Rural Water Resources Management
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Week 05 - Lecture 03
Permianility and Hydraulic Conductivity

Hello everyone, welcome to NPTEL Rural Water Resource Management course, week 5 lecture 3. In this week, we are looking at groundwater hydrological components and properties that can be augmented or can be modified for better rural water resource management. The stress is on groundwater management in these couple of lectures, because it is the most complex water resource to manage. And to understand how much water is available, it is very important to understand these properties from which we could estimate or understand the groundwater potential for the region. With this small intro, let us get into today's topic permiability.

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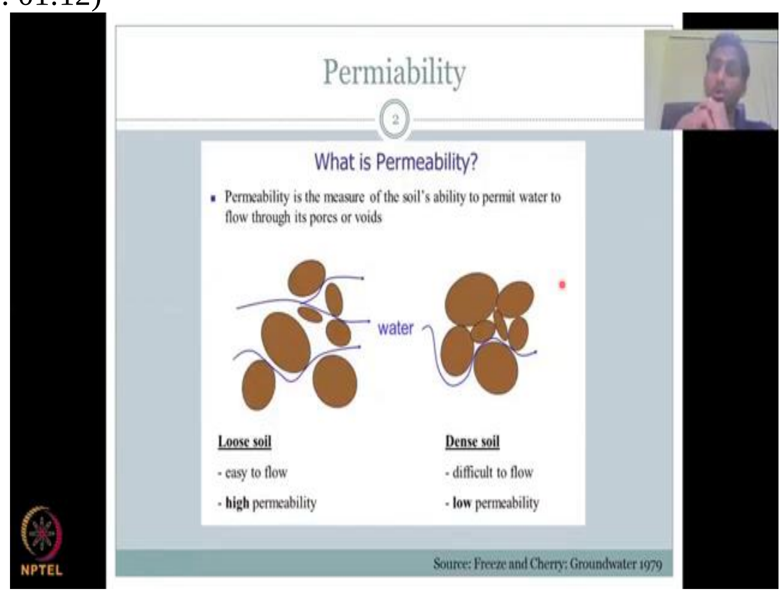

Before permiability, we did discuss hydraulic conductivity in the previous week, but in this current week, we looked at specific yield and porosity. The other more related parameter is permiability. As the name suggests, how do you define permeability? Permeability is the measure of the soils ability to permit so, from permiability you can take permit water to flow through its pours or voids.

So, either way, the first objective is to understand where to get the water and for that you need pores and voids and then you have the permit of water into these voids. And so, like spaces, so that is the soils ability to permit is called permiability. So, let us look at this diagram the first-time water comes in and it goes through all the pores the ground water it can get stored it can fill up the void you can drive out the air and thereby replace the air with water, this is a loose soil wherein the soil particles are not touching each other.

So, the water can easily flow I just want to make a very important point here. So, sometimes we look at books and they say rocks and then soil. So, do not differentiate it from groundwater, because groundwater occurs in the soil profile and also the rock profile. So, the same parameters would exist in both faces, for example, porosity in the rocks or porosity in soil, permiability in the rocks and permiability in the soil. Our goal is to understand the ground waters potential for which the terms do occupy the same meaning in both the soil and the rocks. And please understand if you want to go even further the rocks is what disintegrates, weathers and then form soil.

So, it is not that we are discussing something different, but it is just the depth at which we are if you are at a shallow depth, it is a soil profile. If you go further down, it is a rock profile. So, let us discuss the first image which is the loose soil which means the particles are loosely bound to each other, there is lot of void space and the void may have air or water. Now, water is flowing, groundwater comes in and it finds a void space so water can easily flow in and out.

Why should it flow in and out, so that it can occupy the void spaces once it fills it will flow to the next void space available. So, easy to flow it is high permiability. So, because the soil is permitting, it has high permiability. Then we have a dense soil which means more density of soil particles it is close to each other. And it is showing that water can go through in and out but with some tortuous paths or very very selective paths.

So, here water can go in two paths or even multiple paths here because it is loosely bound. But here water would first hit the surface and then see that this is much easier to flow so it will come around the rock. It does not matter if it has to travel long. So, the distance is not a question here. water would flow through the least resistant path, even if it takes longer distance, it is not smart, it does not think, it does not think that oh we know I can push and get myself quickly to the other end by going through this path, no.

It only flows through the least resistance path. So, water is coming it hits here it has an high resistance whereas here it has no resistance it comes here relatively. So, it comes down and then flows through these cracks. So, the dense soil has very high amount of particles which are connected to each other the solid particles and by that it has very less space and more sorted I would say, so, sorted and some void space are there low permiability.

So, that soil is not permitting water to enter that easily. So, these are two different examples of high permiable soil and low permiable soil. It is not just the density of the soil that is the key factor here some soils can be hydrophobic, which means it repels water. So, then there is no permiability there. So, some soils for example, would repel water, so it naturally would not permit water to flow through its system. So, that is one thing.

The other thing is it just the soils property no, because if you have the same soil, let us say I am taking a sandy soil in both cases, the size matters the size of the grain matters 1 and also the land use pattern matters. So, if you have a forested ecosystem, where roots are there and the roots die, the roots die decompose etc, what happens to the root paths, it becomes void, and those could be making the soil high permiable system. Whereas on the dense soil, maybe it is a barren soil maybe it is compacted soil people who are grazing those kinds of soil. So, it is having a high density, the density could be a soil property or the land use property.

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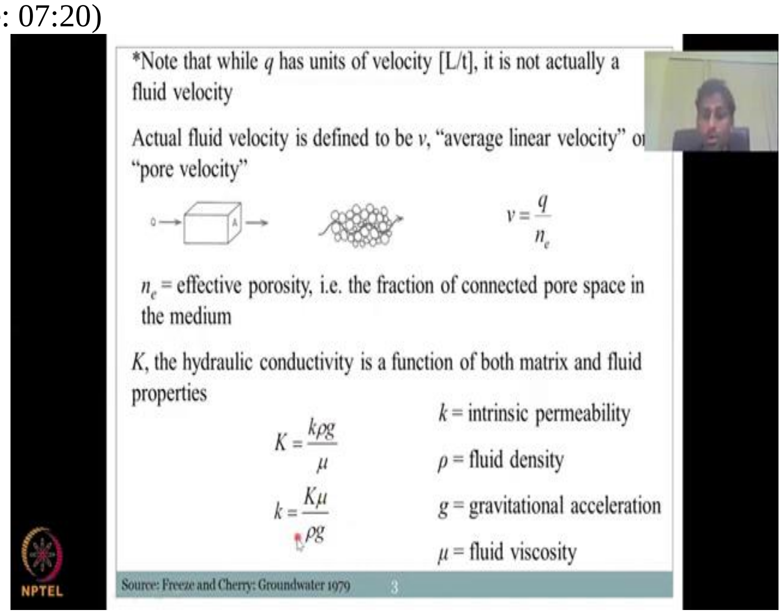

Moving on, note that q which is units of velocity is not actually fluid velocity. So, what is q? q is any velocity, we are trying to estimate the distance over time. So, actual fluid velocity is defined as v. So, if you have a container, and you put soil in it, and you pass through, so let us say 1 meter container, and you are passing through water in one side and then your timing how long the water takes to transfers through the tube.

Right here for example, q through a block or a tube of soil and it comes up. So, you have the time by which it came out and the distance so you can calculate the velocity q, q even though it has a unit of velocity, which is length over time, 1 meter over a number of time, let us say it took 10 minutes, so 1 by 10 minutes the units would be meters per minute, or meters per meter, yeah, meters per minute.

It is not actually fluid velocity, because water does not go through a straight path it is the action fluid velocity is defined to be v, which is average linear velocity or pore velocity because of pore is what allows the water to go through so it can also be called as a pore velocity. So, water is coming in. It does not flow like a cube just goes in and comes out like a tunnel where you have a car coming in and going out on the other side because it is empty the tunnels empty, it is not going to hit anyone it just goes out.

But water moves across and finds the way where it has to go. So, look at how up and down it has to go through a path by this what I mean is the distance might be the same from A to B, but the path it takes would make the distance longer and then by the time longer. So, the average linear velocity which is v is given us q by ne where ne is the effective porosity in the previous slide in the yesterday's class, you would have noticed n is Sr plus Sy which is specific retention plus specific yield.

Here, even though the porosity is that there is an effective porosity because not all pore space conducts water allows water to flow. And that is called and ne affected porosity the fraction of connected pore space in the medium. So, as long as it is connected, so you can have spaces but if it is not connected is as good as for water to flow is as good as say no connection no void space for water.

So, the effective porosity is actually the fraction which is connected between the pores space in the medium when we say medium it could be soil medium rock medium. So, let us define hydraulic conductivity for permiability, we will have another lecture just focus on hydraulic conductivity, which is a very, very important factor for groundwater hydrology. But here what we will do is we will look into just one component in the hydraulic conductivity equation.

So, K is the hydraulic conductivity is a function of both matrix and fluid properties matrix is the soil matrix rock matrix the medium. So, these terms if you start reading the books that have described, you will understand that matrix medium system all these words will be interchanged for the soil profile and also profile or rock profile. Fluid is the water that goes in so you can also call water properties, but water can be mixed with other things so, it is okay to call it as fluid.

So, k is your hydraulic conductivity which is a function of small k which is intrinsic permiability the topic of today's lecture and rho which is your fluid density here it is water. So, you can have water density, g is your gravitational acceleration or acceleration due to gravity g and mu which is fluid viscosity, here we can use water term. So, if you know you are going to do groundwater, then the rho and mu can be replaced by waters values.

So, let us look at the equation k equals to small k in times rho g by mu, now rearranging you get small k on this side and big K times mu by rho g. Since, now you know what are the constants mu, rho, g are all known constants. So, k is nothing but a function of these constants and hydraulic conductivity.

So, let us look at this is how you would define permeability or estimate permeability by knowing k. So, if you know in groundwater hydrology some parameters you could back calculate the other parameters because all of them are a function of the solid space which is your soil and the pore space also it is a function of the liquid, but in terms of groundwater.

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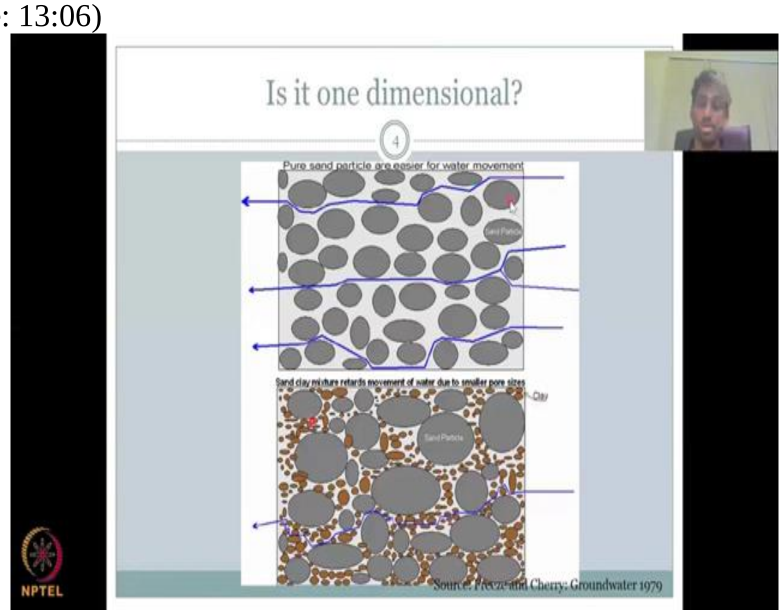

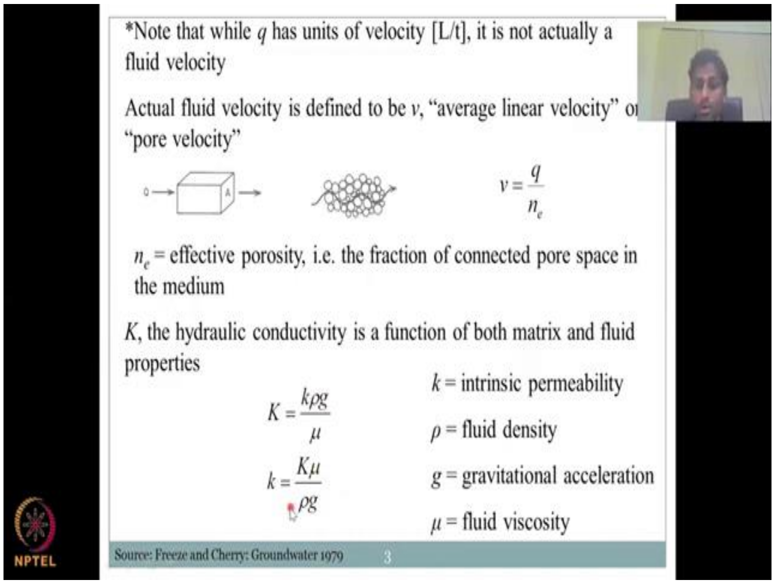

Moving on is it one dimensional is permiability in one dimensional pure sand particles are easier for water movement for example, you are moving from right of your screen to the left. So, water is moving in this direction and all the images that we have seen in the lectures we see one direction. So, water is moving and it is finding the less resistance path or the effective porosity which has made that the pose are connected it is finding that connection and flowing through it.

It finds all these sand particles very distantly separated and it flows through the sand particles. Then you have another medium another example where sand clay mixture returns movement of water into small post sides, the same material, you see the sand is sand, but now if you are mixing clay to it, because sand, silt and then clay but here we are taking a sample which has sand and clay clay is much smaller in size the grain size which is the dark brown component and then you have your gray component which is your sand particle.

So, what happens is your brown particle starts to oppose the movement of water or not permanent, so it is not increasing your permiability but decreasing your permiability. For example, let us take here the water which was coming through water which was coming through is now blocked because of clay. I hope you remember about clay the property as I said it has a very small specific yield so it is very hard to drain water out of it.

And it has high surface retention specific retention which means it will hold on to the water once it goes on to the water. It swells because of the waters volume also, clay mixes and swells. So, once it swells, it will stop the water from going in. So, that is why you could see all the groundwater issues in clay soils pretty, pretty drastic, you do not see recharge, but still farmers are using the water because they see the water, but it does not recharge as frequently as the other aquifers.

Coming back, let us take this path, path 1 and path 3, path 1 you could see that the clay is just stopping right in the front and even if it can go through there is lot of clay and then here you see small small clays on this path, which actually totally block your way through the tunnel. So, there is no pores space that is connected and will have to stop. So, water what it will do? It will flow through the less resistant path or least resistant path it will then jump into here and come slowly through this material.

By this what has happened your velocity has decreased and thereby your water movement hydraulic conductivity has decreased thereby your recharge has decreased. So, this is how a solid material the soils properties rocks properties can impede your groundwater recharge, come back to this slide, where permiability is there your k might be the same, but now if you increase your density of fluid because of the density of your particles mixing with water, understand that water can also take soluble nutrients and soluble salts from your soil material. What happens if rho changes if rho increases your permiability decreases, same way your hydraulic conductivity decreases your permiability decreases. So, it is a very very direct relationship with hydraulic conductivity and an indirect relationship with your density.

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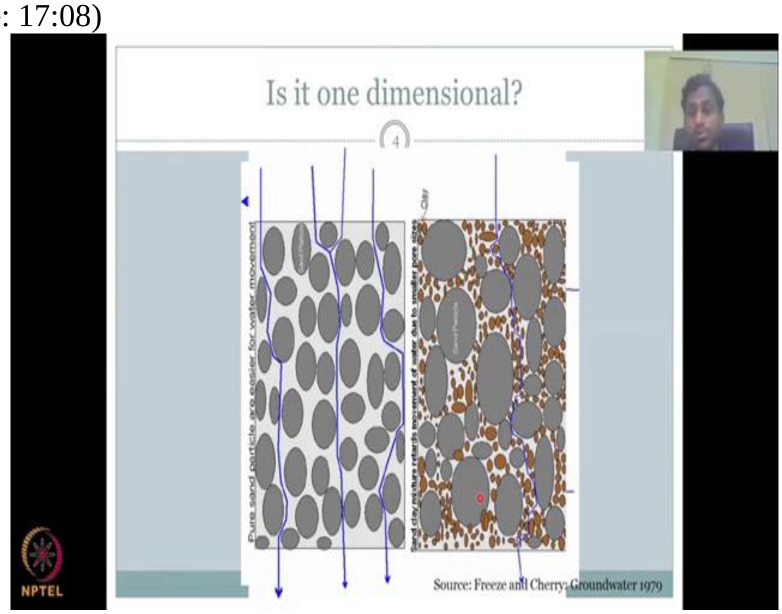

Moving on, is it one dimensional no, you have 3-dimensional movement of groundwater I think we have touched a little bit basics on this water can move in the z plane which is vertical and also in the xy plane which is horizontal natural. So, both of these things is the xy plane and then your z plane water can move up and down up, up due to capillary rise down due to gravity and then in the xy plane which is driven by a slope xy plane is also because of your gravity.

And some part of capillary but mostly xy plane would be on this way. So, it will say gravity acting. Also, when you have plant and other species, which are trying to pull the water, water moves, you have a pump water moves. So, that is your xy plane movement. So, what are you seeing here, you are seeing that it is not one dimensional, the water can move multiple dimensions. So, it is also important to understand the differences in these properties in a 3D plane, not 1D plane.

So, you do have models, groundwater models, and other models which are 1D and it is only used for a specific purpose, you cannot generalize the results into a 3D plane because the 3D version would have different forces acting on it just not just gravity acting on it.

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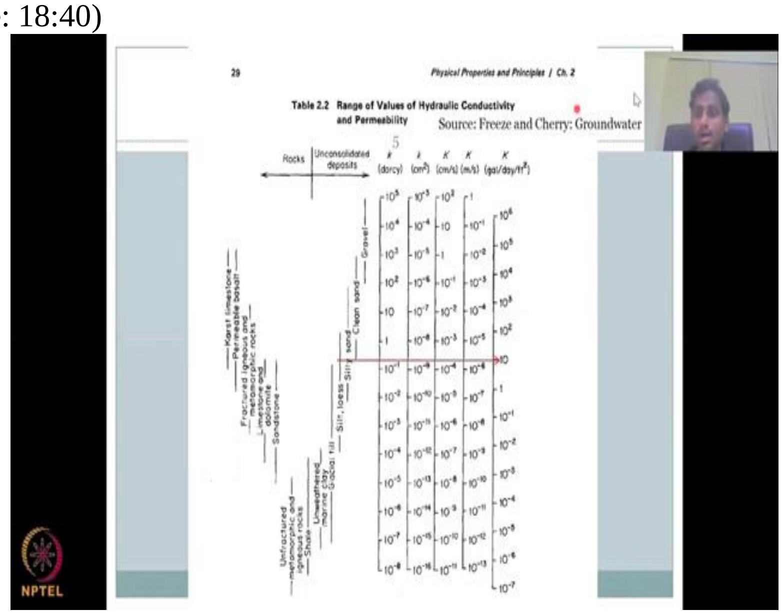

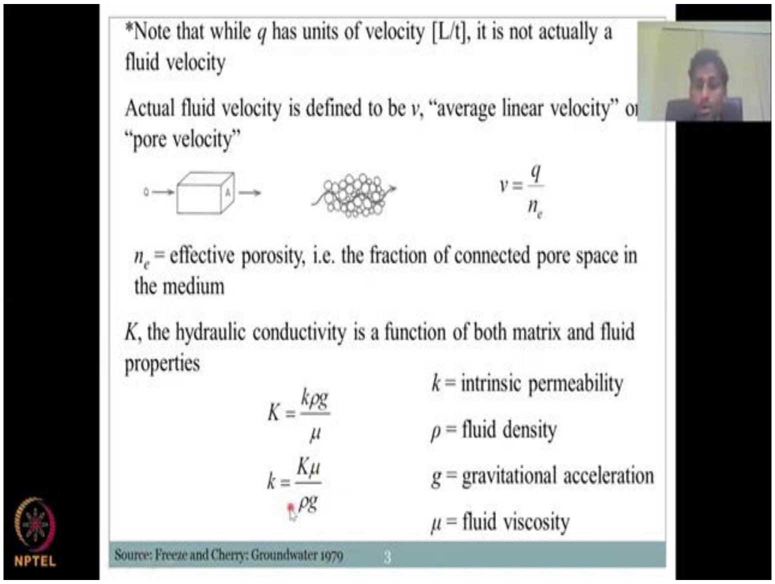

Let us move forward. Let us look at some ranges for permiability. So, as I said, I am now using different sources to interact with you on the values that you could use and most widely used values are from the freezer and cherry book on groundwater 1979. So, you could see here that you have a range for the values and ranges because of the size and also the management of the land, which means gravel does not have one size there are multiple sizes for gravel and depending on the size you have different values for permiability and hydraulic conductivity.

Let us look at the permiability of silty sand as an example for today. Silty sand who has sand in it and a little bit of silt in it not clay we are not mixing clay here but sand so you have clean sand silty sand, silt closes which has some clay on it. But let us take silty sand. And what do you see here is the range, the range for k, the small k is permiability while bigger K is hydraulic conductivity and look at K units it is centimeter square.

Whereas hydraulic conductivity is like a velocity it is length per time. So, there are multiple units K Darcy or K gallons per day per feet square and you could bring it back here because gallons is volume feet square is the area you can calculate you can remove the dimensions to come at length per time all these are length per time where are these are yes length square per area. So, coming back silty sand has K centimeters let us use K centimeters square is anywhere from k, 10 power minus 10 to here 10 power minus 6.

So, think about it 10 power minus 4 is the rage. So, from 10 power minus 10 it can go anywhere to 10 power minus 6 that is the big range for silty sand, I am going to take the average almost the center. The center is around 10 power minus 9 k and for hydraulic conductivity this 10 power minus 4. So, which means 0.0001 for hydraulic conductivity and for centimeter square unit permiability it is 0.0000 eight 0s and 1.

So, think about eight decimals and a 1 spaces decimal spaces nine but eight 0s and a 1 which is such a small number for permiability. So, you cannot say it is negligible if it comes in the denominator because it can pull down your values the range I am saying it is not negligible. So, you need to be very careful in finding the accurate permiability value otherwise, your results your results can suffer by four orders magnitude minus 4, 10 power minus 4 difference anywhere from as I said silty sand is anywhere from minus 10 to minus 6.

So, you have 10 power minus 4 as a difference and which means, so, many units orders of magnitude can be impacted. Also, the other words, you can also understand the permiability can be very high or very low just for one type of solid type. So, just as important to get the properties very very accurate.

Moving on, let us get a small introduction to hydraulic conductivity we will talk about this more in the next class because this is one of the key parameters the others you can assume and get away with it, but hydraulic conductivity assumption should be avoided most easily available through your lab and once you have your hydraulic conductivity estimated you can go back and estimate the other properties. For example, as I said if you know your hydraulic conductivity you can estimate k because you know rho g and mu and if you know k you can go back to your other equations to get other porosity and other values.

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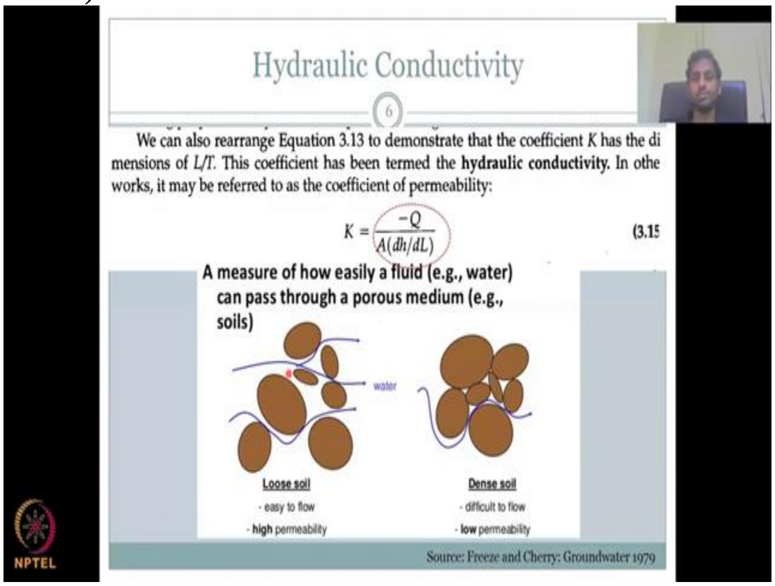

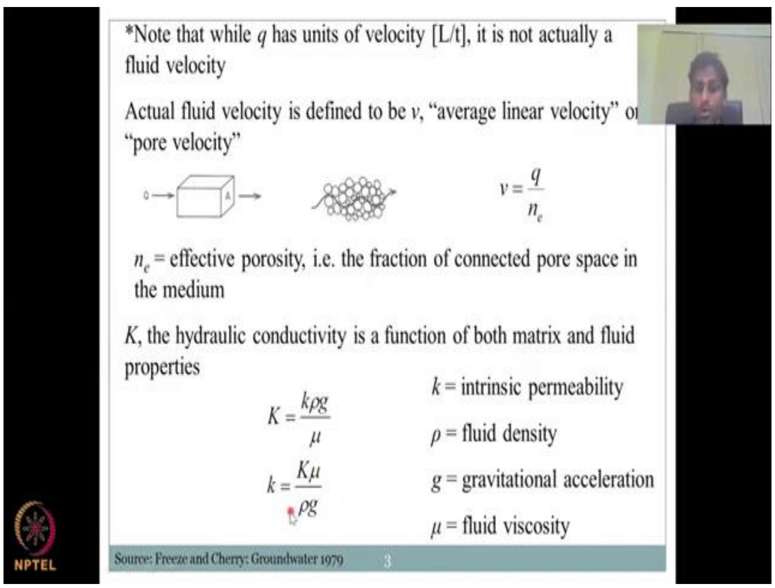

Coming back we can rearrange I am taking the equation from Freeze and Cherry which is basically looking at the velocity over area and getting at what is the speed, kind of a speed or velocity estimate Q is a volume, volume passing through a unit area and the difference between dh and dL is the distance between wells. So, let us look at it rearranging equation the previous equation we get coefficient K has dimensions of L by T which is length over time same units as velocity.

And it can be called as hydraulic conductivity, it may be also referred as co-efficient of permiability, why is it called co-efficient of permiability, because in this equation what it tells you is k is related to or is in agreement relationship with mu and rho g where the bigger K hydraulic conductivity is your coefficient of proportionality and it is that is why it is called as a coefficient you can call it as coefficient of permiability.

A measure how easy a fluid can pass through porous medium. The previous permiability is the soils property of permitting the water to come in. Whereas, hydraulic conductivity is similar, but it is how easy a fluid can pass through which is your velocity kind of your velocity estimate. So, how easy your water can pass through is hydraulic conductivity and it also depends on the permiability.

So, you can use the same figure I am using the same figure here to discuss that, but what you could see is in a loose soil water can easily pass through and that and therefore, it the easy fluid passing property can give you a higher hydraulic conductivity. But then soil it is difficult to pass and so, your hydraulic conductivity is low. So, right now, you can understand it as a velocity and a measure of how easily a fluid example water can pass through the porous medium.

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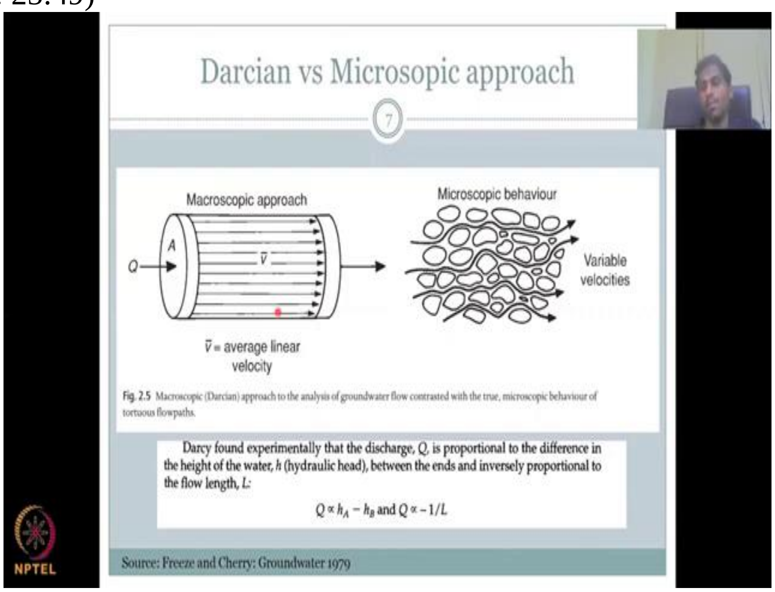

Moving on, you can have two approaches to look at it Darcian versus Microscopic approach whereas, the microscopic approach is very small focused look at the soil profile you can see that the soil particles are all, whereas in a macroscopic everything is put in a tube and you only look at the tube you do not care about what is happening inside you pass Q which is your water volume across an area of cross section water passes through and comes up, and water passes through average linear velocity.

So, you have an average linear velocity Q passes through and comes out whereas, in a microscopic behavior, you can look at variable velocities it is not one velocity for example, water can pass through this path very fast whereas, water can pass through here very very slow. So, this is the difference between macroscopic which is Darcian, Darcian experiments are done using a macroscopic approach whereas, the true which is the real exact world or the complex sample reality there is a microscopic view.

You cannot actually do it yes you have to understand that there are a lot of velocities that can be here in this diagram variable velocities can be high, but can you actually model each and every velocity no. So, what Darcy has done is he has taken a very macroscopic approach where all these velocities kind of cancel each other or it actually averages and smoothies up. So, Darcy found experimentally Darcy he is a scientist for groundwater.

But he was initially an engineer who worked on pipes for fountains to in France to make the fountains beautiful etc and he was finding that how to monitor and measure the water flow through these pipes and then he became kind of groundwater scientist because he got these equations in the lab. So, Darcy found experimentally that the discharge Q which is this one, how much water you apply is proportional to the difference in the height of the water. Hydraulic head which is a high potential to low potential water from groundwater high potential low potential, so, you have a difference in head between the ends from A to B and inversely proportional to the flow land this land.

We will come back in a setup for hydraulic conductivity to expand it further. All you need to know in this slide why we are finishing off today's lecture is that all the experiments are done with a macroscopic view even though the microscopic true reality could be different. So, if someone says are you assuming all this no, it is not assuming but we are kind of averaging the effects into a macroscopic view you cannot go in detail for each and everything you can if you want to focus on a specific problem.

But for groundwater hydrology, the macroscopic view is used not the microscopic you cannot say how many pathways for example, I do not care how many pathways are there, but how much volume is passing through my soil profile is more important.

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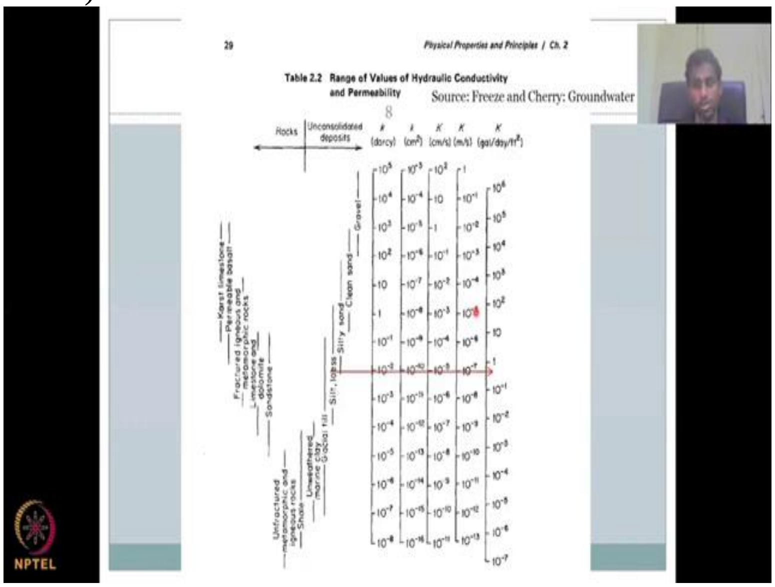

Moving on, as hydraulic conductivity is also given in the freeze and cherry book, you would see multiple values very similar to permiability you will have multiple values multiple ranges and for sure, it is a function between each other because permiability is a function of hydraulic conductivity and if you use water as the liquid that goes through in your experiments, then rho and mu can be estimated.

Because you know the density of water you know the viscosity of water. The sample size has been divided into rocks which is big, big rocks under the soil profile. And unconsolidated deposits, which is above your rock profile. So, you can have a cast limestone, and on top of that a clean sand. So, right now let us say that rocks are much, much deeper in the profile. And unconsolidated deposits are above.

So, let us say you have in this experiment and I am taking silt loess. Silt loess and you can see the hydraulic conductivity ranging from this line to ranging from 10 power minus 9, it is normally given in meters per second. So, let us say 10 power minus 9 up until 10 power minus 5 again another 10 power minus 4 orders of magnitude. So, it can be very, very small hydraulic conductivity. So, it is very important to estimate it as accurate as possible. We will see in future lectures, how do you conduct a hydraulic conductivity experiment in the lab, how the initial equations are made.

It is such a simple equation Q is equal to the discharge, actually, the discharge passes through the tube and you have your hydraulic conductivity, which is a function of your Q times your by the area of cross section and the hydraulic effect difference, just 2, 3 parameters that is it. But your application of hydraulic conductivity has tremendous potential in groundwater hydrology. So, we would look into that by going through how the instrumentation was set up, and how you could understand from this table, which hydraulic conductivity to use this I would conclude today's lecture. Thank you.