propto S$ as $Q = AV$

$V \propto S$

Area of c/s at bottom = $\frac{4}{3}$ (Actual area) in case a spherical cavity is formed.

→ Recharge velocity cannot be increased beyond the critical velocity (depends on soil formation; varies from soil to soil).

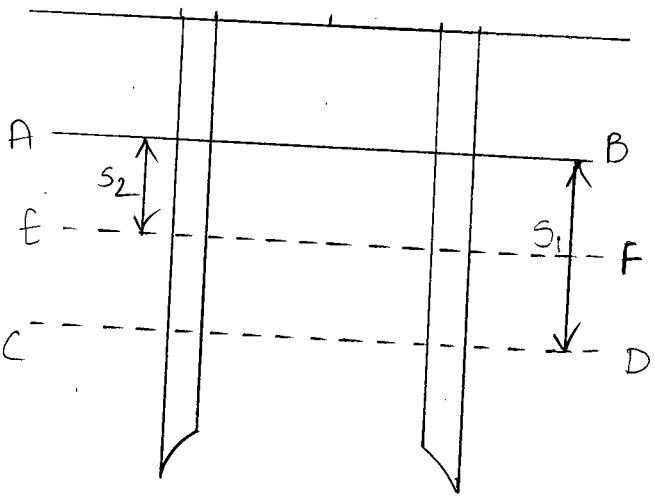
→ Head corresponding to critical velocity is called critical Head.

∴ Working Head = 1/3 (critical head)

→ Q_{max} from an open well corresponds to critical depression head and max. safe yield corresponds to working head.

Recuperation test:

→ When constant head (or discharge) cannot be maintained (unable to maintaine) Recuperation test is performed.



→ Water is pumped heavily, water level (head) drops from AB to CD.

→ wait for time 't' water level recuperate to Ef (recharges)

→ As drawdown varies for every interval of time, discharge too varies

AB ⟶ Initial water level

CD ⟶ water level in the well when pumping was stopped.

s ⟶ Depression head (or) drawdown when pumping.

ff ⟶ water level at time 't' after pumping was stopped.

Let (ds) be change for (dt)

Volume of water entering in dV = Area of c/s A × (ds)
small time (dt)

Let x-x be water level at any time 't'.

s ⟶ drawdown corresponding to x-x.

If 'Q' is rate of recharge in small time (dt).

Volume of water recharged $dV = Q \cdot dt$

We know $Q \propto s$

$Q = c's$

$dV = c's \times dt \longrightarrow$ eq^n ①

$dV = A \times ds \longrightarrow$ eq^n ②

Equating ① and ②

$-c's \cdot dt = A \times ds$

c ⟶ is introduced because as 't' ↑ 's' ↓

$$-\frac{c'}{A} \cdot dt = \frac{ds}{s}$$

by integrating on both sides we get

$$\frac{c'}{A}\int_0^T dt = -\int_{s_1}^{s_2} \frac{ds}{s}$$

at $t=0$, $s=s_1$

$t=T$, $s=s_2$

$$\frac{c'}{A}(t)_0^T = [\log_e s]_{s_1}$$

$$\frac{c^1}{A}(T) = \log_e \frac{s_1}{s_2}$$

$$\frac{c^1}{A}(T) = 2.303 \log_{10}\left(\frac{s_1}{s_2}\right)$$

$$\frac{c^1}{A} = \frac{2.303}{T} \log_{10}\left(\frac{s_1}{s_2}\right)$$

$\frac{c^1}{A}$ is called specific capacity (σ) specific yield of the formation (Aquifer) and its units are

m^3/sec	m^2	m
discharge	area	draw down

We have, $Q = c^1 s$

$$Q = \left(\frac{c^1}{A}\right) \cdot A \cdot s \qquad (\times \& \div \text{ by } A)$$

$$Q = \frac{2.303}{T} \log_{10}\left(\frac{s_1}{s_2}\right) \cdot A \cdot s$$

Experimental values: Given by "maxriot"

Type of soil	(c^1/A) $(m^3/hr/m^2/m)$
Clay	0.25
Sand	0.5
Coarse sand	1.0

These values can be assumed by default if NO time to perform experiment.

while soluing if data is insufficient (rare cases).

Problem-1:

Design a tube well for the following data.

Yield required = 0.08 m^3/s, thickness of confined aquifer = 30m, Radius of circle of influence = 300m, permeability coefficient is 60m/day, draw down 5m.

Sol: Given that

$$K = \frac{60m}{day} = \frac{60}{86500}\ m/s$$

$$K = 6.93 \times 10^{-4}\ m/s$$

$$Q = 0.08\ m^3/s$$

$$b = 30m$$

$$R = 300m$$

$$S = 5m$$

$$Q = \frac{2.72Kbs}{\log_{10}\left(\frac{R}{r}\right)}$$

$$\log_{10}\left(\frac{300}{r}\right) = \frac{2.72 \times 6.93 \times 10^{-4} \times 30 \times 5}{0.08}$$

$$\left(\frac{300}{r}\right) = 10^{(3.534)}$$

$$r = 0.088m$$

diameter, $d = 2r = 0.177m \cong 180m$

$$d = 18cm$$

Problem-2:

A tube well penetrates fully an unconfined aquifer. Calculate discharge from the tube well under the following conditions. Dia of well = 30cm, draw down = 2m, effective length of strainer under above draw down is equal to 10m. coefficient of permeability of aquifer is 0.05 cm/s. Radius of zero draw down = 300m.

Sol: Given,

dia of well = 30cm = 0.3m

Radius, r = 0.15m

Length of strainer, L = 10m

for confined aquifer, (L=b) => b=10m

draw down, S = 2m

coefficient of permeability, $K = \frac{0.05\,cm}{s} = 5\,m/s \times 10^{-4}$

Radius of zero draw down, R = 300m.

we have discharge,

$$Q = \frac{2.72\,KS\,(L + S/2)}{\log_{10}\left(\frac{R}{r}\right)}$$

$$Q = \frac{2.72 \times 5 \times 2\,(10 + \frac{2}{2}) \times 10^{-4}}{\log_{10}\left(\frac{300}{0.15}\right)}$$

$$Q = 9.06 \times 10^{-3}\,m^3/s$$

$$Q = 9.06\ lit/sec$$

Alternatively

S = 2m, L = 10m, H = 12m, h = 10m

$$Q = \frac{1.36 \times 5 \times 10^{-4}\,((12)^2 - (10)^2)}{\log_{10}\left(\frac{300}{0.15}\right)}$$

$$Q = 9.06 \times 10^{-3}\,m^3/s$$

$$Q = 9.06\ lit/sec.$$

Problem-3:

An artesian tube well has a dia of 20cm. Thickness of aquifer is 30m, 'K' is 38m/day. find its yield under a draw down of 4m at well face. Also determine transmissivity of aquifer.

Sol: Given,

diameter, $d = 20cm$

$r = 10cm \Rightarrow 0.1m$

thickness, $b = 30m$

Permeability, $K = 38m/day \Rightarrow 38/86400\ m/s$

$K = 4.39 \times 10^{-4}\ m/s$

draw down, $s = 4m$

Radius of influence 'R' from silchartis eqn

$$R = 3000 s\sqrt{K}$$

$$R = 3000(4)\sqrt{4.39 \times 10^{-4}}$$

$$R = 251.5m$$

yield/discharge, $Q = \frac{2.72 K b s}{\log_{10}\left(\frac{R}{r}\right)}$

$$Q = \frac{2.72(4.398)(30)(4)}{\log_{10}\left(\frac{251.5}{0.1}\right)} \times 10^{-4}$$

$$Q = 0.0422 m^3/s$$

Coefficient of transmissibility

$$T = K \times b$$

$$T = (4.398 \times 10^{-4}) \times 30$$

$$T = 0.0132\ m^2/s$$

Problem-4:

A well penetrates through 10m thick water bearing stratum of coarse sand having K = 0.005m/s. Radius of artesian well is 10cm and is to be worked under a draw down of 4m at well phase. calculate discharge from the well. What will be % increase in discharge. If the radius of well is doubled. Take R = 300m in each case.

Sol: Given,

Thickness, b = 10m

permeability, K = 0.005m/s

Radius, r_1 = 0.1m

draw down, s = 4m

We have discharge, $Q = \frac{2.72Kbs}{\log_{10}\left(\frac{R}{r}\right)}$

$$Q = \frac{2.72\times(0.005)\times(10)\times(4)}{\log_{10}\left(\frac{300}{0.1}\right)}$$

$$Q = 0.156\ m^3/s$$

If radius is doubled,

$r_1 = r$, $r_2 = 2r_1$

$Q_1 = Q$

$$Q_2 = \frac{2.72\,(0.005)\,(10)\,(4)}{\log_{10}\left(\frac{300}{0.2}\right)}$$

$$= 0.1712\ m^3/s$$

% increase, $\Delta Q = \frac{Q_2 - Q_1}{Q_1} \times 100 \Rightarrow \frac{0.1712 - 0.156}{0.156} \times 100$

$$\Delta Q = 9.79\ \%$$

Problem - 5:

In order to determine the field permeability of a free aquife Pumping out test was performed and following observations were made. Dia of well is 20cm, discharge is 240 m^3/hr. R.L of original water surface before pumping 240.5m, R.L of water in the well at constant pumping 235.6m, R.L of impervious layer 210m, R.L of water in observation well is 239.8m. Radial distance of observation well from tube well is 50m. Calculate 'K' also calculate

1) Error in K if observations are not taken in observation well and radius of influence is assumed as 300m.
2) Actual radius influence based on observations of observation well.

Sol: Given,

$Q = 240 m^3/hr$

$r_1 = 0.1m$

$H = (240.5 - 210.0)$

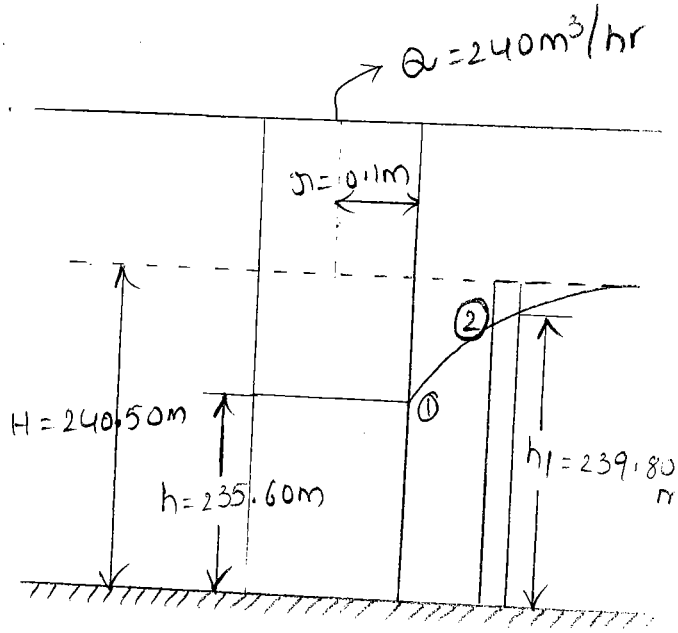
$H = 30.5m$

$h = (235.60 - 210)$

$h = 25.60m$

$h_1 = (239.80 - 210)$

$= 29.80m$



Now by applying thiem's eqn for point ① & ②

$$Q = \frac{1.36K(h_2^2 - h_1^2)}{\log_{10}(r_2/r_1)}$$

$$Q = \frac{1.36K((29.8)^2 - (25.6)^2)}{\log(\frac{50}{0.1})} = 240$$

$K_a = 2.046$ m/hr

1) Consider radius of influence, $R = 300$m

Substitute in dupit's eqn

$$Q = \frac{1.36K\left((30.5)^2 - (25.6)^2\right)}{\log_{10}\left(\frac{300}{0.1}\right)} = 240$$

$$K_0 = 2.232 \text{ m/hr.}$$

$$\% \text{ error in } K = \frac{K_{obs} - K_{act}}{K_{act}} \times 100$$

$$= \frac{2.232 - 2.046}{2.046} \times 100$$

$$= 9.1\%$$

2) Now actual radius of influence be 'R_m'

$$Q = \frac{1.36K_{act}(H^2 - h^2)}{\log_{10}\left(\frac{R}{r}\right)}$$

$$240 = \frac{1.36(2.046)\left((30.5)^2 - (25.6)^2\right)}{\log_{10}\left(\frac{R}{0.1}\right)}$$

$$\log_{10}\left(\frac{R}{0.1}\right) = 1538.41m$$

$$R = 153.84m \cong 154m$$

Problem- 6:

A 60cm dia well is pumped at the rate of 2000lit/min. measurements in near by test wells were made at the same time were: At a discharge of 10m draw down is 4m at a discharge of 20m, the draw down is 2m. The thickness of unconfined aquifer is 40m.

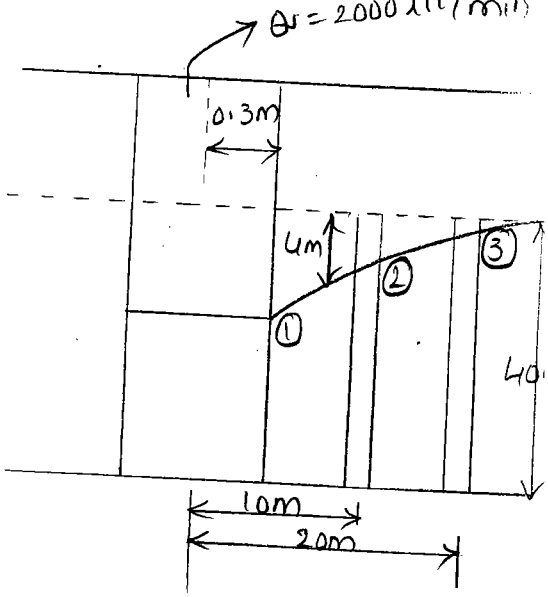
a) find out 'k'

b) If all the observed values are on dupits curve. What was

draw down in drain well during pumping.

c) specific capacity, Radius of influence.

d) what is maximum rate at which water can be drawn from main well.



Sol: Given,

$(Q)_{tube\ well} = 2000$ lit/min

$= 0.033\ m^3/s$

$= 2880\ m^3/day$

$r_1 = 0.3m$

draw downs, $s_1 = 4m$

$s_2 = 2m$

$\therefore h_1 = H - s_1 = 40 - 4 = 36m$

$h_2 = H - s_2 = 40 - 2 = 38m$

a) $Q = \frac{1.36K(h_2^2 - h_1^2)}{\log_{10}(\frac{r_2}{r_1})}$

$\Rightarrow \frac{1.36K((38)^2 - (36)^2)}{\log_{10}(\frac{20}{10})} = 2880 m^3/day$

$K = 4.307\ m/day$

b) Apply theim's eqn at point ① & point ②

$$Q = \frac{1.36K(h_2^2 - h_1^2)}{\log_{10}(r_2/r_1)}$$

$$Q = \frac{1.36(4.307)((36)^2 - (h)^2)}{\log_{10}(\frac{10}{0.3})} = 2880$$

$h = 23.39m \cong 23.4m$

draw down, $s = H - h = 16.6m$

c) Specific capacity, $\frac{C'}{A} = \frac{2.303}{T} \log_{10}\left(\frac{S_1}{S_2}\right)$

$T = K \times b \Rightarrow (4.307 \times 40) \Rightarrow 172.28 m^2/day$

$\frac{C'}{A} = \frac{2.303}{172.28} \log_{10}$ ($S_1, S_2 \rightarrow$ not available)

We know that, specific discharge of the well is discharge per unit draws down

i.e $S = 1 \Rightarrow h = H - S \Rightarrow 40 - 1 \Rightarrow 39m$

apply dupit's eqn, $Q_S = \frac{1.36 K (H^2 - h^2)}{\log_{10}(R/r)}$

$$Q_S = \frac{1.36 (4.307) ((40)^2 - (39)^2)}{\log_{10}\left(\frac{41.5}{0.3}\right)}$$

$Q_S = 216.14 m^3/day$ (m depression head)

~~we have, $Q_S =$~~

d) Radius of influence, $\log_{10}\left(\frac{R}{r}\right) = \frac{1.36 K (H^2 - h^2)}{Q}$

$$\log_{10}\left(\frac{R}{0.3}\right) = \frac{1.36 (4.307) ((40)^2 - (23.4)^2)}{2880}$$

$\left(\frac{R}{0.3}\right) = 138.20m$

$R = 41.46m \cong 41.5m$

maximum discharge of well (at $h = 0$)

$$Q = \frac{1.36 K (H^2)}{\log_{10}(R/r)}$$

$$Q = \frac{1.36 (4.307) (40)^2}{\log_{10}\left(\frac{41.5}{0.3}\right)}$$

$Q = 4377.55 m^3/day$