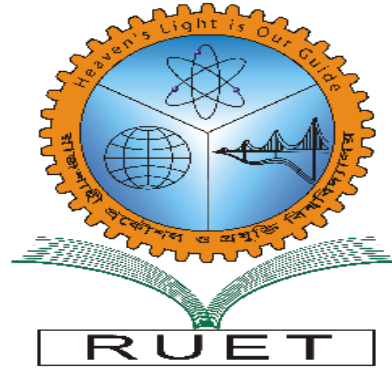


*Heaven's Light is Our Guide*



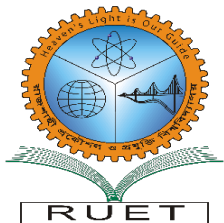
**Rajshahi University of Engineering & Technology**

**Mithun Chakrabarty**

**Lecturer**

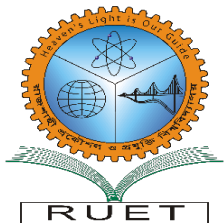
**Department of Civil Engineering**

- ❖ Course code: CE 3221
- ❖ Course Title: Hydrology
- ❖ Credit: 3.00
- ❖ Contact hours/week: 3.00



# Book List:

1. **A Text Book of Hydrology-** [P. Jaya Rami Reddy](#)
2. **Hydrology-** [H.M. Raghunath](#)
3. **Engineering Hydrology, 3E-** [K Subramanya](#)
4. **Ground Water, 2Edition-** [H. M. Raghunath](#)



# SYLLABUS:

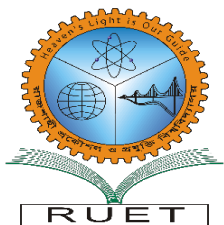
## #part 1: Introduction:

Hydrologic cycle, meteorological aspects of Hydrology, precipitation, water losses, interception, evaporation, transpiration and infiltration.

Run off: Factors affecting run off, estimation of run off, **stream flow**, **stream flow hydrograph**, **overland flow**, **flood rating**, **statistical methods in hydrology**.

## #part 2: Ground water:

Introduction, aquifer properties and ground water flow, well hydraulics, quality of ground water, ground water recharge, design, drilling and construction of water wells.

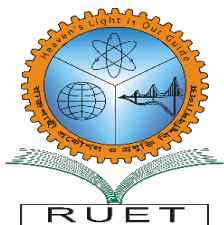


# Hydrology:

New Latin *hydrologia*, from Latin *hydro-* + *-logia* -logy

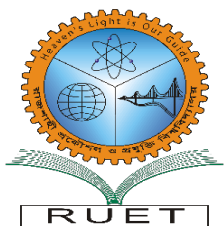
-A science dealing with the **properties, distribution, and circulation** of water on and below the earth's surface and in the atmosphere.

-Hydrology is the science that encompasses the **occurrence, distribution, movement and properties** of the waters of the earth and their relationship with the environment within each phase of the hydrologic cycle.

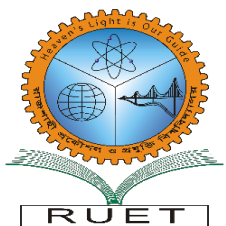


# What Hydrologists Do?

1. Hydrologists apply **scientific knowledge and mathematical principles** to solve water-related problems in society: problems of **quantity, quality and availability**.
2. They may be concerned with **finding water supplies** for cities or irrigated farms, or controlling river flooding or soil erosion. Or, they may work in **environmental protection**: preventing or cleaning up pollution or locating sites for safe disposal of hazardous wastes.
3. Persons trained in hydrology may have a **wide variety of job titles**. Scientists and engineers in hydrology may be involved in both **field investigations and office work**. In the field, they may **collect basic data, oversee testing of water quality, direct field crews and work with equipment**. Many jobs require travel, some abroad.

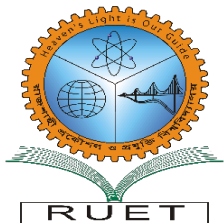


4. In the office, hydrologists do many things such as **interpreting hydrologic data and performing analyses** for determining possible water supplies.
5. Much of their work relies on **computers for organizing, summarizing and analyzing masses of data, and for modeling studies** such as the prediction of flooding and the consequences of reservoir releases or the effect of leaking underground oil storage tanks.
6. The work of hydrologists is as varied as the uses of water and may range from planning multimillion dollar interstate water projects to advising homeowners about backyard drainage problems.

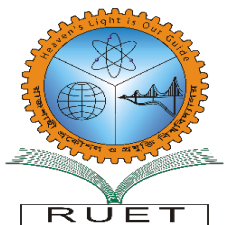


# Careers in Hydrology

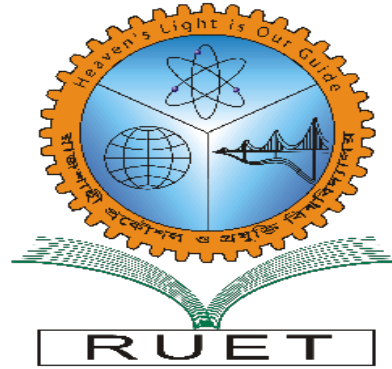
1. Students who plan to become hydrologists need a strong emphasis in **mathematics, statistics, geology, physics, computer science, chemistry and biology.**
2. In addition, sufficient background in other subjects--economics, public finance, environmental law, government policy--is needed to communicate with experts in these fields and to understand the implications of their work on hydrology.



Thank You  
For  
Your Kind Attention



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**Rajshahi University of Engineering & Technology**

**Mithun Chakrabarty**

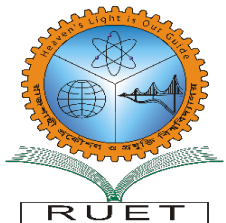
**Lecturer**

**Department of Civil Engineering**

# Lecture-01

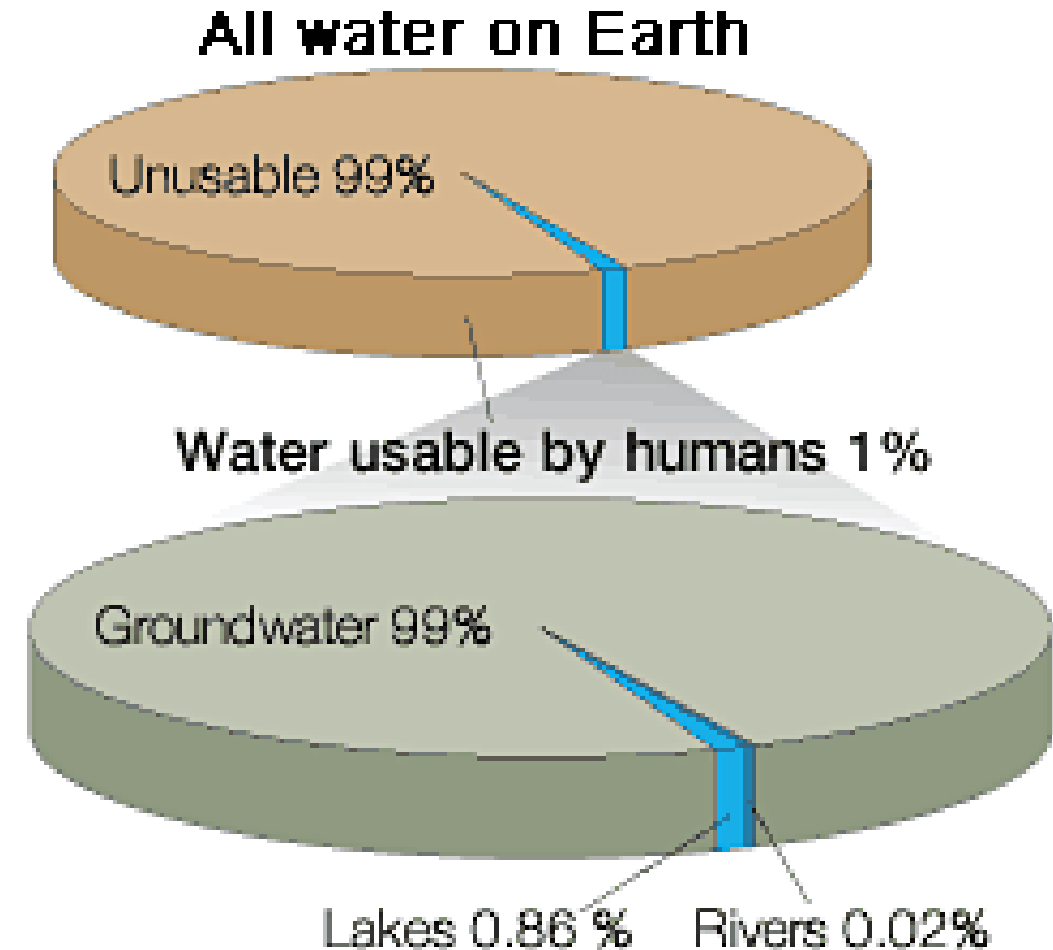
on

# Ground Water



# Introduction

- ❖ Over **70%** of the earth's surface is covered in water.
- ❖ But of that water, just 1% is readily available for human use, and of that **1%, 99%** of it is stored beneath our feet as groundwater.
- ❖ We all rely on groundwater in some way, so it's important that we understand this vital resource.



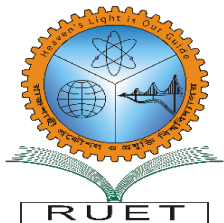
# Introduction Cont...

Since the 1960's, groundwater has been used extensively as the main source of drinking and irrigation water supply. About **75 percent of cultivated land** is irrigated by groundwater and the remaining **25 percent** by surface water. Of the abstracted groundwater about **70-90 percent** is used for agricultural purposes and the rest for drinking and other water supplies.

Table 1. Groundwater development by STW<sup>1</sup> and DTW<sup>2</sup> (BADC, 2005)

Year	No. of STW	No. of DTW	Year	No. of STW	No. of DTW
1985	133,800	15,300	1993	348,900	25,700
1988	186,400	23,500	1995	488,900	26,700
1989	217,900	23,300	1996	556,400	27,200
1991	270,300	21,500	1998	664,700	25,400
1992	309,300	25,500	2001	707,600	23,500
			2004	925,152	24,718

<sup>1</sup> STW = Shallow Tubewell, <sup>2</sup>DTW = Deep Tubewell



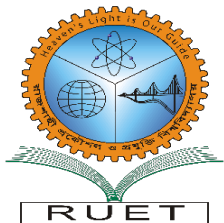
# Introduction Cont...

Table 2. Status of irrigation in Bangladesh, 1995-1996 (WARPO, 2001)

Mode of irrigation	Type of equipment	No. of equipment in operation	Area irrigated	
			ha	%
Groundwater	STW	556,400	1,937,700	57
	DSSTW <sup>1</sup>	19,300	64,600	2
	DTW	27,200	537,900	16
Surface Water	LLP <sup>2</sup>	60,700	577,200	17
	TRAD <sup>3</sup>	673,000	226,400	7
Others		161,800	50,100	1
Total			3,394,900	100

<sup>1</sup>DSSTW = Deep set shallow tubewell, LLP = Low lift pump TRAD = Treadle pump.

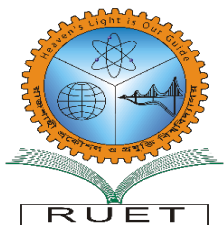
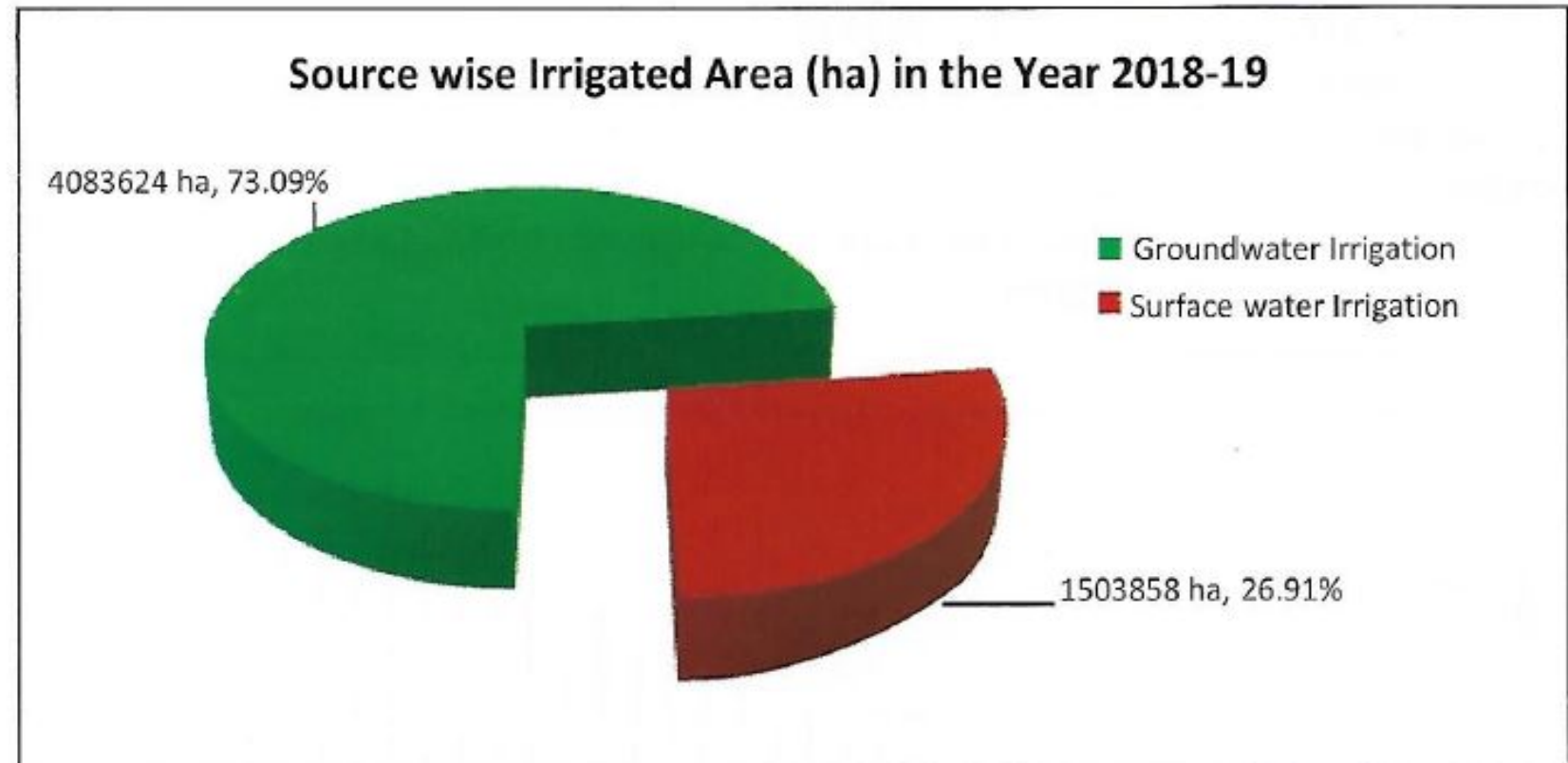
In the year **2018-19**; **37,634 Nos.** Deep Tube Wells, **13,57,532 Nos.** Shallow Tube Wells and **1,87,188 Nos.** Low Lift Pumps are operated in Bangladesh to provide water for minor irrigation. About 73.09% of the total irrigated area is covered by groundwater and the remaining 26.91% area is covered by surface water.



# Introduction Cont...

Table-1: Summary of Surface water and Ground water Irrigation by Different Modes during Rabi Season 2018-19

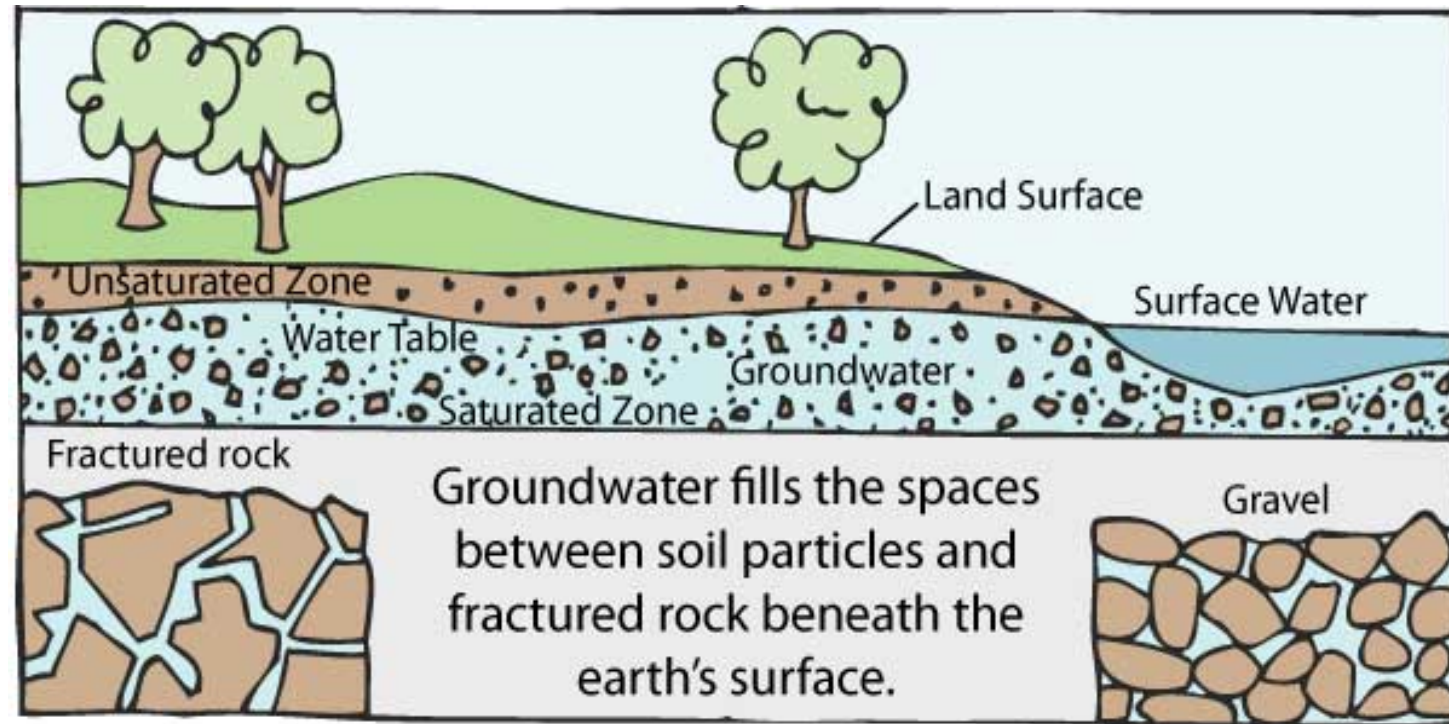
Sl. No.	Mode of irrigation	No. of Equipment	Area Irrigated	% of Surface	% of Total Irrigated	Area Irrigated per Equipment
<b>A. Surface water Irrigation by:</b>						
1	Low lift pump	187188				
2	Gravity flow					
3	Traditional method					
4	Solar Pump	2254				
<b>Sub Total</b>		<b>189442</b>				
<b>B. Groundwater Irrigation by:</b>						
1	Deep tube well	37634				
2	Shallow tube well	1357532				
3	Manual & Artesian well					
4	Solar Pump	533				
5	Dug Well	272				
<b>Sub Total</b>		<b>139597</b>				
<b>GRAND TOTAL</b>		<b>1585413</b>	<b>5587482</b>		<b>100.00%</b>	



# What is Groundwater?

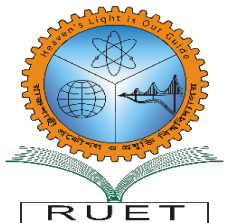
**Groundwater** is the water found underground in the cracks and **spaces in soil, sand and rock**. It is stored in and moves slowly through geologic formations of soil, sand and rocks called **aquifers**.

*The area where water fills the aquifer is called the **saturated zone** (or saturation zone). The top of this zone is called the water table. The water table may be located only a foot below the ground's surface or it can sit hundreds of feet down.*



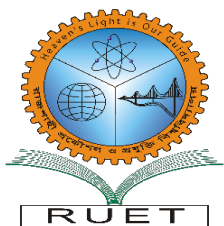
# How much do we depend on groundwater?

- ❖ Groundwater supplies **drinking water for 90%** of the total BD Population.
- ❖ Groundwater helps **grow our food. 70-90%** of groundwater is used for irrigation to grow crops.
- ❖ Groundwater is an important component in many **industrial processes**.
- ❖ Groundwater is a **source of recharge** for lakes, rivers, and wetlands.



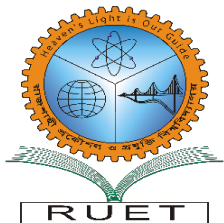
## Advantages of Ground Water(GW) over surface water

01. GW is **clean, colorless**, and almost **free from turbidities**
02. GW is **free from Pathogenic organism** which causes disease
03. GW is **rich with several minerals** which are beneficial to health
04. For most cases GW needs **no treatment**
05. GW have **uniform temperature** in all most all the year
06. About **99% drinkable water** is stored as **ground water**
07. GW is **available for irrigation in dry season** when surface water in not available
08. Ground water storage is **free from atomic attack**

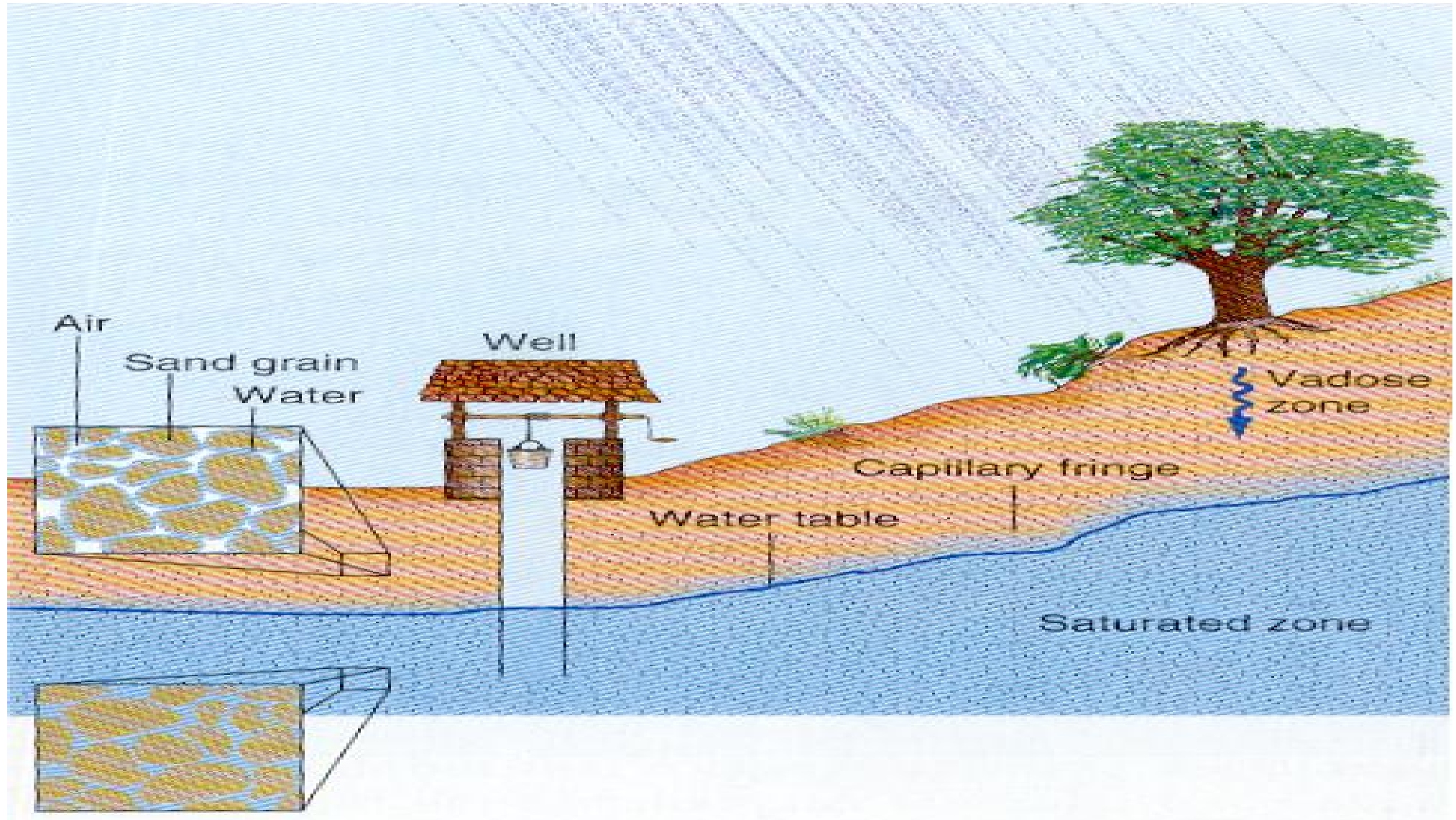


# The Water Table

- ❖ **Saturated zone:** the subsurface zone in which all **rock openings** are filled with water
- ❖ **Water table:** the upper surface of the zone of saturation
- ❖ **Vadose zone:** a subsurface zone in which rock openings are generally unsaturated and filled partly with air and partly with water; above the saturated zone
- ❖ **Capillary fringe:** a **transition zone** with higher moisture content at the base of the vadose zone just above the water table

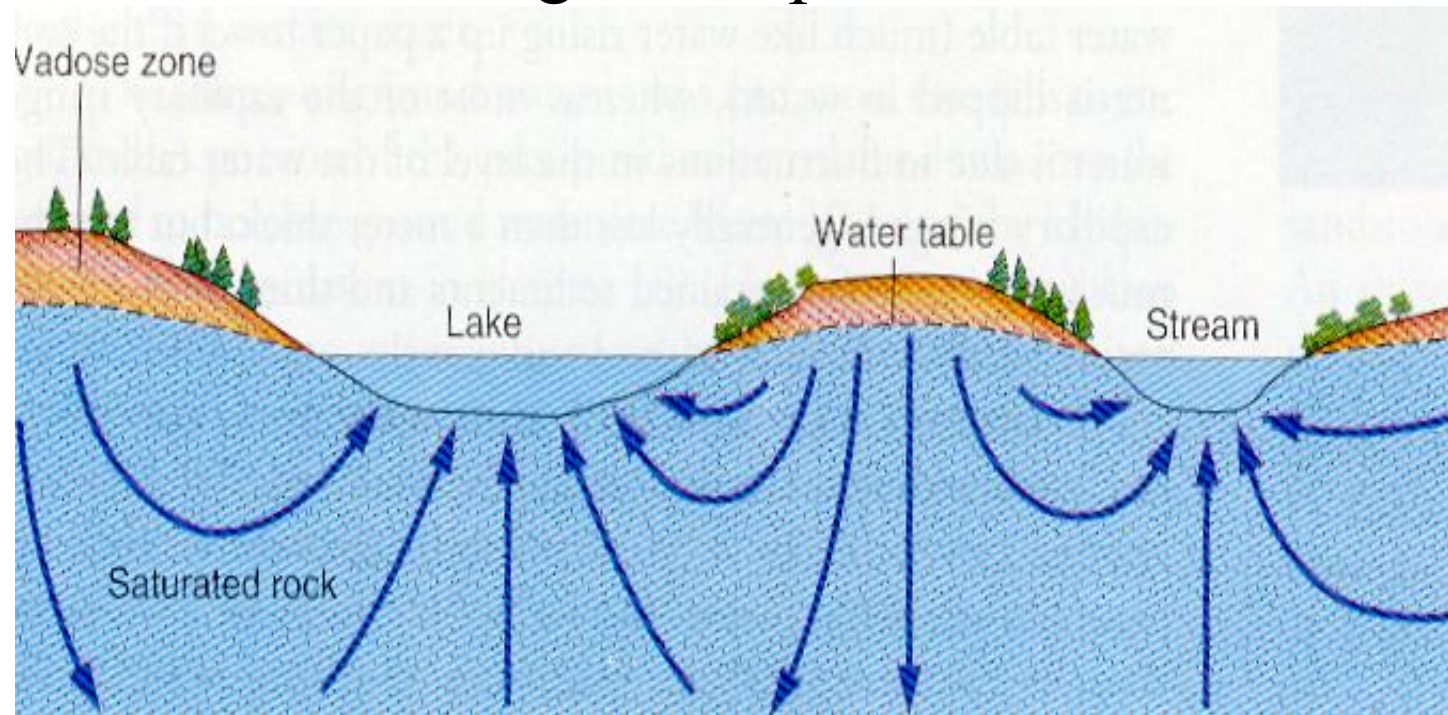


# The Water Table Cont...



# The Movement of Ground Water

- ❖ most ground water moves relatively slowly through rock underground
- ❖ because it moves in response to **differences in water pressure and elevation**, water within **the upper part of the saturated zone tends to move downward** following the slope of the water table

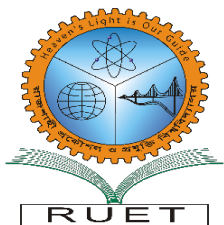


Movement of ground water beneath a sloping water table in uniformly permeable rock. Near the surface the ground water tends to flow parallel to the sloping water table

## Movement of Ground Water (cont.)

### Factors affecting the flow of ground water:

- **The slope of the water table** - the **steeper** the water table, the **faster** ground water moves
- **Permeability** - if rock pores are **small and well connected**, water moves slowly; when openings are **large and poorly connected**, the flow of water is more rapid



# Definitions

## Aquifer

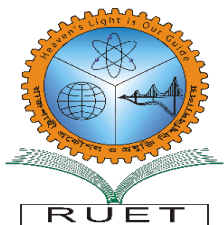
An **aquifer** is an underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt) from which groundwater can be extracted using a water well.

Example: Sand

## Aquiclude

The **opposite** of an aquifer. An aquiclude is a subsurface rock, soil, or sediment unit that does not yield useful quantities of water. It may be porous and capable of containing water, but the transmission rate **is so poor that** it cannot be considered to be a water source.

Clay and shale are typical aquicludes.



# Definitions

## Aquifuge

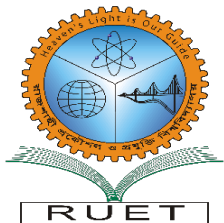
An aquifuge is an impermeable formation **neither containing nor transmitting water.**

Example: Solid Granite, Basalt

## Aquitard

An aquitard is a geological unit that **is permeable enough to transmit water in significant quantities when viewed over large areas** and long periods, but its permeability is not sufficient to justify production wells being placed in it.

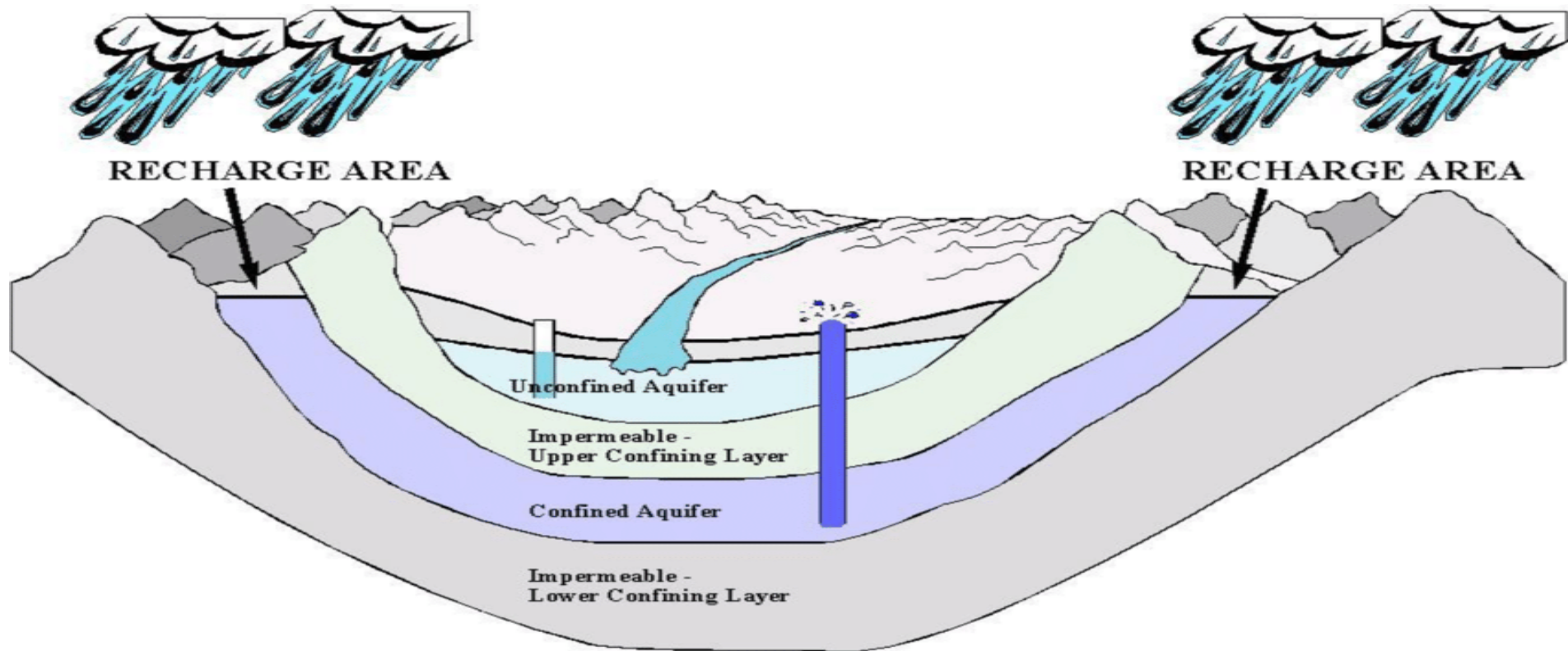
**Example:** Clay lenses interbedded with sand, Clays, loams, and shales are typical aquitards.



# Definitions

## Confined Aquifer

An aquifer that is bounded above and below by impermeable rock or sediment layers. There may or may not be enough pressure in the aquifer to make it an "artesian aquifer."

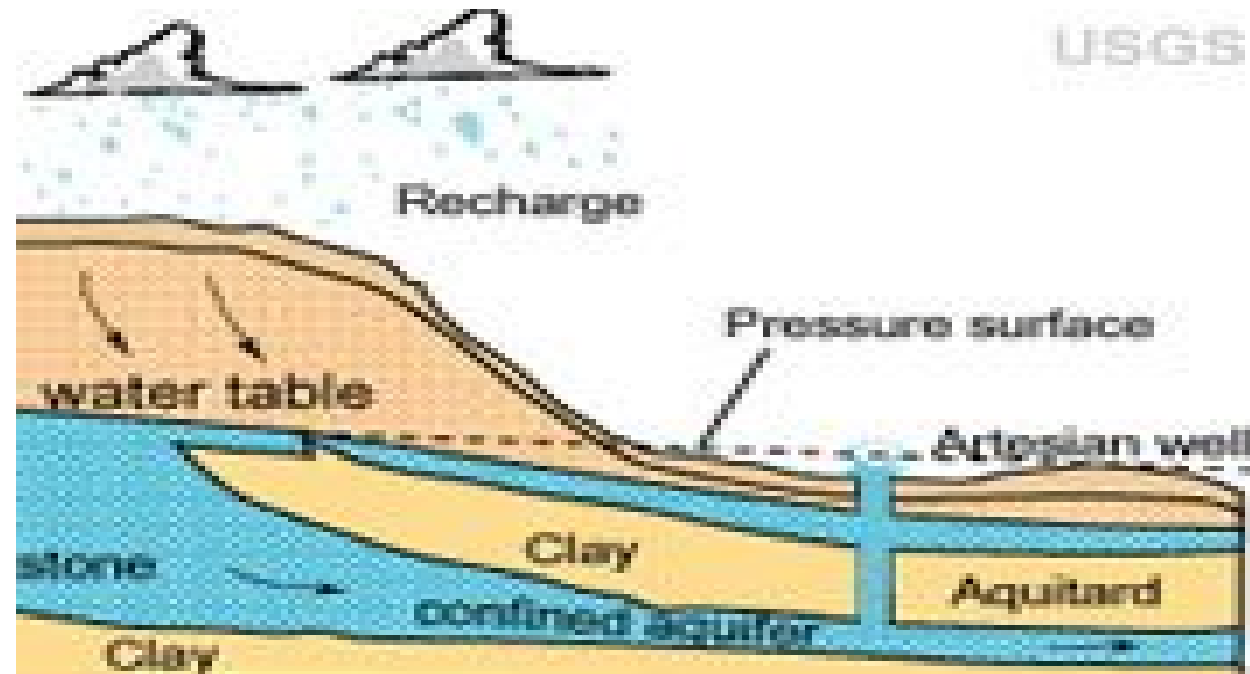




# Definitions

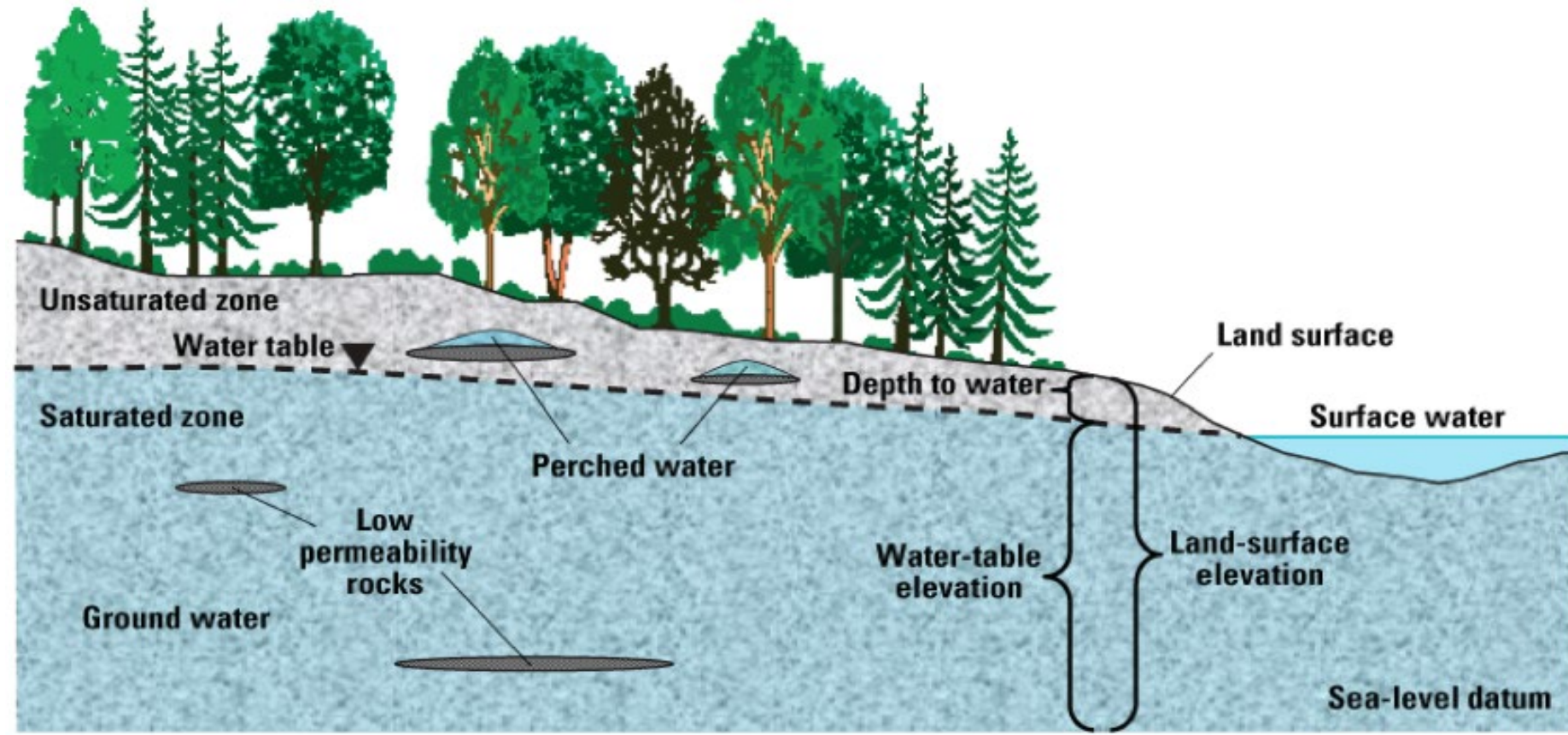
## Artesian Aquifer/Confined Aquifer

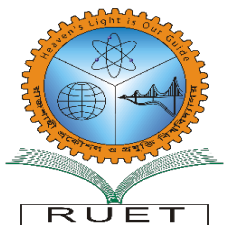
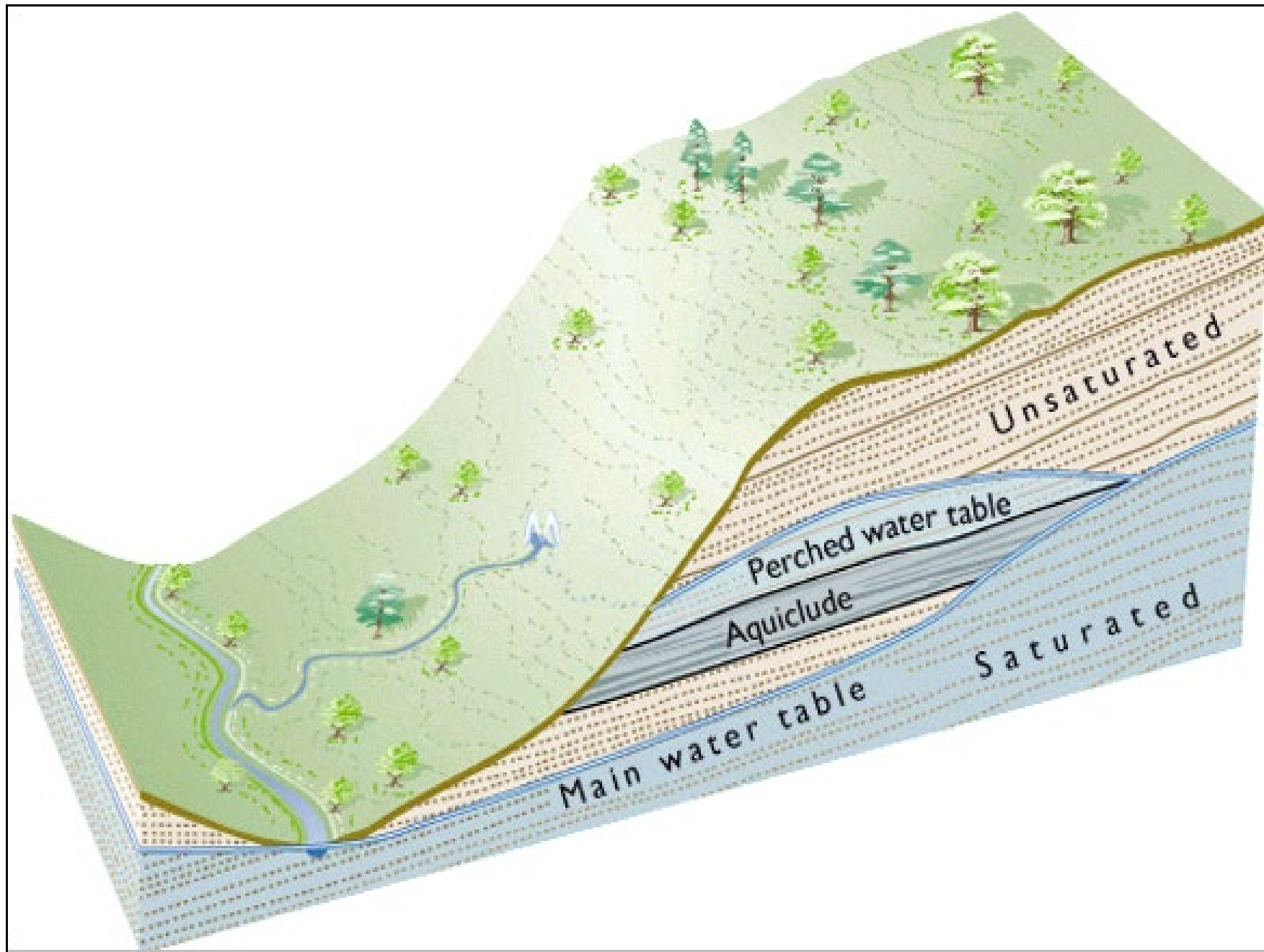
An aquifer that is bounded above and below by impermeable **rock** or sediment layers. The water in the aquifer is also under enough pressure that, when the aquifer is tapped by a well, the **water rises up** the well bore to a level that is above the top of the aquifer. The water may or may not flow onto the land surface.



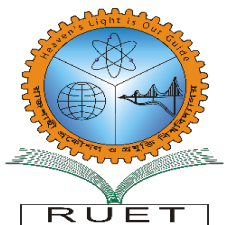
# Perched Aquifer

A **perched water table** (or **perched aquifer**) is an **aquifer** that occurs **above the regional water table**, in the vadose zone. This occurs when there is an impermeable layer of rock or sediment (aquiclude) or relatively impermeable layer (aquitard) above the main water table/**aquifer** but below the surface of the land.

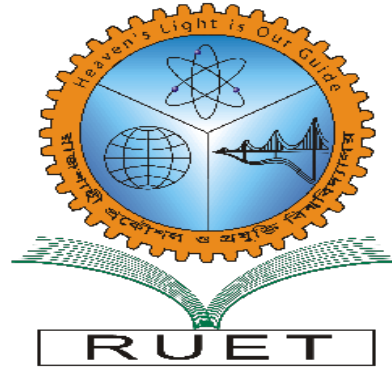




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your kind attention



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**Rajshahi University of Engineering & Technology**

**Mithun Chakrabarty**

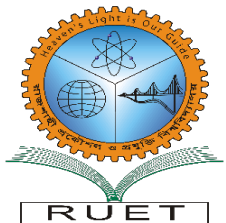
**Lecturer**

**Department of Civil Engineering**

# Lecture-03

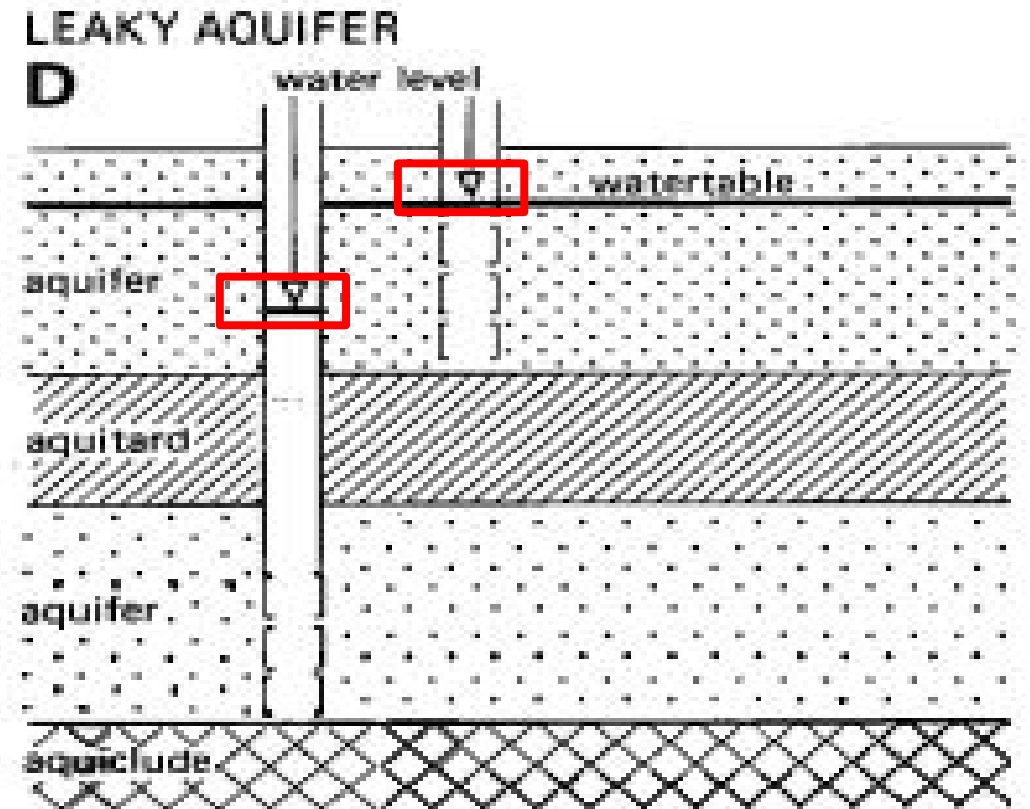
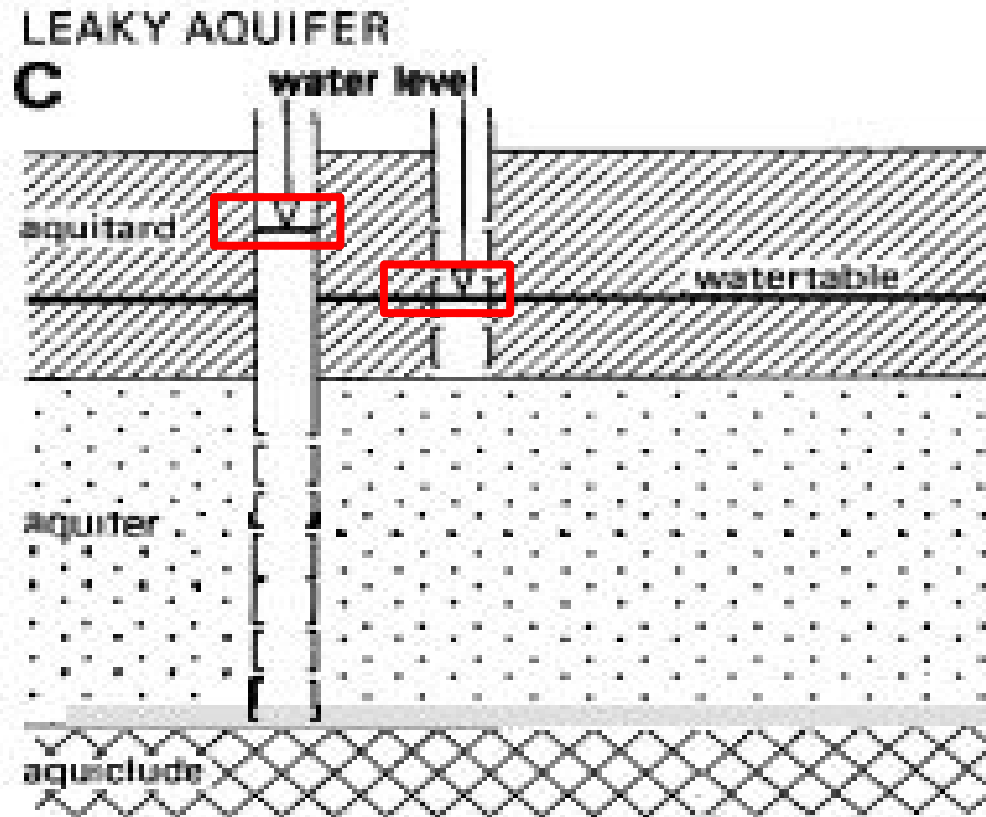
## on

# Ground Water

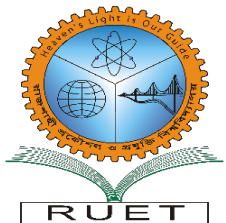
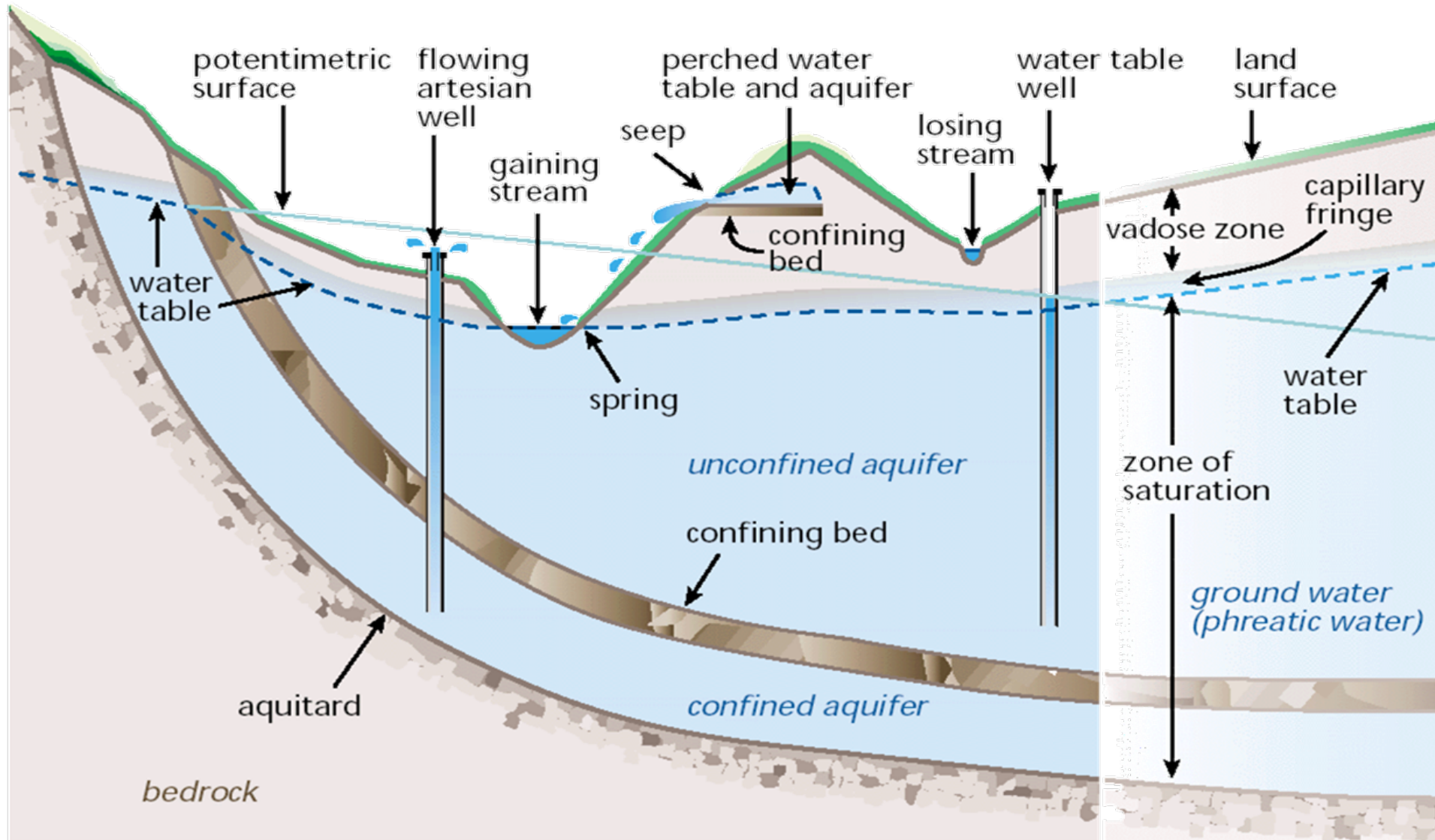


# Leaky aquifer

A **leaky aquifer**, also known as a **semi-confined aquifer**, is an **aquifer** whose **upper and lower** boundaries are **aquitards**, or one boundary is an **aquitard** and the other is an **aquiclude**.



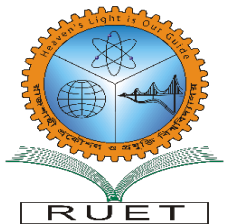
# Definitions



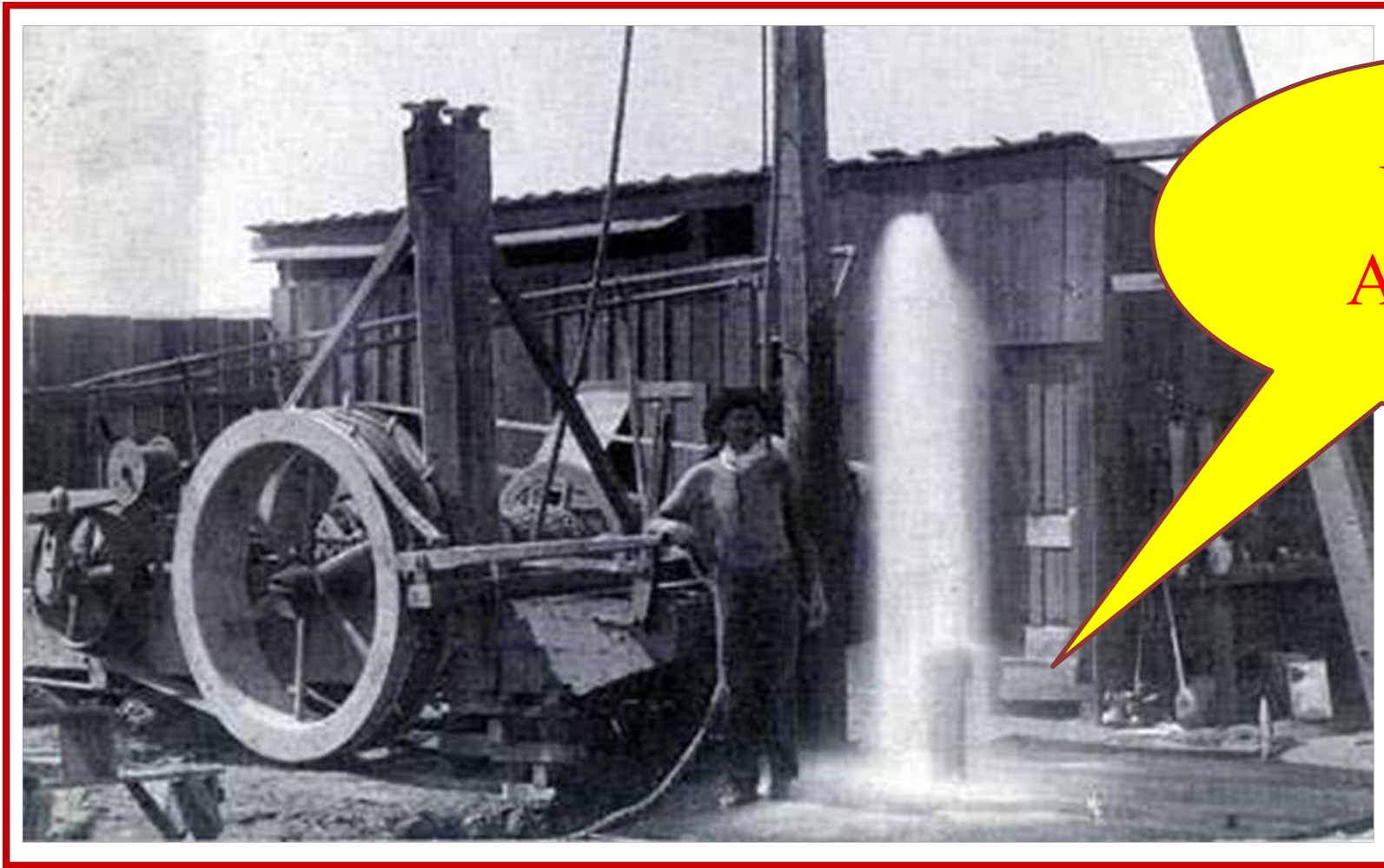


# ASSIGNMENT

Q. What is Piezometric Surface ?



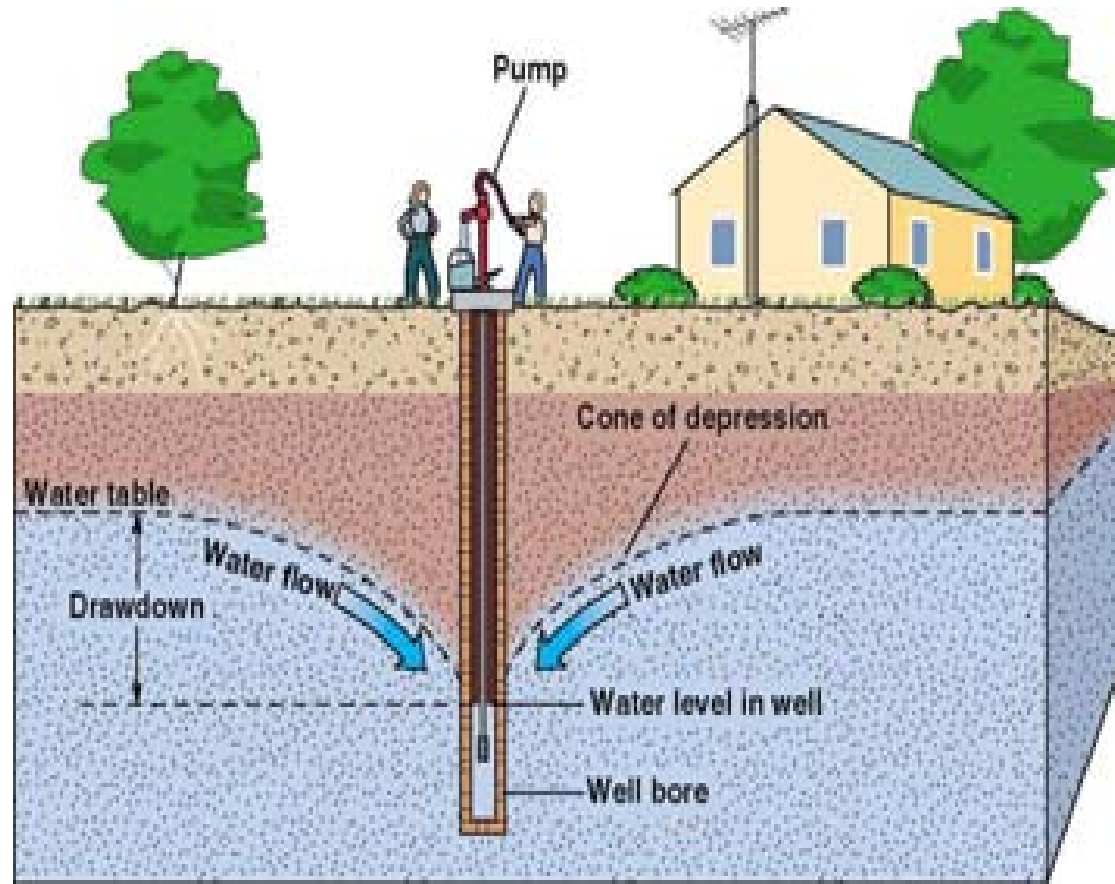
# Definitions



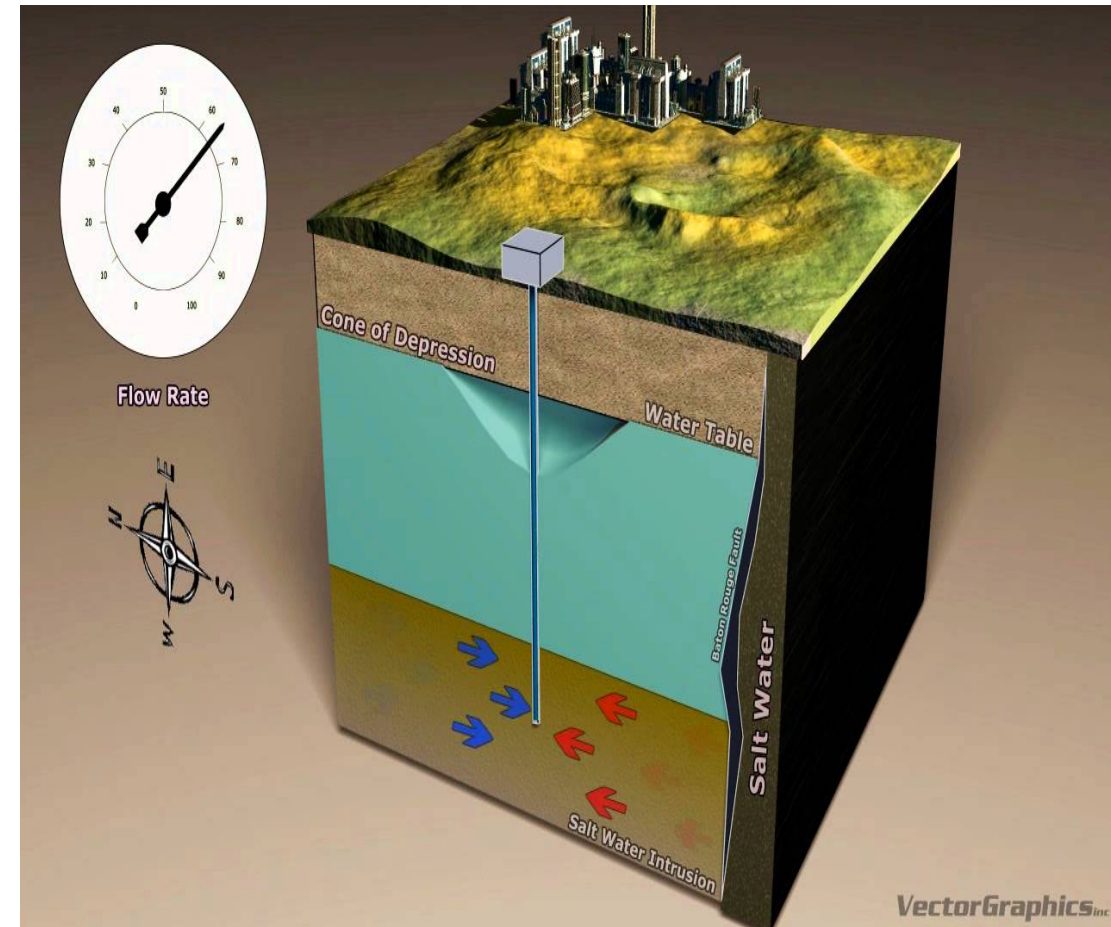
Which  
Aquifer?

# Cone of Depression

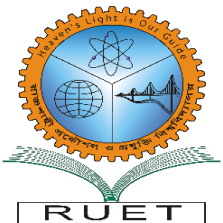
If water is pumped at a constant rate from the well, a gradient in the water table toward the well is created which results in a depressing form of water table. This is called cone of depression.



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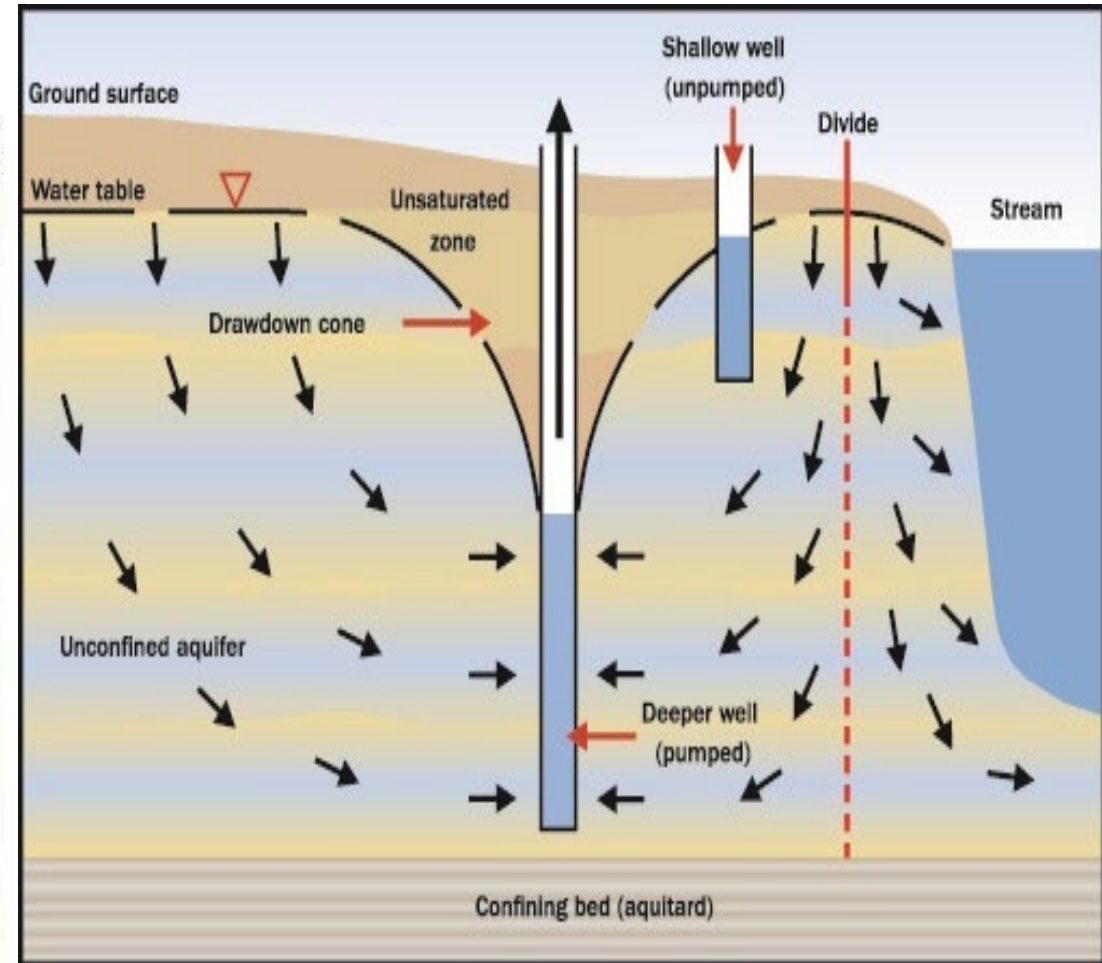
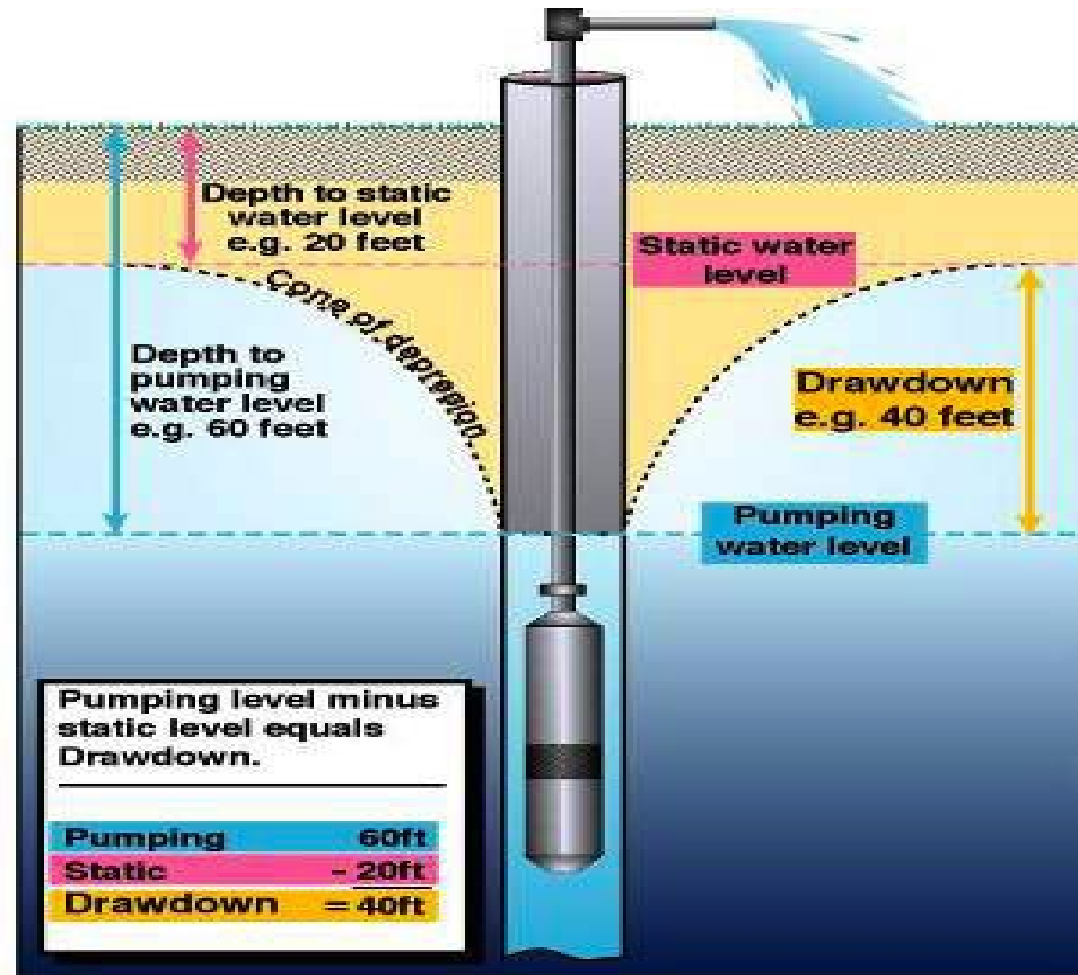


VectorGraphics Inc.



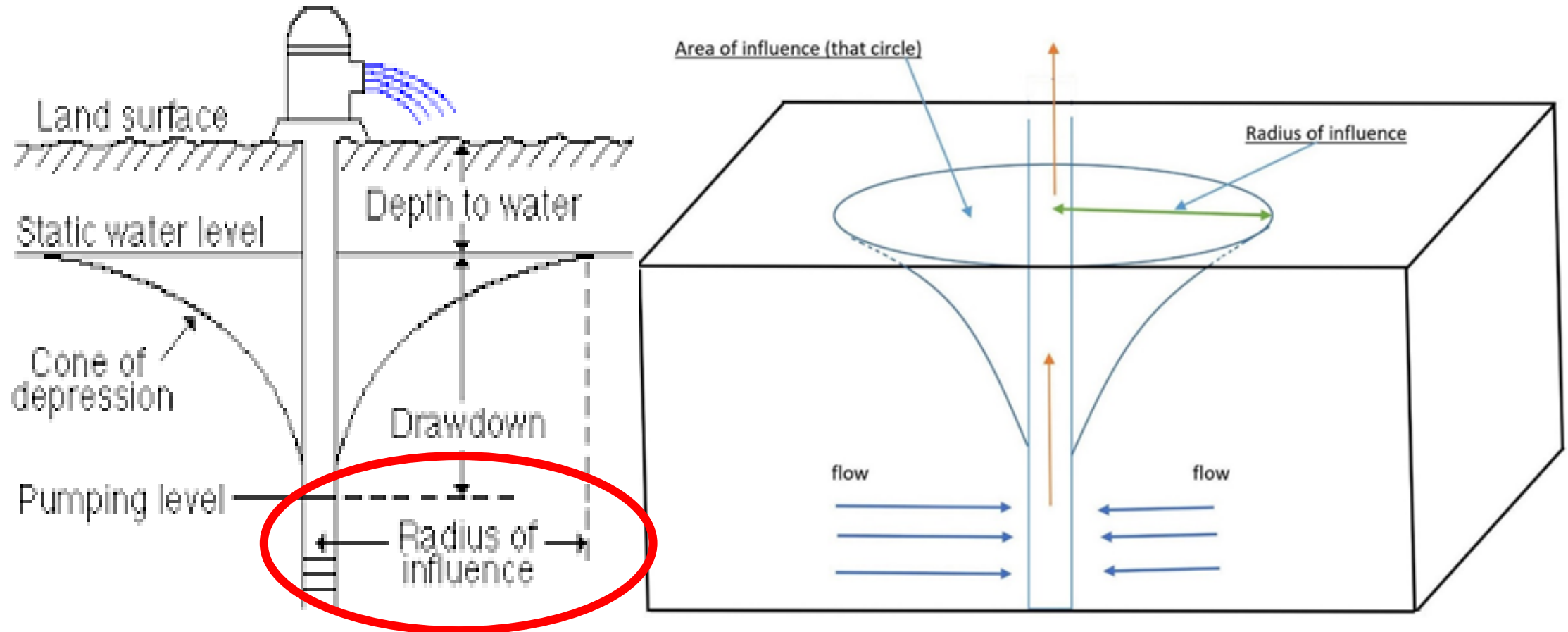
# Drawdown

The decrease in water level at the well with respect to initial ground water table is called drawdown . It is denoted by  $S_w$ .



# Radius of Influence

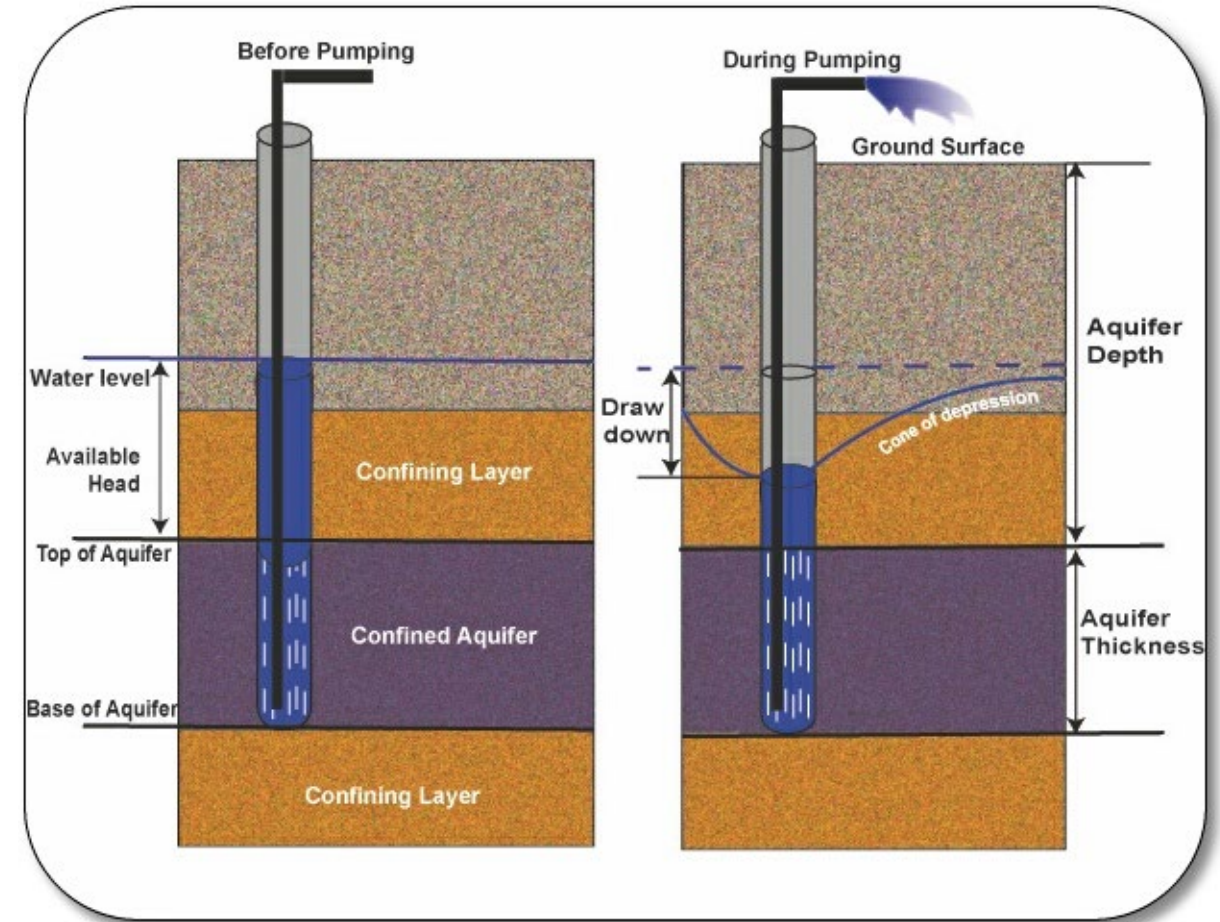
The radial distance from the center of a wellbore to the point where there is no lowering of the water table or potentiometric surface (the edge of the cone of depression)



# Safe Yield

Safe yield is defined as the maximum rate of withdrawal that can be sustained by an [aquifer](#) without causing an unacceptable decline in the [hydraulic head](#) or deterioration in water quality in the aquifer.

When setting the safe yield of an aquifer an attempt is being made to guide [water resource](#) managers regarding the volume of [groundwater](#) that can be abstracted sustainably over the long-term.



# Specific Capacity

## Definition

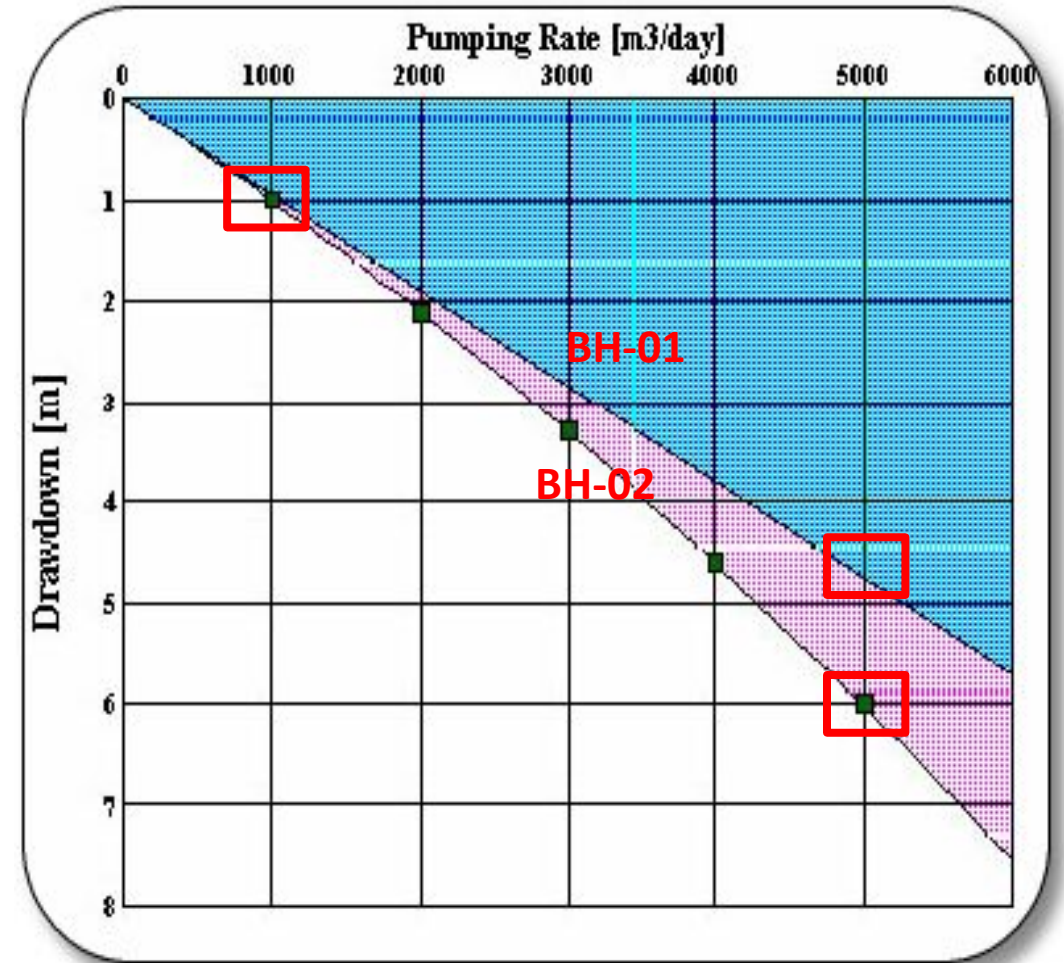
The rate of discharge from a [borehole](#) per unit of [drawdown](#), usually expressed as lpm/m.

## Description

Specific capacity is a measure of borehole performance and is calculated by dividing the [yield](#) of the borehole by drawdown induced by [abstraction](#).

## Why is specific capacity important?

Specific capacity is a measure **borehole productivity and performance.**



# Specific Yield ( $S_y$ )

## Formal definition

The ratio of the volume of water that drains by gravity to that of the total volume of the saturated porous medium.

## Description

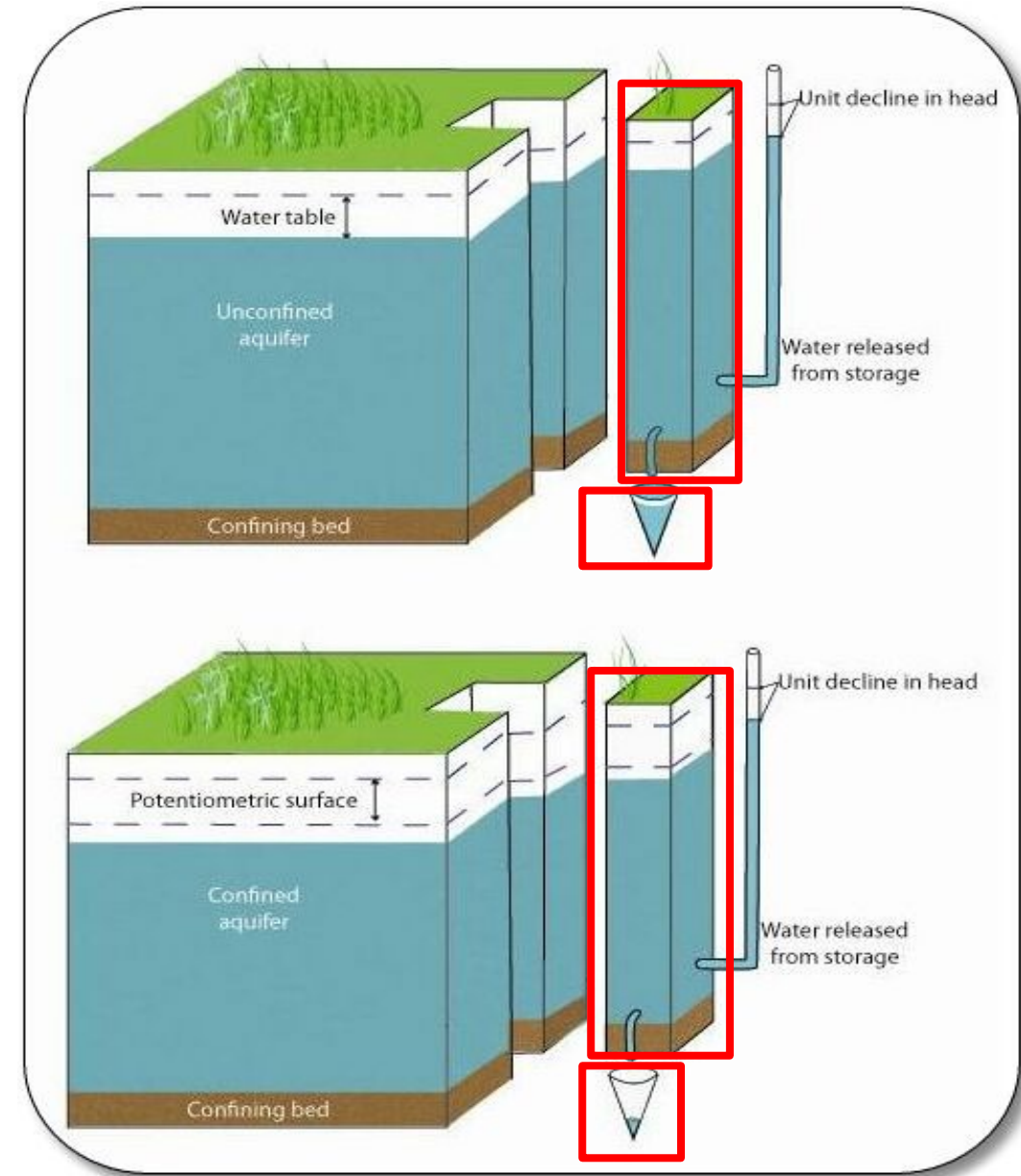
Specific yield is a ratio between 0 and 1 indicating the amount of water released due to drainage, from lowering the water table in an unconfined aquifer.

Thus,  $S_y = (W_y / V) * 100$

Where,  $W_y$  is the volume of the yield water and  $V$  is the bulk volume of the soil or rock.

## Why is specific yield important?

This is a measure of the water released from an unconfined aquifer.



# Specific Retention ( $S_r$ )

## Formal definition

The ratio of the volume of water that retain against gravity to that of the total volume of the saturated porous medium.

Thus,  $S_r = (W_r / V) * 100$

Where,

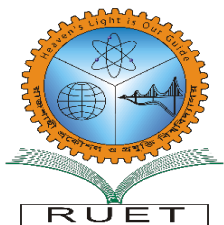
$W_r$  is the volume of the retained water and  $V$  is the bulk volume of the soil or rock.

Since  $W_y$  and  $W_r$  constitutes the total volume of water in a saturated material it is apparent that the porosity will be equal to sum of the specific yield and the specific retention.

i.e.  $n = S_y + S_r$

## Why is specific yield important?

This is a measure of the water retained in an unconfined aquifer.



# Storage Coefficient (S)

## Definition

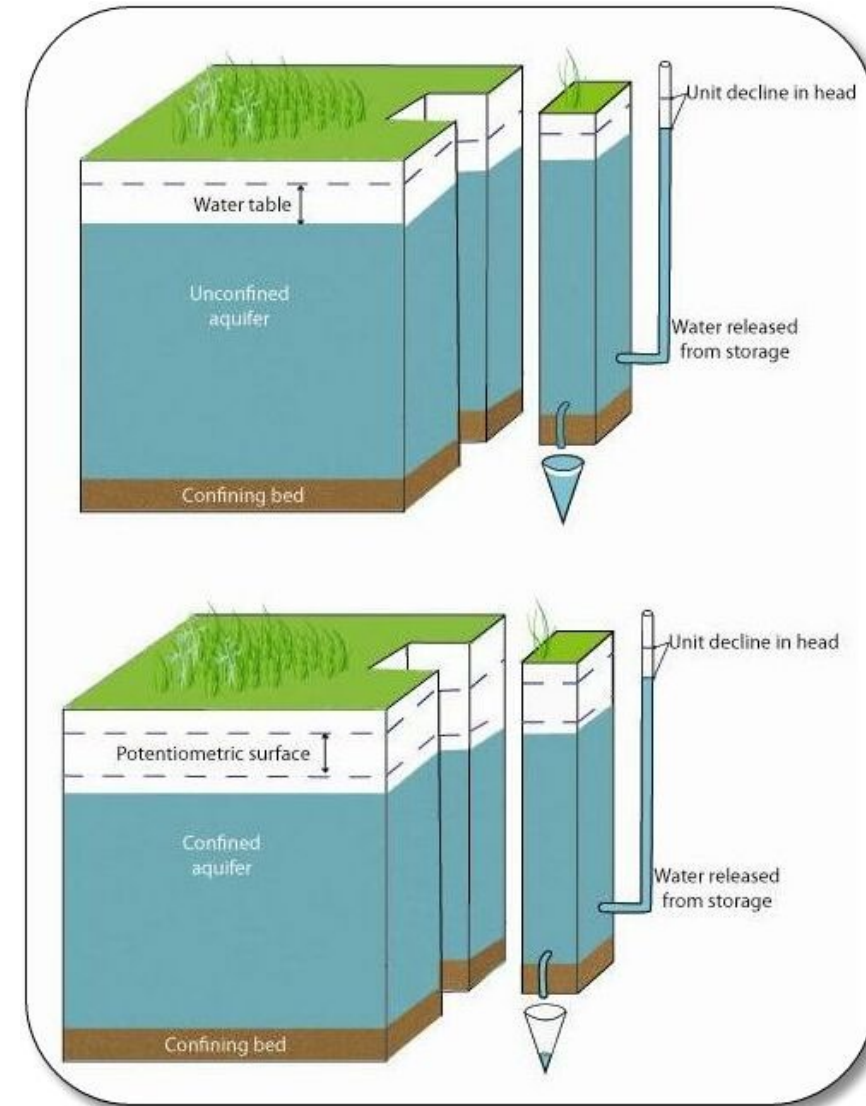
The volume of water an [aquifer](#) releases from or takes into storage per unit surface area of the aquifer per unit change in [head](#).

## Description

It is a volume of water per volume of aquifer released as a result of a change in head. For a [confined aquifer](#), the storage coefficient is equal to the product of the [specific storage](#) and aquifer thickness.

## Why is storage coefficient important?

This is a measure of the volume of water stored and released in an aquifer and is used to quantify the [safe yield](#) of an [aquifer system](#).



# Transmissivity (T)

Transmissivity is the rate at which water is transmitted through a unit width of an [aquifer](#) under a unit [hydraulic gradient](#). It is expressed as the product of the average [hydraulic conductivity](#) and thickness of the saturated portion of an aquifer.

It is commonly measured in gallons per day per foot (gal/day/ft) and can be expressed as:

$$T = bK$$

**b** = saturation thickness of aquifer in feet

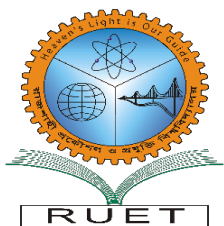
**K** = gal/day/ft

## Description

Transmissivity is a measure of the ease with which [groundwater](#) flows in the subsurface.

## Why is transmissivity important?

Transmissivity is used to calculate the [yield](#) of a [borehole](#), determine the [safe yield](#) of an [aquifer system](#) and predict groundwater movement.



# Aquifer Transmissivity

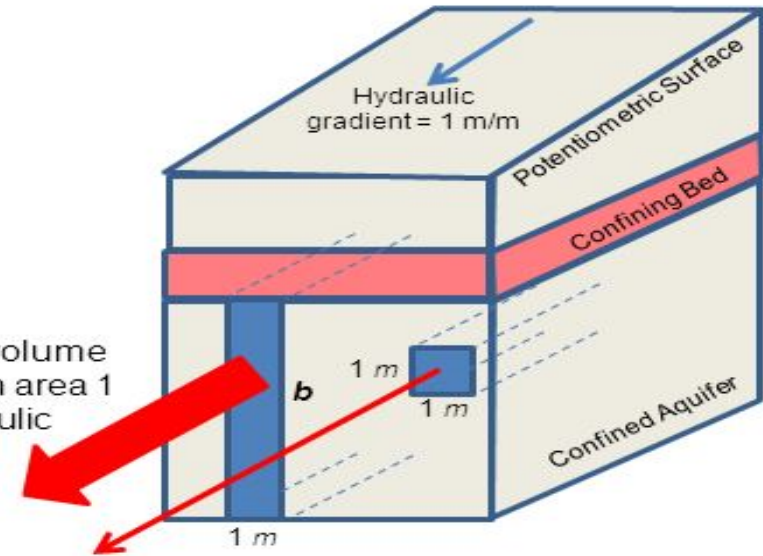
- Transmissivity ( $T$ )
  - Discharge through thickness of aquifer per unit width per unit head gradient
  - Product of conductivity and thickness

$$T = K b$$

$$K(x,y) = \frac{1}{b} \int_0^b K(x,y,z) dz$$

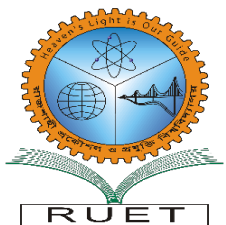
Transmissivity,  $T$ , volume of water flowing an area  $1 \text{ m} \times b$  under hydraulic gradient of  $1 \text{ m/m}$

Conductivity,  $K$ , volume of water flowing an area  $1 \text{ m} \times 1 \text{ m}$  under hydraulic gradient of  $1 \text{ m/m}$

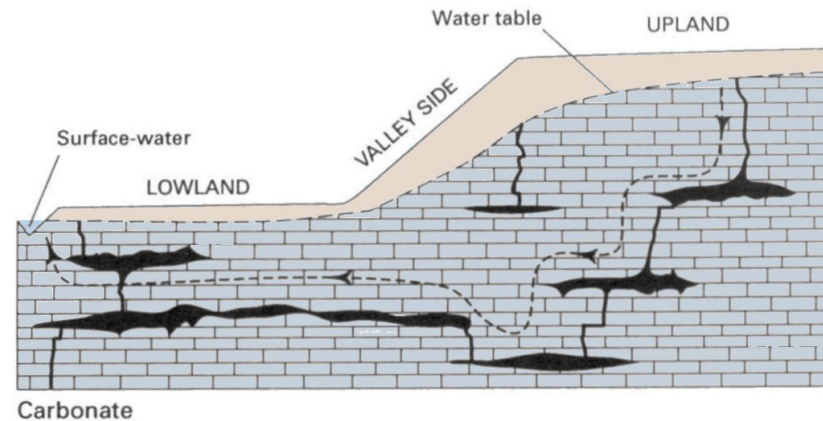
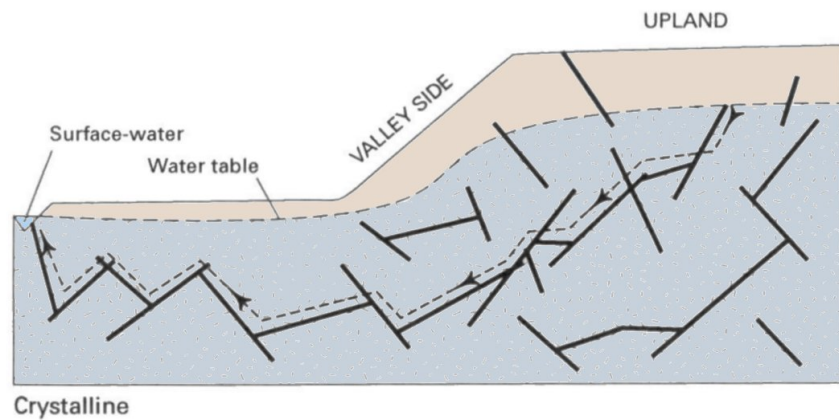
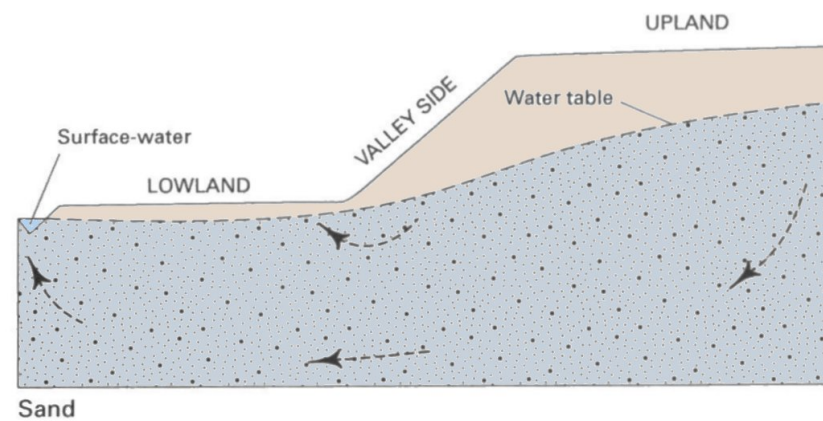
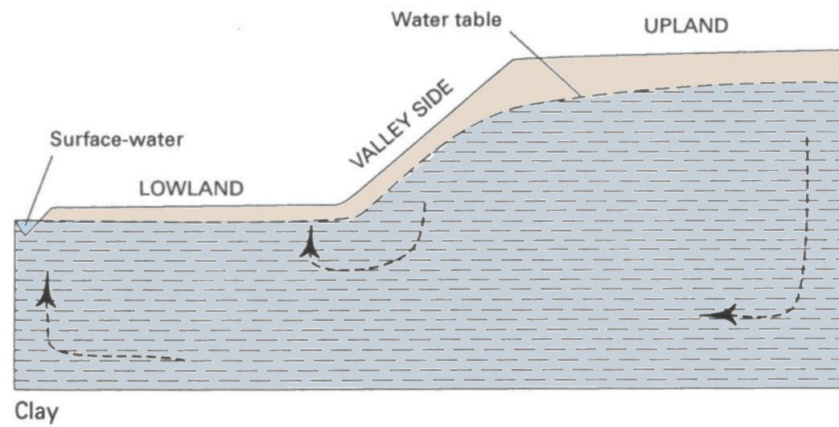


# Overdraft

**Overdrafting** is the process of extracting groundwater beyond the *safe yield* or equilibrium yield of the aquifer.



# Ground Water Movement Directions



← - - - - Direction of ground-water flow

# Hydraulic Head

## Pressure:

$$P = \rho g h_p$$

Where:

$\rho$  = density of water ( $\text{kg m}^{-3}$ )

$g$  = gravitational acceleration ( $\text{m s}^{-2}$ )

$h_p$  = pressure head

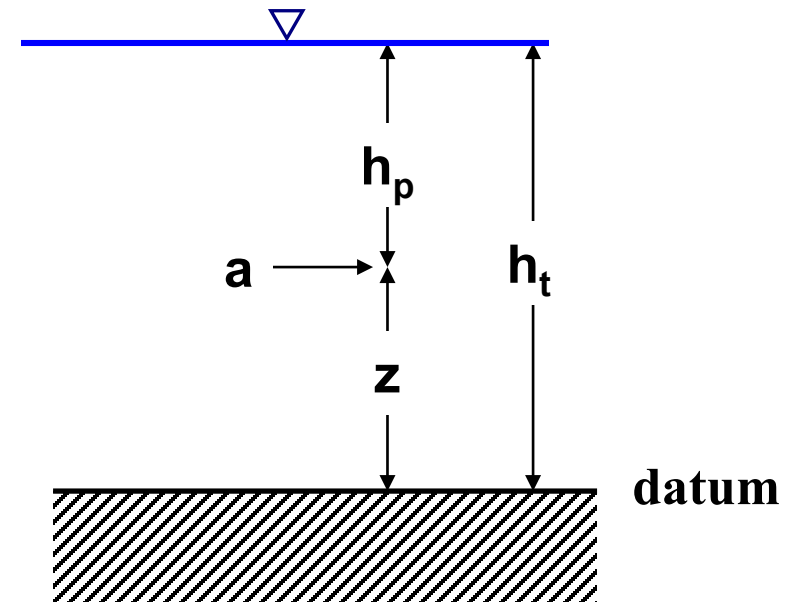
## Total hydraulic head ( $h_t$ ):

$$h_t = z + h_p$$

Where:

$z$  = elevation

$h_p$  = pressure head



# Darcy's Law

Darcy's Law defines groundwater flow:

$$Q = k_v A \frac{dh_t}{dx}$$

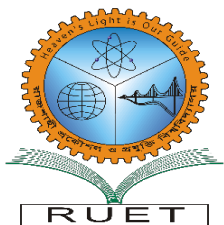
where:

$Q$  is discharge ( $L^3 T^{-1}$ )

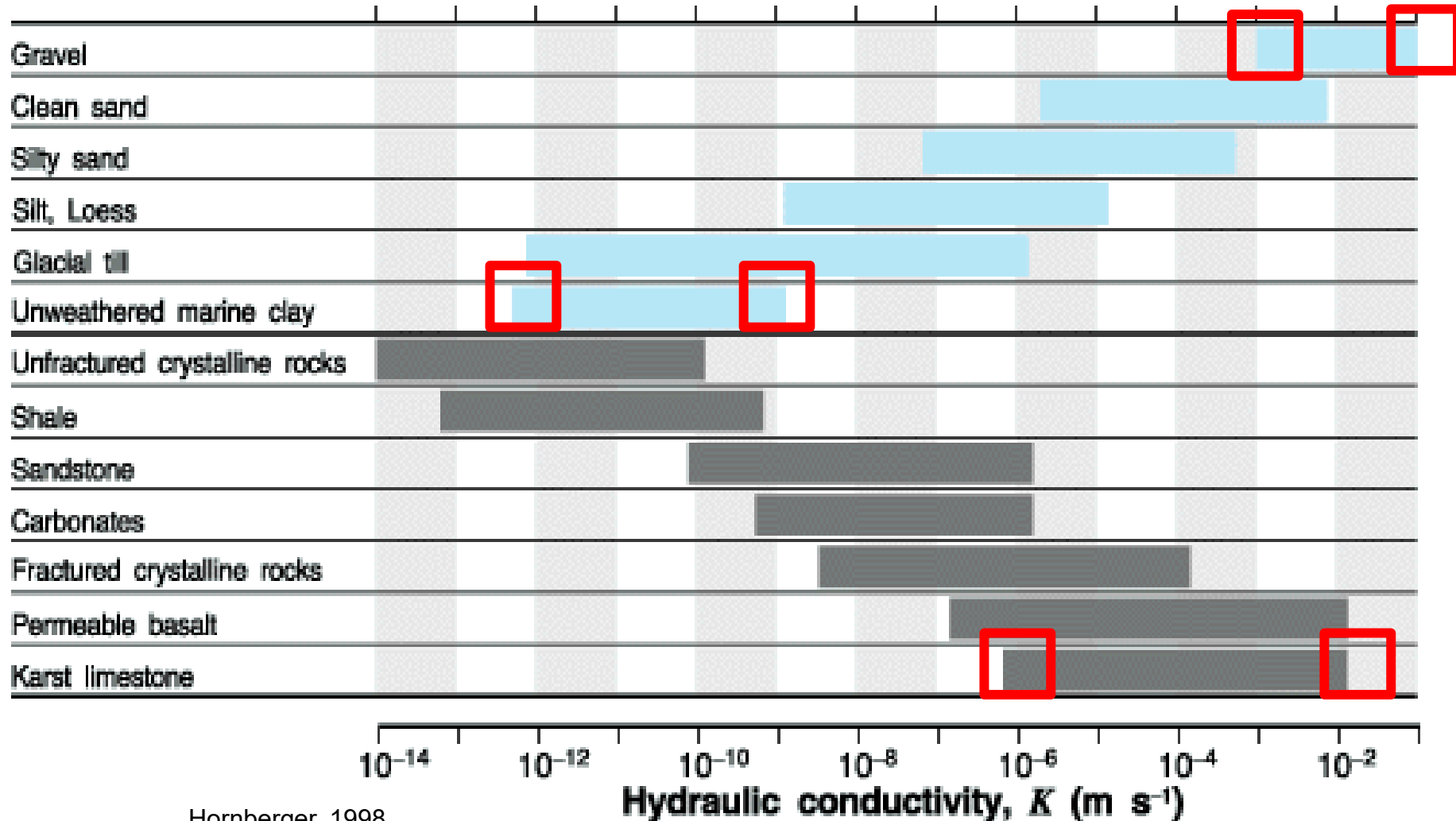
$k_v$  is the hydraulic conductivity ( $L T^{-1}$ )

$A$  is area of flow ( $L^2$ ), and

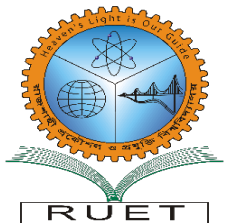
$dh/dx$  is the gradient of pressure, or head



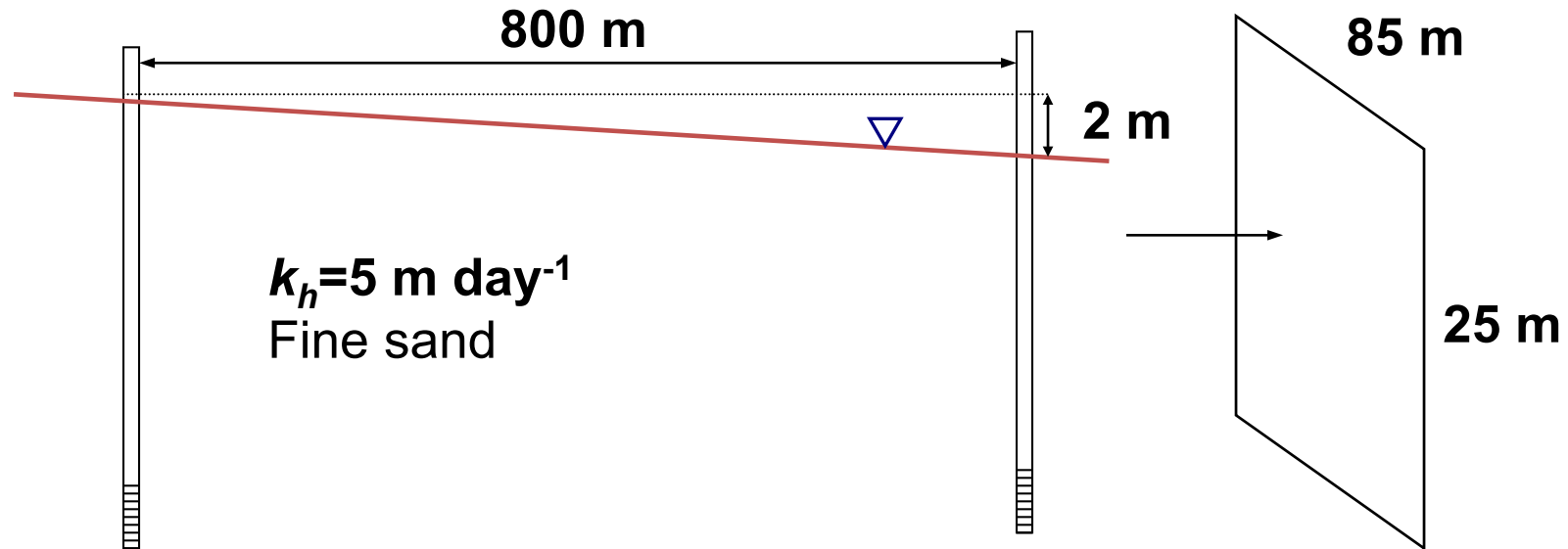
# Hydraulic Conductivity ( $k_v$ )



Hornberger, 1998



# Example



$$\text{Solution: } Q = k_v A \frac{dh_t}{dx} = \left(5 \frac{\text{m}}{\text{day}}\right) (25 \text{ m} \times 85 \text{ m}) \left(\frac{2.0 \text{ m}}{800 \text{ m}}\right) = 26.6 \frac{\text{m}^3}{\text{day}}$$

**Thank You  
For  
Your Kind Attention**

