Water Supply Engineering
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Lecture - 17
Practice Problems

Hello friends and welcome. So this week we have already had six lectures and we did talk about various aspects related to the sources of water, how we select sources for water supply systems. Then we did talk about the surface water and groundwater intake systems. So what are the different surface water intake systems and how we abstract groundwater using well.

We did talk about the hydraulics of well and pumping tests as well. And in the last class, we talked about the conveyance systems and what are the different type of free flow and gravity conduits which are used for the conveying water and what are the pumps that are that typically helps in the providing energy and head for pumping waters. So this is the last lecture for this week. And we will be taking some practice problems in this week.

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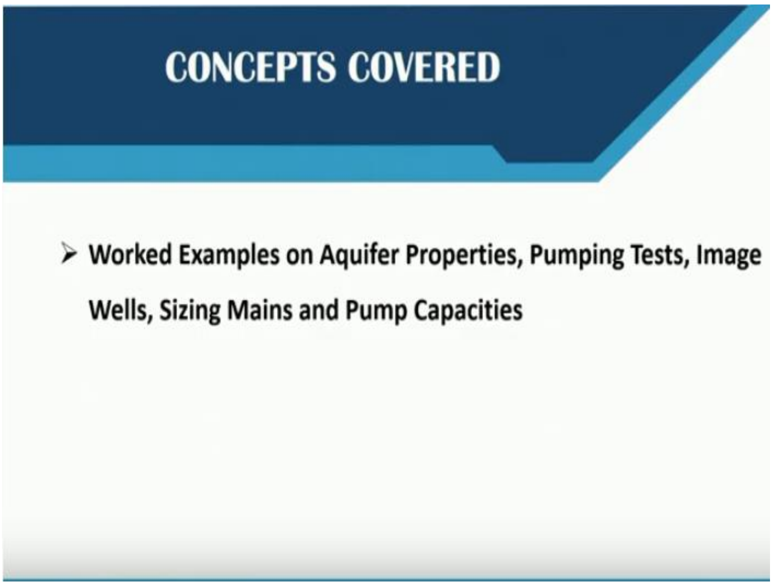

So we will see how basically some worked examples related to the aquifer properties, then pumping tests, image wells, sizing mains and how we determine pump capacity. So the some of the discussions that we had earlier in this week, we will see them through the worked examples.

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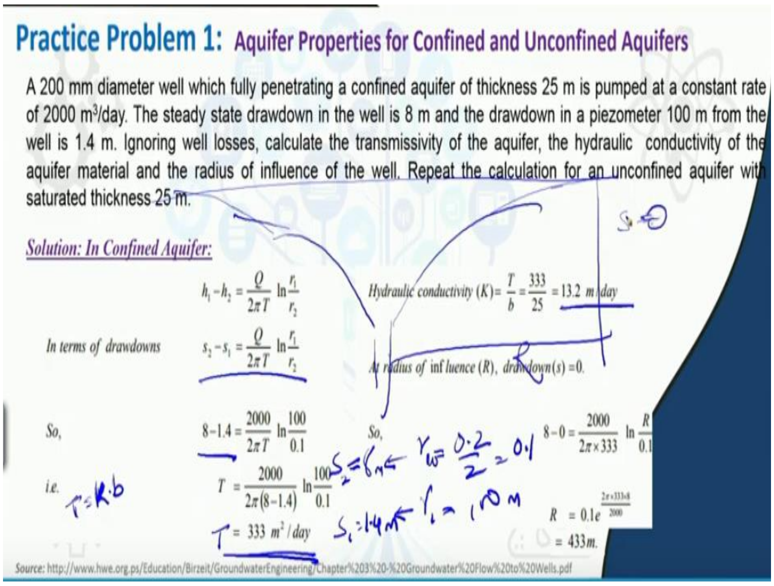

So first problem that we are going to discuss is on aquifer properties for confined and unconfined aquifer. So these are basically simple problems, say the 200 mm diameter well, which is fully penetrating and confined aquifer of thickness 25 meter is pumped at a constant rate of 2000 meter cube per day. The steady state drawdown in the well is 8 meter and the drawdown in the piezometer is 100 meter from the well which is 1.5 meter.

Ignoring the well losses, we have to calculate the transmissivity of the aquifer and hydraulic conductivity of the aquifer material and the radius of influence of the well and we have to show that for the case of unconfined aquifer with saturated thickness of 25 meters. So we have two cases here, one of confined aquifer and one of unconfined aquifer.

So as we discussed okay this is the typical equation used for confined aquifers, okay. The head h 1 – h 2 is Q by 2 pi T ln r 1 upon r 2. This is the same equation which we earlier saw in the lecture and if we make in terms of drawdown so as you know that if say this is your influence. So the drawdown is if this is the original head, so drawdown is this and actual head is this okay.

So if this is the initial head which is say h and at any point the current h and drawdown is S. So we know that S = H – h. Or similarly, h is equal to small h is equal to net head or earlier head minus drawdown. So instead of h 1 we can use h – s 1 and h 2 we can use H – s 2. So this h 1 – h 2 will become s 2 – s 1 okay because h 1 we can write as h 1 – s 1 and so let us say we trying to estimate h 1 – h 2 here, h 1 – h 2 will become H 1 – s 1 minus not H 1 this is the capital H.

So minus again H – s 2. So if we solve this H will get cancelled, this will become negative and this negative, negative will become positive. So it is actually s 2 – s 1. So that way we can see that s 2 – s 1 is Q by 2 pi T, where T is the transmissivity and T is equal to as we know is basically hydraulic conductivity into the aquifer thickness, okay ln r 2 by r 2. Now, we have all the data available here, okay.

So we can say that the diameter of well is 200 mm is given to us, okay. So if we consider the first means here, what we can consider is that, let us say if we say that r 1 is actually the real well here okay. So in the real well it says that the drawdown the steady state drawdown in well is 8 meter okay. So then and the drawdown in the piezometer 100 meter from the well is 1.4 meter.

So we have two values okay. One is 8 meter which is actually in the real well. So for that we have to take the diameter of well itself okay or radius of well. So diameter is 200 mm is 0.2 meter, so 0.2 by 2 so that will become 0.1 meter okay. And then if we say that the other well which is 100 meter, so r 1 becomes 100 meter. Now the drawdown in the real well which is corresponds to r 2 now.

So s 2 is actually how much? Drawdown in the real well is 8 meter and drawdown in this well is 1.4 meter. So now we can write 8 – 1.4, the discharge is 2000 meter cube per day 2 pi T ln 100 by 0.1 and this gives the, because everything is known here. So this gives us the value of transmissivity as 333 meter square per day.

The hydraulic conductivity will be transmissivity divided by aquifer thickness which is 25 meter thickness of aquifer. So 13.2 meter per day becomes the hydraulic conductivity and the radius of influence, so radius of influence will be as we know that generally the radius when you pump a well radius of influence is the point till which you see the effect of drawdown.

So at the end of the radius of influence distance if let us say this distance is R so we will get the drawdown is zero here okay. So we take the drawdown zero for areas of influence and what we get is 8 - 0 this and then we can determine R from here. Now, we know the transmissivity. So R will be 433 meters. So these are the three values for the case of confined aquifer.

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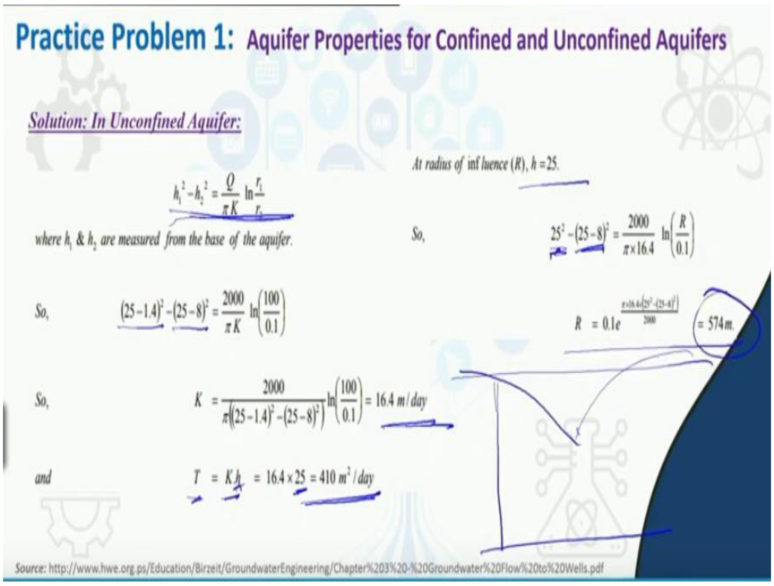

Now if we take unconfined aquifer again we can use the unconfined aquifer equation here okay. This is the typical unconfined aquifer equation. Now h 1 is 25 – 1.4 square, h 2 is 25 – 8 square 200 K ln and from here we can get the value of K. Transmissivity is K times B in unconfined aquifer. In confined aquifer we have a fixed aquifer thickness whereas in case of unconfined aquifer we do not have as such any fixed aquifer thickness.

So what we do take is the water table depth okay. So if say this is unconfined aquifer so this becomes water table depth as the thickness of the aquifer. So initial water table depth, whatever it is we will take that as this thing and we can determine the transmissivity okay. Similarly, we can determine the radius of influence okay. So when there is no drawdown means h value is 25 okay.

So it becomes 25 square means zero drawdown minus 25 minus 80 square and from here we can determine the value of R. So that way we can determine the aquifer properties.

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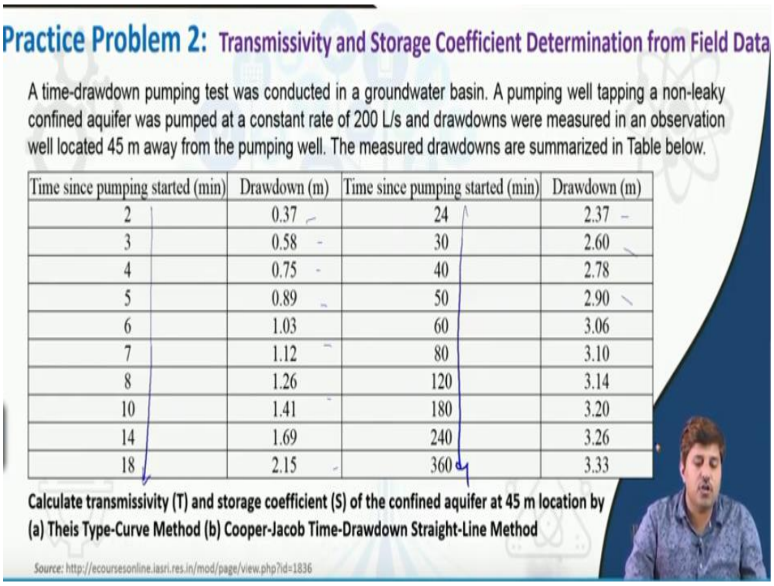

Time since pumping started (min)	Drawdown (m)	Time since pumping started (min)	Drawdown (m)
2	0.37	24	2.37
3	0.58	30	2.60
4	0.75	40	2.78
5	0.89	50	2.90
6	1.03	60	3.06
7	1.12	80	3.10
8	1.26	120	3.14
10	1.41	180	3.20
14	1.69	240	3.26
18	2.15	360	3.33

The second problem that we are going to discuss is on transmissivity and storage coefficient determination and we will be using some field pumping test for this. So the problem is given is that let us say a time drawdown pumping test which was conducted in a groundwater basin. The pumping well taps are non-leaky confined aquifer.

It was pumped at a constant rate of 200 litre per second and drawdown was measured in the observation well located 45 meter away from the pumping well. The measured drawdowns are given here. So what we have at hand is the data. So at different times, minutes as this is in the minutes and this is the basically drawdown data that we have at different minutes.

Now we need to calculate the transmissivity and storage coefficient of this confined aquifer at 45 meter location and we are let us solve this using the Theis type-curve method and Cooper-Jacob time-drawdown the straight-line method, okay. So we are having at hand is the pumping test data okay, which is time versus drawdown data that we have.

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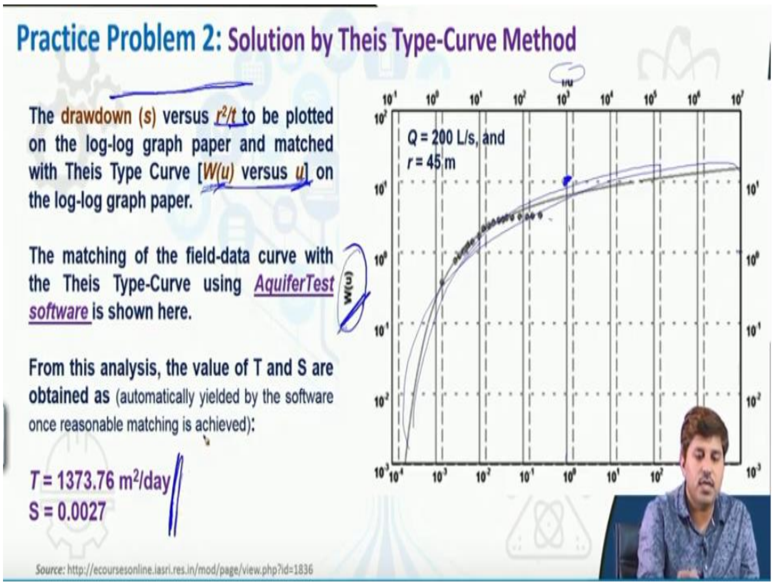

So for the Theis curve type method we know that we have standard well function curve, so 1 by u versus u W, W(u) curve we already have that and we can plot the drawdown versus r square by t curve, okay. Remember we know the drawdown, we know the r square, the distance at which the observation well is there that is r and t we know. So we can plot r square by t versus drawdown okay.

And both is to be plotted on log-log graph paper. And then as we have to match these points, okay, the points which are there, see these discrete points we have for drawdown versus r square t curve. And the smooth curve that we have is actually a well function curve which we will get W(u) versus u. So we have to adjust these curves so that these points match this exact well function curve, okay.

And when this matches then we can take a corresponding point generally one, one point is taken, okay. So let us say we take the value of 1 by u as 1 and value of this also as 1. So this is 10 to the power 0 means 1 okay. So 10 to the power 0 here 10 to the power 0 is 1.

So we can take this as a one, one value and correspondingly we can determine W(u) value and this so from W(u) value, we can actually determine the other properties okay as we discussed earlier. This can be done using a typical software also, so aquifer test software results are shown here and from this analysis software will automatically match.

And as you know that W(u) and like when you get the value of u and W(u) corresponding value of u and W(u) so we can actually get the transmissivity and storage coefficient and transmitting and storage coefficient might be yielded directly from the software as shown here.

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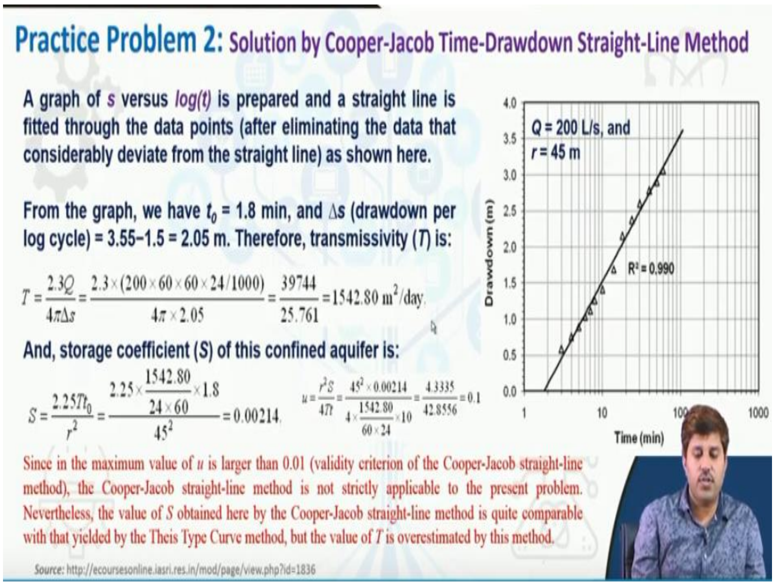

The same problem can be solved using Cooper-Jacob time-drawdown straight-line method as well. So for this we can actually plot the time versus drawdown. Now time is typically plotted on log scale. So we will have log t versus drawdown s and we will expect to get a straight line. So we will get a straight line okay remember r is 45 here and Q is 200 litres per second, okay.

So from this graph, we see that where it is intersecting, okay. So that becomes t 0 and the drawdown will be actually the slope of this graph, okay, per log cycle. So per log cycle slope means from here to here, this is one log cycle okay or this is one log, it cannot come here actually. So 10 to 100 this is one log cycle. So the slope is the basically this difference here okay.

So this is the difference which will be giving you the slope. So it is 1.5 and this is something 3.55 say. So 3.55 - 1.5 2.05 meters becomes delta s. Now transmissivity can be determined as 2.3 Q 4 pi delta s. So this will give us the value of transmissivity and storage coefficient is 2.25 Tt naught by r square and this will give us the value of the storage coefficient okay.

We can determine u also from this one which is coming as 0.1. Now as when we were discussing earlier we did saw that typically the Cooper-Jacob drawdown straight-line method is applicable for the u values like smaller than 0.01 So since here u value is larger than 0.01 so ideally this cannot be directly implemented. However, still we see that the s value obtained here is pretty much same or very close.

Like here S was 0.0027 using the standard time type curve method and here S value is 0.002 around 14, so this is also similar. Whereas, if you see the transmissivity value, so transmissivity value is 1373 here and here 1542. So there is substantial difference in transmissivity which is overestimated by this method, okay.

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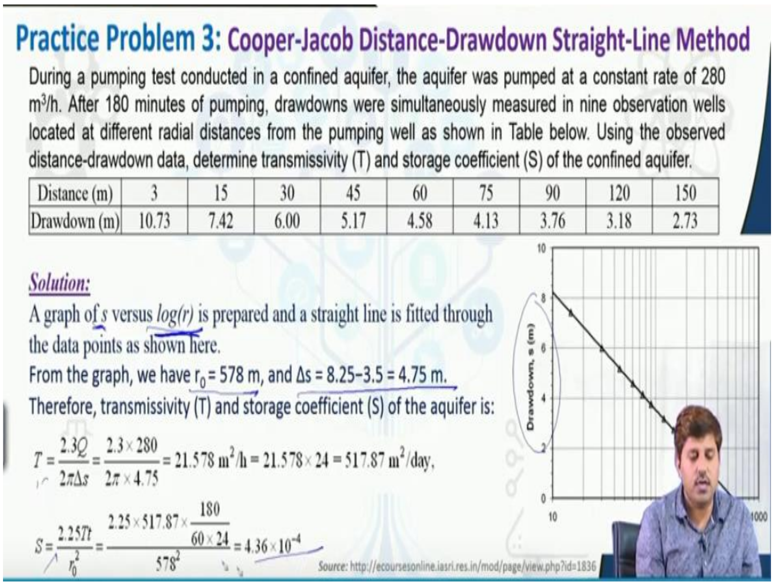

Similarly, we can see another problem which is the distance drawdown straight-line method for Cooper-Jacob, okay. So time-drawdown we just saw and same way, same approach we can use for distance drawdown. So if we let us say we have a pumping data of distance and drawdown, we can similar way plot a graph between distance and drawdown.

So in time-drawdown we have one well and pump at different times whereas in distance drawdown method, we have different wells and basically note the drawdown at the same time. So here time is constant okay and the distance is varying and as per distance the drawdown is also varying. So same way we can also plot here as drawdown versus log r. So r is on a distance curve.

And in a similar way we can note down the r 0 and delta s and use the transmissivity and storage coefficient determination using a standard method.

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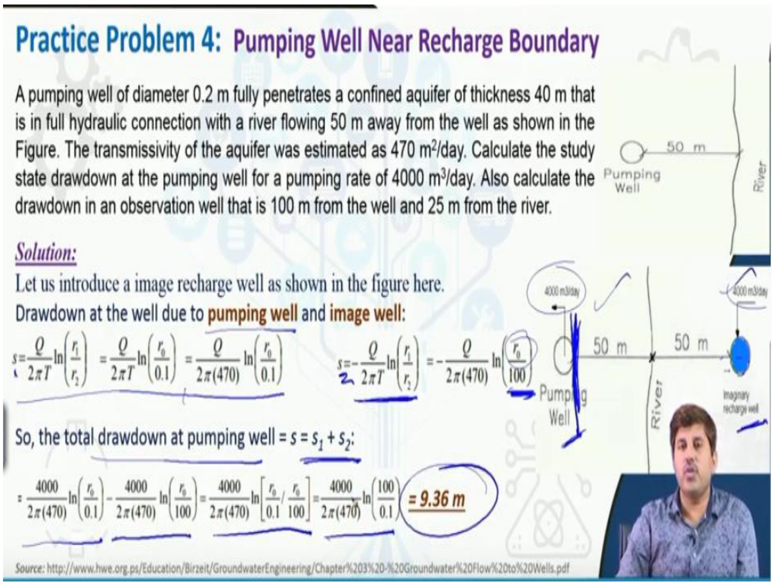

So this is another problem which is of pumping well near a recharge boundary. So we did discuss the boundary problems as well in earlier class. So it says that there is a pumping well of diameter 0.2 meter which fully penetrates a confined aquifer of thickness 40 meter, okay. So the aquifer thickness is given and it is in a full hydraulic connection with a river which is 50 meters away.

So here we have a pumping well and we have a river which is 50 meters away from this pumping well, okay. Now, the transmissivity of aquifer is given to us 470 meter square per day and we have to calculate the steady state drawdown in an observation well that is in the well itself, pumping well itself and in observation well which is 100 meters from the well and 25 meters from the river. So first information let us say consider only in the well itself, okay.

So again, it is a confined aquifer case. So this is the standard equation, drawdown equation okay. So here we know that like r 1 is r 0 itself okay and which is equal to the well radius. So the well diameter is 0.2. So well radius we can take as 0.1 okay and so that is 0.1 and r 0 we do not have observation from two wells here, we have just observation in the well itself.

So consider another well, consider or let us say let us say this is our well, okay. So typically what will what we will see that if this is the initial piezometric head, we will see a drawdown ideally like this, okay. So consider a point where the drawdown is not there r 0 okay. Or the head is equal to so say this is the radius of influence r 0 or r whatever you call that. So if it is r 0 so r 0 and then the another well is the well itself.

So that is the radius of the well is will be taken. So 0.2 is the dia as we took in earlier problem. So r 2 becomes 0.1 and r 0 becomes zero over here means and value some value we do not know as of now, okay. So this is in the case of pumping well, okay standard pumping well.

But now because we have a river flowing and the well is in hydraulic connection of the rivers, so as we discussed earlier, that these kind of cases are considered, we have to put a imaginary recharge well because it is a recharge boundary. If it is a discharge, if it is a like impervious boundary then or no flow boundary, then we will have to use a imaginary discharge well.

But since it is a recharge boundary, so we will use a imaginary recharge well, exactly opposite direction and same distance over here. So we have one pumping well here and one imaginary recharge well here. The flow in both these will be taken same and drawdown at any point will be resulted from the sum of the drawdown of these two wells okay.

So we have a pumping well and as we saw the drawdown due to pumping well is going to this much and we have a imaginary recharge well. Now, if we consider this onto the well surface itself, so distance from here is 100 meters okay. So the drawdown here which is going to be negative because it is a recharge well okay so there is no drawdown as such it will actually replenish it. But the same formula will be applied okay.

This also we do not know so we consider the r 0 is say the point where there is no influence of that okay, that is going to remain the same because discharge is same from both the wells and r 2 will actually become hundred when we are considering this point for analysis okay in the because first point of analysis or well itself. So this is 100. Now, we can consider this as s 1 or this as s 2 and the total drawdown in the pumping well will be actually s 1 + s 2. So this is s 1 and s 2 is negative.

So this is s 2 and we can solve this; r 0 will get cancelled and what we will get total drawdown as 9.36 meter, okay. So that is how we can use this concept. Now the other part say is also calculate a drawdown in a observation well which is 100 meter from the well and 25 meter from the river.

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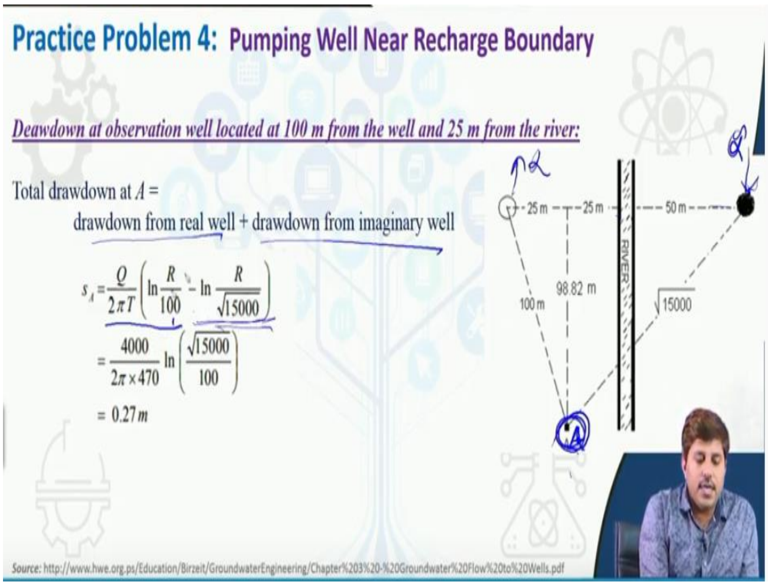

So such a well if this is our river and this is say our discharge well, okay with a flow rate of Q. This is our imaginary recharge well, without again flow rate of Q with the recharge. And we have to have an observation well which is hundred meter from the well and 25 meter from the river. So 25 meter from the river means somewhere here and then you can have a 100 meter from river.

So let us say this becomes our point of interest where we have an observation well A. So drawdown at A will be drawdown from real well plus drawdown from the imaginary well okay. Again similar way Q by 2 pi T ln R by 100 minus ln R by square this distance, okay. So if this is 100, this distance is 50, this is 25. So this is eventually going to be more than that, okay. And that way we can see this.

So again r will get canceled, and we will get drawdown as 0.27 meter in the observation well, okay.

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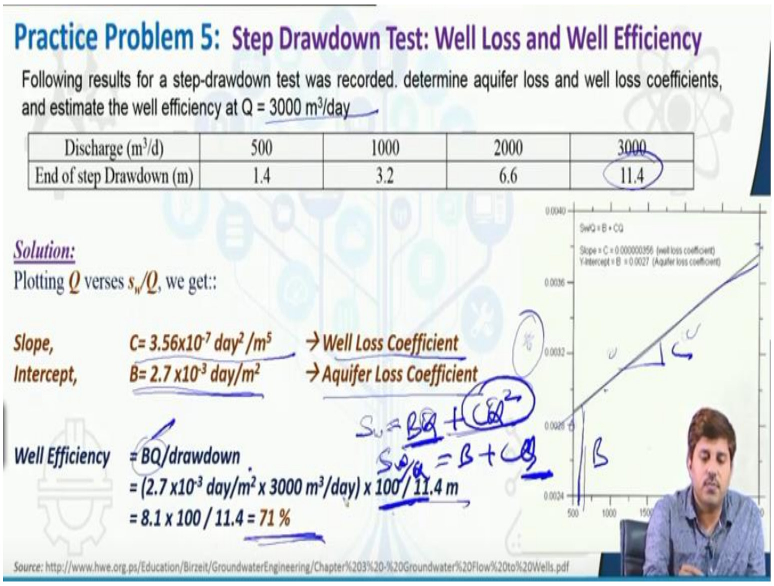

This is another problem or example of step drawdown test which talks about well loss coefficient and well loss efficiency. So it says that the step drawdown test was recorded and aquifer loss and well loss coefficients needs to be determined for the overall and we need to estimate the overall well efficiency at Q is equal to 3000 meter cube per day.

So flow is given to us 3000 meter cube per day and we have as we get in a step drawdown test. So remember step drawdown test will be basically we will be having discharge here and then at the same we will keep on noting the drawdown. When the drawdown stabilizes okay we actually change the discharge. So we get at a different discharge values, okay.

So we get at different discharge values, the drawdown okay and step of the drawdown. So for determining the aquifer loss coefficient and well loss coefficient as discussed earlier, we can use s w by Q, okay. So s w by Q and Q we can plot Q versus s w by Q, and we will get some data points and then we can fit the best fit straight line over here.

The slope of this line okay, will give us the well loss coefficient which is say in this case 3.56 into 10 to the power – 7 and intercept of this line will give us the aquifer loss coefficient. So this way we can get the well loss coefficient and aquifer loss coefficient. The well efficiency as we discussed is the ratio of the theoretical drawdown to real drawdown okay.

So theoretical drawdown is BQ when we ignore the loss coefficient, okay we know that drawdown is typically given as BQ + CQ square okay s w. So this is what is actually the reason for straight line. So if we get s w by Q is equal to B + CQ. And that is why when we fit Q versus s w by Q okay, when we fit Q versus s w by Q, we get a straight line with intercept as B and slope as C, okay.

So this way we get the well loss coefficient and aquifer loss coefficient. Now this is due to well losses and if there is no well loss so theoretical ideally ideal drawdown or theoretical drawdown is BQ. So we take the ratio of BQ versus real drawdown and we have to determine at 3000 meter cube per day so real drawdown is 11.4.

We know B from here so B into this and into 100 divided by 11.4 will give us in a percentage which is coming as 71%. And 71% means the well is performing okay.

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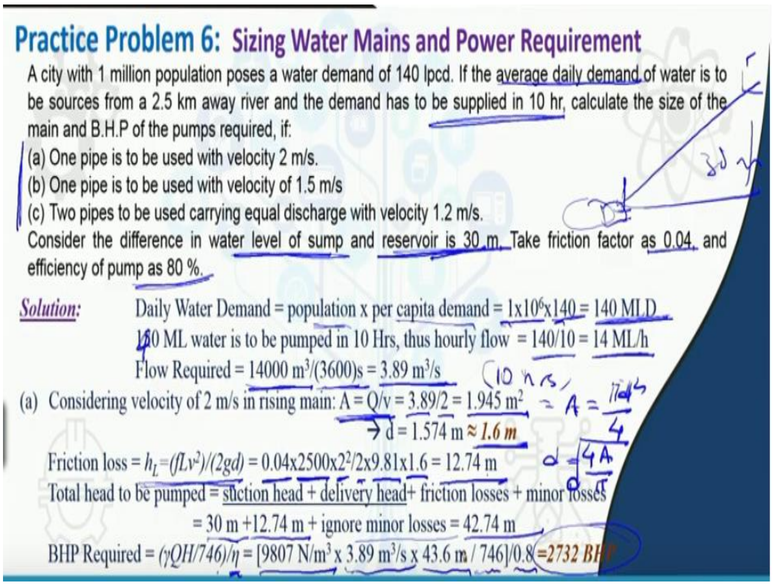

Because efficiency greater than that 70% or greater than 65% is considered fairly good, okay. So this is the another problem which is on sizing water mains and estimating the power requirement okay. So a city with 1 million population say posing a water demand of 140 lpcd.

If the average daily demand of water is to be sourced from a 2.5 kilometer away river and the demand has to be supplied in 10 hours, we need to calculate the size of the main and BHP of the pumps required for these three different cases okay. We can consider the difference in the water level and sump of the reservoir as 30 meter and friction factor 0.04 and pump efficiency as 80%.

So this problem suggest that we have to lay down a rising main okay and the relevant data is provided. The three options that we have to explore is one pipe and using a velocity of two meter per second which is generally a little on higher side as we discussed that velocity in rising main is better in range of 1 to 1.5. Then we can use one pipe with the velocity range of 1.5 meter per second, velocity of 1.5 meter per second.

And the other option is given instead of one we go for two pipe and which has carrying equal discharge and velocity we can keep as 1.2 meter per second. So these are the three cases that we have to explore here okay. Now the population of the city is 1 million that means 10 to the power 6 number of people okay. And per capita demand is 140 litres per capita per day.

So the daily water demand will be the population multiplied by per capita demand. So 1 into 10 to the power 6 into 140, which is 140 into 10 to the power 6 litres per day or we can say 140 million litres per day. 140 MLD is the average water requirement okay. This 140 MLD water is to be pumped in 10 hours okay. Thus the hourly flow is going to be 140 divided by 10 which is 14 million litres per hour right.

Here it is interesting to note that we have to basically design it for average daily demand okay. If we are designing and nothing is given so as a designer we may consider actually designing for the maximum daily demand usually, okay because intake might intake should be designed for maximum daily demand, but again that depends on the working hours and those things.

So maximum daily demand we have to take a peaking factor of around 1.8 okay. So that way we can use a different instead of 140 we have to multiply 140 with 1.8 in order to get the maximum daily demand and we can design intake for that, but here since our intake is actually functional at 10 hours only. So that means, even if the demand is higher, we can operate it for more number of hours instead of designing of the bigger capacity.

So we can still keep the system for the similar capacity and operate it for more number of hours or longer durations if the demand increases. So that way, there is also a possibility that we design for average daily demand which is the average amount of water to be abstracted in a day and we are designing for 10 hours operation. In case demand is higher, we can increase the hours of operation.

All right, so 14 million litres per hour is the flow rate or 14 million litres means 14,000 meter cube and one hour means 3600 seconds. So in meter cube per second we get 3.89 meter cube per second as the discharge which is needed for a 10 hour operation, okay. Remember this is for 10 our operation, okay. So now, let us take these cases one by one.

So first case is, we consider a velocity of 2 meter per second in a rising main and design just one pipe. So we know the discharge. So area of the pipe is going to be the discharge divided by the velocity. So 3.89 divided by 2, 1.945 meter square and this is equal going to be equal to like this is area that will be equal to pi d square by 4 okay. So the dia of pipe we can estimate from here as four times area divided by pi and the square root of this.

So the dia comes as 1.6 meter here, okay. So that is one information that our size of the rising main should be 1.6 meter dia. Then the frictional losses in the pipe h L is fLv square by 2gd. We are using here this equation because friction factor is given to us. So generally friction factor is used in the Darcy-Weisbach equation and that is why we can use this equation where head loss is fLv square by 2gd.

Friction factor is given 0.04, L is 2.5 kilometer that is 2500 meters, velocity is 2, so square of 2 by 2, 9.81 g and dia of the pipe is 1.6. So this gives 12.74 meter as the total frictional losses. Now head to be pumped as we discussed pump needs to provide head for suction purpose, delivery purpose and should be covering the losses of head in the pipe.

So losses are fictional losses, which is also known as major loss and then there are minor loss due to bends and other things. Minor losses are generally small and can be ignored particularly if no information is given about that. So here we can ignore the minor losses. The suction head plus delivery head is given to us like consider the difference in water level of sump and reservoir.

So this includes both because if this is say our sump from where water is being pumped, and our reservoir is located somewhere here. So the net difference is given to us 30 meter okay. So suction head plus delivery head is 30 meters. The frictional losses we estimated 12.74 meter. We can ignore minor losses and this gives us a total 42.74 meter head to be covered.

Now the power required for that in horsepower is gamma QH by 746 and BHP required if we further divide that by efficiency of the pump which is 80%. So we can divide that by 0.8. Gamma is 9807 Newton per meter cube. Discharge is known to us 3.89 and head is known to us. We divide it with 746 and further divide it with the pump efficiency and we get 2732 brake horsepower, which is actually needed for this problem.

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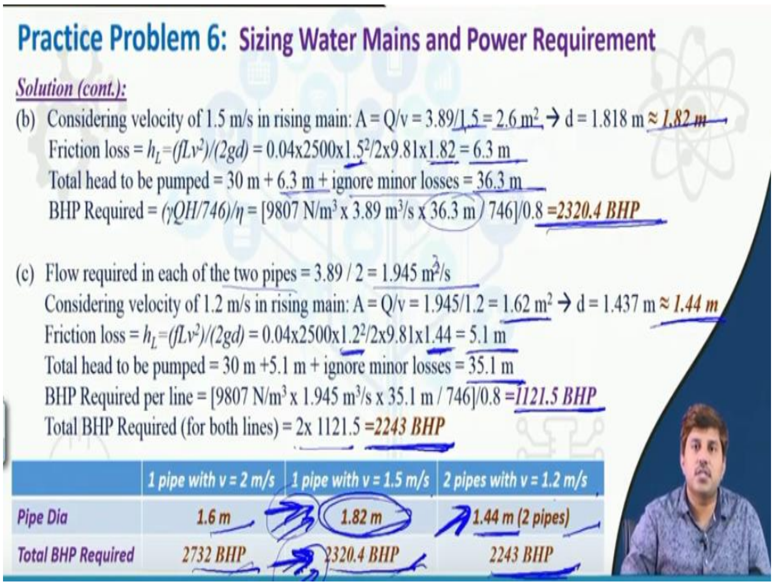

Let us go to the second case. Second case is when we consider velocity of 1.5 meter in rising main, other thing remain same. So area will become 3.89 divided by 1.5. So this will be 2.6 meter square. This will result in dia of 1.82 meter square. Frictional losses similarly, we have everything and instead of square of 2 which was the velocity earlier we will take 1.5 square and the dia of the pipe 1.82.

So this will give us 6.3 meter of the frictional loss head and total head is 30 meter plus 6.3 meter we can ignore minor losses, this will be 36.3 meter. The BHP required will actually be 2320.4 BHP as we estimated earlier, okay keeping the because gamma Q is going to remain the same only h is different here. In the third case when instead of one pipe we are using two pipes with equal discharge.

So the discharge in each of the two pipe is going to be 194 meter cube per second, okay. Now considering the velocity of 1.2 meter per second in rising main we get the area as 1.62 meter square which translates to the pipe dia of 1.44 meter okay. The frictional losses again same way we can estimate instead of v we are using 1.2 meter here and the dia is 1.44.

So 5.1 meter is the total losses and then the total 30 meter is the head and 5.1 meter is to be covered, so 35.1 meter. The BHP required would be 1121.5 brake horsepower for each pipe and we are having two pipes here. So the total BHP required for both the lines would be twice of this number which is 2243 brake horsepower, so if we are using two lines okay.

So as a summary if we see, we had three cases. One is one pipe with velocity 2 meter per second another is one pipe with velocity 1.5 meter per second and another is two pipe with velocity 1.2 meter per second. This is the pipe dia 1.6 meter, 1.82 meter here, 1.44 meter here and this is the total BHP required. Now this results are interesting in a way that you can actually observe what kind of effect happens when you change the velocity or in a rising main.

So let us say one pipe case. So when we are actually having 2 meter per second velocity versus 1.5 meter per second velocity, the dia of the pipe required in case of 1.5 is 1.82 meters, which is more than 1.6 meter. So a larger pipe would be needed okay more going to be the like land acquisition is going to be more, installation cost is going to be more, capital investment is going to increase here okay when we go for a larger dia pipe.

So this will require more of the capital expenditure installation cost, but if you see the operation cost or the power cost in running, so total BHP required here is 2732 BHP whereas here 20.4 BHP, okay. So that means, as opposed to 2732 here you need just 2320 which is almost which is in fact more than 400 brake horsepower less. So the installation of pump is going to be cheaper here.

And running cost is also going to be cheaper here. So when you go with a lower velocity, you can see that you save on the power, you save on the pump installation, but you spend more on the pipe installation. So pipe installation is done for a larger period. Let us say you are doing it for 25 years 30 years period.

So you are expending some amount upfront for the 25 for a project which is going to run for 25, 30 years and then you are saving on putting a maybe a few less number of pumps and on operational cost for a period of 25, 30 years. So what is additional investment required here versus what is net saving over a period of 25 or 30 years here should be seen in order to select which one is preferred.

Similarly, if you go for a two pipe system again you get the dia is reduced 1.44 meter, okay. So installation is going to be further cheaper, okay. But not cheaper in fact, because here you are going to use two pipes okay. Instead of one pipe, you are going to use two pipes of 1.44 mm dia. So procurement of two pipe supply; again, we should it is also impractical to go for huge dia pipe.

So it is better at times to basically break down in as more number of pipes with a smaller dia. So in such cases, we can actually go for a two pipe system where you need to, again you need to see what is going to be the net increment in the installation cost here instead of going for two pipe system than one pipe system.

But the BHP required or the power required in this two pipe system is least of all the three options provided here. It is 2243, so even smaller than this but marginally smaller, okay. So then one need to see okay which one needs to be preferred of all these three option. So the different combinations can give you the different installation and operational cost and the selection should be based on that.

So with this, we conclude all the discussion of this week and next week we will actually talk about some of the storage systems, how we design reservoirs, okay. And we will have subsequent discussion on that in the week four. Thank you for joining and see you.