Engineering Geology
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Lecture - 25
Groundwater – Preliminaries

Hello everyone and welcome back. Today we are going to talk about the preliminary concepts of groundwater.

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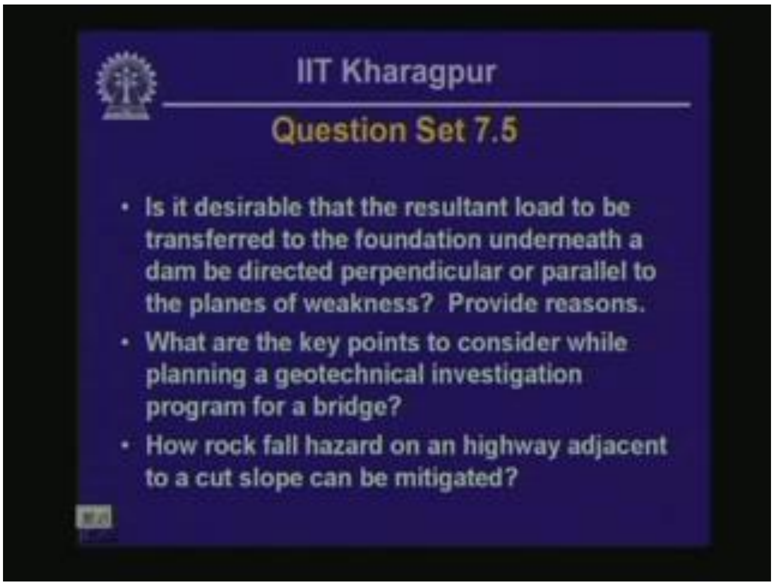

But before we take up the subject matter of today's lesson we are going to consider the look back at the question set that was given in the previous lesson. These are the questions. First one was is it desirable that the resultant load be transferred to the foundation underneath a dam be directed perpendicular or parallel to the planes of weakness? Now let us look at the configuration in order to essentially recapitulating the subject matter of previous lesson.

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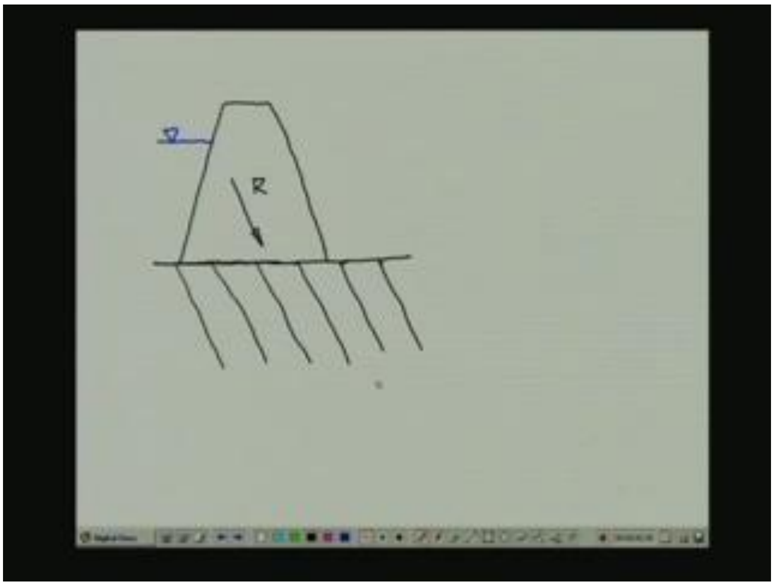

So, let us say we have got a gravity dam which is like this. The cross section of gravity dam is like this, and we have got water retained on the left side of the gravity dam. So, in this case the load to be transferred is going to be directed in this manner. So, this is going to be the resultant. Now we could have, for instance, bedding orientation of this type, and this is going to be the most favorable orientation. Because as we know from our previous discussions as part of this course that the available shear strength of rock is going to be more if it is subjected to deformation perpendicular to the bedding planes than in the direction parallel to the beddings.

So, the strength of the rock that can be mobilized in this particular case is going to be maximum. On the other hand if we had the bedding orientations like this, the shear strength available is going to be minimal. So, we prefer that the resultant is oriented in a direction perpendicular to the direction of beddings for the safety of the dam. Now let us look back to the question set once again. The second question was what are the key points to consider while planning a geotechnical investigation program for a bridge?

Now in this case what I mentioned in the previous lesson was that the low transfer mechanism similar to the way load is transferred in case of a dam. So, it is preferable that we have got the orientation of the resultant of the load to be transferred to be perpendicular to the bedding direction, number one. And the second thing that needs to be needs to be emphasized at this point is that the areal extent over which bridge foundations transfer the load is relatively small in comparison with the dam to foundation contact.

As a result, we need to be really worried about the local variability of the load bearing stratum. So, we need to have a very clear notion from the geotechnical investigation that precedes the bridge design is that what is the variability of the contact between the non-load bearing over burden and the load bearing foundation soil or rock. Now in order to illustrate the problem let us consider a case like this.

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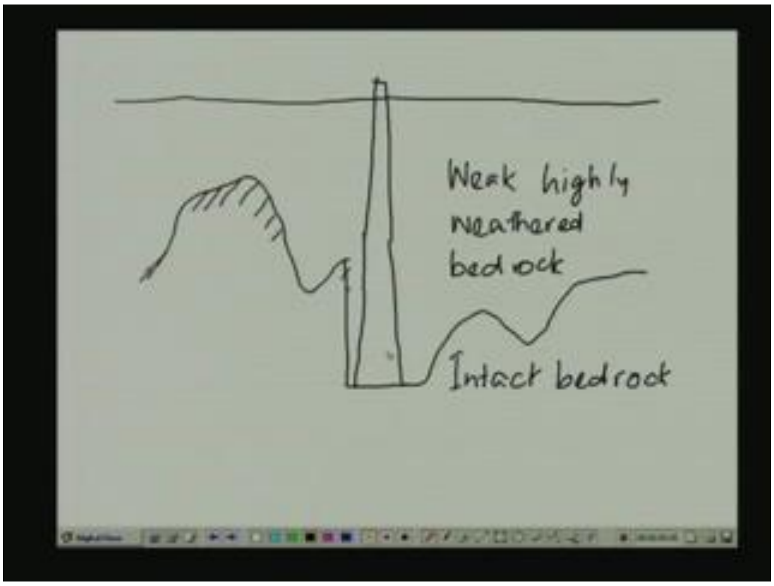

Let us say the bedrock surface is weathered in a very irregular manner. So, this is the surface of the intact bedrock. Now the overburden on top of this intact bedrock is relatively weak; let us call it weak highly weathered bed bedrock. And this one is intact bedrock, and our purpose in this case is to transfer the load to the intact bedrock. Now let us say the bridge foundation comes and rests at a location like this. If we had the bridge construction not properly planed, we could have a location of bridge pier which actually rests on bedrock at such a configuration.

Now this configuration you can easily say from intuition that this particular configuration is not going to be safe at all. And what we need to do if we do not want to laterally shift the location of the bridge foundation, we need to excavate the bedrock to a level like this. And we need to place the pier; we need to bare the pier at a deeper location like that in order to ensure stability. So, we need to be worried about the local variability of the load bearing stratum in terms of the elevation differences in case of a bridge foundation.

Now the third question that was asked on highway adjacent to a cut slope can be minimized. We talked about several different procedures in our previous lesson. Now the first one was that we have to have a protective barrier; for instance we could have fencing on the upper portion of the cut slope like this.

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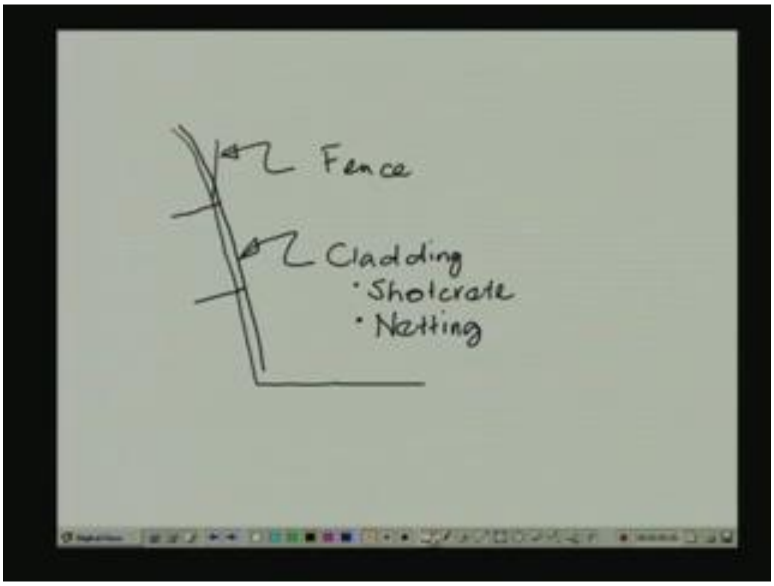

Let us say we have got a cut slope overlooking a highway oriented in this manner. So, we could have a fence. So, this one is a fence. We could have a cladding such as netting; for example rock fall containing netting which is secured on the face of the cut slope in that manner or we could have a shotcrete cladding. So, this could be either a shotcrete cladding or we could have a rock fall protection netting. These are the options.

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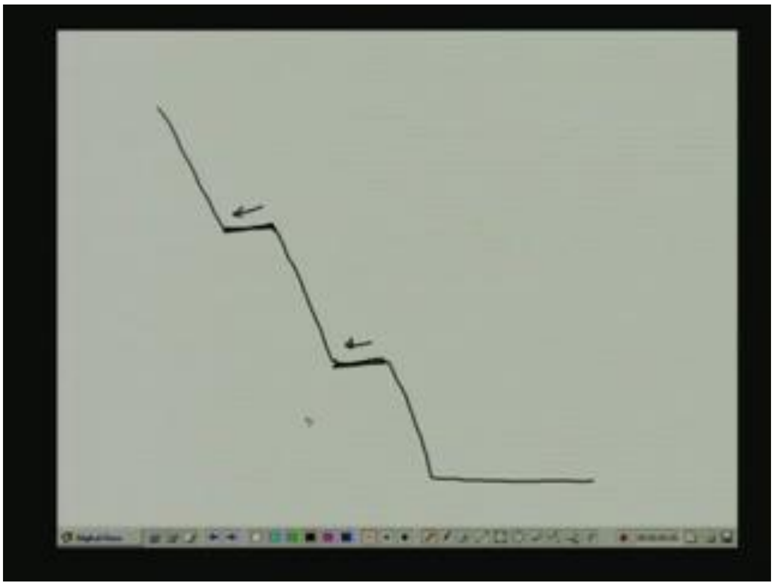

Alternatively, what we could have is that we could flattened the slope, and we could have several intermediate benches above the road cut; that is also going to retain the incidental debris that may fall from the face of the slope, and what is done? These benches are sloped away from the road cut. So, this slope in this direction that actually tends to retain the following debris. So, these are the different options that you could think of while designing a highway adjacent to a rock slope which has got some rock fall hazard associated with it.

Also we could have nailing, we could have rock bolts to secure the potential unstable rock masses; that also is going to control or mitigate the rock fall hazard. So, these are the answers of the previous day’s question set. Now we move on with today’s lesson.

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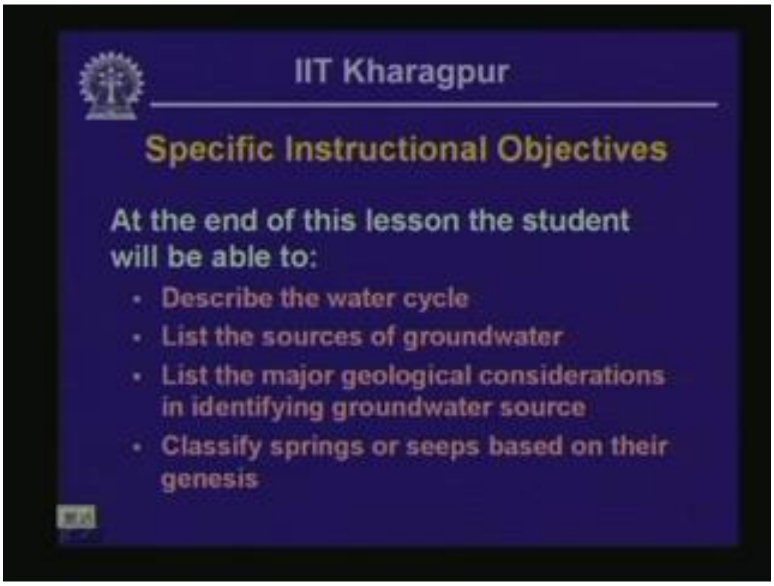

So, what we want to accomplish at the end of this lesson? We would like to be able to describe the water cycle; this was called water cycle where we should be able to list potential sources of groundwater. We should be able to list the major geological considerations in identifying groundwater sources. And finally, we should be able to classify springs and seeps based on their genesis.

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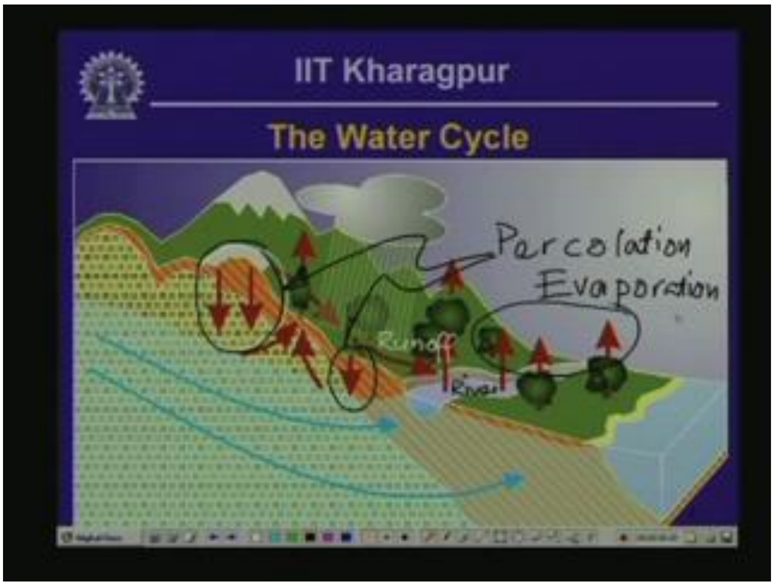

Now with that said we first look at the sources of groundwater, and this particular cartoon shows you the sources of groundwater. Now you can see what are the sources of groundwater. Major sources of groundwater include precipitation; it could be in the form of rainfall or snowfall. And then once the precipitation hits the surface depending on the permeability of the surface soils and rock, a portion of the water that precipitates is going to percolate through the formation. And it is going to get into the underground layers; a portion of which might be available for use. And another portion of the water that precipitates on the surface is going to flow down slope in the form of runoff.

So, this one here, this one here is the percolation that we just now talked about infiltration and percolation. Then a portion of the water precipitating on the surface is going to actually move down slope and directly recharge some surface streams. And then what is going to happen? There might be evaporation taking place from the surface of the water bodies such as a river as shown here or there could be evapotranspiration from the water tapped from underground by vegetation. And this evaporation is again going to lead to the formation of clouds via condensation, and that cycle is going to repeat. This particular combination which we just now talked is called the water cycle. Now water cycle is then associated with the groundwater that is available for human use.

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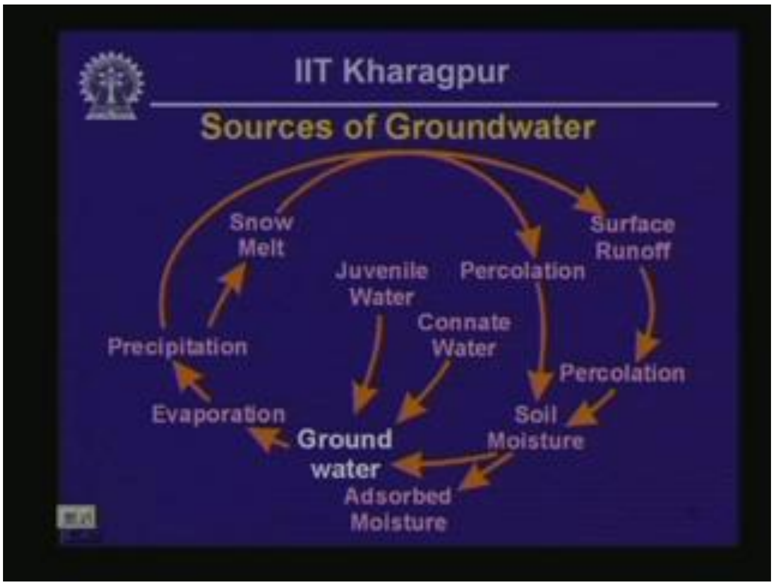

Now this one here is a more formal representation of the water cycle that we just now learned. So, as we stated before we can have precipitation in the form of snow or in the form of rain, and that precipitation a part of it is going to percolate underground. And a portion of it is going to flow on the surface down slope to a water body, and from the water body in turn percolation could take place. And these processes actually are going to lead to an increase of proportion of soil voids composed of groundwater.

In other words, soil moisture would increase; a part of the soil moisture is going to be available in the form of groundwater. And another part is going to be locked within the matrix in the form of absorbed moisture, which is tightly held by chemical bonds on the surfaces of the soil particles. And another part is going to be unavailable for use because there are going to be trapped within non-interconnected soil voids as we are going to see in the next little bit.

There are two other sources of groundwater; we need to consider those two sources as well in order to complete this discussion. One of it is what is called juvenile water, and this is the water that is released directly from magma during the formation of the rock itself. And that might also get trapped within the mass of subsurface formations, and there is another source of groundwater which is called connate water, and this particular water gets trapped within the sediment within non-interconnected voids in fact. And this water can remain trapped even after the sediment lithifies a sedimentary rock forms out of that process.

So, these are all the sources of groundwater, and how groundwater gets recycled? Evaporation might take place, and that in turn is going to lead to precipitation or a portion of the groundwater might, in fact, be trapped for human use. So, this one gives you a more elaborate description of the water cycle that we talked a few minutes back using the sketch of the previous slide.

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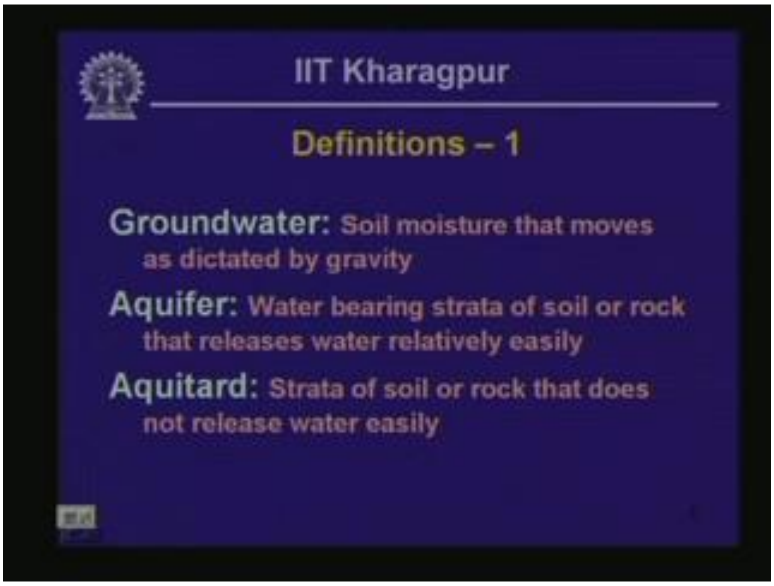

With that stated we can move onto a few definitions. Now what is meant by groundwater then? So, groundwater is essentially a portion of soil moisture that moves relatively easily as dictated by gravity. Then the second definition that you need to consider here is definition of aquifer, what we mean by aquifer. Aquifer is a water bearing layer of soil or rock that releases water relatively easily. So, if you have got a permeable mass of soil or rock which is saturated, essentially that can be called and that can be described as an aquifer.

Then we need to define aquitard. This one is also water bearing; it is also a stratum of soil or rock that can be water bearing, but that water is not released easily. For instance, if we have got a massive saturated layer of clay that might contain a lot of water if it is saturated; now that layer, however, will not release water which is locked in the interstitial space easily upon pumping. Why that is so is because of the fineness of the void space; if we recall from our previous discussion, clay is a fine grained soil.

So, the void space in between individual clay particles is also going to be of very small diameter, because of the fineness of these pathways, the water held within the interstitial void space is held strongly by capillary action. And it is very very difficult to indeed in order to tap that particular moisture from the layer of clay. So, this particular geologic unit fits the definition of aquitard. You can have several other examples of aquitard as we will consider in the next little bit.

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More definitions, definition of aquiclude. Aquiclude is essentially impervious stratum of soil or rock through which no groundwater flow can take place to any practical extent. Another definition, definition of the vadose zone. Vadose zone is the layer of soil or rock which is above water table, and then the definition of capillary fringe. There will be a layer of soil or rock above water table. Water table is essentially simply stated actually water table is the surface of saturated soils, and above that zone of saturation we have got essentially partially saturated soil.

Now capillary fringe is a layer of soil which is partially saturated above water table, and this particular layer gets partially saturated is because of capillary rise of groundwater through this layer. Now if we have got very fine grained soils, then that particular soil can, in fact, be substantially saturated even if we are considering an element within capillary fringe. So, what we are going to have in such a case is that a layer above water table is also for all practical purpose is going to be saturated.

So, we need to actually alter the definition of water table a little bit. By water table then what we are going to mean is a surface below at which the groundwater exsits at atmospheric pressures. So, that is an alternative definition which fits well once you consider the saturation that may be possible in case of fine grained soils because of capillary rise. Now let us get back to the sketch that we considered a little bit earlier in order to illustrate all these concepts.

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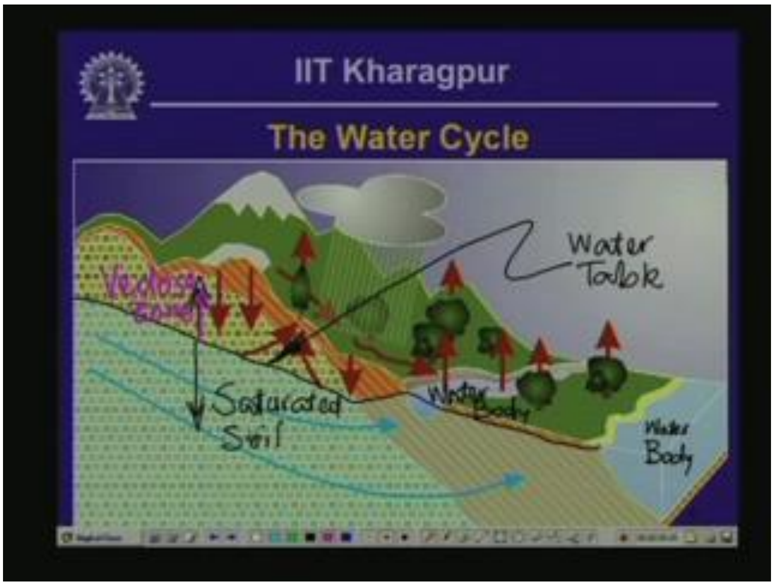

Now in this particular sketch, this one here is the water table and here we have got a water body here, and this one is another water body as we have already stated, because at these locations actually the water table day lights or it cuts through the surface topography. So, this one here is our water table. Below water table we have got saturated soil, and most of the groundwater that flows from one location to another we will look at it in detail later on, but I just wanted to introduce the concept here.

Most of the flow that takes place of groundwater takes place through the zone of saturation, and above water table is the so-called vadose zone. So, that is a layer of unsaturated soil; a portion of vadose zone can be partially saturated because of capillary rise as we have already discussed. Now let us get back to where we were. Learnt, covered all the definitions that are required for the preliminary concepts of groundwater hydrogeology.

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Now what we have already learned also is what is meant by soil moisture to some extent in order to formulize the concept, we have got this list. Now what is soil moisture then? Soil moisture is that portion of groundwater which exists within the pore space of soil or rock which can move under the action of gravity; a portion of soil moisture actually a portion of underground water can move under the action of gravity, and that is called groundwater. And also we have learned a portion of soil moisture. It cannot move under the action of gravity, and this is the portion of moisture which is absorbed on the surface of the soil solids or the water which is locked within isolated pore space.

This particular proportion of soil moisture is not useful as far as human need is concerned. There is another portion of soil moisture which is relatively mobile, but it can be extracted with great difficulty. And this is the water that is held within very fine interconnected pore space which is like a capillary tube of very fine diameter. And because of the capillary tension involved in this particular case, it takes a lot of effort to tap this portion of groundwater, and this portion of soil moisture is also, therefore, not very useful.

So, soil moisture is composed of three different components. One portion which flows relatively easily, and that is the groundwater which is useful for human consumption. Then there is another portion which is trapped within non-interconnected pore space or absorbed. This is not useful thus, and there is another portion of soil moisture that is relatively mobile but held under strong capillary tension. And these last two components are not useful, and therefore should not be considered as part of groundwater.

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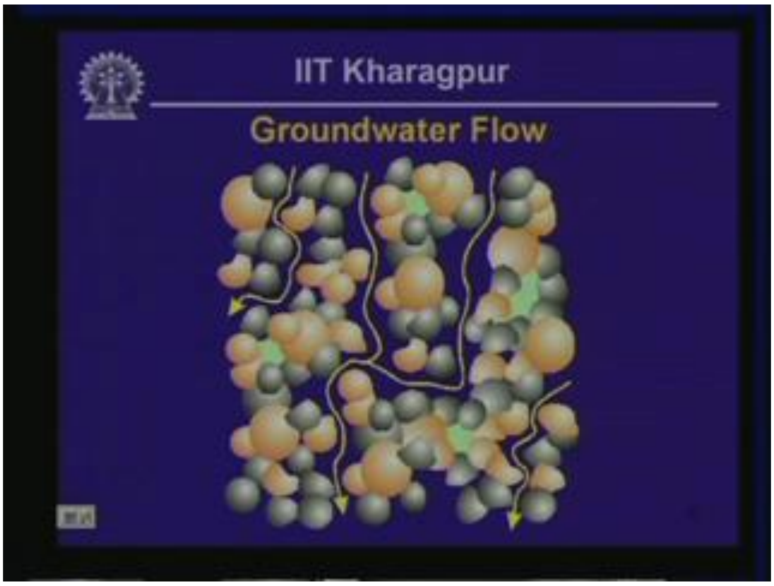

Now with those concepts we look at the process how groundwater flows from one point to another. Now let us consider a matrix of solid particles of that type, and you can see that there is a lot of void space in between the solid particles. And some of these void spaces are interconnected and cuts right through the matrix. So, these are the void spaces that are going to take part in conducting groundwater flow indicated by the yellow arrows there. And then there are some pore spaces which are isolated, and they are not interconnected.

So, these pore spaces although if they are saturated, these pore spaces will not conduct groundwater. They will not participate in groundwater flow. We have not shown the absorbed moisture which is going to be held by electrical bond on the surface of individual soil particles in this particular cartoon. But that portion of soil moisture as we have already stated is also not going to be consider useful source of groundwater, okay.

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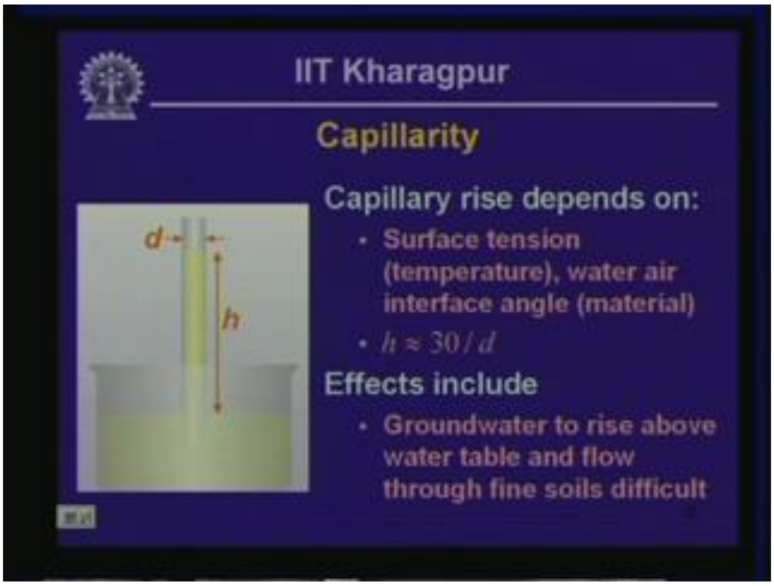

Now another concept which we have already looked at informally and that is the concept of capillary rise. So, what is meant by capillarity is explained in this particular slide. Now let us consider a bowl of water as shown on the left, and let us say we insert a vertical tube of a relatively small diameter into that particular mass of water like shown on the slide there. So, what is going to happen? If you do that, water is going to rise through the tube as shown in that animation there.

So, the amount of rise of water is going to be controlled by several factors. One of that is the diameter of the tube, and the other factors depend on the property of the fluid and the interface between the fluid and the tube through which the fluid is being conducted, okay. So, capillary rise then depends on the surface tension, and because of the fact that surface tension of water depends on temperature. So, the amount of capillary rise will also depend on temperature, and it depends on water air interface angle, and this is a material specific value.

Typically though you can say that the height of capillary rise is approximately equal to 30 divided by the diameter of the tube through which the capillary rise is taking place. And we have learned already what are the effects of capillary rise, because of capillary rise groundwater can rise above the water table. And because of capillary action we have also learnt that flow through fine grained soils is very difficult, okay.

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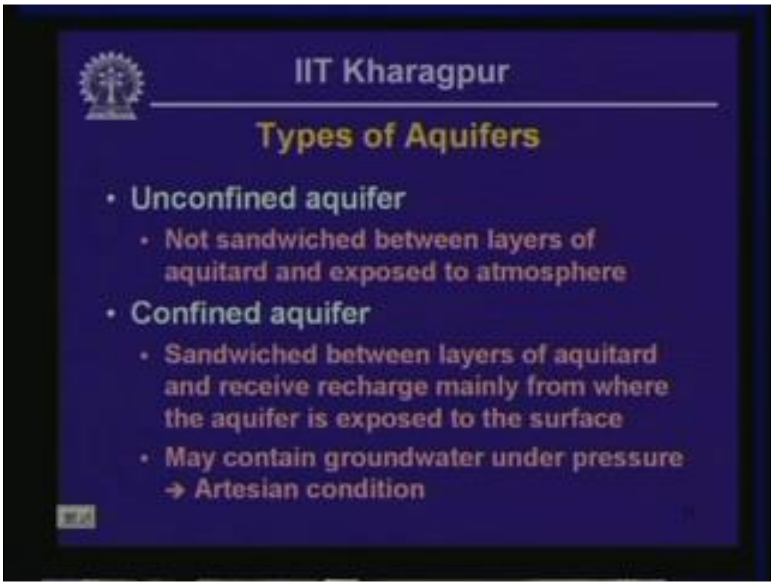

Now we consider the types of aquifers. As we have learned from the previous portion of this particular lesson, by aquifer what we mean is it is essentially a saturated mass of subsurface formations soil or rock which conducts groundwater flow relatively easily. So, aquifers are essentially of two types; one of them is called unconfined aquifer. Now unconfined aquifer is not sandwiched in which in between layers of aquitard, and the aquifer is essentially exposed to atmosphere at some recharge point. Because if the aquifer is not exposed to the atmosphere at least locally, then it is not going to be recharged by infiltrating groundwater and it is not going to be classified as aquifer at all.

Then the second type of aquifer that we can consider here is confined aquifer. Confined aquifer is essentially a water bearing layer which conducts groundwater flow relatively easily. And this particular aquifer is sandwiched in between layers of aquitard, and this aquifer receive recharge only locally where the aquifer is exposed at the surface as we have seen earlier. And confined aquifer often contain groundwater under pressure, and such a condition is called an artesian condition as we are going to see in the next little bit.

So, we have got two types of aquifers then. One is unconfined aquifer in which the aquifer is not sandwiched in between aquitards at the top as well as the bottom. And alternatively, you could have confined aquifer in which you have got an aquifer which is sandwiched both at top and bottom by aquitards.

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Then before we look at the artesian groundwater flow, we are going look at it later on; we first consider how we get groundwater potential. So, groundwater potential depends on how easy it is for groundwater to move through the underground formation. So, it depends on the homogeneity of the soil or it depends on the homogeneity of the subsurface formation which contains groundwater. And what is better is that the grain sized distribution of the water bearing formation should be poorly sorted.

In other words the grain sizes would be quite similar; grain sizes that compose the aquifer would be quite similar. And there should be relative absence of impervious lenses within the mass of the aquifer. So, that tells us that if we have got for instance a poorly sorted deposit of gravel; for instance, a glacial outwash deposit formed by glacial outwash process. That type of soil formation if it is saturated with water is going to act as a good source of groundwater.

So, on the other hand if we have got an alluvial fan if you recall from a lesson that we did some time back, alluvial fan can have representation of several different grain sizes. And it might have even silt size lenses that are relatively impervious. So, that type of soil do not act as a very good source of groundwater. And on the other hand, if we have got very thick massive formation of lacustrine clay that is not going to conduct groundwater at all and for all practical purposes such a deposit can be considered as an aquiclude, Then second point to consider here while considering groundwater potential of a deposit is that the formation preferably should have large interconnected pore space, low tortuosity; that means the interconnected pore space should be aligned without much deviation from straight line. Then partial saturation actually makes a soil relatively impervious is because of capillary tension that develops within the pore space of such deposits.

So, what we want then in case of having an aquifer with the good groundwater potential? We want to have relatively coarser grain matrix which is relatively loose, so that the void space is quite large, and the soil particles within the coarse grain deposit would be of similar size. Then we should have the soil to be completely saturated and the wide space should be interconnected with small tortuosity. And you also need groundwater availability to have good groundwater potential if a soil deposit that meets all the things that we discussed in the previous list, but it has got no possibility to get recharged with groundwater.

Then that particular volume of soil cannot act as a potential source of groundwater, and an example of such a groundwater source is the source of connate water and juvenile water. They often do not have any chance of groundwater recharge; as a result, they cannot act as long term source of groundwater use.

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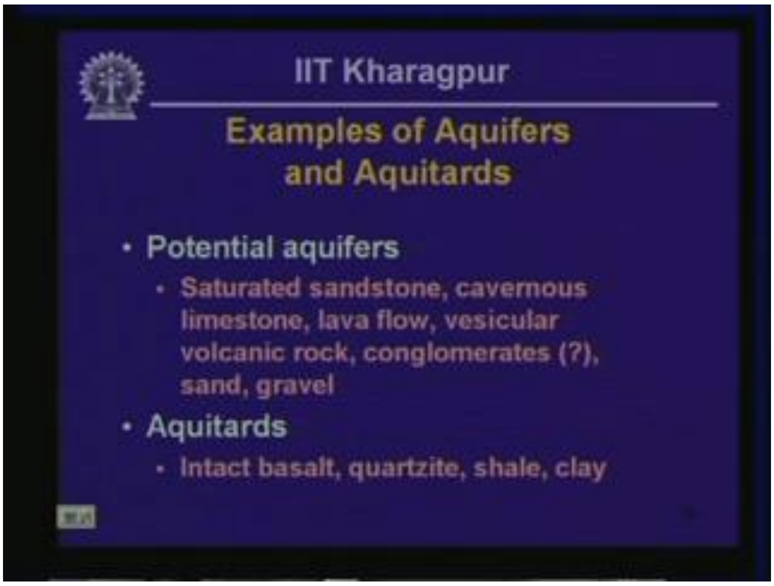

Some examples of aquifers and aquitards as we have just elaborating on the concept that we introduced in the preceding slide saturated sandstone which is relatively poorly compacted; cavernous limestone which has got solution cavities and channels, lava flow, vesicular volcanic rock, some conglomerates which is poorly compacted, and unlithified sand and gravel. They are considered potential sources of aquifers, because all these geologic units they have got large pore space which can conduct groundwater flow.

Second is the types of aquitards intact basalt, quartzite, shale and clay are some examples of aquitards, because if they are massive and if they are relatively free from planes of weaknesses such us joints, shear zones and falls; they are not very good conductors of groundwater. But often time what happens? You do not have any rock that is completely free from joints and fracture zones.

So, you might have some limited supply of groundwater because of the presence of those imperfections within the mass of rock such as intact basalt, quartzite, shale and clay as we have quartzite and shale and by clay here what I meant is unlithified deposit of clay as opposed to clay stone.

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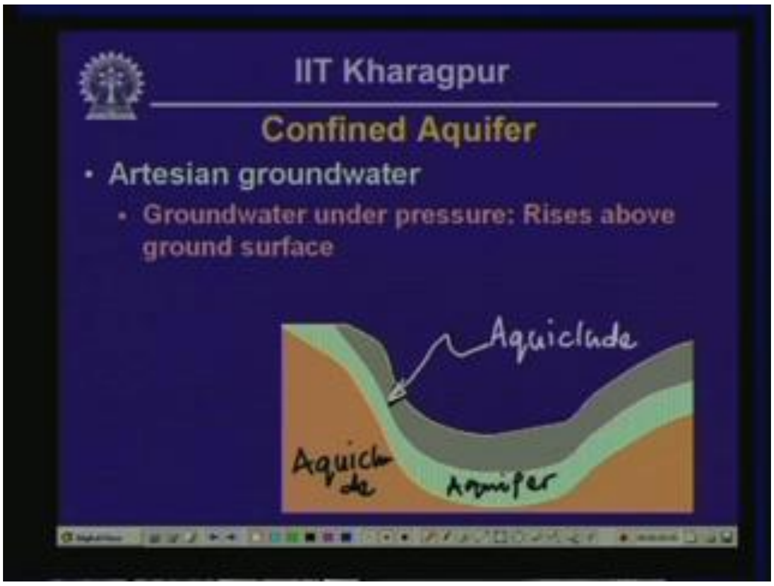

Now getting back to confined aquifer to introduce the concept of artesian groundwater. As we have already learnt artesian groundwater is groundwater under pressure, and because of the pressure it actually rises above the groundwater surface.

Now let us consider an example here. Let us consider a lithology of this type where you have got an aquiclude at the surface. Then our aquifer in this case is sandwiched between two layers of aquicludes. So, this one is also another unit that fits the definition of aquiclude. So, the aquifer in this case is a confined aquifer. You just notice now that the aquifer is exposed to the surface on the left flank of this particular valley upslope.

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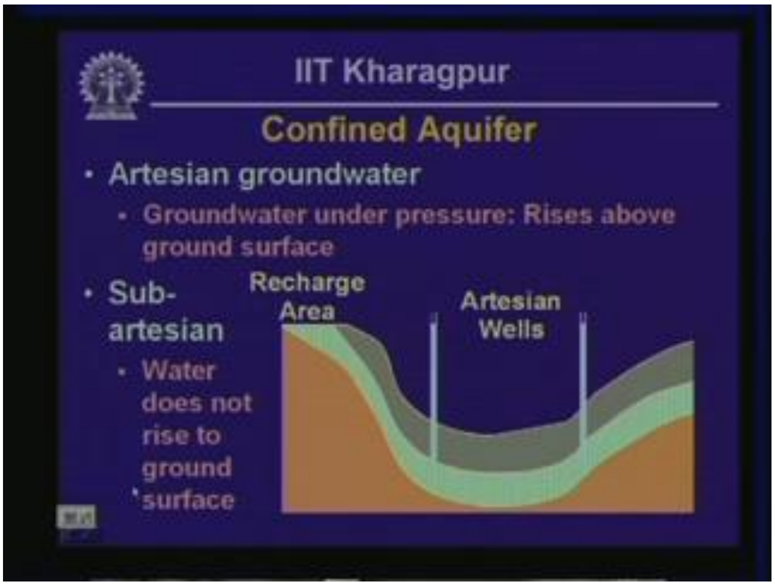

And this is the location from where the aquifer is going to receive groundwater recharge, and now if we install water wells into the confined aquifer, the water surface is going to be rising to the level to which the aquifer is completely saturated or the recharge level for instance. So, this particular aquifer is going to be called an artesian aquifer. And the wells that we installed there are called artesian wells. You could also have sub-artesian groundwater in which the water does not rise to the ground surface. It remains below the ground surface, although the groundwater is under pressure.

So, for instance if we had the water rising in this particular illustration to a level up to here which is below the ground surface, then the wells are going to be called sub-artesian water wells, and the groundwater condition is going to be called sub-artesian groundwater condition.

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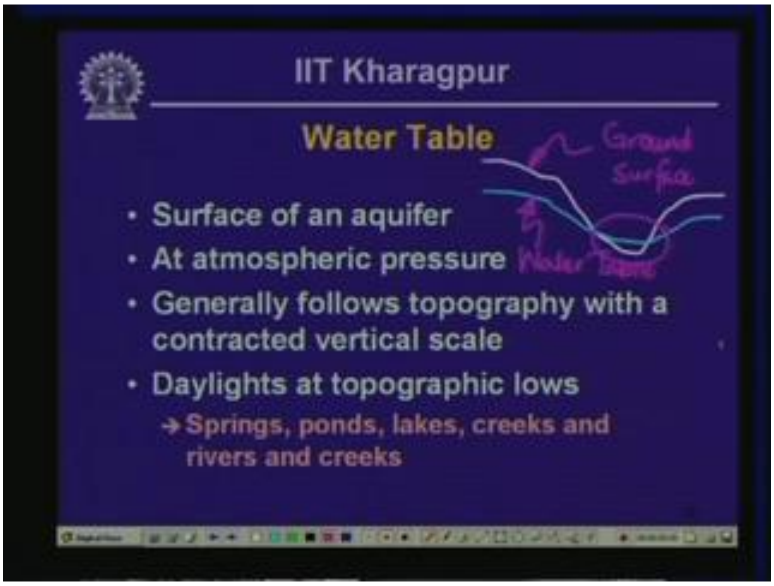

Now definition we have already looked at this concept little bit earlier, definition of water table. What is a water table? Water table is essentially surface of an aquifer which is at atmospheric pressure. Water table generally follows the local ground surface topography although at a contracted vertical scale. Now water table because of the fact that it follows the topography at a contracted vertical scale, it is going to get exposed to the ground surface at isolated locations. So, these locations typically are lead to the formation of springs, ponds, lakes, creeks and rivers.

Let us look at what I meant by this. Let us say we have got a topography like this. And as we suggested the water table in this case is going to follow the topography but at a reduced scale. So, this one here is the ground surface. So, this is our ground surface, and this one is our water table. Notice that at this location because of the fact that it follows the ground contours at a contracted vertical scale at the location of the valley; the groundwater is likely to get exposed to the surface. And this is the location which might lead to the formation of a water course or a spring or a seat or a lake. So, that is the explanation of what I meant there.

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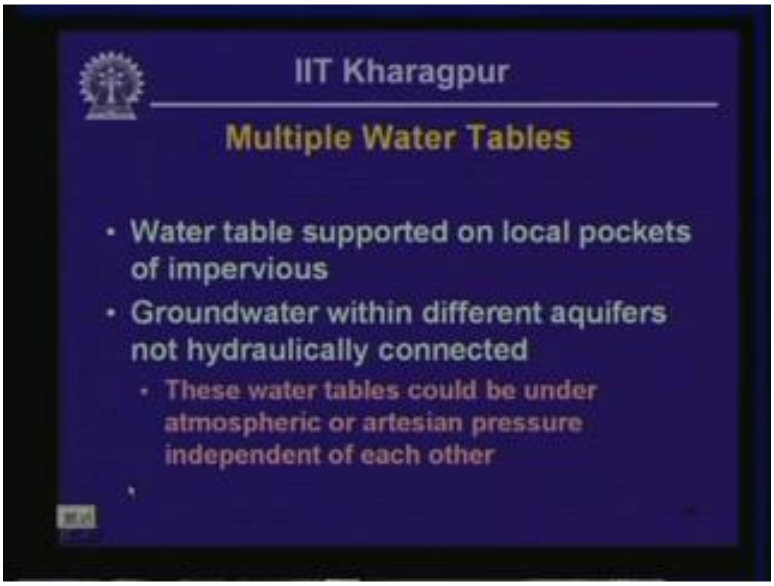

You also should notice that there could be multiple water tables because of the fact that water tables can be supported on local pockets of impervious layers. And groundwater also can be conducted within different aquifers that are not hydraulically connected. These individual aquifers might be in a state of atmospheric condition or there might be independent water table developing within these aquifers, or some of them might be under artesian pressure. And because of the fact that they are not hydraulically connected; each of these conditions are going to develop independently of the conditions within the other aquifers.

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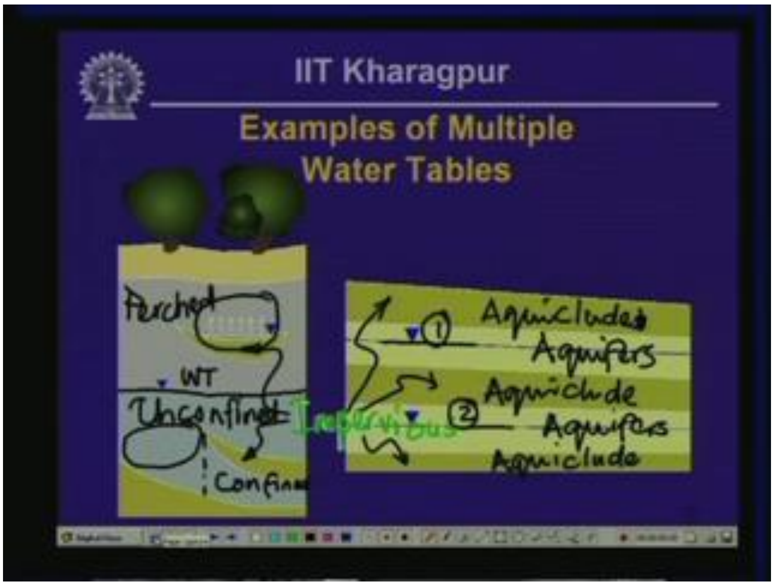

To illustrate what I meant I have got two cartoons here; on the left you can see that there are impervious layers indicated by a greenish shed. So, these are impervious layers and on the impervious layers might be supported an isolated source of groundwater, and this type of groundwater is called perched water table that is. You can have another groundwater which is exposed like that which is below the surface of the zone of saturation of water table like that. So, that is called unconfined aquifer actually. So, this one is an unconfined aquifer. Then this portion of the aquifer is sandwiched by two impervious layers.

So, this is going to be a called a confined aquifer, but this confined aquifer is connected to the unconfined aquifer which is above it in this by hydraulic connection in that area. Now let us get to the cartoon on the right. Here we have got aquiclude layers like this and in between these aquicludes or aquifers which has got independent groundwater table. So, this one is groundwater table one, and that one there is groundwater table two. And these two aquifers are not hydraulically connected. So, these groundwater tables are going to be under independent pressure conditions.

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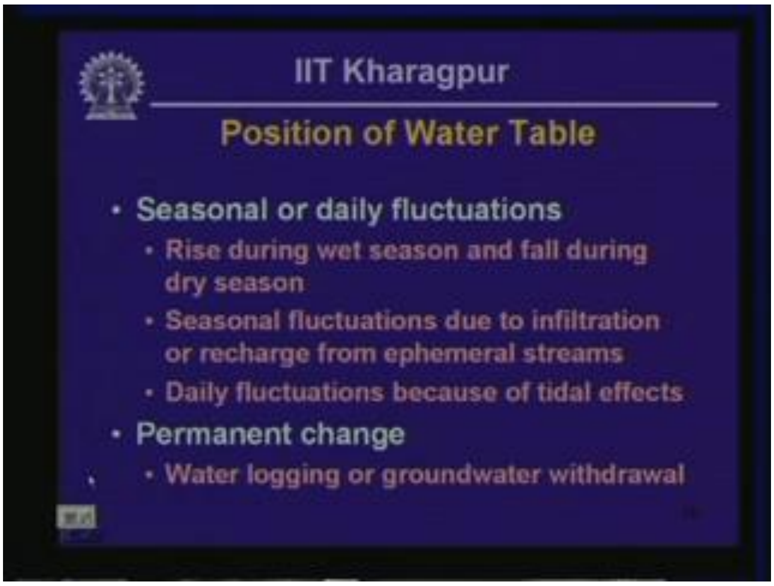

Position of water table can fluctuate seasonally, and it will rise during wet season, and it will fall during dry season. And seasonal fluctuations can also be because of infiltration and recharge from temporary streams of groundwater. And there could be daily fluctuations also, because of tidal effects or there could be permanent changes in groundwater table because of water logging or because of groundwater withdrawal exceeding the rate of groundwater recharge.

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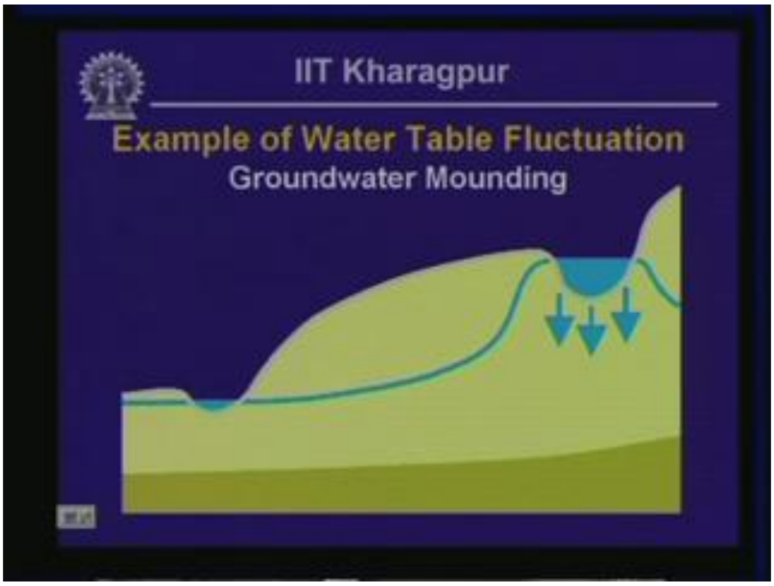

Now, let us look at a cartoon showing the groundwater fluctuation. This is, in fact, going to illustrate the situation called groundwater mounding. Now let us consider a stream that flow upslope on a hilly area, and this stream is a temporary stream that runs only during wet season only after snow melt. So, once the stream becomes full, what happens? Because of recharge the groundwater table is going to rise in that manner, and what you are going to have is a temporary rise of groundwater table. And then after the stream dies, the groundwater is going to get back to the original lower position.

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Springs and seeps as we have discussed they originate because of the appearance of groundwater at a point on the ground surface or over an area. In the first case we are going to have a series of springs, and in the second case we are going to lead to the development of groundwater seeps. The type of springs and seeps are going to be because of water table exposure as we have discussed there, or there could be contact springs or seeps where groundwater is conducted on top of slopping aquicludes, or there could be karst springs which is because of subterranean water channels that is conducted between limestone cavities, or there could be structural springs that arises when joints get exposed at the surface in a jointed rock mass terrain, and the joint is water bearing. So, these are the different classes of springs and seeps that may arise at different locations depending on the geologic and structural characteristics of the subsurface formation.

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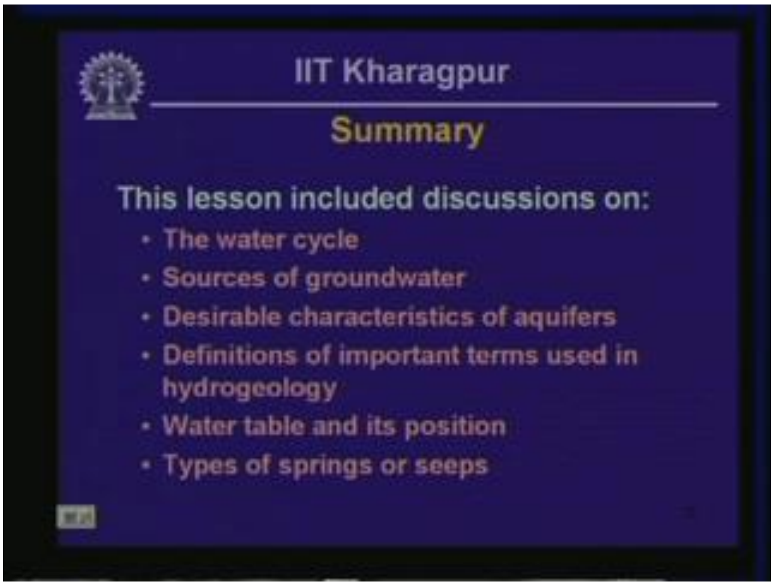

Now we want to summarize them. This lesson we considered some introductory concepts associated with groundwater hydrogeology looked at water cycle looked at different sources of groundwater. Looked at a list that gives the desirable characteristics of aquifers, definitions of important terms used in hydrogeology, water table and its position, seasonal fluctuation of water table, and finally, we looked at a list of the types of springs and seeps.

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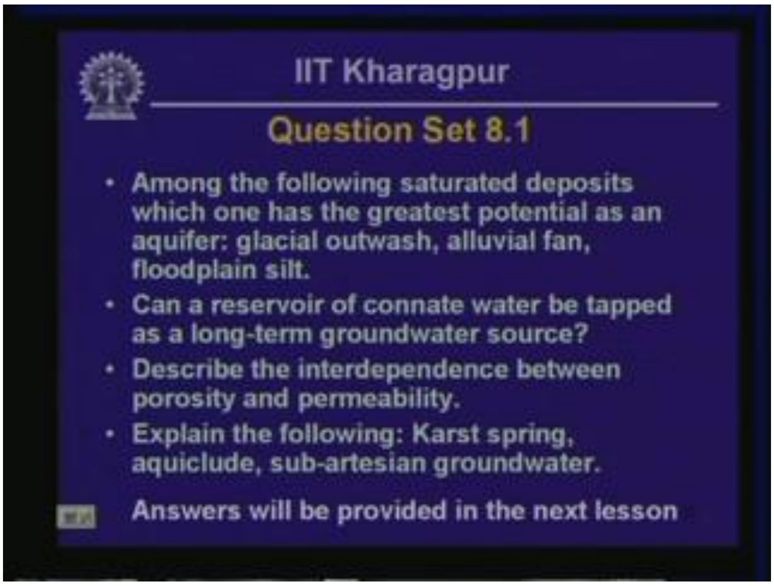

We wrap up this particular lesson with the question set. The first question is among the following saturated deposits which one has the greatest potential as an aquifer: Glacial outwash, alluvial fan, floodplain silt. Second question, can a reservoir of connate water be tapped as a long term groundwater source? Third question, describe the interdependence between porosity and permeability. And the fourth one, explain the following terms: karst spring, aquiclude and sub-artesian groundwater.

Try to answer these questions at your leisure when I will give my answer when we meet with the next lesson. So, until then bye now. Hello every one and welcome back. We are going to talk about ground water flow in today's lesson. But before we get on with ground water flow, let us look at the question set of the previous lesson.

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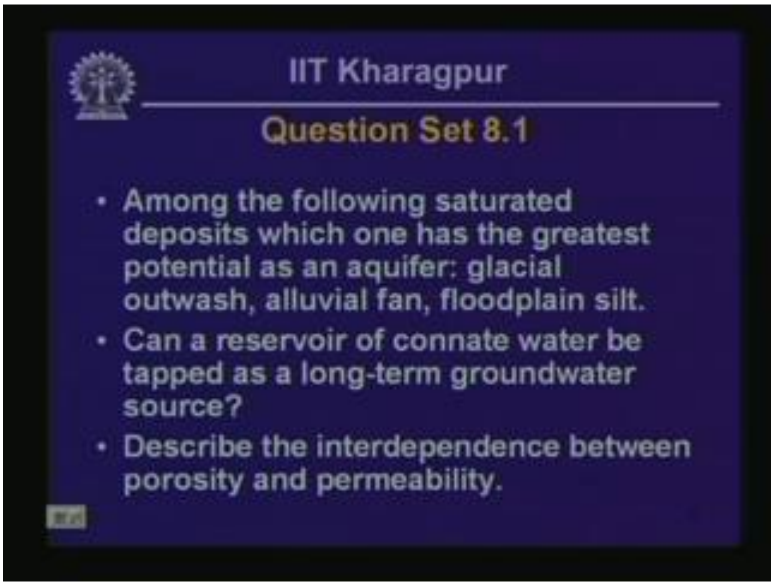

The first question that I gave you last time around was among the following saturated deposits which one has the greatest potential as an aquifer? The three deposits are glacial outwash, alluvial fan and floodplain silt. Now if you recall from our previous lesson, what I said was that in order for the geologic unit to qualify as an aquifer, we need to have fairly coarse grain-size structure of the geologic unit. And as a result what we are going to get is we are not going to prefer floodplain silt, because that is going to have a relatively small permeability. It is not going to conduct ground water quite that easily. So, we are left with the other two alternatives.

Now the glacial outwash and the alluvial fan, among these two alluvial fan is heterogeneous. It is going to have distribution of grain size; grain sizes have got a very wide range. It is going to have gravel size particles to silt size particles, and there might be in fact lenses of silts within the mass of alluvial fan which is going to impede drainage in the long run.