Groundwater Hydrology and Management
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Lecture 11
Groundwater Hydrology Components 1

Hello everyone, welcome to NPTEL course on Groundwater Hydrology and Management. This is week 3 lecture 1.

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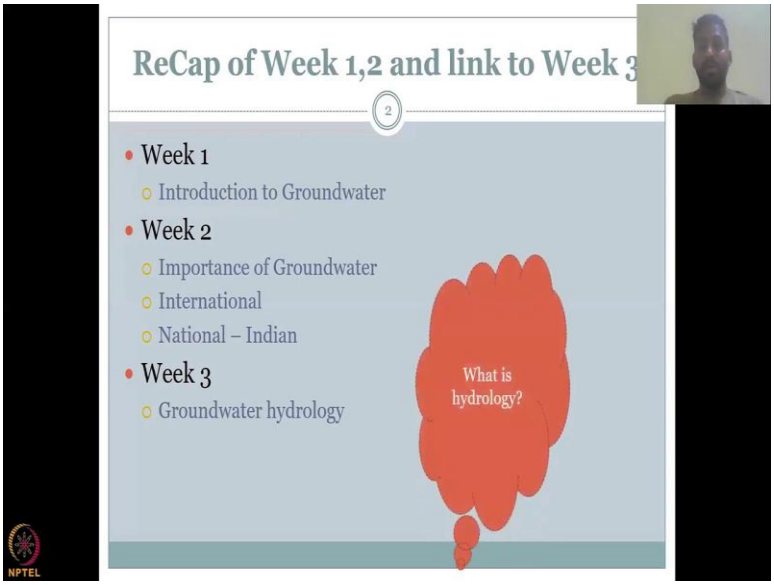

Let us do a quick recap of what we did in week 1 and how it is linked to week 3. So,, in the week 1 we looked at introduction to groundwater, we looked at how groundwater stress is there what are the uses of groundwater what do you mean by groundwater from the hydrological cycle, etc. We built from the understanding of groundwater where it is used more what are the importance's of groundwater, what fields do they sustain and prolong, for example livelihoods domestic use, agriculture, sanitation industry etc.

We focused a lot on the international scale we looked at different countries and continents and saw how groundwater has been used. We also looked at the key segments which use groundwater especially agriculture and within agriculture we also looked at certain crops. Then by the end of week 2, we also moved towards the national scale Indian scale and we understood that there are a lot of issues in groundwater because in many places groundwater is unsustainably used the level of depletion is not sustainable for long-term groundwater use and for the fact that

India is the leading groundwater extractor in the world even though India is not as big as US or China which are ranked number 2 and number 3 in groundwater use still our use is much bigger than China and US, in fact some reports claim that our groundwater use is above the combined use of US and China.

So,, given the fact that the land is less the rainfall is not as much the total net rainfall is not as much as in these two countries it is not right to use so much of groundwater. So, the importance now shifts to conservation we need to conserve groundwater. Before we get into conserving groundwater, we need to know the groundwater hydrology. So, we have linked week 1, week 2 and slowly transitioning into week 3 where we look at groundwater hydrology what does it mean what are the different components of groundwater hydrology. Before that a just quick short review of what is hydrology.

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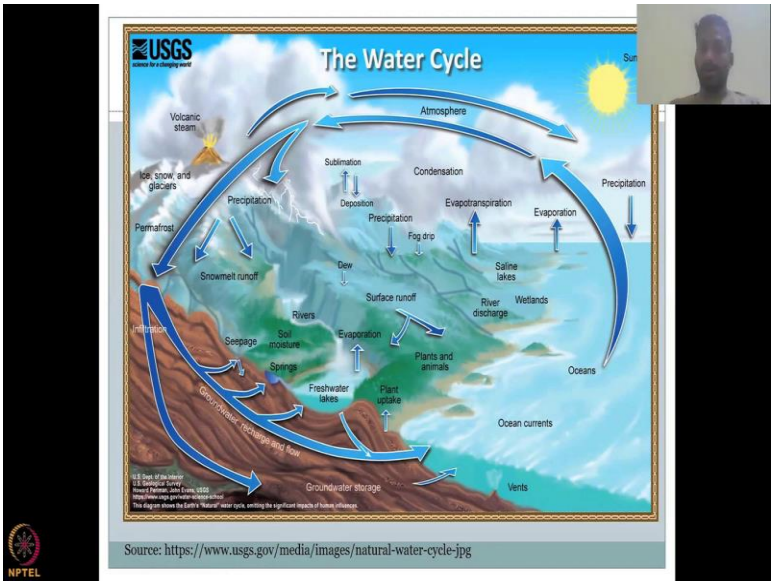

We know hydrology is the study of the movement of water documenting the movement of water and the movement of water is given like a hydrological cycle or a water cycle as this image shows we have already visited this in week 1, I will just quickly revisit some concepts here and then we will dive into groundwater hydrology. So, even though there are multiple major components in the hydrological cycle there are a few components that focus on the groundwater. If you could see here the rain or the surface water let us club all this into surface water all the

water uh sources like precipitation, snowmelt, sublimation, deposition fog drip, dew, rivers, stream, ocean all of this let us club it together as surface water.

And now when the surface water touches the ground, there is infiltration, percolation and then storage of groundwater in different compartments slowly groundwater moves in and out of the earth's crust when it moves out is called discharge then it moves back in it is called recharge, so you see here it is moving out into the lake and from the lake groundwater comes back in. So, the study of groundwater hydrology will look mostly these underground drivers for groundwater movement and that is what constitutes groundwater hydrology.

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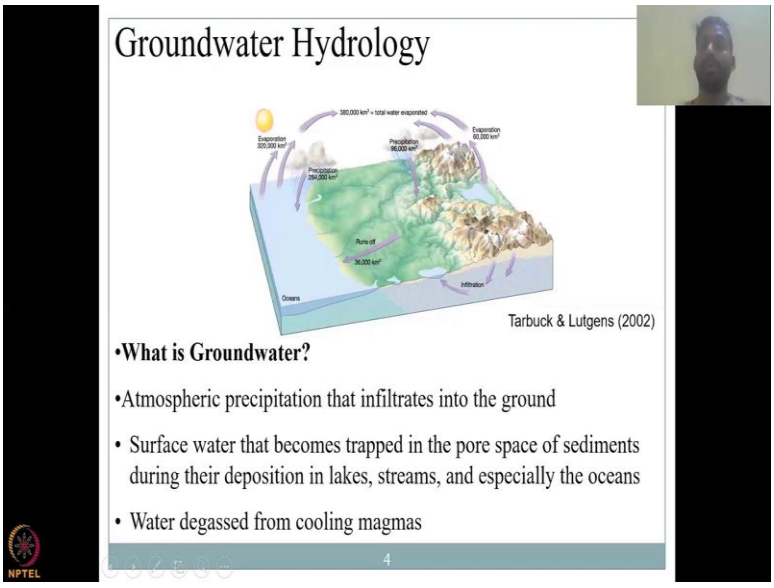

So, you could see here that again the hierarchical cycle is shown because groundwater hydrology is a part of overall hydrology, this is a segment when we talk about oceans and lakes, yes, it is part of a hydrological cycle, we cannot totally take it out, it is some groundwater is given in some snowmelt and so the unit is hydrology or water cycle and then in that one part is groundwater hydrology.

So, what is groundwater? Let us define groundwater to be more specific and where it comes from. Water comes from the atmospheric precipitation which is your rainfall or snowfall or due to multiple resources for atmospheric precipitation and once that water infiltrates into the ground it becomes groundwater, it is the same water but on the top of the surface it may be called as a river lake in the atmosphere it may be called as a precipitation, rainfall, dew, humidity, water

vapor anything but once the water gets into the ground through infiltration it is called groundwater.

Surface water that becomes trapped in the pore space of sediments during depression etc can also constitute groundwater we all know that the plates are moving the continental plates we call they are always in motion you have earthquakes you have new formation of land and some lands of merging, so when the new land forms or when deposition happens the lakes and rivers carry a lot of sediments and when they get deposited on the surface sometimes water gets locked.

Because there is some moisture and then you pile up sediments or a big deposition and you pile it up water is trapped underneath and that can also be constructed as a groundwater. Another source of water is through the chemical reactions that happen underground mostly by watery gas from cooling magmas, so when hot molten lava cools down there is water degas from that element and that water has nowhere to go so it gets trapped.

So, once these trapped waters get connected then it starts to move and you have groundwater hydrology. So, please understand that it is a part of the overall hierarchical cycle and we would focus mostly on the water that is underground and there are some components of water which are only stored they are not connected and if they are not connected still they are part of the hydrological cycle but they do not move. So, because it is connected here you could see water moves down your mountains and then goes into infiltration and comes up, there are some water which can just stay there for a long time everything constitutes groundwater hydrology.

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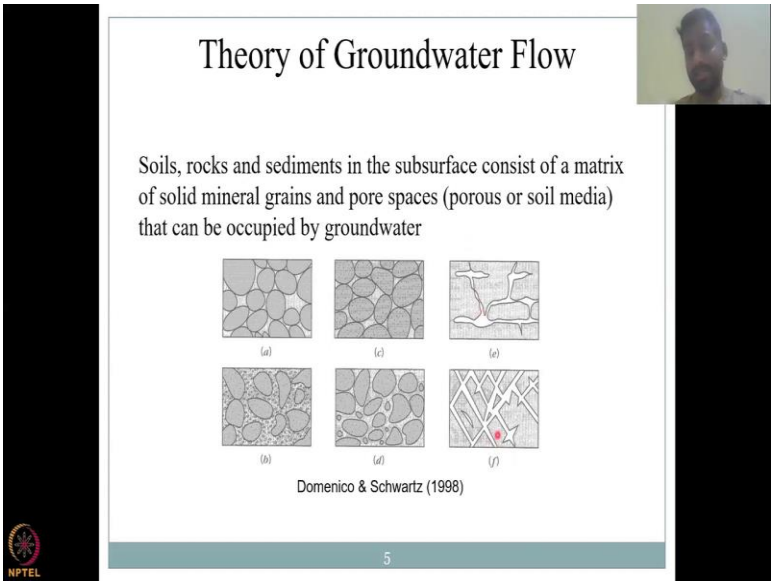

Let us look at the theory of groundwater flow, so the most most basic element for understanding the groundwater flow is to understand where the groundwater is going to be stored, so we know groundwater constitutes of different types of water that gets into the ground but to get into the ground there has to be some space and storage, if it is full solid rock solid rock water cannot get in, so there is some space and that would be a very very important factor for groundwater hydrology.

Soils rocks and sediments in the subsurface and underground ground of a matrix of solid mineral grains and pore spaces have a lot of porous space, porous space means a space with lot of void or a place where inside the sediment and rock there is no raw constituent, it is a void empty place. So, they have a lot of these mineral grains and they are structured in a particular manner and because they are structured there is a possibility of having space.

So, let us take a for example, you have round sediment solid minerals and they are arranged in a fashion that the bigger elements are there and in between the bigger elements you have smaller elements but inside that inside that there is some space so you could see there is a big rock material and then you have another space here, these spaces are where the water can be stored. Then you have within the space there are minutes more sediment present or solid mineral grains that we noticed in the write-up.

Now, there might be some minerals that are present inside which means it is taking away the space but still you have a good amount of space and that would give you more water to be stored What is the difference in c? In c, the mineral also has its own pore space so on the rock on the solid material you have some dots spaces in there where water can be stored. Moving on d is nothing else but the same arrangement but with more finer particles in between thereby taking most of the space. e and f are fractured systems where you have a fracture in the rock and water can get in.

And f is more higher density of fractures more importantly they are connected you can see it is well connected, so that water if enters in one part can actually move through and then come through the other region. So, this porous space is a very very important element in groundwater flow theory. So, without this space there is no groundwater, so if it is full of solid there is no place for the water to be going.

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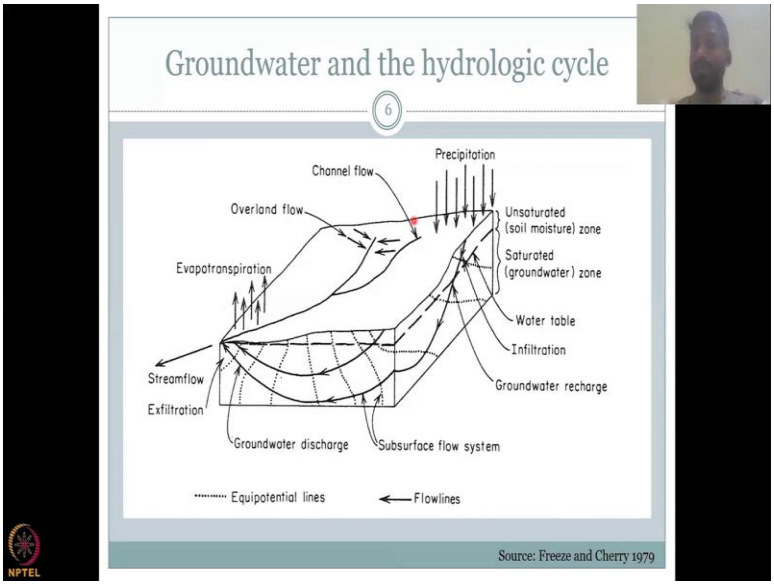

Moving on, let us see the key formations of groundwater from the hydrological cycle. So, I assuming that this is the underground space and it has good porous space it, has a lot of void it has a space where groundwater can enter, so that is the assumption when we draw this conceptual diagram we have precipitation the key element in bringing water into the system. So, first it gets infiltrated it moves through the soil zone and soil moisture is increased which means the soil gets water and the moisture content in the soil increases.

So, that is the first unsaturated zone, then water would still continue to move to the saturated zone we will get into a detailed lecture on what is unsaturated and saturated for now you could look at the top zone and the deeper zones. So, precipitation happens first it goes to the first zone where there is less soil moisture it will wet the soil and accelerate the soil moisture and then it goes down further, it goes down further until it hits the ground water through infiltration and then there is recharge.

So, precipitation now gets into the groundwater and recharges the groundwater. Once you have good recharge it starts to move and it moves and moves until it finds up space in the surface where it can come out and join the surface water body which is your stream flow, your channel flow and overland flow are nothing else but precipitation that is converted into runoff because some of the water might be overland flow it will just hit the land part of it goes down but most of it would still go on the surface as runoff and this runoff can also recharge your groundwater.

There are some losses in the system like evapotranspiration, evapotranspiration is the drying up of water from solid surfaces and also from plants that transpire, so there is evaporation plus transpiration, we will just understand that that is a term which is a big loss to the system it is one of the bigger loss to the system because it takes the water and away from the unit of analysis here the unit of analysis could be a block in a water shell.

So, if you look at most of these illustrations that I would use the physics and the theory is still the same, so we will be using pretty old citations because they have done a very good job example freeze and sherry's 1979 book groundwater is a very very well written book and highly used across the world a lot of policies are written based on that. So, most of the lecture would cover that book because of physics and the fundamentals do not change so you will have all these diagrams and recharge lines explained in detail there which is more an advanced course but I will give you the basics from that book.

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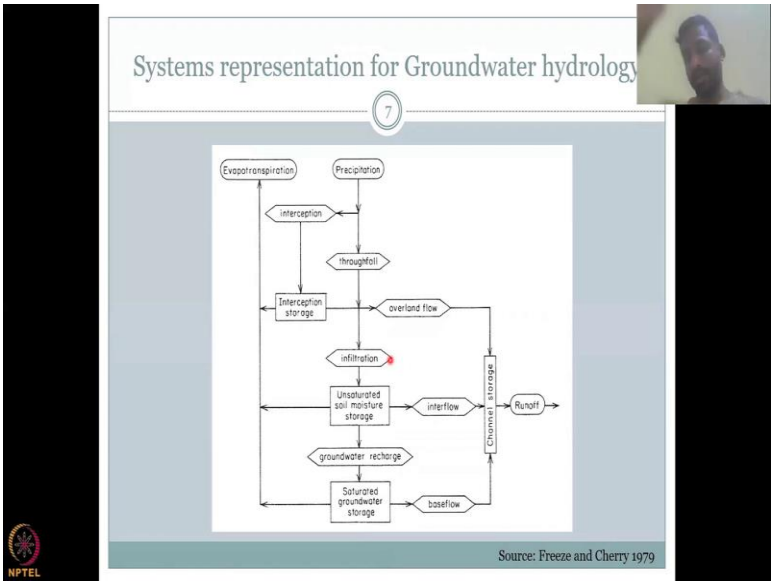

We can also do a systems representation for groundwater hydrology, what is the systems approach? It is a way of showing how by a flow diagram each components give rise to a different component and where there is storage losses in the system. So, we start with precipitation coming into the system our system is the unit of analysis part of the water is getting intercepted interception means you are stopping the water.

So, you are stopping the water through what trees plants think about the atmosphere you have a cloud and then rainfall occurs the first thing it hits is not the land but your trees your trees branches and then it comes down so that is called interception there is some water stored in interception the remaining water goes out as evapotranspiration, remember I told a word about evapotranspiration in the previous slide it is basically a loss of water from the system due to evaporation and transpiration evaporation means drying up you put water on a solid surface after some time due to heat and evaporate it evaporates.

So, because your evaporation drives it. Transpiration is the fact when plants take water through the roots to up to the shoot up to the plant leaf area and then it transpires it out it converts it into a water vapor it mixes into the water vapor. So, all these is as a vapor evapotranspiration is a vapor state, it is a gaseous state not a liquid precipitation is a liquid interception is a liquid storage is a liquid then you have evapotranspiration but for now you please understand that it is a loss to the system.

Moving on, so the plants and trees that are stopping the water goes into interception but there are some water that can still pass through and that is called through fall so water will pass through the system and first thing it will hit is the land, once your rainfall hits the land part of the water will go as runoff it will just slide on the top as runoff and that is called overland flow there are different terms used for runoff there is oval and flow pattern and flow subsurface flow etcetera etcetera, here it is given overland flow.

So, it is runoff or overland flow and then the remaining water can go in as infiltration, so I said rainfall hits this is your land part of it gets infiltrated and goes through but most of it would run through as run off it will go like this due to the slope gravity etcetera. Once it goes into infiltration the first zone it sees the unsaturated zone, unsaturated means not full with water, so the water will enter the unsaturated zone and improve the storage and part of it goes to plants or evapotranspiration.

So, since it is the first zone there is lot of roots and the roots can eventually take water and evapotranspiration contribute to evapotranspiration. Then you have the overland flow that goes into the channel storage which is your river channel, stream channel, canals etc and part of your unsaturated zone groundwater can go as interflow, interflow means between the overland and the bottom aquifer some water can go as interflow the subsurface flow.

So, after the unsaturated zone water is taken up by the plants still some water moves down you can see all of the arrows moving down because of gravity so this is your atmosphere this is your trees and this is your 0-land level the land at 0 and then water moves down still because of gravity.

So, once it comes down below the unsaturated zone it enters the groundwater recharge area, so water starts to recharge and the recharge would give more water to the saturated groundwater storage which is a unit where water is full already and when you put more water the level of the water rises. And from here still plants and trees can take the water as and transpire so the transpiration is still happening through these lines of unsaturated and stored saturated water and part of the saturated water goes as base flow, a base flow is part of the groundwater that goes back into the channels.

So, if you see here your overland flow which is your rainfall goes on the top of the surface into the rivers and then there is some water which will infiltrate slowly infiltrate and part of that goes as into the stream as interflow but there is another water which goes deeper and deeper deeper into the groundwater aquifer and from there it goes into the channel storage. And then it all combines into one unit called runoff and the runoff can be your stream your river and you can eventually join lakes, ponds, ocean or seas, so that it closes the hydrological cycle again.

So, this is a very simplified representation of the groundwater hydrology how groundwater forms from precipitation and then goes through all different compartments, it is also important to note that the contribution of each variable depends on where you take the data from for example your desert there is more evaporation because of the tremendous heat and if the water bodies there is more water stored on the surface, so those kind of things so you have to understand where to use this explicitly but it gives you a very fair broad idea about how water moves what are the major components and then how it comes back into runoff into the hierarchical cycle and does the cycle again.

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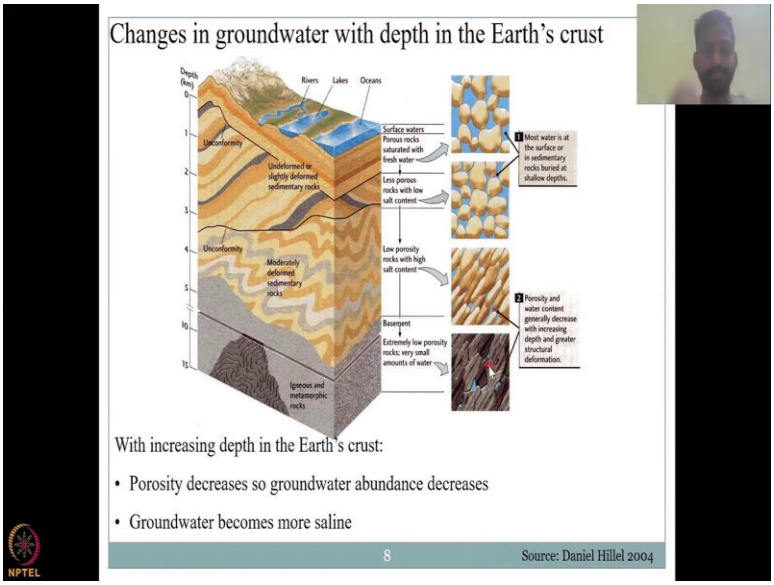

Moving on, we also should understand that when you go down deeper and deeper into the or into the solid zone sediments sand etc these pore space the space where water is stored which is the fundamental for groundwater hydrology is reduced. So, you have the surface you have all the water coming in water moves down into the groundwater system and then it saturates which

means it gives water into the space and then if it goes more down you see that the number of spaces is reducing the volume of space is reducing and that is because the final sediments would clog the space if you go down further the sediments would have more structure more solid rigid structure it will not be disintegrated as on the above and by the means of when it is more structured or platey or something rocks do not have much space in between.

So, you could see that the space has decreased when you go down into the earth's crust and then finally you come to the bedrock region where there is very less groundwater potential because the space is less so when someone talks about groundwater potential it is the potential of the solid under the ground to actually store water how much space is there if the space is very less then the potential is very limited.

So, here you see the potential decreasing from the top to the bottom and the bottom has the least potential. So, what do we have here with increasing depth in the earth's crust from the top you are decreasing in the depth porosity decreases the space between the solid materials and the sediments and etcetera decreases, so groundwater occurrence and abundance decreases.

More importantly groundwater becomes more saline if you go down deeper and deeper because the water is with old rocks that is that are not disintegrated and once the water starts to disintegrate or weather the rock then some salts from the rock would be mixed with the water and becomes saline, saline does not mean salty tasty alone but saline means with salt and salt is from the rock mineral here it is not the ocean salt that we are talking about, it is a mineral the rock will have some particles that will enter as salts.

So, the take home from this message this image is groundwater is important and it comes from the surface to the bedrock this is the rock where no groundwater is available but as we go deeper and deeper you will lose your groundwater occurrence.

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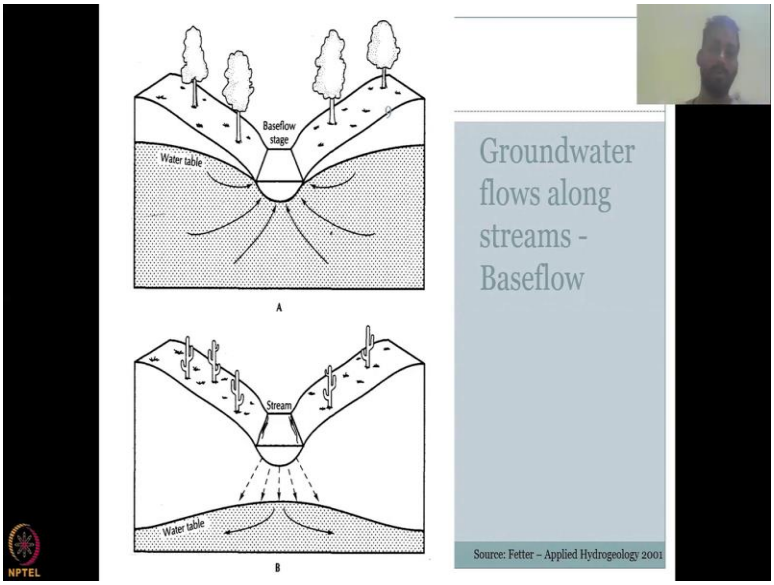

It is also important to see groundwater flow along streams, so this is a forest you can see the trees which is different from the bottom one which is deserts you have cactus here in b whereas in a you have trees, so if we have water coming on the top as a rainfall, it can get into the ground and from the ground it can come back into the river.

So, this phenomena of groundwater providing water to the surface is an input to the stream and thereby the stream is gaining the stream is gaining water. Whereas, in an desert system for example water is available in the stream maybe a canal was broad or big rainfall is there it is concentrating the water and flowing through a river a big channel is there and that channel will give water down to the ground water table because the groundwater is lower than the stream level here if you see the stream level is lower than the groundwater so the groundwater gives water from the high potential to low potential.

So, groundwater table is high potential it goes to low potential which is stream flow. Here, in diagram b now if you do the potential energy for this the groundwater is at a low potential compared to the stream and so the stream can give water to the groundwater, always water flows from high potential to low potential.

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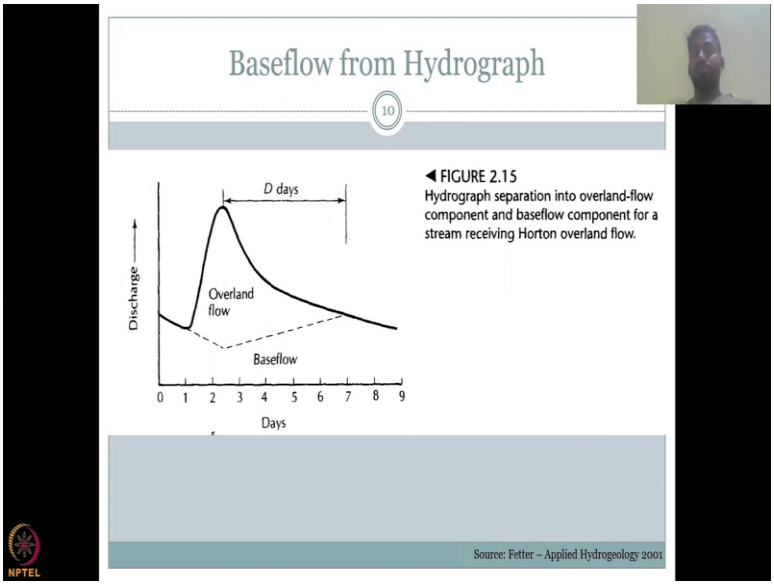

So, this can also be understood from a hydrograph? What is a hydrograph? A hydrograph is the graph with x-axis having the time and your discharge on the y-axis, it is basically a time representation of your discharge of your river. So, if you could see here when there is rainfall then the stream flow picks up but when there is no stream flow happening and no rainfall then it is not a perennial stream it is a seasonal stream but in a perennial stream what happens when there is no rainfall still you see some flow like for example ganges, kaveri etc have flows for a long time right.

And what happens actually is part of the groundwater gives in into your stream flow and that is called base flow and you could easily calculate it by looking at the discharge before the rainfall and after some days from the rainfall. So, before the rainfall so exactly here the second day maybe the rainfall started but before that you still have river water flowing and that is because of base flow contribution which is ground water giving water into the river and after the rainfall stops still after some days your groundwater can come back and give water more to the system.

So, to understand this from the previous diagrams in a groundwater hydrology water is first taken from the surface through precipitation infiltration and percolation then water moves through different compartments and exits back into the stream and that could be called as a base flow, so base flow is nothing but the groundwater contribution to stream flow.

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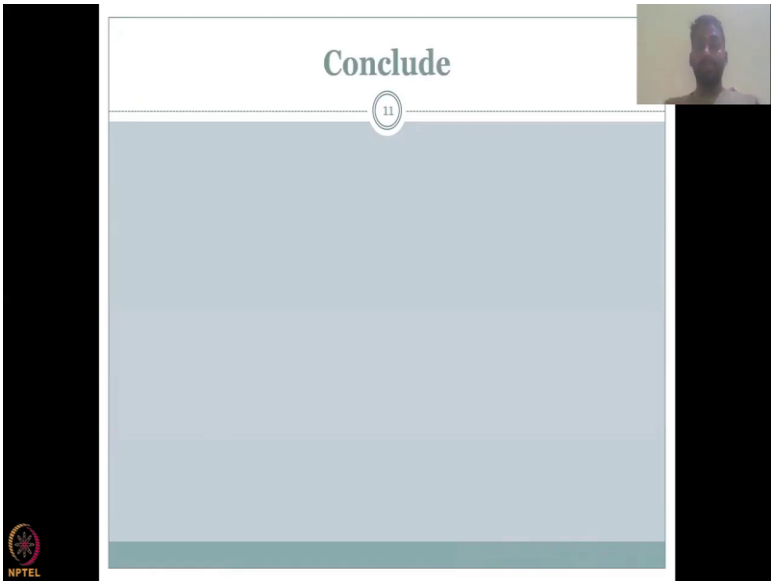

With this, I will stop here for the first lecture I will see you on the second lecture on groundwater hydrology, thank you.