Groundwater Hydrology and Management
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Lecture 42: Aquifer Stratification

Hello everyone, welcome to Groundwater Hydrology and Management, NPTEL course this is week 9 and we are at lecture two. In this week we will be looking at what are the different types of data that is available for effective groundwater management. The first two classes we are trying to find what data is necessary for constructing the aquifer background, here the aquifer background includes the layers, how many layers are dominant and also the boundary of the aquifers.

For this we looked at borelog data or borehole data of which we looked at single bores in the last lecture and multiple bores. So, the borelog data gave us some information about how the layers are present, where the water level is, what type of drill bit is used, what depth do you find an aquitard, an impervious layer, what are the different types of layers present and penetration resistance, all these we will now continue to use with multiple site borelog data and we will find how to correlate this into a meaningful information.

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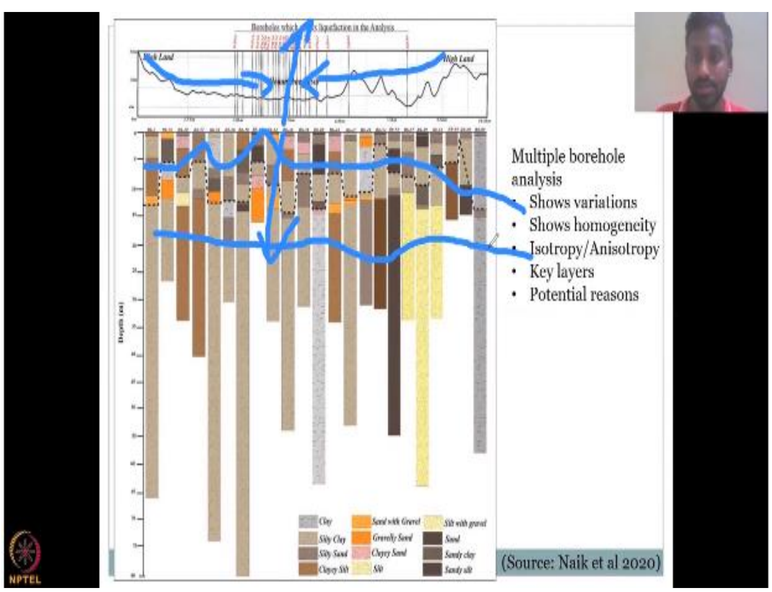

So, this is how a borelog data is taken from a profile, please look at it, here we have the elevation and the distance between the logs. So, right now we will look at this as a cross section of the land, basically you take a land and you slice it, so the land is like this, you slice to see the cross section, you have a highland kind of a mountainous hilly region coming down into a basin going up and down.

So, this is called undulating topography and in the bottom what you see is each borelog placed as a graphical unit, I hope you remember that we took the graph sheet or a sheet where you graph unique borelog information and put in the details of what depths you took measurement, the penetration test, the wetness coefficient all those things.

Similarly, now we will take all the borelogs together and put it across the cross section to find what is the relevance between them, what you want to see now is what information can we harness from these kind of information. Let us look at the way the wells have been taken, you can see here first couple of wells are close to each other and then these wells are farther away, especially this one, so this one is very far away and the elevation of the well along the highlands etcetera, does give you a good pattern of what kind of layers would be present.

So, think about this highlands, the highland is where all the water would flow and so you will have less layers here because the layers are being taken and brought here in the valley, so this is like a valley, a u-shape big elongated u-shape, what you see is water would come down and then bring down the sediments and get deposited, so where deposition happens is called alluvial layers, where the alluvial layers are forming you find many layers.

So, you can see here there are many, many layers compared to this coloring, we have one, two, three, four in the top soil, whereas you have a lesser depth here and more newer ones one, two, three, four, five, so we have one or two layers more that is because of the eroding away and deposition into the lower elevations.

The other factor you see is the depth of the rock, because here you have higher depth, you can see here the depth is high, whereas the thickness is very small here, so all these borelogs will not go very deep but a little bit deep because depending on the penetration test and everything. So, now let us look at what we are trying to see, so the dashed line here gives you the layering or where the connectivities can be made for the water levels, before that let us look at what the analysis brings, it shows a lot of variations, can you see how many layers are coming and the bottom layer is not the same here it is silty clay and then you have suddenly a clay silt and then here you have just clay and same here.

So, neither is the bottom the same, nor the top topmost layer is the same, there is some changes so there is not the same type of layering between the borelogs. Also you note that within the same you have a lot of homogeneity in the bottom which is a deep, deep part but as on the top there is lot of variations.

And you can see some clubbing of the test sites, so for example, here these two could be clubbed together as one type of aquifer is locally present, like this yellow one and then this one etcetera. So, there is some grouping and that is purely because of which sites you took and the depth at which you went.

The same isotropy, anisotropy as I discussed last time in the single well, in the multiple well also you could see where the parameters can show isotropy, whereas in the xyz plane will it change or it does change in the anisotropy case. We can also look at the key layers, how many layers are present, why they are present and I said you have the depth as an indicator and you can look here these wells, these borelogs may have a higher depth because of the shape, it is not a valley it is the peak.

So, wherever the peak is there and a sample is taken you would see more data for the thickness of the layers and multiple layers would be there. Furthermore this leads to more potential reasoning as I said one only when you go to the field you will have more visual of what is happening but just looking at it you can understand that the thickness of this material plays a heavy role in how much depth you can go and if it is high and there is a valley like a u-shape then water moves down from both sides, let me draw it just so that you can understand it.

So, water would flow like this and water will flow like this and then from here the river will flow either this way or this way, so while this water is moving it does pick up all these sediments and other things and that is where erosion happens because when the sediments start to move there is lot of erosion that happens because the erosion is what ends up as sediment and when it gets deposited it becomes layers.

Here somewhere you will have the water table along the same layers as the first aquifer and then you will have the second water layer as the confined aquifer, we will get into how that is being demarcated in the next slides. Same limitations exist what sites you pick, drive the understanding of the model.

So, if you pick too far and you find very homogenous surfaces then you may think that across the plane it is all homogeneous, same way if you pick samples very, very close to each other and there is in homogeneity you may think the whole plane is inhomogeneous but when you move away you might see it is not the case, so all of it depends on the selection of the site and how you select the sides and the depth to which you can assess.

So, here as I clearly you can see not all depths are same, may not be the same because it is undulating but if you take a same thickness of land and you just go in depth in some borelogs and then very shallow in some borelogs that is a mistake you need to change that attitude.

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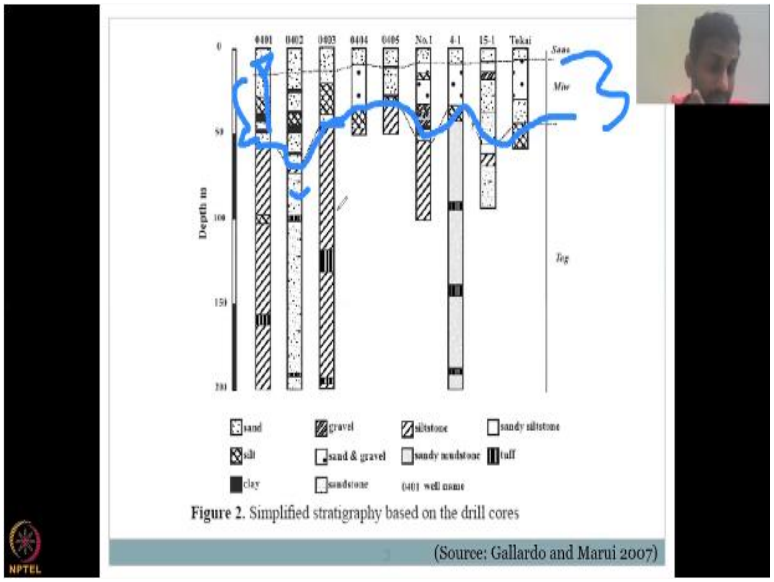

So, let us draw a Stratigraphy, before that let us define what is a stratigraphy? A stratigraphy is stratification or layering, layering of aquifer is called aquifer stratigraphy, how you layer it and why you layer it is dependent on this bore hole borelog data and the process of drawing these stratigraphy by hand that is a very accurate way people started and then you feed it now into models, 3D models and stuff because in those days there were no 3D models.

So, they will do like, this will just draw a column chart and then in the column they will color what is the depth and what material was there and if it is the same material on top of a impervious layer then they will say this is a confined aquifer and if it is not confined just the land on the top they will say it is a unconfined aquifer, so all the terminologies you know but right now we will just show how do you draw it.

So, on the top you see the different numbers of the wells, labeling them is very important and be very, very smart in how you label it because when you look at the label you should know what the location is, time, date is not much important because these do not change, you do not see a time stamp on it but overall it is good to have a time stamp, most important is the x, y location or the lat long of the borelog, the GPS coordinate of the borelog, the elevation of that surface which you can get from the GPS also.

And the depth to which you went, the method is also very important because sometimes when you dig through the borelog your machine would break it and then mix all the aquifers together, the properties together, for example, if you are digging here, there is three, four layers in within 10 meters, so this from here to here is 50 meters, so maybe within 10 meters you have three, four layers and if you go quickly then all the layers will mix in the sample, inside the ground it would not mix but as a sample when you take it out it is mixed, so be careful when you assess these different kind of layers.

So, all this we saw in the week, the first class in the week, now we will look at how the water table is drawn. So, you can see here the top most unconfined material is given as sand, here we have sand and a water table is already present, so once that water table is present in one borelog at least then what we do is we understand that an unconfined water table is present, just for the brightness let me draw it.

So, here is the first borelog and I find water, then what you do is, you continue on the same depth from the top, you continue from the same depth from the top until you see a different layer, so you see a dot, sand and gravel so then the water would just go up and then come along this line, so you could see here that mostly all would be at least on the boundary between the layers or on the same layer, so more or less this line has been adjusted to replicate this line, where the water table would be and that is your first unconfined aquifer or in the phreatic zone, there is a unconfined aquifer and a water table exists, it is saturated.

Then what happens is you have a aquitard or a layer which maybe a combination of different materials is preventing water from going down, that is given by these, all these x, x which is silt and then you have silt clay, here you have silt again, silt again and then you have silt stone, so all the silt is there and in between that there is no water, that is the assumption.

So, here we have the water table which means below this all is water and wherever the silt and clay is it is still holding water because of porous space, look how big the sand and gravel is it has, but suddenly after the sand and gravel it goes to a silt layer, so there is a line which captures all this and then this is the thickness of the first layer.

So, there is only one aquifer layer which is present in this example, let us do it again for clarity. First, they take all the borelogs and place it on next to each other and then they find the first water table, a triangle mark is placed, so is water present from the deepest part to here? No, because inside there is rocks and materials and there is an impervious layer, so we need to find where that aquifer is, the thickness of the aquifer.

So, this is the thickness of the aquifer, not the entire thickness because the entire thickness has a lot of rock, we do not want rock, we want the material which is actually storing the water, so now what happens is water is present below the water table line until an extent where it hits an impervious layer and here the impervious layer is given as, see the silt stone you can see here, they give it a silt stone.

So, once the water comes down, so from the top it is coming down, once infiltration and percolation is happening and then it hits the silt stone then it does not move down according to this thing and you can see wherever the silt stone is the authors have drawn a line to connect them, so what do you do when there is no silt stone, you just go to the nearest type which is silt, so your these ones, this one, this one do not have a silt stone.

So, all this is same I will just put a tick mark to show you that it is all the same, this one so wherever on the top those layers are a line is drawn, on the top. So, now I am going to draw the line which is going to connect all these layers, so you have this, so now this gives you the thickness of water, on the top you do not see that much undulation because almost the water table is an imaginary line which connects the water, down you do see this undulations because the material is not the same.

And that is why a farmer here might have dug 60 meters, the farmer, this farmer has dug 60 meters and got water, whereas this farmer he will run out of water at 50 meters even if you dig down you would not get water, it is very near but you do not, because there is a inhomogeneity or variation in the rock type and that is where it is getting really difficult to understand your groundwater behavior.

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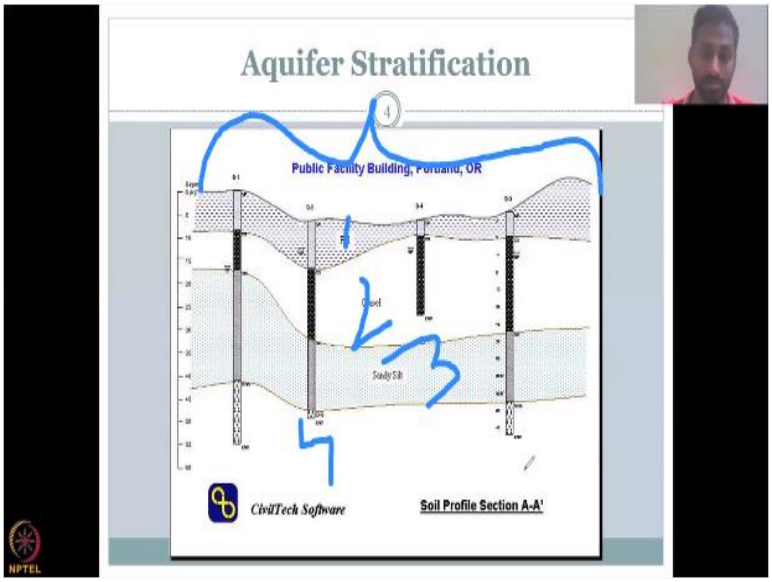

Let us take a very simplified example, one more example, so you have B1, B2, B4 and B3, again the numbering is up to you, you should pick the numbering and you have four wells, how many layers do we have one layer, two layer, three layer and four layers. At the max four layers and here you have only three layers and this one has two layers, actually this one also has a four layer, so this one has two layers.

The layers are also given in the legend, normally should be but if not we can just assume that it is permeable impervious something like that depending on the water table. There is a depth in feet and this is taken in Portland US, so when you come down, the first layer there is no water so the water starts at this layer which is 15 feet below the ground but is it all poorer or full of water? No, what is happening it is getting stopped at an impervious layer and that is given in this arrow marked aquifer or arrow marked rock type aquitard.

So, only this thickness is there for the aquifer, whereas the aquifer thickness comes down and then keeps down lower as it progresses but what happens to this well, there is no water because the depth is less this is where I am trying to say when you have these borelogs and groundwater depths it is very important to look at what is the depth compared to the surrounding, the water quality is not discussed in this entire exercises because that is of course, by itself maybe I will float an NPTEL course on that but here we are looking only at the individual borelogs and this borelog only for water quantity, not water quality.

Why is there a line here, so what it shows that initially water was there but now water has come down, look at it, it is fill, it is gravel and sandy silt, if we know the specific yield we know that water and gravel does not stay long it flows down, it flows down and it goes into the sandy silt and it is happy it stays there. However, in this well location there is no water because all the water would come down.

Let me draw the flow lines how it will look, so water comes like this and comes down like this and here there is nothing which goes into the well because there is no material to support the water, it is not supporting the aquifer or all the water has been drained down because of the gravel presence, there is lot of gravel and gravel has high specific yield, so it does not stay there for long.

And there is no water in this opening, so there is nothing in this well for water as it does come here, this is an impervious layer you can see the dash marks and there is no water going down, so what happens is water comes down and then hits this impervious layer and then slowly starts to build a water table from like this and this is your water table based on the type of material which is present and that is it could be like a alluvial aquifer sans silt clay and it has a lot of core space where water can be present.

Now, you will understand that if you take borelogs you can put the water level in and first make sure you correctly identify the layer types and the layer types talk to each other, all the borelogs talk to each other, so in between if you compare these two borelogs what do you see, I have one, two, three, four layers, I also have one, two, three, four layers the thickness is changing because of the undulating topography.

Because this is undulating, undulating means going up and down, it is undulating purpose of that soil type is also going up and down and then you have the second material which also goes up and down because of the topology, then this material which is the water bearing material has more water here because of the higher elevation of the land or the type of rock, whereas here it is having less thickness, this thickness again.

So, when you take b is normally the alphabet given for aquifer thickness b, a, b small b you could see that the aquifer thickness is not the same but in models, in our assessments we normally use same thickness which is also a limitation, nothing comes close to a complex groundwater real life scenario, models are models, these are also models but only when you have good understanding of the system you can make these assumptions.

So, now we have seen that you can take one borelog and look at the variations but it does not tell you about the aquifer, when you keep different borelogs together now you can have a connecting line between the bottom of the aquifers, this is the bottom of the rock type, this is the top, not worried about this one bottom is the next layer stop.

So, let us say this layer we are concerned, so this layer is top all the top points are connected, there is no top here so we neglect that well, here the bottom of that layer is connected to the bottom and to the bottom. So, now we have a thickness and this is where water is going to be, because all the tops are connected, all the bottoms are connected, this connecting by hand is being now done by your models and called as stratigraphy, so this is what stratigraphy is you take different logs, you identify the layers and then you connect the layers to make a layering across the cross section.

So, in this one log you find four layers, so already layering is there but how does that layer result in stratigraphy across the aquifer, so this across the aquifer will be done by having multiple well logs and connecting them as layers and when you connect them as layers, now you know how many layers are there, so how many layers are there? There is one layer, two layer and three layers, this is the fourth which is just the bedrock you can keep it as a layer or we can say it is the bottom.

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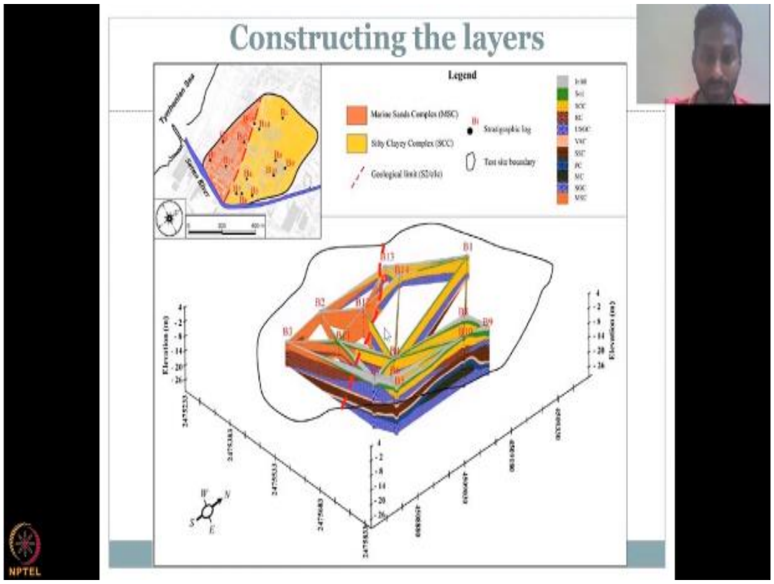

So, this is how studies are going on, so they take these borelogs and then they make these different, different constructions and layerings what do you see here is the borelog locations are kept, where B1, B2, B4, B9 and then different types of solid materials are identified, marine science, silty clay in the study and the depth so now this is a 3D version, you have to look at as 3D, so when you convert this is the top view, you are looking from the top to bottom but when you take the borelog now you can establish a 3D.

So, when you do a 3D, so that is the elevation and going down, so when you do a 3D you can see that some layers are present and they can be connected in one side of the basin, on the other side of the basin red color type is present and then you connect these lines to show how many layers are there, basically stratigraphy.

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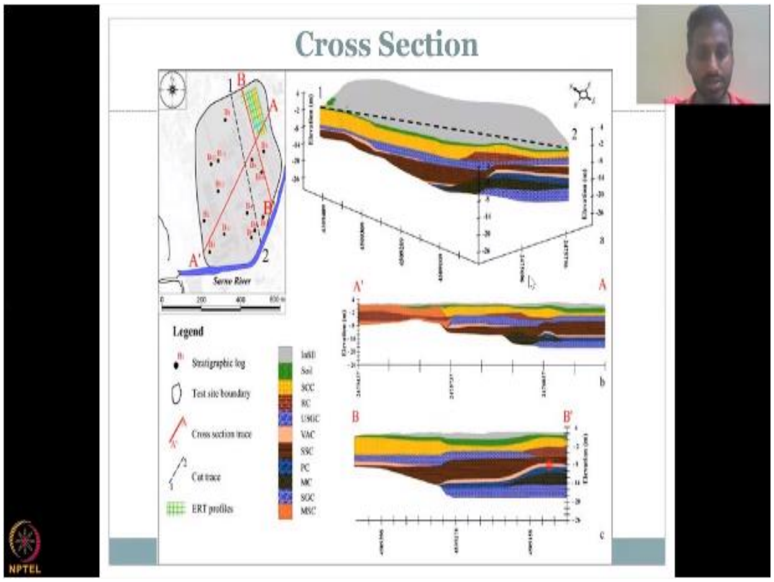

Here also it is the same thing, you see the cross section and if you see through the cross section, this is the side view on the previous one you saw a 3D but now you are just seeing one side and you can see how the layers are talking to each other across a distance, sometimes the layer starts and ends within a couple of meters and it does not extend, so those are all pinching off, which means the layer is thick but then slowly it comes and then closes down, that is called pinching off.

And then sometimes the layer will come out which is called as an outcrop, so it comes out and then stops the other layers, so like this it is coming out and stops the other layers, so this is how you could use the borelogs, you can see the borelogs present and then you take a cross section, a, a dash is a cross section which is a, a dash you cut the basin and then you take a slice and see it the cross section and then you see how many layers are there, the layers differ because of the type of geology present within the basin, there is two distinct layers and that is what is showing up here.

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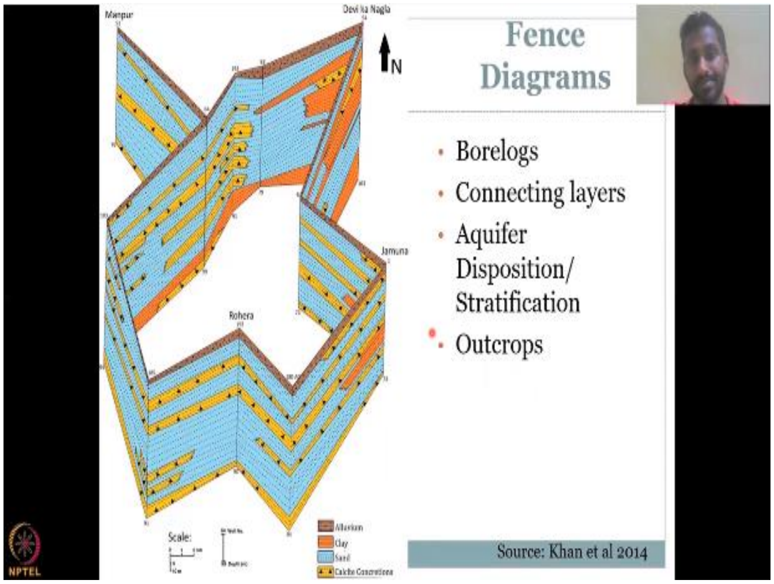

So, now we have seen more examples, it is called either Fence diagrams, you will see the word fence diagrams because you are creating a fence using the borelogs and in between you are connecting all the logs. I will again come back to this Khan et al paper in the next class because we can look at how do you read in between the fence diagrams and also discuss about borelogs connecting layers for disposition stratification and outcrops. I will see you in the next class thank you.