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Sec - D

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Aequifers :-

An aquifer is an underground layer of rock or soil that contains water and yields it in sufficient quantity. Unconsolidated deposits of sand and gravel form good aquifers. Water is taken from the aquifer to the surface using wells and pumps.

Types of Aquifers :

There are of two types of Aquifers.

1) Unconfined Aquifers or water table aquifer
2) Confined Aquifers or Artesian aquifer.

Unconfined Aquifers -

* Unconfined aquifers are those into which water seeps from the ground surface directly above the aquifer.
* Has no confining bed.
* Open to infiltration from surface.
* Unconfined aquifers are sometimes also called water table aquifers because their upper boundary is the water table.

Confined Aquifer :-

* Confined Aquifer are those in which an impermeable rock layer exists that prevents water from seeping into the aquifer from the ground surface located directly above.

* Instead, water seeps into confined aquifer from farther away where the impermeable layer does not exist.

* overlain by a confining bed.
* Confined aquifer are recharged through cracks in impermeable layer.
* Also known as Artesian aquifer

Properties of the Aquifer :-

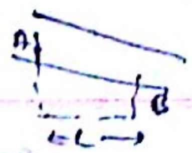
1) **Porosity :-** The amount of pore spaces per unit volume of the aquifer material is called porosity

$$n = \frac{V_v}{V_o}$$

V_v = volume of voids
V_o = vol. of porous medium

Porosity of surface soil decreases as particle size increases.

Hydraulic gradient :- It is the loss of head divided by the horizontal distance or length in which the loss has taken place.



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2) **Specific yield :-**

The actual volume of water that can be extracted by the force of gravity is known as specific yield. (S_y).
The fraction of water held back in the aquifer is known as specific retention (S_r)

$$n = S_y + S_r$$

~~3) Darcy's law :-~~

3) **Permeability :**

As the porosity of a soil affects how much water it can hold, it also affects how quickly water can flow through the soil.
Thus,
The ability of water to flow through a soil is known as permeability of the soil.

4) **Darcy's law :-**

The law of flow of water through soil was first studied by Darcy (1856).
This law states that
" The velocity of water is always proportional to the hydraulic gradient.

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Mathematically -

velocity $\propto$ hydraulic gradient

$$V \propto i$$

$$V = ki$$

multiplying A on both sides

$$AV = ~~Av~~ \; Aki \quad -(1)$$

where k is constant of proportionality and is called coefficient of permeability.

Q or q stands for discharge and is equal to

$$Q = \frac{V}{t} = \frac{\text{volume}}{\text{time}}$$

$$Q = A \times \frac{L}{t} \qquad \left[\frac{L}{t} = \text{velocity}\right]$$

$$\therefore Q = AV. \quad -(2)$$

putting (2) in eqn (1), we get

$$Q = Aki$$

which is darcy's eqn.

where

~~Q~~ Q = flow or discharge

k = coefficient of proportionality

i = hydraulic gradient.

A = Area of cross section

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Coefficient of Permeability :-

Now

$$Q = KAi$$

or

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

If $i = 1$, then

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

then K is called coefficient of permeability. and K is defined as
the discharge or rate of flow per unit area of soil mass under unit hydraulic gradient.

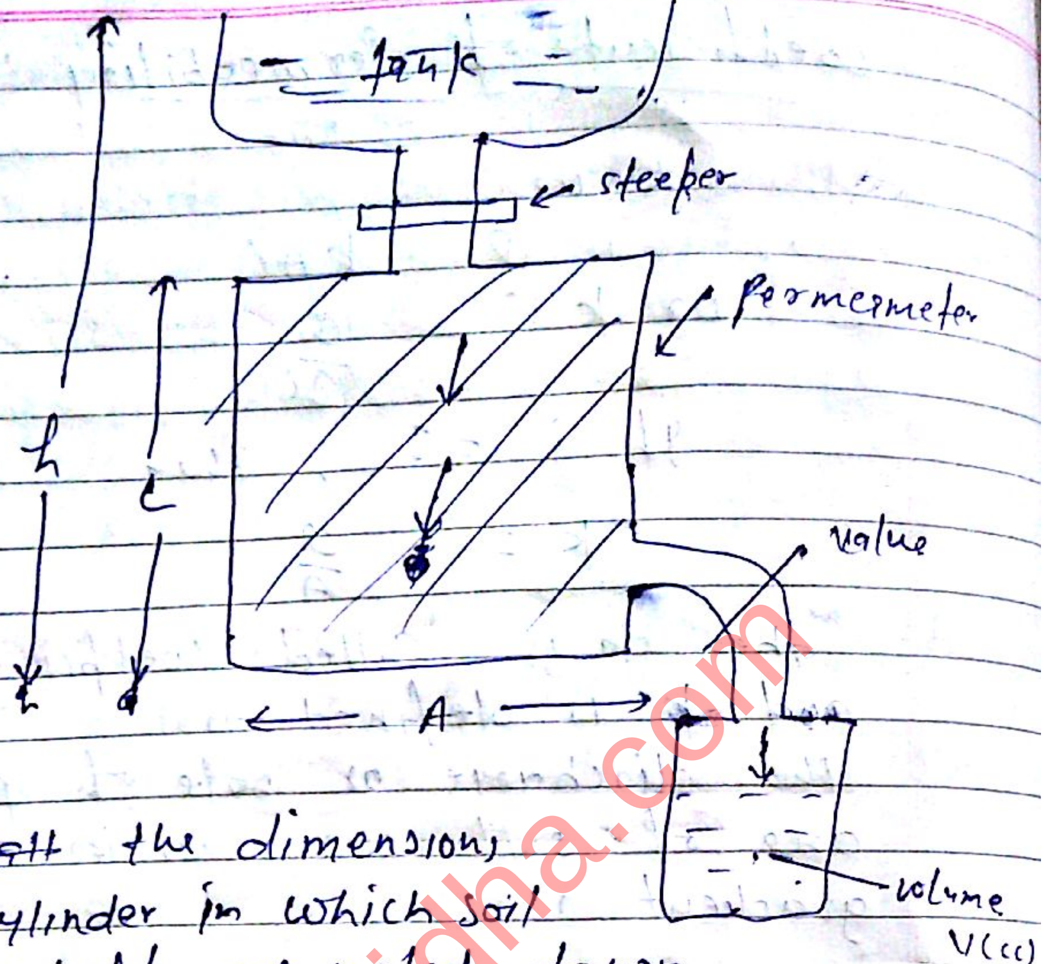
Determination of Coefficient of Permeability :-

There are two methods of determination of coefficient of permeability in the lab and one method in the field.

The method to determine the coefficient of permeability in the lab is:
Constant head permeability test:

Constant Head Permeability test :-

The apparatus used in this test is known as constant head permeameter.



First of all the dimensions of the cylinder in which soil sample is kept are noted down i.e. length, height, area etc.
Then the soil is placed in the apparatus and the two valves are opened.
The time and amount of water are noted down and then used to find

$$Q = \frac{V}{t} \quad , \quad (\text{volume in cc})$$

Then all the data is placed in the darcy's law and the coefficient of permeability is calculated.
Acc. to Darcy's law –

$$Q = KiA$$

and $i = h/L$

$$Q = \frac{KAh}{L}$$

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$$K = \frac{QL}{Ah}$$

L = Length of cylinder
h = head
A = Area of cylinder

Transmissibility :-

The transmissibility is the flow capacity of an aquifer per unit width under unit hydraulic gradient and is equal to the the product of permeability times the saturated thickness of the aquifer

$$T = KH$$

where
K = Permeability
H = saturated thickness of the aquifer

As the water table drops, H decreases and the transmissibility is reduced. Thus the transmissibility of an unconfined aquifer depends upon the depth of GWT.

Storage coefficient :- (S)

The storage coefficient in case of confined aquifer is defined as the volume of water that an aquifer releases from or takes into storage per unit surface area of the aquifer.

It is also known as storatibity → storativity.

Drawdown :-

The drop in the water table elevation at any point from its previous static level is called draw down.

Aquitard :-

It is a saturated geological formation which is poorly permeable and hence it does not yield water freely to wells. Sandy clay is an example of a Aquitard.

Formation Constants :-

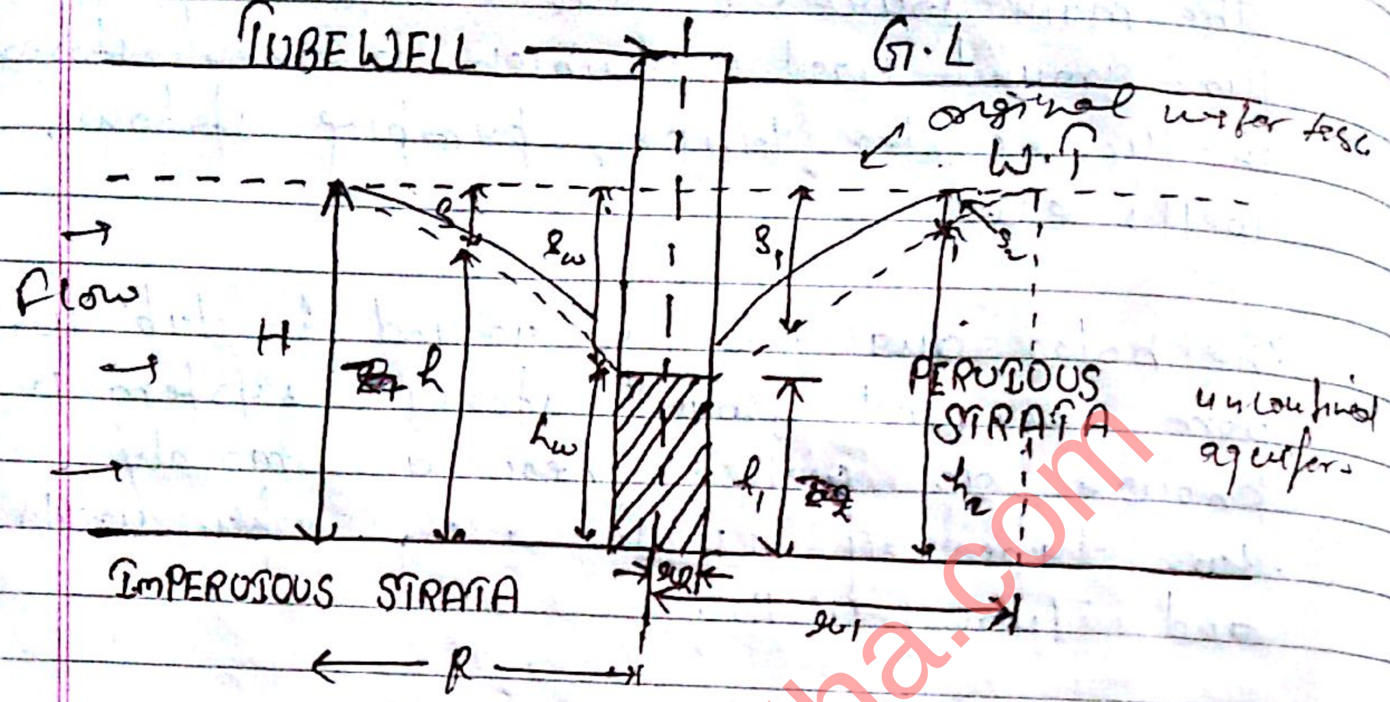
The storage coefficient (S) and the transmissibility coefficient (T) are known as the formation constants of Aquifer.

Steady state Flow to wells :-

The main source of the water supply is the ground water which is then stored in the water tanks, pumping stations, wells etc.

The holes dug into the ground to tap water from the underground storage system is known as well. There are mainly two types of wells i.e. open wells and Tube wells.

Unconfined Aquifer Flow :-



Definition :-

Consider a steady flow from a well completely penetrating an unconfined aquifer.

Assume that the well is pumped at a constant rate Q for a long time and the water level in the observation wells have stablised i.e. equilibrium condition have been reached.

From Darcy's law

$Q = KiA$

$Q = K \frac{dy}{dx} (2\pi xy)$

Integrating

$$Q \int_{r_1}^{r_2} \frac{dr}{r} = 2\pi k \int_{h_1}^{h_2} y\, dy$$

$$Q = \frac{\pi k (h_2^2 - h_1^2)}{2.303 \log_{10} \left(\frac{r_2}{r_1}\right)}$$

or

$$Q = \frac{\pi k (h_2^2 - h_1^2)}{\ln \left(\frac{r_2}{r_1}\right)} \quad \text{--- (1)}$$

where h_1 and h_2 are water levels in the two observation wells at the radial distances r_1 and r_2 respectively from the main well. The Radius at which the cone of depression just commences is known as the radius of influence and denoted by R.

Applying the above eq^n b/w the face of well ($r = r_w$, $h = h_w$) and the point of zero drawdown ($r = R$, $h = H$)

$$Q = \frac{\pi k (H^2 - h_w^2)}{2.303 \log_{10} \left(\frac{R}{r_w}\right)} \quad \text{--- 1(a).}$$

If the drawdown in the pumped well ($s_w = H - h_w$) is small.

$$H^2 - h_w^2 = (H + h_w)(H - h_w)$$
$$2H(H - h_w)$$
$[H + h_w = 2H]$

Then

$$Q = \frac{2\pi K H (H - h_w)}{2.303 \log_{10}\left(\frac{R}{r_w}\right)}$$

$$T = KH$$

$$\therefore Q = \frac{2\pi T (H - h_w)}{2.303 \log_{10}\left(\frac{R}{r_w}\right)}$$

$$= \boxed{\frac{2.72\, T\, (H - h_w)}{\log_{10}\left(\frac{R}{r_w}\right)}} \quad —(2)$$

Numerical :-

A 20 cm well penetrates 30 m below static water level (GWT). After a long period of pumping at a rate of 1800 lpm, the drawdown in the observation wells at 12 m and 36 m from the pumped well are 1.2 m and 0.5 m respectively. Determine

i) the transmissibility of the aquifer
ii) the drawdown in the pumped well assuming R = 300 m.
iii) the specific capacity of the well

[Drawdowns, represented by s_1 and s_2 in two observation wells]

$H - h_w = S_w$

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Sol^n :-

Given values -

$H = 30\,m$, $r_1 = 12\,m$, $r_2 = 36\,m$
$s_1 = 1.2\,m$, $s_2 = 0.5\,m$

$h_1 = H - S_1 = 30 - 1.2 = 28.8\,m$
$h_2 = H - S_2 = 30 - 0.5 = 29.5\,m$

$$Q = \frac{\pi K (h_2^2 - h_1^2)}{2.303 \log_{10} \frac{r_2}{r_1}}$$

$$\frac{1800}{1000 \times 60} = \frac{\pi K [(29.5)^2 - (28.8)^2]}{2.303 \log_{10} \frac{36}{12}}$$

$$= 0.03 = \frac{\pi K [(29.5)^2 - (28.8)^2]}{2.303 \log_{10} 3}$$

$K = 2.62 \times 10^{-4}\,m/sec$ or
$22.7\,m/day$.

i) Transmissibility $(T) = KH$

$= (2.62 \times 10^{-4}) \times 30 = 78.6 \times 10^{-4}\,m^2/sec$

$= 22.7 \times 30 = 681\,m^2/day$.

∴ Dia of well = 20 cm = 0.20 m.
radius (r_w) = 0.10 m

ii) For drawdown case –

$$Q = \frac{2.72\, T\, (H - h_w)}{\log_{10}\left(\frac{R}{r_w}\right)}$$

or

$$Q = \frac{2.72\, T\, S_w}{\log_{10}(R/r_w)} \qquad [H - h_w = S_w]$$

$$= 0.08 = \frac{2.72 \times (78.6 \times 10^{-4})\, S_w}{\log_{10} 300/0.10}$$

S_w =

Drawdown in the well (S_w) = 4.88 m

iii) The specific capacity of the well

$$\frac{Q}{S_w} = \frac{T}{1.2}$$

$$= \frac{78.6 \times 10^{-4}}{1.2}$$

$$= 0.00655 \,(m^2\, sec^{-1}/m)$$

$$= 3.93 \ lpm/m$$

Confined Aquifer flow :

fig

If

If the well is pumped at a constant pumping rate Q for a long time and the equilibrium conditions have reached as shown in fig -

from Darcy's law

$$Q = K i A$$

$$Q = K \frac{dy}{dx} (2\pi x \cdot b)$$

Integrating

Q

$$Q\int_{r_1}^{r_2}\frac{dr}{r} = 2\pi K b\int_{h_1}^{h_2} dy$$

$$Q = \frac{2\pi K b\,(h_2 - h_1)}{2.303\log_{10}\left(\frac{r_2}{r_1}\right)} \quad -(3)$$

Applying above eqn b/w the face of the well ($r = r_w$, $h = h_w$) and the point of zero draw down ($r = R$, $h = H$) simplifying and putting $T = Kb$.

Then

$$Q = \frac{2.72\,T\,(H - h_w)}{\log_{10}(R/r_w)} \quad -(4)$$

Assumptions made in the unconfined Aquifer flow derivation —

* The Aquifer is homogeneous.
* The flow is laminar and Darcy's law is valid
* The flow is radial towards the well and uniform at every point.
* The velocity is proportional to tangent of the hydraulic gradient.
* The water table is at rest.

Numerical :-

A tube well taps an artesian aquifer. Find its yield in litres per hour for a drawdown of 3m when the dia of the well is 20 cm and the thickness of the aquifer is 30 m. Assume the coefficient of permeability to be 35 m/day.

If the dia of the well is doubled find the percentage increase in the yield, the other conditions remaining the same. Assume the radius of the influence as 300 m in both the cases.

Sol^n :-

Given values :-

$S_w = 3m.$

$r_w = 0.10 m,$

$H = 30m.$

$K = 35 m/day$

$T = KH = \frac{35}{24} \times 30 = \frac{175}{4} m^2/hour$

$= 43.75 \ m^2/hour$

$$Q = \frac{2.72 T (H - h_w)}{\log_{10} R/r_w}$$

or

$$\frac{2.72 \ T \ S_w}{\log R/r_w}$$

$$= \frac{2.72 \times 43.75 \times 3}{\log_{10} \frac{300}{0.10}}$$

$$= 102.7 \ m^3/hr$$

102.7×10^3 lph

$$= \boxed{102700 \text{ lph}}$$

The yield

$$Q \propto \frac{1}{\log R/r_w}$$

Other things remain same

If the yield is Q' after doubling the diameter i.e.

$$r_w' = 0.10 \times 2 = 0.20 m$$

$$\frac{Q}{Q'} = \frac{\log R/r_w}{\log R/r_w'}$$

$\log \frac{300}{0.10} = 3.4771$, $\log \frac{300}{0.20} = 3.1761$

$$= \frac{102.7}{Q'} = \frac{3.1761}{3.4771}$$

$$\therefore \boxed{Q' = 112.4 m^3/hr}$$

Percentage increase in yield $= \frac{Q' - Q}{Q} \times 100 = \frac{112.4 - 102.7}{102.7} \times 100 = 9.45\%$

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