Urban Utilities Planning: Water Supply, Sanitation and Drainage
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Module - 03
Collection of water
Lecture - 14
Groundwater Yield

Welcome back~~.~~! In lecture-14, ~~we will talk about~~ Groundw~~ W~~ater Yield will be discussed.

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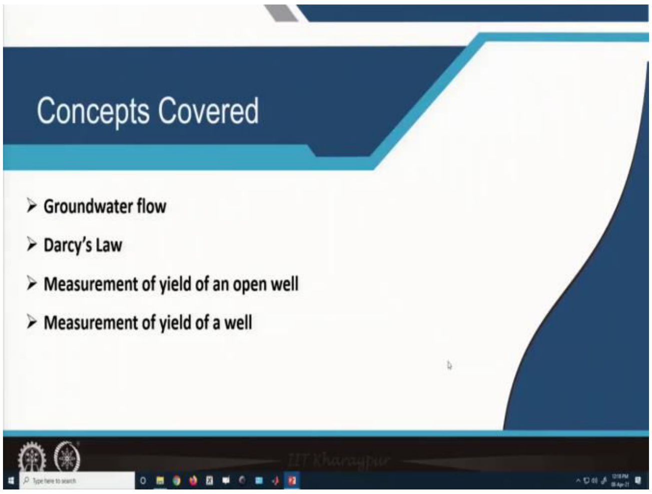

The different concepts that would be covered ~~in this particular lecture will be on~~are groundwater flow, Darcy’s Law, measurement of yield of an open well, and measurement of yield of other wells.

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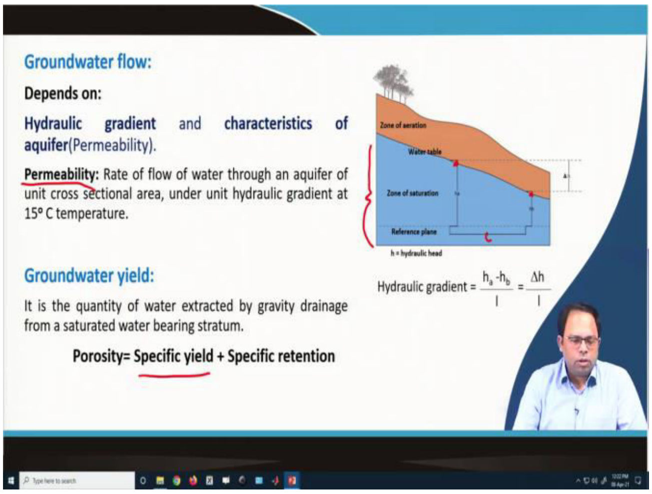

~~So,~~ W~~w~~hen we talk about groundwater flow, ~~we have already talked about~~ permeability and ~~we have already talked about~~ groundwater yield ~~in the~~were covered in earlier lectures. ~~So, we would say that~~ The groundwater flow depends on hydraulic gradient and the characteristics of that aquifer (~~; by characteristics of the aquifer I mean~~ permeability of the aquifer). ~~And~~ Few other things also play a role ~~definitely~~, but in ~~when we talk about~~ ground water flow these two are the ~~two~~ primary criteria that ~~has to~~must be ~~actually~~ investigated.

H~~So, h~~ydraulic gradient:

In this ~~particular~~ image ~~this~~the ~~-~~ blue zone is the~~, this blue zone is this particular area where this is the blue is~~ aquifer and~~. And~~ you can see the level of the water table in this ~~particular~~ aquifer.

~~So,~~ T~~t~~he water table is ~~more or less~~ certain ~~few metres~~meters below the surface ~~from over here~~. ~~And we can see that~~ I~~i~~f we take a reference plane ~~or maybe the impervious stratum below or we can take just like you know a reference frame~~, we can see that “h_a” is the height of water table at ~~this~~ a particular point, and “h_b” is the height of water table at ~~this~~ another ~~particular~~ point from ~~this~~ the~~particular~~ reference plane. T

~~So, t~~he difference between these two height divided by the distance between these two places ~~this~~ given ~~by~~ by ”L~~l~~” is ~~basically~~ the hydraulic gradient~~the difference between this height then there is~~. Hydraulic gradient can also be called as slope of the piezometric surface or

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water table~~So, if I take h a minus h b, and I divide by the distance l, then we get that is that the difference in this two heights~~these two heights, ~~that is delta h divided by l and this is that known as the hydraulic gradient. So, or you can say this is the slope of this particular piezometric~~piezometric ~~surface or this particular surface~~surface ~~of the water table.~~

$$Hydraulic\ gradient = \frac{h_a - h_b}{l} = \frac{\Delta h}{l}$$

~~So,~~ T~~t~~his difference in height is what ~~actually enables~~enables water to flow from one point to another. ~~So, hydraulic gradient, so~~ G~~g~~round water flow depends on this hydraulic gradient between these two points, ~~and also~~and the characteristics of the aquifer or the characteristics of th~~e~~is ~~particular soil~~soil viz.~~. And the by characteristics we mean~~ the permeability of th~~e is particular soil~~soil.

~~Now, let us go through~~Talking about permeability, it ~~. If you remember permeability~~ is the rate of flow of water through an aquifer of unit cross sectional area under unit hydraulic gradient at 15^0 ~~15 degree~~C ~~centigrade~~ temperature.~~, temperature. Now, what it means is, it is a flow of water through an aquifer then this; that means water flows to the aquifer and we take just a unit cross sectional area and under unit hydraulic gradient.~~

If ~~So, if~~ the hydraulic gradient is more, the rate of flow would be higher. Which~~That~~ means, ~~, the amount of the permeability is only defined for each you know for one; that means what we can say is~~ we can obtain a value for permeability under unit hydraulic gradient~~we~~. ~~But obviously, as you can understand when the hydraulic gradient changes, the rate of flow will also change. So~~Therefore, permeability is the constant or ~~as~~ a coefficient that ~~we will use in our~~can be used in the final model.

G~~And g~~roundw~~-w~~ater yield ~~is equal to we have also learned about this that is it~~ is the quantity of water extracted by gravity drainage from a saturated water bearing stratum. T~~So, t~~hat means, th~~e~~is ~~is already~~ water is already held inside the saturated water bearing stratum of th~~e~~his aquifer.

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~~And then we say that~~ S~~s~~ome amount of water would be retained within it, and some amount of water will come out by normal gravity drainage. So, th~~e~~~~is~~ water which is extracted from the aquifer~~that~~ ~~will come out~~ is basically the water that we can ~~actually get~~utilize~~get,~~ w~~. So,~~ ~~t~~hich is termed as~~s~~ ~~is called~~ the specific yield of the~~that for this~~ ~~particular soil~~soil. So, ground water yield and permeability together can be used to formulate a relationship between the flow, the permeability and the hydraulic gradient of the place.

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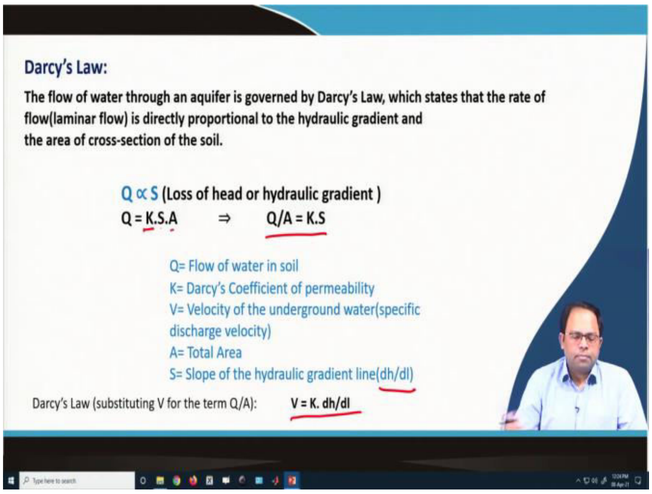

~~So, ground water yield and permeability together when we consider them both. Based on this we can be used to formulate we know that we can formulate a formulate a relationship between the flow, and then between the the permeability and as well as the hydraulic gradient of theat particular placeplace.~~

~~Now,~~ Darcy's Law states that the flow of water through an aquifer is governed by Darcy's Law, ~~and~~ which states that the rate of ~~flow in this particular case the rate of~~ laminar flow is directly proportional to the hydraulic gradient and the area of cross section of the soil.

~~So, when we want to have, when we want to decide~~ F~~f~~or a ~~particular well~~well which~~, then the well~~ has got a larger surface, ~~. So we, obviously,~~ we ~~have to~~must multiply with the overall area for the~~his particular~~ value.

~~So, what~~ Thus, ~~is~~ Q which is the flow of water is directly proportional to S which is the loss of head or hydraulic gradient as per the ~~this is what~~ Darcy's Law~~ state~~, and~~ then~~ it is also proportional to the ~~cross sectional~~cross-sectional area of the soil. Therefore~~So~~, Q is proportional to S and A. ~~So, this~~This is balanced using the~~is~~ coefficient K which is the Darcy's coefficient of permeability.

So, $Q = K \times S \times A$~~to K S A,~~

where Q is the flow of water in the soil, K is Darcy's coefficient of permeability, V is velocity of the underground water. T~~. And this~~he velocity of underground water is basically the specific discharge velocity, ~~that means~~viz. ~~,~~the velocity at which the water is coming out of that ~~particular well~~well.

~~And then~~ A is the total area, and S is the slope of hydraulic gradient ~~line~~ which is given by dh ~~by~~/ dl. ~~So,~~ W~~w~~hen ~~we know the slope of~~ the hydraulic gradient ~~line,~~ ~~and we know~~ the total area is known, the amount of yield from a well can be easily determined ~~we can determine~~ based on the permeability of the surrounding soil.~~ what would be the amount of yield from a particular well~~well ~~that we dig in a particular soil~~soil~~.~~

So, in Darcy's Law, if we~~I~~ substitute Q by A by V where~~ich is~~ Q is the total flow of water divided by area that gives us velocity, and then we get, *V* ~~*is equal to*~~= *K* X ~~*into*~~ *S* or *V* ~~*is equal to*~~= *K* ~~*into*~~ X *dh*/~~*by*~~ *dl*. ~~So, this is another relationship that we can also look into~~investigate~~. So, velocity~~Velocity is also depended on the hydraulic gradient i.e., ~~. T~~more is the hydraulic gradient, the more would be the velocity of flow or the discharge velocity from that ~~particular soil~~soil.

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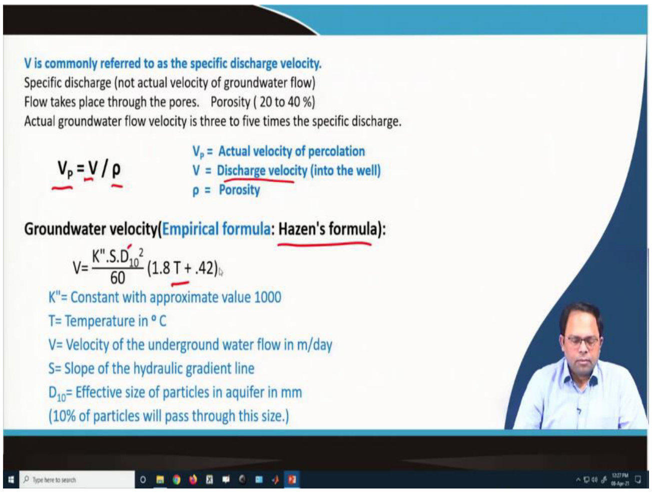

Though ~~Now,~~ V is ~~as we are saying even though we are calling it~~ movement of water underground, it is basically the specific discharge velocity which is different from the actual flow of water inside ground.

~~So, I~~It is the specific discharge and ~~is~~ not the actual velocity of ground water flow, and because flow ~~actually is~~is ~~taking place inside~~happening inside the soil ~~there are~~which has ~~lot of~~ pores ~~in the soil~~. ~~. So,~~ The water has to travel in between the pores~~,~~ and ~~it is~~ not a straight ~~pathpath, or you know a straight forward flow like that~~. ~~So, in that sense,~~Therefore, the water ~~has to~~must travel a larger distance. So, actual groundwater flow velocity is basically 3 to 5 times the velocity of specific discharge ~~or the specific discharge., right.~~

So, ~~groundwater — actual~~ ground water flow velocity ~~that is~~ V p is given by,

$$V_{P} = \frac{V}{\rho}$$

~~the discharge velocity divided by porosity of that particular soilsoil. So, this~~ R~~r~~ho is porosity, and V is the discharge velocity into the well i.e., ~~basically~~ when water comes out of a opening inside the well, whereas~~. And this~~ V p is the actual flow velocity within the soil.

~~Now, there~~There are certain empirical formulas which are~~is also~~ been derived through experiments ~~of course~~ to determine ground water velocity inside soil,~~. And one of that~~ one of those formula is the Hazen's formula.. where V is given as equal to K dash dash into S into D 10 whole square divided by 60 into 1.8 T plus 0.42. Now, what are this valuesthis value?

$$V = \frac{K'' \times S \times {D_{10}}^{2}}{60}(1.8T + 0.42)$$

So, we can see that V is proportional to, so there is some effect of T which is temperature, if you remember we were saying thatas flow happens and permeability is the flowre at 15 degree centigrade. So, temperature plays a role. So, T is there and . And V then it also depends on S, whichS is nothing but the slope of the hydraulic gradient line the same S,. And $D_{,10}$ 10 is basically the effective size of particles in aquifer in millimeter. And D_{10} D 10 signifies 10 percent of the particles will pass through a sieve of this particular sizesize.

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So, if I mention a size of a particular the thisthis size of particles at least 10 percent of the particles will be of that particular sizesize. So, D 10 is equal to effective size of particles in aquifer in millimetre. So, TThe sizesize of the particles is also an indicator of porosity. So, porosity is being considered that, and alsoand you know.

And K" K dash is also that constant with approximate value of 1000. It is a constant which is for the permeability and other constants. . And then

So, overall this equation could be also used to determine velocity of flow inside the ground, and theat unit is in metre per day., ok.

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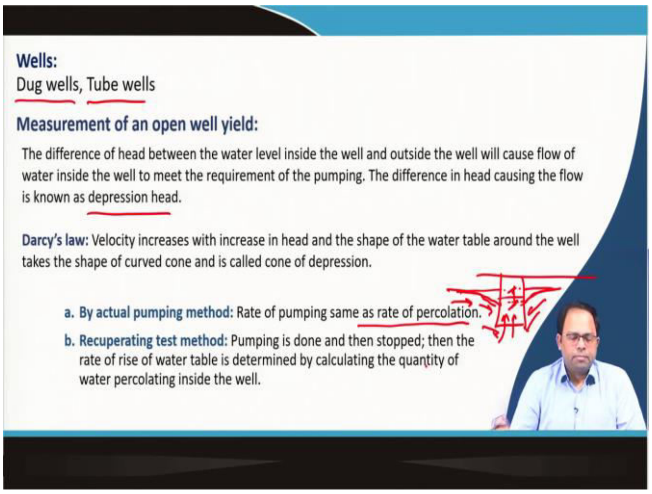

So, now that we know how to determine the yield of ground water and. The next thing and alsoalso, we know that how what is the velocity of flow of ground water, wwe now can determine the sort of yield or what sort ofand quantity of water we can get obtain from particular wellswells.

And tThere are different kinds of wells.

We talk about two kinds of wells over here. One is the dug well which is a standard well that you see in many houses and in most cases itcases it is , it is like a individual, we will actuallydug by is human-sbeings actually do the job, they keep on digging and they put on rings. And they actually youyou know we theythen you create a well at the at your backyard, and Tthis is only possible when the ground water table is at a pretty high level.

And Tthe other is tube wells. Tube wells are could be also put up in certain buildings means in certainand real estate development projects or maybe the municipality even can draw water using deep tube wells. And this Bboth this kind of groundwater sources are used in urban areas,, and alsoand rural and semi-rural areas.

And Wwe need to understand how much water can be drawn from these particular sourcessources. So, this is something where we try learnlearning about the measurement of aan open well yield. First So, first we will learn about how to measure the yield from a dug well or aan open well, and then we will learn about how to measure the yield from a tube well.

So, the howHow is this measurement done, the, and how do we measure that? There are different methods of course, . bBut first of allall, I would like to say the difference of head between the water level inside the well and outside the well will cause flow of water inside the well to meet the requirements of pumping. So thatWhich means, the, what whenever you dig dig a hole in the ground or a well in this particular casecase; the water table in the surrounding soil and the water table inside the well would be at the same level.

Now, ifIf you start drawing water from the well either by means of a pump or by just you know using certain buckets or using containers like buckets, in that case, the water level in the well goes down, this is when t. And when it goes down, then what happens, the water level from the surrounding areas will try to you know water from the surrounding areas will try to enter into the well from the bottom of the well.

~~And difference in head causing the flow be~~to be ~~it that means,~~ T~~t~~he ~~difference~~differences in hydraulic gradient between the inside and outside the well ~~–particular~~is known as the depression head. ~~d. So, this i. And~~ This hydraulic gradient~~- will~~ also ensures that water will flow from the surroundings into the well.

~~And~~ As Darcy's Law states that velocity increases with increases in head, ~~. So, this is what we have derived in the in a few slides, two slides in the previous slide. And~~ therefore, ~~what we see is, because in the velocity of flow increases with the head. So,~~ the more is the head difference, more is the flow.

~~And accordinglyaccordingly, what happens, the slope, the more is the velocity means the slope of that particular whenever~~W~~w~~henever water flows inside th~~is particular~~e well i~~. So, it~~t ~~is~~ flow~~sing~~ from the surroundings~~.~~ and ~~And~~ usually ~~what we see that~~ the shape of the water table around the well takes the shape of a curved cone, ~~and~~ which~~this~~ is called the cone of depression.

For instance~~So that means~~, if there's ~~I have a ground level and if I have got~~ a well, ~~and if I see that this is the~~with a certain water table around the area and ~~in that particular area~~area ~~though. So, when~~ we draw water ~~suppose the water level in the well is over here. So, definitely there~~there is a difference in ~~between~~ the hydraulic gradient between the surroundings and the well.~~, right.~~

So, ~~we will see that~~ th~~e~~is water table bends gradually~~. And~~ while ~~this is where the water from the aquifer will start flowing inside the well and start~~ entering inside the well. ~~, right. And so~~so, ~~this water table actually gets bended. And why~~ T~~t~~his bend happens because the more is the hydraulic gradient, more would be the velocity, and more would be the velocity more will be the bend. Therefore~~So~~, ~~gradually~~ the more you come near to the well you see a more bended surface. ~~So that~~Which is the reason it ~~is why this~~ is called as ~~known as~~ the cone of depression.

~~And then that there~~There are two methods ~~how we can actually measure~~ ~~measure~~to measure the yield of a well, ~~where this two methods~~ ~~these two methods~~which are ~~called~~ the actual pumping method and the recuperating test method. In

~~So, the~~ actual pumping method ~~, it is pretty straight~~ ~~straight forward, that means,~~ the rate of pumping is adjusted using a variable pump ~~may be~~ such~~o~~ that ~~the~~ it would be same as the rate of percolation. Rate of percolation means the amount of entry of water inside the well. ~~So, that means, the,~~On~~ w~~e needs to~~will~~ adjust the rate of pumping such~~o~~ that it matches with the yield of the well~~ right~~.

~~And we can say from the~~Based on the ~~-~~rating of the pump, ~~we can determine what is ~~the yield of the ~~particular well~~well can be determined. ~~-~~Alternatively ~~we can do something called ~~a recuperating test can be done, ~~method ~~where water is pumped ~~pumping is done ~~and then stopped~~ in its~~ a~~. A~~nd then the rate of rise of water level inside the well is used to determine the quantity of water percolating inside the well.

~~So, once we stop~~As the pumping is stopped, ~~that means the ~~there is some difference in the head, and then the ~~we see at what ~~time at which ~~-~~the water will rise ~~come up and how much water is going to come up and we~~is ~~can ~~measured~~ that within that particular time~~time, based~~.~~ ~~And based~~ on which~~that we can determine~~ the yield of the ~~particular well~~well can be determined.

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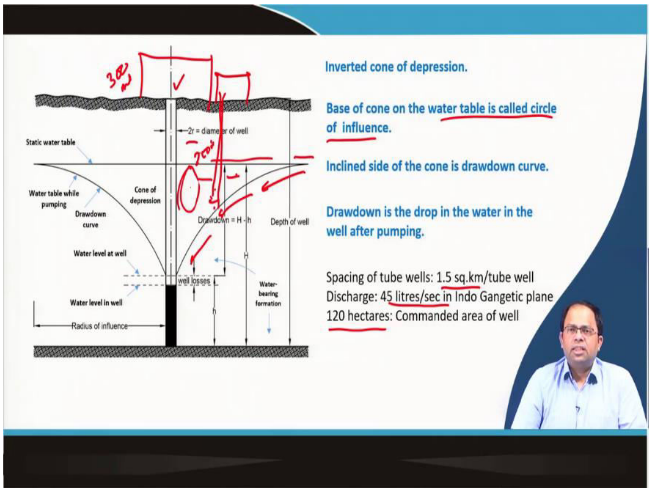

The above~~So, just to show you know in a better figure in this particular figure~~figure, ~~you can see that this ~~is the well with a ~~that has been drawn this one. And then you can see the~~ diameter ~~of the well is ~~2r ~~,~~and ~~this is ~~a static water table. H is the height of the static water table, and ~~the small ~~h is the level of water after pumping. ~~So, this is the level of at where the water table is right now. And ~~O~~o~~nce the water is ~~well starts ~~drawn from the well~~drawing~~

~~when you start drawing water~~, ~~then you see~~ the water table gradually starts bending,~~, and then this is from where the water will start entering.~~

~~And~~ this difference is known as the draw down. ~~a big~~ ~~So, this is the difference this is the draw down. And this~~The curve is known as the draw down curve~~,~~ and the~~is~~ overall cone is known as the cone of depression.

The ~~And the~~ cone of depression ~~has got at the~~when at surface level ~~at~~ of the water table~~. It~~ is ~~basically~~ a circle. So, the circle or~~f~~ the base of the cone is known as the circle of influence. ~~So, base of cone on the water table is called circle of in influence. So, this has got lot of implications, why, I will tell you.~~

~~So, what happens? So, suppose you have got a real estate project like for~~As an example, in a real estate project with a ~~. And you have put in a~~ deep tube well~~ over here, and you are drawing water from here. Now~~, a~~a~~s soon as one starts ~~you are~~ drawing water, the surrounding water table ~~actually is~~bends and water enters into this~~ particular~~ well~~the~~. Let us assume p ~~will be bend like this.~~

~~Now, suppose this p~~eople are ~~actually drawing~~drawing water from ~~height of~~ depth of around 300 metres from this well. ~~So, it is a pretty bigbig deep tube well.~~ Now, ~~you~~ there is ~~have got~~ another building, and due to resource constraints ~~maybe these people do not have so much resource. So,~~ they have dug a tube well till 100~~-, till maybe you know 100,~~ 200 metres. Now ~~what this, what will happen~~ when ~~water is at table when~~ this people from the second building draw water from their well, they will find that their ~~And because the water table has bended, t~~well ~~area there~~ have~~be~~ no water to be drawn~~ from this particular wellwell, because it is in that particular zonezone this particular well~~, because the well ~~. Now,~~ falls in the zone where there is no ground water at all(due to the bend in the water table). Hence, ~~Because the water table is bendedbended, and it is actually notnot availableavailable, and~~ this ~~area~~buildings ~~water is actually youyou know you~~ would not be able to ~~able~~ fetch ~~to draw~~ water from th~~is particular areaarea~~e well. Therefore,

~~So, this building will not be able to get any water. So, that is why~~ we cannot have deep tube wells at~~ very very~~ close proximity ~~,~~and we also ~~we really~~ need to estimate the yield of a well.~~ to determine how much amount of draw down and this will happen and what kind of bending will take place in the in this particular water table so that we can determine at what distances what kind of tables could be put in and so on.~~

~~So, this kind of ground some rules are already there, but that at certain interview cannot have too many deep tube wells in one project.~~ There ~~has to~~must be certain distance between the deep tube wells. Few studies suggest ~~like~~ 1.5 square kilometer per deep tube well which is~~.~~ ~~So, this is~~ the distance or spacing between the deep tube wells ~~you can say~~. ~~So, this or you can say~~ 120 hectares is considered as the command area of deep tube wells. The ~~, and~~ discharge is around 45 litres per second in Indo -Gangetic plane. ~~And what we have found that that~~The centre to center distance between two deep tube wells should be kept more than 600 metres. ~~So, if you keep that, then at least there is some safety considering that the deep tube well is of standard nature.~~

This ~~So, this~~ is how the ~~the this phenomena of this draw~~~~this~~ phenomenon of ~~this is~~ bending of the water table happens which is a huge ~~and that actually is a big~~ problem in urban areas. ~~So,~~ I~~i~~n ~~many we have seen that in~~ many cities people ~~have tomust~~ find that the deep tube wells have gone dry ~~,~~ and they ~~have tomust~~ again put in a new deep tube wells which is at~~would be at a much~~ more depth, -to actually reach the ground water.

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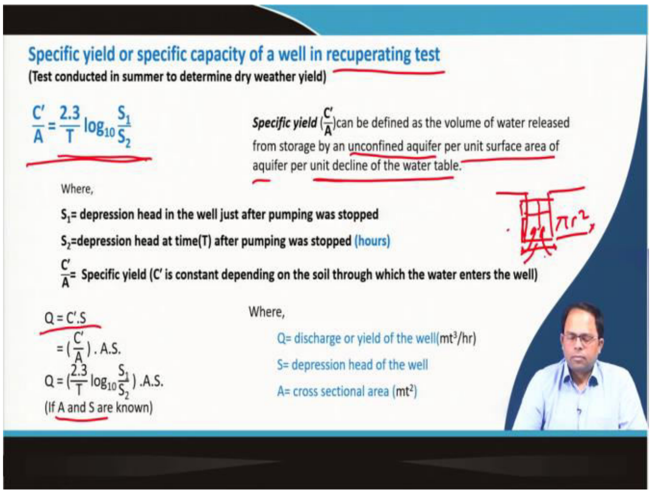

Now, ~~we will~~to determine the yield of a well; ~~or so before we determine the yield~~ there is ~~of course~~ specific yield or specific capacity of a well ~~. And we~~which can be ~~actually determine~~determined ~~it~~ using the recuperating test ~~in this particular exampleexample~~. ~~And~~ T~~t~~he test is conducted during summer to determine the dry weather yield, ~~because of course~~as in summer the yield is lower.

~~So, if we can determine the dry weather yield, of course, we should be save~~saved ~~during the other seasons as well.~~

~~So, specif~~Specific~~y~~ yield C'~~ dash/~~ A can be defined as the volume of water released from storage by an unconfined aquifer per unit surface area of aquifer per unit decline of water table. So, per unit decline of water table ~~that~~ is the hydraulic gradient ~~you can say~~ and per unit surface area of the aquifer.

~~So, that means, from the aquifer if you take a, if you make a hole in the aquifer and from per unit area of the aquifer, this is the amount of water that will come out right; for one you know for per unit decline in water table, so per unit or per unit of hydraulic gradient right. So, this is what specific yield is.~~

~~So, as you can understand if this is specific yield. So, if I remove A, so if I multiply by A, so this would be area of the surface of the well or the surface of the aquifer you know through which it water enters into the well. So, in case of a~~an ~~open well, so we know that in case open wells are like this. There are, at the surrounding, there are rings.~~

~~And you cannot draw water from the surroundings usually water enters from below.~~ The ~~So, in this case the~~ surface is ~~of the is just~~ the area of the well which is a circle ~~of the of this particular diameter~~diameter with area ~~around~~ π~~pi~~ r^2 ~~square~~. ~~So, pi r square is the area of the well.~~ This ~~And using this~~ area is from where the water ~~will~~ enters the well.

The ~~So, definitely when~~when ~~we are~~ specific yield ~~if I multipl~~multiplied~~y~~ by πr^2 ~~pi r square, then we get~~gives the yield of the well, ~~and if, and also~~and per unit hydraulic gradient. ~~Now, if I want to understand that ok the for it is for unit decline of water table and if there the unit decline of water table is even higher, then the yield would be even higher. So, we will again multiply with whatever is the unit decline of water table or in this case we call it a depression head.~~

~~So, in recuperating test what we usually do is, we will first pump we will see at what level the water is. And then what we will do is we will see how much water will be there inside the well at after a certain period of time~~period ~~right. And then we determine what amount of water entered into~~entered ~~the well. And from that we determine the yield of that well.~~

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So, this is how this has been derived. So, where C dash A or specific yield it could be defined it could be derived is derived as 2.3 divided by T and log 10 log to the base 10 of S 1 divided by S 2. Now, where T is basically the depress the time after pumping was stopped, and this is given in hours.

$$\frac{C'}{A} = \frac{2.3}{T}\frac{S_1}{S_2}$$

Where, T is the time after pumping was stopped and is given in hours.

So, obviously, S_1 and S_2 are the depression head in the well. And the S_1 1 is depression head in the well just after pumping was stopped so thiswhich is the lower level and S_2 is the depression head after time T. So, this is after a certain amount of rise(of water level) has happened inside the well.

So, C' dash/ A is a specific yield as you have whiche this is constant depending on the soil through which the water enters intoenters the well. So, this depend based on the you know surroundings soil we get a value of C dash. And soso, as we have seen that Q is equal to C dash total yield is equal to the specific yield into the hydraulic gradient, and alsoand the area. So, specific yield is C dash A into A into S, and o we can replace C dash A by 2.3 by T into log base to the base 10 S 1 in S to the S 1 divided by S 2. And this actually allowsallows us to determine the yield of a well based on the recuperating test.

So, instead of using S Q is equal to you know C dash into A into S, we use C dash by A so that C dash because we know already the value of C dash by A. And soso, we can put that in the equation if so if A and S are known, we can determine the yield of the well or Q. So, Q is the discharge or yield of the well in metre cube per hour, and S is the depression head of the well, and A is the cross sectionalcross-sectional area of the well in metre square. So, cross sectional area of that particular wellwell because water enters through the below.

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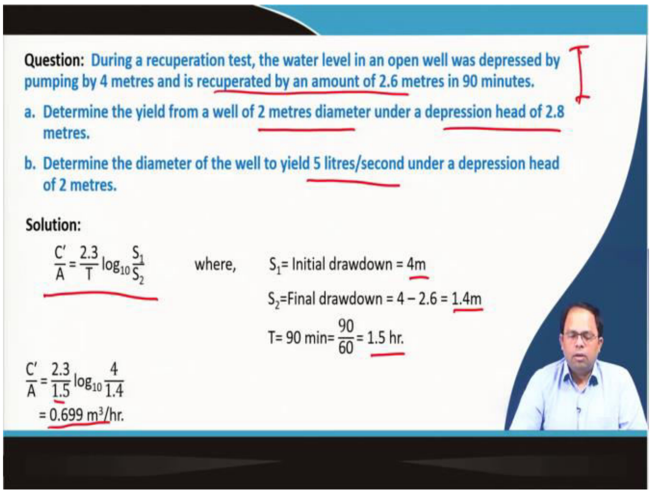

~~**So, let us see one problem. And so,**~~**Question:** ~~-~~D~~d~~uring a recuperating test, the water level in an open well was depressed by pumping by 4 metres and is recuperated by an amount of 2.6 metres in 90 minutes. ~~So, after 90 minutes, it was recuperated by an amount of 2.6 metres. So that means, the depression head is 4 metres minus 2.6 metres right.~~

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a. ~~So, the right, the initial once the pumping was stopped, it was 4 metres below. So, after you know minutes, it was it has gone higher by 2.6 metres. So, the depression head is 4 minus 2.6 metres. So, we need to determine the yield of from a well of 2 metre diameter under a depression head of 2.8 metres.~~

~~So, this is based on the first part, we have to~~ D~~d~~etermine the ~~specific~~ yield from a well of 2 meters diameter under a depression head of 2.8 meters. ~~of the well C dash A value could be determined. And once we determine the C dash A, we have to multiply with the depression head of that particular well and this diameter of area of that particular well and we can get the yield.~~

b. ~~And similarly~~similarly, ~~we can also~~ D~~d~~etermine the diameter of the well to yield 5 liters/second under a depression head of 2 meters. ~~at for to get a yield of certain value like 5 litres per second, how much should be the and with the depression head of 2 metres; how~~

much should be that diameter of that well. So, what should if I want this amount of water what should be the diameter of the well that we should take.

Let us see the solution.**Solution:** So, first we determine the specific yield which is C dash A which is given by the formula which we just learned. And here S 1 is initial draw down 4 metre, S 2 is final draw down which I said 4 minus 2.6 metres, and it is it will come to 1.4 metres and then T equal to 90 minutes which is 1.5 hours, right. So, C dash A is equal to 2.3 divided by 1.5 into log to the base 10 4 by 1.4 which comes to around 0.699 metre cube per hour. So, this is the specific yield of this particular wellwell.

a. **Yield from a well of 2 metres diameter under a depression head of 2.8 metres.**

$$Q = \left(\frac{C^1}{A}\right) \times A \times S$$

$$= 0.699 \times \left(\frac{\pi}{4} \times 2^2\right) \times 2.8 = 6.146 \frac{m^3}{hr} = 1.71\ liters/sec$$

Q = (C'/A). A.S.

= 0.699 x (π4x 22) x 2.8 = 6.146 m3/hr = 1.71 litres/sec.

b. **Determine the diameter of the well to yield 5 litres/second under a depression head of 2 mts.Determine the diameter of the well to yield 5 litres/second under a depression head of 2 mts.**

Q = 5 liters/sec.

$$= \frac{5 \times 60 \times 60}{1000} = 18 \frac{m^3}{hr}.;\ \ S = 2m$$

Q = 5 litres/sec.

$$Q = \left(\frac{C'}{A}\right) \times A \times S$$ = 5x60x601000= 18 m3/hr.; S=2m

18 = 0.699 X A X 2

A = 12.88m²

$$\frac{\pi}{4} d^2 = 12.88$$

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d = 4.05m

Q = (C'/A). A.S.

18 = 0.699 x A x 2

A = 12.88m2

π/4 X d^2 = 12.88

d = 4.05 m

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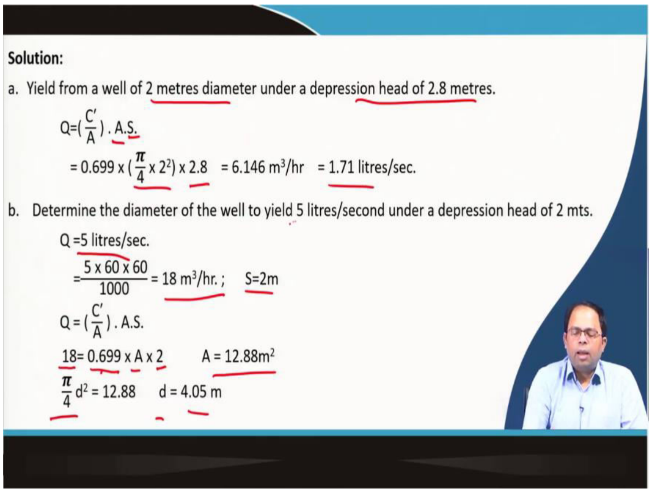

Now, when we determine the yield of the well for of a diameter of 2 metres and depression head of 2.8 metres, so definitely we have tomust multiply the specific yield into the area cross section of the well into the depression head. So, cross section of the head because it is 2 metre diameter, we have taken pi by d square by 4. So, this is the area and into 2.8 is the depression head which comes to around 1.71 litres per second.

And if I want to have a Q yield of 5 litres per second, obviously, I will have to have a bigger diameter. So, I can solve it in this way 5 litres per second, I convert first into metre cube per hour which comes to around 80 metre cube per hour. I do that by multiplying with 60 into 60 seconds into minutes and divided by 1000 because metres to litres, litres to metres has tomust be divided by 1000. And S 2 values 2 metre. So, Q is equal to again the same formula where 18 is equal to 0.699.

So, we already know the yield, we know the specific yield, we know the depression head, only thing we need to know is the area of the well. And from that area, we can calculate the diameter. So, area is 12.88metre square. And using the same formula pi by 4 d square equal

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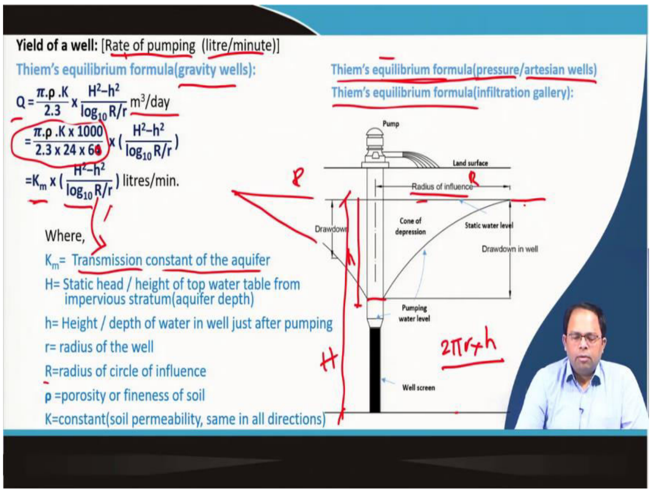

So, now that we have learned about how to determine yield of a open well, where we have not talked too much about it is you know there in open wells are used by houses, but for when The municipal corporation or the urban local body and commercial enterprises extract ground wateriesyou , then they will useusing deep tube wells, and all.

So, that is where we need to; and of course, they will pump the water out and pumping when they pumpIt is usually measured is in litres per minute. T And so we need to determine the yield of these in those systems, w; that means, how much water we can get from there.

So, to do thwe usually use Thiem's equilibrium formula. And Tthis equilibrium formula is different for different purposes. There are three variants of the formula. One is given for gravity wells which are standard deep tube wells, and in where the water is not under pressure , andso it is an open well and it is not a confined aquifer. WhereasAnd so in the other cases, it can be a confined aquifer. In So, it is an artesian well as we have discussed earlier that artesian wells where you draw water is fetched fromfrom a confined aquifer which is .

And then it is under pressure, and because it is a confined aquifer it is under pressure. So, with a little variant of this particular formulaformula, we can use it for you know we can use

~~it.~~ Thiem's equilibrium formula for pressure wells is applied in this case. ~~Then there~~ Then there is Thiem's equilibrium formula for infiltration gallery. ~~which there is again a variant in that particular casecase.~~

~~Now, just before I go into explaining the formula, I will just how it was derived. Now there are few terms that we are using that is first of all~~first ~~it is equilibrium. Why equilibrium?~~ The reason we call it equilibrium is because, ~~it is equilibrium because~~ when pumping is being done from th~~is~~e ~~particular well~~well, we assume that the rate of percolation and the rate of pumping is stabilized, that means, both are at equilibrium~~.~~ a

~~A~~nd for that ~~particular situation~~situation, what is the ~~of water that or what is the~~ yield of that ~~particular well~~well and that is what we determine. ~~So, that is why equilibrium is there.~~

~~And also~~also, ~~you have to~~must ~~understand, this is a~~A deep tube well ~~that it~~ is put inside an aquife~~r. And~~r and we assume that~~, that~~ the entire aquifers depth is being utilized by this deep tube well. ~~And this D~~Deep tube well has got openings on the sides through which water ~~enters into~~enters th~~is~~e ~~particular pipe~~pipe of ~~this~~ the deep tube well. That

~~So, that~~ means, ~~that~~ instead of the lower part of the cross section of the well, more important is the surface area of th~~at this~~e ~~particular well~~well. The ~~So,~~ surface area is ~~basically the diameter of the sorry the; you know~~ 2πr ~~(pi r~~ (circumference) ~~into the~~ x h (height). ~~So,~~ It~~this~~ is the surface area of the well through which water enters~~comes in right~~. ~~So, when Thiem derived this formula what he did was, I will just go to the next page.~~

Thiem's formula:

$$Q = \frac{\pi.\rho.K}{2.3} \times \frac{H^2 - h^2}{\frac{R}{r}}\, m^3/day$$

$$= \frac{\pi.\rho.K \times 1000}{2.3 \times 24 \times 60} \times \left(\frac{H^2 - h^2}{\frac{R}{r}}\right)$$

$$= K_m \times \left(\frac{H^2 - h^2}{\frac{R}{r}}\right) liters/min.$$

Where, ~~Q=Kmx (H2−h2log10R/r) litres/min.~~

Km = Transmission constant of the aquifer

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H = Static head / height of top water table from impervious stratum
H = Height / depth of water in well just after pumping
R = radius of the well
R = radius of circle of influence
ρ = porosity or fineness of soil
K = constantConsidering test well 1:
Q= Kmx (302−282log10R/20) litres/min

Considering test well 2:

Q= Kmx (302−28.62log10R/40) litres/min

Equating both

Kmx (302−282log10R/20) litres/min=

Kmx (302−28.62log10R/40) litres/min

(302−282302−.28.62) = (log10R/20log10R/40)(Refer Slide Time: 31:42)

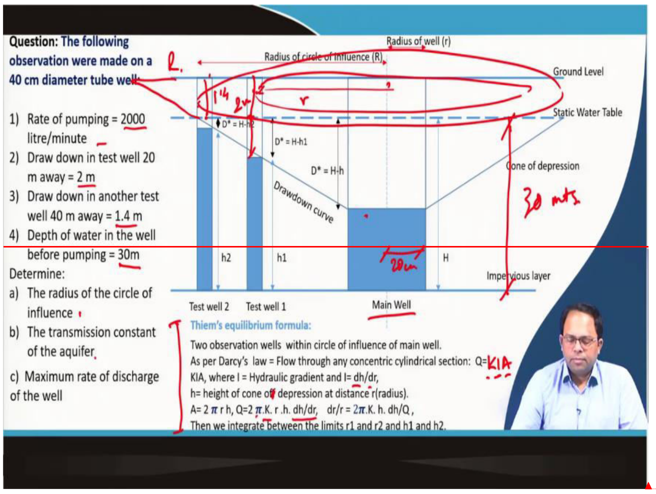
(1.414) = (log10R−log1020log10R−log1040)

log10R= 2.328

(1.414) = (log10R/20log10R/40)

1.414 * log10R-log10R= 1.414* log1040-log1020

R = 212.8 m



In this particular casecase what he did; for example, this is the main well, you can see over here. And two you know test wells were drawn were designed were actually dugdug at certain distances from this particular wellwell.

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And then let us assume that this is test well 1, and test well 2. And then what it was done was these are two observations wells which were within the circle of influence of the main well. So this, that means, whenever you pump from this water, the water table will go down. And within that circle of influence, we will have two test wells.

And as per Darcy's Law we know that flow through any concentric cylindrical section Q is equal to KIA, this is gone here. So, this is again that gradient area and you know that this coefficient, and where I is the hydraulic gradient, and it because we are using this concentric cylindrical sectionsthis concentric cylindrical section we can assume that I is equal to dh by dr. So, dh and dr is basically the height of water table observed in that particular observationobservation well when you draw water from this particular wellwell.

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So, in this particular case, ana dr is the radius of that well. So, if we assume a well which is of radius you know from of size this size, then obviously this is the radius of the well, and the it will because it is on the same draw down curve, it will have the same radius circle of influence right.

So, using that, we can say that that gradient is basically dh by dr, and h is the height of the cone of depression at distance r which is radius. So, based on this, we can say that an A as we just told you that A is equal 2 pi r into h. And so Q is, Q will be 2 pi r, 2 pi r h into K this coefficient into dh by dr which is the gradient ok.

So, dh by dr is a gradient. So, we can also take this in a different form which is dr by r is equal to 2 pi K h into dh by Q into dh divided by the entire thing divided by Q. So, this we just shift Q this side, and we take dr on the other side, and r on the other side. So, if we do that, we get this.

Now, if we integrate between the limits r 1 and r 2, and h 1 and h 2; h 1 and h 2 are the heights of water table in this two test wellsthese two test wells, and r 1 and r 2 are the radius of this two testthese two tests well. Then when we do that, we get a a particular equationequation which could be gradual we can work on that.

And once the final form of that equation is this one, where Q is equal to pi into rho into K divided by 2.3 into h square minus big H square minus small h square divided by log to the base 10 r big R by divided by small r. And this Q is in metre cube per day.

Now, what are these values? Now, what we can say K m is the transmission I will come to that. H is the static head or the height of top of the water table for the impervious stratum or aquifer depth. So, that means, this is the impervious stratum. We assume that the entire aquifer is being utilized by this particular tubetube well.

And this is the static head or the water table. So, this is that you know this entire distance is basically the big H. So, this is the aquifer depth or this height of the top of the water table from impervious stratum or the end of the aquifer.

Small h is the height or depth of the water in the well just after pumping. So, this is the height or depth of the water just after pumping, may be the height of water is until this. So, this is the small h. And r is the radius of the well, and big R is the radius of circle of influence the; you know for this entire you know this one, so this is a big R, this radius of influence big R. And rho is porosity or fineness of the soil; K is the constant or soil permeability which is same in all direction.

So, these are some of the assumptions when this formula was derived like it has to be equilibrium with the soil has to have same permeability in all directions, and this there has to be testtested the test wells are there. And then once we do that, this rho this pi into rho into K divided by 2.3 this again from metre cube today if I convert into litres per minute, I multiply by 1000 divide by 24 into six this 64 over here, and then we can convert all this into K m and this.

So, this was in metre cube per day, and this is litre. So, this is 60 sorry. And so this K m value actually is basically this entire part is taken inside K m ok. So, K m is called the transmission constant of the aquifer.

So, h, so if I can derive K m if I know K m and if I know H square which is the static head or the height of that particular aquifer, and then if I know h square which is the height or depth of water table after pumping, and then if I know the circle of influence, and the radius of that particular this particular well, then we can derive the total yield of that particular well. So, the new thing that comes over here is this circle of influence. If I know yield, then we can also determine circle of influence as well.

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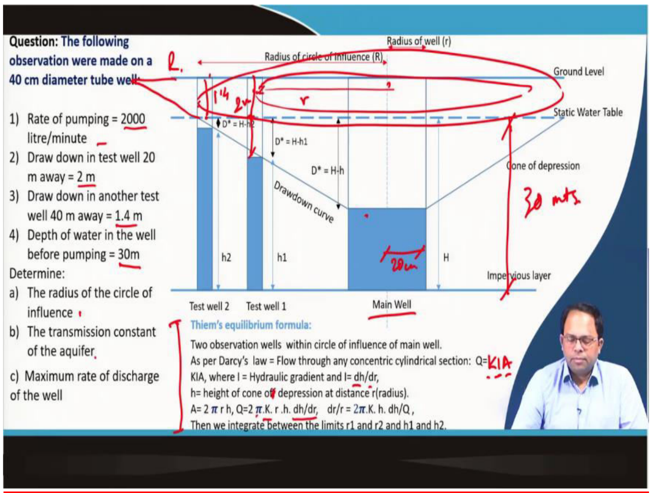

Now, let us look intoinvestigate one problem. I think this we have already discussed. So, in this particular problemproblem, you can see that the following observations were made on a 40 centimeter40-centimeter dia tube well. So, this tube well diameter is 40 centimetercentimeters. So, this is 20 centimetercentimeters. So, of course it is not representative means it is not exactly proportional, butproportional but let us assume theProblem:

Question: The following observation were made on a 40 cm diameter tube well: main well is 20 centimetercentimeters of radius. So, rate of pumping is equal to 2000 litres per minute for this particular well.

1. Rate of pumping = 2000 litre/minute
2. Draw down in test well 20 m away = 2 m
3. Draw down in another test well 40 m away = 1.4 m
4. Depth of water in the well before pumping = 30m

To find:

a) The radius of the circle of influence
b) The transmission constant of the aquifer
c) The specific capacity of the well
d) Maximum rate of discharge of the well

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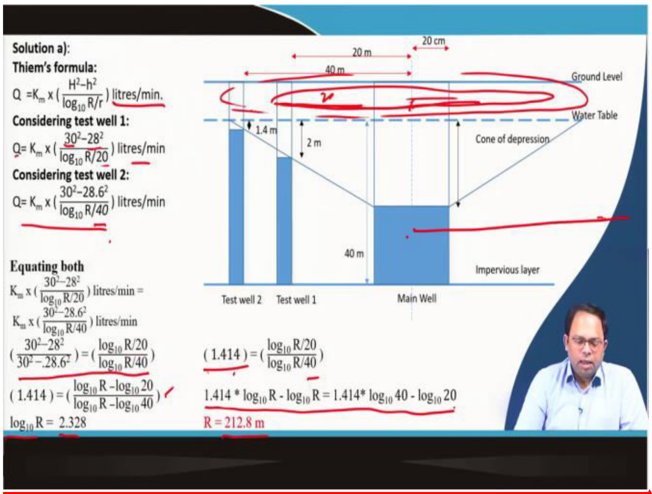

Solution:

a) Thiem's formula:

$$Q = K_m \times \left(\frac{H^2 - h^2}{\frac{R}{r}} \right) liters/min.$$

Considering test well 1:

$$Q = K_m \times \left(\frac{30^2 - 28^2}{\frac{R}{20}} \right) liters/min.$$

Considering test well 1:

$$Q = K_m \times \left(\frac{30^2 - 28.6^2}{\frac{R}{40}} \right) liters/min.$$

~~What we was~~were ~~observed was draw down in the test where 20 metres away, it was observed as 2 metres that is 20 metres away is the first well this is over here. So, this is the radius of that particular; if we assume that this entire well this is a concentric you know area around this particular wellwell.~~ Equating both:

$$K_m \times \left(\frac{30^2 - 28^2}{\frac{R}{20}} \right) liters/min. = K_m \times \left(\frac{30^2 - 28.6^2}{\frac{R}{40}} \right) liters/min.$$

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$$\left(\frac{30^2 - 28^2}{30^2 - 28.6^2}\right) = \left(\frac{\frac{R}{20}}{\frac{R}{40}}\right)$$

$$(1.414) = \left(\frac{\frac{R}{20}}{\frac{R}{40}}\right)$$

$$(1.414) = \left(\frac{R \ - 20}{R \ - 40}\right)$$

$$1.414 \times R \ - R \ = 1.414 \times 40 \ - 20$$

$$R \ = 2.328$$

$$R = 212.8m$$

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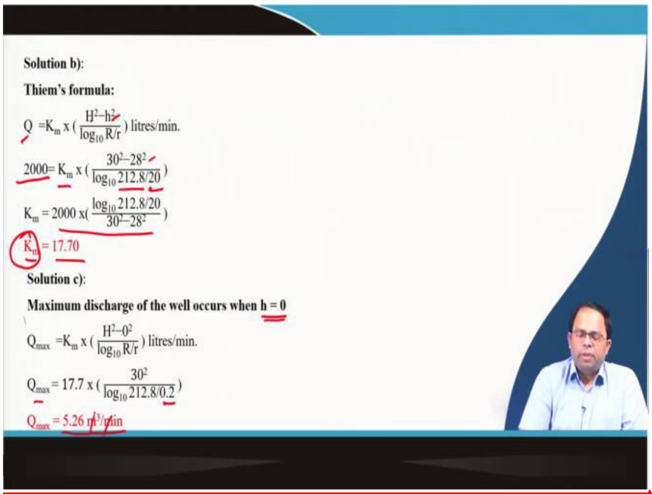

b) **Thiem's formula:**

$$Q = K_m \times \left(\frac{H^2 - h^2}{\frac{R}{r}}\right) liters/min.$$

$$2000 = K_m \times \left(\frac{30^2 - 28^2}{\frac{212.8}{20}}\right) liters/min.$$

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$$K_m = 2000 \times \left(\frac{\frac{212.8}{20}}{30^2 - 28^2} \right) liters/min.$$

$$K_m = 17.70\ liters/min.$$

c) Specific capacity = Discharge at unit drawdown

$$Q_{unit\ drawdown} = K_m \times \left(\frac{H^2 - (H-1)^2}{\frac{R}{r}} \right) liters/min.$$

$$= 17.7 \times \left(\frac{30^2 - 29^2}{\frac{212.8}{0.2}} \right) liters/min.$$

Specific capacity = 345 $liters/min.$

d) Maximum discharge of the well occurs when h = 0

$$Q_{max} = K_m \times \left(\frac{H^2 - 0^2}{\frac{R}{r}} \right) liters/min.$$

$$Q_{max} = 17.7 \times \left(\frac{30^2}{\frac{212.8}{0.2}} \right) liters/min.$$

$$Q_{max} = 5.26\ m^3/min.$$

~~So, this, this entire area is a concentric you know circle, and this is another concentric circle. So, this one is of small r, this is one r. And then this radius of influence which would be somewhere around here this is the large R.~~

~~And soso, draw down in another test well 40 metres away which is 40 metres away. This is 1.4 metres. So, here it was 2 metres draw draw down was observed, and over here 1.4 metre draw down was observed. So, depth of water in the well before pumping was 30 metre, so that means, this is the static height of the water table. So, this is 30 metres.~~

~~So, what we need to determine? We need to determine the radius of the circle of influence that means if I know the radius of circle of influence, I can determine what distance should be the next tube well, right. And that means, we can also determine how what kind of urban~~

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planning or building norms that are we have tomust put into to prevent you know the next building to actually theirtheir deep tube wells were run dry if they are some somewhere in between this radius of influence. So, we have tomust take care of that.

And so we need to determine the radius of circle of influence, we need to determine the transmission constant of the aquifer or K m value. And then we need to determine the maximum rate of discharge from this particular wellwell that is possible. So, right now we are drawing water at 2000 litres per minute, but we want to understand what is the maximum rate at which we can draw water.

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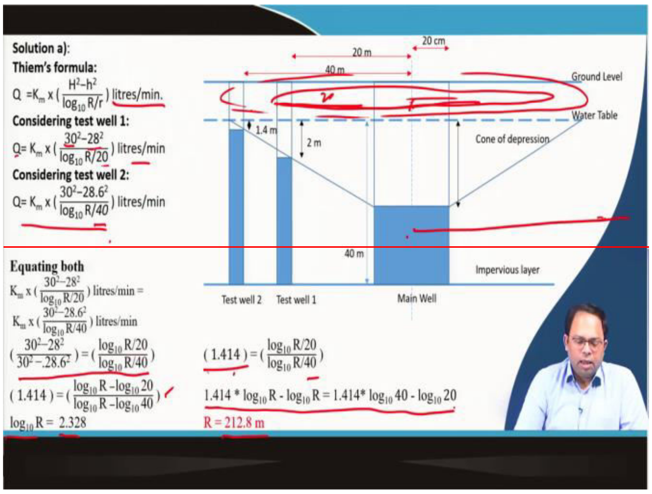

So, using Thiem's formula which is Q equal to K m into square minus small h square divided by log to the base 10 big R by small r in this is given in litres per minute. What we can do is we first we consider this first well, and here we can say if I put in the values for this particular from the values that we have given earlier Q equal to K m into 30 square which is big H which is the static head and then 28 square is the because 2 metre draw down was observed, so 28 square is small h.

So, 30 minus 2 is 28. And then log to the base 10 R by 20 big, why 20 because we assume a concentric. So, this is the radius which is 20 up till this. So, we assume a concentric well of 20, 40 metres diameter or 20 metres radius whatever.

Similarly, for test well 2, we assume you know the second well which is in the same way we consider, but here we take 40 and the draw down is 28.6. So, the height after pumping is 28.6 metres because of 1.4 metres of you know draw down. And this 40 metre is the radius. So, now, this is the second concentric well or circle that we can take. Now, because these are of the same well they are in the same within the same draw down curve we can assume both of them would be same we can equate both of them.

And what we see that, we can when we equate both of themboth, the yield will be same in both the wells. So, K m into this particular the first this one, this value yield is equal to same as this yield, and then we can solve it like this where 30 square minus 28 square divided by 30 square minus 28.6 square equal to log to the base 10 R by 20 log to the base 10 R by 40.

Now, we can solve it simplify it further, this comes to around, once you solve it, it comes to around 1.414, and equal to log to the base 10 R by 20 and log to the base 10 R by 40.

Now, again we can write log 10 R by 20 as log 10 log to base 10 R minus log to the base 10 20 and then log 10 R minus log 10 40. So, when we do that, we can actually nownow solve it, we when we solve it, we get this particular equationequation from where we get log to the base 10 R is equal to 2.328.

And from there, we can determine the value of R which is 212.8 metre. So, 212.8 metre is the circle of influence for this well. So, any other well if you know dug within this 212 metres, it is certainly going to be affected by the pumping of this particular wellwell.

So, at least the next well should be somewhere beyond 212 metres or it could be somewhere in between as well, but you have to adjust the rate of pumping for that well or the timing of pumping to determine the amount of water that you can draw from both this wells. So, this is how we can determine the circle of influence for a particular wellwell.

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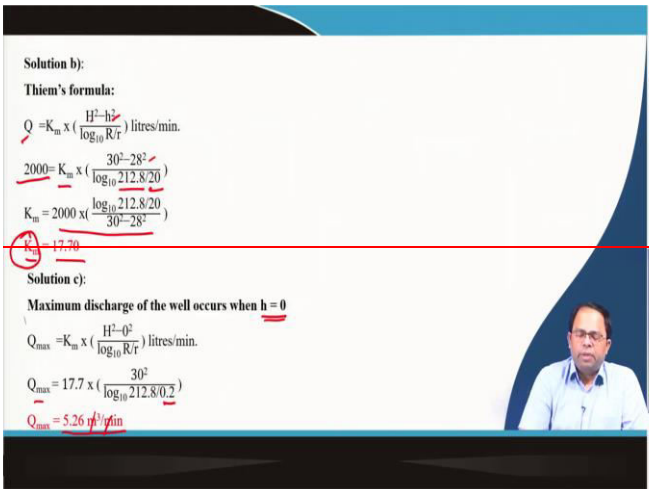

Now based on that, we can now determine K m value because we already know that this particular observationobservation of draw down happened because of a discharge of 2000 litres per minute. So, when we put that in that equation, we can and all the other values we have got like 30 square 28 square and this is R – big R, and this is small r.

And this was the first well the first observation well you can say. And when we equate that we get the value of K m as this which we can solvesolve, and we can get it as 17.70. So, this is the transmission constant of this particular aquiferaquifer.

Now, the final question we have asked is, I have asked is what is the maximum discharge of the well? Now, maximum discharge of the well occurs when h is equal to 0. So, obviously, in this particular equationequation when will Q be maximum; when the value of h square would be less. So, that actually isis it is not, it is a theoretical value. It is the maximum discharge is the theoretical value that means, when the level of water is at the say almost at the same you know there is no draw down as such, right.

So, over here what we can say is when h value is equal to 0, if I put it in the equation, we can see that this can be Q max is equal to 17.7 into 30 square divided by log 10 to the base 10 212.8 divided by 0.2, because our if you remember our radius was 20 centimeter and then Q max equal to 5.26 metre cube per minute. So, this is the value that we can get from this particular equationequation, or you know so if it, it not metre cube sorry; we I think we have to solve it for litres per minute in the same way over here, ok.

So, we will just we need to adjust for that particular valuevalue or it could be I have to check this it is either 5.26 metre cube per minute, or we can give it in litres per minute as well.

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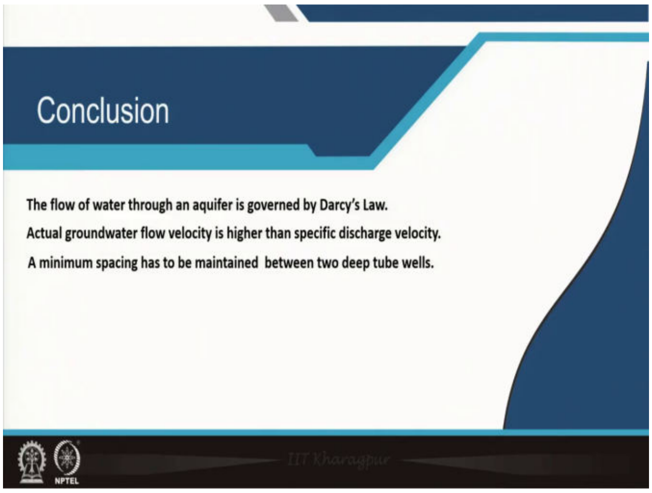

So, toTo conclude the flow of water through an aquifer is governed by Darcy's Law that is what we have learnt. So, we have also learnt Hhow to determine the yield of particular openopen well as well as a deep tube tablewell.

And we have seen that Aactual ground water flow velocity isies higher than specific discharge velocity.

A that is something what we have learnt as well. And ma minimum spacing has tomust be maintained between the two deep tube wells in a, suchо that none of the deep tube wells are affected by each other. So, these are the different things that we have learnt from this particular lecturelecture.

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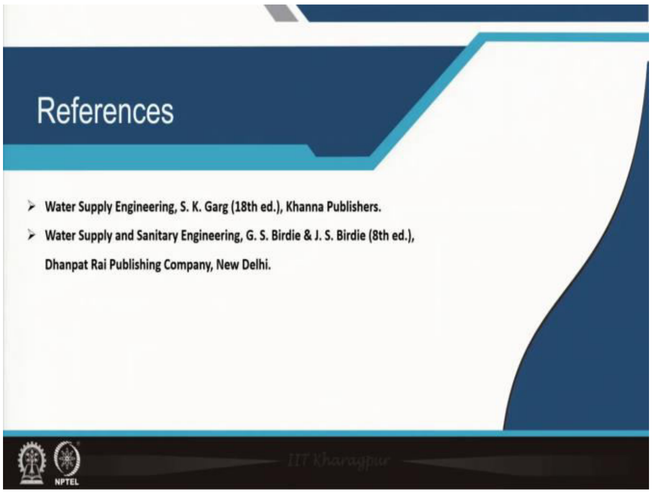

~~These are th~~The references ~~you can~~to study.

~~And thank you.~~