Availability and Management of Groundwater Resources
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Lecture - 29
Law of Groundwater Movement, Darcy's Law and Application (Continued)

Welcome you all in the part 5 of the module 6 law of groundwater movement, Darcy's law and application. So, from the very first lecture we have seen that the groundwater flows inside the surface through the porous formation. Generally, this porous formation is termed as an aquifer. We have also seen that the aquifer is basically classified into two types that are confined aquifer and unconfined aquifer.

So, unconfined aquifer means any porous formation which is having some impermeable formation just below it. So, it will store the water within the formations and then in the upper layer of the water of this formation is termed as the water table. So, this we have studied in greater detail in the previous lectures and the confined aquifer is those aquifers which are having the impermeable formation both at the top as well as at the bottom.

So, here the water will remain inside under hydrostatic pressure and from these two types of aquifer generally we are withdrawing the water from to the earth's surface. So, in this part five lecture just we will discuss about the application of the Darcy's law.

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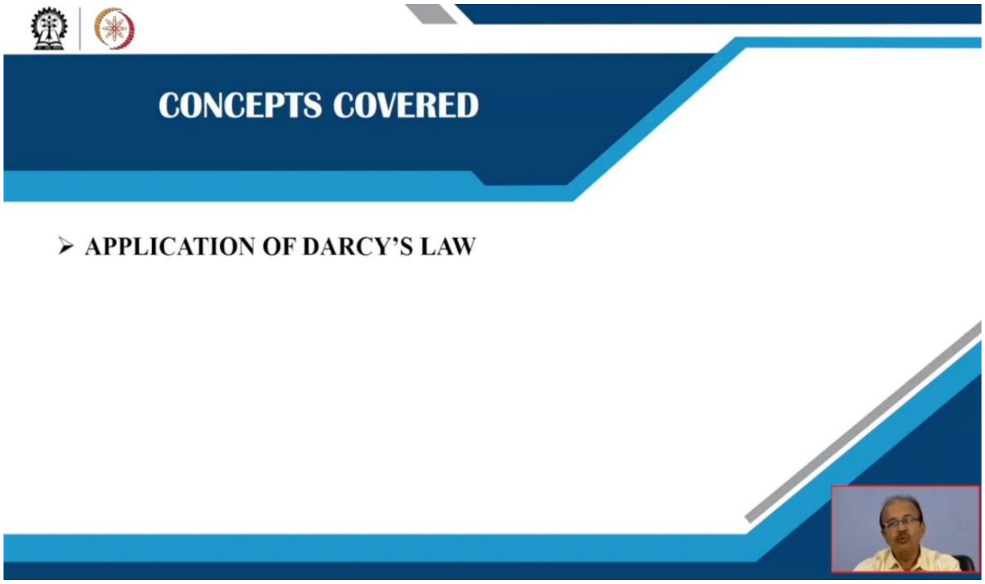

Because we have seen the Darcy's law is very important law for the flow of groundwater movement through the porous formations inside the earth's surface.

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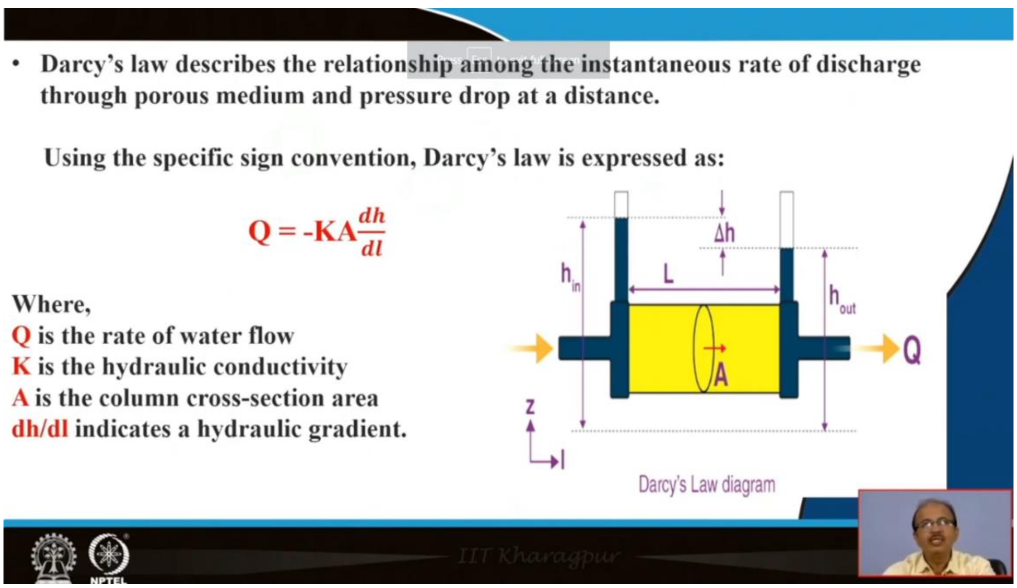

So, here just recalling that Darcy's law is nothing but it is the

$$Q = -KA\frac{dh}{dl}$$

this we have discussed already and generally for the porous medium this law has been given where Q is the rate of water flow and K is the hydraulic conductivity and A is the cross-sectional area and dh by dl indicates the hydraulic gradient. So, this we have discussed in the greater detail in the previous four parts this is the fifth part of the lecture.

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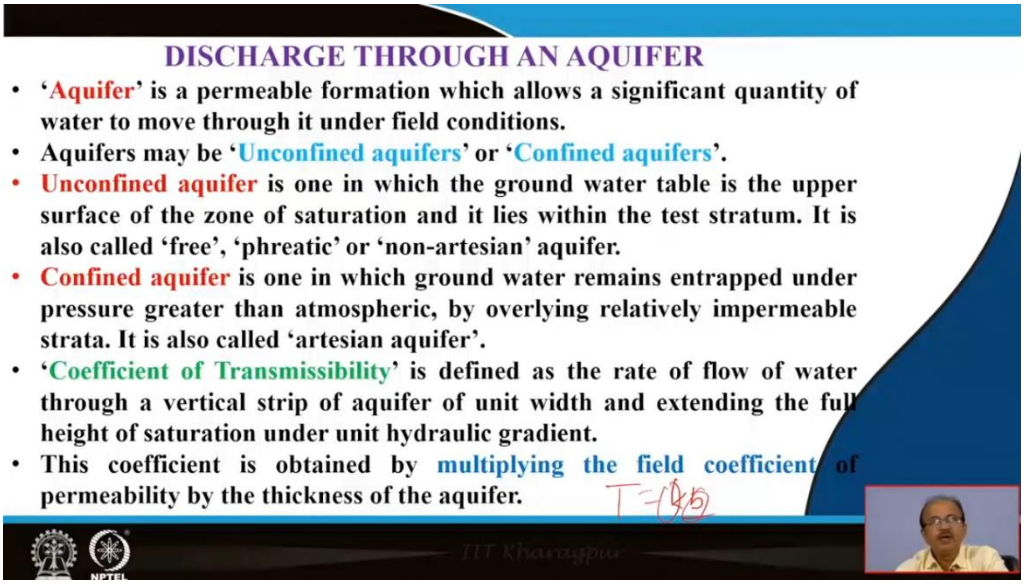

Now in this lecture we will discuss some more issues related with the Darcy's law and its application. So, we all know that aquifer is a permeable formation which allows a significant quantity of water to move through it under different field conditions. So, it is a permeable formation porous formation aquifer is a porous and permeable formation which allows a significant quantity of water to move through it under different field conditions.

So, aquifer may be unconfined or confined as I have discussed just now. Unconfined aquifer is though aquifer in which the groundwater table is the upper surface of the zone of saturation, so you know and it lies within the test stratum it is also called free phreatic or non-artesian aquifer. So, this unconfined aquifer is a very important one generally we are having the water table as the upper layer in the unconfined aquifer.

Whereas the confined aquifer is one in which the groundwater remains entrapped under pressure greater than the atmospheric. By overlying a relatively impermeable strata overlying and underlying relatively impermeable strata and this is also called as an artesian aquifer. So, the basically the about the two types of aquifer we have discussed in greater detail. We have also discussed the coefficient of transmissibility.

It is defined as the rate of flow of water through a vertical strip of an aquifer of unit width and extending the full height of saturation under unit hydraulic gradient. So, this issue has also been discussed in the previous lectures, this coefficient is obtained by multiplying the field coefficient if field coefficient of permeability by the thickness of equal and probably we have seen that T = k*b we have read this thing. So, it is just multiplied by the coefficient of permeability in by the thickness of the aquifer. So, this thing we have discussed in the previous lectures.

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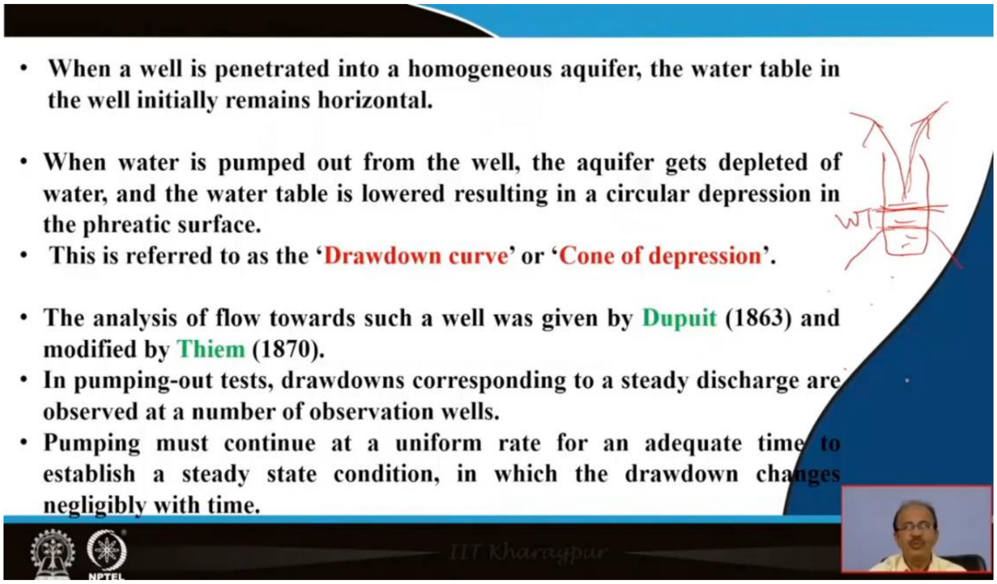

Now what now we will concentrate for the application part of the Darcy's law and we all know that well which is remaining in the field is generally remains in certain aquifer because porous formation is important wherever we see the well and if the well is water, so definitely the well is in the porous formation. It remains in the porous formation and if there is a well and well is a dry definitely that well is not under a very good aquifer that is why water is not in it.

So, these different issues we have discussed we have also discussed that in some well you will get the water throughout the year and in some well you may get the water during the monsoon period or just after the monsoon period but after that it will become dry. So, it means the well is located in a formation which is maybe the clay formation may be porous clay is the porous no doubt but it will hold the water but definitely it will not able to transmit the water.

And we have discussed already that an aquifer is the best aquifer if it is having the sufficient number of pore spaces as well as it is having the tendency of the transmit of water from one aquifer to another aquifer, then only an aquifer may be become a best aquifer. So, the different condition we see in the wells in the field in the ground situation we are seeing the different conditions some wells are remaining filled up with water throughout the year or the maximum period of the year and in some ways become dry after few months of the year.

So, these conditions may exist in the field so if the water is coming to the well definitely the flow of groundwater movement concept is there definitely the Darcy's law concept is there. So, we will discuss some more issues related to it that when a valid penetrated into a homogeneous aquifer the water table in the well initially remains horizontal it will remain initially horizontal. So, if this is a well homogeneous aquifer is there so the water table is this one, we know the upper part of any unconfined aquifer is called water table.

So, this water table will remain horizontal but what will happen when you will just pump out the water from the well so the aquifer gets depleted. So, this will come down aquifer will get depleted. So, water table initially was here now it will come here. So, what will happen it will this water table will come down and it will form a circular cone of depression. So, the cone of depression will start so this is called as the drawdown curve or cone of depression.

So, draw down curve we are getting, as we are just taking out the water above the earth surface of the surface so just the depression, we are finding in the water table and which is termed as the curve of cone of depression. The analysis of flow towards such a well was given by Dupuit, one of the scientists in the year 1863 and which has been modified by theme in 1870. One test is there that is a pumping test so in pumping test drawdown corresponding to a steady discharge are observed at a number of observation wells.

So, generally we are conducting such type of test in the later lectures we may discuss this test in greater detail. So, this is a test we are performing in the field for knowing about the status of the water available in the aquifer formation. So, one observation values one your pumping well is the will be there, so one pumping well will be at this point and several observation will be located just near about this pumping well.

So, through this test we are just taking out the water from these well at the same point at the same time we are just starting to for taking out the water from the well. And then we are just monitoring the level of the water inside the different wells. So, through this we can we are getting the idea about the transmissivity and storativity of the formations. So, in pumping out test drawdowns corresponding to steady discharge observed at number of observation wells.

And the pumping must continue at inform rate for an adequate time what I have discussed just now. It should be the pumping should be in from anywhere if you are pumping out the water it should be started at the same time and at uniform rate for a steady state to establish a steady state condition in which the drawdown changes negligibly with time. So, this thing we have to take precaution while doing the pumping test study.

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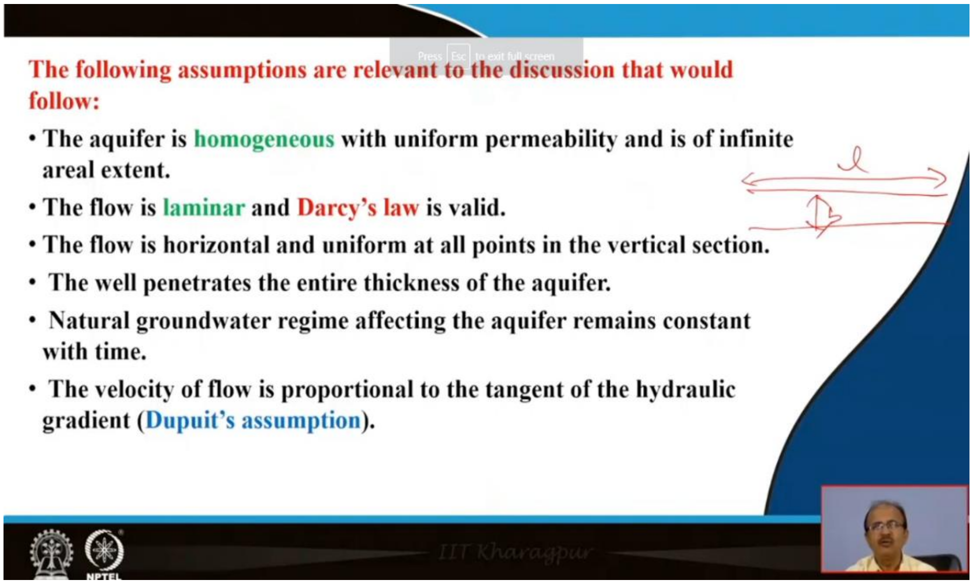

Some more assumptions are here which are very much important for the Darcy's law problem. The aquifer is homogeneous within uniform permeability and is of infinity areal extent. So, both the thing is here that the permeability should be in form and it is of infinite aerial extent the flow should be a laminar and the Darcy's law is valid for the laminar flow, so this assumption is very important.

The flow is horizontal and form at all points in the vertical sections and the well penetrates the entire thickness of the aquifer. So, the assumption is that whatever the thickness of that per say if this is the areal extent of the aquifer inside the surface and this is the thickness of the aquifer. So, both matters a lot the length also as well as the breadth of the aquifer. So, this is the length of the equation the breadth of the aquifer.

Both matters a lot for knowing about the content of volume of water available inside the surface, our topic of the lecture is the availability and management of groundwater resources. So, we must know what should be the important assumptions of the Darcy's law as well. So, natural groundwater regime affecting the aquifer remains constant with time and the velocity of flow is proportional to the tangent of the hydraulic gradient, Dupuit assumption is there.

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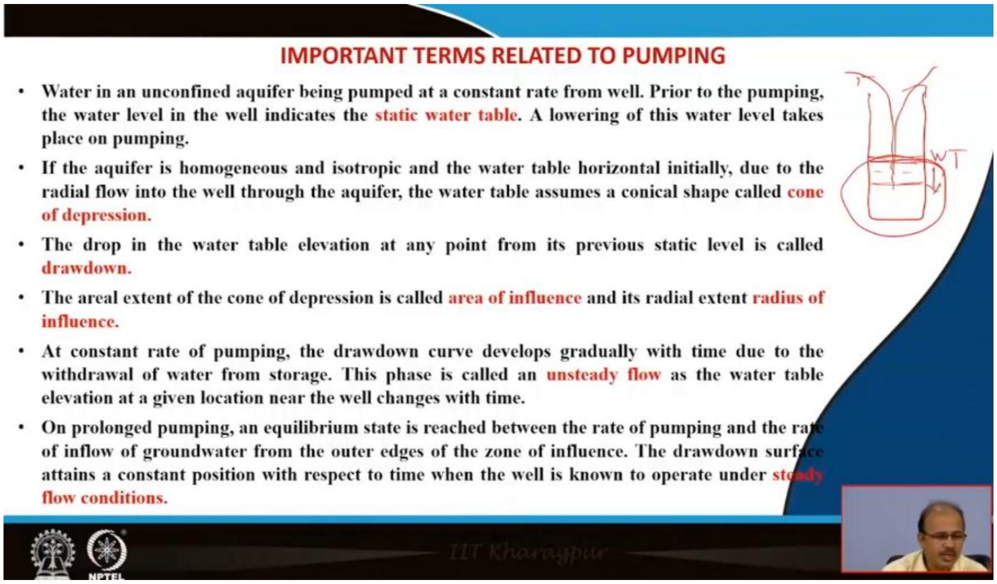

Now some of the important terms related to pumping we will discuss under these some of the cone of depression and about the radius of influence, these are very important terms which usually we find when the we pump out the water from the well. So, water in a confined aquifer being pumped out at constant rate from the well. Prior to pumping the water level in the well indicates whatever the level of the water remains water level remains in the well before pumping that water table is called as a static water table.

So, a lowering of this water level takes place during pumping just the water level because if this is a well, just this is the water table. So, while pumping out water from the well this well just we are pumping out the water so what will happen this is water table actually this is the layer of the unconfined uppermost layer of the unconfined aquifer but while pumping the gradually the level layer will drop this layer of the water table will drop because water is coming going out.

So, this before pumping the level of the water table is called a static water table. During after lowering of this water level take place during the pumping only and if the aquifer is homogeneous because this well is in the aquifer only homogeneous and isotropic and the water table horizontal initially due to the radial flow into the well through the aquifer. The water table assumes a conical shape called cone of depression.

So, this water table will again starts for and going down. So, this if the aquifer remains homogeneous the water table remains horizontal initially but as the pumping will continue due to the radial flow into the well through the aquifer what will happen the water table will assume a conical shape and this conical shape is called as the cone of depression. So, this is very important term regarding the pumping test.

The drop in the water table elevation at any point from its previous static level this drop this water table is just dropping from the static level to this position while pumping. So, this drop is termed as drawdown this is called as drawdown. So, this is called as drawdown whatever the water table is coming down because of the pumping activities. So, now how far the water table has gone down this is expressed by one expression that is known as the area of influence.

And its radial extent is called as the radius of influence. So, these three terms are very important the cone of depression the drawdown and the area of influence or radius of influence. Once again, I am just discussing this issue that a well which remains in an aquifer, aquifer means porous formation, so definitely it is having the water level the uppermost water level and which remains in contact with the atmosphere is called as water table.

So, this water table before the pumping is called as a static water table and while and when the pumping started this water table start going down because we are taking out the water outside this is called a withdrawal of water. So, withdrawal of water is taking place so the water level is going down. So, this form a cone shape conical shape structure within that formation and this is called as the cone of depression, so this is called as the cone of depression.

Now the drop in the water table height from the static; static means before the pumping the existing prevailing your water table. So, from before the pumping and just after the start of the pumping the drop of the water table is called as the drawdown, so this is called as drawdown. And third how far the water table has gone down because of the pumping activity is measured by the area of influence or by the radius of influence during the pumping activity.

So, these three terms are very important. At constant rate of pumping the draw down curve develops gradually with time due to withdrawal of water from storage because any aquifer it stores the water. So, this phase is called as an unsteady flow as the water table elevation at a given location near the well changes with time. So, water table location is changing with time, suppose from one where you are just withdrawing the water for 10 minutes in other way for 20 minutes.

So, different elevation of the water table will remain in two different conditions. Now on prolonged pumping and equilibrium strategies between the rate of pumping and the rate of inflow of groundwater from the outer edges of the zone of influence. The drawdown surface attains a constant position with respect to time when the well is known to operate under this is steady flow conditions. So, these are related important related term with the pumping.

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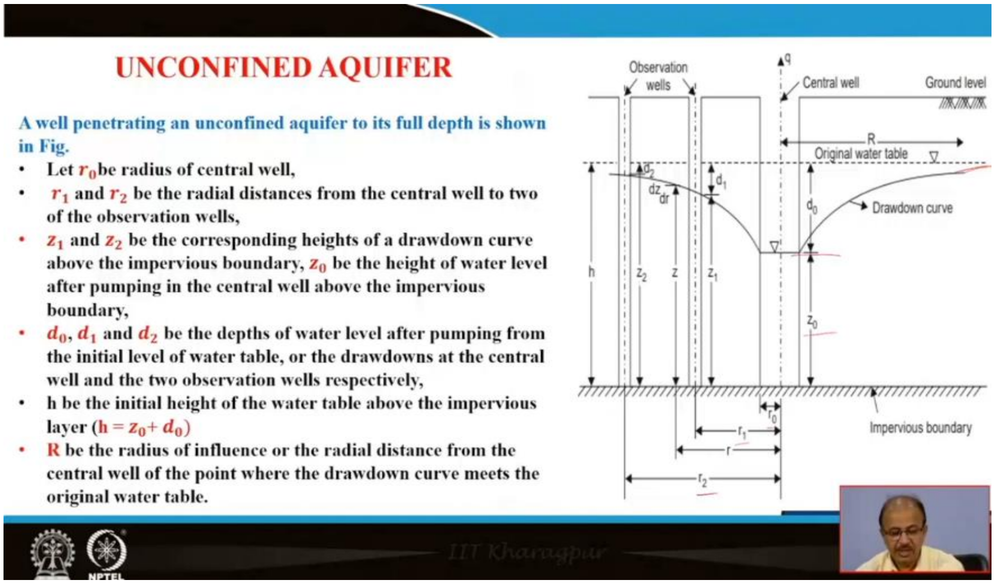

Now just we will discuss these issues with relation to unconfined and confined aquifer. So, this is with the unconfined aquifer we have seen a well penetrating and unconfined required which full depth is shown in figure just the figure you can see here a well here what is happening let r_0 be the radius of central well. So, you just this is the radius of central well this is the central well you see and these two are the observation wells.

So, the r_0 is this one. We can see here this is the r_0 now r_1 and r_2 be the radial distance from the central well to two of the observation well so this r_1 and r_2 and r1 is the radius distance from the central well to the two observation well. So, this is the central well and this is the observation well these two are the observation well. Now z_1 and z_2 be the corresponding heights of the drawdown.

So, this actually this is drawdown curve just the water table has gone down. So, original water table this one but because of the pumping the water table has gone down so it has made one cone of depression and this is the drawdown curve. So, generally to be the corresponding how heights of the z_1 and z_2 you can see here the corresponding heights of the your this is unconfined aquifer this is the impervious boundary and this is the water table.

So, we know for unconfined aquifer the impervious boundary will remain at the bottom and water table remain at the top this water table will remain in the contact with the atmosphere. So, in this if the pumping will continue from any central well and what will happen, we can notice it through the observation well also. So, here z_0 be the height of the water level after pumping in the central well.

So, this is the z_0 this one is the z_0 the height of the water level after pumping in the central well so above the impervious boundary it definitely is above the impervious boundary. Now d_0 d_1 and d_2 be the depths d_0 d_1 and d_2 are the depths of the your this is d_0 then d_1 and d_2. These are the depths of the water level after pumping from the initial level of water table we can say the draw downs at the central well and the two observations well respectively.

So, the here in the central well we are getting the d 0 depth whereas in the well observation where d_1 and objection will d_2. So, then what is happening h be the initial height of the water table above the impervious layer h is the impervious side just height of the water table this is the h which is the initial height of the water table above the impervious layer which you can see this is the water table.

So, $h = z_0 + d_0$ so it is the sum of the $z_0 + d_0$, so R be the radius of influence so R be the capital R be the radius of influence you can see here capital R is the radius of influence or the radial distance from the central well of the point where the drawdown curve meets the original water table. So, here if you will see this drawdown curve will meet with the original water table. So, this much will be your radius of influence.

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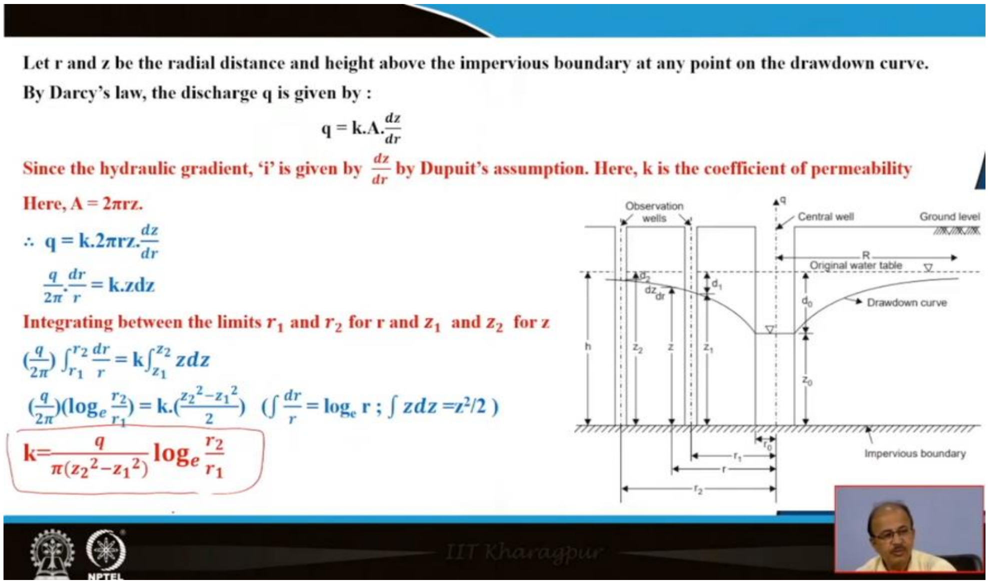

Then what is happening here just you see let r and z be the radial distance and the height above the impervious boundary at any point on the drawdown curve then by Darcy's law because Darcy's law we have seen the discharge q is given by

q = k.A.$\frac{dz}{dr}$

Since the hydraulic gradient, 'i' is given by $\frac{dz}{dr}$ by Dupuit's assumption. Here, k is the coefficient of permeability

Here, A = 2πrz.

∴ q = k.2πrz.$\frac{dz}{dr}$

k.zdz = $(\frac{q}{2\pi}).\frac{dr}{r}$

Integrating between the limits r_1 and r_2 for r and z_1 and z_2 for z

$k\int_{z_1}^{z_2} zdz = (\frac{q}{2\pi})\int_{r_1}^{r_2}\frac{dr}{r}$

$k.(\frac{z_2^2-z_1^2}{2}) = (\frac{q}{2\pi})(\log_e\frac{r_2}{r_1})$

$k=\frac{q}{\pi(z_2^2-z_1^2)}\log_e\frac{r_2}{r_1}$

So, this is for the unconfined aquifer this condition is for the unconfined aquifer.

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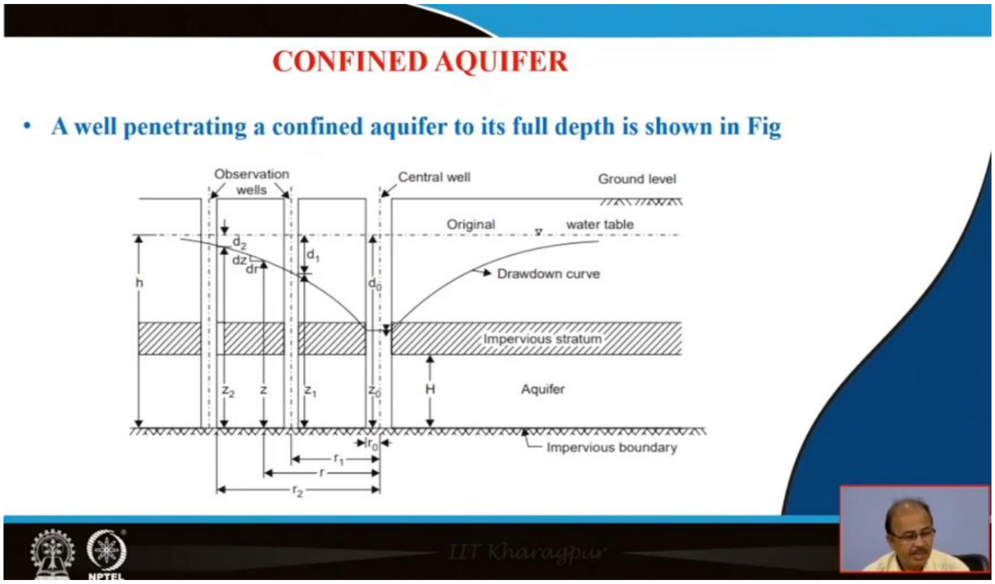

Now for confined aquifer just we know that confined aquifer is having impervious boundary both at the top as well as at the bottom. So, here the constant h we are getting well has been penetrated into confined aquifer to its full depth. The similar pattern is also here whatever water level central well is there observation value is there then you can see the r_0 r_1 r_2 is the same pattern what we have discussed in the earlier slide.

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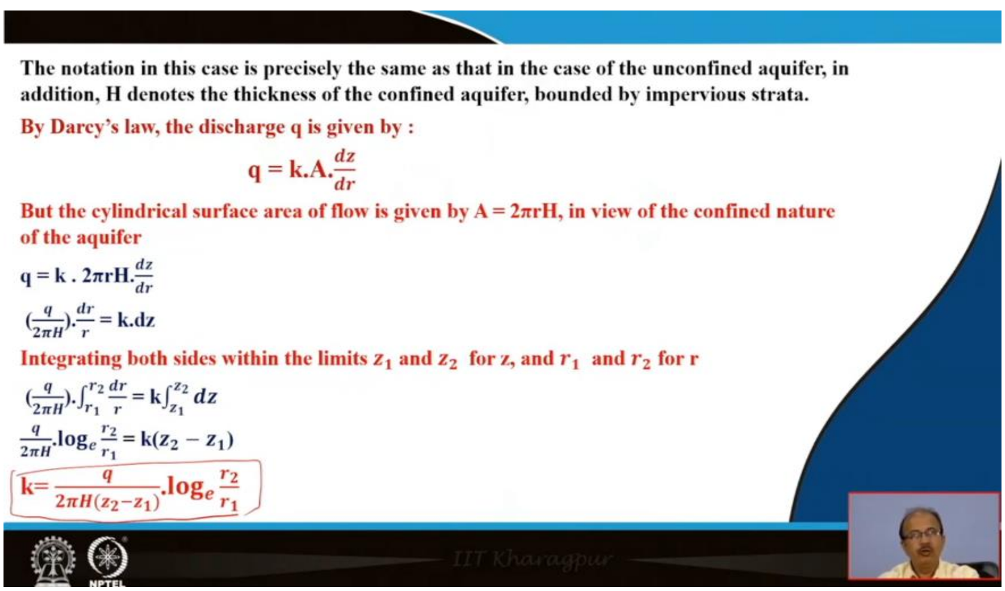

The only thing is that in this we can just find out the q value the notation in this case is the same as that in the case of unconfined aquifer. In addition, only H denotes the thickness of the confined aquifer bonded by impervious strata. So, by Darcy's law q = k.A.$\frac{dz}{dr}$

But the cylindrical surface area of flow is given by A = 2πrH, in view of the confined nature of the aquifer

q = k . 2πrH.$\frac{dz}{dr}$

k.dz = $(\frac{q}{2\pi H}).\frac{dr}{r}$

Integrating both sides within the limits z_1 and z_2 for z, and r_1 and r_2 for r

k$\int_{z_1}^{z_2} dz$= $(\frac{q}{2\pi H}).\int_{r_1}^{r_2} \frac{dr}{r}$

k$(z_2 - z_1)$=$\frac{q}{2\pi H}$.$\log_e \frac{r_2}{r_1}$

k= $\frac{q}{2\pi H(z_2 - z_1)}$.$\log_e \frac{r_2}{r_1}$

So, this is about the different sets of your problems related with the confined and unconfined aquifers with the help of your application of the Darcy's law.

So, in these two cases generally the hydraulic your coefficient of permeability can be find out by knowing the different values given in the problems. So, this is all about your Darcy's law which is a very, ver important law for knowing the groundwater movement.

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So, these are few of the references just mentioning here you please go through it and know more about the topics detail.

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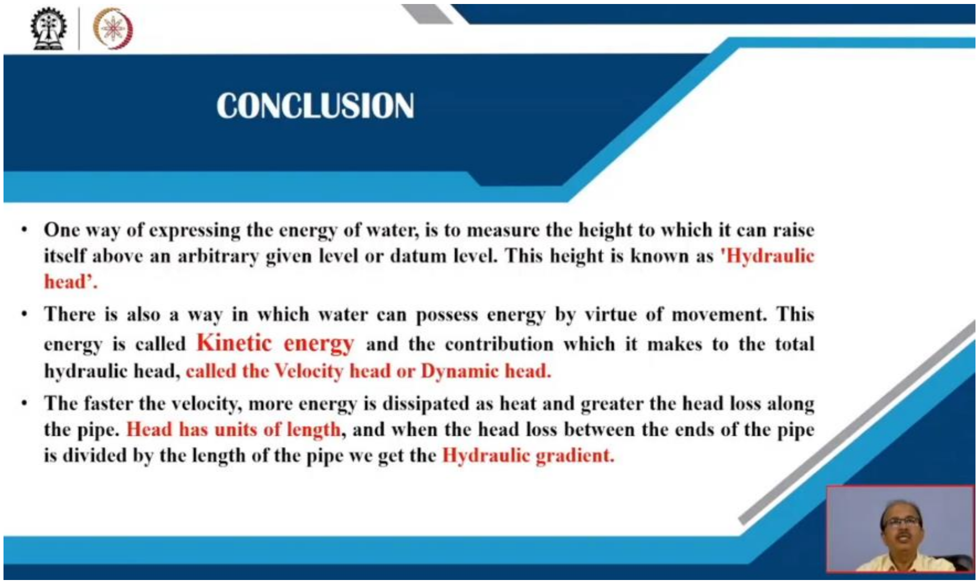

Now just concluding the whole lectures related to the Darcy's law and the groundwater movement that one way of expressing the energy of water is to measure the height to which it can raise itself above an arbitrary given level or datum level. So, this height is a very important term it is known as hydraulic head. So, hydraulic head is very, very important term deciding the flow of your water.

Now there is also a way in which water can possess energy by virtue of movement and this energy is called kinetic energy. And the contribution which it makes to the total hydraulic head is called the velocity head or dynamic head. So, the faster the velocity more energy is dissipated as heat and greater the head loss along the pipe and so head has units of length and when the head loss between the ends of the pipe is divided by length of the pipe generally, we get the hydraulic gradient.

Then we get the hydraulic gradient. So, hydraulic head, hydraulic gradient these all are very important concepts related to the availability and management of groundwater resources.

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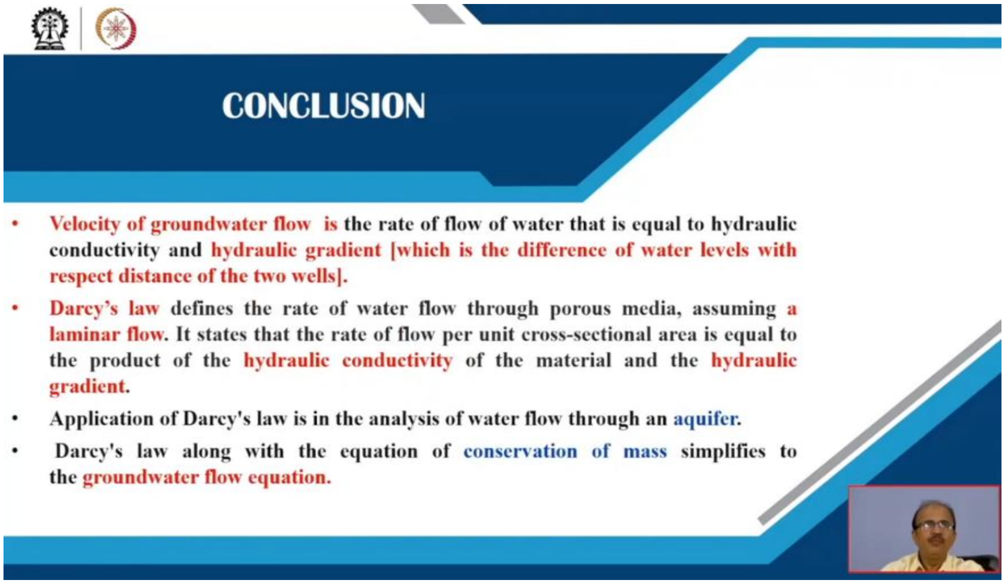

Now velocity of groundwater flow is another important term which is the rate of the flow of water that is equal to the hydraulic conductivity and hydraulic gradient. And gradient we know; which is the difference of water levels with respect to distance of the two wells. So, in total Darcy's law defines the rate of water flow through porous media assuming a laminar flow. It states that the rate of flow per unit cross sectional area is equal to the product of the hydraulic conductivity of the material and the hydraulic gradient.

Application of Darcy's law is in the analysis of water flow through the different types of aquifer, aquifer may be your confined aquifer to unconfined aquifer and this Darcy's law along with the equation of conservation of mass simplifies the real groundwater flow equations. So, this is all about the Darcy's law and its movement, thank you very much to all.