Groundwater Hydrology and Management
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Lecture 22
Flow Nets and Groundwater flow conditions

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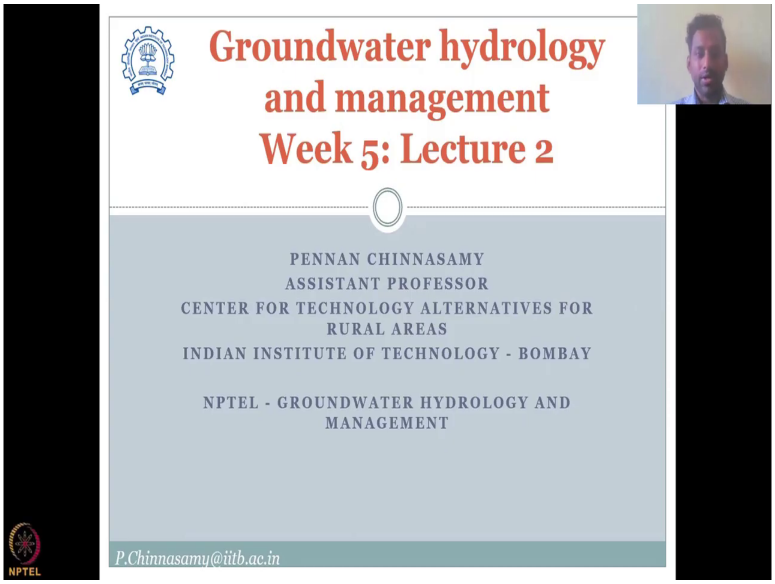

Hello everyone, welcome to Groundwater Hydrology and Management, NPTEL course. This is week 5, lecture 2. My name is Pennan Chinnasamy and I am an assistant professor with Center for Technology alternatives for rural areas IIT Bombay.

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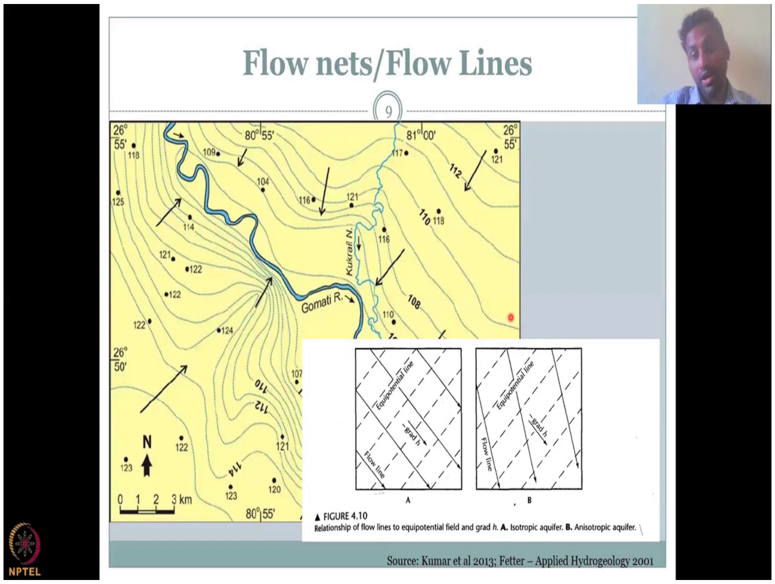

In the last class, we looked at the conversion of hydraulic head as a point into a line of equipotential hydraulic head and those were called contours. We also define what is a contour interval intervals into today's class. We will look another important aspect of these contours and lines which is your flow nets and flow lines. For example, we will take the same example we use for contours we have the well locations and that each well we have a hydraulic head and the hydraulic head if it is similar, we made a line and said this is called contour lines or equipotential lines.

We also mentioned that the groundwater flows perpendicular to these lines from high hydraulic head to low hydraulic head, high contour line to low contour line, and high equipotential lines to low equipotential line. So, in this image you see groundwater moving towards the river, because here it is high 1 to 2 and then it is 1 to 4 here, so, it is coming down.

In between you will have some irregular higher elevations, but that is okay, that is why you have this cone shape but otherwise it does go very smoothly 122, 121, 124 etcetera. On this side we have 121, 112, 118 It does come down into 110 106. So, what is flow lines, how does it differ from your contour lines? Flow lines looks like this. So, you have equipotential line as a dashed line which is your contour line and then you have your flow line which is perpendicular to the equipotential line and it is based on the property of the aquifer.

You can also see where this gradient of h happens, So this a change in hydraulic head the gradient the direction also happens. So, it may not be in the same direction of gradient of h, which you see in the in the figure B and we will see why the difference happens in the next slide.

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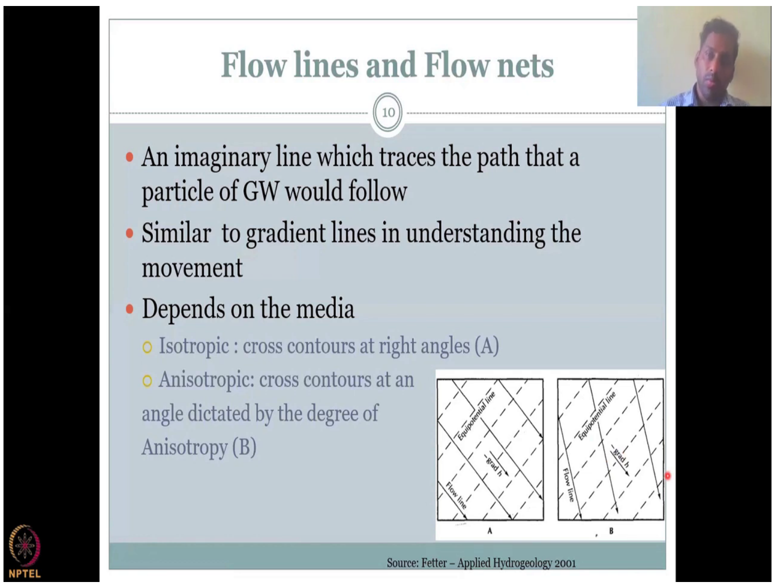

Let us define flow lines and floor nets. It is an imaginary line which traces the path of a particle of groundwater and how it would flow. For example, you have hydraulic head high a well high here and a low hydraulic head. So water will flow from A to B but how it follows the path the imaginary line that captures the path in which the water would flow to is called flow line or flow net. It is similar to gradient lines in understanding the movement when whereas the gradient line gives you the direction and it just says decide xy plane y, z plane etcetera. But it does not give you the line of movement and it does not show you how it changes abruptly whereas flow flow nets do show you that.

It is purely dependent on the media which is your soil profile or your rock profile and what properties it has. For example, let us take an isotropic case in. You see the cross contours at right angles the this equipotential line is a dashed line and your flow line crosses them at right angles.

Why? Because if this is your potential lines, all sides are being pulled by the water equally it is Isotropic.

Let us define isotropic again isotropic means in each plane the variation is the same the magnitude is the same. So it is k x for example k x is equal to k y is equal to k z it is isotropically same and homogeneous. So, in that sense when water goes into a plane, the x direction will pull you in the same magnitude y direction will pull in the same z direction will pull in the same. So, at the end of the day, you have it flowing perpendicular to the contour line.

Whereas an isotropic media where Anisotropic means k x may not be wearing as same as K y. And same with KC also. So, we will all the three planes might have differences but in how it changes from point to point. And in that point, the cross con the flow lines would cross contours at an angle dictated by the degree of anisotropy.

What do you mean by degree of anisotropy? Is how much kx is differing from ky, if ky is very, very strong and higher much much higher than k x in anisotropy then it will be pulled along the y plane. So, here you could see that if this is x and y or like let us have it normally your y and x axis and your y as I said is very, very high. So, even though your equipotential lines such as the water should move along the gradient of H, the flow nets would say that it is moving towards your y direction, why because the y axis is having higher pull higher anisotropy degree of anisotropy.

So, this is where it gives you a difference between the gradient and the flow line. The gradient will just give you the direction as it says this one is a high potential This is a low potential so the gradient is from high to low it flows this way, perpendicular always perpendicular, Gradient is always perpendicular to the contour line, whereas your flow net would also undertake the anisotropy also undertake the property of the soil and then choose a path.

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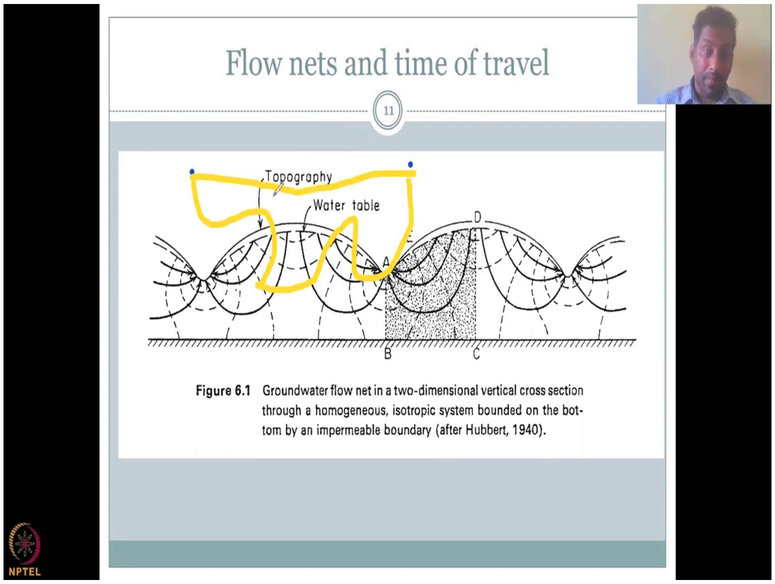

Let us see how we can visualize it and time of travel for water. So, on the top you see the surface and then the dashed line is your water table on the top of the surface and then below the water table, you have the equipotential lines, dashed line which is a contour lines. And the solid line is the floor net. So, if I put a particle here, I am putting a particle here how water flows.

Let us change the color into water color. So, how water would flow is shown by the flow net. So, what it says is it flows from high potential to low potential. So, you see here, the potential the water table is high here and the contour interval is low here. So it will flow from there to down, it does not continue to flow in the perpendicular direction, but it has a tilt, because it knows that the anisotropy is present and it knows where to go it has to go to the stream.

So, the contour lines are there to give you the variation of hydraulic head. However, a particle even though a particle moves from high to low head, it is also the direction is also pulled by the anisotropy and the solid media and the pore space etcetera. So, it is a function of the media in which the non water particle will flow. So, it is a two dimensional image that we are showing here, and what you see here is a vertical cross section.

So, you take a land and then cut the land into like a slice cake, remove the front part and then you can expose the land. So, if you expose the land What do you see is a homogeneous This is a homogeneous isotropic system and underground it is impermeable, so, it always would flow as previously we saw the Particle Flow net would be always in right angle. So, from here right angle right angle right angle and then it was above a straight all right angles to the equipotential line, which is the contour line.

And there could be some differences in a anisotropy, non homogeneous medium, but here because it is dominated by your high elevation and low elevation, the undulating surface, we keep it as how water moves from high potential to low potential. So, now, how does this give a time I put it on the top topic of the slide, flow nets and time travel because we know what path the water particle will take to go and join into the other water body or groundwater aquifer. We know how much time it takes.

You can go from A to B in a straight line or you can take a very torturous line. So, a to b and then you can take a very straight line which is the shortest or you can go around and around and then go here, which is how it happens in the groundwater scenario. And the path the path therefore gives you the time how much time it takes, because the hydraulic conductivity is the same, which means the velocity the permeability of the media would be the same, but the path determines the time and the time also determines the recharge residence time of groundwater, which we have already seen in the previous classes.

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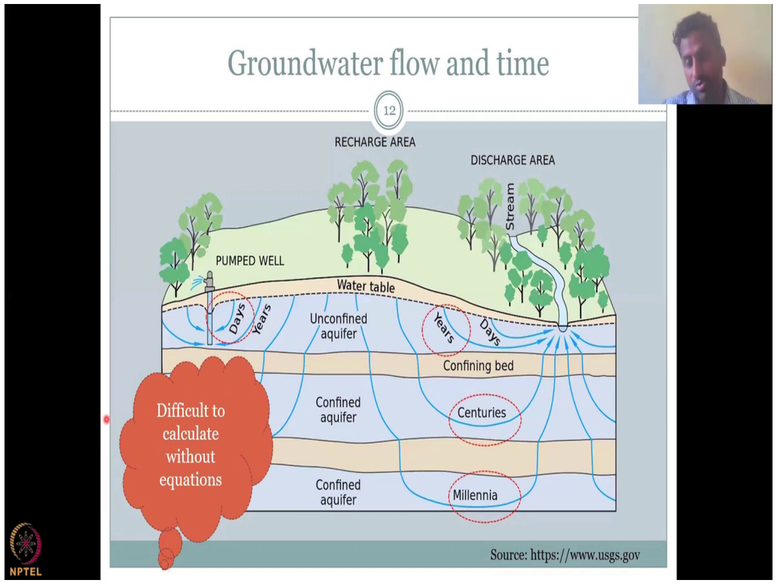

So how does this relate to your groundwater flow and time, as I said, you have these flow nets from the top we have the recharge happening and then flow nets happening and the particles traced to how the water would move. And since, in this scenario, your water moves directly into the pumping well, it is in the unconfined aquifer and it is already saturated. So, it will directly go into the well. This would result in a very quick transfer of water. And that is why it is in days or maximum in years. For example, to three years you will get the water well recharged, if it is a good rainfall year.

When the part of the water goes down into the unconfined permeable layer and then goes down further into the confine layer, it takes more time, because it has to pass through this as I said, and then suddenly the material becomes heterogeneous. And there is a longer time of travel because it gets slow, the path is torturers and the material has changed. So the velocity the hydraulic conductivity, everything has changed, it takes a very slow path. And that path results in a longer time for groundwater flow.

What is up clearly see here that the bar even though this water would take this part, the water particle, this particle would not go down because it sees the confining bed, and it does not have the energy to penetrate or percolate further it will go in the lateral direction and this happens at Century time series. So, for centuries, this will happen this from the groundwater on the top to the confining layer and then to the confined aquifer. This will take centuries to come back to the stream.

Let us go down further the particle, tracer particle in this particle method the water particle would go down in the unconfined then go into the confining bed it enters into the confined aquifer slowly gets percolated into the another confining bed and then goes into the last confined aquifer. This actually takes more than a couple of centuries and in times millennia. So, if you look at the path, the path if you look at the length of the path is not as different than the century path, but because it has to go through different media and each media would have a different property of porosity, hydraulic conductivity and permeability, it takes time.

So, the path and flow net is a very very important concept in groundwater hydrology, which helps you to understand the changes in flow path, because here you could see the flow path instead of going down, we change this course into horizontal because it was not going vertically, it did not have the energy it moved horizontally. And those kind of aspects are clearly understood by your floor net, it is an imaginary line.

So, you can be more or less confident of giving an assumption. It is not the exact path water would take but more approximate path. So, as I said some water would take days years, centuries and millennia all made by the flow path. So, how do you estimate this how do you estimate how the flow path will change? How the porosity and other particles would drag the water particles down? All, this cannot be done on hand by manual calculation, but it has to go through a followed empirical equation which have already been developed.

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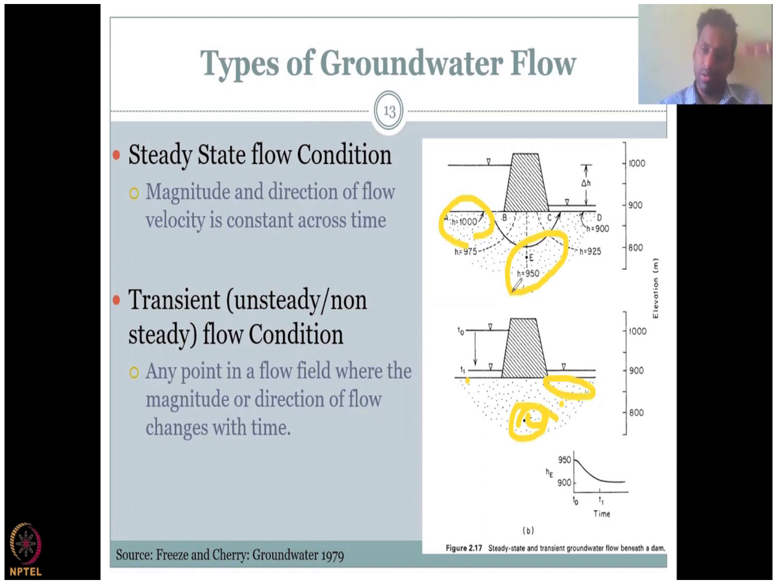

So we will see those equations when we discuss in this week about groundwater equations for confined and unconfined layers. So when we move on, we are going into the types of groundwater flow. So initially we saw how hydraulic head is and from hydraulic head how groundwater flow happens. And then contours we discuss flow nets, we discuss.

Now we discuss the type of groundwater flow, there are two types, A steady-state flow condition and A Transient flow condition. As the name suggest, steady-state means the magnitude and direction of flow velocity is constant inside the material across time. So, for example, if I take a sample here or here or here all the samples would have the same magnitude and direction of flow and it is constant in time.

So, for example, this one let us take this example, this hydraulic head is kept constant and del hatch is what drives it right this is the hydraulic gradient which drives the groundwater flow and it is kept constant and this is a lower head So, always water would flow from A to C. So, AB is this cross section CD. So, let us say water from a B will always go to CD because higher water head compared to lower water head, what is the hydraulic head here it is 1000 and then goes to 975 950 925 900.

So, it always goes from high to low assuming this is a homogeneous isotropic system, you can draw now the flow net as a perpendicular line to the contours. So, this is a 975, this is 1000, this is 950 you could see it cut perpendicularly into the CD zone. So, this is a very constant steady flow because the hydraulic head is kept constant this is also kept constant and somewhere when the groundwater comes in it just being pumped out. So, all of the incoming and outgoing is kept constant and that is where it is a steady-state flow.

Now, what is a transient flow? Transient is unsteady or non steady flow condition. Any point in a flow field where the magnitude or direction of flow changes with time. For example, at E it is not the same velocity and magnitude with time, why because there is a change in the head. So, here we maintain the head constant the water table and then this water table is also made constant. So, there is always a flux at a constant rate.

Here what happens it is not constant and it flows falls down. So, when it falls down to T1, for example, T0 to T1, now, this hydraulic head AB is equal to the hydraulic head condition in CD. So, why would water move do you get the understanding. For example, if this water falls here, now, this water table let us say it is at 1000, hydraulic head and this is also a 1000. So, when 1000 happens at T1 T0 to T1, Time 0 Time 1. Then this would become 0 correct, there is no flow there is no need to flow. But at T0 when time was the initial start this T was equivalent to this E. The flow condition at both these points were equal because the hydraulic head was maintained by the water table at one location and on the other location water was still flowing.

So, if you maintain the water table that is maintaining the hydraulic heads across the domain, then you get a steady-state flow whereas in a transient flow, the hydraulic head which drives the system changes, for example, if this comes to T1 here, then there will not be any flow. So, the flow that actually promoted water movement from AB to CD now is going to be stopping because it is at the same water potential.

So, this is an important concept to understand that in real life scenarios, it is mostly transient in nature groundwater flow conditions, it is not a steady-state condition, because to maintain a steady-state condition, there is a lot of energy needed, you have to push water into the dam and then also maintain the hydraulic heads same whereas, that had does not happen in the natural condition always there is a change which is represented more by the transient steady-state condition.

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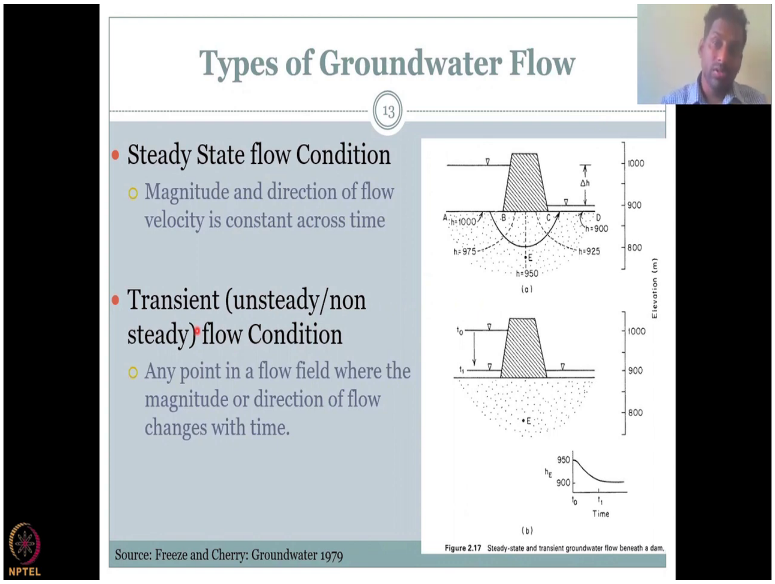

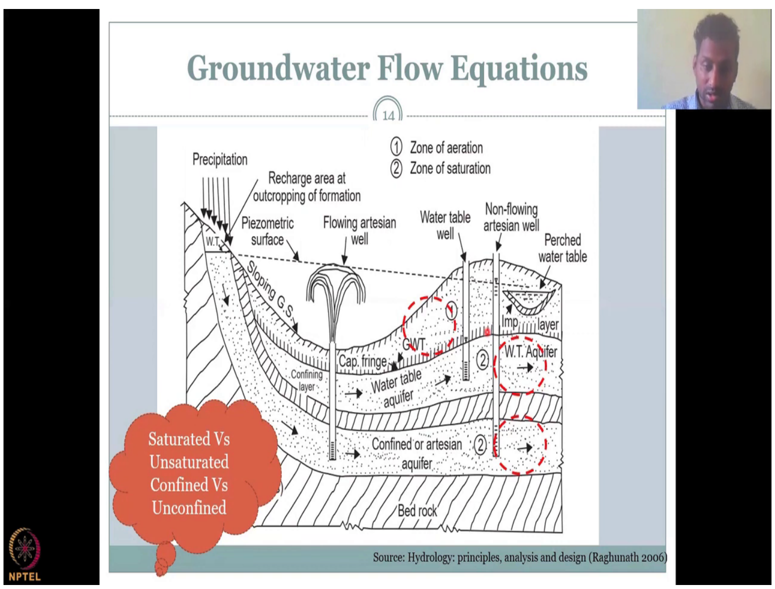

So, we will be looking at groundwater flow equations, as I mentioned, we have defined the flows the hydraulic head, contour lines, flow nets, we had to decide if there is two types of major flow steady-state and transient most of the models that you would see are using steady-state flow because that is the easiest less data intensive but transient is the reality in nature. So, we will be seeing how those things happen.

And now, we will be looking at an introduction to the groundwater flow equation and you would see that there are multiple different types of groundwater scenarios. So, we have to be careful not to use the same groundwater flow equation to all it is not an assumption that you will use it for all.

So, what are the different conditions we have saturated versus unsaturated system. So, you have in this location you have number one is a zone of aeration where water can still come and occupy the pore space. So, it is a unsaturated system whereas, underneath it on the water table and underneath the imaginary water table line, there is a saturated zone, zone of saturated so, there is a saturated equation that will consider.

So, then what happens is you have confined versus unconfined as we mentioned the confining layer which is present here defines the location of your confined aquifer unconfined aquifer. So, you have an unconfined aquifer above the impervious layer and below the impervious layer you have the confined aquifer. So, the unconfined is totally going to be recharged by the surface water and surface precipitation whereas, the confined aquifer gets recharged from very very far away.

Since the processes are different and the assumptions are very very different, we will look at different equations for each setting. Example the first setting is a what is the setting it is a unconfined unsaturated system the water is not fully saturated, we will have a different equation for that. Then we have a unconfined aquifer but saturated system it is a porous space with full of water. And the last we have a confined aquifer with a saturated system because here below the impervious layer all pore spaces full of water as you see in the diagram.

So, quickly if we look at it, two of them can be combined which is your saturated unconfined aquifer groundwater equations may be combined with your confined aquifer saturated condition. The saturation saturations can be clubbed together, but please understand that this line this imaginary line that separates the saturated and unsaturated can fluctuate like the transient I showed in the previous slide. So, suddenly if there is pumping then this line would come down which means the confined aquifer conditions that you put here in the unconfined saturated layer will not work because your saturation layer comes down the time water table comes down.

Similarly, if water is recharging, there is no pumping and water table goes up then this unconfined unsaturated pore space equations will go away because you have full of water. So, it has to depend on how you use the system what kind of assumptions you would like to make for the groundwater equation.

In the previous classes, we also gave an introduction to Darcy we will be looking at Darcy's equations to start with and how they are used widely in the world. We would also look at what are the key parameters and data that is needed for Darcy's equation and as I said between one and two the zone of elevation and zone of saturation there are some changes some differences which cannot be explained by the Darcy's law.

So, you will be using a different law. When you use a different law and you say that it is because of the saturation then please understand you have to give the data on saturation, which normally it is very hard to get. So, theoretically different equations can work. However, practically on the ground without data these cannot work. So, that is where it is very important to have groundwater equations with basic data that is needed to run the equations. Otherwise, it will not run well. So, I will see you in the next class, where we look at these equations in. Thank you