Rural Water Resources Management
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Week 05 - Lecture 04
Hydraulic Conductivity 3D

Hello everyone, welcome to Rural Water Resource Management NPTEL course week 5 lecture 04 last two weeks, we were looking at ground water hydrology and different components. In this week, we are focusing on certain components that are very important for understanding groundwater hydrology and for conducting recharge and discharge experiments and also to better manage groundwater hydrology.

By managing groundwater hydrology, there could be good potential for rural water resource management. So, this is the aim of this week's lecture on identifying groundwater parameters and to see how we could maximize rural water resource management. Groundwater plays a key role during climate change extremes like floods and droughts and also it creates a decentralized access to water rather than having a centralized water scheme. For example, irrigation schemes and or dams, and canal water etc.

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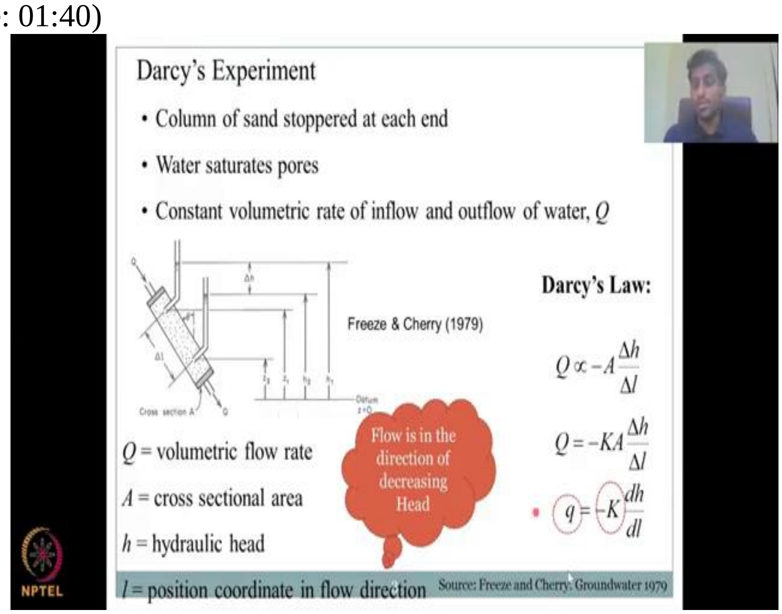

So, let us get into the peak discussion on what are the key properties for understanding the water hydrology. Today's lecture would get into hydraulic conductivity. In the today’s lecture we gave an introduction to hydraulic conductivity but did not get into full theory how it is estimated, etc. Let us start with the person who was very keen at identifying hydraulic conductivity.

He was Darcy who was a French engineer by background and his work was to maintain the fountains, water fountains in France, he found that he needed to have a better equation for flow of water through the system. And there it was, he discovered the ground water equation flow equation and also found out some key parameters. Let us first look at his experimental setup, which is a very basic setup, everyone can do it in the lab.

So, he had a column of sand stopper at each end. So, you see here, this is a tube in which Darcy had put sand full on both sides, and then stoppers, stoppers like rubber stoppers or even cardboard, so something that can stop the sand from falling and also stop the water from drilling. So, let us assume it was rubber stoppers and you had tubes to funnel the flow. So, that you could easily capture better then dripping down.

So, it was tilted to an angle, so that gravity can act and pull the water. So, that is the only force in this experiment. If you see there is no pumps from the bottom to pull the groundwater it is purely through gravity and the intrinsic properties of the soil for example, specific yield, permeability, permissibility etc etc. All of these which are functions of the porosity, the properties of the density properties of the soil and also the properties of the fluid like viscosity and density.

So, what happens is first he slowly input a known volume cube into the experimental setup. Water saturate the pore so, first it was unsaturated soil. So, when you start pouring water slowly the water would saturate the pores. There same column can be done with soils or rocks or any medium where groundwater hydrology is discussed. So, first thing you saturate the post which is fully full, send it with water if you fully pour water on it fully in the send it of to maximize all the pore spaces to fill up with water then water fills up and starts to drip down.

So, you need to monitor how much water you send and how much water you kept. Q and Q, which means you want to get the full water. So, first saturate the column, so, that whatever water you apply can be taken out on the other side constant volumetric rate of inflow and outflow of water was maintained at cube. So, this was the only engineering concept, where the water volume coming in should be equal to the water volume coming out, there is no storage of water here why because already it is saturated, unless it is saturated, you will not have this condition.

For example, let us take an unsaturated soil, what would happen is water would store in these pores and minimum water would come up compared to the water you are applying induced water would come up. In this case, what is happening is since it is saturated the full water passes through the column then he had two tubes to monitor the hydraulic head or the water level. So, one tube was at the top end and another tube was a topper bottom. So, the equation was done to find the water flow between these two tubes not inside versus outside, but between the two monitoring tubes.

These small monitoring tubes can be assumed as a well, whereas your tube with the soil can be assumed to be the groundwater system like an environment. So, in an environment like in a landscape, this can be your landscape has a slope gradient so that water can come down and you have two monitoring wells. Now, each well is recording difference of water table height, why because of the pressure.

And it equates to the atmospheric pressure. So, when water flows in let us say it comes up to this height, which is h1 from the 0 the data the mean ground 0. So, the 0 was taken to be the 0 where the stopper tube touches the ground and also the 0 was common for all the measurements. So, you have a data which is 0 and from there h1 was the first tubes water level height or the well's water level height and then the second well recorded a water table height at h2.

The difference is then delta h and then you had the elevation, the elevation of the opening of the tubes or the wells. The opening of the wells was z1 and then z2 for the second well. So, all you needed is if you have a well what is the opening the base the base of the well from the 0 point is z1 and z2 and then you had the height of the water table h1, h2. Suppose you do not have water what happens your h1 is equal to z1 which is the base of your well.

What else was mentioned the distance between these two wells was mentioned which is del l change in l. So, Darcy's law found out that Q which is the discharge coming out of your in my experimental system was proportional to the negative area of the cross section, the tubes cross section or your cross section in the ground and del h by del l, where del h is the height of the water table difference between well 1 and well 2 and del l is the distance between them.

Once you have a proportionality, you have a proportionality constant and Q is equal to minus, so convert proportionality into an equal you put a proportionality constant, which is minus K, the minus comes to the K now, so you have minus KA del h by del l. And Q is a volumetric concept, wherein a discharge as a volume is being mentioned. Suppose, you wanted velocity, velocity is one dimensional, whereas, Q is three dimension.

So, Q divided by the area the big Q volume divided by the area which is 2 dimensions you remain at one dimension which is length. So, length is here and you have your length, etc here, so meters per second is your K. So, let us look at Q is a volumetric flow rate and then you have your cross section area is A as l square, I do not care this l in units. So, you have a single dimension whereas l portion flow direction is here.

So, what do you find is the unit dh and dl cancel out. So, q takes the units of hydraulic conductivity which is meters per second or centimeters per second which is l per unit time. Why is it negative? Negative here is not a concept of reducing your flow, but to tell that the flow is in the reducing direction, which means it goes from top to bottom high potential to low potential. So, it is not direction negative here is a direction concept not at reducing concepts. So, when you add this to other values.

So, for example, you want to measure the value of water coming in groundwater system, and you already have one liter, suppose one liter is coming through this tube, you estimate it through this equation, you cannot put a minus sign saying that minus 1 and another minus 1 litter or well is going to be 0 liters in your bucket. No, it is not that so, negative is a direction you need to use it but when you are talking in absolute terms a negative goes out it becomes a quantity. So, negative tells that your volume is coming but in a negative decreasing trend.

So, slowly all the water would come down and it will reduce. So, that is why the negative comes. So, in absolute terms you can remove the negative sign. So, this is taken from freeze and cherry the groundwater book as I said, which I will use extensively in this course, flow is in the direction of decreasing head, which means your head is your high h1 is high compared to h2. So, it is in a decreasing head direction to let that know for the readers and for people who are using this equation Darcy put a negative sign.

It is not something that you can add and subtract this is a sign to give the direction of flow, in other terms, Q is also looked at upon as the velocity so you have your discharge and velocity discharge is a volumetric concept. Whereas the velocities a meter per second concept as a flux or rate.

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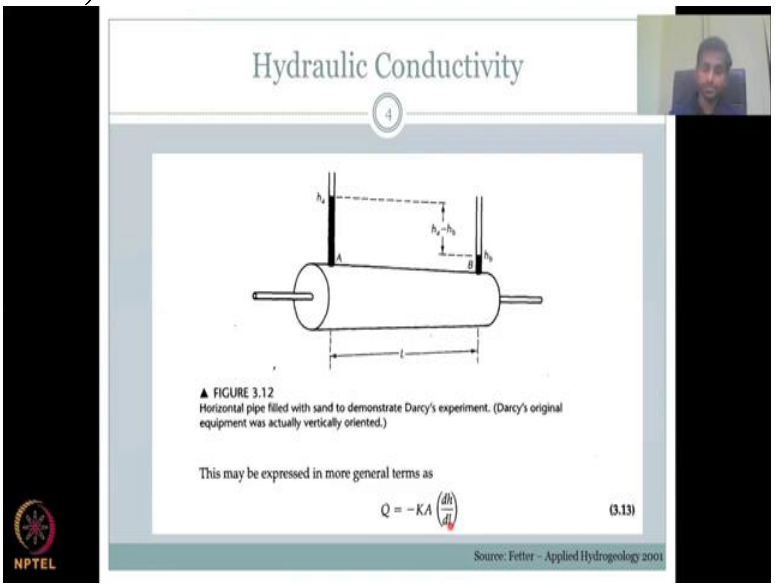

It is a different diagram from a different book here you do not see the slant in your tube, but it is the same concept horizontal pipe filled with sand to demonstrate Darcy's law, Darcy's original experiment was actually vertically oriented as I said like this here, they have kept it in a planner vision to show that you can also push water. So, they are pushing water and h1 well or here is it is ha well, A well will rise the water level is rise to ha and then at b it rises to hb.

So, it is a reducing trend from ha to hb there is a difference and there is a difference between the distance of the two wells. So, you take that as dl the distance between the two wells as small dl or change and dh is the change in your hydraulic head between the two observation points. So, what it also means is when you do a groundwater equation, normally you take two points and find the flow then you go to the next two points and find the flow dh by dl is also called as the hydraulic gradient because that drives the direction of flow. So, dh by dl as a single unit can be called as a hydraulic gradient. So, for example, in my hydraulic gradient is going in the negative side you could show that it is dh is going on decreasing and so it is the negative side.

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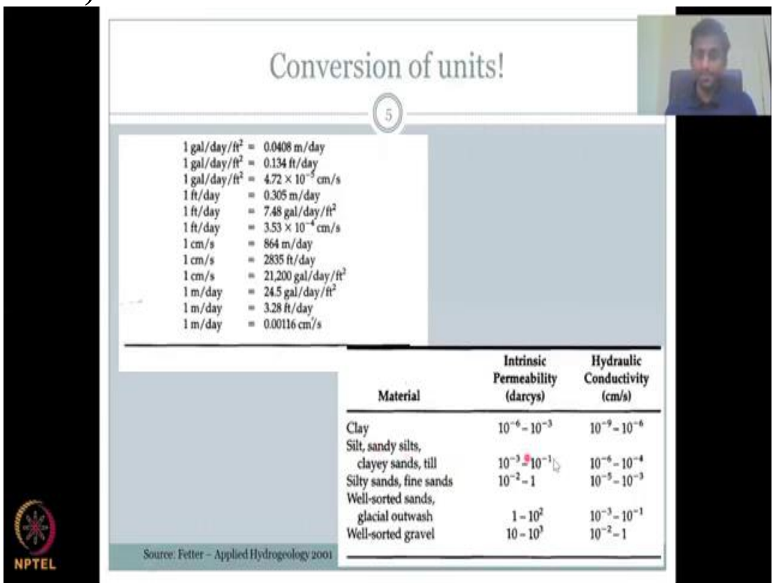

Conversion of yours is very important hydraulic conductivity can be given in multiple units. But especially if you equate it you will get it as meters per second or l by t length by time. So, here let us look at gallons is a volumetric concept. And feet square is an area concept. So, if you take l cube by l 2 we will have l which is 1 dimension and day is a times so n by d. So, all these would be given the basic length over time concept. But in different units and unit conversions are there.

So, when you read different books always pay place close attention to the units do not assume it is always meters per second or centimeters per second, because it will become a drastic change. I have seen a lot of reports where they missed it, they thought it was meters per second, but it was centimeters per second or millimeters per second, it depends on your experiment and how they estimated.

Hydraulic conductivity has good relationship with intrinsic permiability, which is having units as Darcy's. So, Darcy also has a unit after him because the intrinsic permiability was estimated during his experiments. And it came out very clear that it is not just the process or the property of the liquid, but also the property of the solid matters. And permiability, which is the amount of dopamine permiability by the solid, how much the solid permits the water to enter is a key factor for groundwater hydrology.

And it differs between the materials in the soil or rock and also the size class. So, if you look at here clay, silt, silty sand well sorted sand, well sorted gravel all have a size difference. Similarly, they also have a range between themselves clay can range anywhere from size, the given a buffer, or within a particular range, it has a different size classes. So, depending on that your intrinsic permiability also has a range, so as your hydraulic conductivity. So, let us look at some hydraulic conductance from this book applied hydrogeology from Fetter which is also a very good book for groundwater hydrology.

So, 10 power minus 9, 10 power minus 6 centimeters per second, and you could see that it slowly gets bigger, the hydraulic conductivity gets bigger, because when it goes to positive it becomes bigger. So, 10 power 2 is much bigger than 10 power minus 9. So, you can look at how slow, the water can move in a clay system. So, 10 power minus 9 centimeters per second. So, multiply it by the number of seconds in a year.

And you could see that barely the ground water would move only a meter or not even a meter much, much less. That is why if you remember in one of the courses, we looked at groundwater recharge and movement, and I estimated it to be somewhere in years and days for a shallow aquifer. But for a deeper aquifer or confined aquifer, it ranges from hundreds of yours to million year, which is 1000 years. And this is where distance of even 1 kilometer from the recharge point do the access point for groundwater can take years.

So, it is very important to understand why it takes years, it is because the function of the porosity is a function of the fluid and the solid material. And you can identify that by just looking at the material like your physical clay, then you can clearly say ground water is going to move very, very slow, you can easily pull it out that is different that is your pumps capacity, you can put another pump in and pull it out.

But here, what we are talking about is your recharge. And also, if there is water far away and you want to put a pump and access all the water, it would not move only around the radiant circumference of your well, you can access water. So, that is why some wells are abandoned because they assumed to be giving unlimited water supply, but they run out pretty soon. So, it is very important to understand these dynamics and dynamic properties when you do groundwater management.

So, the basic thing here to take off is you can identify the material, and then go back to these books to identify the hydraulic conductivity, you have centimeters per second, then if you say you are going to put recharge structure on the top, let us say your check dam and someone asks you how long does it take for water to move from the check dam to your deep aquifer or the well you could estimate the distance both depth and then you can look at the hydraulic conductivity.

Now, you have the distance you have the velocity you can calculate the time it takes the water to move. The next class I will give you some examples on how much time in a year you have and let us take one year for example, how many seconds you have and given 1 year and this hydraulic conductivity, how much distance does this water moving claim? Let us do one example for clay and one example for well solid soil. Let us do that in next class.

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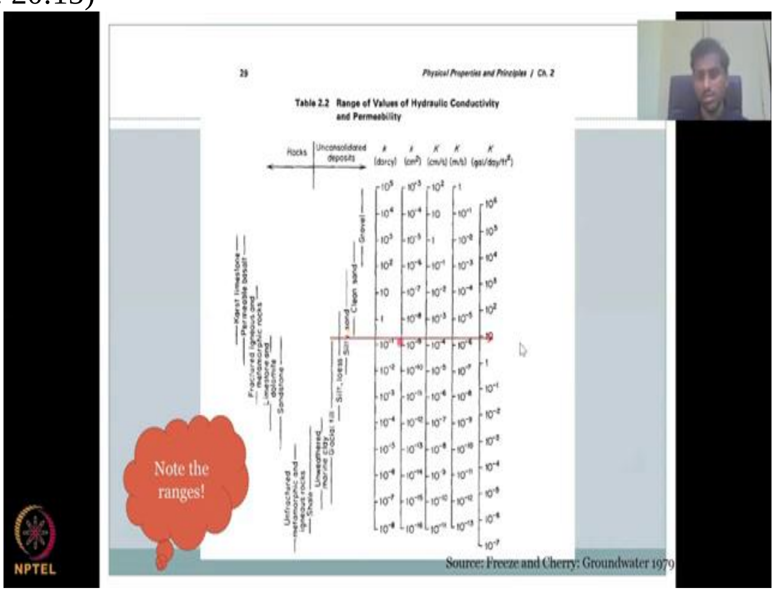

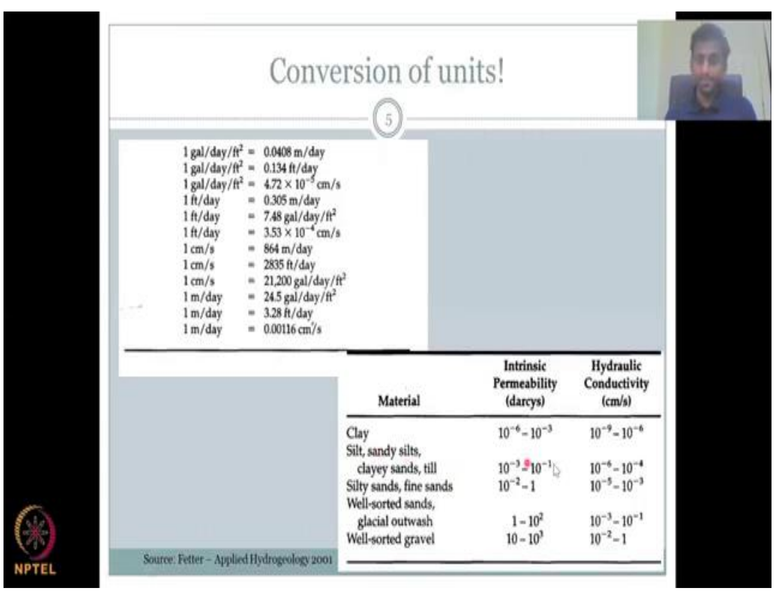

You can also go back and compare between books on the values, let us do a quick comparison here clay ranges from 10 power minus 9 to 10 power minus 6 centimeters per second. And let us look at clay you do not have place on it is silty sands, 10 power minus 6 or 10 power minus 4. So, silty sand is on here. So, it has values at 10 power minus 4, 10 power minus 5. So, 10 power minus 5, until 10 power minus 1. So, you will see that even between your well documented and well cited books, you have some changes and there it was 10 power minus 5 to 10 power minus 1.

Here it is 10 power minus 6 to 10 power minus 4 there is some differences. So, you need to be very careful in what you are estimating and which book you are consistently using. So, use one book or reference consistently throughout your studies or even your assessments good. So, we looked at hydraulic conductivity, we will stop here and the recap class I will show you a sample of how much distance water given your centimeter per second estimates for silt sand or clay.

Let us take clay for example, and then we also looked at hydraulic conductivity as a property, it can change pretty fast. And we will also look at some concepts of hydraulic conductivity in the next class in the domain specific ranges always know the ranges and there will be overlap in the ranges. For example, if someone gives you a hydraulic conductivity value and you need to estimate what type of material it is, it is also going to be difficult because let us take this one.

If it is 10 power minus 4 they give you it can be a silty sand or a silty lose or even a clean sand because it is in the range on the buffer of the border of the range. So, all three materials can have a similar hydraulic conductivity. So, it is your utmost duty to find where or which type it is. So, always you can say it depends on where the samples been taken, how it is been managed, but if you want the exact the median of the range then you can say it is silty sand.

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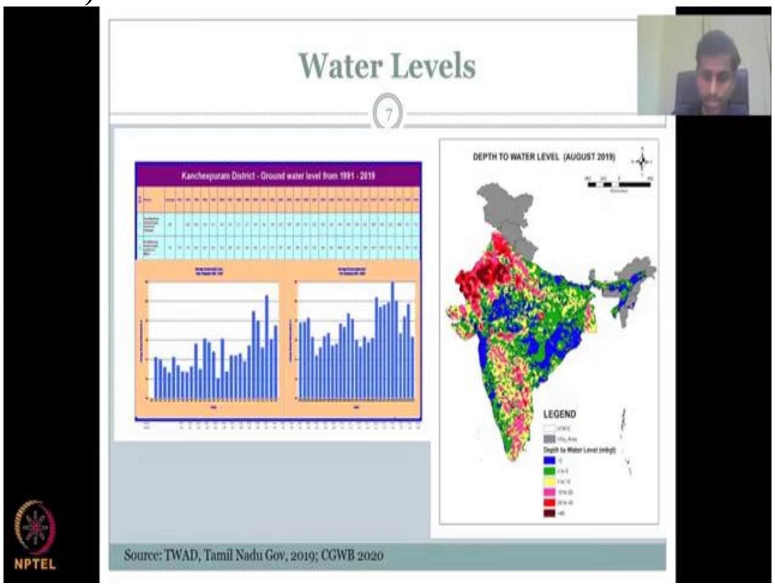

Let us look at water level since water levels we discussed in your experimental setup in Darcy now, you know that given two water wells, I can estimate the discharge between them or the hydraulic conductivity and groundwater flow given by Q. So, water levels are very important and that is why the central groundwater board and all government groundwater boards are monitoring the water levels, whereas the geology the soil type may not need to be monitored regularly.

But still, you can get away with having a long-term database on your soil or your geology material, what you actually need is a dynamic changes in the water level to estimate groundwater flow. Let us take an example from TWAD, TWAD water department. What you could see here is you could look at Kancheepuram district groundwater level from 1991 to 2019 almost 30 years and what you could see is the water levels are going up in some locations and going down and up cyclic in some locations.

Reason for the cyclic pattern. You see up down up down is because it is mimicking your rainfall pattern which is also up down you have a monsoon and then a dry period monsoon dry period. So, the same thing is captured in your water levels. It also tells you a secret that the well is in the shallow aquifer. Because as per the class we discussed, the recharge can take days to a year if it is a shallow and your rainfall pattern happens every year and same way you will see a pattern going up and down every year, which tells that it is a shallow aquifer.

Suppose it is a deep aquifer. You do not see the cyclic pattern that often it will be buffered because it takes a long time for the water to come. The other reason for cyclic pattern is also the extraction, a farmer would extract water only in the summer season not in the rainfall season if it is a good rainfall. So, when they extract the water level comes down. So, along with summer, where evapotranspiration occurs also you are extracting water due to the pumps in groundwater usage during summertime.

And that leads to these kinds of images of depth to water level in your monsoon post monsoon etc. So, August here would be your monsoon season and that is why good green color in central India etc etc. So, green and blue are healthy water levels and what you see here is there is good amount of water levels in your wells most of the wells because it has been recharged by the recent monsoon in 2019.

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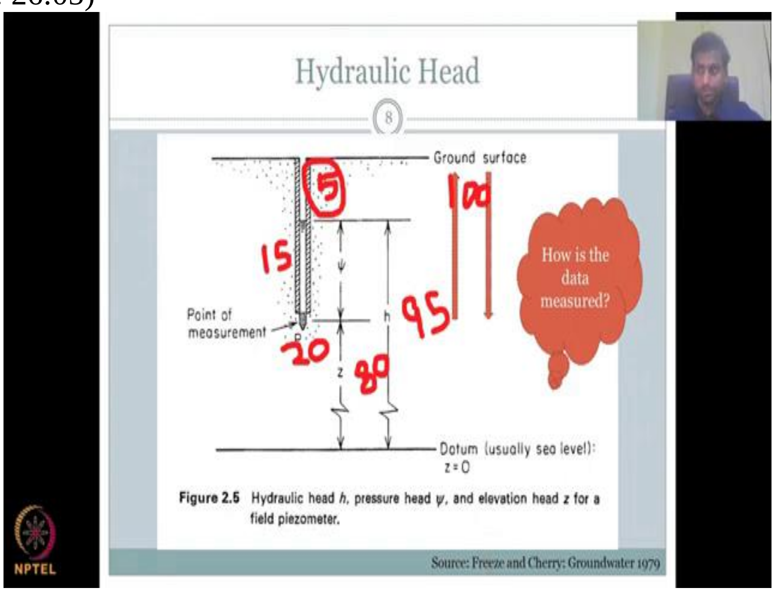

So, given your water level, now, you have a database for water level. Now, you understand how the collected data is by putting a tube or a meter in the well and estimating the depth of the water level how deep is the water level from the ground. So, you have the ground surface and you put a tape here to measure this level suppose it is 5 meters. So, you would record it as 5 meters depth to water level.

Now, comes your different parameters in your hydraulic conductivity estimations, we saw hydraulic head we saw hydraulic potential how do you estimate? So, you estimate it by the methodology given by freeze and cherry in groundwater book you have your data which is 0 your sea level your sea level is 0.

So, for every location you can get a data which is your elevation, elevation from the ground surface. So, let us say that you have this data to be 100 meters. So, the ground is at 100 meters from your data which is your sea level and your well is 20 meters deep of the 20 meters you have water level at a depth of 5 meters.

So, what is this water it is 15 meters. So, let us do the calculation here. I can also write it down for you. So, you have this to be 100 meters, you have 100 meters from 0 to ground and this is 5 meters and then this is 15 meters because the depth of the well is 20 meters. How do you estimate all the other parameters? The depth of the well is 20 meters or the height of the well is 20 meters and from the ground you have to estimate these values.

So, let us do one by one from your ground surface, which is 100 meters you know h which is at this level at the 15 meters from the base of the well. So, what would this be so, it is just 100 minus 5 correct. So, the whole thing is 100 which you have until this and you know the depth to the water level is 5 so, this would be 95. Since you know 5 meters is the depth to the well and you know the depth of the well is 20 meters which is 20 you have estimated the remaining which is 15. So, 15 plus 5 is 20.

So, psi is 15. Now, you know 20 meters is the depth of the well which means from the top it is 20 meters and the ground is that 100 meters. So, this would be 80 meters which is 100 minus 20. Now, all these values have been estimated. So, the hydraulic head which is h is 95 meters, all these estimates just using one value, which is your depth to water level and you should know the depth of the well the base of the well where the measurement happens.

So, if you have a tape you can go through the depth and find the depth of the well or it should be on the logs when they made the welds and you have estimated the depth to the water level just using that level only that you need to monitor every other time you can estimate the all the other parameters. So, hydraulic head is 95 your pressure head side is 15, and elevation head z for a field piezometer is 80. So, all these parameters you would use, but what would you use for your hydraulic conductivity experiment, which is a 95.

So, one well is 95 suppose the other well is 90, then del h is what? 5 meters and if the distance between them is 10 meters, then del h is 5, del l is 10 meters, then you have the area of cross section and you can estimate Q using the hydraulic conductivity. So, all you need is the area of cross section between the two wells and d, you can even let go of the area because if you want to Q which is the velocity of the water, you could just take K times del h by del l and here you do have del h and del l and the K you can take from the understanding the material of the soil and you can estimate your flow.

So, the end goal is to estimate the flow. So, this is what hydraulic models do for you if you just give the water level correct. But this I would like to stop the today's discussion on hydraulic head hydraulic conductivity and water levels in the next class we would wrap it up and also look at the changes in hydraulic conductivity across the system. So, this is how data is measured. I would just stop here and please use units consistent this all these units should be of the same si or British or any unit you follow. Please use the same scheme for everything. So, this I would conclude today's lecture, thank you.