IIT KHARAGPUR

NPTEL ONLINE CERTIFICATION COURSES

Irrigation and Drainage

Lecture No: 26 Irrigation Wells

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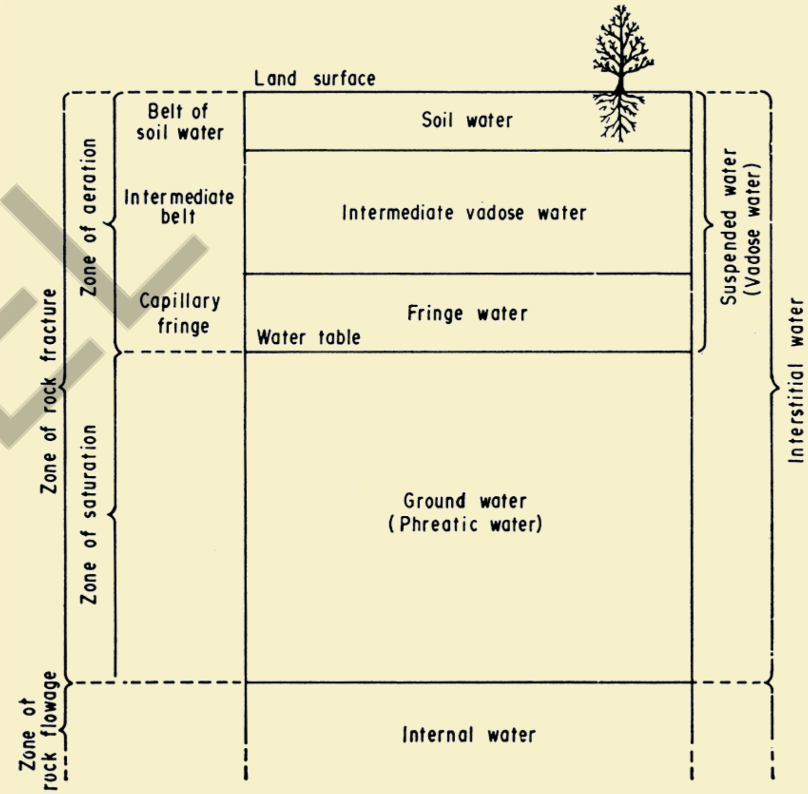
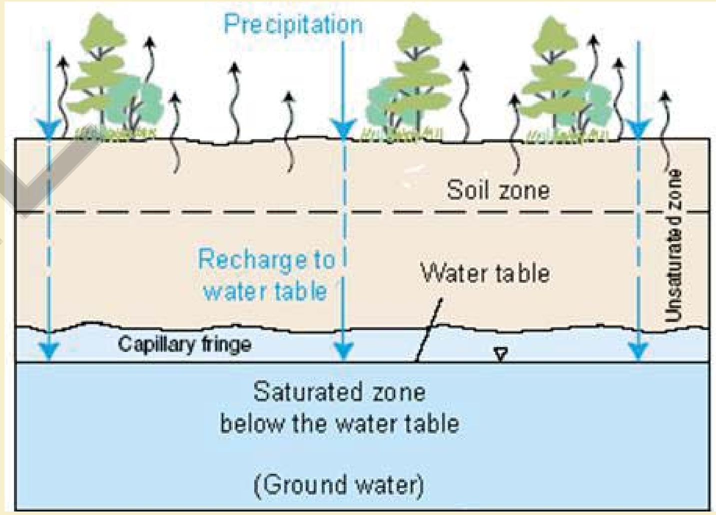
Soil Water Zones

- ✓ Beneath the surface of the earth, there exist a large fresh water
  - o Soil moisture
  - o Vadose water
  - o Groundwater
  - o Deep lying Groundwater
- ✓ Water in the unsaturated zone above the water table is called vadose water.
- ✓ The volume of vadose water below the soil moisture zone is estimated to be 10000 mi^3. which is a potential ground water recharge



Soil Water Zones

- ✓ The zone aeration acts as filter for surface water passing through it.
- ✓ About 0.5 miles below the water table 1Mmi^3 of groundwater.
- ✓ ~ 3000 times grater than the volume of water in all rivers
- ✓ The ground water below 0.5-5 miles is not recoverable
- ✓ Ground water accounts for nearly 2/3rd of fresh water resources of the world
- ✓ Groundwater flows slowly at rates: 10-15m/day
- ✓ At great depth, water may takes 10000 years to pass through an aquifer and some water is completely stagnant



Example 26.1:

Assume that world's recoverable groundwater is 4×10^6 Km^3. For how long will this water be able to meet the needs of the worlds population of say 5 billion, if per capita daily consumption is taken to be 4000 L.

Solution:

$$World\ population\ =\ 5\times10^9$$

$$Per\ capita\ daily\ consumption = 4000\ \text{L}$$

$$Total\ world\ daily\ consumption\ = 5\times10^9\times4000 = 2\times10^{13}\ \text{L/day}$$

$$Total\ ground\ water\ supply\ = 4\times10^6\ \text{Km}^3$$

$$= 4\times10^{15}\ \text{m}^3 = 4\times10^{18}\ \text{L}$$

$$Time\ to\ supply\ water\ will\ last\ for\ = \frac{4\times10^{18}}{2\times10^{13}} = 2\times10^5\ \text{days}$$

$$= \textbf{548 years (Ans.)}$$

Types of Geological Formations

Aquifer: A geological formation, or a part of formation, or a group of formations that yield significant quantity of water is defined as aquifer. (e.g. sand, gravel, etc.)

Aquifuge: A geological formation that contains no inter connected pores therefore, can neither absorb nor transmit water is termed as aquifuge (e.g. solid granite, etc.)

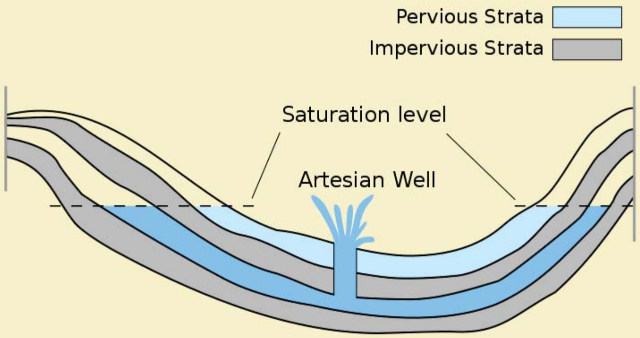
Aqiclude: A geological formation that is porous and contains water but is not capable to transmit water in significant quantity is termed as aqiclude (e.g. Clay, etc.)

Aquitard: A geological formation whose hydraulic conductivity is too small to permit development of well or spring but sufficiently large to influence the hydraulics of aquifer adjacent to it. (e.g. Sandy clay, etc.)

Types of aquifer

1. **Confined aquifer:**

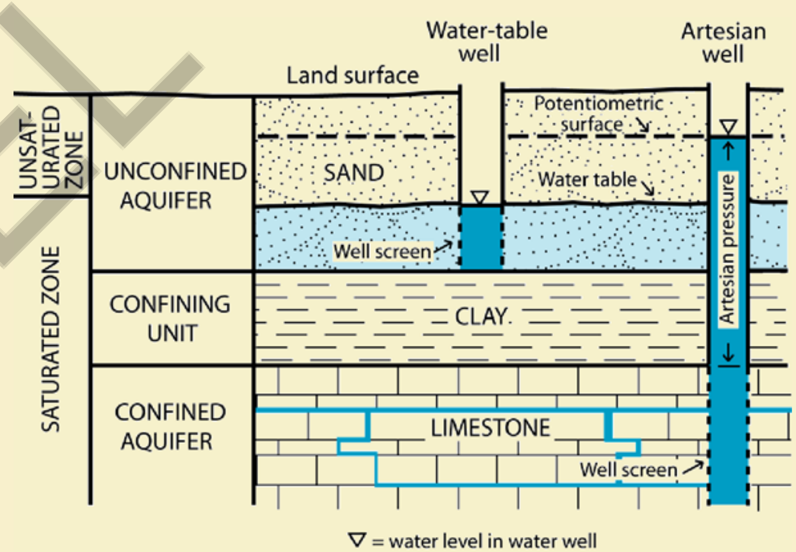
   - ✓ In these aquifer, ground water is confined under pressure greater than atmospheric by over lying impervious (**aquiclude**) or semi-impervious strata (**aquitard**).
   - ✓ When the water level in the well penetrating the confine aquifer rises above the ground, called **flowing well** otherwise, it is called **artesian well**.
   - ✓ Rise/fall of water in well results due to the hydrostatic pressure in the strata.



Types of aquifer

2. Unconfined aquifer:

- ✓ These are called phreatic or water table aquifer. The upper surface of the zone of saturation is under atmospheric pressure and is called **water table**.
- ✓ Rise and fall in the water table results primarily form changes in volume of water store in the structure.
- ✓ When piezometric surface fall below the bottom of the upper confining stratum the confined aquifer become an unconfined aquifer.

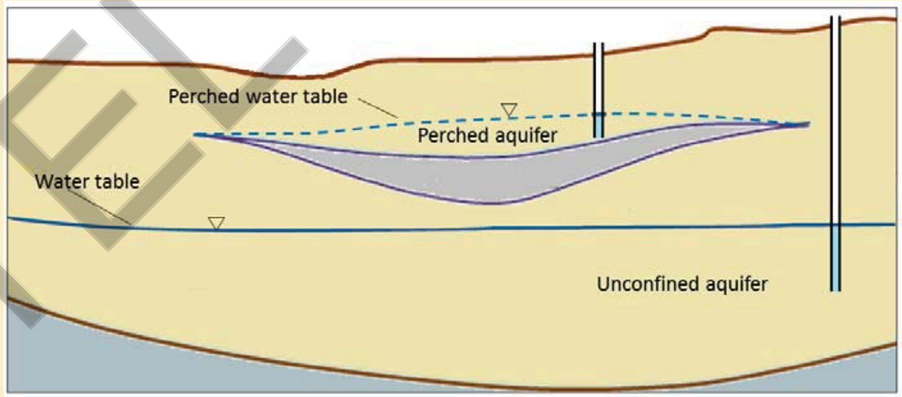


https://igws.indiana.edu

Types of aquifer

3. Perched aquifer:

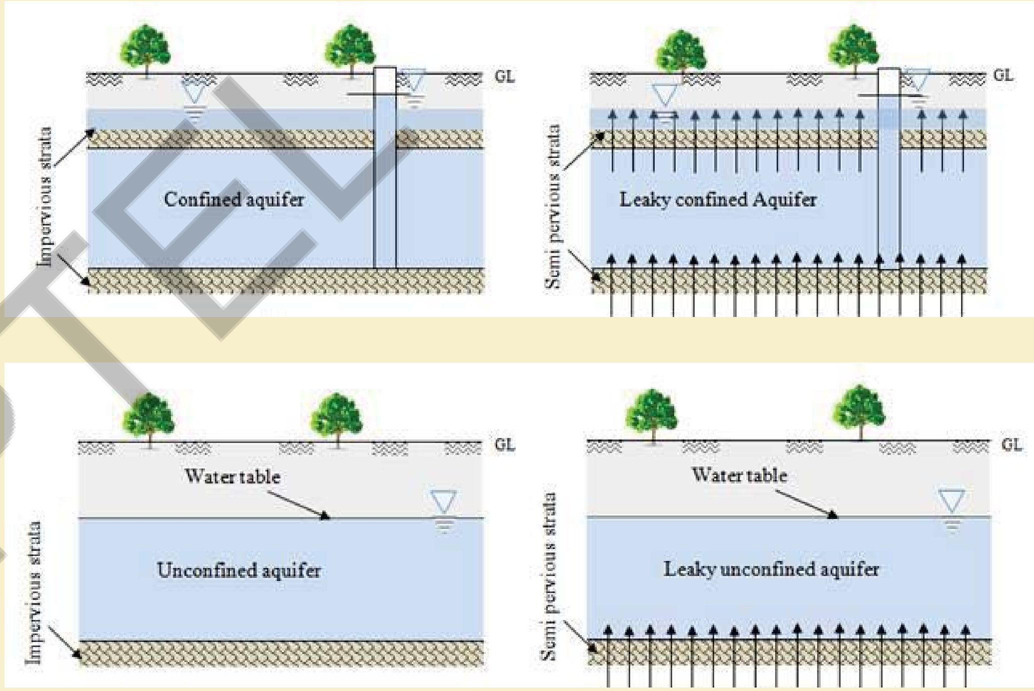
- ✓ It is a special type of unconfined aquifer
- ✓ It occurs when ever a relatively small, impervious or semi-pervious stratum supports a groundwater body that is above the main water table
- ✓ Clay layer are sedimentary deposit causes this water table
- ✓ This can be semi perched if the stratum is semi-pervious layer.



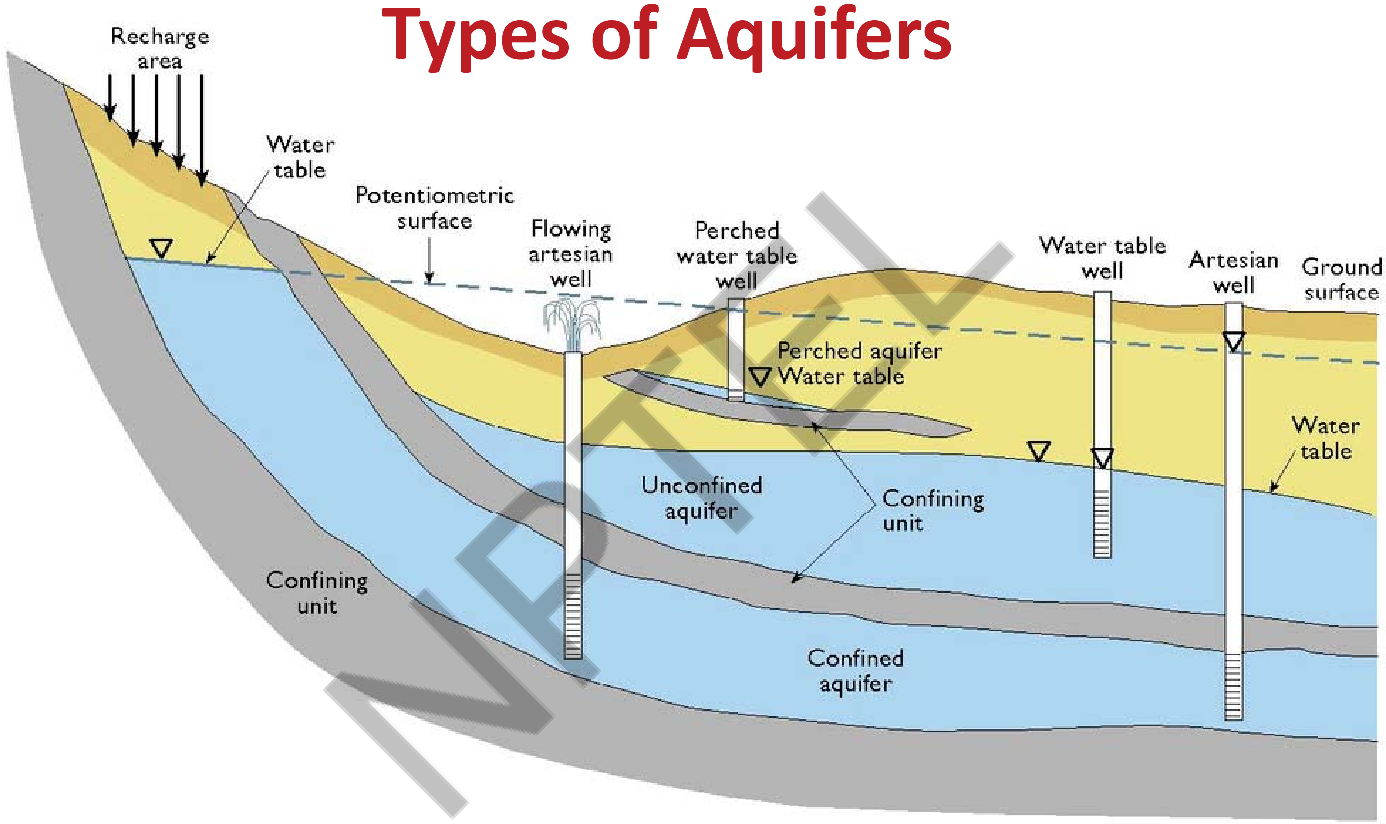
Types of aquifer

4. Leaky aquifer:

- ✓ One of the boundary layer should be semi-pervious can be confined, unconfined or perched
- ✓ Leaky-confined, Leaky-unconfined and Leaky-perched



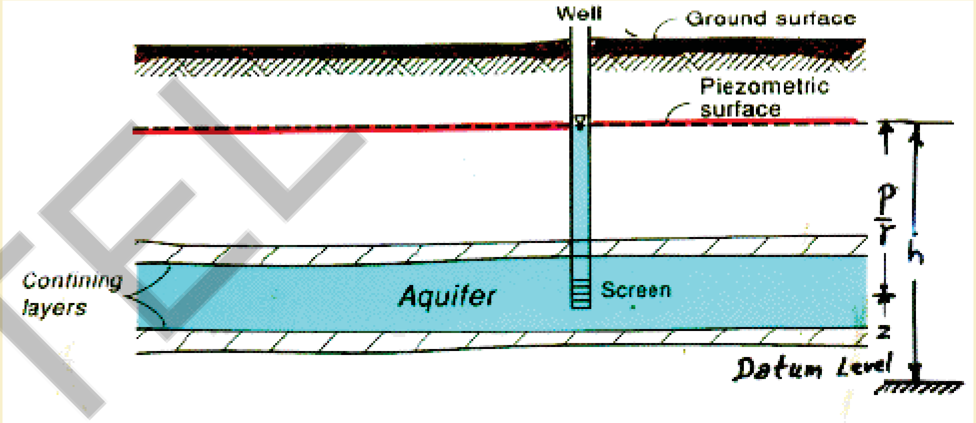
Types of Aquifers



Modified after Harlan and others, 1989

Piezometric (Potentiometric) surface:

- ✓ It is an imaginary surface coinciding with the hydrostatic pressure level of the water in the confine aquifer
- ✓ The elevation of the surface at a given point is define by water level in a well penetrating a confined aquifer at that point
- ✓ Place a key role in the identification analysis and synthesis of flow in confined aquifer



Water Table:

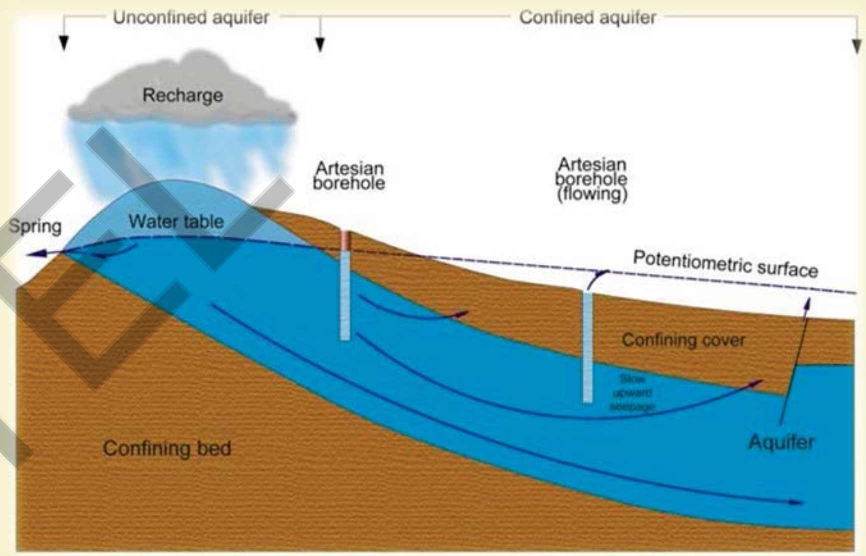
- ✓ The upper surface of the zone of saturation under atmospheric pressure is called water table
- ✓ Phreatic surface

Recharge Area:

- ✓ A region suppling water to a ground water basin is called recharge area

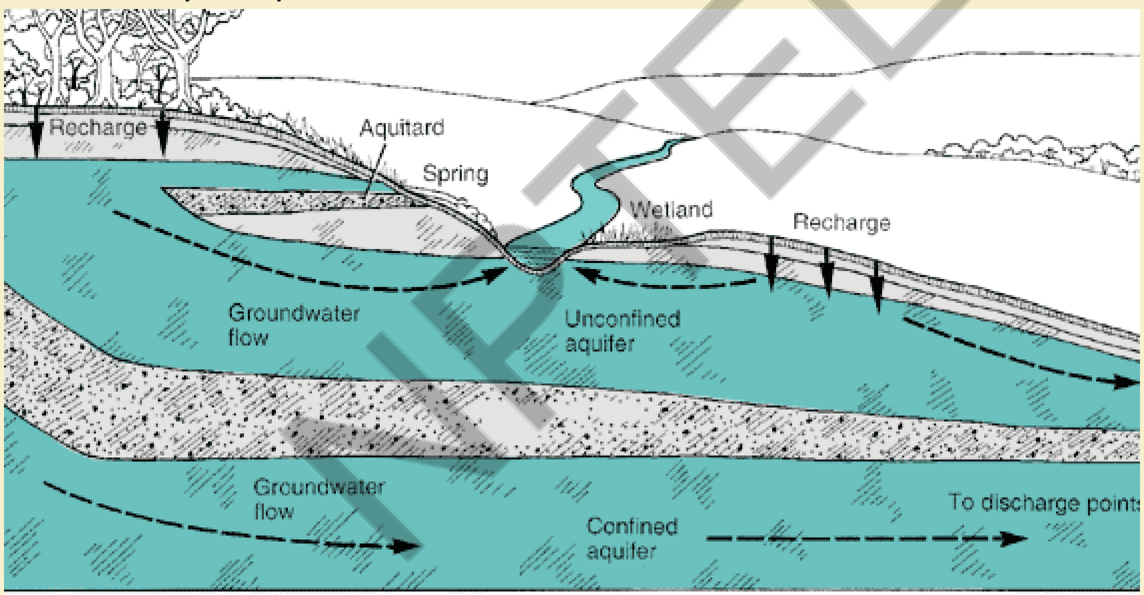
Ground Water Basin:

- ✓ Physiographic unit containing one or more aquifer
- ✓ They are connected and interrelated



Spring

- ✓ When water flow naturally from the aquifer to the ground surface is called as spring.
- ✓ It is a component of hydrosphere



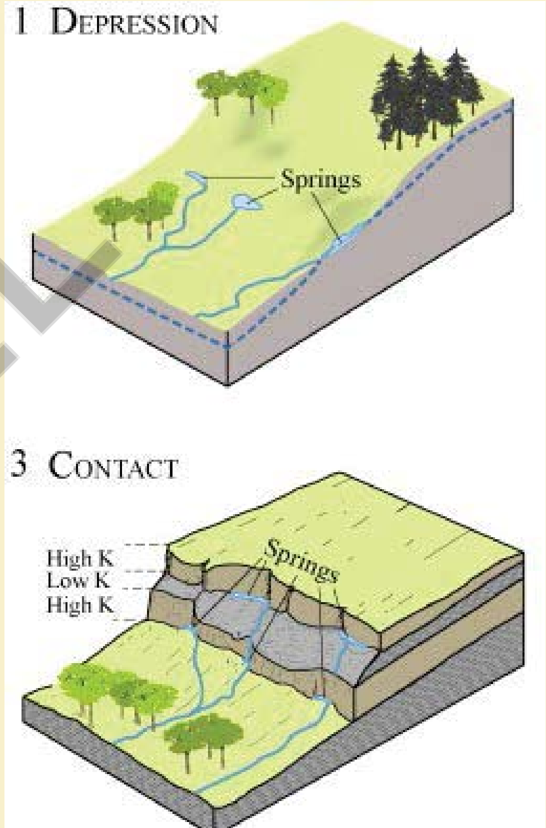
Types of spring

1. **Depression springs**

   Depression spring formed where the ground surface intersect the water table.

2. **Contact spring**

   Created by permeable water bearing formation overlying a less permeable formation that intersect the groundwater



https://doi.org/10.1016/j.envsci.2011.04.002

Types of spring

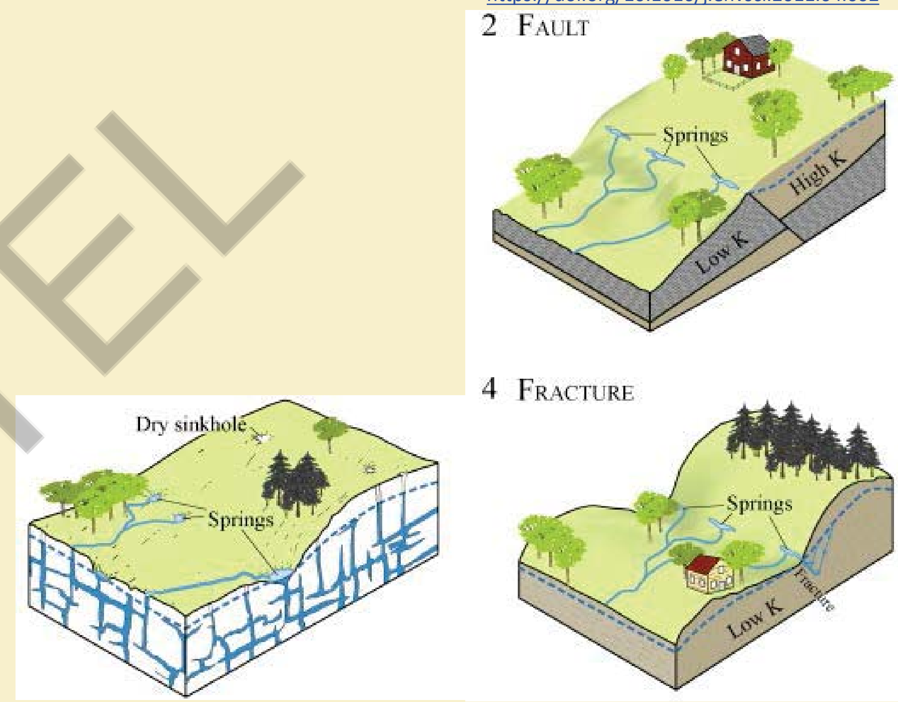
3. **Artesian spring**

   Resulted from release of water under pressure from confined aquifer either at outcrop of the aquifer or through an opening in the confining bed.

4. **Tubular or fracture spring**

   Issuing from rounded channels, such as lava tubes or solution channels or fracture in impermeable rock connecting with groundwater.

https://doi.org/10.1016/j.envsci.2011.04.002



Tubular or fracture spring

Aquifer Properties

1. **Porosity (Week1: Lecture 3 of Soil Properties-2)**
2. **Void ratio (Week1: Lecture 3 of Soil Properties-2)**
3. **Effective porosity:**
    - ✓ The portion of void space in a porous material through which fluid can flow
    - ✓ It is the portion that experiences the flow process

Aquifer type	Effective porosity
Lime stone	0-20%
Sand	25-50%
Clay	40-70%

Aquifer Properties

4. Permeability:

- ✓ Measure of media's ability to transmit fluid under a hydro potential gradient
- ✓ Approximately proportional to the square of the mean grain diameter

$$k \cong Cd^2$$

Where, k= intrinsic (specific) permeability, m^2 or darcy

C = dimension less coefficient (shape factor)

d= mean grain diameter, m

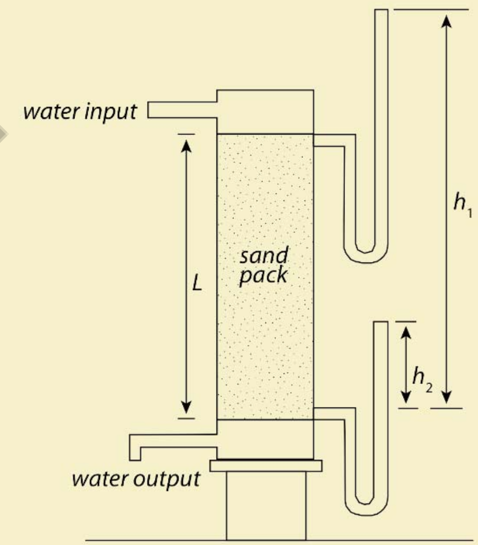
- ✓ $1\ darcy\ =\ 9.87 \times 10^{-13}$ m^2
- ✓ It is the property of soil (not water property)

Aquifer Properties

5. Hydraulic conductivity:

- ✓ Volume of water that moves through a pours medium in unit time under a unit hydraulic gradient through a unit area measured at right angle to the direction of flow.
- ✓ Property of both soil and water
- ✓ Constant of proportionality in Darcy's law

$$Q = -K\left(\frac{dh}{dl}\right)A$$



Where, Q= Discharge; $\frac{dh}{dl}$= Hydraulic gradient (i); h= Head loss; l= Length; A= Area of cross-section; K= Hydraulic conductivity

Aquifer Properties

$$K = \frac{\rho k}{\mu}$$

Where, K= hydraulic conductivity, m/d

μ= dynamic viscosity, kg/m/d

ρ= unit weight of water, kg/m^3

k= intrinsic permeability, m^2 or darcy

Aquifer type	Hydraulic conductivity (K), m/d
Clay	10^{-8}-10^{-2}
Sand	20-100
Gravel	100-1000
Sand stone	0.001-1

Thank You!!

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Irrigation and Drainage

Lecture No: 27 Aquifer Properties

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Example 27.1:

In a soil stratum, the hydraulic conductivity at the surface is 2×10^{-3} cm/s. it uniformly reduced to 4×10^{-4} cm/s at a depth of 22 m as shown in figure. If the water table is 3 m below the surface, determine the average hydraulic conductivity of the stratum.

Solution: for linear variation, the hydraulic conductivity at a height (bottom as datum) can be expressed as

$$K = 4 \times 10^{-4} + \left(\frac{2 \times 10^{-3} - 4 \times 10^{-4}}{22}\right) \times x$$

$$K = 4 \times 10^{-4} + 0.727 \times 10^{-4} \times x$$

Hydraulic conductivity is a continuous function of depth

$$\bar{K} = \frac{1}{b}\int_0^b K dx$$

$$\bar{K} = \frac{1}{19}\int_0^{19} (4 \times 10^{-4} + 0.727 \times 10^{-4} \times x)dx$$

$$\bar{K} = 10.9 \times 10^{-4} \text{ cm/s}$$

$$\boldsymbol{\bar{K} = 0.942} \textbf{ m/d (Ans.)}$$

Validity of Darcy's law:

- ✓ The Darcy law valid when head loss is directly proportional to the velocity of flow
- ✓ Darcy law valid for laminar flow
- ✓ Reynolds number (R_e) is used to measure the validity of Darcy law

$$R_e = \frac{Inertial\ force}{Viscous\ force} = \frac{\rho V L}{\mu}$$

Where, ρ= density of fluid; V= flow velocity; L= length or diameter; μ= viscosity

- ✓ Darcy law is strictly valid when R_e<1. but practically, Darcy law may be applied to flow condition that exit when R_e<10.

Example 27.2:

Check the validity of Darcy law, if the

density of water 1000 Kg/m^3

viscosity 0.004 Kg/sm^2

Diameter of pipe = 0.2 mm

Velocity = 0.0025 m/s

Solution:

✓ Reynolds number (R_e)

$$R_e = \frac{\rho V L}{\mu} = \frac{1000 \times 0.0025 \times 0.0002}{0.004}$$

$= 0.125$, Which is less than 1.

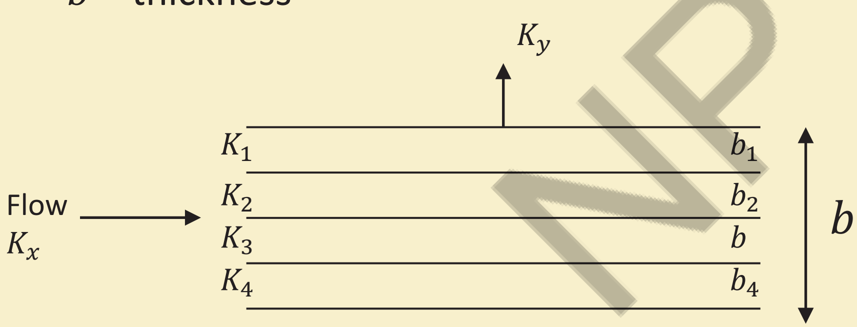
6. Transmissivity (T)

- ✓ Rate at which water is transmitted through its unit width under a unit hydraulic gradient
- ✓ Coefficient of transmissivity or transmissibility
- ✓ Characterizes the ability of aquifer to transmit the water

$$T = K \times b$$

Where, K =hydraulic conductivity

b = thickness



$$K_x = \sum_{m=1}^{n} \frac{K_m b_m}{b}$$

$$K_x = \sum_{m=1}^{n} \frac{b}{\sum_{m=1}^{n} \frac{b_m}{K_m}}$$

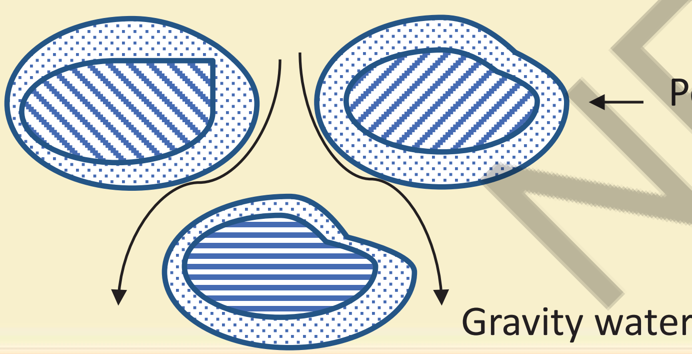
7. Specific Retention (S_r):

- ✓ Defined as the ratio of the volume of water that the soil, after being saturated, will retain against the force of gravity to its own volume.
- ✓ Specific retention also known as field capacity or water holding capacity

$$S_r = \frac{V_r}{V}$$

Where, V_r = volume of water retained mostly by molecular attraction and surface tension

V = total volume



Total pores = Pores occupied through gravity water+ field capacity

8. Specific Yield (S_y):

- ✓ Represents water yield from water bearing materials
- ✓ Specific yield is the ratio of the volume of water that (the material after being saturation) will yield by gravity to its own volume
- ✓ Specific yield also called as effective porosity

$$S_y = \frac{V_g}{V}$$

Where, V_g=volume of water drain by gravity

V= total volume

$$S_y = \eta - S_r$$

Some portion of soil water is difficult to extract, held by adhesive force and then retained.

9. Apparent Specific Yield (S_{ya}):

- ✓ Define as the ratio of the volume of water added to or removed directly from the saturated aquifer to the resulting change in volume of aquifer below the water table

$$S_{ya} = \frac{V_{ga}}{V}$$

Where, V_{ga} = volume of water removed directly from the saturated aquifer

V = total volume

$$S_y < S_{ya}$$

10. Specific storage (S_s):

Define as the volume of water that a unit volume of the aquifer releases from storage under a unit decline in hydraulic head.

$$S_s = \gamma\eta\beta(1 + \frac{\alpha}{\eta\beta})$$

Where, γ= unit weight of water ; η= porosity ; β=compressibility of water= $\frac{1}{K_w}$; K_w= bulk modulus of elasticity of water ; α= vertical compressibility of the solid = $\frac{1}{E_s}$; E_s= bulk modulus of elasticity of aquifer skeleton

$$S_S = \gamma\eta\beta + \gamma\alpha$$

Where, $\gamma\eta\beta$= storage drive from the compression of water ; $\gamma\alpha$= fraction drive from the compressibility of aquifer

It is the property of confined aquifer.

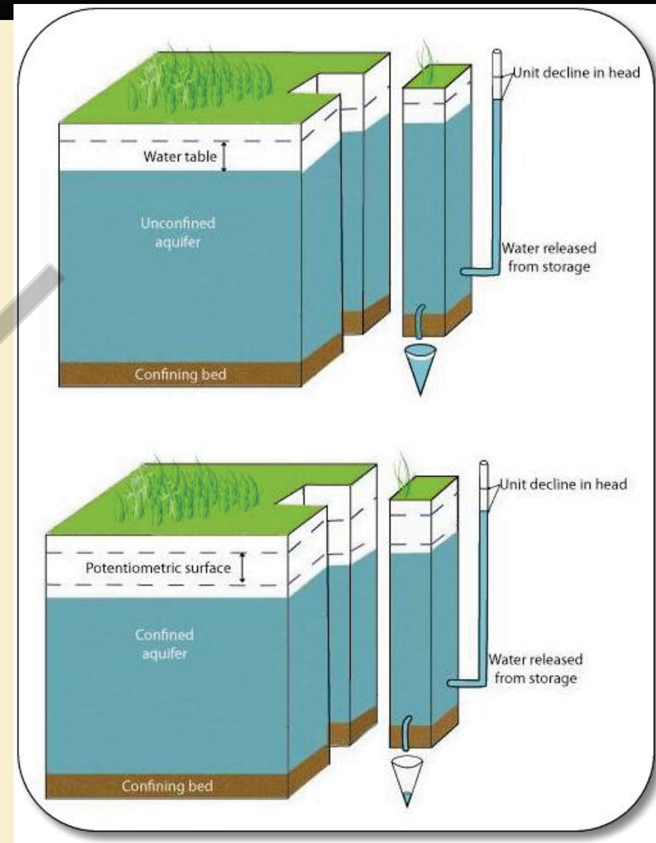
11. **Storage coefficient/**Storativity **(S_c):**

- ✓ It is also called a Volume of water release from storage per unit surface area of the aquifer per unit decline in the component of hydraulic head normal to the surface
- ✓ In a vertical column of unit area extending through the confine aquifer the S_c equals the volume of water release from the aquifer when the peizometric surface drops over a unit distance.
- ✓ The term Storativity applies to both confined and unconfined aquifer

$$S_c = S_s b$$

Where, S_s= Specific storage of the aquifer materials; b= thickness of the aquifer

- ✓ S_s varies from 10^{-5}-10^{-3} (confined aquifer) and 0.1-0.3 (Unconfined aquifer)



Example 27.3:

A confined aquifer of 40 m thickness has a porosity of 0.3. Determine the specific storage and storage coefficient. If $\alpha = 1.5 \times 10^{-9}$ cm^2/dyne and $\beta = 5 \times 10^{-10}$ cm^2/dyne.

Solution:

Given, Thickness (b)= 40 m = 4000 cm; porosity = 0.3; $\alpha = 1.5 \times 10^{-9}$ cm^2/dyne

$\beta = 5 \times 10^{-10}$ cm^2/dyne; γ= 1g/cm^3 × 980 cm/s^2 = 980 dyne/cm^3

As we know that, $S_S = \gamma\eta\beta + \gamma\alpha$; $S_S = 980\, (\frac{dyne}{cm^2}) \left\{1.5 \times 10^{-9} + 0.3 \times 5 \times 10^{-10}\, \frac{cm^2}{dyne}\right\}$

$\boldsymbol{S_S = 1.62 \times 10^{-6}}$ **per cm (Ans.)**

$S_c = S_s b$; $S_c = 1.62 \times 10^{-6} \times 4000$; $\boldsymbol{S_c = 6.47 \times 10^{-3}}$ **(Ans.)**

Example 27.4:

In an area of 120 ha, the water table dropped by 5 cm. If the porosity is 28% and specific retention is 9%, determine the specific yield of the aquifer and change in ground water storage.

Solution:

As we know that, $\eta = S_y + S_r$

$$28 = S_y + 9$$

$$S_y = 19\%$$

$$Change\ in\ ground\ water\ storage\ = area\ of\ aquifer \times drop\ in\ ground\ water \times S_y$$

$$Change\ in\ ground\ water\ storage\ = 120 \times 5 \times 0.19$$

$$= 114 \text{ ha-m}$$

$$= \mathbf{114 \times 10^4}\ \textbf{m}^3\ \textbf{(Ans.)}$$

Example 27.5:

A phreatic aquifer, extending over an area of 220 km^2, has a Storativity of 0.15. Estimate the amount of water lost from storage if the water level fall 0.16 m during drought.

Solution:

Given,

Area 220 km^2

Storativity = 0.15

water level fall = 0.16

$$Volume\ of\ water\ lost\ = Storativity \times area \times drop\ in\ water\ level$$

$$= 0.15 \times 220 \times 10^6 \times 0.16$$

$$= \mathbf{5.28 \times 10^6}\ \mathbf{m^3\ (Ans.)}$$

Example 27.6:

In an area 1 km^2 in extent, the initial water table was at a depth of 25 m below the ground surface. After applying an irrigation, the water rose to a depth of 24 m. letter on, an amount of 3×10^5 m^3 ground water was pumped out resulting in drop in water table by 2.2 m. Find out the specific yield of the aquifer and the volume of recharge during irrigation.

Solution:

$$Volume\ of\ water\ drained\ in\ lowering\ water\ table\ by\ 2.2\ m\ =\ area \times 2.2$$

$$= 1 \times 10^6 \times 2.2$$

$$= 2.2\ \text{mm}^3$$

$$Specific\ yield = \frac{volume\ of\ water\ pumped}{volume\ of\ aquifer\ drained} = \frac{3 \times 10^5}{2.2 \times 10^6} = 0.136$$

$$Volume\ of\ recharge = Area\ of\ aquifer \times rise\ in\ water\ table \times specific\ yield$$

$$= \mathbf{1 \times 10^6 \times 1 \times 0.136 = 136000}\ \boldsymbol{m^3}\ \textbf{(Ans.)}$$

12. Hydraulic resistance (semi confined aquifer):

- ✓ It is a reciprocal of leakage factor or resistance against vertical flow
- ✓ Property of semi-permeable layer of the semi-confines aquifer

$$C = \frac{B^2}{Kb}$$

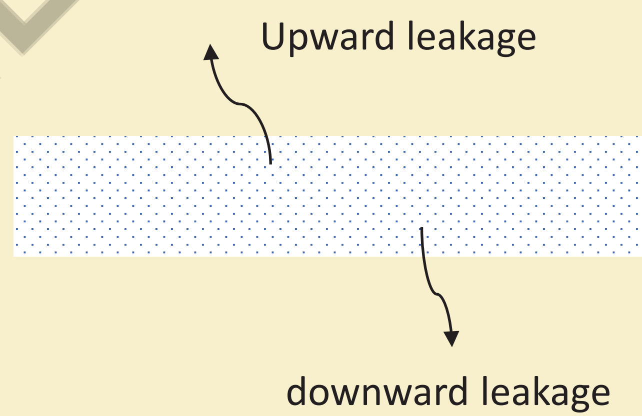
Where, C= *hydraulic resistance, days*

B= leakage factor, m

K= hydraulic conductivity, m/d

b= thickness of confined aquifer

- ✓ The hydraulic resistance is varying from 10^2-10^6 min



13. Leakage factor (B):

- ✓ Determines distribution of leakage into or from the semi-pervious layer
- ✓ High value indicates grater resistance of semi pervious strata

$$B = \sqrt{KbC}$$

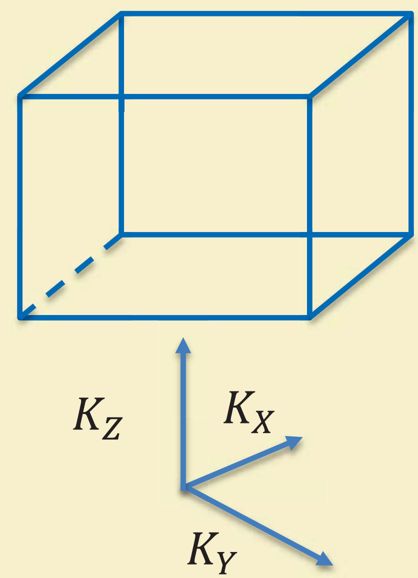
Where, K= hydraulic conductivity, m/d

b= thickness of confined aquifer

C= hydraulic resistance

14. Isotropy and homogeneity

- ✓ If aquifer properties are independent of the direction – isotropic
- ✓ If all properties of the aquifer are constant or independent of its location-homogeneous
- ✓ Homogeneous depends on location
- ✓ Isotropic depends on time
- ✓ K_X, K_Y, K_Z are same



15. Anisotropic and heterogeneity

- ✓ If its properties are dependent on the direction – isotropic
- ✓ If all properties of the aquifer depend on location-heterogeneity
- ✓ K_X, K_Y, K_Z are not same

Thank You!!

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Irrigation and Drainage

Lecture No: 28 Well Hydraulics

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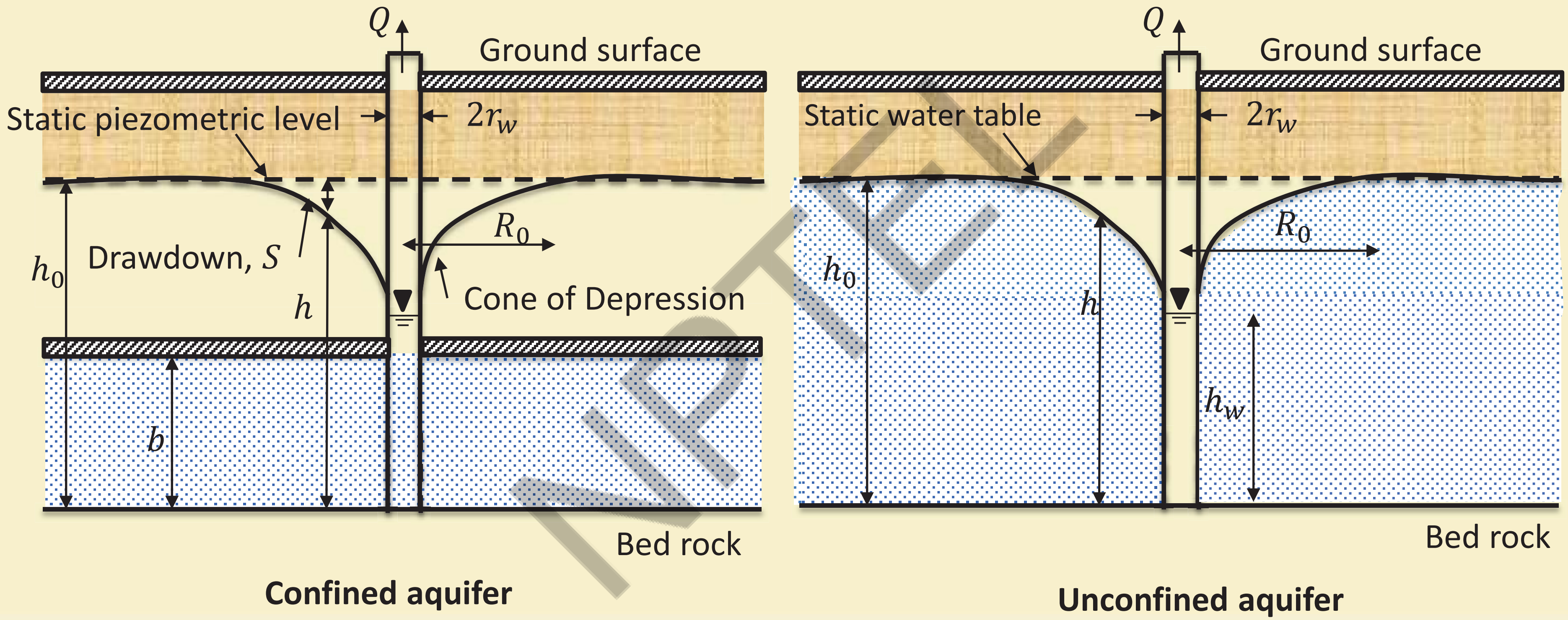
Drawdown pattern



Important Definitions

1. **Static water level:**
   - ✓ The level at which the water stands in a well before pumping starts
     - o Water table in phreatic wells
   - ✓ The pressure at static water level is atmospheric
   - ✓ Expressed as the vertical distance from the ground surface to water level in the well
   - ✓ Static water level for artesian wells is above water table
2. **Piezometric surface:**
   - ✓ Height at which water will stand in a piezometer or pipe open to atmosphere and extent to the confine aquifer

$\textit{The rise of water in the pipe } (h) = \frac{P}{w}$; P= pressure at the bottom; w= unit weight of water

Important Definitions

3. Pumping water level:

- ✓ Level of water in the well when pumps at any given rate
- ✓ This is variable and changes with pumping rate (dynamic water level)

4. Drawdown:

- ✓ Difference between static water level and the pumping water level

Limit of drawdown:

- o Tube casing in the boundary point of drawdown

5. Area of influence:

- ✓ The area which gets affected by the pumping of the well is called area of influence
- ✓ The boundary is called circle of influence

Important Definitions

6. **Well yield:**
   - ✓ Volume of water discharge from it per unit time (L/s)
7. **Specific capacity of a well:**
   - ✓ Yield per unit drawdown (L/m-sec)
8. **Open wells:**
   - ✓ Dug wells to water bearing formation
   - ✓ Drive water from formation close to the surface
   - ✓ Large diameter of open well permits storage of large quantity (dia.: 1.2-1.5 m)

Important Definitions

9. Semi confined aquifer properties:

- ✓ Hydraulic resistance (property of semi confined layer):
- ✓ Characterizes the resistance of the semi pervious layer to upward or downward leakage

$$C = \frac{B^2}{Kb}$$

Where, C= hydraulic resistance, days

B=leakage factor , m

K= Hydraulic conductivity, m/day

b= thickness of semiconfined aquifer (stratum between impervious and semi pervious layers), m

$$C \rightarrow \infty, K \rightarrow 0 \text{ (impervious)}$$

$$C \rightarrow 0, K \rightarrow \infty \text{ (Aquifer)}$$

Important Definitions

10. Leakage factor:

- ✓ It determine the distribution of leakage into or from the semi pervious layer

$$B = \sqrt{Kbc}$$

$$c = \frac{D'}{K'}$$

Where, K= hydraulic conductivity

b= thickness of aquifer

D'= saturated thickness of aquitard

K'= hydraulic conductivity of aquifer

- ✓ B is determined by pumping test
- ✓ High value of B indicate the greater resistance of the semi pervious strata and flow

Important Definitions

11. Tube wells:

- ✓ Tube wells are constructed by pushing a pipe below the ground surface and pashing through different geological formation consist of water bearing and non water bearing strata
  - o **Blind pipe** is located in non water bearing strata
  - o **Perforated pipes or well screen** is placed in to the aquifer (10-20 cm diameter)

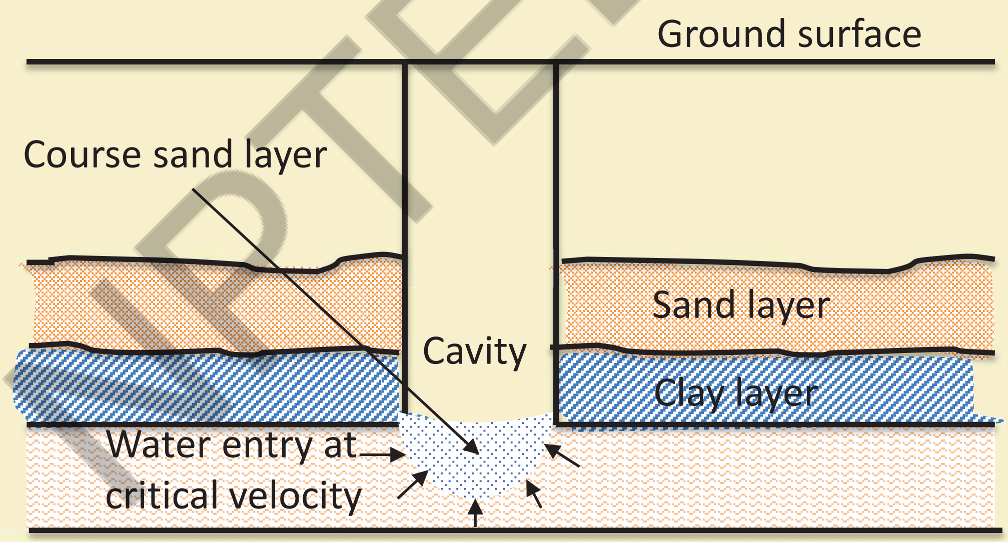
12. Filter points:

- ✓ Popular in deltaic region
- ✓ Pipe consist of screen at shallow depth

Important Definitions

13. Cavity well:

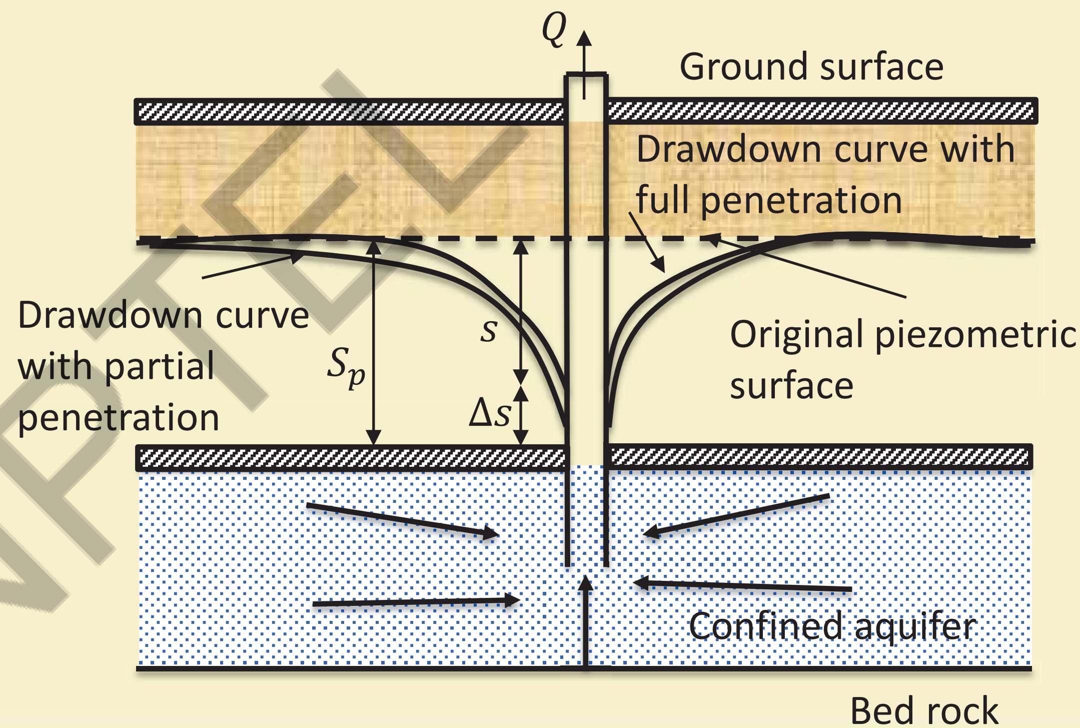
- ✓ The tube well penetrates through confined aquifer and does not consist of screen
- ✓ The water penetrate only through bottom opening



Important Definitions

14. Partial penetrating well:

- ✓ A well having screen length less than the aquifer thickness known as penetrating well
- ✓ The flow is three dimension because of vertical flow components near the well

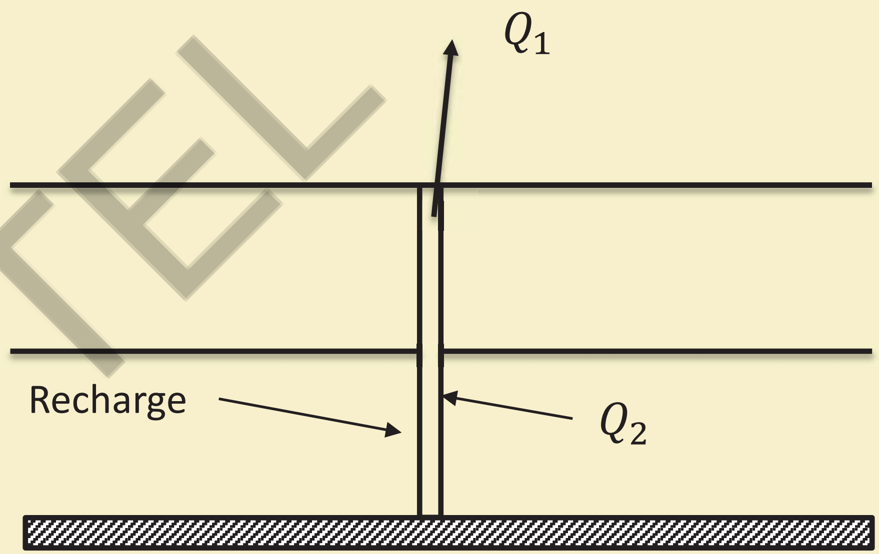


Steady State Radial Flow to Well

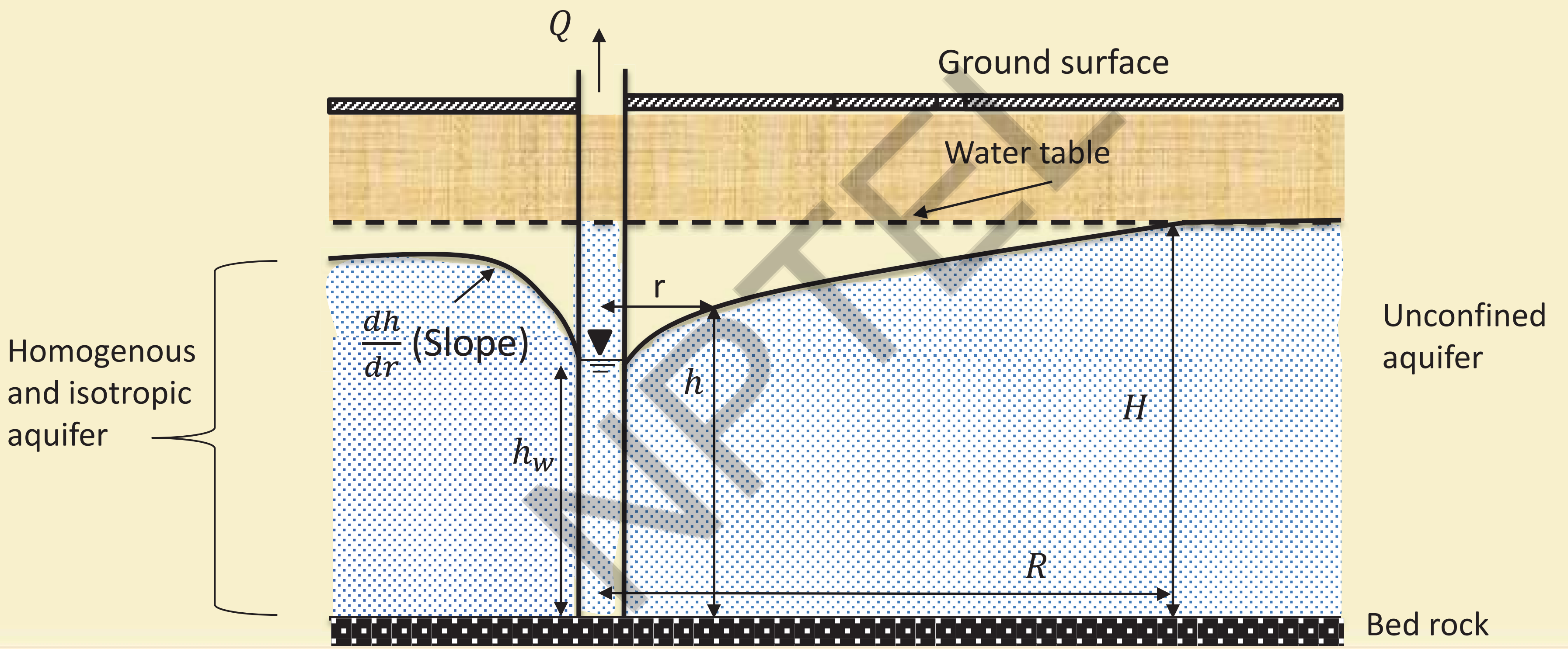
The flow is steady when the flow velocity at any single point in the system do not change over time

$$\frac{dv}{dt} = 0$$

Occurs when $Q_1 \cong Q_2$



Steady State Flow to Well in Unconfined Aquifer



Steady State Flow to Well in Unconfined Aquifer

Assumptions:

1. Flow is horizontal and penetrate the well radially
2. The well is pumped at a constant rate
3. The Dupuit-Forchheimer assumptions are valid

Using the Darcy's law

$$Q = Kia$$

$$Q = 2\pi rhK\frac{dh}{dr}$$

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

Steady State Flow to Well in Unconfined Aquifer

$$\int h\,dh = \int \frac{Q}{2\pi K}\frac{dr}{r}$$

Boundary condition: $h = h_w$ at $r = r_w$

$h = H$ at $r = R$

$$\int_{h_w}^{H} h\,dh = \frac{Q}{2\pi K}\int_{r_w}^{R}\frac{dr}{r}$$

$$\frac{H^2}{2} - \frac{h_w^2}{2} = \frac{Q}{2\pi K}\ln\left(\frac{R}{r_w}\right)$$

$$Q = \frac{\pi K (H + h_w)\,(H - h_w)}{\ln\left(\frac{R}{r_w}\right)}$$

Steady State Flow to Well in Unconfined Aquifer

$$Q = \frac{\pi K (H + h_w)\,(H - h_w)}{\ln\left(\frac{R}{r_w}\right)}$$

Where,

Q= Discharge, m^3/s

K= hydraulic conductivity, m/s

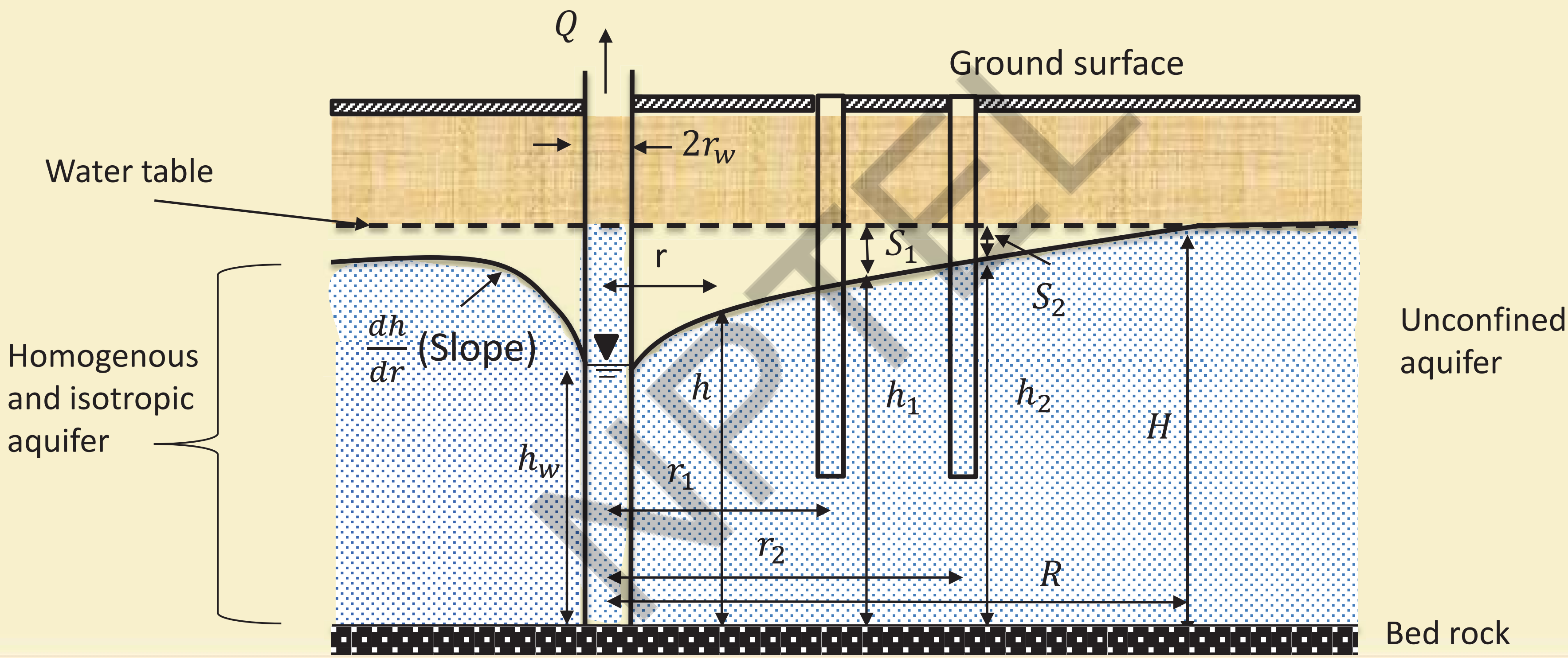
H= optimum water level in well, m

h_w= pumping water level, m

R= radius of influence, m

r_w= radius of well, m

Estimation of K and T of the aquifer



Estimation of K and T of the aquifer

Assume that there are two observation well installed at a distance r_1 and r_2 from well. The drawdown are S_1 and S_2

$$h = H - S$$

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

Or

$$Q = \frac{\pi K ((H - S_2)^2 - (H - S_1)^2)}{\ln\left(\frac{r_2}{r_1}\right)}$$

Estimation of K and T of the aquifer

$$Q = \frac{\pi K((H - S_2)^2 - (H - S_1)^2)}{\ln\left(\frac{r_2}{r_1}\right)} \times \frac{2H}{2H}$$

$$Q = \frac{2H\pi K\left(\frac{H}{2} - S_2' - \frac{H}{2} - S_1'\right)}{\ln\left(\frac{r_2}{r_1}\right)}$$

$$Q = \frac{2\pi T\,(S_1' - S_2')}{\ln\left(\frac{r_2}{r_1}\right)}$$

Where, T= transmissibility (m²/s) = KH

$$\frac{(H - S_2)^2}{2H} = \frac{H^2 + S_2^2 - 2HS_2}{2H}$$

$$= \frac{H}{2} - (S_2 + \frac{S_2^2}{2H})$$

$$= \frac{H}{2} - S_2^1$$

where, $S_2' = S_2 + \frac{S_2^2}{2H}$

Estimation of K and T of the aquifer

$$Q = \frac{2\pi T\ (S_1' - S_2')}{\ln\left(\frac{r_2}{r_1}\right)}$$

$$T = \frac{Q\ln\left(\frac{r_2}{r_1}\right)}{2\pi\ (S_1' - S_2')}$$

The value of T and K can be estimated by observed wells.

Example 28.1:

A 25 cm diameter well in an unconfined aquifer is pumped at a uniform rate of 3000 l/min. The drawdown observed at 1m and 100 m distance from the center of the well are 8 m and 0.4 m, respectively. Assuming the thickness of the saturated part of aquifer is 25m .

Solution:

$$Discharge\ (Q) = 3\ \mathrm{m^3/min}$$

$$r_1 = 1\ \mathrm{m}$$

$$r_2 = 100\ \mathrm{m}$$

$$h_1 = H - s_1 = 25 - 8 = 17\ m$$

$$h_2 = H - s_2 = 25 - 0.4 = 24.6\ m$$

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

$$K = \frac{Q}{\pi\,(h_1^2 - h_2^2)} \ln \frac{r_2}{r_1} \quad = \frac{3}{\pi\,(24.6^2 - 17^2)} \ln \frac{100}{1}$$

$$K = \frac{3}{\pi\,(605.16 - 289)} \times 4.605$$

$$\boldsymbol{K = 0.0139}\ \textbf{m/min}$$

$$T = K \times H$$

$$T = 0.0139 \times 25$$

$$\boldsymbol{T = 0.3475}\ \textbf{m}^2\textbf{/min (Ans.)}$$

Thank You!!

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Irrigation and Drainage

Lecture No: 29 Well Hydraulics

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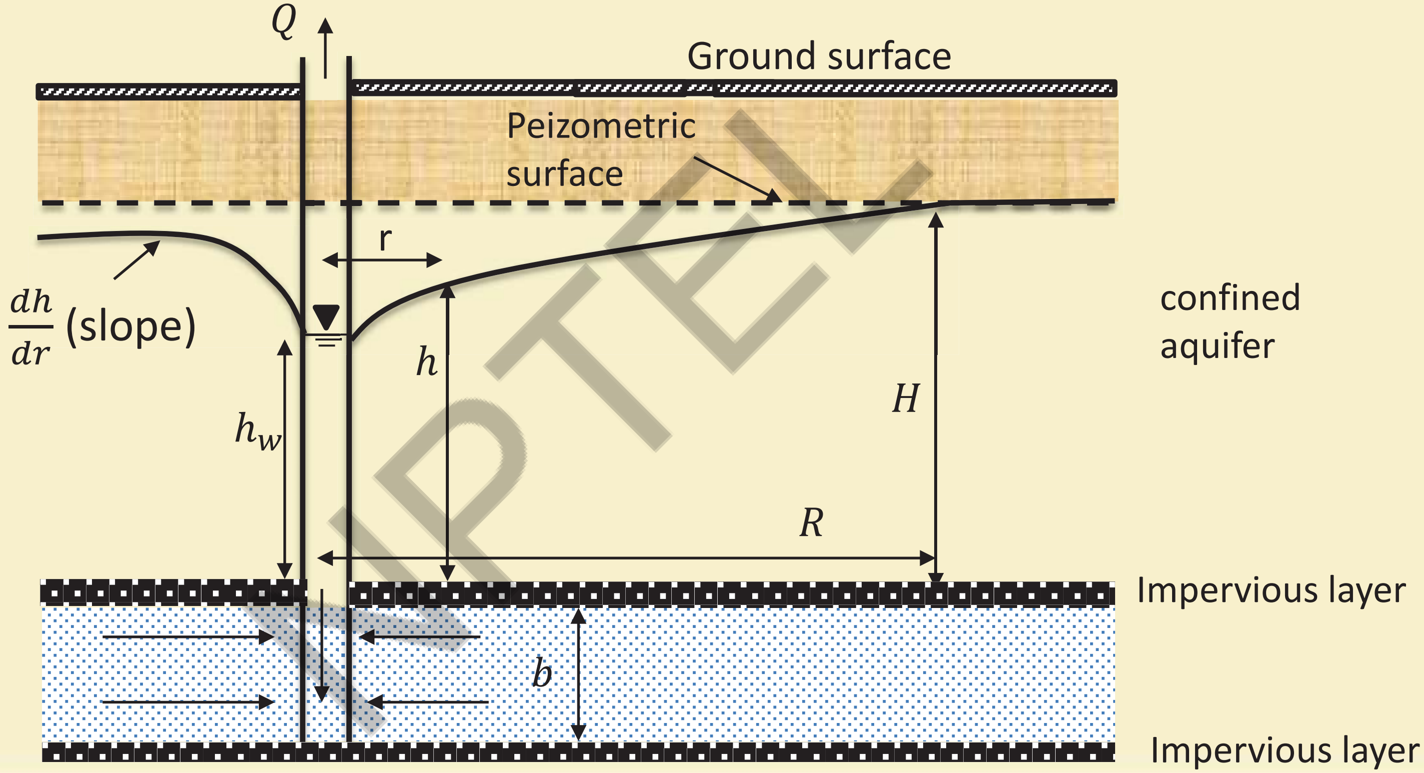
Steady State Flow to Wells in Confined Aquifer



Steady State Flow to Wells in Confined Aquifer

Assumption:

1. Aquifer is homogeneous and isotropic and having a uniform thickness
2. Pumped well penetrate entire thickness of aquifer
3. Flow of well is in steady state
4. Top and bottom aquifer bounded by bed rock or impervious layer
5. The well is pumped at constant rate
6. Aquifer is seemingly infinite areal extent

Using the Darcy's law

$$Q = Kia; \qquad Q = 2\pi rbK\frac{dh}{dr}$$

Steady State Flow to Wells in Confined Aquifer

$$dh = \frac{Q}{2\pi bK}\frac{dr}{r}$$

$$\int dh = \int \frac{Q}{2\pi bK}\frac{dr}{r}$$

Boundary conditions: $h = h_w$ at $r = r_w$

$h = H$ at $r = R$

$$\int_{h_w}^{H} dh = \frac{Q}{2\pi bK}\int_{r_w}^{R}\frac{dr}{r}$$

$$H - h_w = \frac{Q}{2\pi Kb}\ln\left(\frac{R}{r_w}\right)$$

Steady State Flow to Wells in Confined Aquifer

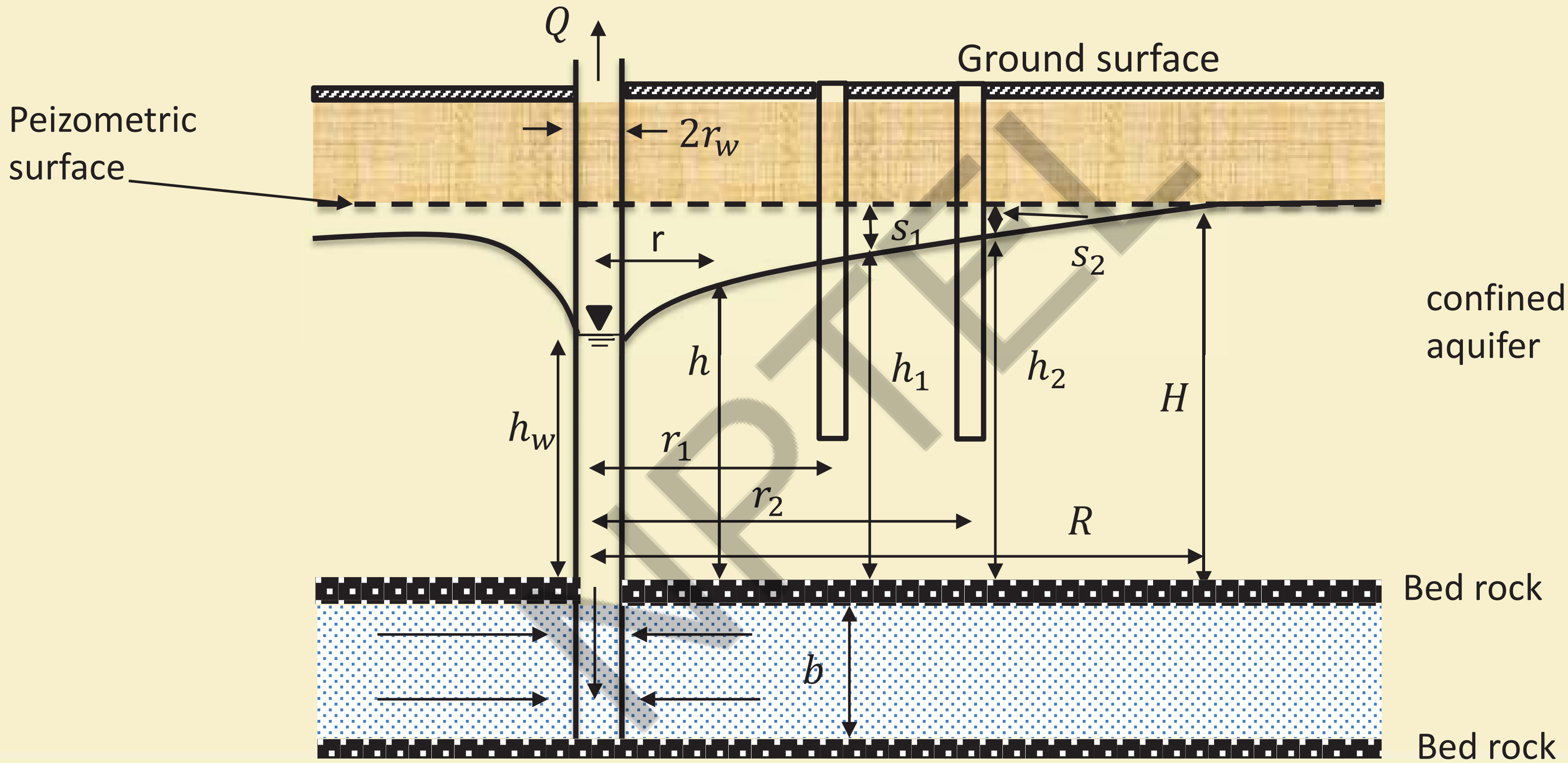
$$Q = \frac{2\pi K b\,(H - h_w)}{\ln\left(\frac{R}{r_w}\right)}$$

The equation also called as **Dupuit and Thiem** equation

Where, Q = Discharge, m^3/s; K = hydraulic conductivity, m/s; b = thickness of confined aquifer, m

h_w= pumping water level, m; R= radius of influence, m; r_w= radius of well, m

Estimation of K and T of the Confined Aquifer



Estimation of K and T of the Confined Aquifer

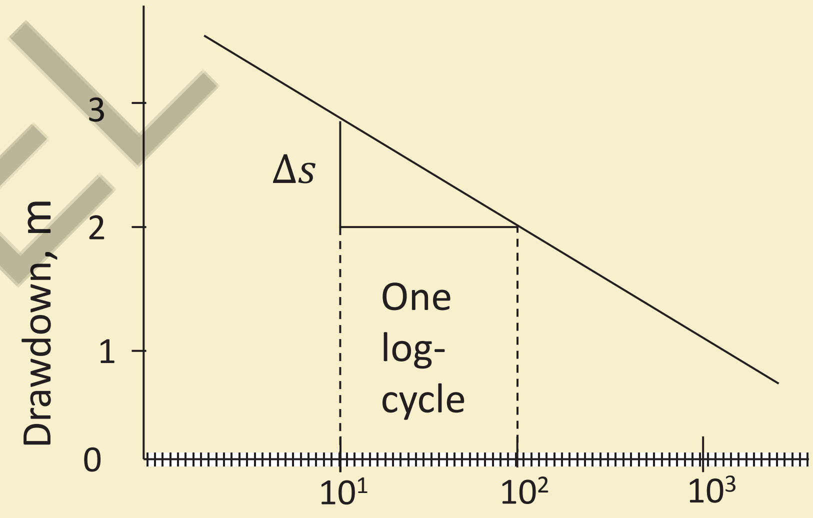
Assume that there are two observation wells installed at a distance r_1 and r_2 from the well.

The drawdown are s_1 and s_2

$$\ln\left(\frac{r_2}{r_1}\right) \text{ for the log cycle} = 2.30$$

$$Q = \frac{2\pi K b\ (H - h_w)}{\ln\left(\frac{r_2}{r_1}\right)}; \qquad = \frac{2\pi T\ \Delta S}{2.3}$$

Knowing Q and ΔS from the graph, Then K and T can be estimated



Distance from the center of the well, m; Log-scale

Example 29.1:

A 10 cm diameter well penetrates a 10 m thick confined aquifer. The steady state drawdown were found to be 2.5 and 0.05 m at distance of 10 m and 40 m, respectively from the center of the well. When the well was operated with a constant discharge rate of 125 l/min for 12 h. Using the Dupuit-Thiem equation, calculate the transmissibility and hydraulic conductivity.

Solution:

$Q = 125 = 0.125$ m³/min

r_1=10 m

r_2= 40 m

$s_1 = 2.5$ m

$s_2 = 0.05$ m

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

$$T = \frac{0.125 \times \ln \frac{40}{10}}{2\pi\,(2.5 - 0.05)}$$

$$T = \frac{0.125 \times 1.386}{15.392}$$

$$\boldsymbol{T = 0.0113\ \mathrm{m^2/min}}$$

$$T = K \times b$$

$$0.0113 = K \times 10$$

$$K = \frac{0.0113}{10}$$

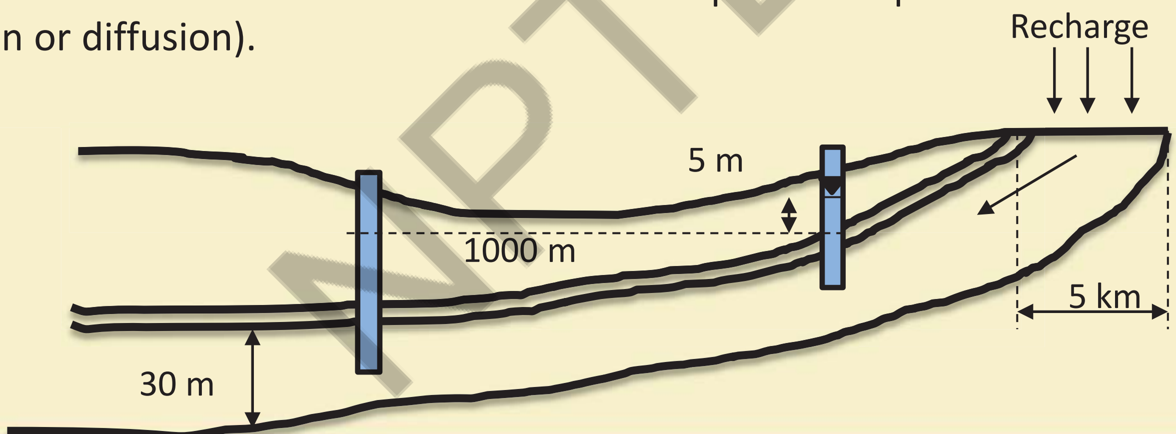
$$\boldsymbol{K = 0.00113\ \mathrm{m/min}}\ \textbf{(Ans.)}$$

Example 29.2:

A confined aquifer has a source of recharge as shown in figure. The hydraulic conductivity of the aquifer is 50 m/d and its porosity is 0.2. the piezometric head in two wells 1000 m apart is 55 m and 50 m, respectively, from a common datum. The average thickness of the aquifer is 30 m and the average width is 5 km.

a. Determine the rate of flow through the aquifer

b. Determine the time of travel from the head of the aquifer to a point 4 km down stream (assume no depression or diffusion).



Solution:

$Area\ of\ the\ cross\ section\ of\ flow\ =$
$30\ m \times 5\ km = 15 \times 10^4\ \text{m}^2$

$$Hydraulic\ gradient\ (i) = \frac{(h_1 - h_2)}{L}$$

$$= \frac{55 - 50}{1000}$$

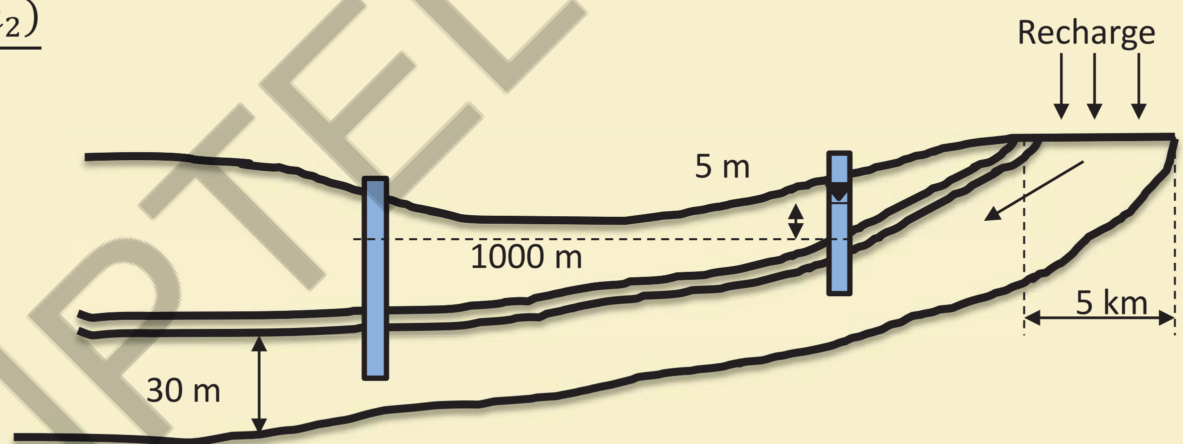
$$= 5 \times 10^{-3}$$

$$Rate\ of\ flow\ (Q) = KiA$$

$$Q = 50 \times 15 \times 10^4 \times 5 \times 10^{-3}$$

$$= 37500\ \text{m}^3/\text{d}$$

$$Dacy's\ velcity\ (V) = \frac{Q}{A}$$



$$V = \frac{37500}{15 \times 10^{-4}}$$

$$= \mathbf{0.25\ m/d}$$

$$Seepage\ velocity\ (V_v) = \frac{V}{n}$$

$$= \frac{0.25}{0.2}$$

$$= \mathbf{1.25\ m/d}$$

$$Time\ to\ travel\ 4\ Km\ down\ steam\ t = \frac{4000}{1.25}$$

$$= 3200\ \text{days}$$

$$= \mathbf{8.77\ years\ (Ans.)}$$

Example: 29.3: Theim Equation

- 1-m diameter well
- $Q = 113\ m^3/hr$
- $b = 30\ m$
- $h_0 = 40\ m$
- Two observation wells,

  $h_1 = 38.2\ m$ (@ $r_1 = 15\ m$)

  $h_2 = 39.5\ m$ (@ $r_2 = 50\ m$)
- Find: Head (h_w) and drawdown (s_w) in the well

Solution:

$$T = \frac{Q}{2\pi\ (S_1 - S_2)} \ln \frac{r_2}{r_1}$$

$$T = \frac{113}{2\pi\,(1.8 - 0.5)} \ln \frac{50}{15}$$

$$\boldsymbol{T = 16.66\ m^2/h}$$

Since $\boldsymbol{h = h_0 + \frac{Q}{2\pi T} \ln \frac{r}{R}}$ then

$$h_w = h_2 + \frac{Q}{2\pi T} \ln \frac{r_w}{r_2}$$

$$h_w = 39.5 + \frac{113}{2\pi \times 16.66} \ln \frac{0.5}{50}$$

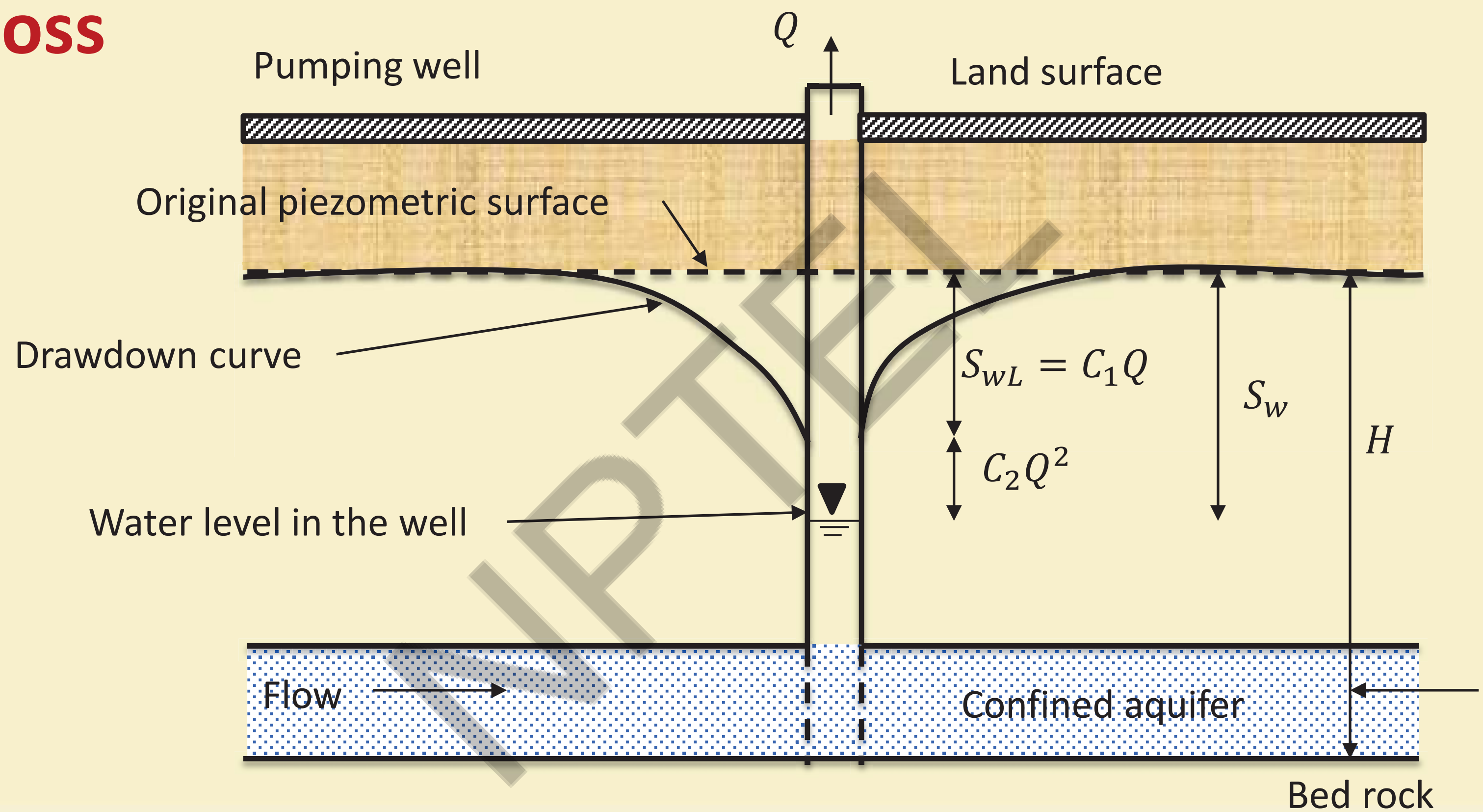
$$\boldsymbol{h_w = 34.5\ \mathrm{m}}$$

$$s_w = h_0 - h_w$$

$$s_w = 40 - 34.5$$

$$\boldsymbol{s_w = 5.5\ \mathrm{m}\ \text{(Ans.)}}$$

Well loss



Q
Pumping well
Land surface
Original piezometric surface
Drawdown curve
$S_{wL} = C_1 Q$
S_w
H
$C_2 Q^2$
Water level in the well
Flow
Confined aquifer
Bed rock

Well loss

In a pumping artesian well, the total draw-down at the well S_w can be considered to be made up of three parts

1. Head loss require to cause laminar porous media flow called formation (aquifer) loss, S_{wL}
2. Drop of piezometric head required to sustain turbulent flow in the region nearest to the well where the Reynolds number may be larger than unity, S_{wt}
3. Head loss through the well screen and casing, S_{wc}

$$S_{wL} \propto Q \text{ and } (S_{wt}\ and\ S_{wc}) \propto Q^2$$

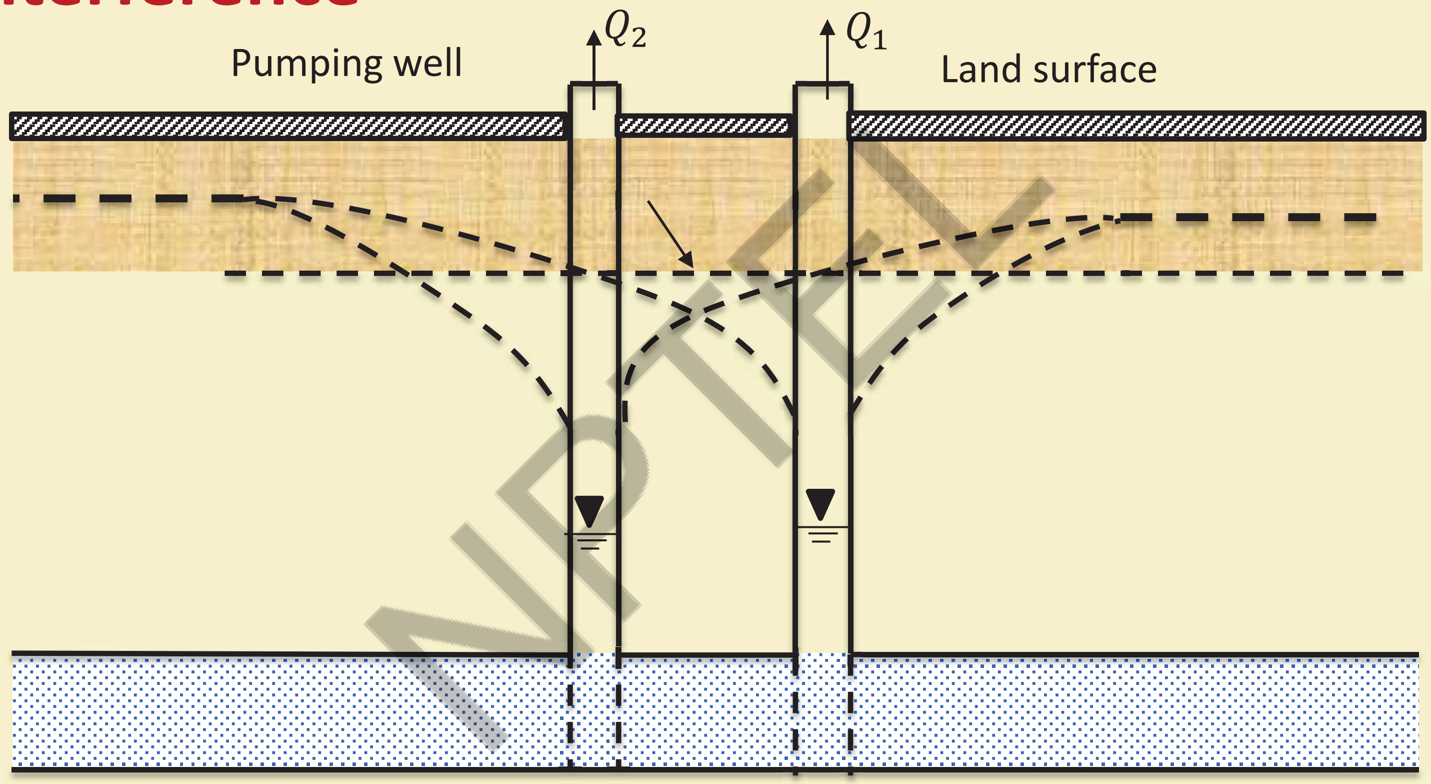
$$S_w = C_1 Q + C_2 Q^2$$

Where, $C_1\ and\ C_2$ = constant

$C_1 Q$= formation (aquifer) loss

$C_2 Q^2$ = well loss

Well Interference



Thank You!!

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Irrigation and Drainage

Lecture No: 30 **Tutorial: W6**

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Example W6.1:

Thickness of capillary zone above the water table varies __________

(Ans. Inversely with the pore-size of soil) **(GATE 2017)**

Example W6.2:

A cavity well is a tube well which has ________

(Ans. no strainer or a blind pipe) **(GATE 2017)**

Example W6.3:

The sum of 'specific yield' and 'specific retention' for an unconsolidated geologic formation is equal to its _______

(Ans. Total porosity) **(GATE 2017)**

Example W6.4:

Dupuit-Forchheimer assumptions are used for analyzing groundwater flow in ____________

(Ans. unconfined aquifers) **(GATE 2015)**

Example W6.5:

Capillary water is held in the soil due to _____________

(Ans. Surface tension force) **(GATE 2011)**

Example W6.6:

A watershed of 100 km^2 is underlain by an unconfined aquifer having hydraulic conductivity of 15 m/day and specific yield of 0.20. If 30 million m^3 of water is pumped from this aquifer through uniformly distributed wells, the average drop of water table over the watershed in meters will be __________

(GATE 2017)

Solution:

Given, A= 100 km^2

Q= 30 million m^3

specific yield = 0.20

Change in ground water storage = Area of the aquifer × Drop in water table × Specific yield

$30\times10^6 = 100\times10^6 \times$ Drop in water table × 0.2

Drop in water table= 1.5 m (Ans.)

Example W6.7:

A fully penetrating tube well in a 30 m deep confined aquifer with hydraulic conductivity of 4×10^{-4} m/s has 50 L/s discharge. The drawdown and radius of influence are 5 m and 250 m, respectively. Diameter of the tube well in mm is ____________ **(GATE 2016)**

Solution:

Given, b=30 m; $K=4\times10^{-4}$ m/s

Q= 50 l/s = 0.05 m^3/s

R= 250 m

S= 5 m

$$Q = \frac{2\pi Kb\,(H - hw)}{\ln\left(\frac{R}{r_w}\right)} = \frac{2\pi Kb\,s}{\ln\left(\frac{R}{r_w}\right)}$$

$$0.05 = \frac{2\pi \times 4 \times 10^{-4} \times 30 \times 5}{\ln\left(\frac{250}{r_w}\right)}$$

$$\ln\left(\frac{250}{r_w}\right) = \frac{2\pi \times 4 \times 10^{-4} \times 30 \times 5}{0.05}$$

$$\ln\left(\frac{250}{r_w}\right) = 7.539$$

$$r_w = 0.133 \text{ m}$$

$$r_w = 133 \text{ mm}$$

Diameter of the tube well = 266 mm (Ans.)

Example W6.7:

An unconfined aquifer covering an area of 50 ha has a hydraulic conductivity of 20 m day^{-1} and specific yield of 12%. After a significant rainfall event, the water table rises from 17 m to 14.5 m below the ground level. Assuming no abstraction and outflow of groundwater during the recharge period, the amount of groundwater recharge contributed by the rainfall in m^3 is ___ **(GATE 2015)**

Solution:

Given, Area= 50 ha

specific yield = 12%

Change in ground water storage = Area of the aquifer × Drop in water table × Specific yield

= 50×10000× (17-14.5) × 0.12

Change in ground water storage due to rainfall **= 150000 m^3 (Ans.)**

Example W6.8:

In a falling head permeameter test, the initial head is 0.30 m. the head drops to 0.10 m in 40 min. The permeability of a soil sample, 0.06 m high and 50×10^{-4} m^2 in cross-section area, is found to be 1×10^{-6} m/s. The size of the stand pipe in m^2 is **(GATE 2011)**

Solution:

Given,

h_1 =0.3 m ; h_2= 0.1 m ; t=40 min= 2400 sec ; L=0.06 m; A=50×10^{-4} m^2; K=1×10^{-6} m/s

$$K = \frac{aL}{A\,\Delta t}\ln\left(\frac{h_1}{h_2}\right)$$

$$1\times10^{-6} = \frac{a\times0.06}{50\times10^{-4}\times2400}\times\ln\frac{0.3}{0.1}; \qquad = a\times5\times10^{-3}\times1.0986$$

$$\boldsymbol{a = 1.82\times10^{-4}}\ \textbf{m}^2\ \textbf{(Ans.)}$$

Example W6.9:

An unconfined aquifer is pumped at a constant rate of 10 L/s . Steady state drawdowns measured at radial distances of 30 m and 60 m are 0.80 m and 0.70 m, respectively. Original thickness of aquifer is 30 m. Transmissibility of the aquifer is ______ **(GATE 2007)**

Solution:

Given,

$$Q = 10\ L/s = 864\ \mathrm{m^3/d}$$

$$T = \frac{Q \ln\left(\frac{r_2}{r_1}\right)}{2\pi\,(s_1' - s_2')}; \qquad s_1' = (s_1 - s_1^2/2H)$$

$$T = \frac{864 \times \ln\left(\frac{60}{30}\right)}{2\pi\,(0.789 - 0.692)}$$

$$\boldsymbol{T = 982.29\ \mathrm{m^2/d}}\ \textbf{(Ans.)}$$

Thank You!!