Rural Water Resources Management
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Week 04
Lecture 01
Groundwater Hydrology

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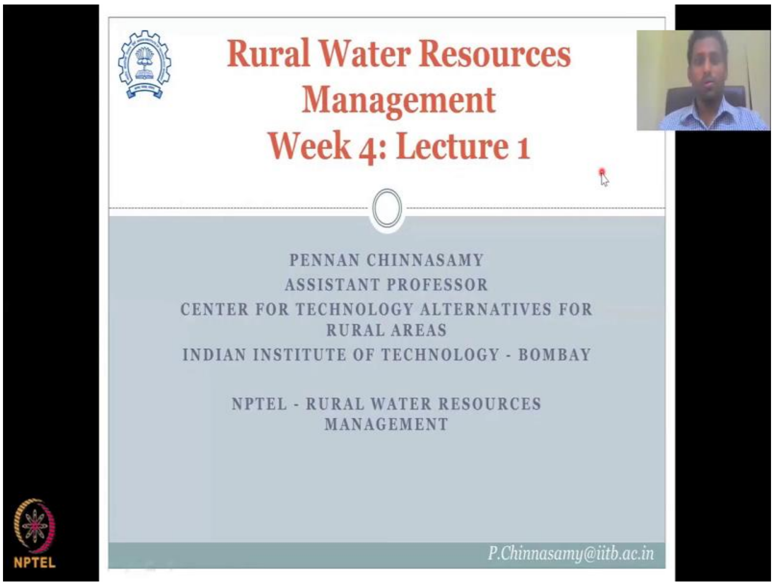

Hello, everyone, welcome to NPTEL course on Rural Water Resource Management week 4, lecture 1.

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This is the recap for week 3, and then we will see how it is linked to week 4, in the week 3 and also week 2 we looked at introducing the Hydrological Cycle. We also discussed key parameters, we identified 6 parameters for the Rural Water Resource Management, which are very important. Out of that 3 were discussed in week 2 and in the last week, we discussed surface water structures and what constitutes surface water storage, soil moisture, and groundwater.

Slowly we understood that of the resources for small scale and rural livelihood options, we do need better groundwater management. So, somewhere there has been higher focus on groundwater use in agriculture. So, the idea for our course moving on is to have a couple of more lectures, more focused on Groundwater Hydrology.

So, this would help specially in the coming seasons with climate change extremes to manage water in a better fashion, because we need to understand where to store water and also the demand and supply for these resources and in especially groundwater which is more complex in nature.

So, with this, let us jump into week 4. So, what we will be looking at in week 4, we will be defining the groundwater hydrology what constitutes the hydrology for groundwater, what are the key factors where water is stored, and how to understand in storing these waters using natural and artificial means.

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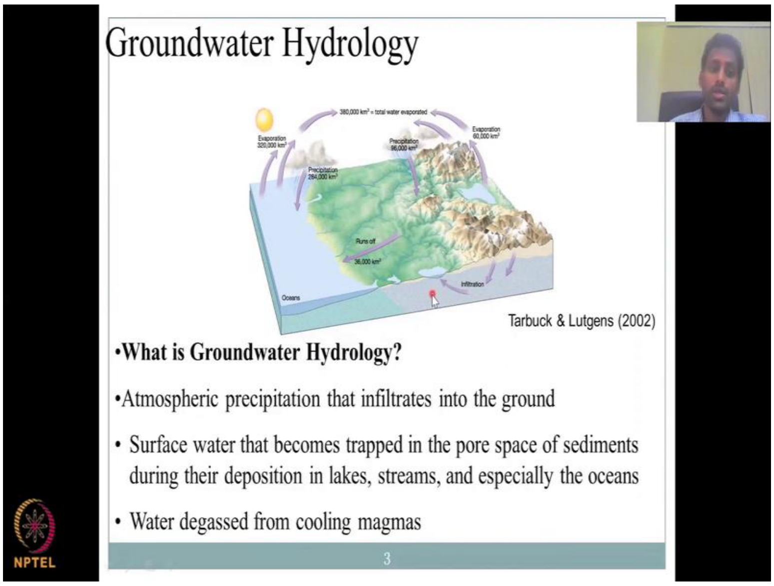

So, to introduce we know the overall hydrology, we know how much water is coming in, let us do a quick volume related hydrological estimate. So, around 284,000 Kilometer cube precipitation is just an example. So, is falling on the planet in this particular area, study area and then there is division of preservation in different forms this could be in rain, snow, etc., so, if you add all of them it would come more or less to your total water evaporated and how much is condensed and screeched. So, only some part is given as runoff and some direct precipitation which directly falls on oceans but most importantly water infiltrates. So, evaporation happens from open surfaces, but then water infiltrates and then gives back to some open sources, etc.

So, what is Groundwater Hydrology? The study that focuses more on the ground word movement of water and or deeper movement of water under the earth's crust is called Groundwater Hydrology. So, the factors are the same for the overall hydrology also. So, atmospheric precipitation infiltrate, so it is not that it has a different source of water, precipitation is the source for all the water and the precipitation is from the atmosphere, it could be from rainfall, it could be from snowfall, or any other methods that are given earlier.

So, the water infiltrates into the ground through gravity, and then you have surface water that becomes trapped in the pore space of sediments during their deposition in lakes, streams and especially ocean, so, when water is moving, sometimes it can get trapped. So, for example, a river is flowing and suddenly sediments fall on it and sediments keep on piling like a landslide movement of plates earthquake, tectonic, etc.

So, what you see is if suddenly there is a locking of water, then water gets stored underneath. So, that is water which is stored in the pore spaces of sediments and or rocks during their deposition lakes, streams, especially oceans are constitute for the groundwater. So, either way we will also get into where it gets stored, especially in sediments and rocks.

Water degassed from cooling magma. So, under the ground there are magmas which flow which is molten material, very hot material. So, when it flows, sometimes the water is degassed and that gets stored under the ground in pockets and or in sediment pores and that also constitutes the groundwater.

So, there are groundwater sources that come from different parts, but most important is the precipitation, the precipitation converts into surface runoff and the surface runoff gets stored into the water because of your piling up of sediments or also lakes moving underground and then water gets locked, so, the surface water which is being transported, sometimes get stuck and under the ground and because of this it actually constitutes the groundwater.

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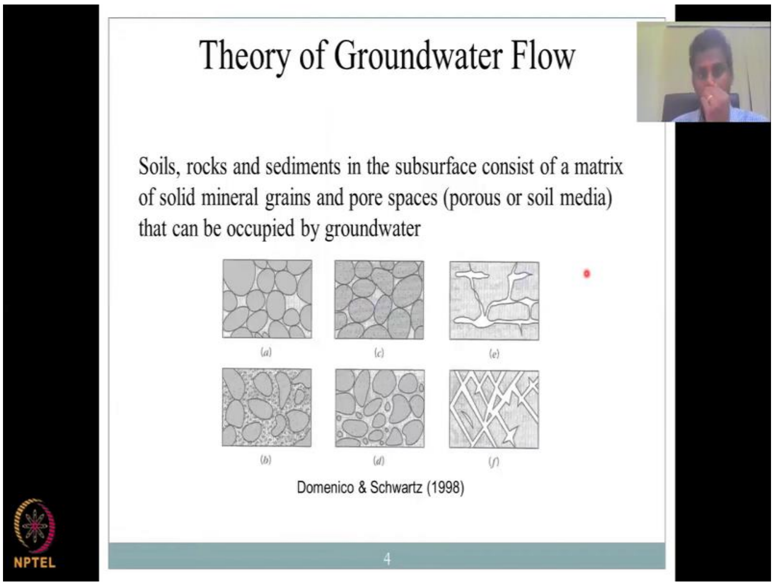

Theory of Ground water flow, soils, rocks and sediments in the subsurface consist of matrix of solid mineral grains and pore spaces. So, we have seen this earlier also any material you have in the surface, subsurface would contain sediments, soil, rocks, etc., but with pore spaces, which is a space that is empty, not solid and that space can be filled up with air or water. So, that gives a name of porous soil, porous soil or soil media. So, now, water has a storage unit to go and fill itself.

So, when water is flowing, it is looking for where can it go and settle or continue moving from high potential to low potential and the void spaces are a perfect unit. So, the pore spaces get filled up with water, you could see how different pore spaces are available in the material, each one is a different material and sometimes pore spaces are in the solid material like your sponge, your sponge you used to clean is a material, but inside in a pores, like cheese, cheese may have pores inside.

So, those kind of things can store water in between and also inside the solid and but mostly the solids are solid so water cannot go in, some solids have cracks. So, the cracks can also take water and constitute groundwater, we have a mixture of these bigger and smaller sediments sizes in the soil medium or also water in and out of your soil medium and the fractures in different formats.

So, all these would give a potential place for water to store and once enough water is stored and connections are made it starts to flow, so starting point of characteristic fluid flow. So, why is it called the fluid because in these pore spaces, water can be mixed with air. So, that medium that phase is called fluid face. So, fluid flow through porous media is given by Darcy's law, only two laws that are most widely used for groundwater studies. One is the Darcy's law the other one is Richardson’s law, but of these two Darcy's law is very simple, very effective and has been used widely across the world.

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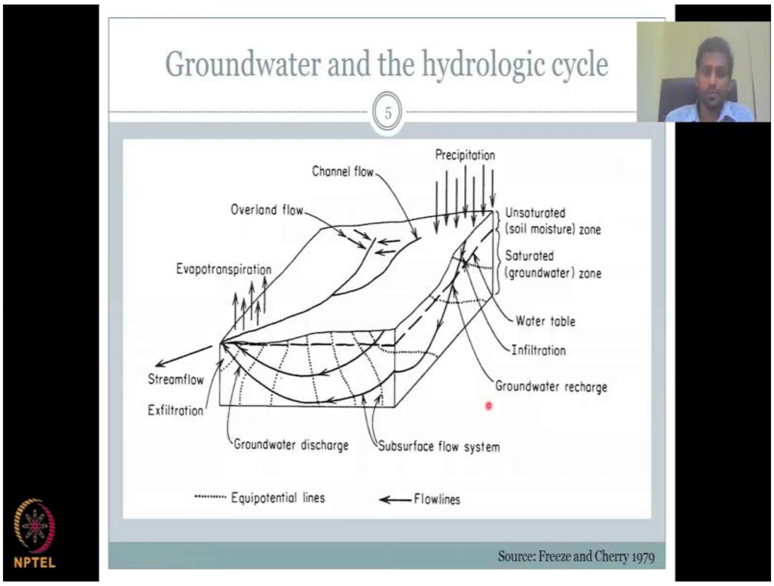

Let us now look at a focused groundwater hydrology diagram groundwater. In the earlier hydrological cycle, we looked at the overall hydrological cycle, right now, we will be looking at the groundwater hydrological cycle. As with all cycles, we have to identify what is the source for groundwater, and as I said, precipitation is the source. So, precipitation occurs on the surface until then, is the normal hydrology.

So, it is not groundwater hydrology, but then when water starts to infiltrates, then the first soil material which does not have soil moisture is called the Unsaturated Zone. And that is where water moves in, because there is space, unsaturated means not enough water, not fully occupied with water. So, there is a space where water can enter. So, water first enters into that and then it hits another soil profile or a material where it is saturated with groundwater, could be a rock material, it could be your soil material.

So, you can come down and you could see that water moves down further because of the higher potential to lower potential gravity, etc. So, water is getting recharged into this and establishes the groundwater table which is a dashed line. So, now you have water precipitation coming in through infiltration, the first step precipitation is getting into the surface through infiltration. And once it gets into the Unsaturated Zone, groundwater recharge happens, you are recharging the groundwater through precipitation and then a healthy water table is formed.

Sometimes your water would come back up into the surface which is called your subsurface flow. And most importantly the water can come at the end point which is your ocean, streams, rivers, etc. right here and that is your groundwater discharge or base flow contribution.

So, if you look at the groundwater part alone, there are a lot of complex dynamics, on the top what would happen is precipitation can also get into your runoff and get into the streams as overland flow, channel flow and along the stream also there can be some recharge, so, not only on the surface, but along the rivers also there can be some recharge. Similarly, at the stream level also water can come from groundwater into the stream. Why? Because your streams are the lowest depression.

So, when it is low and groundwater it is at higher potential, ground water will flow from high to low. So, that is what is happening in this arrow marks it is coming, but once it sees a lower potential water will move in and evaporate transpiration picks it up to complete the overall hydrological cycle.

So, you could see here that two components from the overall hydrological cycle which is precipitation and evapotranspiration are also in the groundwater cycle, but with more complex components under the ground, so, groundwater is mostly under the ground, the sources and losses can be above the ground. So, once the water comes up, if it is evapo transpiration is taking place, then it is a loss to the system.

So, flow lines are given by these and equipotential lines are equal head, equal potential. So, which means water would not flow from one point to another point, but along those lines because the potential is equal, only when there is a potential difference, a potential gradient, you could see water moving. So, for example, you have two water levels at the same level which is equipotential, why would the water move, will it move from A to B no, only when A is higher, it will move from A to B or if A is lower water will move from B to A. So, if A and B are at the same level water will not move.

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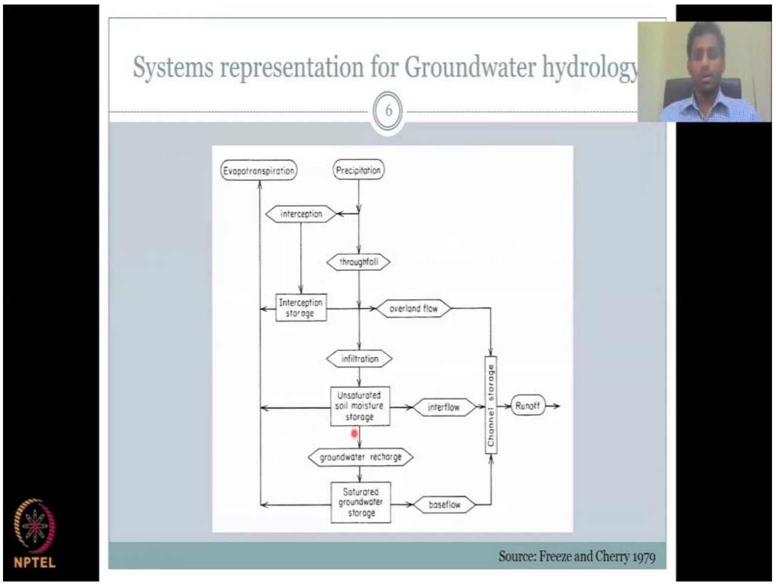

Freeze and Cherry has also given a flowchart kind of systems view for hydrology for groundwater, let us look at it in detail. So, you start as the source, as a precipitation, the precipitation enters and now you have to visualize that you are the water. So, you are the water coming from the clouds, first what will you see? You will see, you are from the clouds, you are coming down you will see trees, because trees are at a higher elevation above the ground. So, you will see trees.

So, once the trees you hit you have interception. So, the leaves and the branches might be. So, for example, these are, this is a branch and the leaves and your water would hit and intercept, some water is lost and some water can be stored on the leaves. So, that is interception, interception storage.

But then, what is the use of water, water will just stay on the leaf as wet and then dry off, so same like your car, water can fall on the car, what will happen is it will go inside the car, no, it will slowly evaporate. So, that evaporation happens here not transpiration, but evaporation. Understand that when we talk about evapotranspiration term, sometimes it might be only evaporation, but to keep it simple and collected the two terms are combined together. So, do not ask tomorrow Sir, you said evapotranspiration, but interception cannot be transpiration, true, it is only evaporation, but it contributes to the evapotranspiration total volume.

Moving on, so, there is some water that goes through for now visualize yourself again, if your trees do not capture, do not intercept your water then what happens you go through, so that is called through fall. So, you are falling down, falling down and touching the surface. So, right here you would have a surface which is missing here, but that is understandable.

So, you throughfall then you have a surface here is the land surface, what happens in the land surface part of the water now visualize yourself you hit the land and you start to move laterally as overland flow because that is much easier to go rather than going into the ground because you have a solid.

So, while your overland flow is occurring, some water is converted, your perspiration water is converted into channel storage, where will the water flow, all the water around the ground will flow and find a low depression and it will go through that depression and that is your channel storage, river, stream, etc., So, all the water would come down and go into the channel storage and then goes as runoff.

So, I am closing this loop now. So, what is remaining is infiltration. So, while this overland flow is happening, means some water droplets, which hit the ground and slowly know that because of instead of going overland flow I will go inside because of gravity, it moves slowly down and that first unit of storage it visualizes is it ceases your unsaturated soil moisture storage. So, there are two storage units, one is unsaturated and then a saturated, so, the unsaturated has less water. So, water can move into the soil and go inside and gets stored.

So, some water is stored, but some is taken by plants. So, what would happen, exactly it will go as transpiration. So, the evapotranspiration term now gets more input from transpiration. There is some soil evaporation also which comes through this, good. So, now what happens to the water that is not taken by plants, gravity is still pulling it down. So, it will go further down, what is below the root zone, what is below your unsaturated, it is a saturated water storage unit.

So, you have now two compartments, one compartment is unsaturated, water goes in saturates it, but still because of gravity and force of pulling of water it comes down, soil wants water. So, when it comes down the saturated zone is there where fully water is there. So, you can still add water where water then would move laterally because vertically it cannot move there is bedrock.

So, that is what is happening, some water is still taken by trees. So, even the deep groundwater storage you could have transpiration because your tree zone has a better and higher, deeper root than your plants, plants might go up to a couple of meters, but your trees can go much further, examples are pine and cactus those kind of trees would have extensive networks of roots.

But there are another channel. So, what happens to some of the unsaturated flow, it goes as interflow as I said some of the water which goes into the soil can come up back out. So, when it comes back out, it becomes interflow goes to the rivers streams and runoff. So, it closes the loop in that direction.

What happens to the groundwater that is down in the deep aquifer, the deep aquifer or the saturated zone water is full now, now we have a full bucket what does happen, it overflows, when it overflows it cannot pick a direction which it likes, but it has to follow the physics which is high potential to low potential.

So, it will follow the gradient, the slope gradient or the land gradient and go towards that side. And it will go through as base flow because it eventually, the deep aquifer will eventually go and join the rivers, ocean, lakes. And that part where it comes is downward movement, through the downward channels and into the river is called your baseflow. Then it goes back to your channel storage and runoff.

So, the runoff or discharge in the river can have multiple inputs, one is your overland flow the water hits and comes straight, some goes as inter flow which comes into the ground and then comes back out and then the baseflow which water goes deeper into the aquifer stays there for some time and then comes out.

So, if you are looking at a flood protection, let us say and you know that these are very, very small components but here the runoff is too much, where would you put infrastructure to reduce the peak, you will put it in the baseflow. So, which means you will put more water in the groundwater storage unit and then your baseflow would come later into the runoff, thereby the precipitation and runoff are not same, but the same time, but first precipitation happens and after 2, 3 months your baseflow gives water to the runoff, thereby slowing down the runoff, thereby bringing down the peak.

This is the interesting part in Groundwater Hydrology and the Ganges water machine which I told works on this. They pump this part out so that water can go through, gets stored and later in the season, non-monsoon season it fills up and then the baseflow happens, run off happens.

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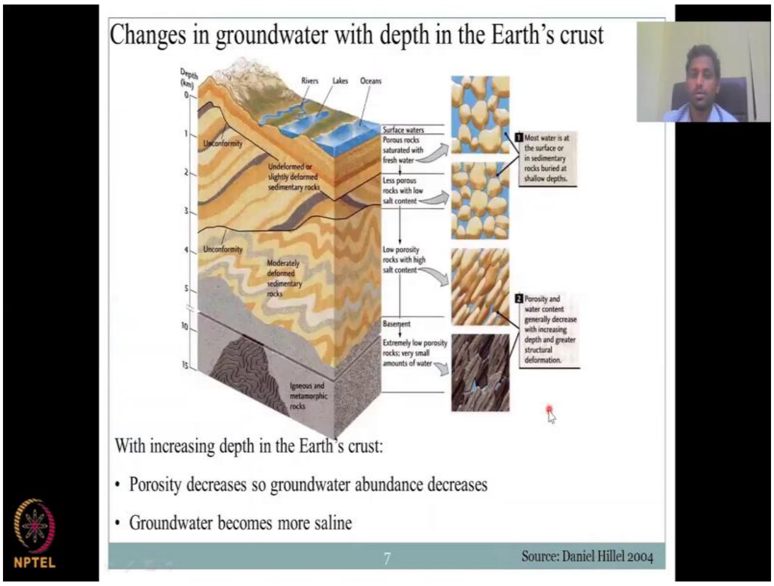

Changes in groundwater with depth in Earth's crust. This is an important diagram where you see water recharges vertically down and as I said, this is your bedrock kind of area where not much water is there. So, what is water sea? When a water molecule moves down, it finds a surface waters where there is less, sediments and stones, so everything is water in the surface water. Then underneath, right underneath it you have the sediments soil right here also, where you have big pore spaces, the volume of the space between the solid is big so water can store.

Now, let us go down a little bit further, if you go down a couple more layers where the root zone is, where plants take up water, this size of the empty space is now less. So, less volume of water comes in. So, just look visually, the first image has more solid volume, and also more water volume, come to the next image, the solid volume is bigger, much bigger than the water volume, then if we go down further now we are moving down, vertically down, if we go down further, what you could see is very less amount of space for water to be stored and more structured soil because the soil is not weathered.

So, if you go up here and soil is fully weather, less weather and very very less weather. And here is almost not much weather. So, what it is not breaking up, soil is on breaking up only when it breaks up, you have spaces for water. So, when you go down further, you have less water and then when you go down to the bedrock kind of region, extremely low porosity, extremely low amount of space for air or volume of water to be stored. So, very small amounts of water is stored.

So, water goes to the first phase, then slowly down. And then the second phase, which is more consolidated rocks, you do not have much space. So, now here is the concern, just look at the depth 0 to 15 kilometers only. So, here is the doubt, when you start as a farmer and put your wells here, farmer, urban settlement in your house, you are putting a well and accessing this water, you are fine, because water space is there, you pull the water, water can come in. Well and good, but when you go further and further down, you are accessing very less amount of water.

When you put the well down, you will see a lot of water, so you should not be fooled, saying oh, I am seeing lot of water, water will come in now, no, it is because the water has been stored in a longer period. But once you take the water out, it takes another 10, 5 years to full of water to come in. So, you are at loss and this is the complexity of Groundwater Hydrology.

With increasing depth in the Earth's crust, porosity decreases. The porosity is the term that gives you the space for air and water inside the soil profile. So, that decreases, so groundwater abundances decreases. So, as you move vertically down, as the depth increases, it comes very less space for groundwater.

Groundwater becomes more saline because water is staying in close approximation with the rock for a long time. I did use this word that these waters can be you pump it, it recharges, pump it, recharges but these two layers, if you pump it, it takes a long time for the water to recharge because water has been staying there for a long time.

So, when water stayed there for a long time with the rock, it does get some of the nutrients from the rock, it gets some signatures from the rock and what does it become? It becomes saline, saline means not salty alone, but rock’s salt comes in. For example, if you go to some villages, they will see the water is sweet, groundwater is sweet.

It is not sweet because of sugar or anything else that material, that solid that has been in that area has the tendency of sweet the salt has a sweet thing, taste not all salts, when we say salts for rocks, it is not all saline, which means not salty that you put in your food, this is a different salt.

So, the salt content can be different taste, it can be pungent, it can smell differently. So, understood, understand that salt means different in different depths also and materials also. So, because of water is staying there for a long time, it gets saline. So, it is very important to understand salinity.

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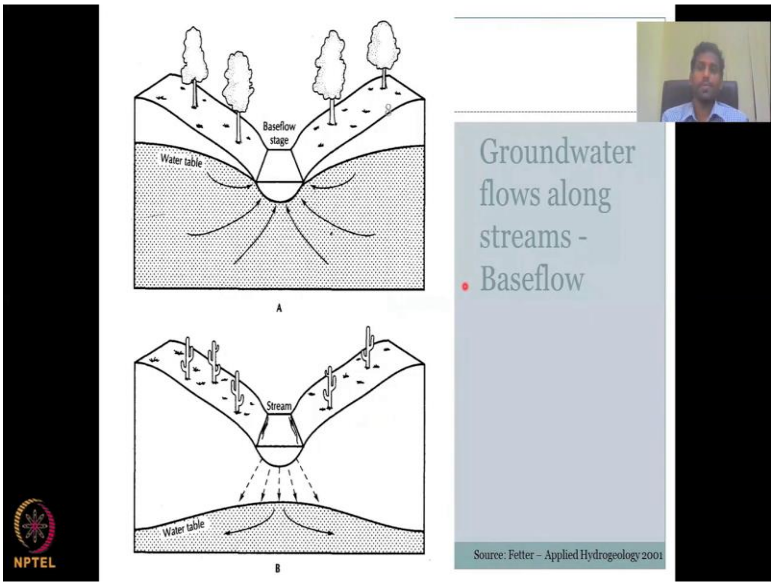

Moving on, let us look at the river alone and see how groundwater can come in or go out of the system. So, when there is a river flowing, and the river is flowing at a lower potential compared to a high potential of groundwater, groundwater will flow from high potential to low potential. In other terms the groundwater feeds the river, we call it as feeding the river and the river I look gaining stream, gaining river because I gain water from the groundwater.

Let us take a desert look at the trees, it is very clear that one is more lush green trees etc. Whereas the other one is deserted thing, in a deserted thing your stream is there, but if groundwater table is much lower because there is less rainfall to recharge the groundwater. And so, the groundwater table, the groundwater level is at a much lower depth compared to the other regions.

And suddenly when there is rainfall, there is a river flowing, what would happen your river would instead of gain water from groundwater, it will give water to the groundwater, same principle, water moves from high potential to low potential. So, in this diagram, in diagram B, your high potential is the stream over river and it will give water, it has to give water to the groundwater.

So, that is where some people try to line in cement, using cement and other materials like plastic, tarp, etc. along these channels, so that in dry areas, so, that water when it goes, it does not get lost down, but it has to go through the farmer. And think about it, it is more energy consuming to take this water rather than this water because it has a very less depth.

So, you can easily pump it up, but this one would require a couple of very strong pumps to get the water. So, driving message here is stream can be a gaining stream I can be gaining stream, if I get water from the groundwater a stream can be a losing stream when it gives water to the water table for groundwater. And it depends on where you are and what is the geology, how the forest system as but most importantly, it is driven by your water potential, is your stream at a higher potential compared to the groundwater then the water is been released.

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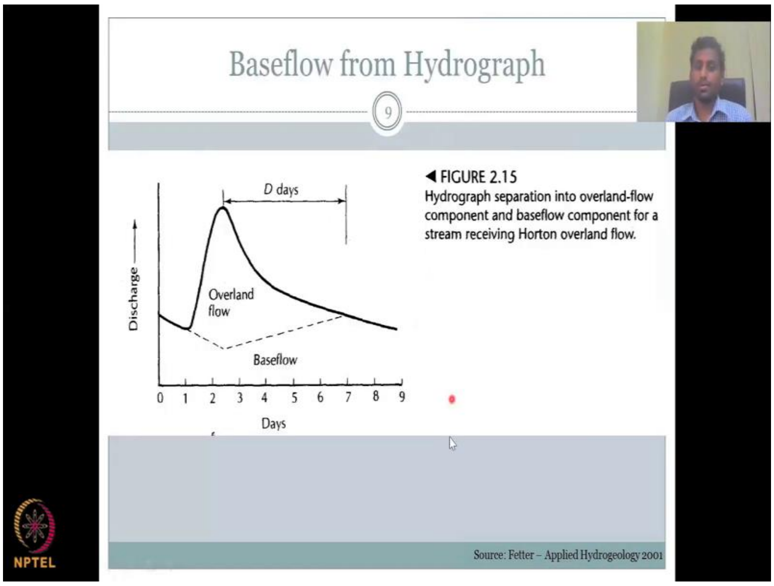

We also looked at the base flow hydrograph, I have to revisit it here so that we understand it once more that discharge versus time is a hydrograph and how do we know the different components. So suddenly, when there is a big rainfall your discharge picks up, the water level or water flow in the stream picks up, meter cube per second for example, it picks up and that is called the rising limb where the rainfall is occurring, then after some days it comes down as the, after it attains the peak, it comes down as a losing limb.

So, this is called the losing limb of the hydrograph and what is being released much lesser, runoff comes in much less compared to the previous face and it comes down. When there is no rainfall, if you see water flowing that is because of base flow, the groundwater which goes in and comes back out into the streams. So, here how do you separate it by elongating your baseflow line before the rainfall just elongate it and then it will come to the peak. So, draw a line to the peak because after the peak there is a switch of your hydrograph.

So, same way you have to switch back to the line of the hydrograph and that will give you the baseflow component, now I know the discharge comes down during a rainfall, the discharge in the base flow comes down during the rainfall, why? Because when your rainfall is occurring, your level in the stream goes up. So, water will flow from high potential to low potential. So, the base flow contribution, the base flow giving into the stream is much less.

So, we stop, we come down, it does not go to 0 but it comes down and then after the rainfall withdraws and after the concentration is attained, time of concentration or your runoff is attained, the peak is attained the limb comes down, so you have a recession limb, in the recession limb, what happens is, your water comes down very slowly. But your baseflow now picks up because now your baseflow the groundwater is at a higher potential than the stream. So, water would be given from your groundwater component to the river. And that is what is happening an elongating to couple of more days.

So, you see in beautifully that baseflow comes down, hits the peak and after the peak there is a switch in your hydrograph same way there is a switch in your baseflow and then hits that line. So, after this everything is also baseflow, before this is also baseflow. So, you look at how to take a hydrograph and separate into different components. Most importantly understand how to estimate the baseflow.

We also looked at the hydrological components for groundwater, most importantly infiltration, Unsaturated Zone, Saturated Zone. In the next class we will also look in more details for Groundwater Hydrology, will see you there. Thank you.