Water Supply Engineering
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Lecture - 15
Well Interferences, Well Losses and Efficiency

Hello friends, welcome back and we will continue our discussion what we started in the previous lecture. So we were talking about the groundwater withdrawal systems and we did discuss that what kind of well structures can be provided, what are the various well components and how we use well hydraulics for analyzing the systems, the capacity or potential of the withdrawal under different cases confined, unconfined aquifers in the transient state and the steady state.

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So to continue that we will be talking in this particular lecture about multiple well systems. So what happens when more than one well is there in the same aquifer, so what kind of interferences that well creates on each other. We will touch upon partially penetrating well as well.

And then we will be discussing about the cases where there is certain boundary near the well, how it affects the withdrawal from well or drawdown, what we receive from the well and towards the end we will be talking about well losses and efficiency and the step drawdown test.

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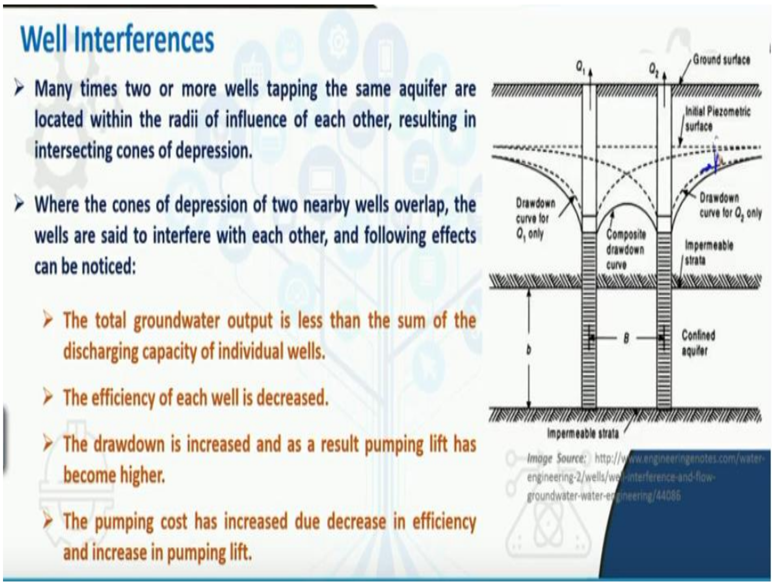

So well interferences when we say or the multiple well systems, when there are more than one well tapping the same aquifer and are located close enough so that their cone of depression overlaps, okay. So what happens if their radii of influence is overlapping, so then they will, their cone of depression kind of intersect each other and that leads to change the drawdown pattern of the well, okay.

So what happens, when there is basically cone of depression of say two wells which are nearby overlaps, then there would be interference and this interference typically, what it leads to, the total groundwater output becomes less okay the efficiency of each well might get decreased, the drawdown is increased as a result of basically pumping lift which becomes higher.

So at same place, the drawdown might become higher and then as the efficiency has decreased and pumping lift increases, so the overall pumping cost of the system is also likely to increase, okay. So what happens that if say we have two wells and the dashed line that you see here are say the original drawdown curve of well two and this is the original drawdown curve for well one.

Now, when the interference take place a resultant drawdown like it will be lesser, if the drawdown becomes higher. So for the same discharge, if we want to keep the discharge same, the drawdown will be higher. So as a result we will see that initially which was supposed to come to this dotted line actually comes to the greater depth.

These points particularly would be of higher influence which is in between the wells and other side also gets affected.

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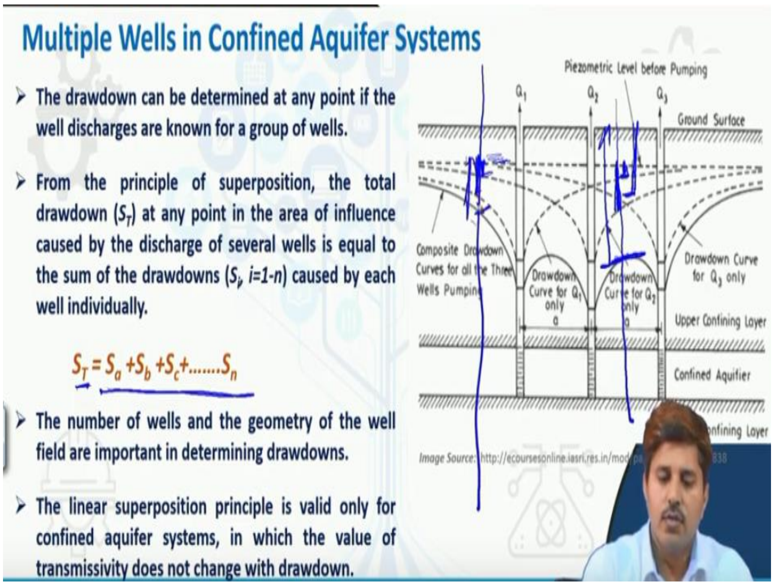

So how this affects under different conditions. So what happens if we take a case of say confined aquifer, the drawdown can be determined at any point if the discharges are known. Now, how it is determined? It is determined based on the simple principle of superposition, okay. So what happens that if say drawdown for any individual well at any particular location is say S 1.

So for well one it is S 1, for well two it is S 2, for well three it is S 3 that way **so** at just one particular location. So the total drawdown at that particular location will be summation of all these drawdowns, okay. So the genetic formula can be considered as the total drawdown S T would be summation of the drawdown of these wells where let us say for if we want to take this particular section, okay.

So due to well one the drawdown is this much here due to well two the well two drawdown is this much, say this much. And due to well three which is this one the drawdown is again this much. So we have these three drawdowns, okay. So due to well one, due to well two, due to well, three. Now if we add all these three, so we will get the total drawdown at this particular location, okay.

Similarly, at any if you want to say at section here, so due to well three, there is no drawdown here. So the third component becomes zero because it is actually already touching here. Due to well two the drawdown is this much whereas due to well one the drawdown is this much. So if we sum this and this together so we can get the actual drawdown over here.

So this is what is the simple principle of superposition which is used for determining the drawdown, okay. Of course, it will depend on number of wells and the geometry of wells okay for finding the drawdown. However, this linear superposition principle is only valid for confined aquifer cases okay where the transmissivity does not change with the drawdown because we consider the thickness of aquifer as same.

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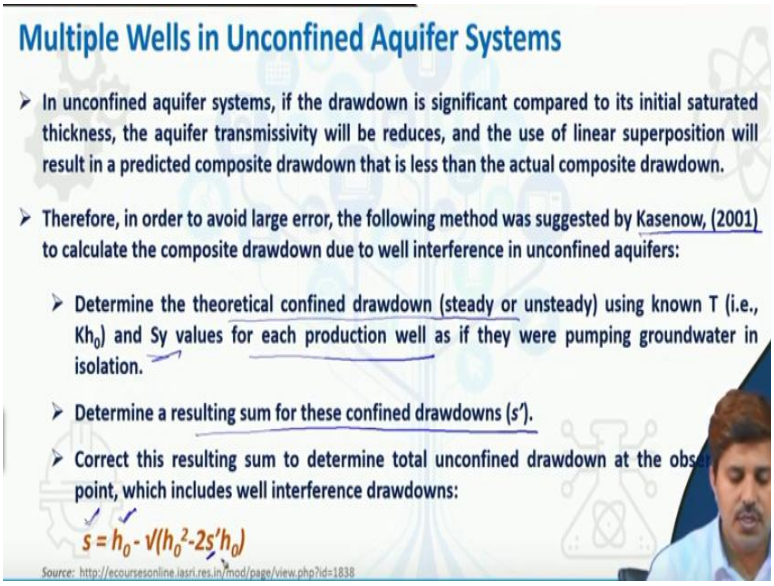

So since the thickness of aquifer b is the same in case of confined aquifer, the transmissivity remains same. But in case of unconfined aquifer, as the drawdown increases the thickness of aquifer decreases. So the transmissivity will actually change, okay. It will be reduced and as a result this super position principle does not work well on case of confined aquifers, in the case of unconfined aquifer.

So for unconfined aquifer, there is a method suggested by case now, which says that we should determine the theoretical confined drawdown for and in System for each well and then we get the resulting drawdown for a confined considering it as a confined case. So like we did from the superposition principle which is s prime and we have to correct this in order to get the real drawdown.

So real drawdown at a point will be the initial point minus square root of h naught square minus 2s which is actually the corresponding drawdown for the case of confined aquifer into h prime. So this is the correction which is used in order to get the net drawdown in case of unconfined aquifers when more than one wells are there.

So first we will use the similar superposition principle but we need to apply this correction because the transmissivity reduces okay. And that kind of results in the large error if we use the simple drawdown for the case of confined aquifer to non confined aquifer systems as well. So this correction is used for the case of non confined aquifers.

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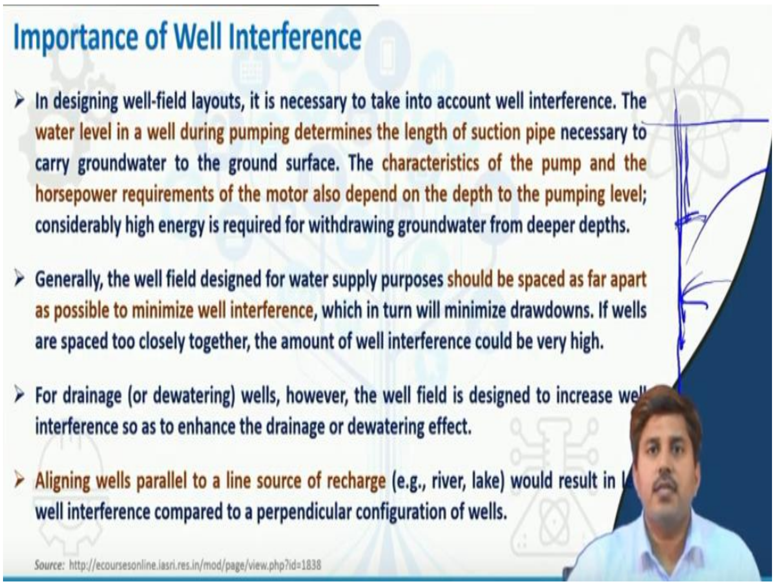

The determining well interference is quite important because when we design a well-field layout it is necessary to take into account all the well interferences, okay. The water level in a well during the pumping is taking place will typically determine the length of the suction pipe.

Now for say if we end up considering that drawdown at this point is going to be let us say this is our original level and we consider the drawdown is going to be this much and we put a well actually, but if drawdown is higher our net intake to the well is going to be lower. So length of section pipe is needed will also depend on what is the net drawdown at the well level, okay. So that is important.

Further, if you want to pump from the deeper sections we have to increase the power of pump, pumping cost, okay. So all those will actually depend on the what is the net drawdown and that is why it is good to estimate it quite precisely. Further if we are trying to withdraw water for the purpose say water supply or similar purpose, then we should space the well as far as possible so that well interference is reduced.

Because as we discussed that well interference will eventually lead to decrease in the efficiency increasing the cost; so we want to minimize the well interference. But if we are planning drainage or dewatering wells for certain area then we can actually space the wells closer so that the net drawdown becomes higher and the area is drained out quickly, okay.

Align, further like if we have to go for multiple well systems, it is good to align well parallel to a line of source of recharge like river or lake rather than the perpendicular to these sources, okay.

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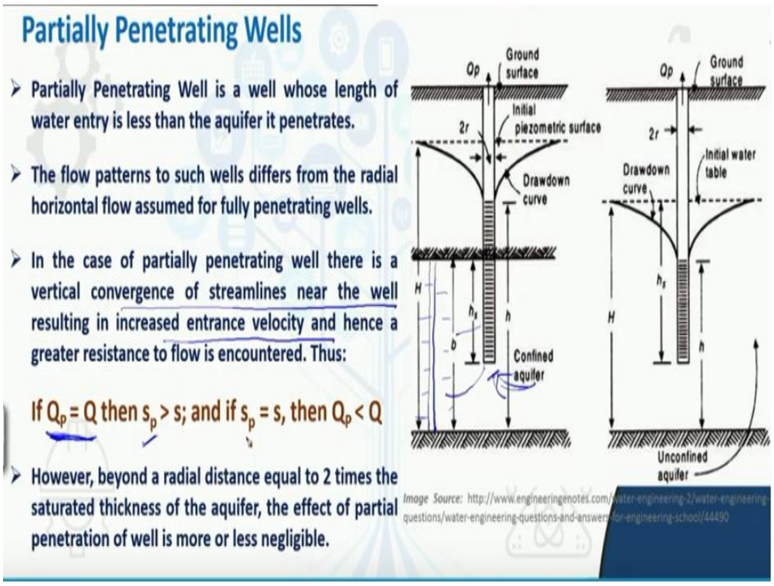

There are partially penetrating wells as well which is well whose length of water entry is less than the aquifer it penetrates. So normally the standard cases that we studied so far we consider that if this is say our aquifer thickness, so the well is, entire well is actually covering the entire thickness. So that is basically fully penetrating well. But there are several cases in the field when we do not actually know the exact thickness of aquifer many times.

So we end up a partially penetrating well like in this case of confined aquifer or this case of unconfined aquifer with a partially penetrating well. So the difference here is that flow pattern to such wells does not remain radial here because, what we assume generally in a fully penetrating well that flow pattern is completely radial towards the well in the vicinity of well, but here it does not remain radial.

It does not remain basically exactly horizontal, the flow pattern changes. And there are streamline that converges near the well and that results in the increased entrance velocity. So velocity at the entrance increases and as a result greater resistance is encountered.

So what happens in such cases, in case of the partially penetrating wells if we want to keep the discharge same, so if we want to have a same discharge as a fully penetrating well from a partially penetrating well, then we will be actually encountering greater drawdown. Or if you want to keep the drawdown same, then we will actually get the lesser discharge as opposed to a fully penetrating well.

So this kind of effect is there when the well is not fully penetrated in the aquifer systems. However, these effects are more closer towards the well where well is there and if we go radially the distance equal to two times of the saturated thickness of the aquifer, where this effect is more or less negligible. So we would not get like if this is our aquifer thickness we go beyond this point.

So here flow is more or less still remains horizontal. So the effect on the drawdown or the discharge more or less is minimizes or it actually becomes nearly negligible.

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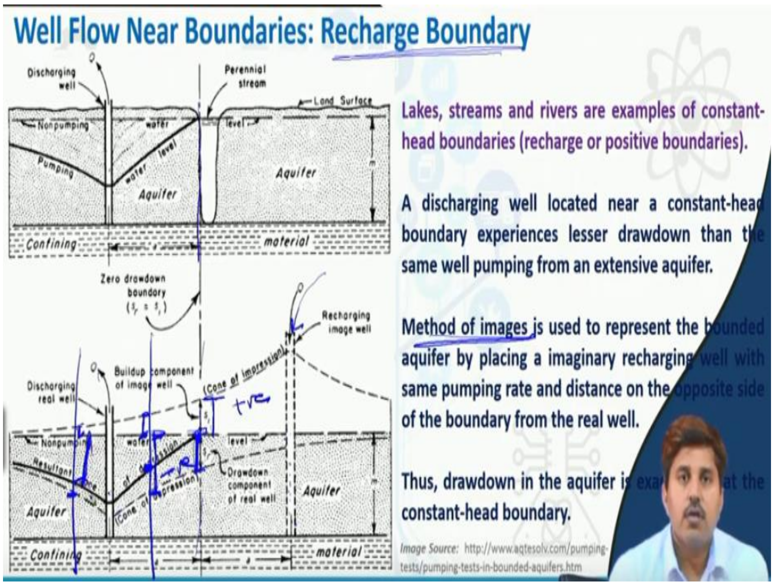

The other case is basically when the wells are near certain boundary. Now this boundary could be generally two type. One is the recharge boundary or what we typically call as the constant head boundary where the water level or head is fixed, while other is the barrier boundary, what we call no-flow boundary, okay. So in both the cases again we kind of go for superposition principle mainly.

Now what happens in case of the recharge boundary, so recharge boundaries are like lake, streams or river where basically the water level is fixed, okay. Now if you are operating a discharge well over here and beside there is a river or lake or water body with water level fixed. So of course you cannot get a water level as this, okay. Even if its original drawdown curve is like this you cannot get.

Because you know that this is saturated water body, so water level means at this point the drawdown has to be at the level of water or original water level, okay So at this point you have zero drawdown okay where the water body is there. Now if you are having a zero drawdown here, so that means your drawdown level is going to change, okay. Your drawdown level will actually be changed.

So instead of the original drawdown which typically for this well would be say like this would now be a**,** we will see a different drawdown curve. So in order to get the actual drawdown, how the drawdown will behave, we use method of images. Now this method of images say that we actually take a image well at the equal distance and equal pumping rate on the other side of the boundary.

So if let us say this is our point of boundary, okay and this is our actual well, the real discharge well, so we take an image of this well right at the other side of the boundary, this is imaginary actually okay. It is not actual well we are going to take, it is an imaginary well, but this is what we consider okay. So we take an actual, we take an imaginary well, and this imaginary well would be of recharge type, if it is a recharge boundary.

If it is a recharge boundary or basically constant boundary, this imaginary well has to be of recharge type. Now if we consider this, if we do not consider any water body over here and we consider this kind of long extended aquifer system. So our original cone of depression is say this shown in the dotted line here. This is our original cone of depression, okay.

Now we know that at this particular point, our drawdown has to be this much but it is actually zero. It is actually zero. So if at the same distance we take another recharge well with the same flow rate, but recharge not discharged. Here we are actually taking a discharge so this is leading to the kind of depression in the water table. But if we do a recharge, it is basically cone of impression that will be forming, state of cone of depression.

So and because it is at the same distance and rate is same, so ideally the amount of like the drawdown here would be basically covered by the same amount of impression over here so that the net drawdown at this point becomes zero. So drawdown at this point at basically the constant head boundary or recharge boundary would become zero.

So we have to have a recharge well, which is leading to the same amount of impression or same amount of positive head at this particular point, okay at the point where the head is constant so that this becomes zero. Now we have another well. It is not we have do not have to match only here. But once we know that okay we are having a well and which is having to, so we will actually form the cone of impression of this.

And as the principle of superimposition suggest we will add these two. So one is negative, this is a negative and this is a positive head. So we will add these two over the period of entire this thing and as a result like if you want to see at this point, so our actual drawdown means our ideal drawdown should be this much, but this much is covered by our recharge well.

So this will be subtracted and this we will get this point as our net drawdown okay. Similarly, if we want to take drawdown here, so our actual drawdown means a theoretical drawdown due to this well has to be here, but the recharge well will increase the head by this much. So as a result this will be subtracted and our actual drawdown will remain only this much, okay.

So this way we can actually kind of see the actual drawdown in such boundary cases, okay.

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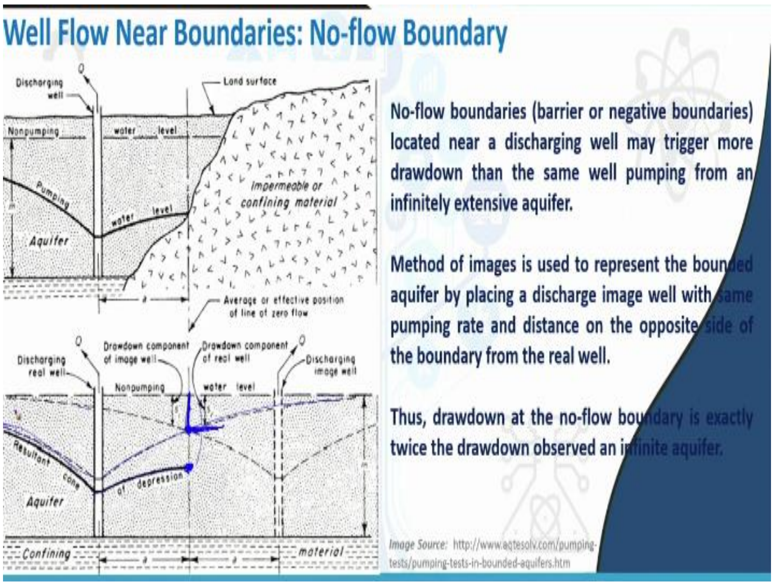

Similarly as we said we can have a no-flow boundary which is actually due to this is called barrier or negative boundaries which let us say there is impervious material. So there is no head. So of course, it cannot like water table or depression cannot go over here. So naturally in this cases if this is the it is ideal cone of depression, okay. But if there is a boundary here, which does, impermeable boundary here, which does not allow for any further depression over here.

It is actually impervious or confining material. So there is no way that our water can be extracted here and cone of depression can penetrate this. So in that case what will happen that this also serves as a boundary okay and serves as a no-flow boundary. So flow cannot actually go further at this point forwards.

Now what happens that this also is solved with the imaginary well system only but instead of having a recharge well as we had earlier we will, at the same distance we will have a discharge well, okay. And we will then it is kind of a two well system as we discussed earlier and then principle of superposition will be implied here. So if we are having say original if this is our original cone of depression, okay.

If this is our original line of drawdown and for the another well the discharge here, same discharge is happening at this point. So at this particular point, it is actually going to have the same drawdown okay and it will be extended further. So what happens at this no-flow boundary, the actual drawdown is the double of the theoretical drawdown that would have been had there not been any boundary.

So this is say your drawdown in case of no boundary. So actual drawdown will be double of this because there are two discharge wells. So both are causing this much so it will get double and we will get this point and for all other points it will be principle of superposition will be implied and we can get the resultant drawdown curve over here, okay.

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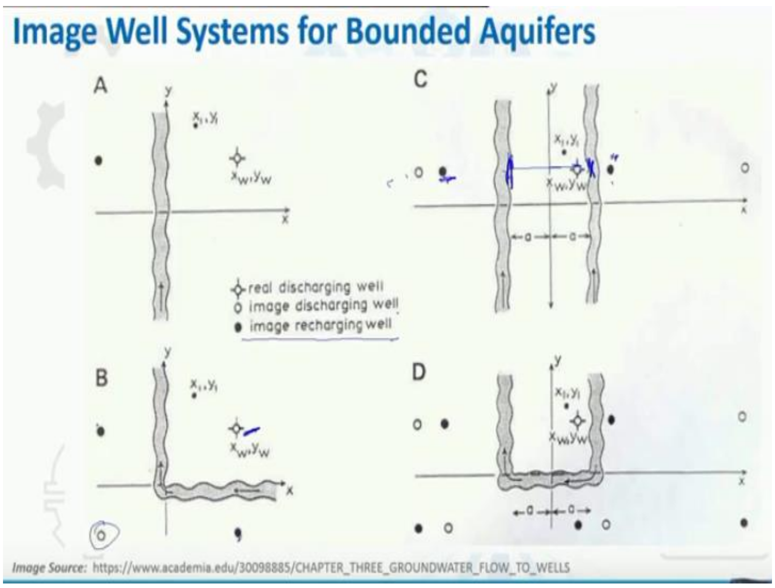

So this is how we kind of put imaginary well systems in order to get the real drawdown. So these were the simple cases when we have one well and one boundary, but we may have, we may have systems which are basically bounded by several system. So if we have that kind of aquifer let us say this is our recharge boundary, okay. Now this is our real well. Now, there is two side of the boundary okay.

We have two side boundary. Now for this we will have the dark one is the image recharging well and the hollow ones are image discharging well. So we will have a well here for this and we will have a well here for this okay. And because there is this kind of system, so we will have to have, again a image discharge well over here. If it is just one system, it will be here.

If there are two systems this is our actual this thing. So based on like this, this boundary head we will have a recharge well here. Based on this boundary head we will have a recharge well here, okay. But in order to counter this recharge well again we will have to have a discharge well for this as here and then discharge well for this as here. So similarly, if there are three boundaries, so we will actually have to have get to a system of the recharge and discharged wells.

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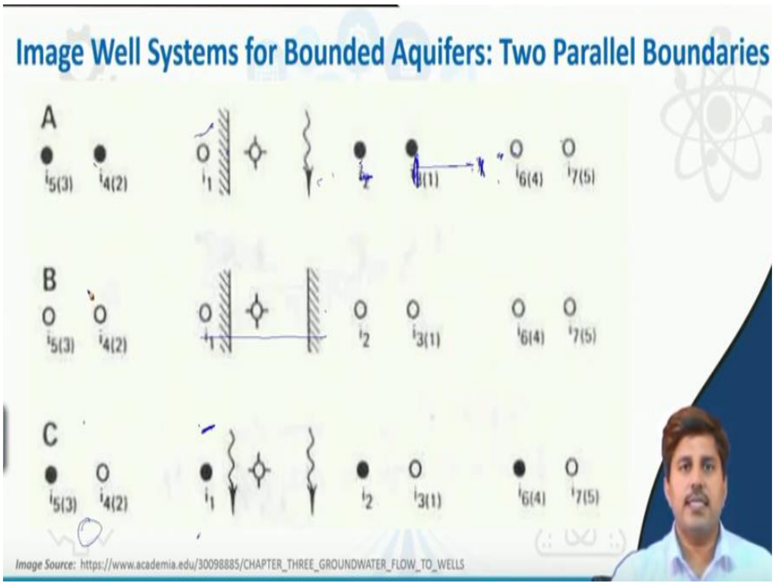

It is more like if there are parallel boundaries, so again like if you see this is your actual well, so for this no flow condition, for this no flow boundary we will have to have a discharge, imaginary discharge well here okay. And for this flow boundary or saturation boundary we will have to have an imaginary recharge well here, okay.

But this imaginary recharge well will actually be like compensated with another there is a boundary so there will be another recharge well and for this there will be another discharge well. So that we will have a series of system and we will have to kind of think of like we can actually get more number of such systems in line, but then since the effect of the as we prolong effect will be getting neglected.

So we will have to see how many well systems we want to see okay till the, that depends on the discharge also. So depending on the level of discharge and that way.

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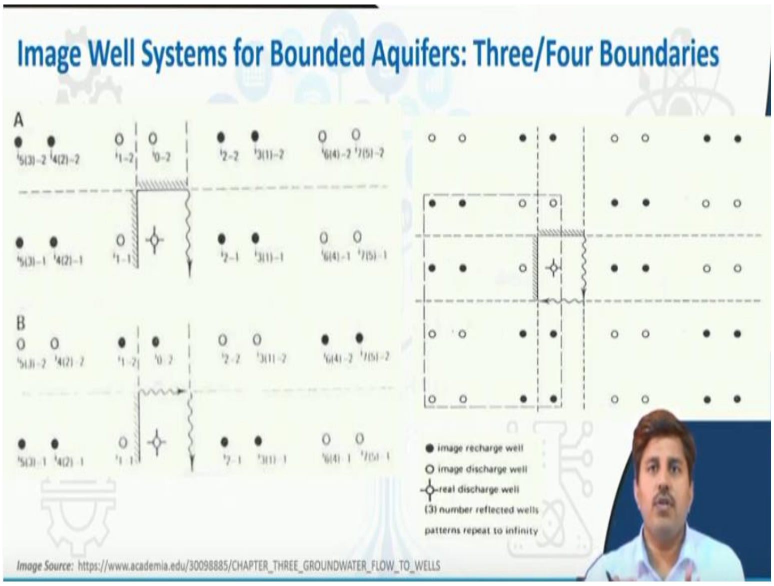

Similarly, we can have image well boundary systems for three to four boundaries okay, when more number of boundaries are there, so that is also possible. And remember that for a say this is a four number of boundary. So for just for one well, we may have so many image wells and this can actually further continue also because say this, now this will also have an effect on this boundary.

So there will be a corresponding well here. For this corresponding image well, there would be having another well here so we can get into a series of wells just for one well okay depending on what kind of boundaries it is encountering. But the concept is simple that in case of the, in case of the no-head means, in case of the constant head boundary, constant flow boundary discharge well will be imaged with a recharge well and a recharge well will be imaged with a discharge well correspondingly.

In case of the no-flow boundary, a discharge well will be imaged with a discharge well and a rechargeable will be imaged with a recharged well. So that is how we get a series of wells that way.

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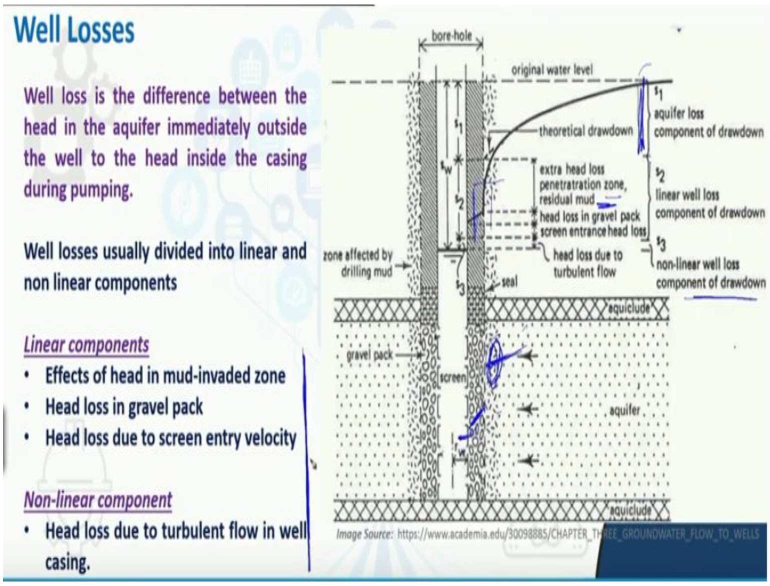

This is what we have been discussing so far what how basically we can get the drawdown and how effectively we can see the what kind of discharge can be taken out but the drawdown that we estimate is actually the drawdown which should be there theoretically, but what happens that when the like let us say this is our drawdown curve ideally it should come here.

But when we penetrate a well, when we basically penetrate a well like this, so there would be kind of some, there would be some muddy zone in the surrounding okay. So there would be extra head loss when the penetration, water penetration takes place with the residual mud. Because when we are actually doing a boring, we replace the soil and then there is a extra mud which will be collected across the well and this will lead to additional head loss when water penetrates through this zone.

So there will be a head loss related to that. Then there would be a gravel pack near the bed. So when water penetrates through that gravel pack, it is basically just head loss, the penetration takes place here. It is not that it will be actually penetrating for this, this is a concrete zone, okay. So these are concrete zone. Penetration actually takes place here but when water comes penetrating here in this muddy zone, there will be extra head loss due to that which is reflected here.

Then when it actually goes through this gravel pack okay, so then there would be additional head loss then it enters through the screen. So there would be basically screen entrance loss okay and when water flows through this, so it is basically a turbulent flow. So there would be head loss due to that.

So there is lot of additional head loss takes place which is generally not estimated when we just use the basic equations, okay, Theis or Thiem's equation for estimating the head loss or net drawdown. So well losses is essentially the difference between the head of the aquifer immediately outside and in the well a head inside because of all these losses.

And as we said that there are different components and some of these components are linear and particularly the turbulent flow one is actually nonlinear. So overall drawdown if you see so there is a drawdown due to aquifer loss component, the standard equations which predict.

Then there is a linear well loss component which is due to the, due to basically interaction through the residual mud, due to interaction through the entering through the gravel pack, due to entering through the screen and then there is a nonlinear well loss component which is actually due to the turbulent flow in the well casing okay. So these are the different components of the well losses and that is what leads to the extra drawdown in case of the well.

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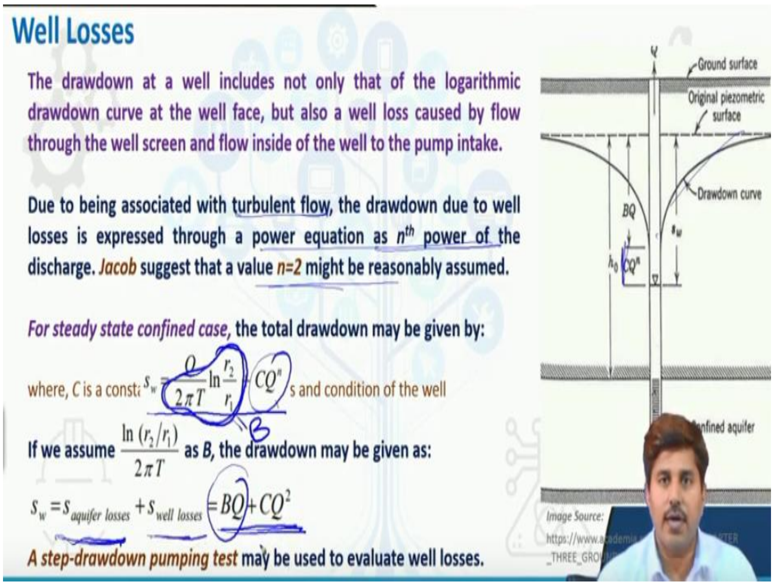

So drawdown at any well will then include not only the logarithmic drawdown which is typically determined okay. So this is the standard drawdown as you see. Apart from this there would be additional component for drawdown in the form of well losses. So for steady state confined case typically as we see that drawdown is this and then there would be additional component CQ to the power n.

Now it is considered a power equation because of the nonlinear nature of the losses, okay. It is the turbulent flow. So that is that is why we express this as a power equation with nth power. And Jacob has suggested that n might be taken as 2 as a reasonable assumption okay. So if we assume this is what the question we get and if we assume this term say as B so then our equation turns S w = BQ + CQ square.

Now your BQ is the aquifer loss component which is usually we get from the drawdown equation and CQ is the well loss, CQ square in fact or CQ to the power n is the well losses component okay and a simple step drawdown test might be useful in order to determine this well losses component.

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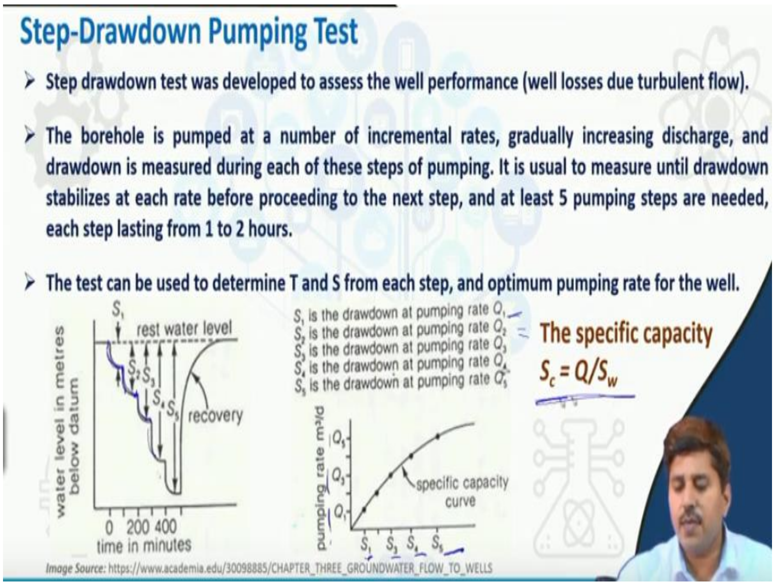

So the step-drawdown test is actually usually developed for the well performance which is well loss and well efficiency, okay. So what happens that the bore well is pumped and number of incremental rate, typically more than five discharge rates are taken. So what happens that initially we will start discharge at certain rate and then once the drawdown stabilizes over here we change the discharge, we increase the discharge.

So again, we will get a new drawdown, as it gets stabilizes we will change the discharge. So step means we actually keep on increasing the discharge in various steps and noting the drawdown for that. Typically the drawdown means we should continue the it for one to two hours each step so that the drawdown gets stabilized.

Ideally in practice, it may not reach a stable but when the like the reduction in the drawdown becomes very less okay, less than a meter say per in a hour or so. So then we can actually consider it to be quite stable and that drawdown is noted. So what we will get, we will get basically the different drawdowns at different discharge levels, okay. And then we can determine the specific capacity which is the ratio of the discharge to the drawdown at each step, okay.

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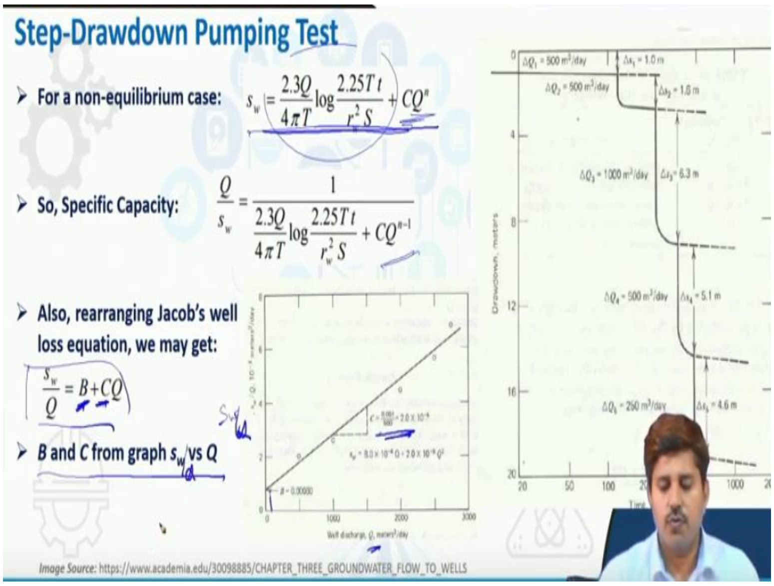

And we have to see kind of that whether the specific capacity becomes constant or not, okay. So for a non equilibrium case for example, okay this is what is the typical equation. This is the traditional equation and then this is the well loss component. So specific capacity can be determined if we divide it basically, if we divide Q by S w. So this is what we get the specific capacity.

For determination of well losses, remember our well loss equation S w = B q + CQ square. So if we divide it with the Q, so what we get this kind of equation. Now, if we plot S w by Q versus Q, so then we get a linear equation and slope of this will be C and the intercept will be B okay because then it becomes a equation y is equal to mx + C form and this becomes the intercept and C becomes the slope.

So using a step-drawdown test that way we can get the B and C from the graph of the S w by Q versus Q, okay. So that is how we can actually estimate the well losses.

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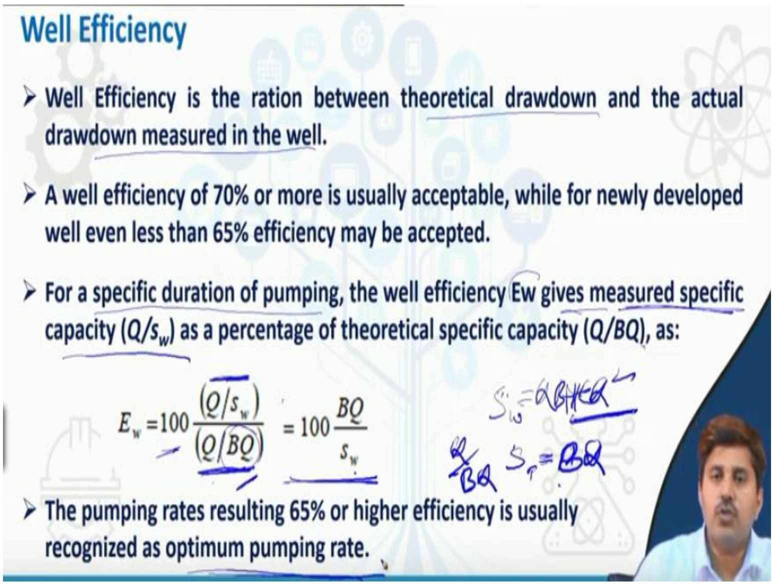

Then another aspect of well is actually well efficiency. Now well efficiency is the ratio between the theoretical drawdown and the actual drawdown that is measured in the well okay.

Normally, as we define the efficiency for a specific duration of pumping the well efficiency which is E w is actually measured the specific capacity as a percentage of means, the measured specific capacity whatever is specific capacity we are able to determine, that is basically Q/S w is our measured specific capacity as a percentage of theoretical specific capacity which is Q/BQ, okay.

So remember our typical equation is of drawdown okay is Q into B + CQ square okay. So from here we get Q/BQ is actually our, so if that is the discharge and this is the like the drawdown if we exclude the well losses, okay. If we ignore the well losses then our theoretical drawdown becomes equal to BQ okay because CQ square is the well loss component, okay. So this is our theoretical drawdown.

And the specific capacity as we know is discharge by drawdown. So discharge is Q and if you divide Q by S the theoretical drawdown BQ. So Q/BQ becomes our theoretical drawdown, theoretical specific capacity and actual capacity which is S w is actually equal to BQ + CQ square. So it is Q/BQ + CQ square or Q/S w is the actual capacity. So if we solve this, it is because it is in a percentage.

So we multiply it with 100. And if we solve this we get 100 BQ/S w where BQ as we said is actually the theoretical drawdown versus the actual drawdown, means versus the real drawdown, okay. So that is how well efficiency is represented. It is a ratio of the theoretical drawdown to that of the actual drawdown measured in the well okay. If well efficiency is 70% or more, we usually accept it.

If it is less than 65% or 70% we often consider that well to be inefficient. However, for newly developed well, even a 65% efficiency may be accepted. There is general thumb rule that basically if the efficiency resulting 65% or higher usually 70% of higher, we consider that as optimum pumping. rate. So we should pump the well at that rate where the efficiency is good for the well purpose, okay.

So these are the points what we need to consider when we go for the groundwater withdrawal okay. Of course, the further detail can be available are actually available in any groundwater hydrology or groundwater hydraulic books, okay; so can be studied. We will close the discussion on to the groundwater abstraction here. And in next class, then we will be talking about the conveyance system.

So how basically, pumps and conveyance systems are used to transfer the water from the abstraction point whether it is groundwater abstraction or surface water abstraction to the treatment point. So see you in the next class. Thank you for joining.