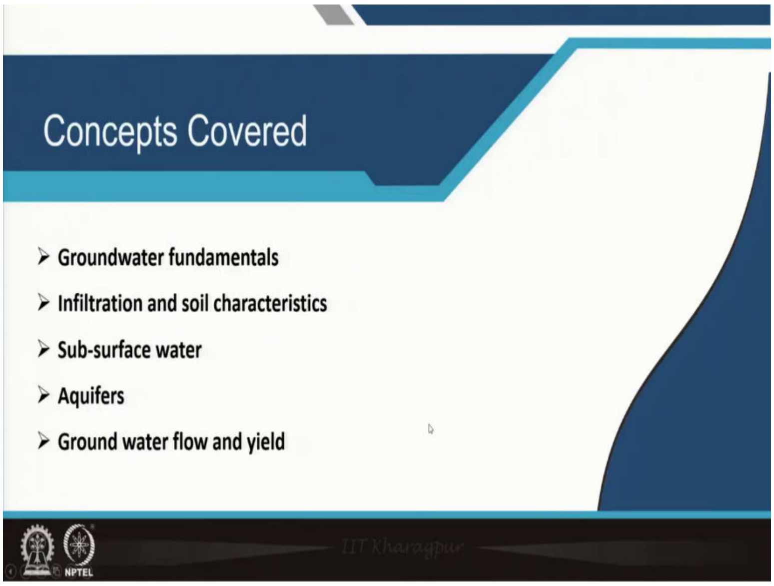
Urban Utilities Planning: Water Supply, Sanitation and Drainage
Prof. Debapratim Pandit
Department of Architecture and Regional Planning
Indian Institute of Technology, Kharagpur

Module - 03
Collection of water
Lecture - 12
Groundwater Properties and Flow Characteristics

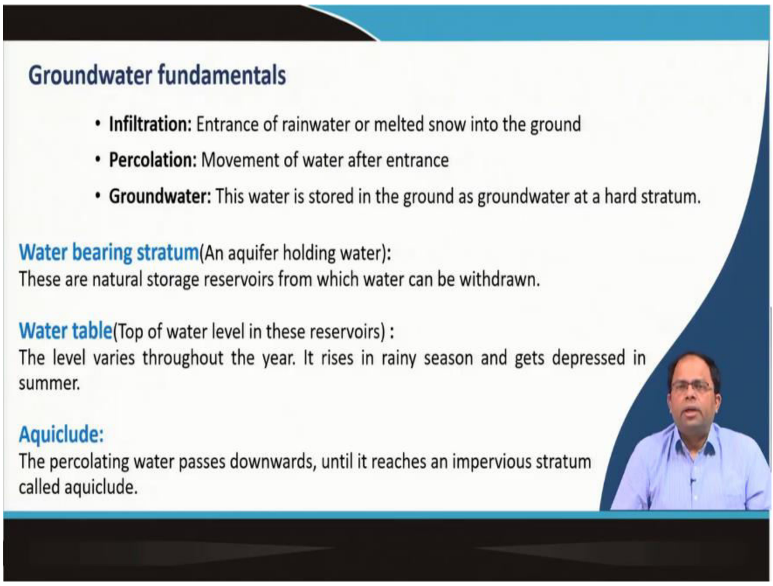
Welcome back. In lecture 12, we will cover Groundwater Properties and Flow Characteristics.

(Refer Slide Time: 00:37)



The different concepts that we will cover in this lecture are ground water fundamentals, infiltration and soil characteristics, sub surface water, aquifers and about ground water flow and yield.

(Refer Slide Time: 00:54)



Groundwater fundamentals

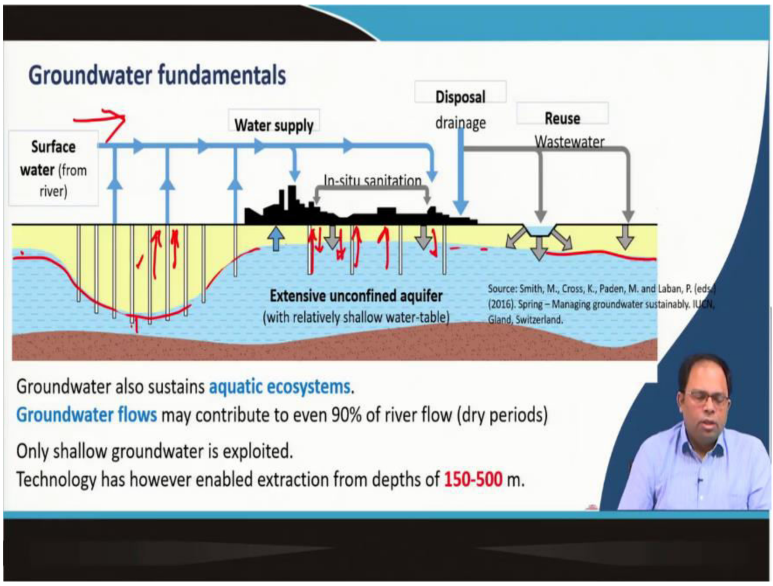
So, let us first talk about the basics which we have discussed in the last lecture. Infiltration is the entrance of rainwater or melted snow into the ground, percolation is the movement of water after entrance, that is, the movement of water inside the soil. And ground water is the water that is stored in the ground as ground water at a hard stratum. That means the water cannot go further down and it is prevented by a hard stratum or an impervious surface and that is stored in the soil as ground water.

So, as we understand the water that is stored inside soil is also stored in the pores of the soil and this particular layer of earth which holds water is known as the water bearing stratum or an aquifer holding water.

So, these are natural storage reservoirs from which water can be withdrawn. So, this not only holds water, but can also withdraw water from them. Then we also have something called a water table, which is the top of the water level in these particular reservoirs; that means, in these particular aquifers the level varies throughout the year and it rises in rainy season and gets lowered in summer. So, during rainy season the water level goes up and in summer it goes down.

So, this is the level of water inside this aquifer. An aquiclude is the impervious stratum at which the water is being stored. So, these are the basics that we should know before we start talking about ground water.

(Refer Slide Time: 02:38)



Now ground water has got also certain other aspects such as aquatic ecosystems; some bacteria and other organisms can be found in ground water.

Groundwater flows may contribute to even 90 percent of river flow during dry periods. So, that means, the amount of flow that we see in a river could be contributed not only from surface flows, but also sub surface flows. And only shallow ground water is exploited, that means, we do not exploit ground water from very deep.

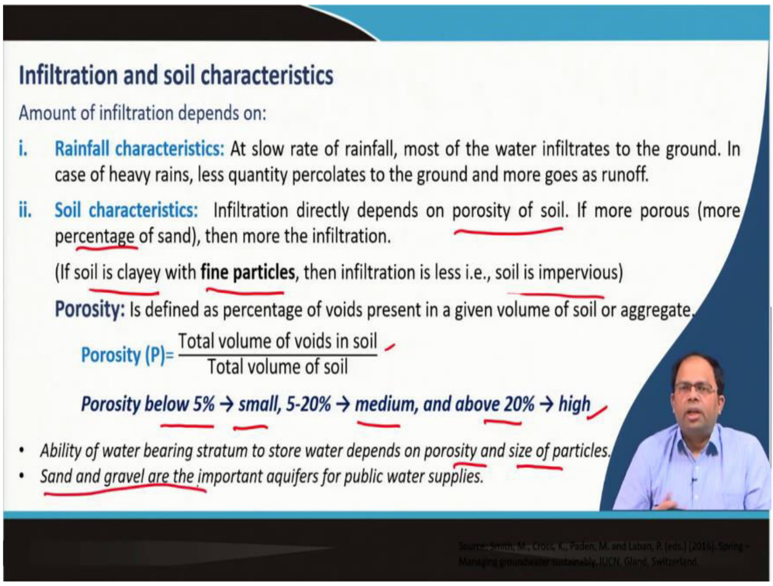
Even though technology allows us to extract from around 500 meters depth. For this purpose, we construct deep tube wells which can extract water to even beyond from 150 to 500 meters. However, we should limit our ground water extraction to shallow levels, otherwise we will have other problems which will be discussed in the subsequent lectures. The image actually shows you the overall setting of an urban area, as you can see that the blue band in the image is the aquifer, the brown band is the impervious surface of the aquiclude and the yellow area is the zone above the aquifer. You can also see that the water level at two points are different. This is because water is being drawn at one of these points.

The deep tube wells draw water from this particular area and as we draw, the water table bends to form a cone of depression.

City authorities and urban authorities get water for supplying an urban area from surface sources as well as ground sources. Both these sources get treated or sometimes, the groundwater is not treated and directly supplied. Some industries and large complexes draw ground water themselves.

Some amount of ground water comes from recharge because buildings have rain water harvesting system or sanitation systems where the treated waste water is actually allowed to percolate. Thus, the water that is being used in the cities are disposed and some part of it is reused at certain areas. For example, in an oxidation pond, some amount of water recharge happens. So, this is the cycle of ground water or how ground water is being used along with surface water and is finally disposed and it goes into the rivers from where it evaporates and again the hydrologic cycle of water prevails.

(Refer Slide Time: 06:26)



Infiltration and Soil Characteristics

Before we look into ground water, we need to understand different characteristics of the soil and infiltration that determines how ground water will be formed or how ground water flows within a particular area.

<u>Infiltration</u>

The amount of infiltration depends on the rainfall characteristics of a particular area and also the soil characteristics. In case of very slow rate of rain fall, most of the water infiltrates into the ground and in the case of heavy rain, less quantity percolates to the ground and more goes as runoff because it takes certain time for the water to get inside the ground or percolate inside the ground. If you do not give that time and if there is huge amount of rain fall, then it goes as run off. So, rainfall characteristics do play a role in the amount of ground water or amount of infiltration that happens.

Soil characteristics

Similarly, soil characteristics also have a large role. For example, infiltration directly depends on the porosity of soil. If the soil is highly porous with more percentage of sand, then infiltration rate is high. Porosity of soil refers to the percentage of the pores in the soil. If soil has more pores, there is more chance of water getting stored there or to get inside. In case of sand, infiltration rate is high whereas in clay it is low. This is due to the smaller size of these particles which makes it almost impervious. Therefore, size of particle as well as the pores within the particles determine what kind of water will infiltrate and eventually what kind of ground water will be there in that particular area.

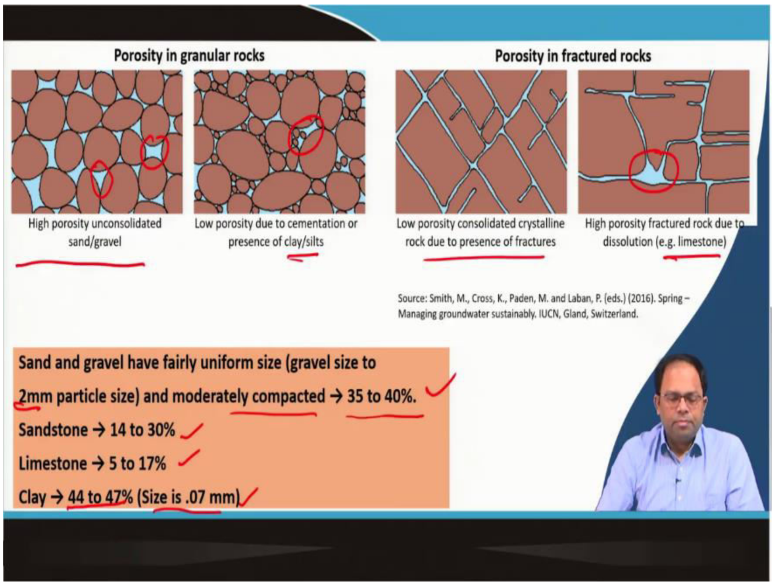
Porosity is defined as the percentage of voids present in a given volume of soil or aggregate. So, it is expressed using the following equation:

$$\textbf{Porosity (P)} = \frac{\text{Total volume of voids in soil}}{\text{Total volume of soil}}$$

So, if porosity is below 5 percent, then we call it small, if 5 to 20 percent, we say its of medium porosity and if its above 20 percent, it is of high porosity.

Therefore, the ability of water bearing stratum to store water depends on porosity and size of the particles. Sand and gravel are the important aquifers for public water supply where we can draw a lot of ground water.

(Refer Slide Time: 09:36)

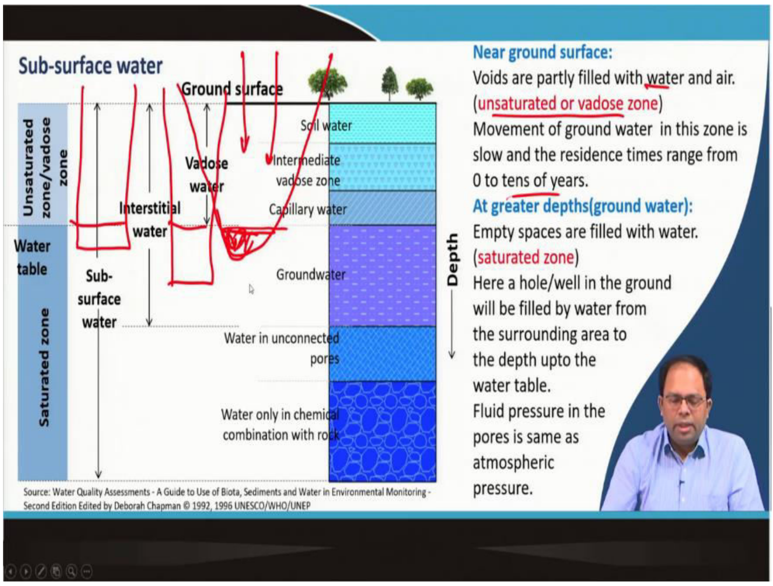


So, you can see over here that, this is sand and gravel. It is highly porous and these are unconsolidated and hence there are a lot of gaps in between the particles and these are of larger size. There is enough space for water to be stored. In the case of clay and silt, even though there are pores, porosity is low due to cementation or presence of clay silt.

Thus, if we have clay and silt then automatically even though this may be porous, but because of the small size the total amount of water that could be held in this particular soil is less. In case of rocks or stone we can see voids created in the rocks. You can see water held in low porosity concentrated crystalline rock due to presence of fractures. So, within the fractures of the rock the water is stored. Some stones have high porosity due to dissolution, i.e., some material is dissolved. Thus, more amount of space is created for storing water such as in case of lime stone. So, limestone can hold more water compared to other kinds of rock. So, let us see some of these values. Sand and gravel have fairly uniform size and gravel is larger up to 2 millimeter in size and sand is a little bit smaller. Coarse sand is around 2 millimeter and fine sand is around 0.5 mm. So, when this is moderately compacted, we can see porosity levels around 35 to 40. So, this is the porosity level of compacted sand and gravel. Similarly, sandstone has got a porosity level of 14 to 30 percent limestone of 5 to 17 percent and clay of around 44 to 47 percent.

Clay is highly porous, but because the size of pores is so low, around 0.07 mm, it is almost impervious. So, it is not only porosity, but also the size of particles that determines the amount of water that would be held in a particular aquifer.

(Refer Slide Time: 11:57)



Sub-surface water:

Let us see how water is stored in the ground. So, this image actually shows the entire sub-surface water. The top most part is the unsaturated zone or this is called the vadose zone. The water gradually infiltrates through this particular zone and then the zone below till we find the entire pores to be filled with water.

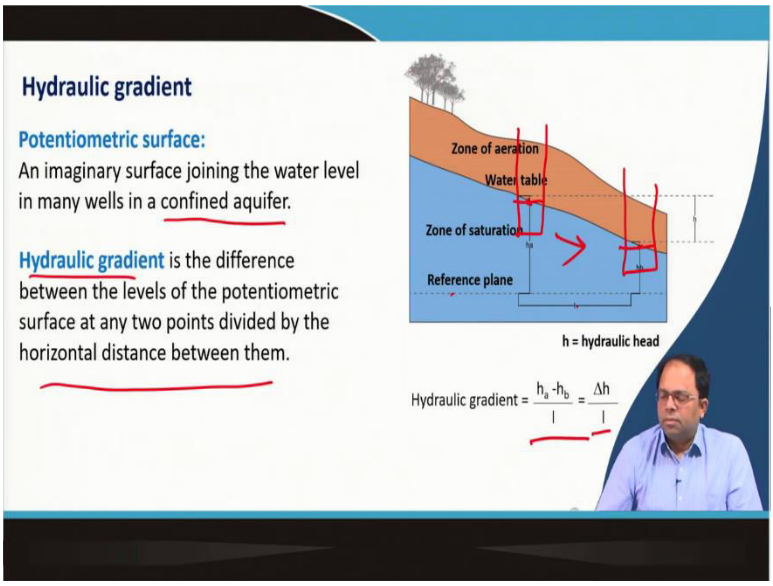
Water table is the level where the fluid pressure in the pores is same as the atmospheric pressure. So, at this point, the fluid pressure balances with the atmospheric pressure.

Near the ground surface voids are partly filled with water and air. Both water and air is present and this is the unsaturated or vadose zone. Movement of ground water in this zone is slow, and residence time ranges from 0 to 10 of years.

Depending on the kind of soil, it could be very fast or could be even years of time for the water to reach from one zone to another. Whereas at the saturated zone, we see that the empty spaces are completely filled. If we dig a hole or a well in the ground it will be immediately filled with water from the surrounding area to a depth up to the water table.

In many villages people dig some of the river channels and then they get water if they do not have any surface water source.

(Refer Slide Time: 14:25).



Hydraulic gradient

The next concept is that of hydraulic gradient. Now, as we know that water is not only stored, but water also moves inside the ground and this is determined by the hydraulic gradient.

So, hydraulic gradient is the difference between the levels of the potentiometric surface at any two points divided by the horizontal distance between them.

The water table is at different heights at different zones. An imaginary surface joining the water level in many wells is in a confined aquifer is called the potentiometric surface.

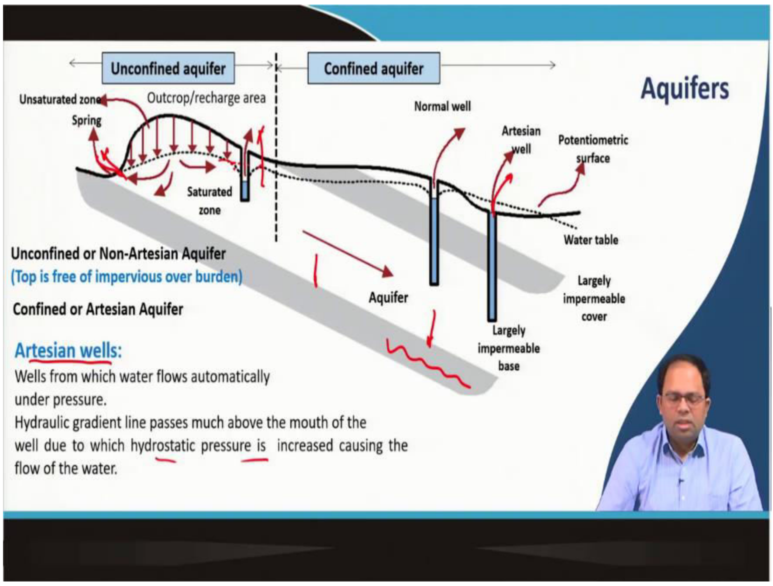
The hydraulic gradient between two place determines the flow of water; that means, water will flow from higher level to lower level, that means, the difference in between the levels of the potentiometric surface in both these locations and that determines the flow velocity.

So, over here you can see this is h_a, this is the level at which water is available, this is the h_b and this is the impervious stratum, this is the reference plane and divided by this distance, which is l and we get Δh by l which is the hydraulic gradient.

$$\text{Hydraulic gradient} = \frac{h_a - h_b}{l} = \frac{\Delta h}{l}$$

So, this concept is very important when we determine flow of ground water inside a particular surface.

(Refer Slide Time: 16:50).



There are two types of aquifers; confined and unconfined aquifers. So, in this image you can see that the first part is unconfined aquifer and the second part is confined aquifer. The grey band is the impermeable base and water cannot flow beyond it. This is the water bearing stratum. Above this is the saturated zone, but we have got another impervious layer above as seen in the slide.

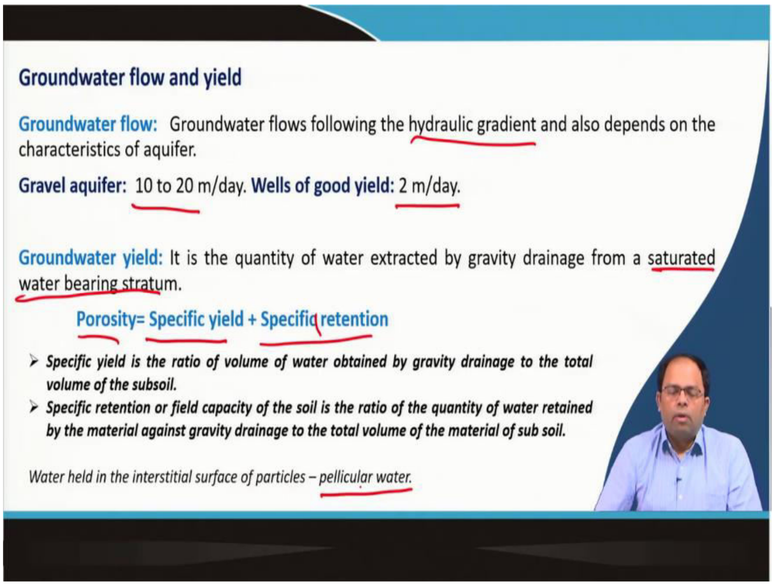
Therefore, a confined aquifer has an impervious layer above and below it whereas, an unconfined aquifer has no impervious layer on top.

So, the top is free of impervious layer in the case of non-artesian aquifer. So, these are the two other terms that we use; confined is also known as artesian aquifer and unconfined as non-artesian aquifer.

You can also see the level of water table in this particular image. So, what you see over here is, we have dug a well and of course, the water table would have been somewhere around here, but we are now pumping the water out so the water table will bend around this point and it will forms something called as a cone of depression which will be explained in the subsequent lectures.

In this particular case, because of the undulating surface of the earth, the potentiometric surface is above the ground level. Thus, if a well is dug here, you will see water automatically coming out. This is known as the artesian well. Artesian wells are wells from which water flows automatically because the hydraulic gradient line passes much above the mouth of the well due to which hydrostatic pressure is increased causing the flow of water. So, this kind of artisan wells are also possible and we also need to understand what are confined aquifers, and what are unconfined aquifers.

(Refer Slide Time: 19:18)



Groundwater flow and yield

Finally, we look into ground water flow and yield. Ground water flow is the flow of ground water that happens inside a particular aquifer depending on the hydraulic gradient of that particular aquifer. Thus, based on the hydraulic gradient we can determine in which direction and at what rate the flow will happen. We usually find in gravel aquifers the flow to be around 10 to 20 meters per day whereas, in case of wells of good yield it is around 2 meter per day. So, in normal wells we find a rate of flow 2 meter per day whereas, in gravel aquifers it is around 10 to 20 meters per day. So, that is the flow of ground water inside this particular aquifer.

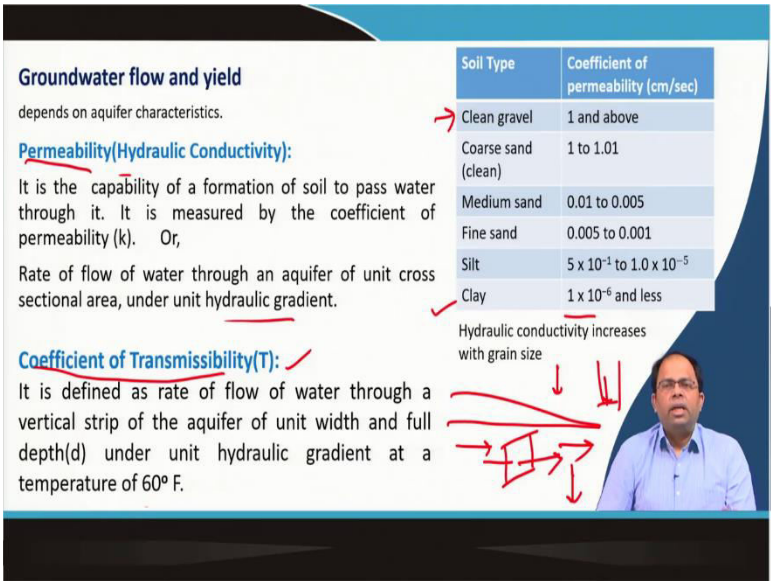
Now, ground water yield refers to the amount of ground water that we can extract from a particular aquifer. It depends on the quantity of water extracted by gravity drainage from a saturated water bearing stratum.

Because of the hydraulic gradient some amount of water starts coming out due to gravity. Similarly, some amount of water is retained or held back in the pores because of interstitial attraction.

Thus, porosity is composed of 2 parts; one is called the specific yield and the other specific retention. That means, how much water would be retained inside the pores and how much water would be coming out of the pores which together is the total volume of water that is being stored which is nothing but porosity.

So, specific yield is the ratio of volume of water obtained by gravity drainage to the total volume of subsoil; that means, if a well is constructed, the amount water coming inside that well from that surrounding subsoil or surrounding aquifer is the specific yield of that particular soil. Specific retention or field capacity of the soil is a ratio of quantity of water retained by the material against gravity drainage to the total volume of material of sub soil. So, this is the amount of water that will be held back inside the pores, because of other attraction forces. Water held in the interstitial surface of particles is known as pellicular water.

(Refer Slide Time: 22:21).



Next we look into two aquifer properties or characteristics of the aquifer, this is known as permeability which is also known as the hydraulic conductivity and the other is coefficient of transmissibility.

Permeability

Permeability is the capability of a formation of soil to pass water through it. So, it is measured by the coefficient permeability. Depending on the characteristics of a particular aquifer, certain amount of flow will happen at a certain speed.

Flow depends on the hydraulic gradient and the characteristics of the aquifer. In some aquifer it is higher and some it is lower. So, more the permeability, higher is the flow provided that we assume one unit hydraulic gradient and unit cross sectional area.

So, rate of flow water through an aquifer of unit cross sectional area under unit hydraulic gradient is permiability.

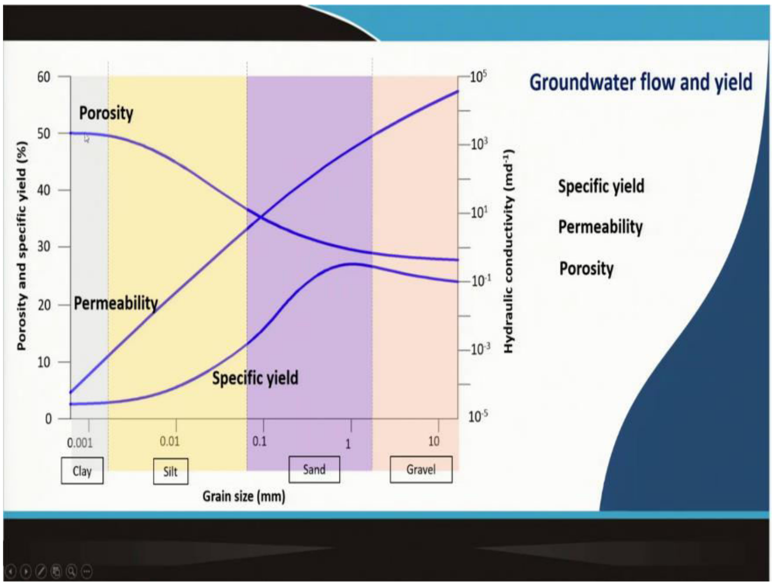
In the case of clean gravel, the coefficient of permeability is given in centimeter per second. For coarse sand it is about 1 to 1.01, medium sand 0.01 to 0.005, for silt 5×10^{-5} and for clay it is even less 1×10^{-6}. So, you can see that, in clay it is difficult for water to move. In silt it is also difficult, but in gravel and all it is much faster.

In addition to permeability which more or less determines the flow in horizontal direction, we need to determine how much water goes below. This is determined by the coefficient of transmissibility which is defined as the rate of flow of water through a vertical strip of the aquifer of unit width and full depth d under unit hydraulic gradient at a temperature of 60-degree Fahrenheit.

But, we are mostly concerned with permeability because we want to understand how much water enters into a well and sometimes we also need to determine the transmissibility which determines how much amount of water at what speed at what flow rate the water will go down after getting inside the soil.

So, for determining yield of a well or tube well, or for using ground water as an intake source for urban areas, we are concerned with permeability in most times.

(Refer Slide Time: 25:41)

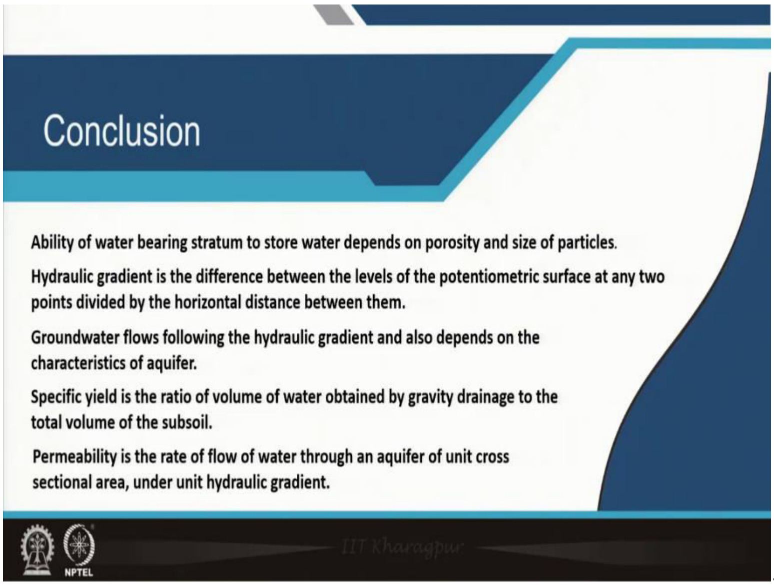


So, this is the graph which shows how for different particles or different kinds of soil, like clay, silt, sand and gravel these 3 parameters vary; porosity, permeability and specific yield.

So, you can see clay has 50 percent porosity. In case of gravel the porosity is lower. But for permeability which determines the flow rate of water inside the soil, clay has got lower value due to its lower grain size as we have already discussed. On the other hand, for gravel, the permeability is very high. So, even though porosity is lesser compared to clay, the permeability is much higher.

Similarly, specific yield refers to the amount of water we can get from an aquifer. For clay, it is very less and the value gradually increase for sand and marginally decreases for gravel. Specific yield increases for sand and gravel and permeability is also high that is why specific yield is high, but porosity is lower. Clay even though have higher porosity, have less specific yield and less permeability.

(Refer Slide Time: 27:38)



Conclusion

So, to conclude, ability of water bearing stratum to store water depends on porosity and size of particles. Hydraulic gradient is the difference between the levels of the potentiometric surface at any two points divided by the horizontal distance between them.

Ground water flows following the hydraulic gradient and also depends on the characteristics of the aquifer. Specific yield is the ratio of volume of water obtained by gravity drainage to the total volume of the subsoil and permeability is the rate of flow of water through an aquifer of unit cross sectional area under unique hydraulic gradient.

(Refer Slide Time: 28:16)

So, these are some of the references you can follow.

Thank you.