Module - 1

Introduction

Importance of Ground water

→ Ground water which is in aquifers below the Surface of the earth is one of the Nation's most important natural resources.

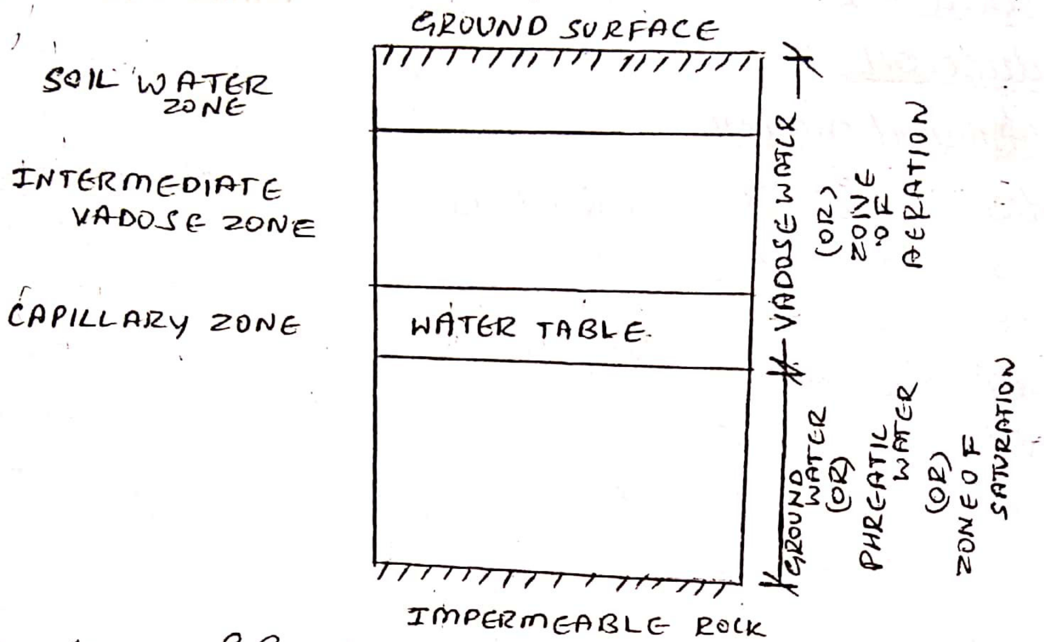
› The availability of Surface water is greater than ground -water. However, owing to the decentralised availability of ground water, it is easily accessible and forms the large share of agricultural and drinking water Supply. At present nearly one fifth of all the water used in the world is obtained from ground water resources.

The dependence of irrigation on ground water increased with the onset of the Green revolution, which depends on intensive use of inputs such as water and fertilizers to boost form products.

· The overall contribution of rainfall to the Country's annual ground water resource is 68%. India is fast moving towards a crisis of ground water overuse and contamination. Recharge of groundwater has to be lone option to reverse this trend.

Global ground water storage is roughly equal to the total amount of fresh water Storage in the form of Snow and ice pack, including the North and South poles. This makes ground water an important resource that can act as a natural storage that can buffer against shortage of Surface water, as in during times of drought

Vertical Distribution of Subsurface water



Water in Subsurface appear's in mainly two zones
zone 1 -> vadoze zone (or) zone of aeration (or) unsaturated zone
zone 2 -> Saturated zone (or) phreatic water zone (or) ground water zone

zone 1

- Zone of aeration consists of interstice (voids) occupied partially by water and partially by air.
- Zone of aeration lies between earths surface and water table.
- The main component's of this region are Soil and ra
- The degree of Saturation for the Soil will be less than 1.

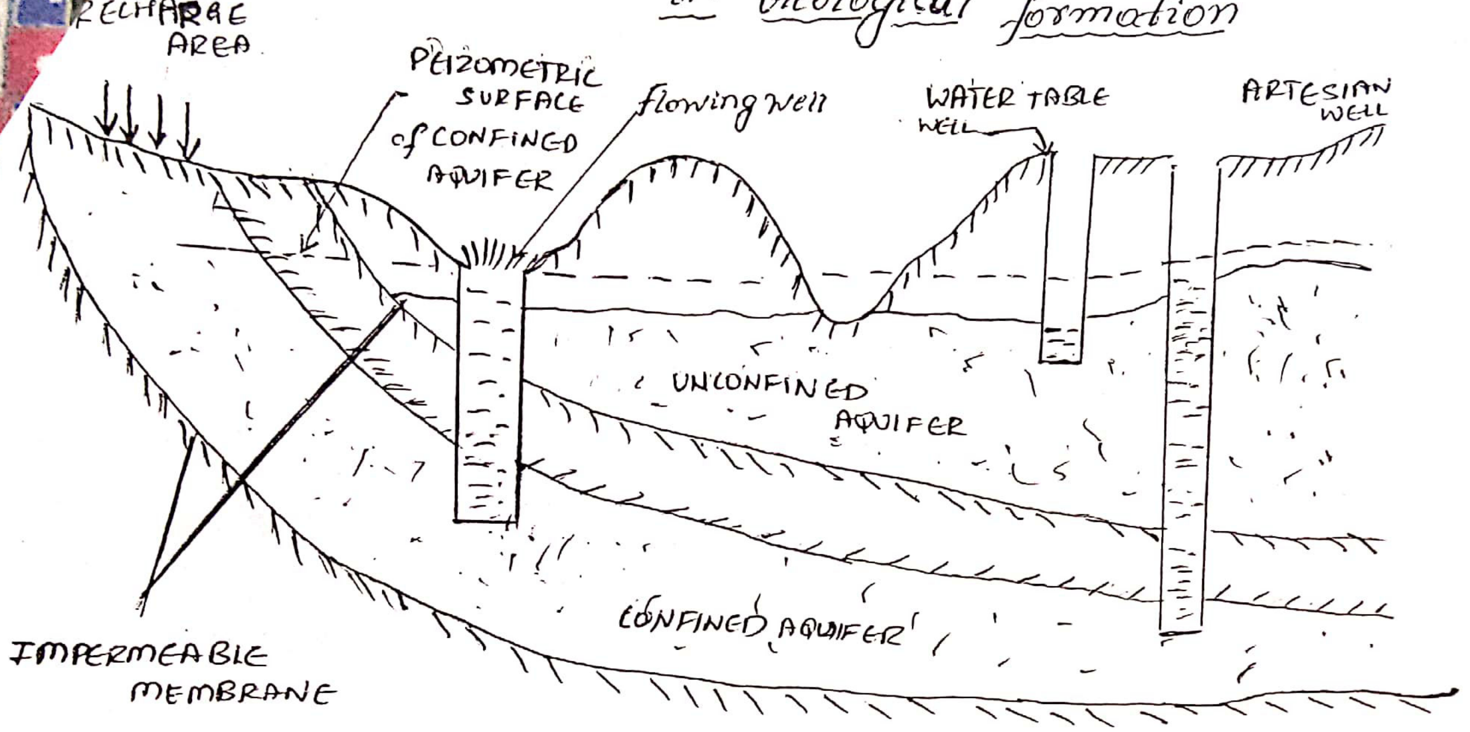
zone 2

- The phreatic zone, or zone of saturation is the area in an aquifer below the water table in which relatively all pores and fractures are Saturated with water.
- The degree of Saturation will be 1 for the Soil in this region.
- At all points on the water table, the pressure will be atmospheric.

zone one is again classified into three Sub zones
i) Soil water zone ii) capillary zone iii) Intermediate vadose zone

Soil water zone is divided into
i) Hygroscopic water zone ii) capillary water zone
iii) Gravity water zone

...rance of Ground water in Rocks and Soil (or) in Geological formation



Ground water occurs at various locations below the earth's surface depending on the physical properties of various formation that exist. The above figure show a typical cross-section of the earth's crust showing the occurrence of groundwater. The different types of Geological formation are

i) Aquifer → Confined Aquifer
→ Unconfined Aquifer

ii) Aquiclude

iii) Aquitard

iv) Aquifuge

Aquifer - formations which contains groundwater and at the same time which are sufficiently permeable to transmit and yield water in usable quantity are called the Aquifers.

→ They may get recharged directly from above through the process of precipitation and infiltration or they may have the recharge area somewhere else on the earth's surface

→ The amount of water contained by the aquifer depends on the porosity of the aquifer formation, while the amount of water that it can yield depends on its

(1)

<u>Unconfined Aquifer</u> [<u>free Aquifer</u> (or) <u>phreatic Aquifer</u> (or) <u>Non Artesian Aquifer</u>]

-> An aquifer having water table in it is called an unconfined Aquifer

-> for this aquifer, water table serves as the upper surface while a less permeable (or) essentially impermeable layer forms lower boundary.

-> The impermeable layer underlying an unconfined aquifer may be made of clay, shale, solid limestone, igneous rock

-> The water table in an unconfined aquifer varies in undulating form and in slope.

-> A well penetrating into an unconfined aquifer is called <u>water Table -well</u>

<u>Confined Aquifer</u> [<u>Pressure Aquifer</u> / <u>Artesian Aquifer</u>]

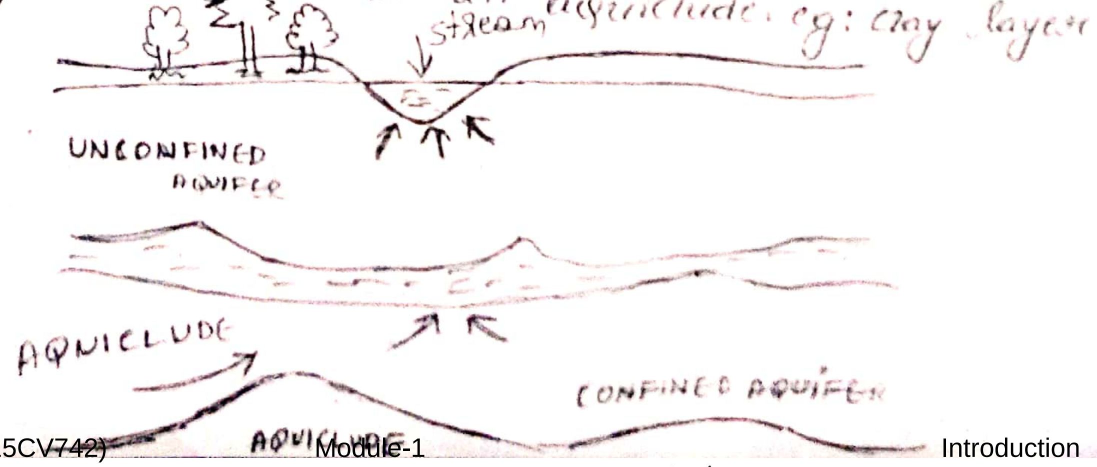
-> When an aquifer is sandwiched between two layers of much less permeable material (or) essentially impermeable layer then it is called a confined aquifer.

-> Confined aquifer are completely filled with water and they do not have a free water table.

-> If a well penetrates into the confined aquifer. water level in the well will rise to piezometric level, such a well is called an <u>artesian well</u>

-> If the piezometric surface at the place of the well is above the ground level, the confined aquifer will yield a free-flowing well also known as a <u>flowing well</u>.

<u>Aquiclude</u>: A geological formation which is saturated and which may contain large amount of water because of its high porosity but cannot transmit water as it is relatively impermeable is called an aquiclude. eg: clay layer



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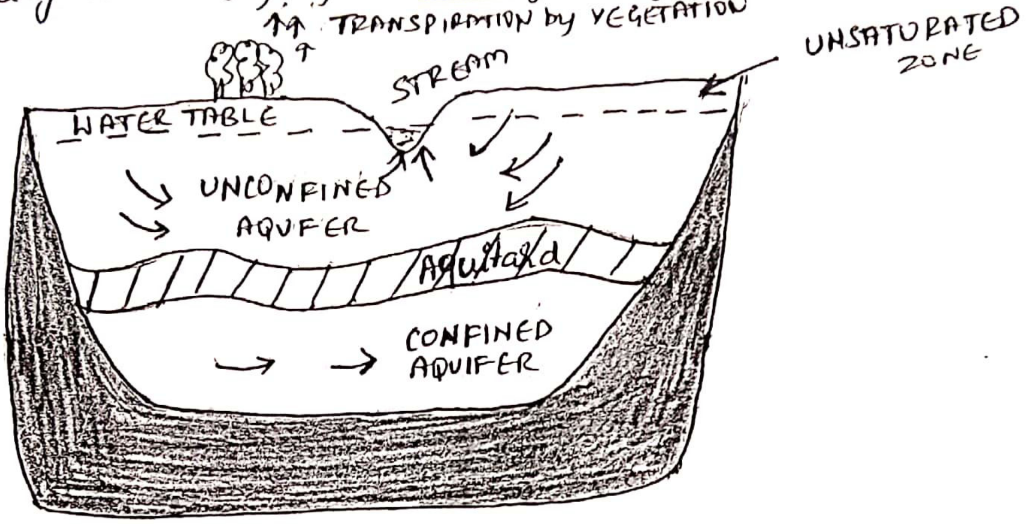
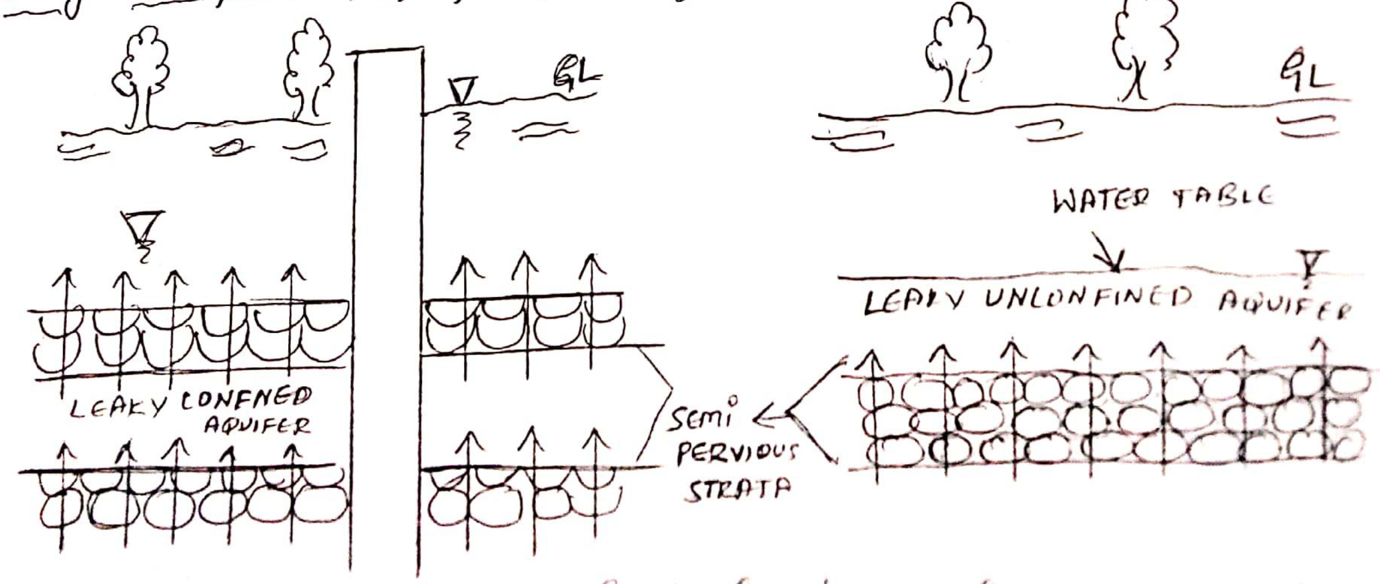
Aquitard: It is a saturated geological formation which is poorly permeable and hence it does not yield water freely to wells. There will be flow of water to (or) from an adjacent aquifer. Sandy clay is an example of aquitard.



Aquifuge: It is an impervious geological formation which neither contains nor transmits water. Solid granite is an example of aquifuge.

Leaky Confined Aquifer & Leaky unconfined Aquifer



Top and bottom layers of confined aquifer is generally impervious however some times these layers may be semipervious in nature. In such case water may gain/leak through these semipervious layers. The aquifer is then called leaky confined aquifer.

An impervious layer serves as the bottom boundary of an unconfined aquifer. Some times the bottom of unconfined aquifer may be semi pervious. In such case water may gain/loose through these semipervious layer

The aquifer is then known as Leaky unconfined aquifer

> Leaky aquifer will be bounded by on (or) two aquitard.

> When a well in a leaky aquifer is pumped, water is withdrawn not only from the aquifer, but also from the overlying and underlying layers.

> In nature, truly confined aquifers are rare.

> Example for leaky aquifer: Sand or Gravel that are in subsurface and which are — confined between low permeable layers, such as Silt.

Module - 2

Aquifer parameters

→ Porosity
→ Specific yield
→ Permeability
→ Transmicibility
→ Specific retention
→ Storage Co-efficient (or) Storetivity

→ **Porosity (n)**

More empty space
→ More porosity

Smaller soil partic
Less empty spaces
→ Less porosity

The ratio of volume of pore space (void space) to the volume of formation (rock's) is called porosity

i.e Porosity $(n) = \frac{V_v}{V}$ where V_v = volume of void space
V = Total volume of formation (rocks)

Sedimentary rocks → Porosity is more
Igneous rocks →
Metamorphic rocks → } Porosity is less as these are formed under high pressure and temperature

According to classification of sedimentary rocks
Well rounded → Greater porosity
Poorly sorted → Lesser porosity
Well cemented rocks → Least porosity.

→ **Specific yield (S_y)**

It is the ratio of the volume of water which will drain freely from the material to the total volume of the formation

i.e Specific yield $(S_y) = V_d / V$

V_d = Volume of water which will drain
V = Total volume of formation (rock)

(2)

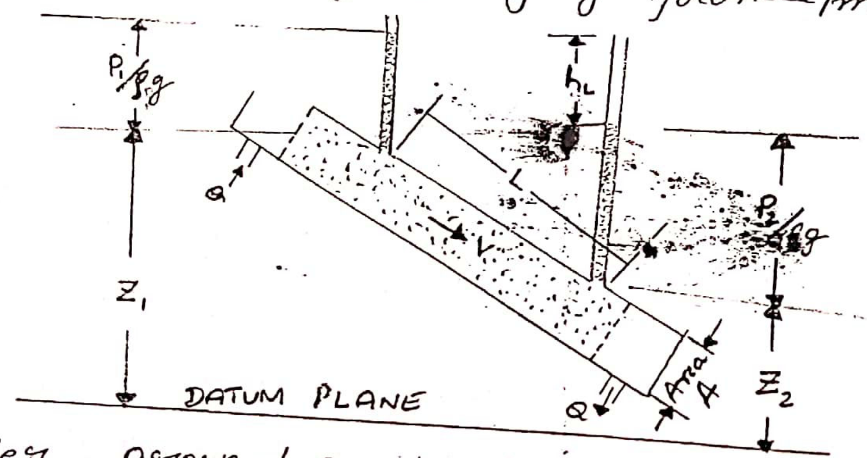
Specific yield depends on
* Grain Size
* Shape & Distribution of pores
* Compaction of formation.

for fine grained soil → Specific yield is less
for Coars grained soil → Specific yield is more

Permeability

The permeability of material is a measure of its capacity to transmit water (or) any other fluid through its voids or pores.

Ground water is transmitted through aquifer at very Small velocity ranging from 1m - 500m / year



Consider ground water flow through porus medium

Let $P_1/\rho g$ = Pressure head at Section ①

$P_2/\rho g$ = Pressure head at Section ②

Z_1 & Z_2 = Datum head at Section ① & ②.

$v_1^2/2g$ & $v_2^2/2g$ = velocity head at Section ① & ②

Applying Bernoullis equation to Section 1 & 2)

$$\frac{P_1}{\rho g} + Z_1 + \frac{v_1^2}{2g} = \frac{P_2}{\rho g} + Z_2 + \frac{v_2^2}{2g} + h_L$$

h_L = Head loss

Neglecting the velocity heads as velocity of groundwater will be very small

$$\frac{P_1}{\rho g} + Z_1 = \frac{P_2}{\rho g} + Z_2 + h_L$$

$$\boxed{h_L = \left(\frac{P_1}{\rho g} + Z_1\right) - \left(\frac{P_2}{\rho g} + Z_2\right)}$$

Experimentally it is found that discharge Q from the aquifer depends upon h_L, L & A

Where L = length between section 1 & 2

A = Area of flow

$$\therefore Q \propto \left(\frac{h_L \times A}{L}\right)$$

$$Q/A \propto \left(\frac{h_L}{L}\right)$$

$$v \propto \left(\frac{h_L}{L}\right)$$

$$\boxed{v = -k\left(\frac{h_L}{L}\right)}$$

If distance b/w 2 piezometers is small then

$$v = -k\left(dh/dl\right)$$

The -ve sign indicates loss of head takes place in the direction flow (or) vice versa

Where k is known as hydraulic conductivity (or) co-efficient of permeability.

v = velocity of water through porous medium (or) Darcy's velocity

$\frac{dh}{dl}$ = Hydraulic gradient

Imp

Darcy's Law states that rate of flow per unit area of an aquifer is proportional to gradient of potential head measured in the direction of flow i.e. ($Q/A \propto h_L/L$) (or) ($v \propto h_L/L$).

If $Re < 1$, then Darcy's law is applicable

$Re > 1$, then Darcy's law is not applicable

Where $Re \rightarrow$ Reynolds number

$$R_e = \frac{\rho v d}{\mu}$$

$\rho \rightarrow$ Density of water

$v \rightarrow$ velocity of water / Darcy velocity

$d \rightarrow$ Diameter of void's space

$\mu \rightarrow$ Dynamic viscosity

Hydraulic Conductivity (or) Co-efficient of permeability (k)

It is defined as the rate of flow per unit area of aquifer under a unit hydraulic gradient

W.K.T from Darcy's Law $v = -k \times \frac{dh}{dl}$

$$Q = A \times v$$

$$\left(\frac{Q}{A}\right) = v$$

$$\therefore \left(\frac{Q}{A}\right) = -k \times \left(\frac{dh}{dl}\right)$$

(or) $k = \frac{(Q/A)}{(dh/dl)}$ — $(Q/A) \rightarrow$ Discharge per unit area; $(dh/dl) \rightarrow$ Hydraulic Gradient

for unit Hydraulic Gradient i.e when $(dh/dl) = 1$

$$k = (Q/A) \text{ (or) } k = v$$

unit of v is m/s

Since velocity of Groundwater is very less it is expressed in terms of m/year

$\therefore$ The same unit holds good for co-eff of permeability

Intrensic permeability

Intrinsic permeability is the property of the medium only and it does not depend on the fluid properties.

Based on Hagen poiseuille equation for laminar flow

$$k = \frac{C \times d_m^2 \times \gamma}{\mu}$$

Where
- $k \rightarrow$ Hydraulic Conductivity
- $\mu \rightarrow$ Dynamic viscosity
- $C \rightarrow$ Shape factor.
- $d_m \rightarrow$ Average Grain Size
- $\gamma \rightarrow$ Sp. weight

W.K.T $\gamma = \rho \times g$

$$k = \frac{(C \times d_m^2) \times \rho \times g}{\mu}$$

$$k = \frac{(C \times d_m^2) \times g}{\nu}$$

$\langle \nu \rightarrow$ kinematic viscosity

$\nu = \mu / \rho$

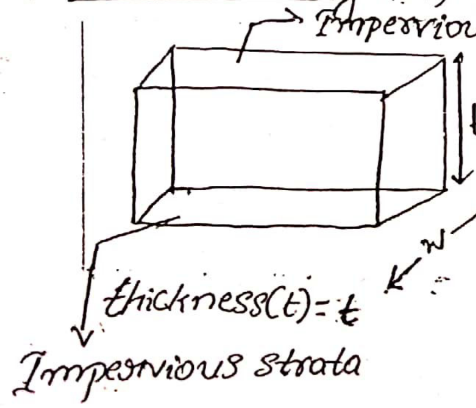
Intrensic permeability is the product of $(C \times d_m^2)$

unit of intrens[redacted]permeability $\rightarrow m^2$ or cm^2

1 Darcy $= 0.987 \times 10^{-12} m^2$ (or)

1 Darcy $= 0.987 \times 10^{-8} cm^2$

→ Transmissivity (or) Transmissibility (T) or Transmissivity co-effi



Discharge through an aquifer is given by $q = A \times V$

Where $A \rightarrow$ Area of flow

$V \rightarrow$ Darcy's $\quad t \rightarrow$ Thickness of aquifer

i.e $V = -k \times (dh/dl)$ $\quad$ Width of aquifer(w) = 1

$$q = (t \times 1) \times -k \times (dh/dl)$$

$$q = (t \times K)(-dh/dl) \quad \langle \text{thickness } (t) = 1 \rangle$$

The transmissibility of an aquifer is the product of hydraulic conductivity k and of an aquifer. $\boxed{T = (t \times K)}$

The unit of hydraulic conductivity(k) is m/year & of width (b) is m

∴ unit of Transmissivity is m^2/year

∴ $q = T \times (-dh/dl)$ (or) $\boxed{T = \frac{q}{(dh/dl)}}$

> Specific Retention (S_r)

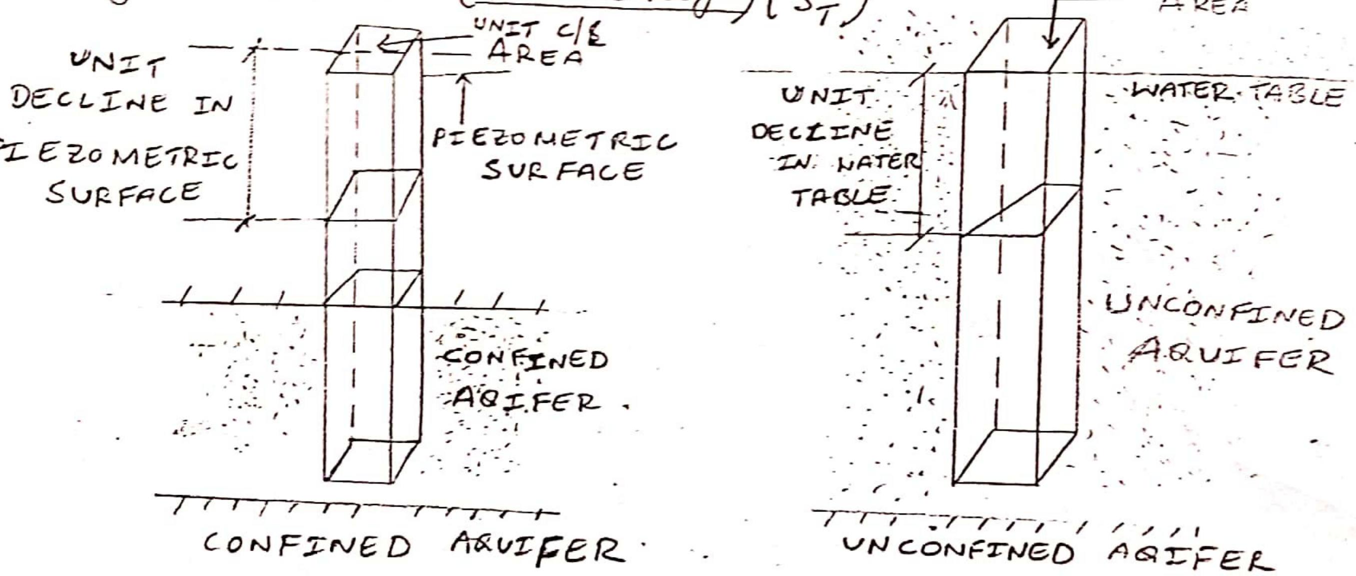
The specific retention is defined as ratio of volume of water retained in the material to the volume of formation (or) material (rock)

i.e Specific Retention $(S_r) = \frac{V_r}{V}$

V_r → volume of water retained

V → volume of formation or material

Storage co-efficient (Storativity) (S_T)



orage co-efficient is defined as the volume of water that n aquifer releases from (or) takes into storage per unit urface area of the aquifer per unit drop of water able in case of an unconfined aquifer & per unit drop f piezometric surface in the case of confined aquifer

Permeability of isotropic and unisotropic Soil

→ If the properties of soil has same value when measured in different directions, then such soils are called isotropic soil.

Permeability is the same along any direction in the isotropic soil mass

The permeability depends upon the grain size distribution, porosity, shape and arrangement of pores, properties of the pore fluid and entrapped air.

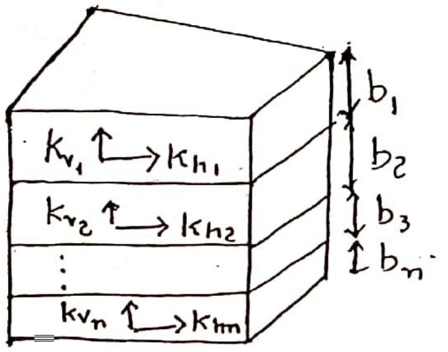
Unisotropic Layered Soil

→ If the values of properties of soil are not same when measured in different directions, then such soils are called unisotropic soil.

→ Permeability will not be same in the unisotropic soilmass

→ Many soils are formed in horizontal layers as a result of sedimentation through water. Because of seasonal variation such soil tend to be horizontally layered and this results in different permeabilities in horizontal & vertical direction

→ To determine permeability of unisotropic soil, samples are obtained from each layer and their permeabilities are determined.



The average permeability k_x & k_y in the horizontal and vertical directions are calculated as

$$K_x = \frac{1}{b}\left(k_{h_1} b_1 + k_{h_2} b_2 + k_{h_3} b_3 + \cdots k_{h_n} b_n\right)$$

$$K_y = \frac{b}{\left(\frac{b_1}{k_{v_1}} + \frac{b_2}{k_{v_2}} + \frac{b_3}{k_{v_3}} \cdots + \frac{b_n}{k_{v_n}}\right)}$$

Where

$k_{h_1}, k_{h_2} \cdots k_{h_n}$ → Permeability of each layer in x-direction

$k_{v_1}, k_{v_2} \cdots k_{v_n}$ → Permeability of each layer in y-direction

b → Total thickness of the aquifer

$b = b_1 + b_2 + b_3 \cdots b_n$

Assumptions of Darcy's Law

According to Darcy's Law $v = -k \times (dh/dl)$

where $k \rightarrow$ co-efficient of permeability

$(dh/dl) \rightarrow$ Hydraulic Gradient

$v \rightarrow$ Darcy's velocity

The following assumptions are made in Darcy's law

→ The Soil is Saturated

→ The flow through Soil is laminar

→ The flow is Continous and Steady

→ The total cross sectional area of Soil mass is considered

→ During verification of Darcy's law from the experiment, the temperature at the time of testing is 27°c.

Limitations

› Darcy's Law is based on the assumption that the flow occurs through the entire cross-section of the material without regard to Solid and pores. Actually the flow is limited to pore space only.

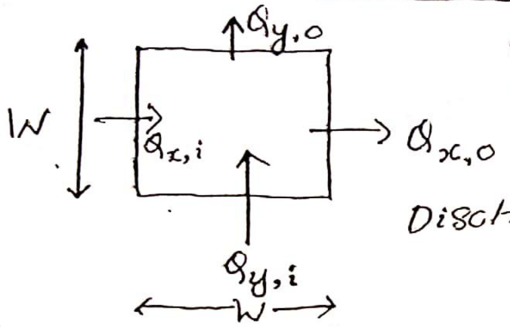
› Darcy's Law is found to be valid for the flows with Reynold's number less than 1 (unity) only.

› Darcy's law is applicable only for Steady flow

› Darcy's law is not applicable for the non continous flow

9)

* General ground water flow equation / 3-Dimensional equation (or) Laplace equation



(Thickness = unity)

Consider an aquifer having the dimensions of W metre & thickness of unity

Discharge through an aquifer is given by

$Q = A \times V$

$A \rightarrow$ Area of flow

$V \rightarrow$ Darcy's velocity (or) velocity of ground water

W.K.T

Darcy's velocity $(V) = -K \cdot \frac{dh}{dl}$

$K \rightarrow$ co-efficient of permeability

$\left(\frac{dh}{dl}\right) \rightarrow$ variation of head with respect to observed length

$Q = (W \times 1) \times -K \times \frac{dh}{dl}$ (Area of flow $(A) = W \times$ Unit thickness)

Rate of flow of water in x-direction getting into aquifer is given by

$Q_{x,i} = (W \times 1) \times -K_x \times \left(\frac{dh}{dx}\right)_i$

Transmissivity $(T) = K \times$ Thickness of aquifer

$T = (K \times 1)$ i.e $T_x = (K_x \times 1)$

$\therefore Q_{x,i} = W \times (-T_x) \times \left(\frac{dh}{dx}\right)_i$

Rate of flow of water in x-direction getting out of aquifer is given by

$Q_{x,o} = (W) \times (-T_x) \times \left(\frac{dh}{dx}\right)_o$

III^{ly}

$Q_{y,i} = (W) \times (-T_y) \times \left(\frac{dh}{dx}\right)_i$

$Q_{y,o} = (W) \times (-T_y) \times \left(\frac{dh}{dx}\right)_o$

volume of water in the aquifer is given by

$= (Q_{x,i} - Q_{x,o}) + (Q_{y,i} - Q_{y,o})$

W.K.T Storativity $(S_T) = \frac{\text{volume of water}}{\text{Surface} \times \left(\frac{dh}{dt}\right)}$

(10)

volume of water = $S_T \times (S.A) \times \frac{dh}{dt}$ S.A → Surface Area of aquifer

$$(q_{x,i} - q_{x,o}) + (q_{y,i} - q_{y,o}) = S_T \times (S.A) \times dh/dt$$

$$\left(w \times (-T_x) \times \left(\frac{dh}{dx}\right)_i - w \times (-T_x) \times \left(\frac{dh}{dx}\right)_o\right) + \left(w \times (-T_y) \times \left(\frac{dh}{dy}\right)_i - w \times (-T_y) \times \left(\frac{dh}{dy}\right)_o\right) = S_T \times (w^2) \times \frac{dh}{dt}$$

$$(-w \times T_x)\left(\left(\frac{dh}{dx}\right)_i - \left(\frac{dh}{dx}\right)_o\right) + (-w \times T_y)\left(\left(\frac{dh}{dx}\right)_i - \left(\frac{dh}{dy}\right)_o\right) = S_T \times w^2 \times \frac{dh}{dt}$$

$$\frac{T_x\left(\left(\frac{dh}{dx}\right)_i - \left(\frac{dh}{dx}\right)_o\right) + T_y\left(\left(\frac{dh}{dy}\right)_i - \left(\frac{dh}{dy}\right)_o\right)}{w} = S_T\left(\frac{dh}{dt}\right)$$

If w is very small then head difference h can be expressed interms of 2nd order differential equation of x & y

$$T_x\left(\frac{d^2h}{dx^2}\right) + T_y\left(\frac{d^2h}{dy^2}\right) = S_T\left(\frac{dh}{dt}\right)$$ → 2-dimensional G.W flow equation

$$T_x\left(\frac{d^2h}{dx^2}\right) + T_y\left(\frac{d^2h}{dy^2}\right) + T_z\left(\frac{d^2h}{dz^2}\right) = S_T\left(\frac{dh}{dt}\right)$$ → 3-dimensional G.W flow equation

The above equation is for unsteady flow

for Steady flow $(dh/dt) = 0$

$$\frac{d^2h}{dx^2} + \frac{d^2h}{dy^2} + \frac{d^2h}{dz^2} = \frac{S_T}{T}\left(\frac{dh}{dt}\right)$$

$$\boxed{\frac{d^2h}{dx^2} + \frac{d^2h}{dy^2} + \frac{d^2h}{dz^2} = 0}$$ → Laplace equation

(or) $\boxed{\nabla^2 h = 0}$

(Dimensional)
1D Ground water Steady flow through confined aquifer's between two water bodies [Without Recharge]*

(or)

Steady unidirectional flow in confined aquifer's [Without Recharge]

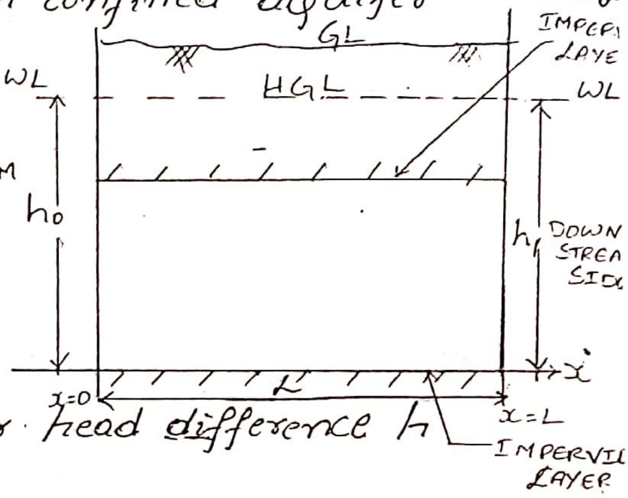
Consider a steady 1D flow through confined aquifer

W.K.T for 3-Dimensional flow

$$\frac{d^2h}{dx^2} + \frac{d^2h}{dy^2} + \frac{d^2h}{dz^2} = 0$$

for 1-Dimensional flow

$$\frac{d^2h}{dx^2} = 0$$



To find the final expression for head difference h

Integrating $\frac{d^2h}{dx^2}$

$$h = c_1 x + c_2 \rightarrow eq^n 1)$$

$c_1 = ?$ & $c_2 = ?$

Consider the boundary condition's

i) @ $x=0$ $h=h_0$

$h_0 \rightarrow$ water level @ upstream side

$h_0 = c_2$

(or)

$$\boxed{c_2 = h_0}$$

ii) @ $x=L$ $h=h_1$

$h_1 \rightarrow$ water level @ down-stream side

$$h_1 = c_1 \times L + h_0$$

$$(h_1 - h_0) = c_1 \times L$$

$$\boxed{c_1 = \frac{(h_1 - h_0)}{L}}$$

$$\therefore h = \frac{(h_1 - h_0)}{L} x + h_0$$

on re-arranging

$$\boxed{h = h_0 - \left(\frac{h_0 - h_1}{L}\right) x}$$

$L \rightarrow$ length b/w considered section

$$\boxed{\frac{dh}{dx} = -\left(\frac{h_0 - h_1}{L}\right) \times 1}$$

Discharge /unit width is given by

$Q = A \times V$

$A \rightarrow$ Area of flow

$V \rightarrow$ Darcy's velocity

W.k.T

$$v = -k \times \frac{dh}{dl} \rightarrow -k \times \frac{dh}{dx}$$ [k → Co-efficient of permeability]

$A = w \times t \; (m^2)$ (t → Thickness, w → unit width, $w = 1$)

$$\therefore q = (w \times 1) \times (-k) \times \left(\frac{dh}{dx}\right)$$

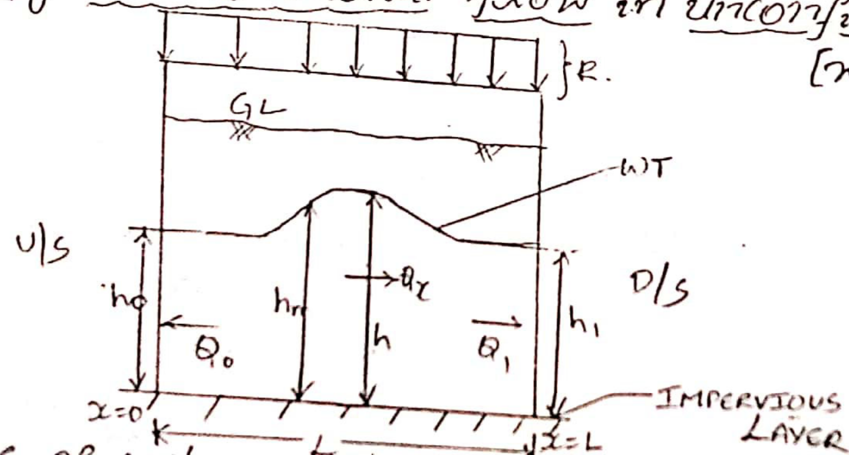
$$q = -T \times \frac{dh}{dx}$$ ⟨ $T = w \times k$ → Transmissivity ⟩

$$q = -T\left[x - \frac{(h_0 - h_1)}{L}\right] \quad \text{(or)} \quad \boxed{q = T\frac{(h_0 - h_1)}{L}}$$

1 Dimensional Ground water flow through unconfined aquifer b/w 2 water bodies [with Recharge]

(or)

Steady unidirectional flow in unconfined aquifer [with Recharge]



R → Rate of recharge into the aquifer

L → Distance b/w 2 Section's (or) water bodies

h_m → Maximum head of the water table

h → General level of the water table

h_0 → Level of water body in the upstream Side

h_1 → Level of water body in the downstream Side

Q_0 → Discharge toward's upstream Side

Q_1 → Discharge towards downstream Side

Q_x → Discharge from general level of water table towards D/S

A → Area of flow = General level of the water table × unit width)
= (h × 1)

The General Ground water Steady flow governing equation is given by

$$\frac{d^2h^2}{dx^2} = \frac{-2R}{k}$$

on integration

$$d^2h^2 = \frac{-2R}{k} \times dx^2$$

$$h^2 = -\frac{2R}{k} \iint dx^2$$

$$h^2 = \frac{-2R}{k \times 2} x x^2 + c_1 x + c_2$$

$$h^2 = \frac{-R}{k} x x^2 + c_1 x + c_2 \longrightarrow eq^n\ 1)$$

Boundary Condition's

@ $x=0$ $h=h_0$ $\boxed{h_0^2 = c_2}$

@ $x=L$ $h=h_1$ $h_1^2 = \frac{-R}{k} \times L^2 + c_1 \times L + h_0^2$

$$\boxed{\frac{h_1^2 - h_0^2 + R/k \times L^2}{L} = c_1}$$

Substituting for c_1 & c_2 in equation ①

$$h^2 = \frac{-R}{k} x x^2 + \left[\frac{h_1^2 - h_0^2 + R/k \times L^2}{L}\right] x + h_0^2 \longrightarrow eq^n\ ②$$

$$h = \sqrt{\frac{-R}{k} x x^2 + \left[\frac{h_1^2 - h_0^2 + R/k \times L^2}{L}\right] x + h_0^2}$$

The above equation represents general level of watertable

W.K.T $Q = -k \times h \times \frac{dh}{dx}$ $\left[\because Q = A \times V \quad V = -k\frac{dh}{dx} = -k \times dh/dx \right.$ $A = h \times$ unit width $\left. \therefore Q = -k \times h \times dh/dx \right]$

Substituting for $h \times dh/dx$ on differentiating eq^n 2)

$$2 \times h \times \frac{dh}{dx} = \frac{-2Rx}{k} + \left[\frac{h_1^2 - h_0^2 + \frac{R \times L^2}{k}}{L}\right]$$

$$\therefore h \times \frac{dh}{dx} = \frac{-R \times x}{k} + \left[\frac{h_1^2 - h_0^2 + R/k \times L^2}{2L}\right]$$

$$Q_x = -k \times \left[\frac{-R \times x}{k} + \frac{(h_1^2 - h_0^2 + R/k \times L^2)}{2L}\right]$$

when $x = 0$ $Q_{x=0}$

$$Q_{x=0} = -k \times \left[\frac{(h_1^2 - h_0^2) + (R/k \times L^2)}{2L}\right]$$

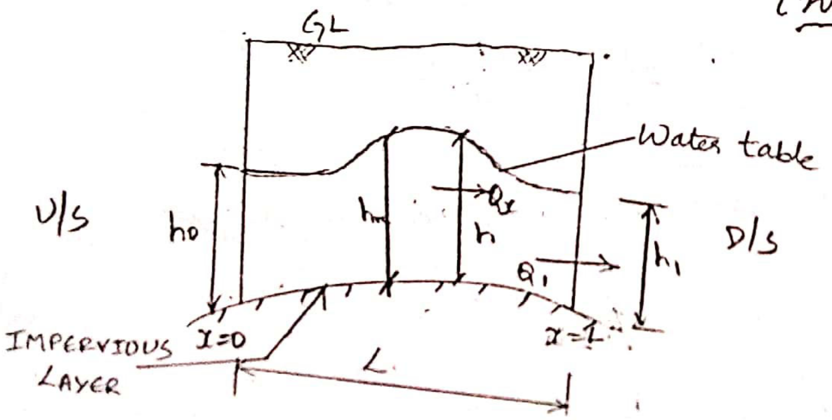
when $x = L$

$$Q_{x=L} = -k\left[\frac{-R \times L}{k} + \frac{(h_1^2 - h_0^2 + R/k \times L^2)}{2L}\right]$$

1 Dimensional Ground water flow through unconfined aquifer b/w 2 water bodies [without Recharge]

(or)

Steady unidirectional flow in unconfined aquifer [Without Recharge]



L → Distance b/w 2 Sections (or) waterbodies

h_m → Maximum head of the water table

h → General level of the water table

h_0 → Level of water body in the upstream side

h_1 → Level of water body in the downstream side

Q_0 → Discharge towards upstream side

Q_1 → Discharge towards downstream side

Q_x → Discharge from general level of water table towards d/s

→ Area of flow = $(h \times 1)$

W.K.T $\frac{d^2h^2}{dx^2} = \frac{-2R}{k}$ [with Recharge] } General Groundwater Steady flow governing equation

$\frac{d^2h^2}{dx^2} = 0$ [without Recharge]

on integration

$h^2 = c_1 x + c_2 \longrightarrow eq^n\ i)$

<u>Boundary</u> <u>condition's</u>

i) @ $x = 0$ $h = h_0$

ii) @ $x = L$ $h = h_1$

Substituting 1st boundary Condition in eqn i)

$\boxed{h_0^2 = C_2}$

Substituting 2nd boundary Condition in eqn i)

$h_1^2 = (C_1 \times L) + h_0^2$

$C_1 \times L = h_1^2 - h_0^2$

$\boxed{C_1 = \frac{h_1^2 - h_0^2}{L}}$

Substituting for C_1 & C_2 in eqn i)

$h^2 = \left(\frac{h_1^2 - h_0^2}{L}\right) \cdot x x + h_0^2 \longrightarrow 2)$

$h = \sqrt{\left(\frac{h_1^2 - h_0^2}{L}\right) x x + h_0^2}$

W.K.T $q_x = -k \times \left(h \times \frac{dh}{dx}\right)$

Substituting for $(h \times dh/dx)$ on differentiation eqn 2)

$\therefore 2h \times dh/dx = \left(\frac{h_1^2 - h_0^2}{L}\right)$ (or) $h \times \left(\frac{dh}{dx}\right) = \left(\frac{h_1^2 - h_0^2}{2L}\right)$

$\therefore \boxed{q = -k \times \left(\frac{h_1^2 - h_0^2}{2L}\right)}$

Problems

When 3.68 million m^3 of water was pumpedout from an unconfined aquifer of 6.2km² aerial extent, the water table was observed to go down by 2.6m. What is the specific yield of the aquifer.
During the monsoon season if the water table of the same aquifer goesup by 10.8m, what is the volume of recharge.

S i) volume of water pumpedout = $3.68 \times 10^6 m^3$

W.K.T Sp.yield = $\frac{\text{volume of water drained (Pumped)/recharged}}{\text{volume of the aquifer Considered}}$

$$S_y = \frac{3.68 \times 10^6}{\text{Area extent} \times \text{water level drawdown}}$$

$$S_y = \frac{3.68 \times 10^6}{6.2 \times 10^6 \times 2.6} = 0.228$$

ii) volume of recharge = ?

W.K.T Sp.yield = $\frac{\text{volume of water recharged}}{\text{volume of the aquifer Considered}}$

$$0.228 = \frac{\text{volume of water recharged}}{6.2 \times 10^6 \times 10.8}$$

Volume of water recharged = $0.228 \times 6.2 \times 10^6 \times 10.8$

$\Rightarrow 15.26 \times 10^6 m^3$

(or) 15.26 million m^3

The water table levels in two observations wells 350m apart are 210.5m and 206.25m. If the hydraulic conductivity & porosity of the aquifer are 12.5 m/day & 15%, what is the actual velocity of flow in the aquifer.

S W.K.T

from

Darcy's Law $v = -K\left(\frac{dh}{dl}\right)$

Where V = Darcy's velocity

k = Hydraulic Conductivity = 12.5 m/day

$\left(\frac{dh}{dl}\right)$ = Hydraulic Gradient = $\frac{210.5 - 206.25}{350}$

$\therefore \left(\frac{dh}{dl}\right) = \frac{4.25}{350}$

$V = -12.5 \times \frac{4.25}{350} = -0.1518 \, m/day$

W.K.T

Actual velocity of flow through aquifer (V_a)

$$V_a = \frac{V}{n}$$

where n = porosity of the aquifer

$$V_a = \frac{0.1518}{0.15} = 1.01 \, m/day$$

3) A Sample has a hydraulic conductivity of 10m/day. What would be it's intrensic permeability? what is it's hydraulic Conductivity in cm/s? what would be it's Hydraulic Conductivity at 30°C

Note [20°C] { At std temp, Dynamic viscosity. $\mu = 0.01$ gm-cm/s

W.K.T Hydraulic Conductivity $(k) = \frac{(C \times d_m^2) \times g}{\nu}$

$\boxed{K_0 = C \times d_m^2}$ → Intrensic permeability

ν → kinematic visocosity

$$k = \frac{K_0 \times g}{\nu} \quad (or) \quad K_0 = \frac{k \times \nu}{g}$$

μ = Dynamic viscosity

$\nu = \mu / \rho$

$$\therefore \boxed{K_0 = \frac{k \times \mu}{\rho \times g}} \quad (m^2 \text{ (or) } cm^2) \}$$

Ans

$$K_0 = \frac{k \times \mu}{\rho \times g} = \frac{10 \times \frac{100}{24 \times 60 \times 60} 0.01}{1000 \times 9.81 \times 1000 \times 10^3 \times 10}$$

$$\boxed{K_0 = 1.1798 \times 10^{-7}\ cm^2}$$

$k = \frac{10 \times 10^{2}}{24 \times 60 \times 60}$

$k = 0.0115\ cm/sec$

NOTE $1\ Darcy = 0.987 \times 10^{-12}\ m^2$ (or)

$1\ Darcy = 0.987 \times 10^{-8}\ cm^2$

for $0.987 \times 10^{-8}\ cm^2 \longrightarrow 1\ Darcy$

$1.1798 \times 10^{-7}\ cm^2 \longrightarrow ?$

$$\boxed{\therefore K_0 = 11.95\ Darcy}$$

NOTE

for kinematic viscosity (ν) for water @ 20°c is 0.01 cm²/sec and @ 30°C is 0.008 cm²/sec

W.K.T $K \propto \frac{1}{\nu}$

$$\frac{K}{K_t} = \frac{\nu_t}{\nu}$$

$K = 10\ m/day = 0.0115\ cm/sec$

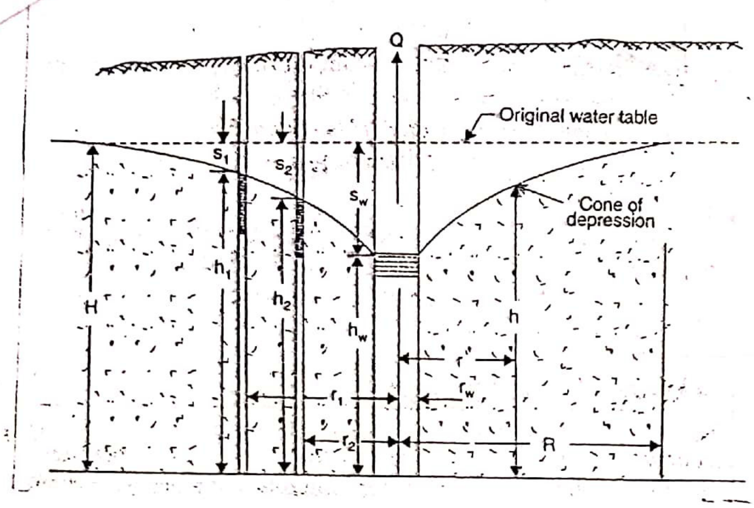
$$\frac{0.0115}{K_t} = \frac{0.008}{\frac{0.01}{1000 \times 1000 \times 10^{-6}}}$$

$K_t = 0.0137\ cm/sec$

$\therefore$ Hydraulic Conductivity @ 30° $(K_t) = 0.0137\ cm/sec$

Module - 3

Well Hydraulic's



1. Drawdown:

-> When the water is pumped out from a tube well, the water level in the well as well as in the vicinity of the pumped well is lowered. The lowering of the water level at any point as a result of groundwater pumping is called drawdown at that point.

-> The drawdown is maximum at the well and goes on reducing on reducing away from the well till at some distance the drawdown is zero.

2. Hydraulic Gradient:

owing to the differential lowering of water level a difference of head is created between the water level at the well and original groundwater table. The head difference per unit length is called hydraulic gradient.

3. Cone of Depression:

If the water is pumped at a constant rate from the well, a gradient in the water table towards the well is created which results in a depressing form of the water table. This is called cone of depression.

⑧

Radius of Influence :

It is distance from the centre of the well to the point at which the drawdown is zero. The point at which drawdown is zero indicates the outer limit of the cone of depression.

Radius of Influence depends on

a) Aquifer characteristics b) well discharge
c) Duration of pumping d) slope of water table.

Steady flow:

Steady flow or equilibrium flow is a condition in a pumped well when equilibrium is reached between the discharge of the pumped well and the recharge

unsteady flow:

The unsteady flow indicates non-equilibrium condition. This type of flow exists from the moment groundwater pumping starts from the well till the steady state is reached.

Partially penetrating well:

When the tube well doesnot extend to full depth of the aquifer but draws water from partial depth of the aquifer, the well is called partially penetrating well.

Specific Capacity of well

It is a measure of the productivity of a well. It is a ratio of the pumping rate and drawdown in the well.

$$Sp.\ capacity = Q/(H_1 - H_2) = Q/S \quad \left(S = (H_1 - H_2) \right)$$

Where Q is well discharge & $(H_1 - H_2)$ (or) S is drawdown

Radial flow (in)to wells

The analysis of groundwater movement will be greatly simplified if the vertical flow components are neglected and the ground is assumed to move primarily in the lateral direction. Such flow is called Radial flow.

** Dupuit or Thiem equation *

Steady Radial flow to a well in an unconfined Aquifer

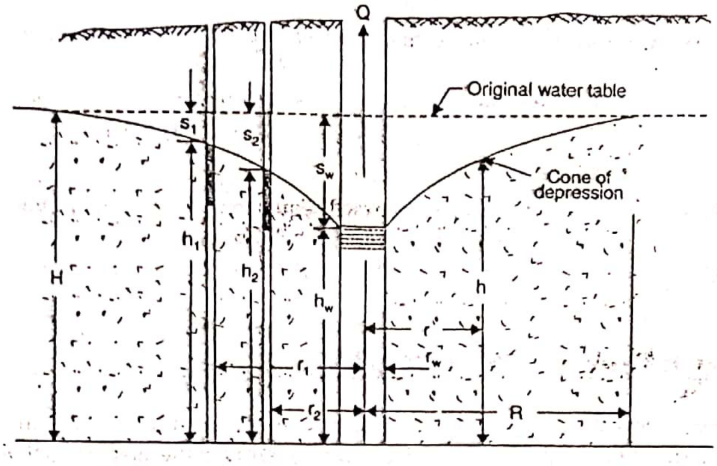


FIGURE 9.12 Steady flow to a well in an unconfined aquifier.

Consider Steady Radial flow

Let $h \rightarrow$ The depth of flow at any radial distance r from the well.

$A \rightarrow$ Area of flow $\rightarrow 2\pi r h$

The discharge Q into the well is given by $Q = A \times V$

$V \rightarrow$ velocity of flow

According to Darcy's Law $V = k \times dh/dr$

$Q = 2\pi r h \times k \times dh/dr$ $\quad \left[\text{or } Q = 2\pi r T \times \frac{dh}{dr} \right]$

$T = h \times k \rightarrow$ Transmissivity

(or) $h \times dh = \frac{Q}{2\pi k} \cdot \frac{dr}{r}$

Integration of the above equation with the known boundary conditions at the two observation bores

when the radial distance is $r_1 \longrightarrow$ Depth of flow is (h_1)

When the radial distance is $r_2 \longrightarrow$ Depth of flow is (h_2)

$$\int_{h_1}^{h_2} h \cdot dh = \frac{Q}{2\pi k} \int_{r_1}^{r_2} dr/r$$

(4)

$$\frac{(h_1^2 - h_2^2)}{2} = \frac{Q}{2\pi k} \cdot Ln \frac{(r_1)}{(r_2)}$$

$$\boxed{Q = \frac{\pi \times k (h_1^2 - h_2^2)}{Ln\left(\frac{r_1}{r_2}\right)}}$$

natural logarithm
↳ Ln

Common Logarithm
↳ Log

In the absence of observation wells

$$\boxed{Q = \frac{\pi \times k [H^2 - h_w^2]}{Ln\left(\frac{R}{r_w}\right)}}$$

where
R → Radius of influence
H → Head of water corresponding to R
h_w → water level in the well
r_w → Radius of the well

(or)

** $$\boxed{Q = \frac{2\pi T \cdot S_w}{Ln(R/r_w)}}$$

T → Transmissivity
S_w → Drawdown in well

imp
The following assumptions are made to derive above equation
i) The well is pumped at a constant rate.
ii) The well fully penetrates the aquifer.
iii) The aquifer is homogenous, isotropic, horizontal and of infinite horizontal extent.
iv) water is released from storage in the aquifer in response to a drop in water table.

Steady Radial flow to a Well in a Confined Aquifer.

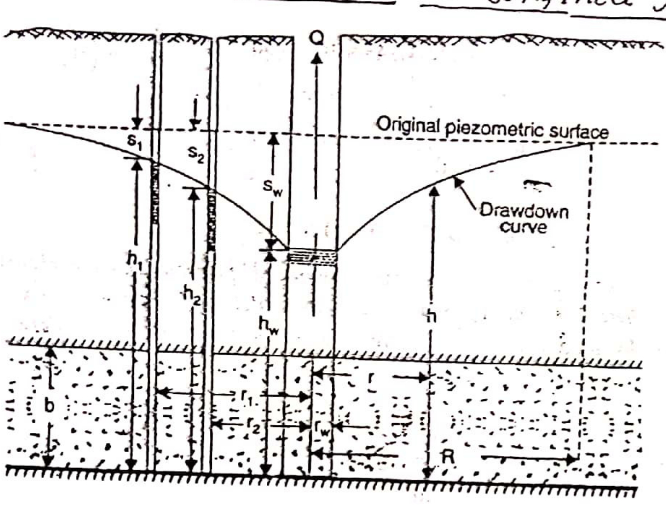


FIGURE 9.13 Steady flow to a well in a confined aquifer.

The flow around a well penetrating fully into a Confined aquifer of thickness 'b' under Steady-State condition is Shown in fig.

The discharge flowing into the well through a Section which is Situated at a radial distance r is given by

$$Q = A \times V$$

where $A \rightarrow$ Area of flow $\rightarrow 2\pi r \times b$

$V \rightarrow$ velocity of flow

According to Darcy's law

$$V = K \times dh/dr$$

$$Q = 2\pi r b \times K \times dh/dr$$

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

Integrating the above equation for known boundary Conditions.

When the radial distance is $r_1 \rightarrow$ Depth of flow is h_1 (water level)

When the radial distance is $r_2 \rightarrow$ Depth of flow is h_2 water level

$$\int_{h_1}^{h_2} dh \times 1 = \frac{Q}{2\pi b \times K} \times \int_{r_1}^{r_2} \frac{dr}{r}$$

$$[h]_{h_1}^{h_2} = \frac{Q}{2\pi b \times K} \times \ln\left(\frac{r_1}{r_2}\right)$$

$$h_1 - h_2 = \frac{Q}{2\pi b k} \times \ln\left(\frac{r_1}{r_2}\right)$$

$$Q = \frac{2\pi\, b \times k \times (h_1 - h_2)}{\ln\left(\frac{r_1}{r_2}\right)}$$

W.K.T Transmissivity $(T) = k \times b$

$$\therefore Q = \frac{2\pi \times T\,(h_1 - h_2)}{\ln\left(r_1/r_2\right)}$$

(or) In the absence of observation wells

$$Q = \frac{2\pi \times T\,(H - h_w)}{\ln\left(R/r_w\right)}$$

Where $R \rightarrow$ Radius of influence

$H \rightarrow$ Head of water corresponding to R

$r_w \rightarrow$ Radius of well

$h_w \rightarrow$ Water level in well or head of water in well.

(or)

$$Q = \frac{2\pi \times T S_w}{\ln\left(R/r_w\right)}$$

$$S_w = (H - h_w)$$

$S_w \rightarrow$ Draw down in the well

Yield of Well

Yield of well is the rate at which water percolates into the well under the Safe maximum working head. It is expressed in m^3/hr (or) Lt/min

Safe yield(Q) of a groundwater basin may be defined as the amount of water which can be withdrawn from it annually without producing any undesirable effect.

Any withdrawal in excess of Safe yield is called overdraft.

$Q = C \cdot A \cdot H$ { C → Sp. yield A → cross Sectional area of flow. H → working hea

Specific yield of well

Rate of water percolation in the well or yield of a well in m^3/hr under a head of one metre is called the Specific yield of the well. Specif yeild depends on i) position of water table ii) permeability & porosity iii) Rate of water withdrawal iv) quantity of water storage

The yield of openwell can be determined by any one of the two methods i) Pumping Test ii) Recuperation Test

i) Pumping Test (or Safe yield Test)

-> In this method the water level in the well is depressed through large withdrawals of water till the working head is reached.

-> At this Stage the discharge from the pump is regulated So that the rate of withdrawl equals the rate of inflow into the well.

-> Under this equilibrium condition, the volume of water pumped out in the unit time gives the Safe yield of the well. The Safe yield is expressed in m^3/hour

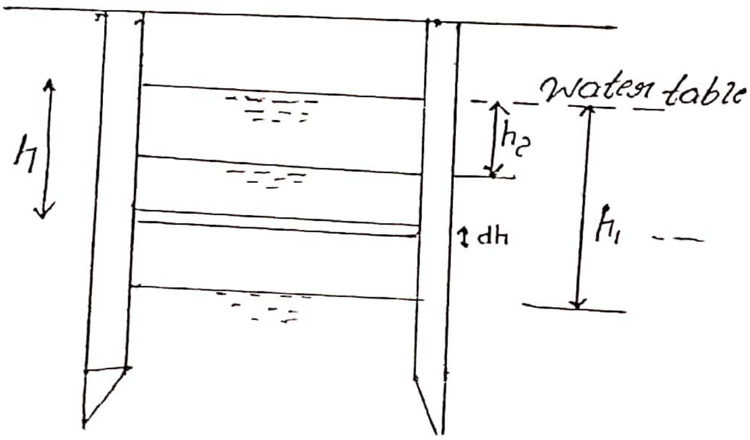
(NOTE) When the pumping is not taking place the water level in the well is Same as the general water table level in the Surroundings of the well. When the pumping is taking plac the water level in the well is depressed & the difference between the water table level & the water level in the well is known as the depression head.

When the depression head is large it may cause the dislodging of Soil particles. This head is called Critical depression head working head is taken to be 1/3rd of Critical depression head

(8)

Recuperation Test (Specific yield Test)

→ In this method, the water level in the well is depressed to some level below the normal water table level and then pumping is stopped. The water level in the well start's recuperating [Get back to normal level]. The time taken by the water to rise to some other level is noted. From this data the specific yield of the well can be foundout as explained below.



Let the water level be depressed by h_1 m through pumping. After time of T hours let the depression head be h_2 m. Let h be the depression head in the well at a time t after the pumping is stopped.

Let dh → change in depression head in a small time dt

W.K.T $\boxed{Q = C \cdot A \cdot H}$ → eq^n 1) C → Sp. yield

Q → Safe yield

A → cross sectional area of flow into the well

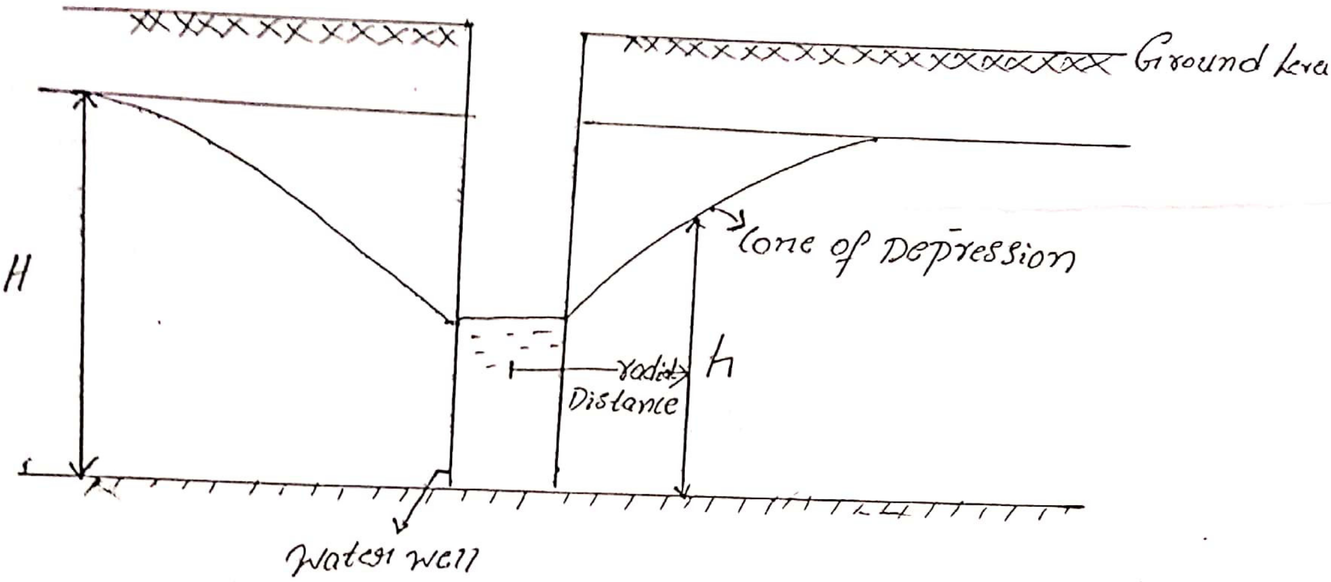
H → Working head H

$$C = \frac{2.303}{T} \log\left(\frac{h_1}{h_2}\right)$$ T → Time in hours

From the field h_1 & h_2 values will be taken along with noted time T.

Once the value of C (Sp. yield) is calculated it can be substituted to equation ① to get the value of Q (Safe yield) can also be calculat

General equation for unsteady flow condition towards a well in form $\frac{\partial^2 h}{\partial x^2} + \frac{1}{r}\frac{\partial h}{\partial r} = \frac{S}{T}\cdot\frac{\partial h}{\partial t}$ –



$H \Rightarrow$ Thickness of aquifer

$h \rightarrow$ Depth of flow at any radial distance :

According to Storativity (Module 2)

$$\frac{\partial v}{\partial t} = \frac{\partial h}{\partial t} \times S \times A \quad (or) \quad \frac{\partial q}{\partial r} \times \partial r = \frac{\partial h}{\partial t} \times S \times A \rightarrow eq^n\ 1)$$

$S \rightarrow$ Storage co-efficient

$A \rightarrow$ Area of the aquifer

$$\left\langle \because \frac{\partial v}{\partial t} = \frac{\partial q}{\partial r} \times \partial r \right\rangle$$

$\frac{\partial v}{\partial t} \rightarrow$ Rate at which the aquifer releases water from (or) takes into the storage

$v \rightarrow$ volume of water released / horizontal area of aquifer

$\frac{\partial h}{\partial t} \rightarrow$ Rate of drop of water table

From Darcy's Law $Q = A \times V$ where $V = K \times \frac{\partial h}{\partial r}$

$$Q = A \times K \times \frac{\partial h}{\partial r}$$

$$A = 2\pi r \times h$$

$$\therefore Q = 2\pi r \times h \times K \times \frac{\partial h}{\partial r}$$

$$Q = 2\pi r \times T \times \frac{\partial h}{\partial r} \quad \langle T = h \times K \rangle$$

Transmissivity

$$\frac{\partial Q}{\partial r} = 2\pi T \times \frac{\partial}{\partial r}\left[r \times \frac{\partial h}{\partial r} \right]$$

$$\frac{\partial Q}{\partial r} = 2\pi T \times \left[\frac{\partial h}{\partial r} + r \frac{\partial^2 h}{\partial r^2} \right]$$

Substituting for $\frac{\partial Q}{\partial r}$ in eqn 1)

$$2\pi T \times \left[\frac{\partial h}{\partial r} + r \times \frac{\partial^2 h}{\partial r^2} \right] = \frac{\partial h}{\partial t} \times S \times A$$

$$A = 2\pi r \times 1$$

$$2\pi \times T \times \left[\frac{\partial h}{\partial r} + r \times \frac{\partial^2 h}{\partial r^2} \right] = \frac{\partial h}{\partial t} \times S \times 2\pi r \times h$$

$$2\pi \times T \times r \left[\frac{1}{r}\frac{\partial h}{\partial r} + \frac{\partial^2 h}{\partial r^2} \right] = \frac{\partial h}{\partial t} \times S \times 2\pi r \times h$$

Let depth of flow $h = 1m$

$$\therefore \boxed{\frac{\partial^2 h}{\partial r^2} + \frac{1}{r}\frac{\partial h}{\partial r} = \frac{S}{T} \times \frac{\partial h}{\partial t}}$$

Interference of wells & it's effects

Many times two or more wells are located in the same aquifer and are close to each other. Then it is possible that their cones of depression may intersect each other. When such a situation exists the wells are said to interfere with each other becouse the zone of influence of one well overlaps the zone of influence of the other well.

Thus when closely spaced multiple well system exist in an aquifer causing interference following effects can be noticed.

i) The total groundwater output will be less than the sum of the discharge capacity of individual wells.

ii) The efficiency of each well is decreased

iii) The drawdown will increase and as a result pump lift increase

iv) The pumping cost will increase due to decrease in efficiency and increase in pumping lift

In view of the above effects it is necessary to properly demarcate the well field to provide most economical pumping system.

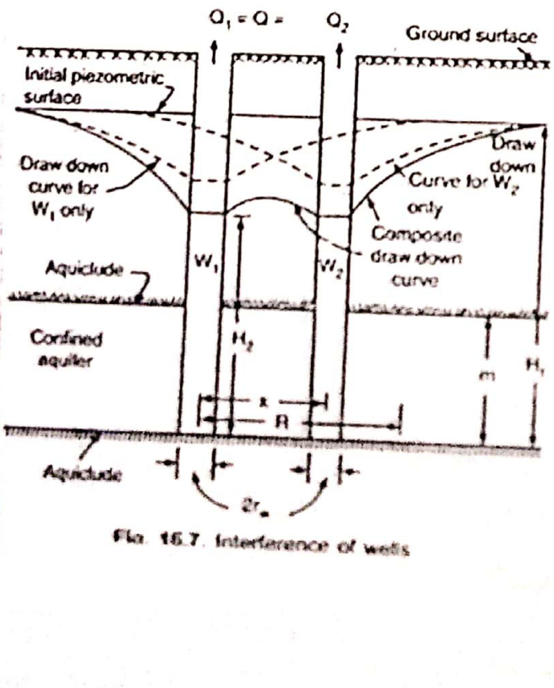
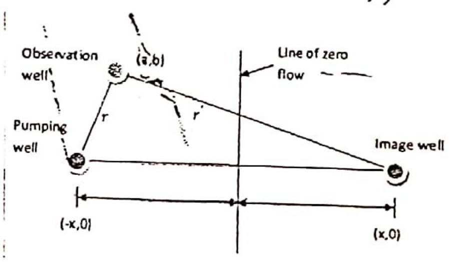


Fig. 16.7. Interference of wells

Image Well Theory [Method of Superposition]

Pumping tests are sometimes performed near the boundary of an aquifer (impermeable layer). When an aquifer boundary is located within the area influenced by a pumping test, the assumption that the aquifer is of infinite extent is no longer valid to conduct pumping test.

To overcome this imaginary wells are taken into account which will help to calculate the parameters of an aquifer. The well that creates the same effects as boundary is called image well.



Consider the figure above

The pumping well is at a distance of x from the impermeable boundary (layer). In order to calculate actual drawdown at the observation location, an image well is considered at a distance of x on the other side of the line of zero flow. The distance of the observation well from the pumping well is r and from the image well is r'

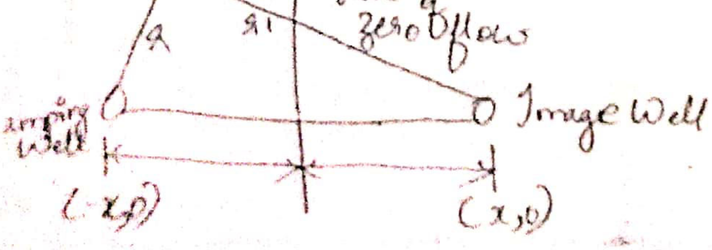
for steady state condition of a confined aquifer the drawdown at the observation well can be obtained as

$$S(a,b) = \frac{Q}{2\pi T} \ln\left(\frac{R}{r}\right) + \frac{-Q}{2\pi T} \ln\left(\frac{R}{r'}\right)$$

$R \rightarrow$ Radius of influence

$Q \rightarrow$ Discharge into the well

$T \rightarrow$ Transmissivity



Ground water exploration

Ground water exploration is the investigation of under-ground formations -> to understand the hydrologic cycle, -> to know the ground water quality, and -> to identify the nature, number and type of aquifers.

Methods of Ground water Exploration

i) Surface methods
 (a) Geologic methods
 (b) Remote Sensing
 (c) Surface Geo-physical methods
 - -> Electrical resistivity method
 - -> Seismic refraction method
 - -> Seismic reflection method
 - -> Electromagnetic method
 (d) Magnetometer & Gravity meter
 (c) Soil temperature details.

ii) Subsurface methods
 (a) Test drilling
 (b) Geophysical logging
 - -> Electrical logging
 - -> Radioactive logging
 - -> Induction logging
 - -> Sonic logging
 - -> fluid logging

SURFACE METHODS

-> Geologic Methods

* It involves collection, analysis and hydrogeologic interpret-ation of existing geologic data/maps, topographic maps, aerial photograph and other pertinent record.
* The type of rock formation will suggest the magnitude of water yield to be expected.
* Nature and thickness of overlying beds will enable estimates of drilling depths to be made.

-> Remote Sensing

* Although remote sensing data do not directly detect deeper subsurface resources, it has been effectively used in groundwater exploration as remote sensing data helps in drawing inferences on ground water potentiality of the region.
* Ground water study of an area requires knowledge of nature of lithological units occurring in the area, their structural disposition, geo-morphic setup, surface water conditions

nd the climate of the area. These can be studied through
atellite images and aerial photographs. (2)

Remote Sensing data are very accurate, fast and reliable as compared to the conventional data collection. Before geophysical investigation, the remote sensing data give the knowledge of the geological structure.

Surface Geo-physical Method's

Geophysical investigation's involve simple methods of study made on the surface with the aim of ascertaining subsurface detail.

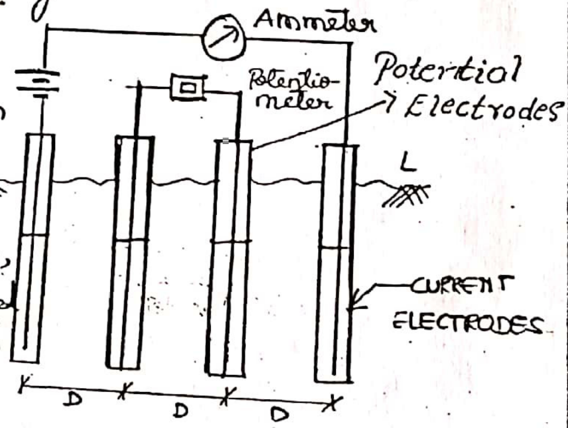
Importance of Geophysical Investigation

These investigation's are carried out quickly. Large area can be investigated in a reasonable short period.

Geophysical instruments used in the field are simple, portable and can be operated easily. Field work will not be labourious.

> Geophysical investigation helps in locating and assessing groundwater potential and it's quality.

Imp Electrical Resistivity Method.



Electrical resistivity method is based on the principal that each soil has different electrical resistivity depending upon the type of soil, water content, compaction & composition thus saturated soil has lower electrical resistivity as compared to loose dry gravel soil.

The distance b/w 2 electrodes depends on the depth of exploration (or) depth after which ground resistance has to be measured. Certain amount of current is passed b/w the 2 outer electrodes and potential drop b/w the inner electrodes is measured by potentiometer.

The mean resistance is calculated by using a formula

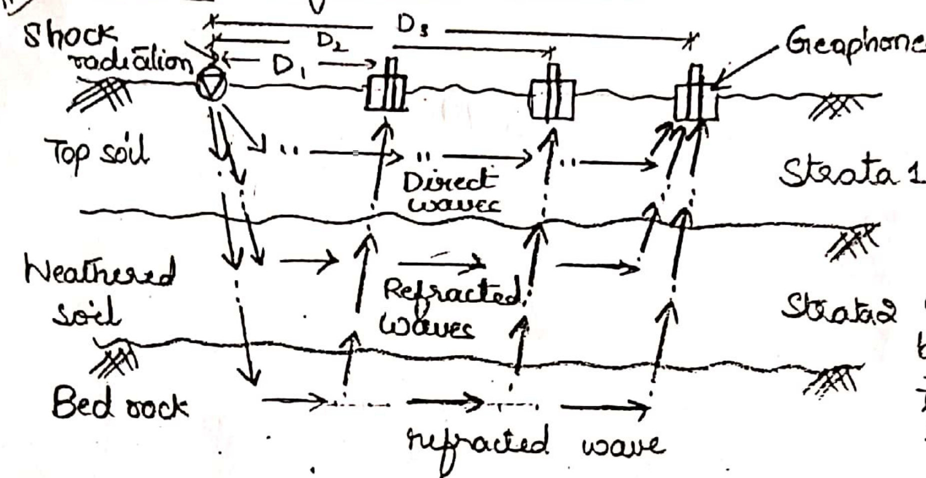
$\rho = 2\pi E/I$ where, ρ = mean resistivity in ohm-cm

E = Potential drop b/w inner electrodes in V

I = current flowing b/w outer electrodes in A

The average value of resistivity of various types of soil have been already established based on experimental test. Thus by knowing the value of change in mean resistivity of sub soil strata at the site, it is possible to identify the nature of distribution of diff types of soil & also it is possible to find the existence of sub surface water

→ Seismic Refraction method (Imp)



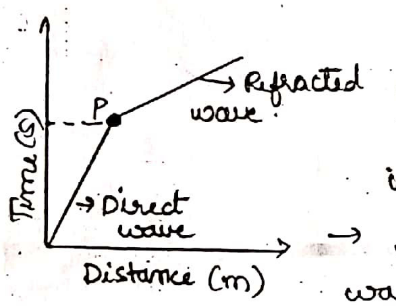
→ This method is based on fact that seismic waves have diff velocities in diff types of soil. Further the waves are refracted when they cross the boundary between diff types of soil

→ This method consists of generating shock waves near the ground surface, these shock waves are picked up by the geophones. The spacing of the geophones depends on the amount of details required & depth of strata to be investigated

→ Some waves travel directly from shock point along the ground surface in the direction of geophones, these waves are called direct waves (or primary waves.

→ Some waves travel in downward direction & gets refracted & are called as refracted waves.

→ Knowing the time taken by waves to reach geophones & distance of geophones from shock points, the time v/s distance relation can be established as shown in fig.



→ The point 'P' represents simultaneous arrival of direct waves (i waves) & refracted waves. The distance from the Y axis & the point P is known as critical distance.

→ If V_1, V_2 & V_3 are the velocities of seismic waves (direct waves & refracted waves) then depth of soil strata can be estimated using the relation

$$H_1 = \frac{D_1}{2}\sqrt{\frac{V_2 - V_1}{V_2 + V_1}} \; ; \; H_2 = 0.85H_1 + \frac{D_2 - D_1}{2}\sqrt{\frac{V_3 - V_2}{V_3 + V_2}}$$

→ This method gives the details of the soil & the rock structures which may contain sub surface water

(4)

Magnetometer and Gravimeter method's

↳ The magnetic method enables detecting the magnetic fields of the earth Which can be measured and mapped. Magnetometer's are used to measure the magnetic field and variations.

Magnetic field Contrast's are Seldom (ಅಪರೂಪ) associated with groundwater occurrence, the method has little relevance for exploring ground water.

Gravimeter method

Gravity is directly related to the density and volume of the earth materials beneath the point being measured.

The density and volume of the earth materials indicates the presence of ground water.

The Common type of gravity measuring instrument is the gravimeter.

Soil Temperature

The high Specific heat of groundwater can cause a Shallow aquifer to act as a heat Sink that influence the near Surface temperatures to a measurable extent.

On measurement of Soil temperature, the presence of Shallow aquifer Can be Confirmed.

Measurements of Soil temperatures are made at about 45cm below the land Surface using an Electronic thermometer.

Subsurface Methods

→ (a) Test Drilling

- Drilling small diameter holes that furnish ~~information~~ information on subsurface strata in a vertical line from the surface is called test drilling.

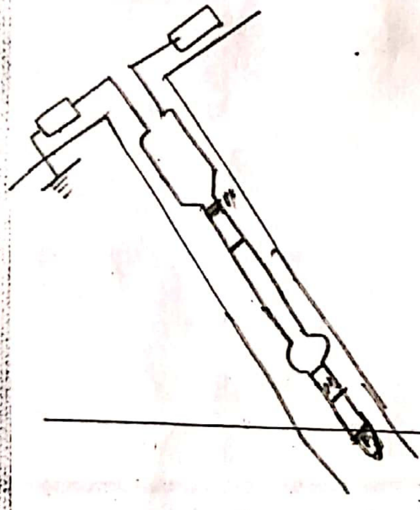
useful in

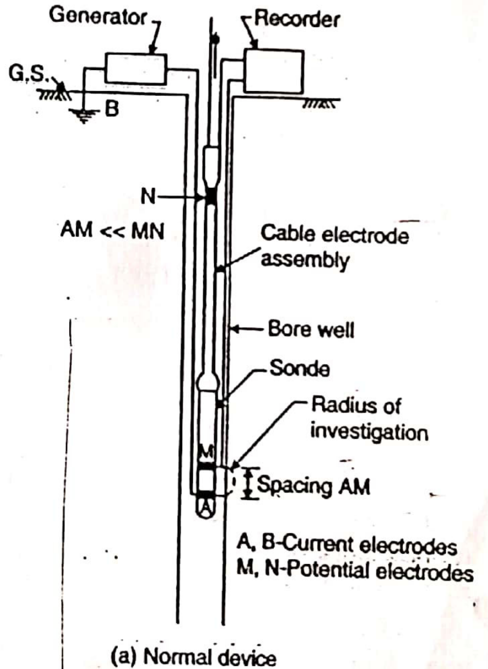
* verifying other means of groundwater exploration
* Confirming groundwater conditions prior to well drilling
* Serving as observation wells for measuring groundwater -levels and for conducting pumping tests.

If found fruitful, many atimes the test holes are redrilled or enlarged to form pumping (or) production wells

→ (b) Geophysical Logging

i) Electric Logging





(a) Normal device

→ A four electrode arrangement is commonly employed in measuring resistivity from bore holes

→ A current (I) is passed between the electrodes A and B while voltage is measured between electrodes M and N. One current electrode is always on the ground potential & it's effect is negligible.

→ There are two systems of electrode arrangements

i) Normal electrode arrangement

ii) Lateral electrode arrangement.

6

In normal arrangement, the distance MN is large Compared to the distance AM.

If AM is Small, Say 40cm it is called a 'Short Normal' & if it is longer Say 160cm, it is called a 'Long Normal'

In the Lateral arrangement MN is very Small Compared to the distance AM.

By proper interpretation of the resistivity data from the field observation, it is possible to identify the water bearing formation's and accordingly limit the depth of borewell drilling.

Radio-active Logging

Radio-active logs are of two types --

1) Those which measure the natural radiactivity of formations (Gamma ray log) and
2) Those which detect radiation reflected from or induced in the formation's from an artefical Source (Neutron log)

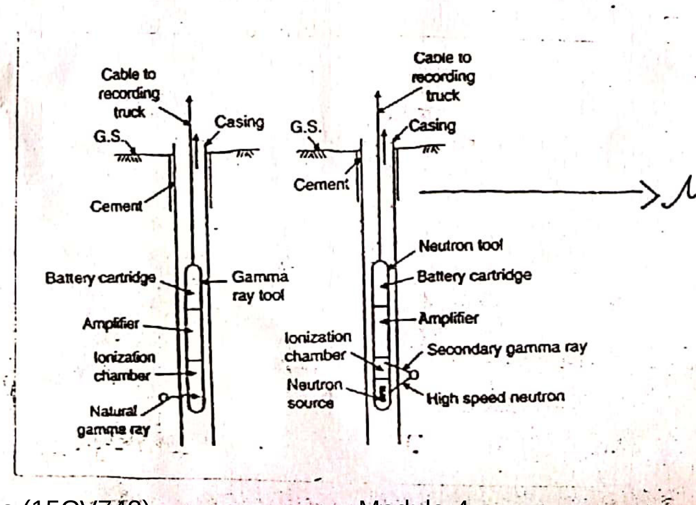
Gamma ray log's

The ground water occurence in the Subsurface is mainly related to the distribution of permeable layers eg: Sand, gravel, weathered rocks.

The minerals in gravel and Sand emit less gamma ray's than minerals in Shales and clay.

The emitted gamma rays are recorded to analyse the presence of ground water.

Gamma ray log →



→ Neutron log

ii) Neutron Logging

- → Neutron rays are used in determining the presence of water.
- → A fast neutron source is used to bombard (ಸ್ಫೋಟಿಸು) the rock. When an individual neutron collides with a hydrogen ion (of a water molecule), some of the neutron's energy is lost and it slows down.
- → A large number of slow neutrons, as recorded by a neutron counter indicates a large amount of fluid.

iii) Induction Logging

- → In this method conductivity of the geological formation (reciprocal of resistivity) is measured by means of induced alternating current.
- → Insulated coils (for induction), rather than electrode are used to energise the formations.
- → By proper interpretation of the conductivity data of the geological formation, it is possible to identify the presence of water.

iv) Sonic Logging

- → The sonic log records the time required for a sound wave to travel through a specific length of formation in situ - bore log.
- → Subsequently speed of sound in subsurface formation is calculated.
- → The speed of sound depends on the porosity of the formation and their fluid content. Hence speed of sound's value indicates the presence of water.

$$\text{Porosity}(n) = \frac{1/V - 1/V_m}{1/V_f - 1/V_m}$$

V_m → velocity matrix

V_f → fluid velocity

V → formation velocity

(8)

> Fluid Logging

Fluid logging includes

i) fluid temperature log ii) fluid resistivity log

Note: Sonde → An instrument probe that automatically transmits information about it's surroundings to recording point.

> fluid temperature log.

→ Sondes are used to measure the temperature inside the bore hole or log.

→ Sensors attached to the Sonde - continuously measures temperature as it travels down the bore hole.

> The variation in temperature data are used * to identify aquifer's or perforated sections.

* to provide information on source of water helping to recharge

i) fluid resistivity log

→ fluid resistivity logging is the measure of resistivity of the fluid b/w two closely spaced electrodes in the hole. If the water has more salt, resistivity will be high.

→ The data of resistivity will help to locate the interface between salt and fresh water.

→ If the salt water intrusion is more, the water is not suitable for usage.

Module - 5 [Ground Water Development] & [Ground Water Recharge]

(1)

→ Types of well's

A water well is an excavation (or) Structure created in the ground by digging, driving and by drilling to access ground water in underground aquifers. wells are classified as i) open well and ii) Tube well

open well

→ These are the wells which have comparatively large diameter's and low discharge. [$20 m^3/hr$ to $200 m^3/hr$]

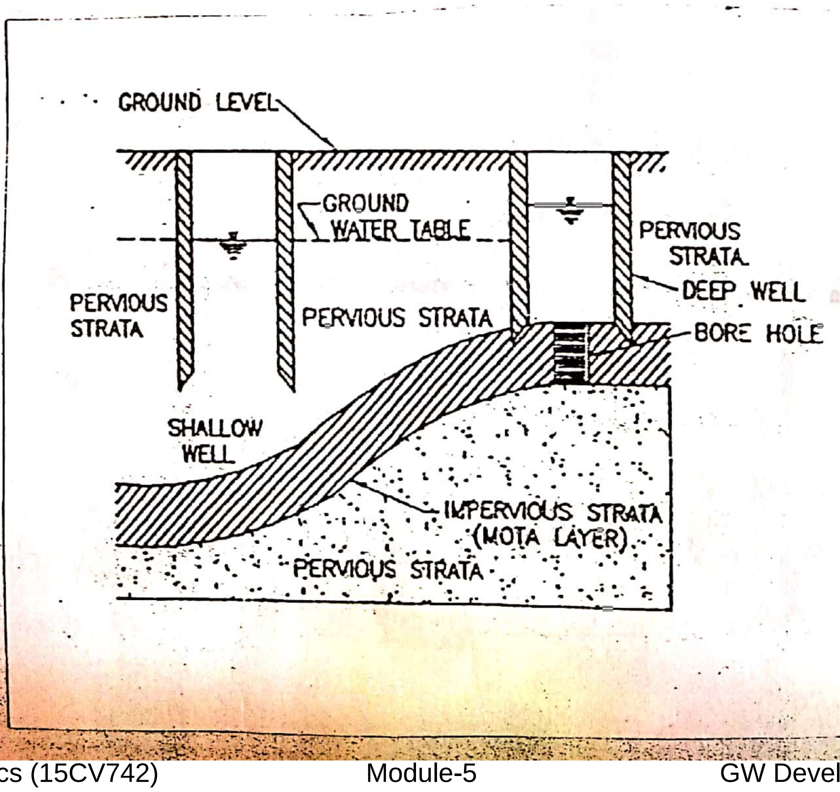
→ The depth of well's will be 2-20m

→ They are constructed by digging therefore they are also known as dug wells.

Classification of open well (a) Based on Depth

1. Shallow open well: These are the wells resting on the water bearing strata and gets their supplies from the surrounding materials.

2. Deep open well: These are the wells resting on the impervious layer known as mota layer beneath which lies water bearing pervious layer and gets their supply from this layer.



· Based on type of wall

› Kacha well's

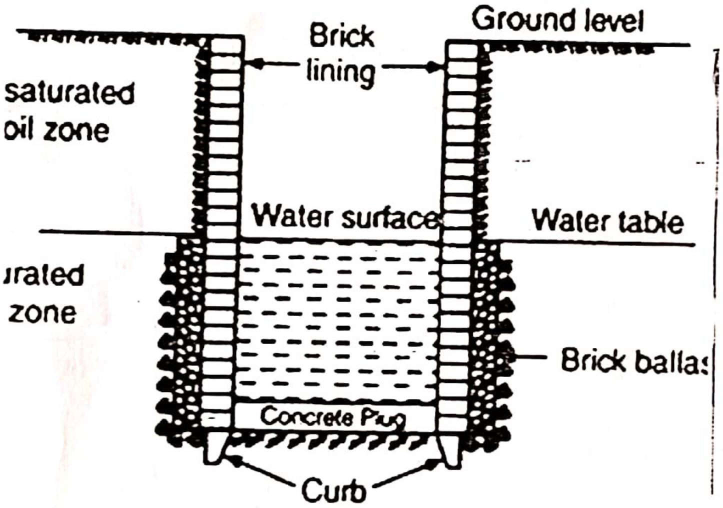
These type of well's are only constructed when water table is high as these type of well's sometimes collapses.

· Well's with pervious lining

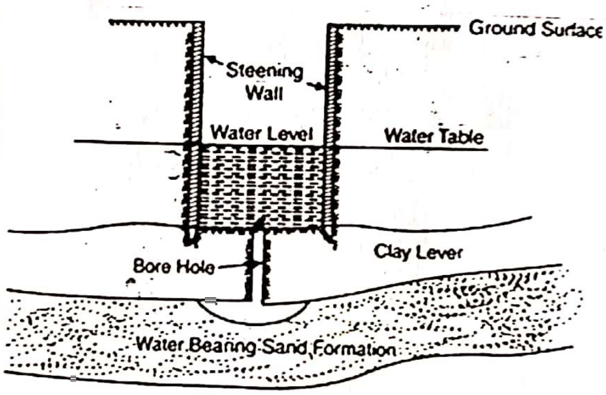
-> In this type, the wells are lined with dry bricks (or) stone masonry.

-> Water contribution to the well takes place through the sides

-> This type is very suitable when subsoil is formed of gravel (or) coarse sand deposits.



Well with pervious lining



Well with impervious lining

› Well's with Impervious (or) pucca (permanent) Lining:

· In this type, the well lining is set in lime mortar (or) cement mortar.

· This type of well is suitable in the regions with alluvial soil formation.

› once constructed, it forms a permanent source of water as long as ground water condition's are good.

› These wells are deeper than than the well with pervious lining.

-> Water contribution to the well takes place through bottom of the wells.

Tube wells [Bore-hole]

→ A tube well is a long pipe sunk in ground intercepting one or more water bearing strata

→ As compared to open well the diameter of tube well will be very less

→ The depth of tube well depends on depth of water table

→ Tube well is drilled by machine.

Classification of Tube well

(a) Based on Depth

i) Shallow tube well:

→ These are the wells which has depth limited to 30m

→ The maximum discharge will be $20 m^3/hr$

ii) Deep tube well:

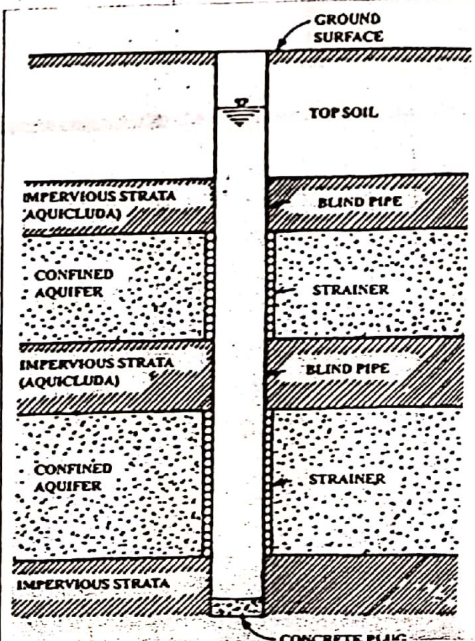
→ These are the wells which have maximum depth of about 600m.

→ The maximum discharge will be more than $600 m^3/hr$

(b) Based on Supply System i) Strainer type tube well

→ In this type of well a strainer (wire mesh) with small openings is wrapped around the main pipe which also has large openings such that area of opening in strainer and main pipe remain's same.

→ The type of flow into the well is radial.



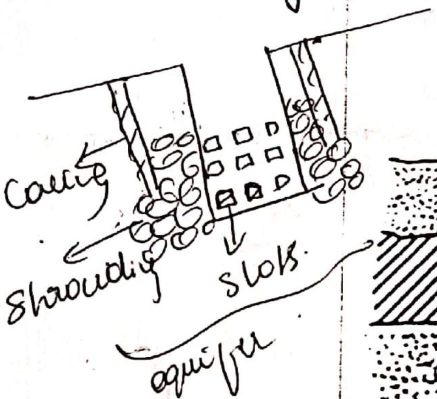
Cavity Tube well:

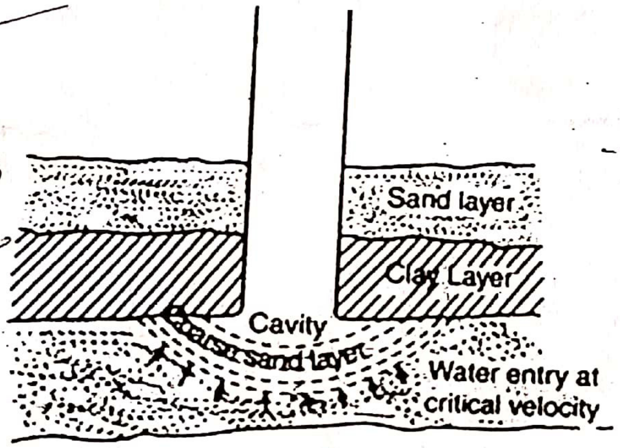
> A Cavity type tube well consists of a pipe sunk in ground upto the hard clay layer.

> It draws water from bottom of well.

> In the initial stages fine sand is also pumped with water and in such manner a cavity is formed at the bottom so the water enters from the aquifer into the well through this cavity.

3) Slotted type.





Methods of Construction of Tube well [Drilling Methods]

(i) Boring & Driving

ii) Construction of cavity wells with the help of Hand boring set and plunger

(iii) Jetting

iv) Core Drilling

v) Rotary Drilling [Hydraulic]
a) Normal Circulation drilling
b) Reverse circulation drilling

(vi) Cable-Tool percussion Drilling

vii) Rotary-cum-Hammer Drilling (Down the hole hammer)

→ Jetting

* In jetting method, a chopping bit is attached to a length of connected drill rod which drills the subsurface.
* The water at high speed from water supply pit is passed through a hose on to the drilling rod and bit. This water jet loosens the subsurface materials and transports them upwards and out of the hole. These subsurface material settle in settling pit allowing water to move towards water supply pit.
* A combination of jetting, driving casing and washing out samples and further drilling completes the formation of well.
* Small truck having jetting drills, tripod, pulley, winch and a pump can be used to

(a) Drill the hole
(b) Install the casing and screens
(c) Develop the well and
(d) To install water lifting pump

Note → Hose → flexible pipe for conveying water

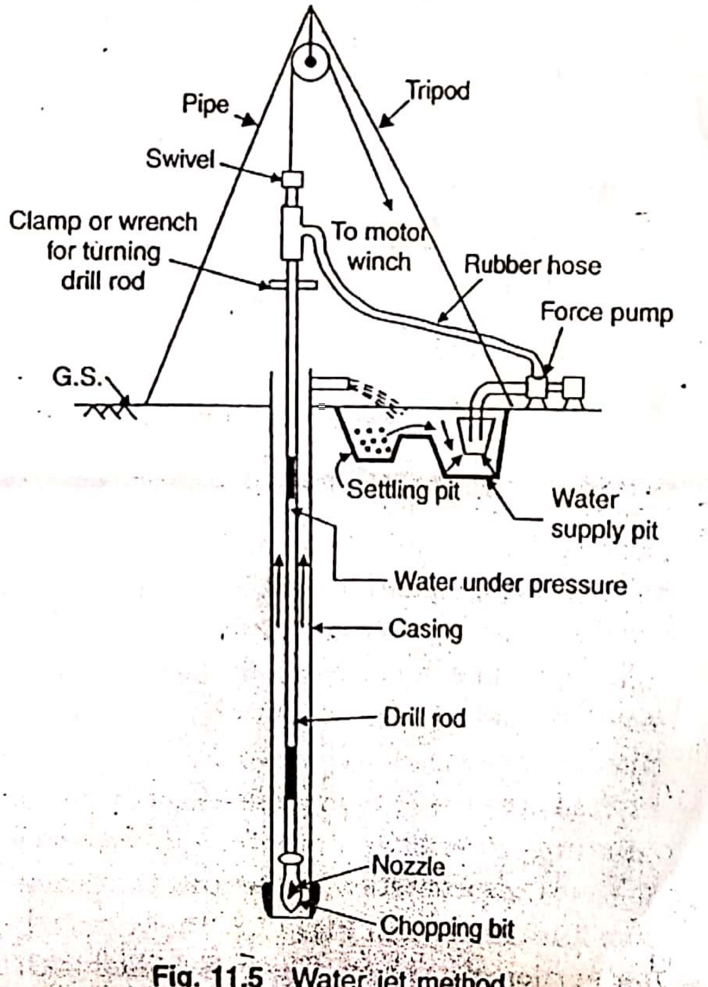


Fig. 11.5 Water jet method

Rotary Drilling [Hydraulic]

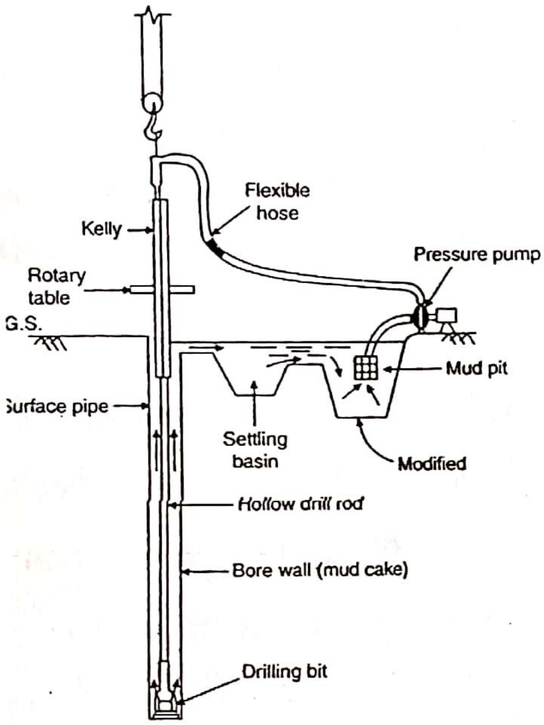
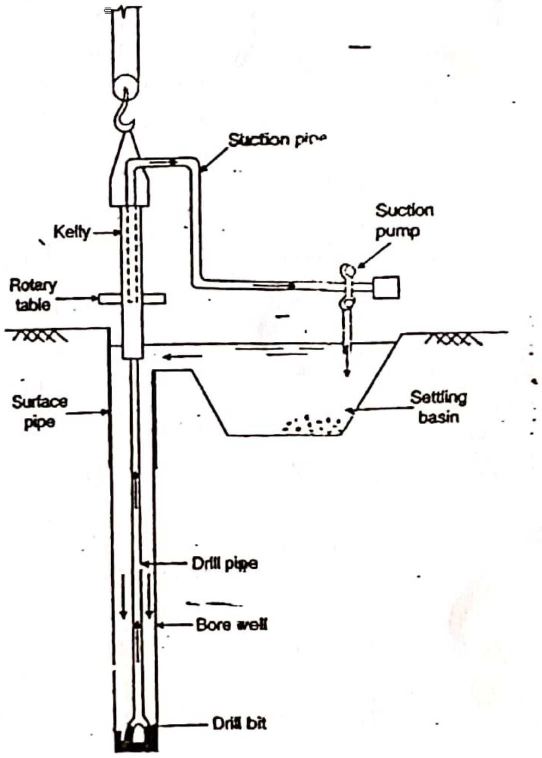


Fig. 11.7 Hydraulic rotary drilling (straight circulation)



. 11.10 Hydraulic rotary drilling with reverse circulation (reverse

Normal Circulation Drilling

This method consists of a rotating drill bit attached to hollow drill rod.

Mud fluid is passed through the hollow drill pipe on to the bit by a mud pump. This fluid brings the cuttings drilled by drill bit upwards which flow to a Setting pit where the cuttings settle out and then overflow to a Storage pit. The mud fluid fluid will again recirculate from Storage pit. The mud fluid forms a layer on the wall of the borehole which seals the pores to prevent loss of fluid into permeable formation.

> The combination of drilling, removal of cuttings with the help of mud fluid & subsequent casing completes construction of well.

Reverse Circulation Drilling

> This method consists of a rotating drill bit attached to hollow drill rod.

-> Circulation of large amount of water is done with the help of Suction pump. The water flow down from setting basin into bore well by gravity. (7)

-> The cuttings drilled by drill bit will be carried upwards with this water as suction pump lifts water along with cuttings and discharges back into setting basin.

-> The cuttings settles down at the bottom of settling tank, the clear fluid returns again to borehole by gravity.

-> The combination of drilling, removal of cuttings with the help of circulating fluid & subsequent casing completes construction of wells.

Cable-Tool percussion Drilling

-> This method consists of a tool string or string of tools comprising the drill bit, drill stem, drilling jars and rope socket.

-> The tool string is suspended by a cable from a walking beam [truck mounted]

-> The cable pulls the string of tools up and down as brought about by walking beam at the surface. The heavy bit at the end of string of tools has a blunt chisel end which cracks, chips the rock by repeated blows.

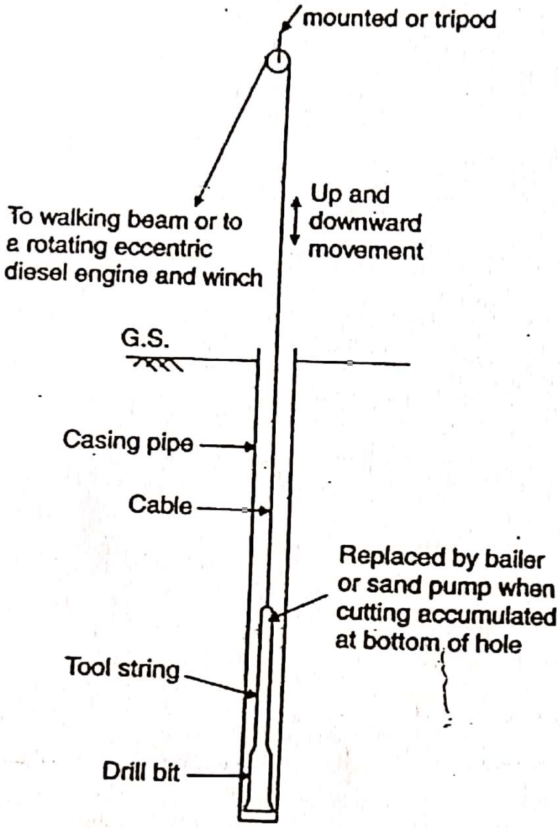
-> Water must be added to form slurry if drilling is done in dry formations.

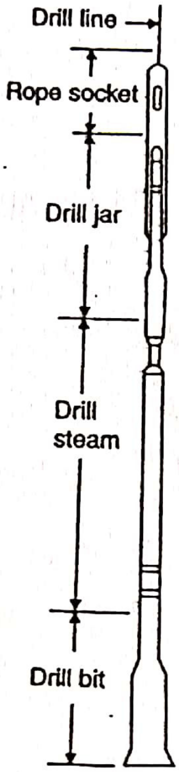
-> Drilling is relatively slow and casing has to be provided as the drilling progresses.

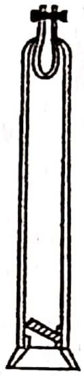
-> Drilling is started with a large diameter and diameter is reduced telescopically after drilling certain depth.

-> This method is suitable for rock, medium hard, soft & boulder formation.

Diagram ->


mounted or tripod
To walking beam or to a rotating eccentric diesel engine and winch
Up and downward movement
G.S.
Casing pipe
Cable
Replaced by bailer or sand pump when cutting accumulated at bottom of hole
Tool string
Drill bit


Drill line
Rope socket
Drill jar
Drill steam
Drill bit



c. Bailer

Design of Tubewell

A water well has to be designed to get the optimum quantity of water economically from a geological forma[tion]

A tubewell design involves selection of

→ The diameter of the well and that of the casing
→ Depth of the well
→ length and Location of the screen including a) Screen size b) Shape c) % of open area
→ Screening and casing material.

Well diameter [& that of the casing]

* The size of the well should be properly chosen since it significantly affects the cost of well construction.
* It should be large enough to accommodate the pump that is expected to be required for pumping water.

Depth of the well

* The depth of a well & the number of aquifer it has to penetrate is usually determined by electrical resistivity method
* wells are usually drilled upto the bottom of the aquifer permitting greater well yield.

Length and Locatiotion of the Screen

* 70 to 80% of the aquifer thickness in which borewell pip[e] will be present is screened.

The screen must be placed adjacent to the aquifer.

(a) Screen size (diameter) → Depend's on diameter of well casing

(b) Shape → i) slotted screen (vertical slots)
ii) V-shaped continous slots
iii) The Louver-type of screens
iv) Rectangular slots.

} Based on the particle size of the earth material any one of these shaped screen will be chosen.

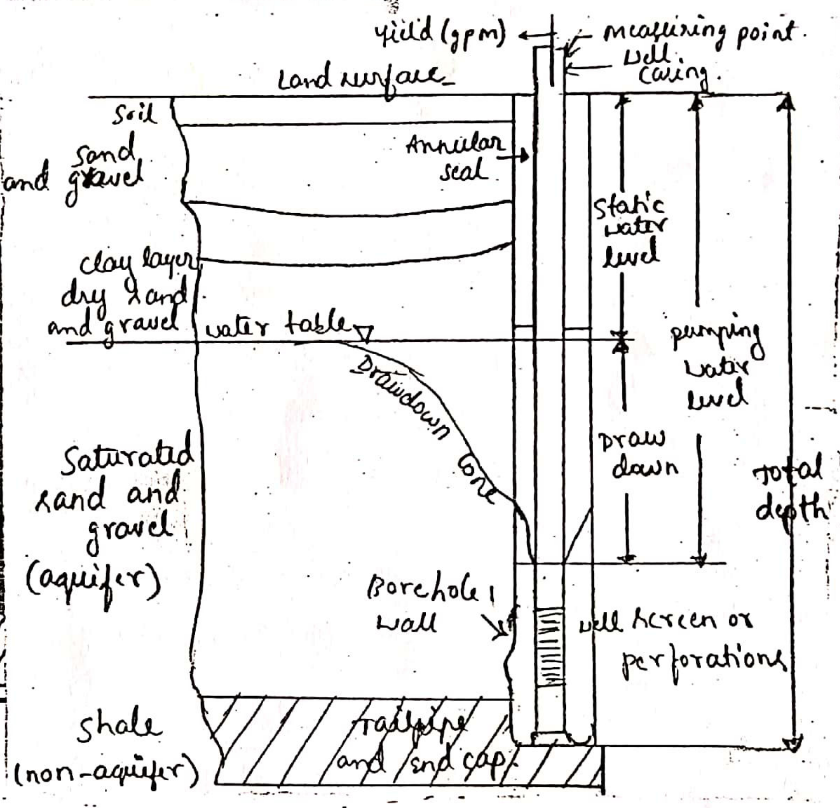
(c) % of open area → If amount of open area in the screen is more the water enters borewell quickly from the aquifer.

Screening and casing material

→ PVC pipes are very widely used as casing pipe.
→ Screens are being made of metal such as GI steel, brass...

Along with this intake portion of the well must be placed in those zones having the highest hydraulic conductivity. The aquifer materials having high effective size(D_{10}) and low uniform co-efficient (Cu) will have high hydraulic conductivity.

- D_{10} & C_u is determined by seive analysis



Construction of Dug wells)

* These are constructed by first digging a pit
* Then a curb (which is a circular ring) with a sharp bottom is inserted. After this
* Masonry wall upto some distance above the ground is constructed
* Subsequently excavation proceeds which leads to sinking of curb & then masonry is further extended leading to completion of well construction.
* The water enters from the bottom portion or from sides based on the lining.
* Based on the subsurface formation wells are lined with dry bricks or lining is set in lime mortar (or) cement mortar.

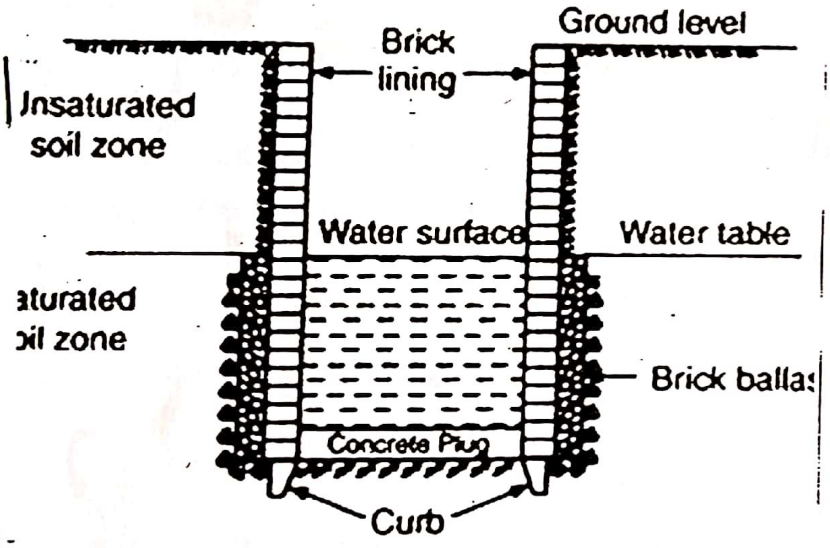
Design Specifications -

-> Diameter - 1 to 5m
-> Depth - 3 to 15m
-> The side walls - Brick masonry (or) precast concrete ring's
-> Average Discharge - 0.004 m^3/sec

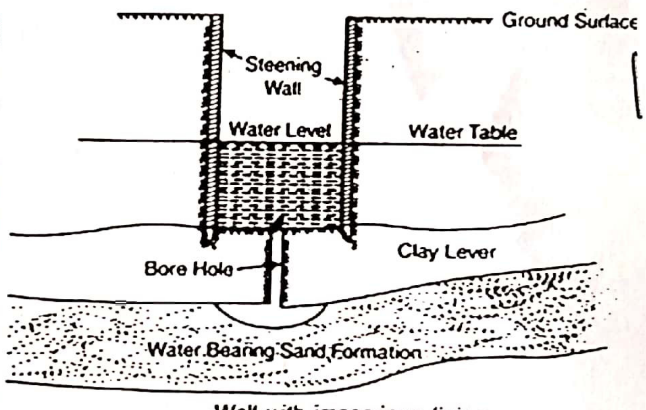
-> When subsoil is formed of gravel or coarse sand deposit's - wells are lined with pervious materials.

-> When subsoil is of alluvial formation - wells are lined with impervious materials.

-> For well's with pervious lining brick ballast of about 20mm is packed behind the lining atleast upto the ground water table from bottom. Along with this 1m thick concrete plug in the bottom is provided.



Well with pervious lining.



Well with impervious lining

Dug wells

Pump's for lifting water

The Selection of a proper pumping set is important to ensure continued Satisfactory yields from wells and the factors to be considered are

i) finished inside diameter and total depth of the well
ii) yield from the well
iii) The desired pumping rate
iv) Hours of pumping per day required
v) The total head on the pump
vi) The lowest pumping water level
vii) The power required
viii) The quality of water, whether corrosive, clear (or) Sandy

Pumps could be of
-> Plunger pumps
-> Jet pumps
-> Submersible pump
-> Air lif pump
-> centrifugal pump
-> Deep well vertical turbine -pump

Among the above jet pump & Submersible -pumps are commonly used

Well Type	operation	features
Shallow well Jet pump	Pump sits above ground and draws water out through one inlet pipe.	-> for depths of 25 feet deep or less -> one way check valve keeps pump primed
Deep well Jet pump	Pump sits above ground and draws water out through one pipe & pushes water through another pipe.	-> for depths greater than 25 feet (less than 100 feet) -> May include a tailpipe to ensure well is never pumped out -> Requires a foot valve to prime the pump.

Well Type	Operation	Features
Deep well · Submersible pump	Single pipe comesup from inner portion of well and connects to a Pressure tank.	-> for depth of 25 feet to 400 feet deep -> Must be pulled from well casing for repai -> Submersible pumpun Submerges below the lowest pumping wat level. -> The water proof Cab Supplies power to the motor.

Working principle of Submersible pump

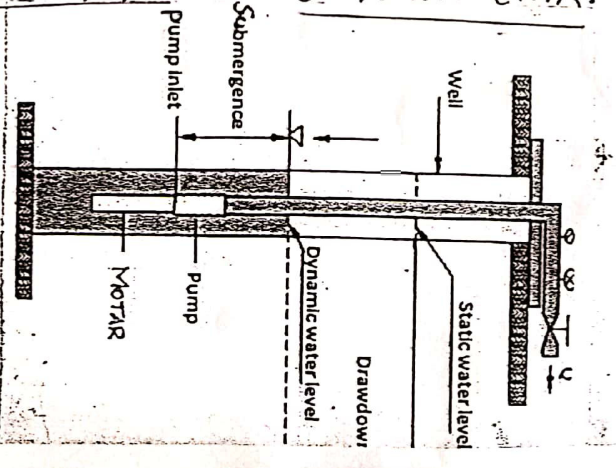
-> A Submersible water pump pushes water to the Surface instead of Sucking the water out.

-> Most Submersible pumps are long cylinder's that are about 3 to 5 inches around and 2 to 4 feet long.

-> when the power (electric) Switch is Switched on, an electrical current is Sent down through an electrical wire to the submersible water pump.

-> Impellers Contained within the body of the pump Starts turning. The rotation of the impellers sucks water into the body of the pump.

-> The impellers then push the water out of the pump & up through the pipe to the water tank.



Horse power of the pump motor

The power of the motor = $\frac{\gamma_w \cdot Q H}{\eta}$ Nm/s (i.e watts)

$$H.P\ (metric) = \frac{watts}{735} = \frac{\gamma_w \cdot Q H}{735\eta}$$

Where Q = Discharge to be delivered in cumec's (cm^3)

H = Total lift i.e the head against which motor has to work in metres.

γ_w = unit weight of water in N/m^3

η = Efficiency of the pumpset

The total head (H) against which the motor has to work consists of

› Maximum depth of water level below the ground level

› Maximum depression head

› velocity head

› friction loss in the tube pipe including losses at bend.

i.e $h_f = \frac{4 f l V^2}{2gd}$

f' = Co-efficient of pipe friction

l = length of the pipe line

V = Velocity of flow in the pipe

d = Diameter of the pipe line

Losses at bend can be taken as 25% of h_f.

Conjunctive use of Surface water and Groundwater for Sustainable water Management

Water planner can achieve a better management through basis wide strategies that include integrated utilization of Surface and ground water which may be defined as Conjunctive use.

Necessity, techniques, benefits & economics

Conjuntive use of water is necessary because of following benefits.

i) A large Sub-Surface Storage at a relatively lower cost and safe against any risk of dam failure.

ii) Provides water supply during a series of drought year's

iii) Efficient water use from well spaced wells due to smaller surface distribution System than a canal-irrigai System

iv) water table can be controlled by pumping groundwater from wells which prevents water logging in canal irrigated areas

v) Both water conservation & flood protection can be achieve

vi) A subsurface scheme can be developed in a shorter period

vii) In project under conjuctive use of water, tube well loads can be reduced by releasing surface water for irrigation during period of pek power demand thus resulting in lower power cost.

viii) Crop water requirement can be ensured right through the year using surface water during the monsoon and ground water supplies when the surface water is not available

x) Ground water and Surface water can be mixed in proper proportion's to obtain a desired water quality for irrigation

x) Integration of the two types of schemes can be obtained with the existing water resources without the loss of earlier investment.

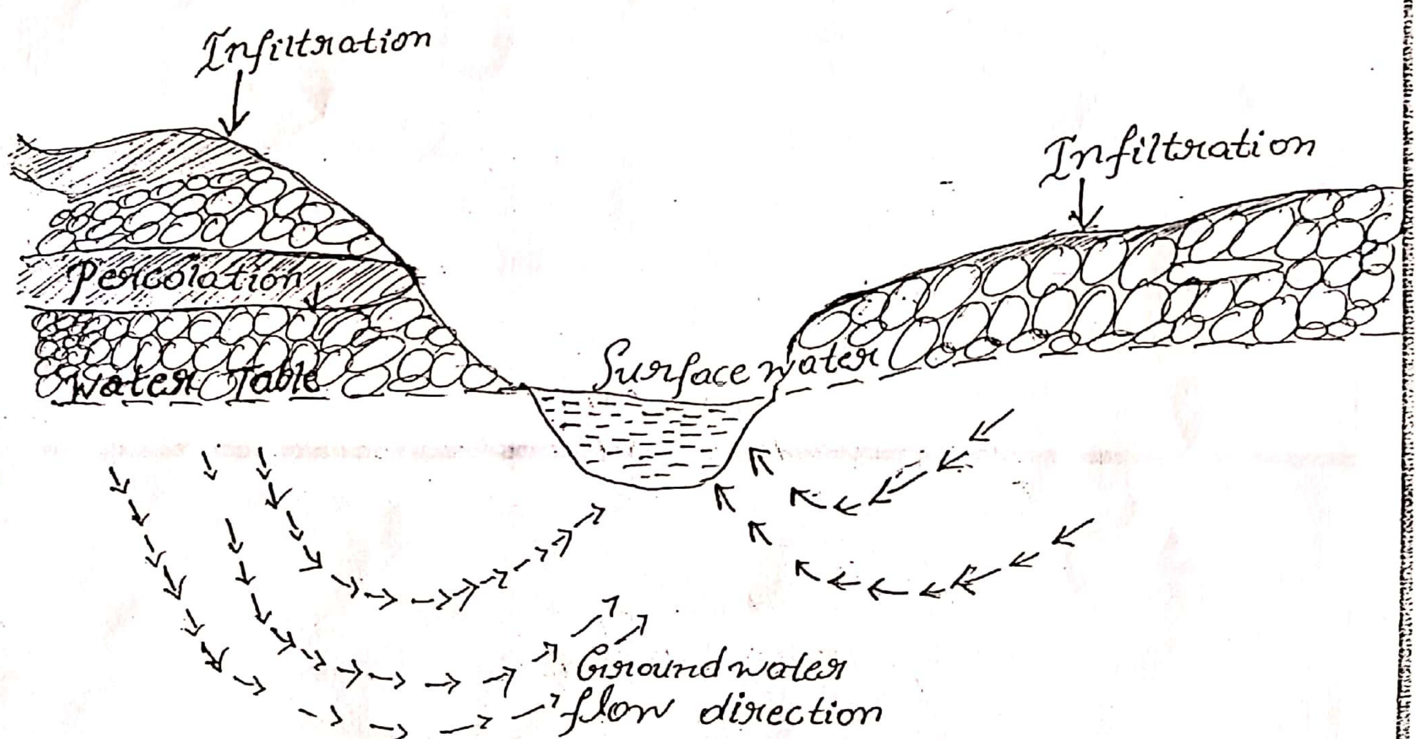
Ground Water Runoff (or) Groundwater flow

water infiltrates below ground and recharges groundwater in areas where permeable deposits are found at the ground surface.

In the aquifer, the porosity, permeability and other factors determine how fast the ground water moves.

Groundwater can flow a few centimeters to a few metres a day in sand or gravel aquifer, and tens of metres a day (rapid) or more in some highly fractured bedrock aquifers. In general, groundwater moves from areas of recharge towards areas of discharge such as springs, streams, lakes or wetlands

water infiltrating or recharging in the hills or uplands travels down to the water table aquifer, then moves horizontally through the various formations until it reaches and discharges into a surface water body.



Artificial Recharge of Groundwater

Artificial recharge is a process by which the groundwater reservoir is augmented artificially. The rapid urbanization and deforestation have considerably reduced the groundwater recharge in many parts of the world. The reduction in groundwater recharge and over exploitation of groundwater due to increasing demands, the groundwater table has been depleted in many parts of the world. For example, the groundwater table in some parts of Delhi has been depleted by 20 to 30 meters in a span of 60 years. Same is the condition in other major cities in India and other parts of the world. As such there is a need to increase the groundwater recharge by some artificial means. In this lecture, we will discuss some of the methods use for artificial recharge and also the methods use in estimation of groundwater recharge.

Techniques of groundwater recharge

The artificial techniques use for groundwater recharge can be divided in two groups, *i.e.* direct method and indirect method. Further, the direct method can be sub grouped as surface method and sub-surface method. The main objective of the surface method is to enhance groundwater infiltration by providing more residence time with the help of structural and nonstructural measures. Some of the structural measures are contour bunding, percolation tank, check dams, *etc*. On the other hand, afforestation falls under the category of nonstructural measures. The induced recharge method and aquifer modification method falls under the category of indirect method.

Direct Methods

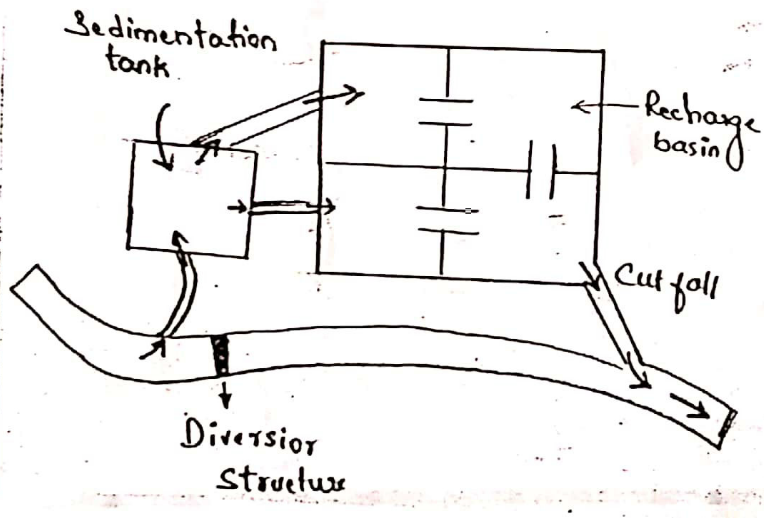
Surface method

1. Percolation tank

In this method, series of earthen dams are constructed on suitable sites for storing of adequate quantity of surface water. The tank area should be selected in such a way that significant amount of water infiltrates through the bed of the tank and reaches the groundwater table. This method is very effective in alluvial area as well as in areas with hard rock. This method is very useful in providing continuous recharge after the monsoon.

2. Flooding

This method is suitable for relatively flat region where water can be spread as a thin layer. Water is distributed over the region using a distribution system. This method can achieve higher rate of infiltration in a region having thin vegetation cover or sand soil cover. Figure shows a schematic diagram of recharge basin.

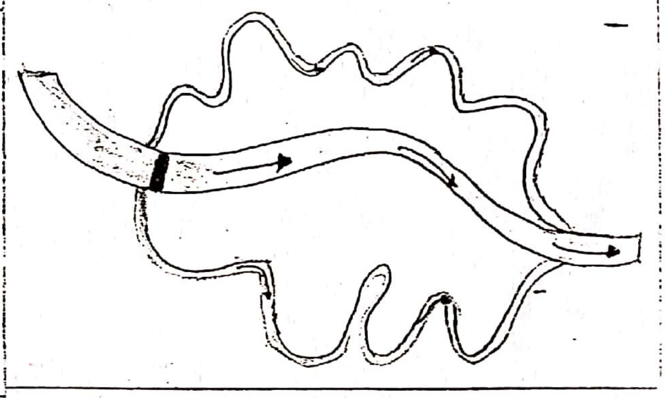


3. Stream augmentation

In this method, seepage from natural stream or river is artificially increased by putting some series of check dams across the river or stream. The placing of check dams spread the water in a larger area which eventually increases groundwater recharge. The sites for the check dams should be selected in such a way that sufficient thickness of permeable bed or weathered bed is available for quick recharging the stored water.

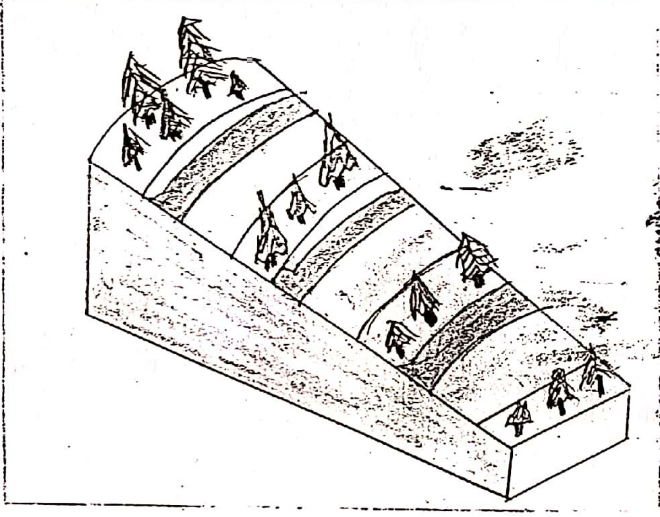
4. Ditch and furrow system

This method is used for uneven terrain. In this technique, a system of closely spaced flat bottom ditch or furrow is used to carry the water from the source. This system provides more opportunity to percolate the water into the ground. The spacing of the ditch depends on the permeability of the soil. For less permeable soil, more densely spaced ditch or furrow should be provided.



5. Contour bund

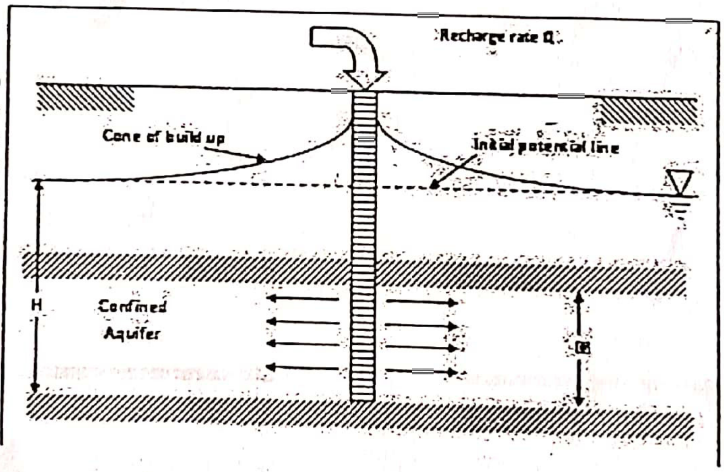
Contour bund is a small embankment constructed along the contour in hilly region to retain the surface runoff for longer time. This scheme is adopted for low rainfall area where internal subsurface drainage is good.



Subsurface method

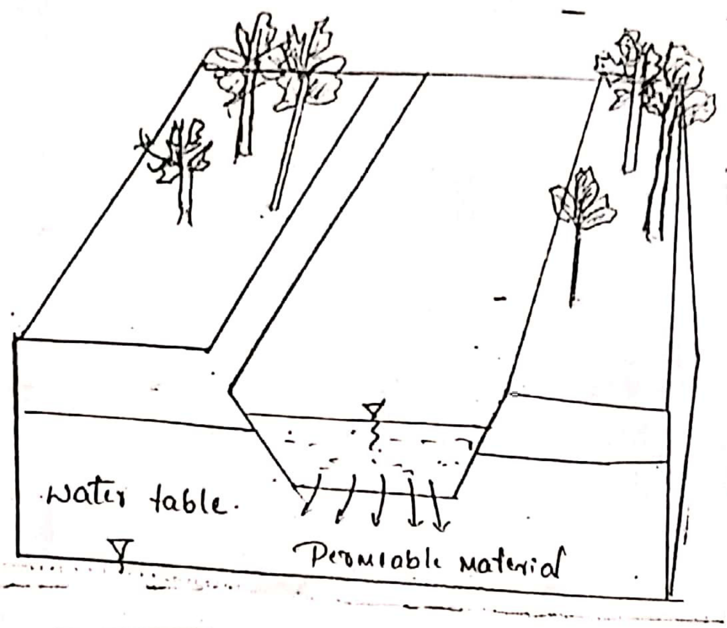
1. Recharge well

Recharge wells are used to recharge water directly to the aquifer. Recharge wells are similar to pumping wells. This method is suitable to recharge single wells or multiple wells. This method is costlier than the other method as wells are required to be bored. However, sometimes abandoned tube wells can be used for recharging water into the aquifer.

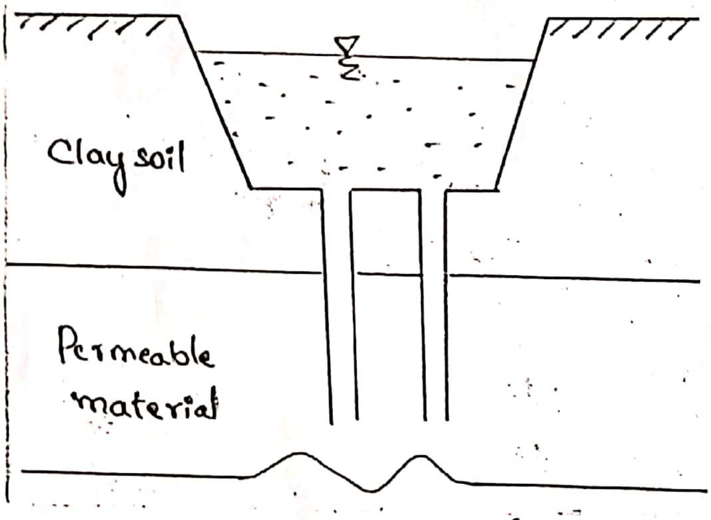


2. Dug well

Dug wells can also be used to artificially recharge the groundwater. Generally, water level of dug wells depletes during the non monsoon period. Sometime the dug wells even dried up in the non-monsoon period. These dug wells can be used for recharging groundwater. The water from various sources can be collected through a distribution system and can be discharged at the dug wells.



3. Pits and shafts Recharge pit of variable dimensions are used to recharge water to unconfined aquifer. Most of the time, especially in case of agricultural field, a layer of less permeable soil exist. Due to the existence of the less permeable permeable strata, the surface flooding methods of recharge do not show satisfactory performance. For such type of cases, recharge pit can be excavated which are sufficiently deep to penetrate the less permeable strata. On the other hand recharge shaft is similar to the recharge pits, but the cross sectional size of the recharge shaft is much lesser than the recharge pits. Like the recharge pits, recharge shafts are also used to recharge water to unconfined aquifer whose water table is deep below the land surface and a poorly impermeable strata exist at the surface level.



Indirect method

Induced recharge

It is an indirect method of artificial recharge. In this method water is pumped from the aquifer hydraulically connected to the surface water sources like stream, river or lake. Due to pumping, a reverse gradient is formed and water from the surface water source enters into the aquifer and thus the aquifer is recharged . This method is good, especially when quality of the surface water is poor. The filtration of surface water through soil strata removes the impurities of the water. Thus the quality of the water receives in the wells is much better than the surface water.

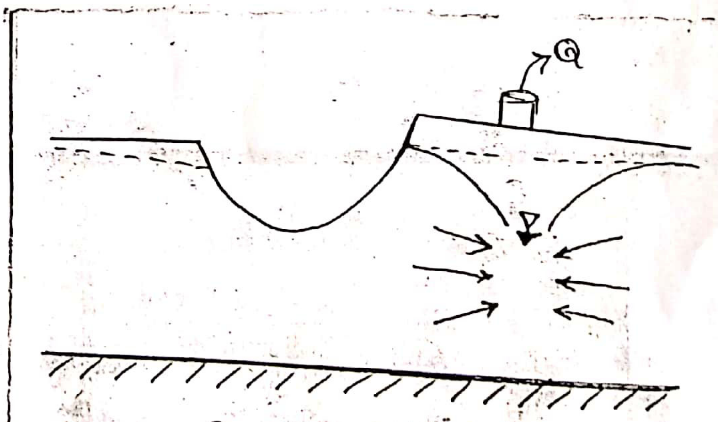


Fig: Induced recharge

Aquifer modification method

This is also an indirect method of artificial recharge. In this method, some techniques are used to change the aquifer characteristic so that aquifer can store more water and also can transmit more water. After application of these techniques, more recharge takes place under natural condition as well as under artificial condition. The most commonly used techniques are, bore blasting method, hydro-fracturing method, jacket well techniques, fracture seal cementation and pressure injection grouting, etc.

1. Bore blasting method

This method is used to increase the fracture porosity of an aquifer. Shallow bore wells are drilled in the area where fracture porosity of the aquifer is planned to increase. These bore holes are blasted with the help of explosive which creates fracture porosity in the aquifer.

2. Hydro-fracturing method

Hydro-fracturing is used to improve the yield of a bore well. In this technique, water is injected at a very high pressure to widening the existing fracture of the rock. The high pressure injection of water also helps in removing of clogging, creates interconnection between the fractures, and extends the existing length of the old fracture. The high pressure injection also creates new fracture in the rock strata. As a result of these, the water storing and transmitting capacity of the strata increases.

3. Jacket well techniques

Jacket well technique is used to increase the yield of a dug well. In this method, the effective diameter of the well is increased by drilling small diameter bores around the well in a circular pattern.

4. Fracture seal cementation and pressure injection grouting

This technique is used to control the outflow from an aquifer. Cement slurry is injected into the aquifer using mechanical means or manually near to the aquifer outlet like spring, etc. The injection of cement slurry helps in reducing the fracture porosity of the aquifer near the outlet which will eventually reduce the outflow from the aquifer.