Groundwater Hydrology and Management
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Lecture 17
Groundwater Hydrology Components 6

Hello, everyone. Welcome to Groundwater Hydrology and Management. This is week 4, lecture 2. In this week, we will be looking at some more concepts and components of the groundwater hydrology, which are very important to understand and model the groundwater movement.

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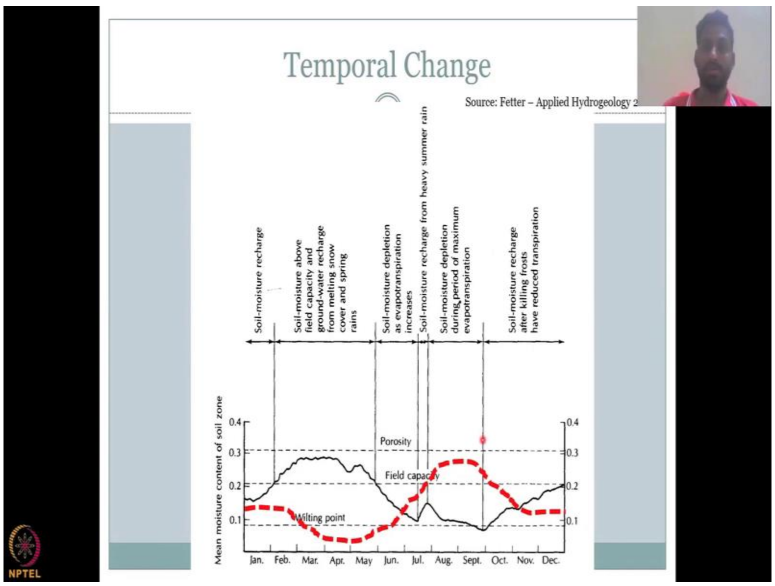

In the last lecture, we looked at porosity and we also looked at the temporal change of porosity. How porosity is not a constant throughout a season and it changes as per the water use and recharge and discharge of groundwater. We took an example of a cold region, now I am just putting in somewhere very near to IIT Bombay or in Maharashtra, how it will look at so you have a, you start with a porosity of around 0.1.2 in a particular field.

And sooner or later, you would experience, we are doing a calendar year, so we are starting in Jan and slowly it decreases due to the less amount of recharge through rainfall and also the rising temperature. Once you hit March and April, there is possibilities of the, it is get really hot. So, the possibilities are there for the soil moisture to be totally extracted below the wilting point, whereas there is a lot of loss of plant growth, plants die and wilt.

And after that during your major seasons of rainfall which is your June it starts to rise. Around May end, you will have less plants so there will be some reversal of your soil moisture by less plant uptake transpiration but most of the plants would see more water in June. So, June when the monsoon kicks up, the water levels steadily rise in the soil moisture or the pore spaces, the pore space has more rainfall recharge.

And then you will have a peak after the post monsoon season which is the post monsoon season would peak around September or October and the rainfall would stop, but the recharge will still continue to happen, and you will see it until October and then comes down after the post monsoon season.

So, then it comes back to the normal Jan values of soil moisture. So, this is how in a typical system where you have the June, July, August as the rainfall season you will see a cyclic pattern in the soil moisture, all of this is driven by your plant water uptake and temperature and also your monsoon season.

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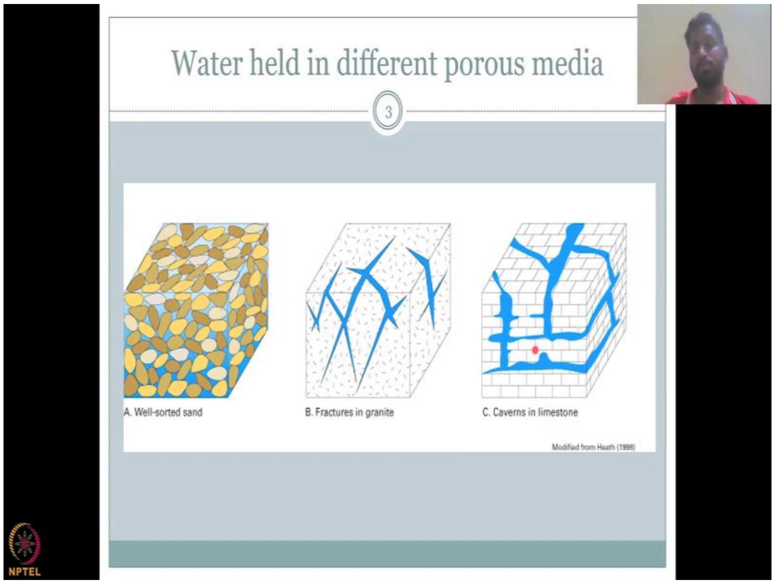

Moving on, it is noticed that water is held in different units, so you have a well sorted sand in the first a, figure where you have water entering into the pore space and then keeping it in the full stretch of the pore space which means it is fully sorted. Then you have a fracture in granite aquifer, the first was a sand aquifer where it is well sorted whereas figure b is a granite with a lot of fractures.

And in between the fractures water is stored, you could see that some fractures are connected, whereas some fractures are disconnected from each other. So, which means water can be pumped through one fracture and all the water levels will come down or recharge also can happen in one fracture and all the fractures would recharge, whereas, there are some fractures which are disconnected and they kind of become a small aquifer by its own.

Then, we have the caverns in limestone or as I said this is cut by water so initially it was all full of bricks like bricked rock not sandstone bricks but limestone for example. And then, water enters through the system and starts to dissolve the rock and thereby increasing the porosity and there will always be connections so you see that water is well connected between the soluble rock and this gives life to caves and caverns in limestone, cast geology. So, this is how water is held in different porous media initially in limestone the pore space is less but as and when water comes in the pore space is high.

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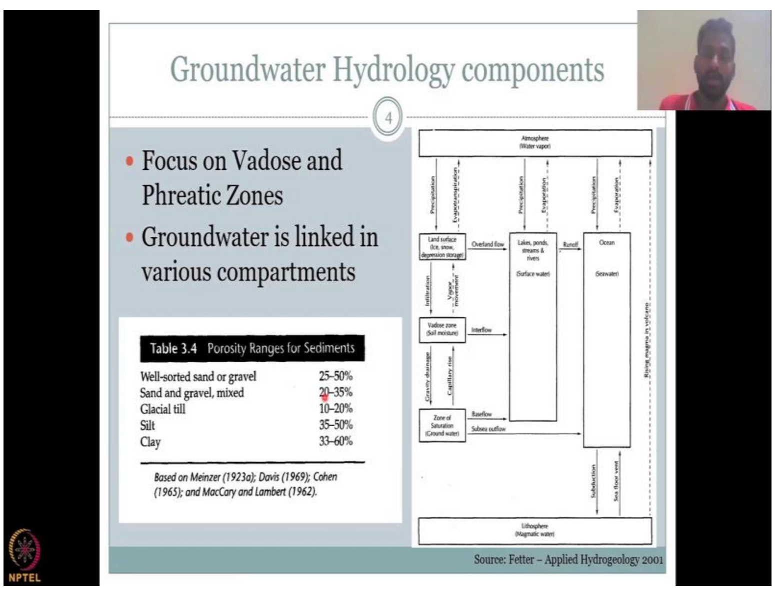

So let us look at how the contribution of groundwater is there for different components. We started with the Vadose zone and then go into the Phreatic zone. In other words, we start with the unsaturated zone and then go into the zone of saturation or saturated zone. And it is very important to link it to the other components of hydrology, especially the surface hydrology components.

Let us take a quick look from the atmosphere we start with precipitation which is rainfall, rainfall can come in ice, snow and other kind of precipitation. So, precipitation can give water to the land and from the land there is infiltration which goes into your soil moisture, porous space, the porosity where water can go into the pore. Initially the pore is not full of water so, it becomes a partially saturated zone or vadose zone and then it moves into the fully saturated zone in the pore space which is called your zone of saturation or phreatic zone.

And that is totally due to your gravity drainage, gravity pulls the water so water goes into your pore space until saturation is achieved. The reverse would be the loss of water from the soil matrix or rock matrix and that would be first go from downwards up bottom to up you have the capillary rise because of your pore space and the surface tension along the pores, water can rise up, how water rises through a straw.

So same way how water can rise up, very limited water can rise up from your saturated into your vadose zone. Water can also rise up because plants are pulling the water and so along with capillary rise there is an upward pull of groundwater and so soil moisture is always kept in a good condition, good for moisture content.

And from the soil moisture it is more a loss to the system because there is vapor movement, some water is being evaporated and most of the water is taken out through transpiration, plants trees, living things would extract the water from the ground water or soil moisture for a porous space back into the vapor, atmospheric space. So, in the atmosphere water is mostly in the vapor phase. So, you saw here how water enters the pore space and from the pore space it goes into the ground water through percolation and through gravity.

So now there are lateral losses or lateral links to the ground water. Let us see some of them. From the top it is not groundwater, the rainfall happens some water goes in most of the water goes as overland flow or surface flow. And once it enters under the ground, there is interflow which means some soil moisture can come out back into the lakes, ponds and rivers as surface water or you can just hover along the subsurface and come out into the rivers and lakes.

So that big compartment of surface hydrology would take your soil moisture and ground water but most of the groundwater would come from your saturated zone as base flow. So base flow is the component from the groundwater which goes into your lakes and rivers, all of this is through the pore space connectivity in your aquifers.

And there is a subsea outflow which directly goes into the oceans and sea water that is deep, deep aquifer which is going down deeper and after it reaches to the bedrock it can move and connect to the oceans, that is where you saw springs and some warm water coming into the oceans purely because of your groundwater component.

From your lakes and ponds surface water there is precipitation also entering into the lakes and also evaporation. No transpiration, because there is not much plants there, some algae some wetlands are there but most of it is surface water evaporation back into the vapor. Same, some of the lakes and ponds can continue to give water to the oceans as runoff and that is also where you have in oceans precipitation and evaporation.

So, most of the groundwater is explained on the left-hand side where you have rainfall coming in and it first saturates the vadose zone, the vadose zone is either partially saturated or full or dry soil, fully not saturated. So, saturation is the process where the pore space has water, when rainfall enters in it adds on to the water to make the groundwater saturated but if there is no water totally dry soil then it can absorb some water.

There is always porosity ranges for sediments and taken from a lot of resources. I am putting some values here around 25 percent to 50 percent for sand and gravel. Gravel is having big surface area but when it has irregular shapes there is a lot of more void space. On the other hand, sand also has a big surface area because it adds to it but most importantly it is well sorted and it has some space in between, whereas sand and gravel mixed would have 20 percent to 35 percent this is where you have gravel and sand enters the pore space.

So, as I said you have gravel like without jamming or without gluing on to each other there is some space. It is irregular so there is some space but if the space has sand and sediment which is fine, then it dries out the porosity. So, there is less porosity in a sand and gravel mixed system and then when you go to glacial till it is more and more sediments entering into the system.

Silt is a combination of sand silt and clay could be having around 35 percent to 50 percent porosity range. Clay is the least it does not have much. Loam is called the sand, silt and clay combination, silt is fine sand. So, you have a good porosity coming when you have gravel, big gravel and sand can actually add into the porous space.

So, all these values are mostly from global estimates and that is why you have a range, the range can be dependent on how much sand is present. For example, in a mixed system and mostly all these systems are not pure clay, pure silt or pure sand there is some mixture unless and otherwise you are in a beach. In a beach you have pure sand so that is how you can assess the different ranges.

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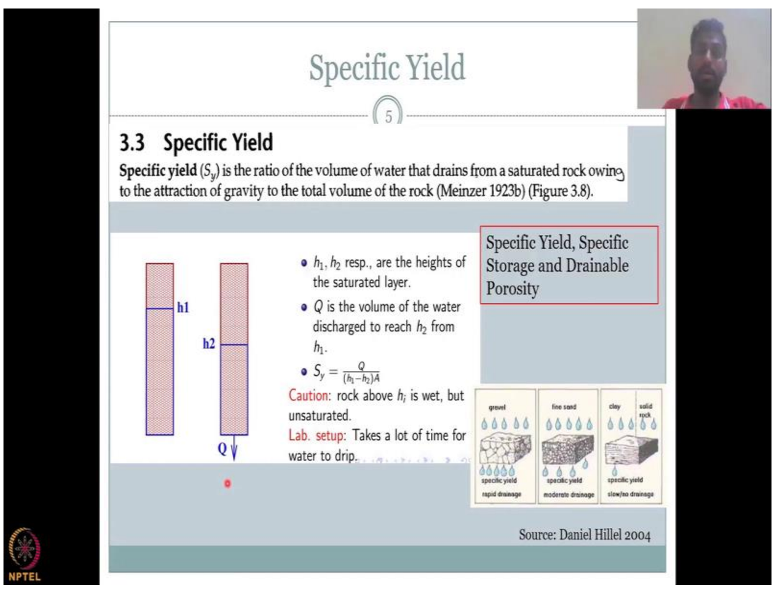

So, moving on from one porosity, now we move to the other property in groundwater hydrology which is very, very important, it is called the specific yield. Let us define specific yield. Now it is defined as the ratio of the volume of water that can be drained from a saturated rock. Again, it is a fully saturated rock, how much water can be drained, it is a ratio of the water that can be drained to the attraction of gravity because gravity is taking the water to the total volume of the rock.

So, there is one compound let us look at it graphically. So, you have a rock which is total height is h and then right now it is not fully saturated, it is saturated up to h1 and when you remove a volume of Q, Q is the water which is removed through gravity. So specific yield has to be in a natural condition, you do not pump water and say its specific yield, you have to let the system rest and through gravity how much water is lost. The volume is lost is Q and the height reduction is h1 minus h2, so from h1 the water level has come to h2 and the cross-section area is A.

So, if you multiply the reduction in height which is h1 minus h2 times the area you get the volume of the rock that has been giving out this volume of water. So, Q is the volume which came out. So, you have to understand there are actions due to gravity, this total specific yield is only due to gravity. So, you have to do it in a lab setup where you take a rock material or a solid soil matrix, you pour water and you wait till the specific yield is reached. It takes a lot of time because gravity acts very slow but it is a very important factor, let us see why.

So, if you have a field and you have a rice planted in the field and you want to apply water, water goes into the soil, you know per rice plant how much water it takes and for the area you can multiply the number of plants to get the total estimate. Normally, you know how, what is the distance between the rice plants and so for an acre you can easily estimate how many rice plants would be there and what is the total water needed for the crop per acre.

Now if the soil has a very high specific yield what happens? Then the water can be drained quickly so you need to apply more water. So, the gravity would actually quickly remove the water thereby reducing the water available for plants. So specific yield is that very, very important term in porosity, in groundwater which gives you how much water is extracted through gravity. It has different names specific yield, specific storage and drainable porosity. I like the last term which is drainable porosity, because it connects us with the previous component that we saw porosity.

So, the porosity might be there, but how much is drainable is very important and that drainable through gravity is caused [Technical Difficulty] So in a gravel the specific yield is very high water can come in fast and also go out fast, rapid drainage, very quick drainage. Fine sand is having a good matrix but however because it is loosely bound, if you pick sand you can see it just falls, pours through your hand. So, it is loosely bound so it allows water to go in quickly and come out, it is moderate drainage not as fast as your gravel but it still has good drainage.

Whereas clay and solid rock has slow or no drainage wherein it stops the movement of water down, it arrests the water and prevents drainage, prevents gravity from pulling the water. So, for a plant you can see that, you might say that clay is good because it stops the gravity and keeps the water in the soil. However, the same process by which clay holds on to the water, the plant cannot take the water out. So, if drainage cannot take it out, your plant also cannot take it out.

So, you need a mixture of these properties for specific yield for good plant growth. But now we will focus on the groundwater term, how much water is remaining is good for your groundwater aquifer. Your specific yield might be high to send the water in fast but if the water is connected through a river or ocean sea then the groundwater is lost. So, it has to be slow, so the groundwater recharges and also maintains the level.

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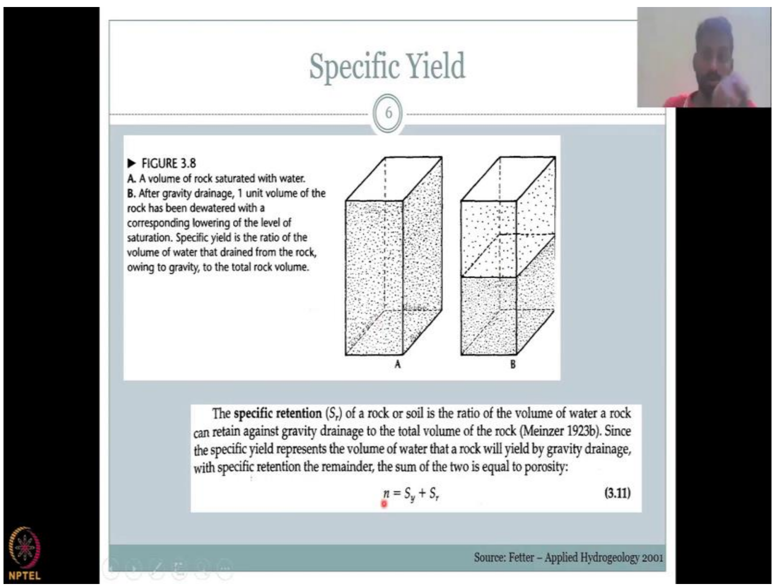

Let us look at one more unit diagram, in the first diagram we have a volume of a rock which is saturated fully with water and then one unit volume of the water has been de-watered or drained in b and there is a lowering of your saturation, you can see the water level is fully saturated in a and in b, it lowers by a unit volume of the rock. Specific yield is the ratio of the volume of water that drained from the rock owing to gravity to the total rock volume.

So, you have the total rock volume that given to this specific yield. So specific yield is a very good very important measure to hold on how much water can be drained by gravity and what is remaining, it also gives you an understanding of how much water is remaining in the pore space. So let us give it a name, to identify what water is remaining in the pore space. And that is given by specific retention, or SR, specific yield is normally called SY whereas SR, is the specific retention.

As the name says, retention is the process of holding on, it keeps the water back. So, SR of a rock or soil is the ratio of the volume of water a rock can retain against gravity. So, the specific yield is owing to gravity, gravity pulls the water whereas retention is the property of the rock in holding on to the water against gravity, to the total volume of the rock, the ratios.

So, you can leave the ratios in specific yield and specific retention out just to understand that in a pore space how much water is drained by gravity and also in a pore space how much water is retained by the soil property in specific yield it is due to the gravity and the property of the rock or soil. Similarly in retention the property of the rock and soil plays a vital role because it holds on surface tension is high it holds on to the water absorption, absorption would be high, chemical properties would be high to hold on to the water.

Since specific yield represents the volume of water that a rock will yield due to gravity the specific retention is the remainder of the porosity. Therefore, if you take a porous medium half of the water or part of the water could be given out by specific yield, whereas the remaining water is held on due to specific retention.

So, if you start with a fully saturated system like in figure a, the sum is just the specific yield how much water is lost to gravity plus your specific retention which is the water held on due to the poor material property. So, it is just basically the sum of these two terms will give you your porosity in a fully saturated system. If it is not fully saturated what happens you have some air so that air would be added to the n component along with SY and SR.

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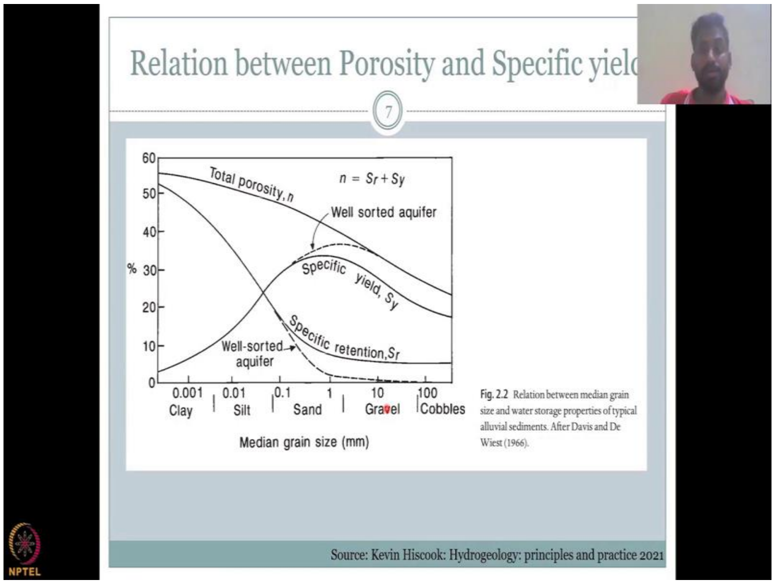

So let us take the relationship between specific yield porosity and specific retention in a fully saturated system. How does it look like? So, in clay and you could see that the total porosity could be high as 60 percent in clay, compared to that in gravels and cobbles and sand. So, if you start with clay in a well the specific yield could be very, very low as I said it does not allow water to pass through and gravity cannot pull the water because clay holds on to the water.

So, when you look at clay materials you could see that when you apply water it actually forms into a rubbery kind of a material, it prevents, it swells, it takes a water and starts to swell, when it swells it stops the water from passing through and that is causing a very low specific yield and this is the size, the size of the grain of clay. The clay grain is very, very small so there is a lot of attachment between the particles and the porosity is very high and, same silt, sand and gravel and cobbles.

The grain size is given on the x-axis and the y-axis gives you the specific yield and also the specific retention along the porosity all are same units as percentage. So, the specific yield picks up in silt and sand the space between the grain, between the material increases so you have more space for water and air but the specific yield also mentions that it gives off the water.

So, the porosity is actually coming down from clay to cobbles and the specific yield rises because gravity can easily pull the water out but when it comes to gravel and cobbles it tries to come back down in specific yield, because some of them would hold on to the water. In a well sorted aquifer, what is well sorted? The sizes are same, similar and they do not have porous space on the top.

So, in a well sorted aquifer your water could be fully drained out which is the total porosity would occupy the water, the water would be full with the porosity space but it can be fully drained also. So somewhere a specific yield can be equal to the porosity which means the retention is 0, no water is available and that you could see on gravels and cobbles.

Especially in gravels in beaches you have big, big rocks along the beach and when water comes in it just goes down, there is nothing, the water is stored in the gravels, it just flows down and which means your retention is 0, specific yield is very high, total porosity is specific yield. Once the water is removed, the pore space only has air there is no water, no retention.

Let us see the opposite. You have high retention, water is held on to the material in clay, it comes down as the size of the grain increases, so it comes down pretty high, the specific retention and in a well sorted aquifer, the well-sorted aquifer like your gravel as I said water flows through, so your retention is 0, whereas your specific yield is high.

So always you can add all these together to get your total porosity and your total porosity in a saturated system is always equal to your surface retention plus surface specific retention plus specific yield. And these are the property of your solid surface and also the gravity. The gravity is a constant across so you can only look at both of them as for the material that is why we have the material on the x-axis to understand this. And please understand that once the porosity is drained a specific yield is draining the porosity, the remaining space is taken by air.

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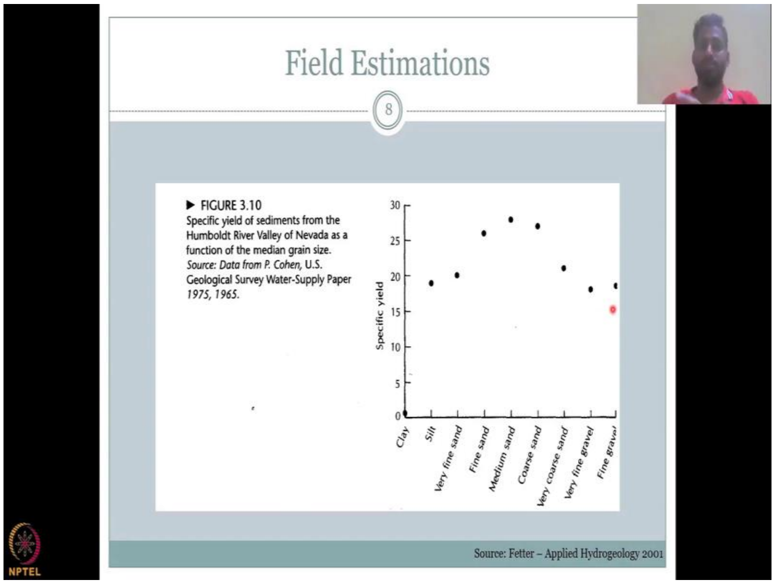

Quickly I will show you a field example taken in the U.S. for different size and class of material which is given on the x axis, the grain size as I showed in the previous would be very, very small in clay and increases to high values on the x axis, fine gravel is high. So, the specific yield is almost 0 in clay and suddenly rises, so silt and very fine sand will have space where the water can enter and gravity can also pull.

So specific yield increases as the size of the material increases and when it comes to very fine gravel and fine gravel the fine means it has small particles within the gravel which actually slows down the specific yield. So even though the size is high your specific yield is reduced slightly because of the presence of intermediate solid materials.

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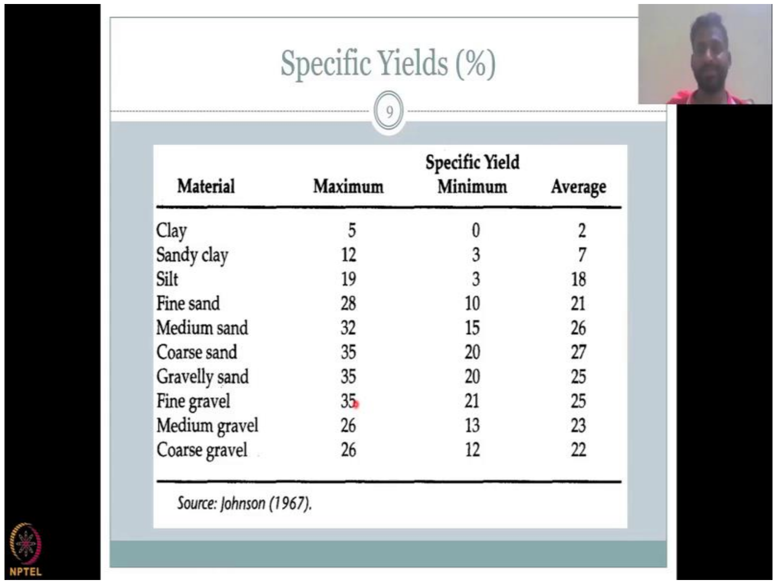

Material	Maximum	Specific Yield Minimum	Average
Clay	5	0	2
Sandy clay	12	3	7
Silt	19	3	18
Fine sand	28	10	21
Medium sand	32	15	26
Coarse sand	35	20	27
Gravelly sand	35	20	25
Fine gravel	35	21	25
Medium gravel	26	13	23
Coarse gravel	26	12	22

Then you can look at the specific yield as percentage and depends on the clay, it is type of rock which is clay, sandy clay, silt etcetera. The soil and rock as I said is a transferable term in groundwater hydrology because you can say clayey soil, clayey rocks which are brought by the weathering off or turns into clayey soil. So gravelly sand is a lot of gravel which is weathered and becomes gravely sand or soil.

So, what you can see here is the material and you have a maximum specific yield and a minimum specific yield as a percentage and normally what do you use for studies is the average. So, 5, 0 average is 2, I think you are safe in using the mid value or the average value. So, all these even though the studies are pretty old are mostly constant and depends on the site, so your site might have different clay, red clay, black clay et cetera.

So, depending on the species of clay or the type of clay your specific yield range is there and also depending on the amount of mixed. So, when you say sandy clay it means sand is mixed with clay and the percentage of sand in clay could be different and that drives the specific yield value. If you look at the variations, the variations are pretty high when it comes to medium sand, the sand maximum is 32 and 50 and then gradually comes down to 35 and 20 which is around 15 percentage differences in coarse sand, gravel sand et cetera.

So, the max values are ranging at 35 for all the sand units and gravel units. Whereas, the lowest value or in clay with specific yield as 0 and wherever clay is mixed it pulls down the specific yield value. So, this course does give you an introduction to these components, so that you understand when you look at a groundwater aquifer, the groundwater report from Central Groundwater Board these are the terms that they will use, they will use porosity, specific yield and aquifer recharge.

So now you know what specific yield is and how it is related to the material that is present and the mixture of the material. With this, we will conclude today's lecture, I would see you in the next lecture where we discuss more on the groundwater components. Thank you.