Groundwater Hydrology and Management
Professor Pennan Chinnasamy
Indian Institute of Technology, Bombay
Lecture 18
Groundwater Hydrology Components 7

Hello, everyone. Welcome to NPTEL Groundwater Hydrology and Management course. This is week 4, lecture 3. In this week we are continuing to see the important components for groundwater hydrology.

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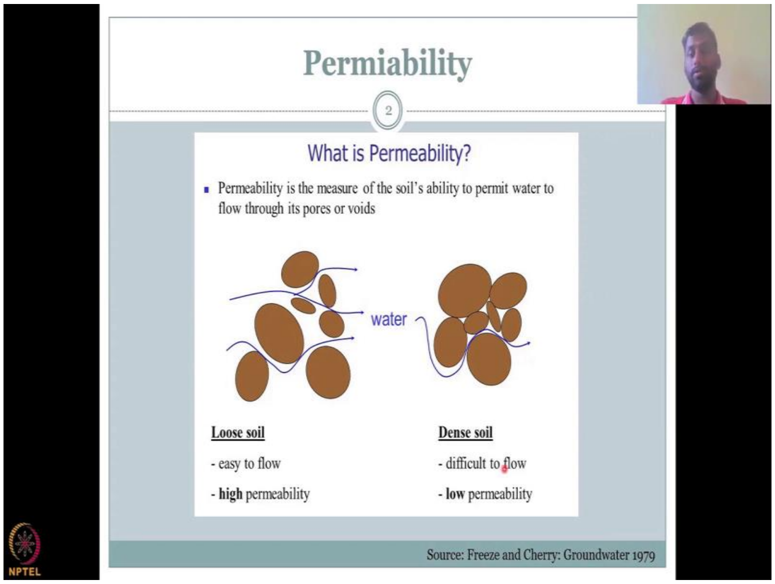

The last class we looked at porosity and how it changes and affects the groundwater movement, we understood that specific yield and specific retention are a function of the porosity or depends on the porosity. And also, we looked at how the water can move through the porous space and then drawdown due to gravity and some materials would keep the water along with it, the solid material particles would cling on to the water and that would be your specific retention.

In today's class, we will look at permeability. What is permeability? We can define it as the measure of soils ability to allow or permit water to flow through its pores or voids. Something like your conductance in electricity. So, you have a material and how is the material allowing water to pass through, the material is your soil, rock particles et cetera.

In hydrology we call it as the matrix, the matrix is the arrangement of solid soil and other particles. And through the matrix, how does water flow and how does the matrix allow the water to pass through and that is called permeability, derived from the word permit. If you search permeability, you might find that the word spelling is different in different terms. So, you can have both spellings in different books.

Moving on, you have loose soil. So, let us see how a loose soil will differ from a dense soil. In a loose soil, loose means the solid particles are loosely bound and there is a lot of space in between and you could see that water can move through easily through the material. In other words, the solid particles permit the water to move freely. Just by looking at this, you can also know that this property is also a function of the porosity and the function of the material.

You can manage the porosity or manage the permeability by compacting or tilling those kinds of activities. But just for a soil you can take you have in intrinsic value or dependent value based on the material. So, in a loose soil, water can easily flow and it is called high permeability. In a dense soil where the particles are densely packed, closely packed, the porous space is less. And because of the porous space is less, the permeability is less. So, in a dense soil, it is difficult to flow the water due to the low permeability.

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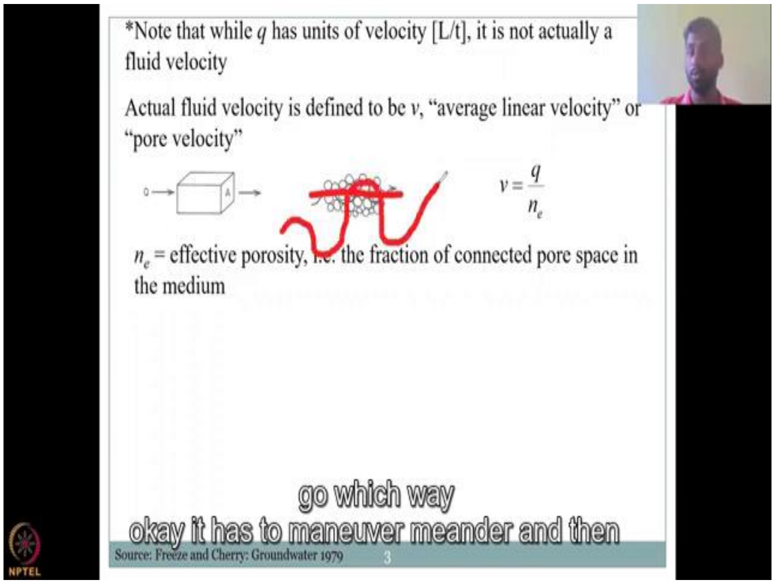

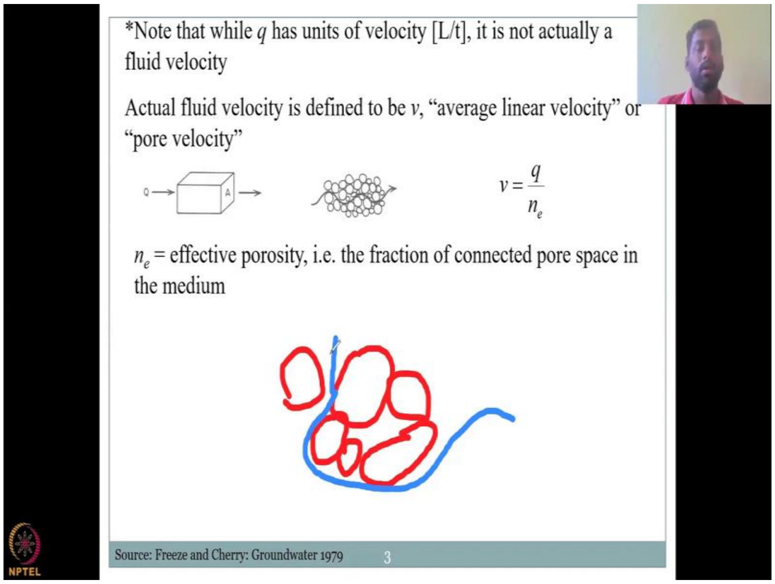

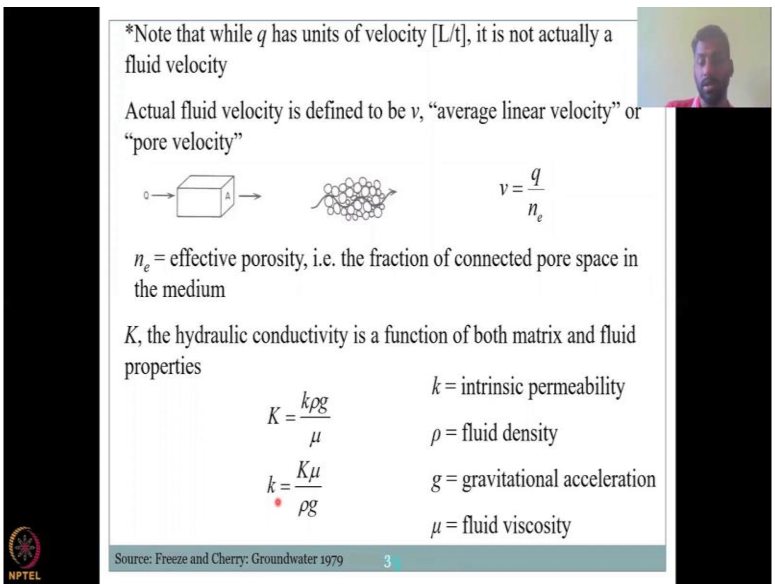

So, let us take very microscopic view of what is happening. Note that Q has units of velocity which is length time in dimensions, it is not actually a fluid velocity. You can understand that it is not actually the fluid velocity even though it is meters per second or centimeters per second. We do not call it a velocity; it is the ability of the material to allow the water, how fast water can pass through. But even though the units are say similar to velocity, it is not the actual fluid velocity.

Just take this example, where you have Q is the discharge going through a cross section of a block A, this is a macroscopic v in that you can say this is a velocity. So, you have Q going in it has Q coming out, you have a car going on a river, on a road, it goes through the road and cross section can be put to see how fast it goes, that is velocity.

However, in a fluid material and in solid soil material, your water does not take the shortest path, you can see that the path is torturous or it goes around and around until it finds the easiest way to get through. So, why not water go up, because the solid particles are jam packed, water will not go up. So, it might come down. So, the understanding here is it is not the straight line that the water will take.

It has to maneuver, meander and then go which way is least you know resistant, you can see that behavior in rivers also. You do not see the rivers straight; you see them curving up and down up and down depending on the resistance to flow. So, the water particles would go through the path where it is least resistant and it may not be a straight line. So, it is not a linear velocity, but average linear velocity. You can average it out, take out the noises or it is the pore velocity because it depends on the pore space. The space in between the material it is called pore velocity.

And it is given as v is equal to q by ne, q is the velocity of the or here we define it as the average linear velocity is v and the pore velocity can be taken as v, whereas your q is your permeability. And also, ne is your effective porosity, which means the fraction of connected pore space is a medium. So, you can have pore spaces. Let us draw it here. You can have pore spaces in between the material, but are they connected? This was what we are seeing them as connected through the pore or is it seeing it disconnected.

So, for example, you might have a pore space here, but water does not see it connected, how much of it is actually connected is the matter. So, you can have like this materials and water cannot pass through. So, because of that, it has to go through like this. And that is kind of meandering process path. So, your effective porosity is the fraction of connected pore space in the medium. It is also a function of your soil material and also the management practice.

If you till the soil, for example, there will be more connections. And that is why you see before irrigation farmers normally till the land, they plow the land. And so, when they apply water it quickly passes through, if they do not, what happens is water stays on the top, slowly it infiltrates and leads to groundwater recharge. But what happens is if it is on the surface too long, it gets evaporated. So, the farmer is at loss if they do not use the water carefully.

So, coming back we are at ne which is effective porosity i.e., the fraction of connected pore space in the medium, in the matrix or soil and it is a good function to be noticed which is a property of the soil particle. Then we move on to another very, very interesting, very important relationship between the permeability or intrinsic permeability is intrinsic to the property of the material.

So, it is given as k rho g by mu is equal to big K and K is called hydraulic conductivity, it is function of both the matrix and the fluid. So, this is the first time we are bringing water into the picture. So, so far we talked about it is the function of the matrix the solid particles and how they are arranged. But this parameter which is hydraulic conductivity brings in the properties of the fluid, the fluid being water here.

And please understand that there will be any other motion within the ground it could be oil, it could be petrol, whatever you want to call it crude oil or soluble salt et cetera, chemicals. So, all these would have different velocity, different higher conductivity based on the density and that property is only held by the hydraulic conductivity called K. So, how is K defined? And how is it related to the permeability?

K is equal to small k or hydraulic conductivity is equal to the permeability times the fluid density times g which is the gravitational acceleration divided by mu. And you have mu as the fluid viscosity. So, all this fluid can be put for water. So, we have if you are using water for groundwater, understanding groundwater for recharge et cetera we put the values for water and it becomes rho is water density and mu is water viscosity.

So, look at it here it is not only the ability of the soil or the solid particles to allow water, but also the reaction or the interaction between the solid and the water. So, fluid density is very, very important, thick water cannot pass that easily it has to be fluid enough and the viscosity can actually drag. So, if the fluid is highly viscous, then your solid particles will tag onto it and will not allow the fluid to pass through. So, here is where you have a fluid viscosity coming into the picture.

So, now, density of water can also change depending on the composition of the water. So, if you have a very salty water, the density is different compared to a freshwater which is recharge through rainfall. And the freshwater when it stays with the rock material long enough many,

many decades or years, you have a salt which is dissolved in the water and the fluid water density and viscosity does change.

So, now when we rearrange this equation, you get k which is intrinsic permeability or just permeability is your hydraulic conductivity by mu. So, mu hydraulic conductivity times a mu by rho g. So, what you have here is just rearranging the terms and you get the units of intrinsic permeability. Let us do the units to just check if we are doing it correctly.

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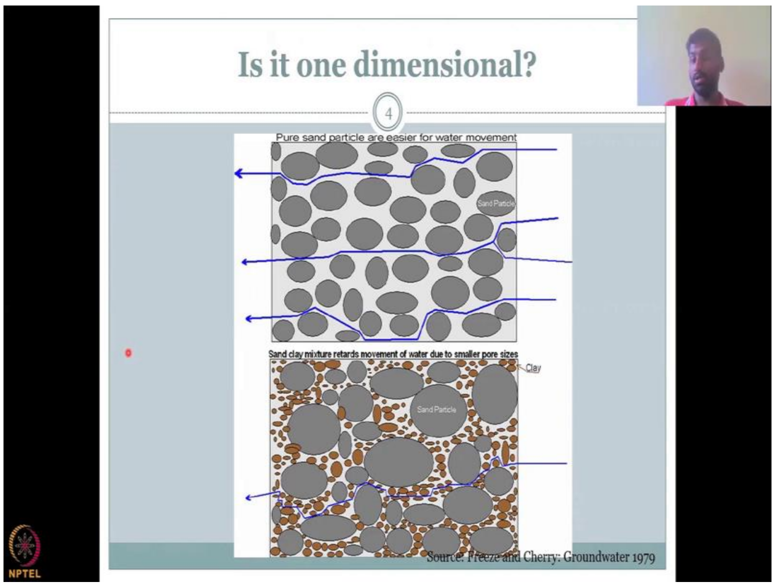

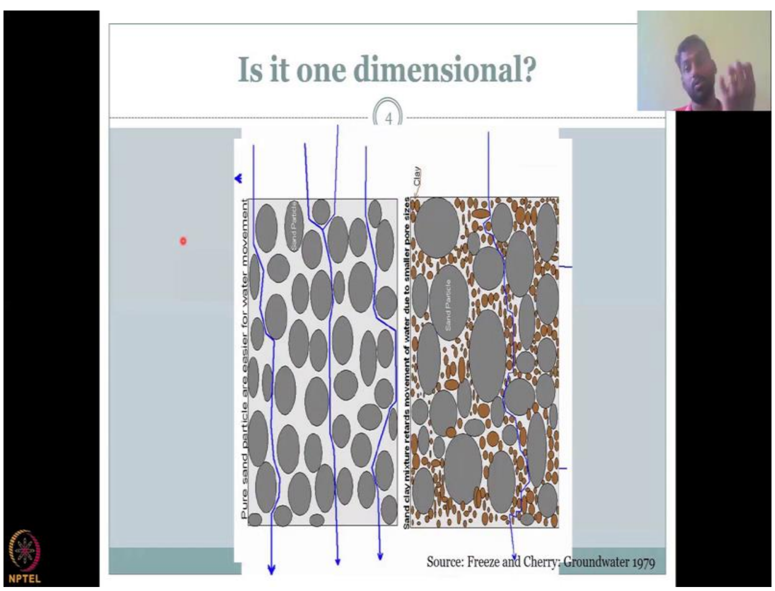

We will look at some examples of values, but before that, we need to understand all my diagrams till now all the book diagrams also. You see one dimensional movement either it is left to right or right to left. Like for example, pure sand particles are easier for water movement because water passes through easily, the pure sand has a high effective porosity which means the fraction of pores which are connected is very, very high.

And if you come to sand clay mixture, as you see here you have sand, the same sand with clay and other particles inside, then what happens is the pore space is there. But it is not well connected, it is retarding the movement of water which means stopping the movement of water and that is not good for the intrinsic permeability because the effective porosity is very less.

So, you could see water flowing from here in this screen right to left and in the previous examples we saw water moving from left to right. But is it one dimensional is the question, is it just xy plane or can we introduce another plane? Yes, for sure, we do need to understand that water actually moves from vertically down and then goes horizontal. So, there is three-dimensional movement of water and on the three dimensions these properties would change.

So, now we are converting one dimensional in for three-dimensional problem. So, water can come along the z plane or it can go to zx or zy. So, all these planes are important for movement of water you cannot restrict it just to one dimensional, it is a three-dimensional movement. So, and the process and the forces acting on these would also change. So, for example, if water is moving in the previous way left to right, which is after it reaches [Technical Difficulty] but the activity of gravity does not affect your intrinsic permeability, nor your hydraulic conductivity.

So, the gravity is there, but it does not readily pull more. However, when you have it vertically moving, you cannot neglect the gravitational force because that is what is pulling the water. And in this case what happens is the water is actually stored in the saturation level through gravity, through gravity there is more water coming in. So, when more water comes in it has to dissipate, it has to move laterally. So, gravity also plays here indirectly, but more force would directly act on the vertical structure.

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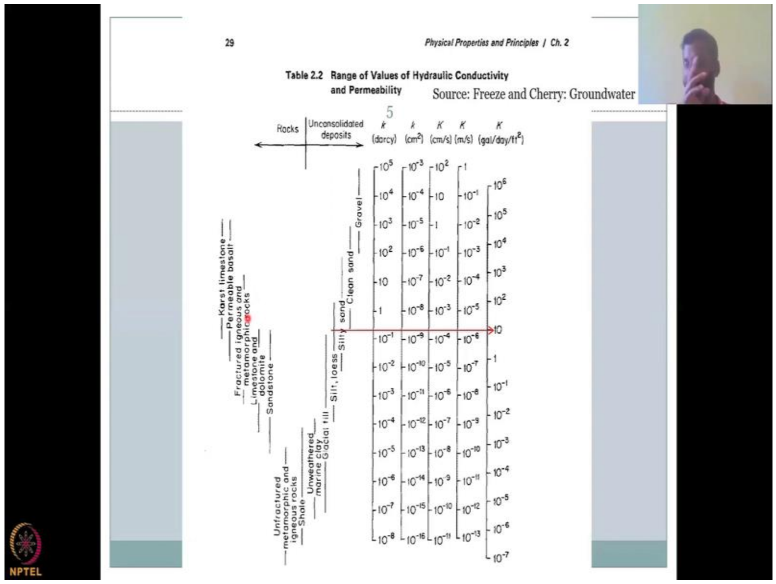

So, let us look at the values and the units. For hydraulic conductivity it is units of velocity which is given as meters per second. Whereas your permeability it is a centimeter square or it is called Darcy. So, Darcy invented these terms. So, he has his name associated with it, we will look at Darcy's experiment in the coming lectures. So, Darcy is given after his name the unit. So, Darcy is equal to centimeter square times 10 power 2. So, you can see just a magnitude or a difference here.

So, the small k is permeability and the big K is hydraulic conductivity. So, please note that we need to understand the hydraulic conductivity properties in detail in the coming class, but we look at permeability and how it shifts. So, this values are taken from Freeze and Cherry which is a book of groundwater, the authors are Freeze and Cherry and they are very, very well-known across the globe for groundwater work.

And this book is kind of used like the rule book in many, many groundwater research institutes and the data they have has been validated. So, I am using the same thing here. Here on your left-hand side what you see is the type of the rock or the deposit for soil. So, this is more your soil type and whereas here it is more of a rock type, because groundwater can go in and go into the soil structure and can also come down deep into the deeper aquifers where you have more rocks.

So, groundwater equations can be used as per depth change. So, let us look at a particular value and how to use this conceptual data. So, you have all these different rock and soil properties what you see is a range, if you understand previously even for porosity, we did not give you one value we gave a range of values. Same way here you have a range which starts from let us say silt let us say silty sand, it starts from this point to this point. So, all this throughout this is silty sand.

So, first you have to understand what is your rock material or your soil type, go to the soil type. And then you can look at the range, let us look at the range of permeability here. It is a centimeter square. So, from 10 power minus 10-centimeter square to 10 power minus 6 is the range 10 power minus 4 orders of magnitude difference. So, you can pick anywhere you want. I normally pick the center value because kind of averaging out the other values.

And like this, you could apply it to different, different data. So, since K which is your hydraulic conductivity is a function of your permeability, while the other terms are just your mu and viscosity the density and also your acceleration due to gravity all are constants for water, you could quickly do the calculations to get at K and that is what this graph does it.

So, 10 power minus 9 let us say is kind of the average I wanted to take centimeter square and that equals to approximately 10 power minus 4 centimeters per second or whatever minus 6 meters per second or in other units 10 gallons per day per feet square. So, you can see there is a volume of water moving through a cross section and if you take off the area of the cross section it is purely velocity kind of a relation.

Let us take centimeter square. So, the permeability is 10 power minus 9 for silty sand. Not very slow but not fast either. And you could see that fast way you want to look at the word fast for groundwater movement, you can look at hydraulic conductivity which is your K, because it is almost in length per unit time and when you see centimeter per second what do you see is water takes that long to pass through a silty sand.

If it is very, very fast medium let us say gravel you can have it as 10 centimeters per second. So, think about water and a gravel bed, if you pour water, water will move through the medium, through the gravel there at 10 meters per second. If you want to apply this to a real-life scenario, let us take the cricket pitch and if you see rain is coming, they quickly run and cover the pitch but before that the rain has already started and water has come on to field.

But as soon as they take the cover you see that the rain is not much affecting the pitch or the grass why is because they have under the pitch at under the grass a very, very highly hydraulic conductive soil, it could be a mixture of gravel and sand and silt where water when it goes it just flushes through. So, quickly you will lose the water which means quickly you keep the system dry.

In other sport you see this golf. Golf courses are made like this. And that is why it is very expensive the sports to maintain the greenery and also the water budgets. So, when we see water applied to cricket pitches, it is a lot of water because it has to first give water to the grass but also it flushes very fast in the system. These are the same concepts that you would use when you are constructing a vertical farming or a farm on the rooftop because soil is there you apply water, water has to go through but excess water has to rush out through the system, otherwise water will clog and leak into your building.

So, you have to understand the hydraulic conductivity of the soil and how fast water can move. Whereas permeability is the how much the material can allow the water to pass through. So, you have different materials here. And I would assume all the materials in the world are represented by these simplified versions. You can either find it as a silt sand or you can either find it as a rock, let us do a quick comparison.

So, silty sand can also correspond to a metamorphic rock or fractured igneous rock. It can also be part of a permeable basalt. So, the basalt is what is present in most of India, along with your fractured rocks will call hard rock aquifers and this is where the rock is present. So, the silty sand values also correspond to your permeable basalt and fractured igneous metamorphic rocks.

So, if you are using a groundwater model, the first things it will ask is it water? The second thing is, is it a what is the soil property, what is the soil type of soil and what is the hydraulic conductivity. So, even though there is a range, if you do not use the range, it will get the average value. So, be careful about using hydraulic conductivity values in your model.

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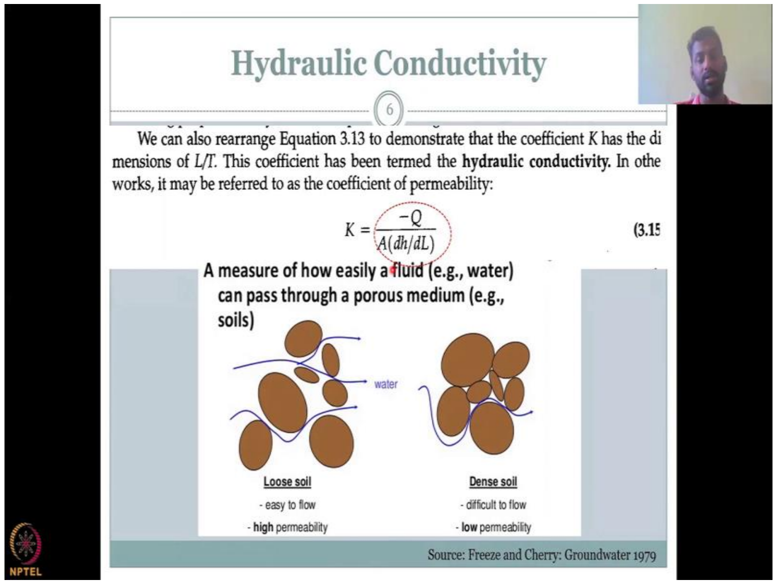

So, let us look at hydraulic conductivity in detail. We can rearrange the equation to give the previous equation to have K which has dimensions of meters per second or length per time. And it actually is equal to K is equal to minus Q by A dh by dL. What is dh and dL we will look at it in the following slides. So, basically the equation is a measure of the fluid, initially it was measure of, permeability was measure of [Technical Difficulty] and how easy it allows.

But here we are going to do it as a fluid example water and how it can pass through a porous medium. So, the image is the same, as the previous discussion we looked at the ground particles. Now, we look at water. So, loose soil easy to flow, high permeability, high flow, high hydraulic conductivity. Same way you have dense soil, low permeability, low porosity, low hydraulic conductivity.

So, conductivity is a function first of the fluid property and also the soil property. It has a minus sign for a reason, we will discuss that how it looks by looking through the equation of hydraulic conductivity and the experimental setup as done by Darcy himself in the following lectures.

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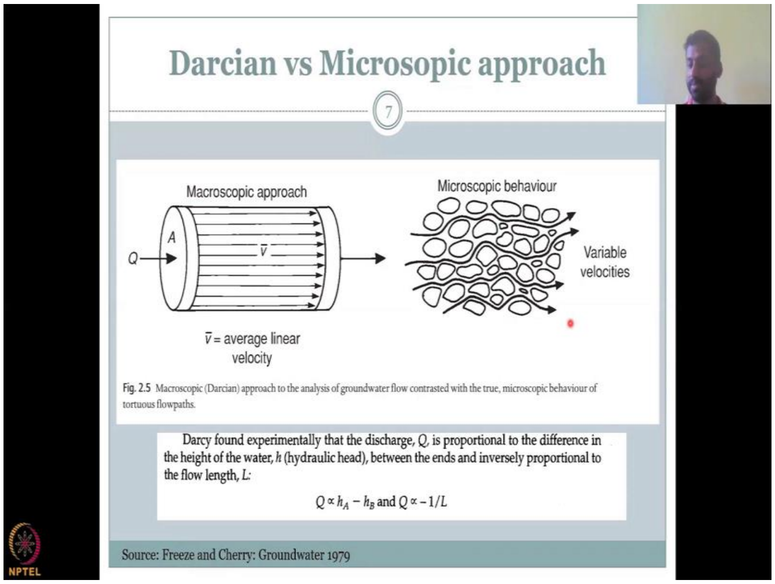

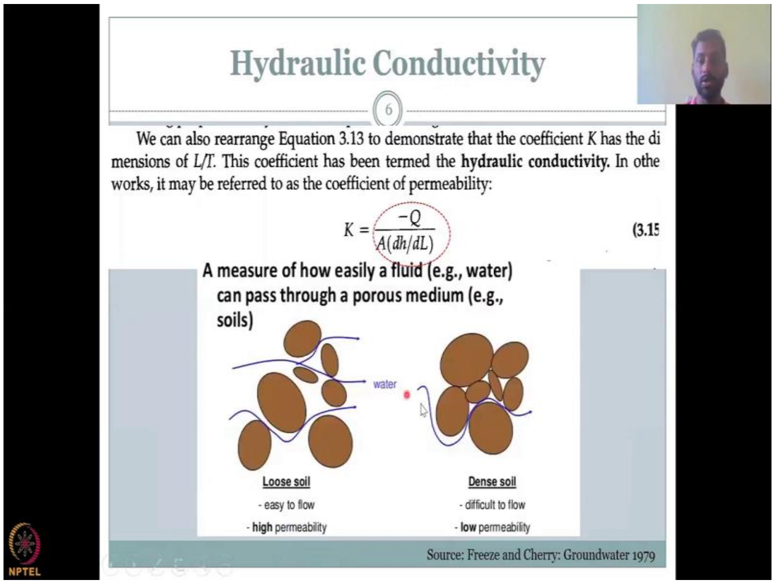

For before that we will finish the microscopic and macroscopic view. So, what is a macroscopic view, is a solid view. It is combining all these small particles into one unit that is a tube, you are not looking at soil individually as soil particles, but you are looking at soil as a tube. And in the tube by passing water Q discharge goes into a cross section A at a average linear velocity v meters per second and it comes out.

However, if you take the macroscopic view out and put the soil in a for example, microscope to look at the microscopic view, you would see water slowly going through and not straight. In a macroscopic view you cannot see the water movement, you assume that water is going straight.

But in a microscopic view, you can actually see that it is not going straight but in a torturous way or meandering way.

And it is variable velocities here the velocity of the top of the tube is the same as the velocity at the bottom of the tube. Whereas here you have velocity moving up, velocity moving in the middle section and on the end sections at different velocities. This is the key understanding between the macroscopic which is also the Darcian view and the microscopic approach.

Darcy found experimentally that the discharge Q is proportional to the difference the height of the water, hydraulic head between the ends and inversely proportional to the flow length. Which is L between the length and we will look into detail on how this experiment was set up, along with how this equation was arrived in the following. I would like to stop today's lecture. Thank you.