Groundwater Hydrology and Management
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Lecture 21
Contours and Hydraulic Gradient

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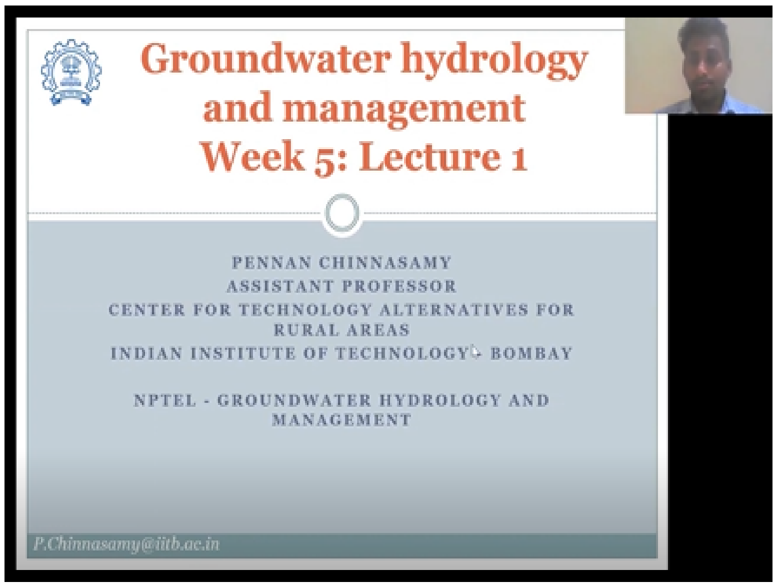

Hello, everyone, welcome to Groundwater hydrology and management, NPTEL course, this is week 5, lecture 1. In the past week, we looked at the important components of groundwater hydrology. Specifically, we looked at hydraulic conductivity, specific yield, porosity, etc. And then we looked at how to estimate the water level from the top of the well to the bottom of the well.

Then, we looked at the elevation of the well, and how to estimate pressure head and hydraulic head. So, now we have the elevation of the water level from the mean sea level. So, that is that net we want because from there, we can establish the gradients. In today's lecture, we will be further looking at how to use those data and also how to understand the movement of water.

In the week five, we will also look at the governing equations of groundwater flow specific to the aquifer type. And specific to the amount of soil moisture present in the medium. It could be a saturated system or an unsaturated system.

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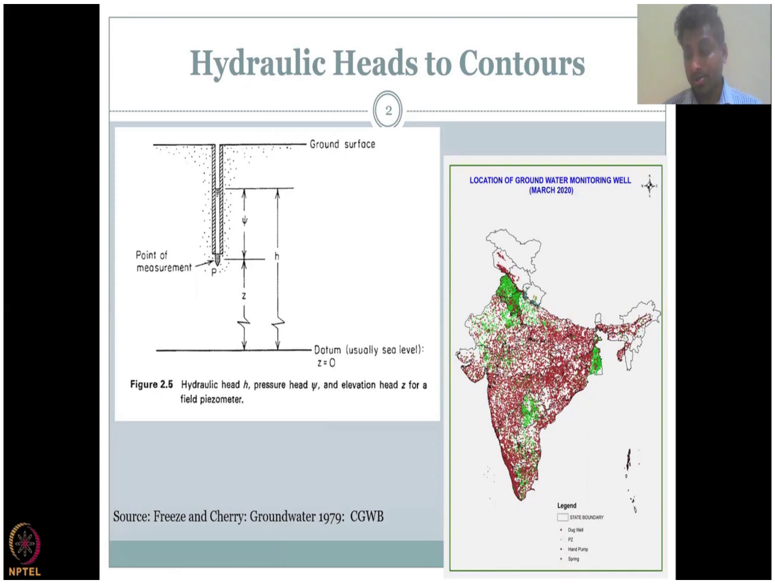

So, let us move on, we did look at this estimate of the hydraulic head, which is total h summation of z plus psi and z was your elevation head. And your psi was your pressure head; we added both to get the hydraulic head. So now you have the elevation of water from the mean sea level which is zero. These are different exercises on how to calculate it, I hope you understood how to do the calculations and subtract.

Now, let us use this. For example, the most important groundwater monitoring body in India is a central groundwater board, which monitors around 50,000 wells across India. You could see the distribution of the wells across India and most of it is present in high groundwater extraction regions so that we could quantify the groundwater use and also management practices can be made.

So you do not see much in the northern parts of Kashmir, Assam those regions because also it is hard to get the monitoring data, the monitoring well into the ground. So now we have this data. So what do you do with it. So now you have a groundwater level data, and we know that at least from the government record, we have around 15,000 wells, we can convert them into contours. So, I would define what a contour is in the next slide.

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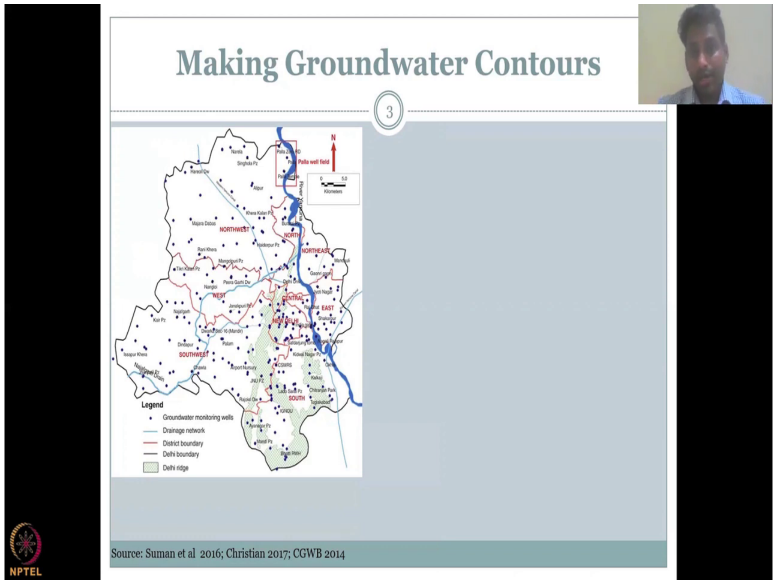

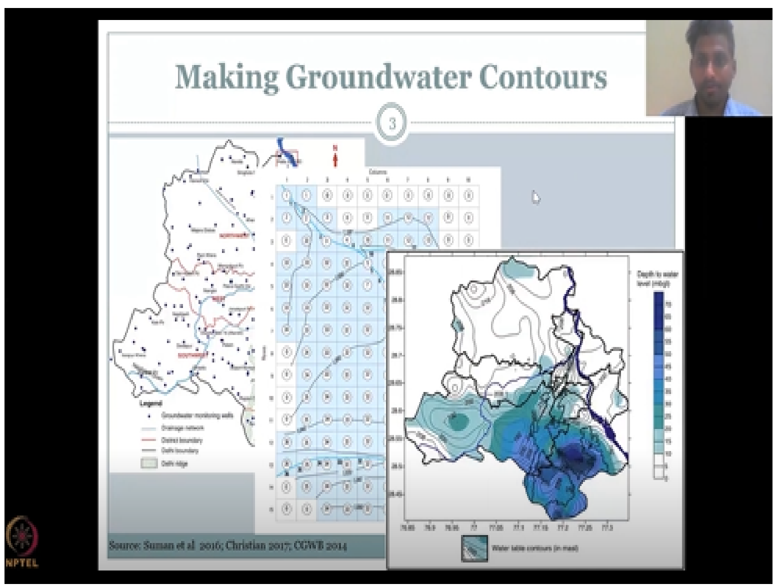

So contours are the elevation of the hydraulic head connected along a line so that it represents a unique and uniform groundwater elevation or groundwater level across the study area. So in the previous slide, I showed you the map of India and where the wells are, but let us look at a closer look of one particular study by Suman et al, where they show the location of groundwater monitoring wells and the data is taken.

So, once you take the data, you have estimated the hydraulic head, which is the elevation of the water level from the zero level. From there we are trying to get more information, how water flows between the wells, we take only two wells, we definitely know water flows from the water flows from the higher potential to lower potential, which means higher hydraulic head to lower hydraulic head. There is a straightforward question.

But in terms of a larger area, for example, this study area, you could see that there are multiple wells and the water level in the well will determine which side the groundwater will flow. And so, for that, we make a map of all the locations of the groundwater level. And then we add the data for the same time, please note, you need to have the same time recording of all the wells. And that is why I am asking you to use central groundwater board data, because it is either peak monsoon, post monsoon, or summer or winter.

So, you have four times they would monitor the water levels, and it is at a particular season, so at least more or less the level of water is captured uniformly across a study area. So, we have, for example, you take the peak monsoon, which is the water has gone into the wells, and then the water has recharged the well the water level has gone up. So let us assume that you take the groundwater level in these wells during the peak monsoon. What happens, you first make a grid of where the wells are, and you have the locations, for example, in this location.

In this study, I am just using a kind of a graph for rows and columns, you could see that only those areas where you have the water level recorded, you can have the elevation connected. So here in this figure, you could see that the water levels at these points are all at thousand hundred meters above sea level. So you first populate the wells and then populate the data of the groundwater level at each well.

Then what you have to do is connect the wells which have equal groundwater level. So this line is called equipotential line. And a map with all the equipotential lines is called a contour. This can be used for contours for elevation, contours for other aspects also, but since this is a groundwater, we call it groundwater contour. And the water levels are ground water levels and the groundwater hydraulic head. So the hydraulic head along these points is the same, which is thousand hundred meters above sea level.

The next values I have, let us say I have 1080. So 1080, more or less, I have 1079, or 1081, or something. But you have to find the wells with similar groundwater levels, and then connect them. So this line you see here is made of connecting all the wells of the same groundwater level, which is 1080. Then moving on, there are some wells, so here, we do not have any well data, because look at here, not all the area is full of groundwater level, you only pick the points where you can connect.

So not all points would be connected, for example, I would have a water level reading there. Or I would have a water level reading here, a water level reading here, etcetera. So all these wells were around thousand hundred. So I marked thousand hundred as a line and draw it cross connecting these dots. So that is one contour line at an elevation of thousand hundred. Then what do I do is I go to the next wells to see what is the water level for example, if there is thousand hundred here, then I will have to connect it to this one also, for example here, but since that is not the case, we are not connecting it.

And that will not be readily connecting also; maybe you will have one point standing out but do not connect it. It is mostly across the area where you have to connect. Then we have these water levels, which are at 1080. So 1080 along this line and it has been connected through this line. So, you have all the line all the wells along this line having 1080 meters as water level. So, the first exercise is to map the wells which we have done in the in the previous slide. And then we map all the data that is having the same record of the water level.

And then we have, so this is the first exercise as I said you map the water levels then you map or draw the line connecting the line of all the wells with the same water level. Let me clear this, and then you have all different lines coming up. So here in this example, you have 1100, 1080, 1060 and around 1040, 1020. So what is the minimum interval between these lines it is 20 meters, right, because 1060 and 1080 if you subtract it, it is 20 meters, 1060 and 1040 is 20 meters. So this is called the interval of the contours.

So the contour line could be thousands, or hundreds or fifties, etcetera, but how close are they depends on the interval. So if you say, one meter interval contour level, then you will have multiple lines running through, like, for example, one line here, one line here, etcetera. But it really does not make sense because it makes the map very congested. So you do not do that. So what you have is you can keep a good interval, depending on the water level.

So in this water level 1080 and 1060 there could be some wells which are 1070, but we do not add it because the interval the minimum interval is 20. So you group all the wells 2080, or you group all the wells 2060. So you can make and choose between that because it does not change the hydrology, it does not change how the groundwater flows, it just makes your map look better, so that we can understand the groundwater flow.

So, the first exercise get the wells, get the water levels and then connect all the lines understand what is the what could be a good water level contour interval. And here in this case, it is 20 meters; otherwise, it will be for example, if I had five, then there will be another line here which is 1075. And then here another line, which says 1070 and then here 1065 and then 1060. So it always goes down, it does not jump 1080, 1095, 1075 no, it will fall through a gradual pattern or that is how groundwater flows.

So, then, we move on to what next after we have mapped these things, the next would be to clean the other wells which do not have data and you come up with a depth to water level map along with the contour in a same image. So if you look at the study, what they have done is they have taken the wells only the wells that they want to be portrayed in the contour, they connect it with lines.

So now in this in this image, you do not see the wells because all these lines represent 216 meters above sea level and these are 2 8 meters 208 meters etcetera. So, you have 192, 220, 208. So, how does water flow? As I said water flows from higher potential to lower potential in the previous exercise, this is not the same area it is just a blowup have a very different exercise is to show how the map is made. So here you could see that the water would flow from thousand hundred to thousand sixty because it flows from high potential to low potential.

Moving on, in this image, you can draw the similar diagram to show how the water flows. So you know 216 and here it is 208 and there is a 208 and then there is a 200. So, groundwater will flow this direction, from high potential to low pressure. So, first one 216 to 208 and from 208 to 200. And always it flows perpendicular to the line, draw this again, it flows from here it goes like this perpendicular and then perpendicular cutting through the lines, it goes to 192.

So, this is how groundwater flows not along the line, because along the line the potential is same, for example, in this line, it is all 208 so, there is a well for 208 as another well at 208, water will not flow it will just stop because there is no need to flow it is both same potential, it will only flow when one well is above and one is lower in higher potential and water would flow from high potential to low potential.

So in this diagram, as you see, water will flow from high 216 to 208 and then 192, etcetera, and from here also and then from here also you have this arrow I will stop here, and from here also 208 to 200 to 192, so there in this lake it looks like a lake or a depression, groundwater flows from all directions towards the lake, this similar thing can be observed along the river networks. So, if you see here this is a river network and along the river the elevation is low because that is a deeper elevation and that is where water is. So, water would flow from high elevation to low elevation and the river is gaining water because of groundwater, what did we call this system as a gaming stream.

So, these two images are showing how you get the water levels from a map and then convert it into contours and then understand the groundwater flow direction. Magnitude is different, which is the volume the rate the flow, which we will be estimating through the governing equations, but it is also important to understand the direction of groundwater flow.

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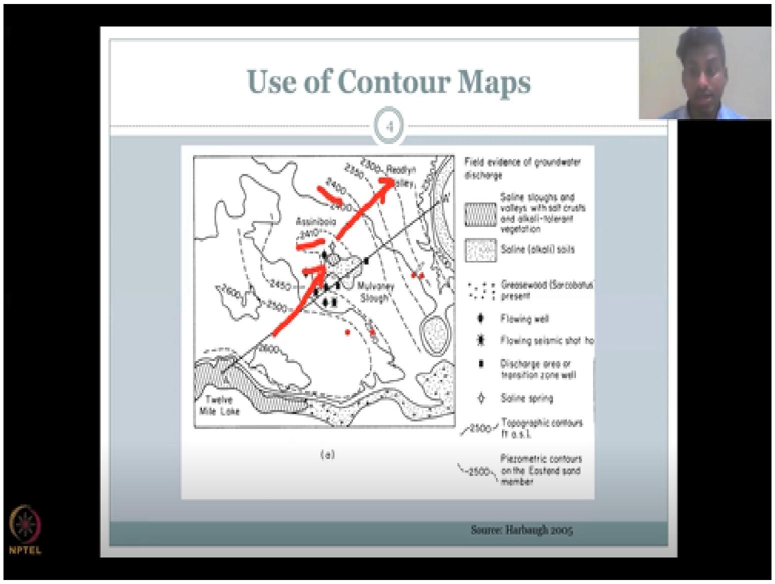

Moving on, once you have it and clean all the other data from your map, it is a very, very important informative map that can tell a lot of things let us take for example, in this study, we have saline sloughs and valleys which is a different geology and then an alkaline soils which is the dot there is a cross section let us not worry about it and then there is a greasewood type of material present here there is a flowing well and short, short hot springs and then discharge area or transition zones are here.

And then you have a topographic contour, which is at 2500 feet above sea level. So, you have two types of contours as I said, one contour could be just the elevation of the land. So, you connect all the points with the elevation of the land or you can take the piezometric contours, which is the ground water elevation. So, let us not worry about the elevation of the land we are looking at more groundwater. So, if you look at the dashed lines here, which you can see along here,. So, you can find that the groundwater would flow from high potential to low potential which is 2500 2450 and then to 2410.

Similarly, draw it also. Similarly, water would flow to this area. Then water would flow to this area, and then water would flow from 2000 350 400. So here also you can have water flowing from this area. Because continuously decreasing 2600 goes to 2500, 2450, 2410, and then goes down to 2300 the groundwater level, so you have a continually falling groundwater level, which means the direction is from bottom to up, or here, we will call it a south to north.

The other reason is very important to understand the geology types and how these also influence the groundwater direction, but we will only worry about what is the contour what is the contour interval. So here, if you see the groundwater contour interval is how much the least between the two contours. And that would be around 10, because here we have dash line at 2410 another dash line at 2400. So that will be around 10 me feet above sea level.

And just so that you can see so 2000 this is not a groundwater level, it is a elevation level, sometimes your elevation is at the same level of the groundwater, it can happen we saw artesian wells, flowing wells, etcetera. So this is how more and more information can be brought. We can also look at if the contour is following the topography. So the topography tells me that here it is 2500 and the groundwater is almost 2500 here the difference between the elevation and the groundwater.

And here the groundwater is at 2300 whereas; here the elevation of the land is 2400 which means the land is here and below the land 100 feet below the land is the groundwater aquifer. So, these information can be overlaid on, on top of each other for more decision making and to understand which side the groundwater flows. Please understand that these all these data can nowadays be available for free and open source and you can put it in a GIS environment to quickly analyze it even the GIS environment is free of cost it is open source.

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Then as I did by my pen drawing pen on the slide, you can also see that groundwater models are there where you they could also put in these kind of arrow marks or gradients, how the groundwater flows and in this particular study, you could see how, you could see how the flow directions have been made.

So, first they took the points of the groundwater and they made the they made the groundwater well map on the surface and then they took the water levels from the groundwater it is meters we have 104 meters, 116 meters, etcetera, etcetera. And then they made the contour map of the wells. So, what did they find, they find, you can see here how they have labeled it water table elevation meters above sea level, and the number is 110 is just a example of the contour number and here it is 110 meters above sea level.

So, you can just put so, so here it is 110, 108, 106 they could have use a different color, but its we could still see the difference, because this is a smaller number and this is a bold number. So, the first thing is as I say, put down the wells put down the hydraulic head and then connect line through the common water levels. So, let us take this 110 so, they put 110 right near 118 and 116, but some of these wells may be on the line of 110 so it is okay.

And then what we also found out that is the groundwater flows from high potential to low potential, so from 112 to 110, 108, 106 so, it flows through this direction as their arrow marks also say. Second thing is what is the interval contour interval and the contour interval is that is the well, so, the contour interval is 112 minus 110, which is two meters and all the others are also two meters it goes by two so, the contour interval in this particular figure is meters of sea level.

So, all this is done now, let us see what understandings we can get we can get is that the water flows to the river Gomati River as per the study of Kumar et al so, the water is flowing from a higher elevation to the Gomati River, the Gomati River is getting water through base flow and groundwater flow.

And so, it is a gaining stream in some regions the water might be going through. So, like this, it will go through to the other side of the bank, which means in one side of the river, the river is getting water from the groundwater on the other side. So, this is the gaining part and then on the other side, it is losing the water to this side, but in this case, you could see that both the water is coming towards from both the sides was the reverse of groundwater is losing and giving water to the stream to recharge and flow.

So it becomes a gaining stream. So, from this, we can have more structures in the map like Himalayas so, this is the Gomati Rivers so it is in Ganges plain. So you can have other features in your map and get more understanding why this groundwater is flowing towards this direction we have elevation gradient, you can have a pumping station you can have an urban city which is pumping the water. So, all these things can aid in changing the groundwater direction towards one particular point. So, here it is a river we are understanding that it is because of higher elevation from the Himalayas.

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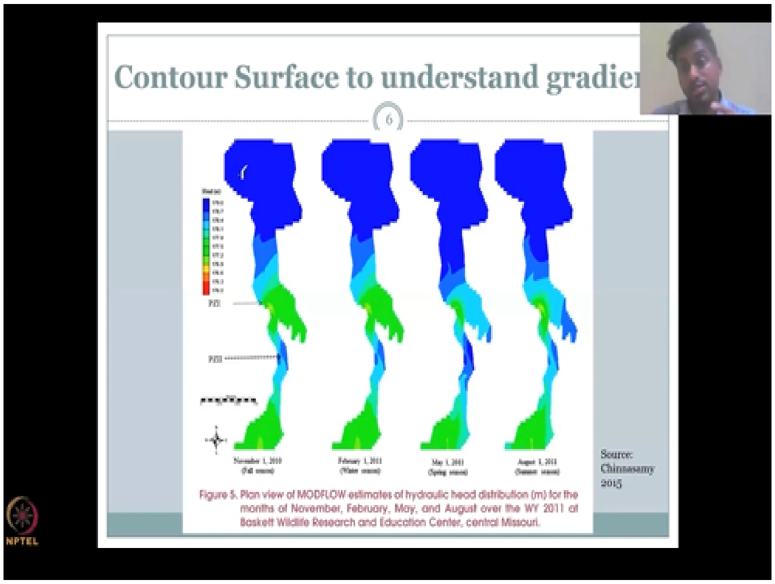

You do not have to stop there you can also make a surface in the previous examples; we saw that we can make our groundwater contour and if you can interpolate the wells. So if you have well data you can convert it into a line, but if you have the well data and between two points and then multiple points you can interpolate between, between them to make a contour surface.

So here what you see is the highest hydraulic head, which is above the mean sea level in meters. And also you see, the interval is around point three to point one. And here we do not look at lines, but it is a coloring scheme that has been used. So this study site also has dissolved meters, which is groundwater wells coming in. So it is a model, groundwater surface. And it also helps you to understand the gradients. So, let us quickly look at how the groundwater flows, it flows from high head to low head.

So, in the coloring scheme, it should flow from blue color to red color, we do not have red color here, but we do have the green color. So, groundwater flows from north to south, but something else is happening. So, it is actually gaining some water here. So, maybe there is a stream which is giving water to the groundwater. And also then it loses more in the bottom part, which is the southernmost part of your study area.

Also, we could see that it is seasonally variant the amount of water that comes in. So there is a fall season, winter season and spring season and this study was done by Chinnasamy in Missouri. So, you could see that how the groundwater changes between seasons can also be mapped and understood well, using these contour lines or contour surface mostly interpolated between the points, there are multiple interpolation techniques to get groundwater into a surface, we will not discuss that fully because that is beyond the scope.

But I would recommend you could use IDW method, inverse distant weighted method so that it can capture the groundwater within a radius, so for example, if you have two wells one well here one well here, let us add more four wells and you do IDW then it will take only the nearby wells and then interpolate, it will not take these wells and interpolate because it is far away. So, the distance increases, so, the weightage of these wells decrease.

So, this interpolation is very important, because nearby well stop to each other rather than different wells, and then the groundwater gradient is made. So, all this could be done with models quickly and more easily more effectively with because there could be a lot of error. So when you do it by hand, contours are easy, but when you do it by hand to connect, interpolate these wells and you have to physically measure the distance between the wells and then run interpolation codes and then interpolate is going to be hard.

So we always use GIS software or MODFLOW and other types of water models. We will look into some models in detail in the coming lecture. But with this we would end today's lecture on how to understand a particular hydraulic head in isolation we saw last week but in today's lecture, we saw how to look at it in combination? How can that information can be converted into a contour map and from the map how the movement of water the direction of water can be understood.

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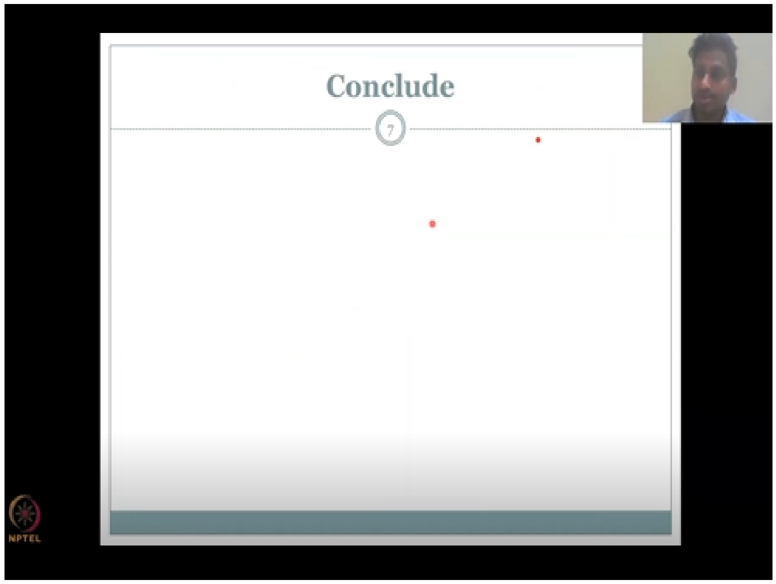

With this I concludes today's session. I will see you in the next class.