Groundwater Hydrology and Management
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Lecture 04
Introduction to Groundwater 4

Hello everybody, welcome to NPTEL Groundwater Hydrology and Management course. We are at now, week 1, lecture 4. So, this week is about an introduction to groundwater hydrology and groundwater occurrence. So, it is very important to touch the basics before we jump into specifics of the course.

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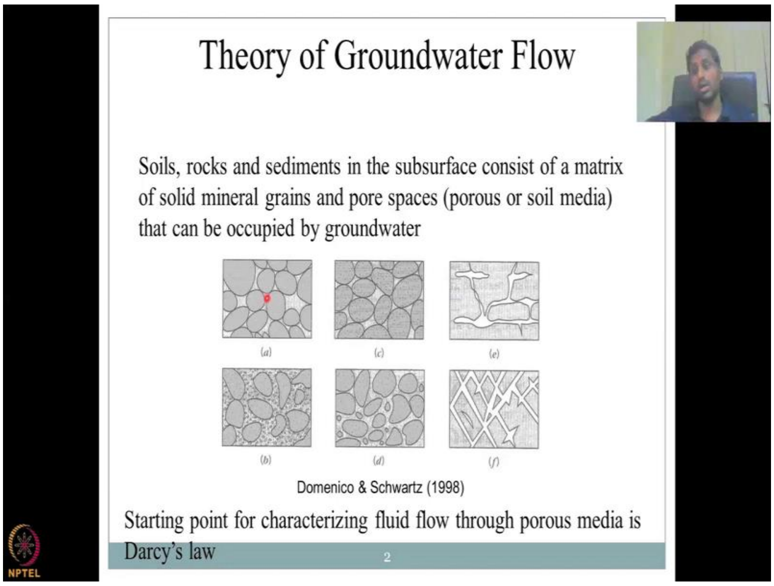

So, please understand that it is more like a sensitization week where we understand different concepts and some of the very important concepts of groundwater hydrology, movement, recharge, discharge will be discussed in the future please look at the syllabus and this week will be introduction. So, let us start with a theory of groundwater flow.

Soils rocks and sediments in the subsurface consists of a matrix of solid, minerals, grains and pore spaces. So, when we look at groundwater movement, I have a figure in a couple of slides, it is not only on the deep part of your earth, which is like from the ground it is not only the deepest part or in the shallow part or the upper surface, rainwater can occur anywhere depending on is it saturated, is it moving or not.

So, soils, rocks and sediments all in the subsurface consists of a matrix of solid materials. The solid mineral is what makes the rock or what makes soil for example, if you say silt, clay etcetera, that is particles of the soil. When you say metaphor, make magmatic rocks, so those are the rocks, those are the rocks that make the material the soil profile.

So, the solid mineral grains is very important. However, they are not jammed together, they are not stuck together inside because of the irregularities in the shape. So, they are not like a brick where you keep and cement in between, it will have spaces. Those spaces are gone pore spaces, so, this space you could see as grey color in the figure is pore spaces and porous or soil media.

So, the pore spaces have space inside the soil profile, where there is no solid material or solid mineral grain, but it is a void space where air and water can get it we would look into the specifics of what is the percentage, how do you calculate this etcetera. But to introduce groundwater, this is where the groundwater would emerge in or introduce itself in recharge and stay. It can stay for long in one pocket or it could connect through the pores like one pour can be connected to the other pore and the groundwater can flow.

So, this is the basic theory of groundwater wherein, water is infiltrating as per the hydrological cycle and there should be a space inside the solid medium to host the water. So, this matrix always have porous medium, porous means with spaces. take your sponge that you use to wash your car or wash your dishes, the yellow colour sponge most probably would know it has holes in it.

So, the solid material is like a soil, the yellow color could be like a soil, but it has holes in it. And those holes depending on where you keep the sponge can have water or air. If you squeeze it and hold it upside down for a long time all the water will come out and it is only air inside, if there is no air it will be like in a smaller size squish, but it is not squished. So, it bounces back because air wants to get in.

If you push the sponge in water, what happens all the pores, all the holes will now be filled with water. The same thing here, if you have rainfall and the soil is allowing your water to get into and store in the porous that constitutes your groundwater. Starting point for characteristic fluid flow through porous media is Darcy's law.

So, there is a law called Darcy's law which is the base and very, very widely used equation to characterize the flow across the medium, across the porous medium. And that constitutes groundwater flow because the equation gives you Q, a discharge as volume or Q as a velocity. So, you can either take the amount of water that flows as groundwater flow through Darcy's law or the velocity at which it can flow through Darcy's law.

So, we have multiple media here or like a sample, let us say ABCDEF. So, what you could see here is the solid particles which are in darker color are arranged in a sorted manner, and it has spacing, and that space can take water or air. And this is the basic theory for groundwater. If the water can get into these pores and replace the air, then groundwater can be stored, it need not fully replace it, we call that unsaturated, but if it is fully saturated, then it can connect to between pores.

Look at the other example, the solid material also can have holes, as in, you can see some rocks on the surface, it might have some holes, and some holes can even go through the rock material. And inside that water can go, so that is given in your diagram c. In your d, what do you see is between the voids between the space where there is porous space, you can have smaller minerals present in it.

So along with water, there will be a smaller minerals. And then here the smaller minerals plus a porous media are porous rock, you can see here, whereas e and f are more fractures. So, it is like a rock with a fracture in it. And water can seep in through it. It is interesting to understand the fracture can store water, but the movement or application of water can also lead to fractures. Because rock weathers, you have to weather the rock to form soil.

So while it is weathering, some water particles can get in, and water expands when it is cooled. And so it can actually form cracks in your rock. And those cracks are called fractures. And it can either be small, or irregular or more regular pattern depending on the material of the rock, the type of rock, and they can be connected or not connected, depending on the rock material. So, once if they are connected, then the water will flow.

So, from these diagrams, what you understand is groundwater flow, let us say from left to right can occur and it is not a river. In a river, you do not have rocks and stones everywhere, you have it on the bed of the river on the sides, and maybe one or two obstacles inside the river. But here always the material is present, always there like for example, these are the raw materials, then water flows through them.

And that is how groundwater flow and aquifer groundwater table everything is estimated, because some people assume that when you talk about groundwater, you have a river flowing underneath your ground. No, because when you dig a well, what do you see you see only water there is no solid particles only the solid particles on the ground. So, that does not mean that your water is like a river under the ground, because you have a well you dug out the solid you can see it. If you put back the solid then the water would relocate and it will pass through the cracks and then flow so, it will still flow, but it will pass through the cracks and then flow.

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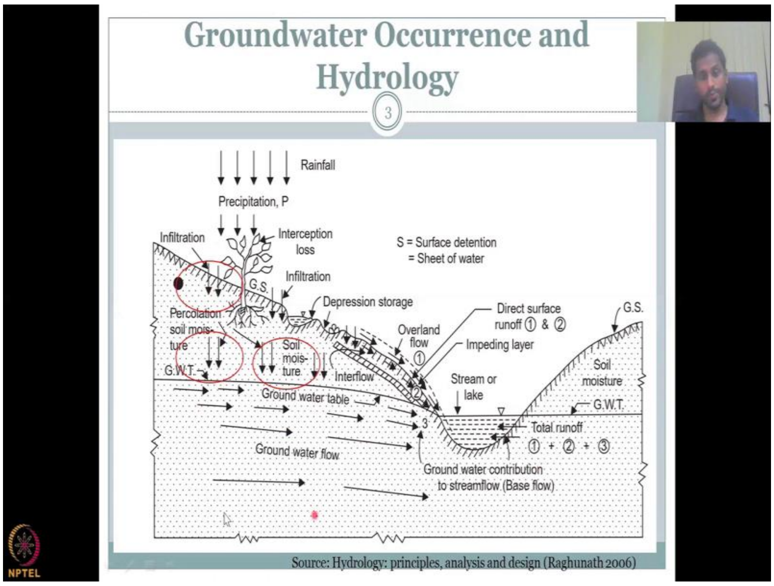

Let us take another focused groundwater hydrology diagram for explanation. So, you have precipitation, which is the key resource for water to come in. As I said, it is a function of the fluid which is here the water, it comes in and hits your surface and an infiltration happens. So, that is a process by which rainfall precipitation can get into your land. And under the land surface or lithography what you see is water moves through the soil and is being taken up by the plants, animals, whatever is living under the soil.

And some of the water which is remaining which is not taken up by the plants get to go further down. Why does it move down? It is because of gravity. Gravity acts for pulling down for the first initial velocity and also the acceleration of water moving down. So, once it moves down, it comes to a level where there is full water across the profile along with the sediments along with the solid. So, which means at this level below this level, all the pore spaces is full of water there is no air.

So then, you have an imaginary water table line, a line below which you have water in all the spaces inside the solid sphere. So, all the soil you have full of water, soil or rock material whatever the media is, you have full of water and you can draw an imaginary line which is called the water table. Please do not confuse this and this line this line is your stream flows if you stand in a river, you draw a line where the river height is. So, from the river height until the ground it is water, but you do not see any sediments any solid particles.

Here solid particles are included. So, if someone wants to calculate the volume of water, you cannot just take this area and say, I know the height, I know the breath, I can take the volume of the water, no. Because you have to subtract the volume of the solid. So, all this calculations we will be doing in this class through understanding the equations of groundwater hydrology. So, percolation happens and then water comes in and relocates.

Some of the water still stays behind as soil moisture which is the beauty and also the driving factor for plants to survive, trees to survive. Suppose soil does not hold on to water and soil moisture, what happens? All the water will fall down into the groundwater and so there will not be any plant life because plants cannot extend the root that deep. It is very hard for plants to get to that because both biomass has to go down and also the pressure to take it up to the top of your plant or tree is pretty high.

So, the energy consumption is more you only see those kinds of plants in deserts where they have very deep roots or very lateral roots because there is less rainfall. The normal plants your crops your fruits, orchards do not do that. So, you can imagine like a pot plant, if you have a pot plant, the root zone is only two but if you have a plant where it needs more water, then the root zone will go down.

So, this is the way water can occur, groundwater can occur into your groundwater profile and once it hits your water table, the imaginary line is created underneath which water can flow. So now, water flows through that region.

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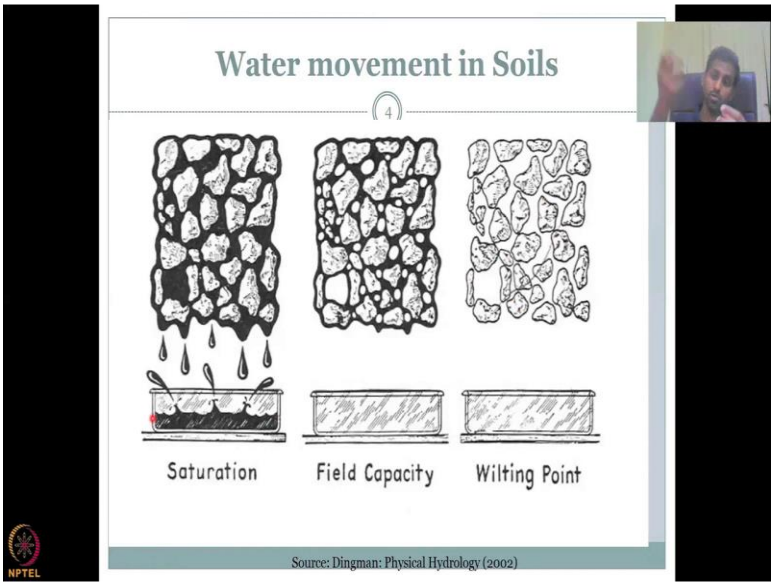

So, more water movement in soils is also very interesting and important to understand. So, in this course what you will see is, we will define porosity, we will define this pore space and how it is calculated. Then, we will identify how water comes into these pore spaces and how it becomes saturated, filled capacity and wilting point.

So, just to give a brief, saturation is when the all the solid particles are present along with water which means the void space does not have any air, it is full of water and gravity is still acting on it that is why what was falling down. So, is it falling and splashing. Field capacity is that stage after you stopped watering, you stopped watering your soil what happens is the water moves down due to gravity.

So, gravity is pulling the water and it stopped because after some time it cannot the soil holds on to the water. that holding on to water is an intrinsic property of the soil type. And that is where we have some soils as good soils for agriculture some as very bad for agriculture. You do not expect plants to grow in sand, you do not expect plants to grow in gravel because water if you pour it this goes down. You need a soil that supports plant life by holding on to the roots holding on to the water and slowly feeding the water into the plant.

So, this soil is ready it is at field capacity which means all the spaces are full of water or some air you have some air particles compared to this. But more importantly, the water stops going down and is all available for the plants to take up. The some very little water which the soil will never give up. So, but that it can be kept it is not a big fraction of the volume of water. So, some water will always be kept and that you could see in this stage.

So now, we are moving from here to here where the plants have taken up the water or the water has been evaporated from the soil and the soil is now at wilting point. The soil moisture is now at wilting point, which means any plant growing on that wilt and it will droop and if you do not irrigate it will be replaced, it cannot survive.

So, this is a warning for the farmers to irrigate the field once you see the plants dropping the leaf turning yellow in color, which means the plant is suffocating it does not have nutrients, nutrients go through water so it does not have water. So, suddenly he or she can go and irrigate.

So, this is that stage where all the pore space is almost gone, the pore space with water is almost gone and the remaining water is held by the soil particles and it is not given for plants. So, think about in the groundwater terminal. Now, we have discussed the plants please go back to the previous slide where we discussed that after plant take up whatever water is available, it goes down to percolation.

So here, these two stages would have some water coming down where field capacity is almost done, but still some one or two droplets is there which can contribute to your groundwater. But in saturation water still moves down. So, can you expect groundwater flow , a good groundwater flow in a wilting point soil? No, because it will be down much much down if the water is there, then the plants cannot pull the water and this this phase will not be there.

So, the phase actually exists for groundwater, the best phase is a saturation phase where water comes down, soils are full of water, it can take water for the plants and the remaining water goes down for percolation.

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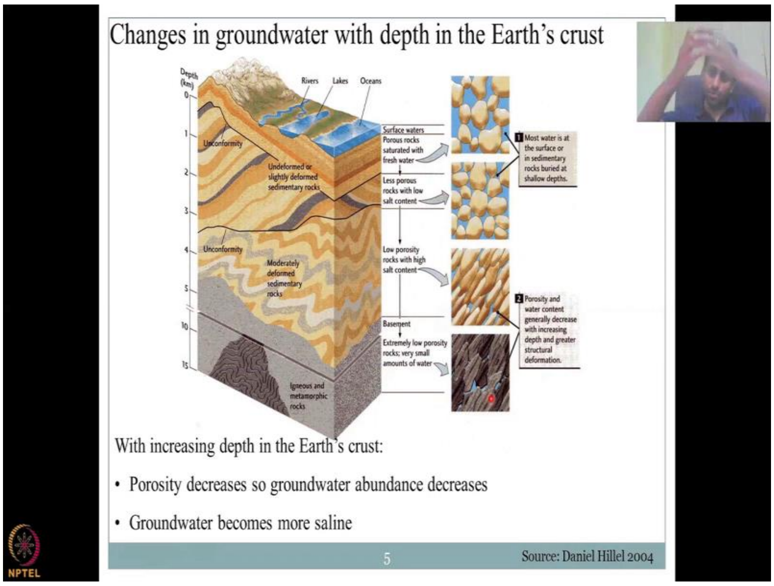

Is this the same scenario throughout the depth of the soil profile from the top of the surface? No it is not. Why? Because there are changes in groundwater storage with depth in the earth's crust. Let us take the earth's crust, this is the top of the earth and you have different water bodies and rainfall occurring. Let us leave the terms out for now let us discuss 3 to 4 depths in the soil profile.

And the profile goes up to the bedrock. The bedrock is the rock which is not whethered yet into soil. So, those who are civil engineers and earth scientists, they know the process of soil formation and there are some NPTEL courses for it. How soil is formed? It is because the rock which you see on the bottom weathers, disintegrates, is acted by natural forces to form smaller particles and in becomes soil.

You can see here this is black in color than brown brown brown so I am not going to get into the soil formation process. But I am going to show you that the bottom part is still consolidated, the rock is a rock whereas, the top part is it is unconsolidated, it is converted into soil.

So, now let us walk through as a water that falls on the rainfall on the ground. So, rainfall is occurring or what is stored here is here is there. It is available for recharge. So, water is recharging. Once it hits the top part, there is a lot of pore space. The pore space which we saw in the previous slide is available because plants have created that space the soil itself is in a very good aerated mode and less compaction more spaces available for infiltration of water so most water is at the surface in sedimentary rocks buried at shallow depths shallow.

So, there is four depths shallow, shallow and other shallow middle range and deep. Let us call it that way. So, there is freshwater which entered and it is stored. Now if it is saturated, water will still move down. So now, we go to the second layer around here what do you see it is also similar to the previous layer, but the pore space is less because some more solid is there more solid particles are there. So, water gets stored in the second face.

Then you move further down, if you go further down, the rocks are not as well developed into soil in this stage. It is not much weather so you still have the structure of the rock you can see here the structure the platy structure, etcetera. And that allows more compaction and also arrangement of your rock material that the pore space is limited, low porosity rocks with high salt content, we leave the salt quality, out but now we will just focus on is there space for groundwater not much.

Porosity and water content generally decreased with increased depth and greater structure formation/deformation. So, if you go down further, you have more solid material. So, if you look at solid materials less, increasing, increasing and much more. So, solid material is there more which means your space for water and air is less and that is where it becomes extremely low porosity, extremely low water availability for groundwater.

With increasing depth in earth's crust, porosity decreases, the space for water decreases, so groundwater abundance decreases. And when water becomes more saline, which we will be looking at, in the water quality slides. Coming back to your understanding of this to apply in field, if you are a farmer, you put a well here are you going to get the water? Yes, because you have good water supply in the pores, you can easily drill also down because of the solid materials less, so drilling costs will be less.

But when you go further, further deep, what happens the drilling itself is a very complex process, we will have to drill through all these solid materials. And even if you do the probability of hitting a water pocket to get the water is very less or a porosity high region in the deep aquifer is less. Here, the probability is much high and the pores are interconnected. So, it will flow even if you misplace your well still water can flow.

But here it is not like that, you have to be for example, if there is a fracture, we saw here, if you do not hit the correct part in the fracture, you miss the weather, if you put it here, there is no water if you put it here all these factors will contribute. So, that is what is important to understand when you understand as with depth increase, the porosity decreases with porosity decrease the groundwater storage also decreases stress.

There is no point in just going on deepening your well. If you go to rural areas or urban areas where they have wells, just ask them, have you deepened your well in the past 10 years, they will say yes, because the ground table has gone down, the level of water under the ground has come down. So, I have to put more labor into deepening the well. Most probably they would put the rig back in and then drill deep or they will just abandon the well, go to another location and drill freshly. The same cost just you have to do the piping etcetera.

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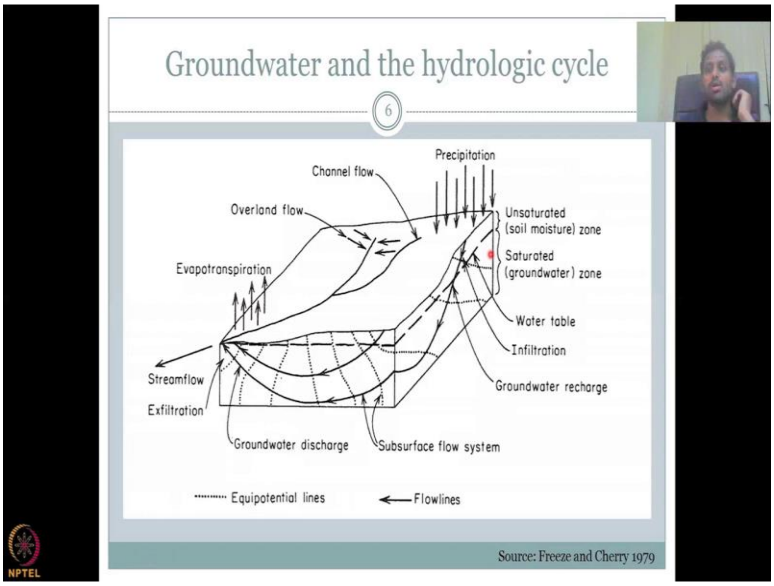

So, understand the theory that for groundwater you do need to have a space for the water to infiltrate and store. And once the space is connected, it can flow. Let us go to groundwater and the hydrological cycle. Now I am going to focus only on the groundwater hydrological cycle. So, of the overall cycle, we can focus on just the hydrology part for groundwater. Let us differentiate that.

So, you have precipitation, which is hydrological overall hydrological process and an important contribution important component in the groundwater hydrology. Then you have channel overland flow which is fed by the precipitation. So, when precipitation happens, water can run into the rivers and some water is lost fine. So, now, these channels and the land which gets a precipitation can provide a pathway for water to infiltrate.

So, infiltration happens, you see here the first stage where water moves into the soil profile and the soil profile is categorised, the top part is unsaturated which means there is less soil moisture or the space; the space between the soil particles still has space for water because normally it is with air and water and if it is fully with water, it is saturated.

Now, as we move down the imaginary line comes up, which is your water table, you can see here it is called the water table and underneath the imaginary line, all the pore spaces is full of water it is fully saturated. So, infiltration occurs far and good. Now you hit the water table. And you start the flow, because you have created a gradient. Why does water flow, any water? Water flows because it wants to be in the most lowest potential.

So, if you have two wells or two water levels and one is low, this water would flow to this path because water wants to flow from high potential to low protection. If it is isolated like for example in a cup, it doesnt. But if they are connected through the pores, the law of nature says it has to flow from high potential to low potential. Same like your temperature. Temperature goes from high to low.

It has to equate it has to balance and then for example it is like these two high potential low potential water will flow until and otherwise it is the same and then there was no flow or it will always flow because it wants to get to the oceans which is the least potential 0. So, that is a mean level of 0 and until it reaches 0, it will flow. How fast it flows is dependent on the fluid properties and your solid properties which we will see in the following slide.

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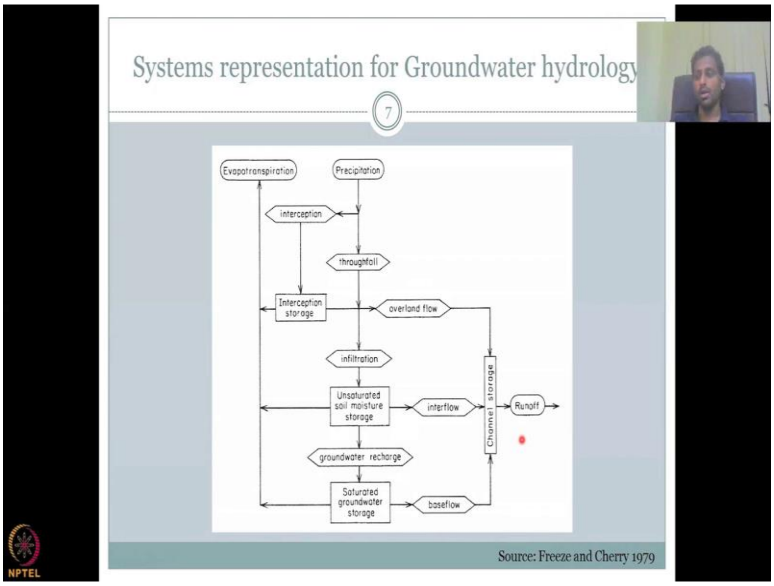

So, based on this we can have a systems approach representation of groundwater hydrology the hydrological situation. You have precipitation, part of the precipitation goes as interception which means the plants and trees which are the can actually cut through the rainfall occurrence and catch the rainfall, for example, broadleaf trees banana leaves etcetera.

So, when rainfall happens you see the trees are wet, which means some volume is captured by these leaves that is called interception. What happens the interception, it becomes interception storage and evaporate translates mostly it is evaporation because sunlight is falling it evaporates.

What happens to the remaining it goes through the trees that is called through fall, through the trees, through the branches until it hits the land surface which is here. Once it hits the land surface, what happens part of the water goes up overland flow which means surface runoff. The remaining water goes down further as groundwater infiltration or soil moisture infiltration.

So, water infiltrates into the soil, goes to the unsaturated soil moisture storage which is your soil with less amount of water more air. So, it will, water will go in and replace the air because water is heavier than air it can replace it and then some part of the water is taken up by the plants for transportation. Some of the ground water in the soil moisture can go as into flow and into channels which is rivers and then go as runoff. So, once all of this goes into reverse it goes as runoff because rivers then join your ocean.

What happens to the water after your unsaturated? It goes to the saturated zone which is called the groundwater recharge. So, here it is soil moisture recharge infiltration, and here it is percolation into the groundwater recharge. So, what happens here groundwater recharge is happening, it goes into the saturated groundwater storage.

So, there is already a component in your soil profile, which has water fully which means all the pore space is full of water and that is called a saturated zone into that it will go. So, what happens when the saturated zone already has water? So, where will the water go? All it does is it raises its level. So, here also soil is there here soil is there, but this soil has water. So, when water goes into the soil, it would just the water table will just go up to the soil where it is not fully water and now the incoming water can store.

It can store and part of it can be taken by plants and trees released back into the atmosphere as evapotranspiration whereas, the remaining can still go as baseflow. Again why does it go as base flow, because water flows from high potential to low potential. And if your river is at 0 or your sea is at 0 location, then water will eventually flow down. So, on the whole groundwater cannot just stay there, it has to move, how fast it moves depends on the depth in which you have the water.

But eventually it will move into the baseflow and then baseflow goes into rivers which is your rivers, stream storage etcetera. And then that contributes into runoff. So, the runoff happens and which is your stream discharge, river discharge, and eventually all of this all the rivers all the streams would go into your oceans because that is the elevation.

Why does rivers flow from a high potential to low potential, because water wants to go from high potential to low potential. You have a waterfall you do not see water going up? Water fall, so water comes around the mountains and from there it falls down goes through the rivers and then river meets the ocean. For calculation purposes, oceans are at 0 level and that is where we say that is 0 height and from there we say what are the elevations?

With this systems approach I would like to conclude today's lecture. I will see you on other side of lecture 5, thank you.