**Groundwater Hydrology and Management**
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**Lecture 16**
**Groundwater Hydrology Components 5**

Hello, everyone. Welcome to NPTEL Groundwater Hydrology and Management course. This is week 4, lecture 1. The past week lectures, we were looking at the introduction to groundwater and some components that are very important for groundwater. In this week, we will do a recap of week 1, 2, 3 and see how the past three weeks are linking with this current week.

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In the first week. we looked at the introduction to groundwater wherein we understood what is groundwater, how much fresh water is available on the planet. And out of the fresh water, how much is groundwater. In week 2, we looked at the importance of groundwater at both international and national stages. In the international stage, we quantified groundwater in different major aquifers and we found that one-third of the groundwater basins are tremendously stressed, they are under depletion unsustainable abstraction and so there is one third of them under tremendous stress.

Then we came to the Indian context in week 2, and we stressed on the fact that India is the leading groundwater extractor in the world with approximately 260-to-265-kilometer cube extraction per year. We also looked at what are the major drivers for groundwater depletion and we found that it is mostly linked with agricultural and industrial use. In agriculture, we also looked at some crops like wheat, rice and sugarcane that were consuming more of water.

In week 3, we looked at the groundwater hydrology concept and we looked at the major components for groundwater hydrology. The same way we will also look at some groundwater hydrology concepts for this week because there is a lot of components and since this is an undergraduate level course we will look into detail some of the components, not all, but some components which would help you to understand groundwater hydrology and also to run models.

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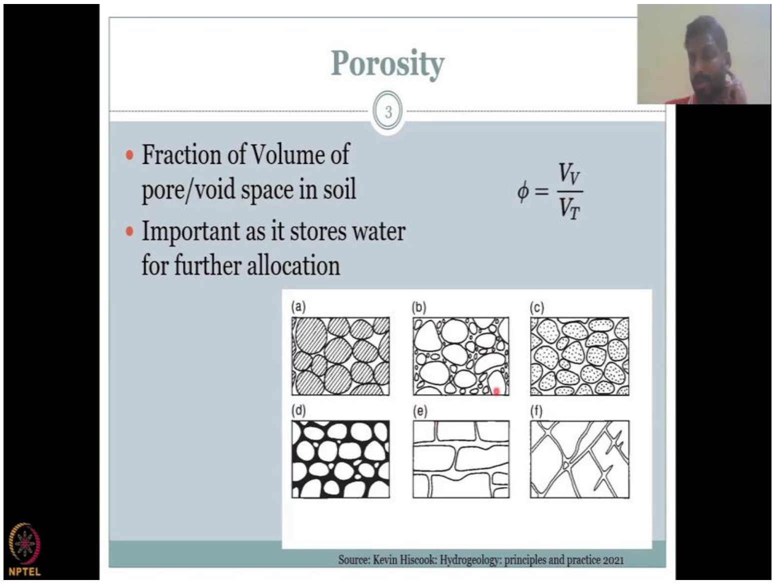


Moving on, the first and very very important component would be porosity. The porosity is defined as the fraction of volume of pore and void space in soil. It gives you a fraction of the total volume of the solid of voids and voids is the space in between the solid material, we looked at it in the previous week's lecture and divided by the total volume of the solid. So, this porosity gives you a good fraction, a ratio of the amount of space for space present inside a solid material to the total volume of the material.

So, think about it, if you, if the volume is too big compared to the pore space, then the phi or the porosity value is very, very less. And such a less porosity medium or a solid or a sediment cannot store more water. It is important to understand this value as it stores further, the water for further allocation, for the percolation which is movement of water under the ground and also for groundwater movement.

Quickly, let us look at a, b, c, d, e and f the images on the screen you can see that the blank space that is present inside the solid material is the volume of void. And the total volume of all this would be Vt and if you just sum all these volumes together it will be total Vv. So, the ratio gives you porosity.

The pore space can be filled with air or water that is okay, but now we are very interested only in the space. It can be filled with water, it can be filled with a mixture of air and water, it can be anything that can be occupied. However, it should not be the solid material, it should not be sand so that for example is given in b, you have a material but in between you have some smaller materials. So, we need to subtract all of those while we estimate the volume. There are different ways to estimate the porosity and first let us look at why it is very important.

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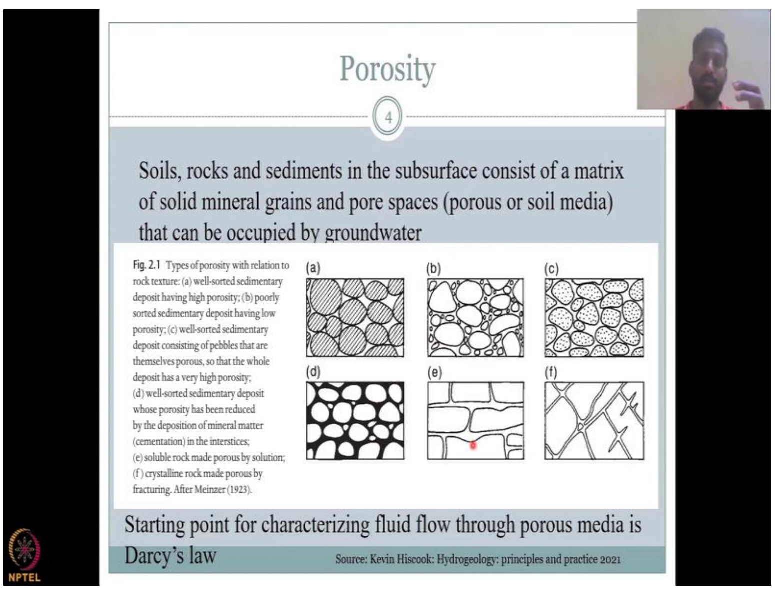


Soils, rocks and sediments in the surface and subsurface consists of a matrix of solid mineral grains and more spaces. When you say matrix it is an arrangement of the solid material, we have the rocks and smaller rocks present in the material which forms matrix and they are not gelled together, they are stuck together but there is some space and that space is called space or the total medium is called porous or a soil media.

And this is the space where groundwater can go in, groundwater is not going to take out a sediment and then get itself stored, that could happen in a flood another situation. A normal groundwater recharge infiltration needs a space. For example, if you have solid rock which is not weathered and rain water falls on it, water will not move in because there is no pore space. It will just wet the rock and the water will flow down.

However, here we are looking at a case where the water needs to move in and that movement is through the soil material or solid matrix. Wherein, it goes through the pore spaces and joins the pore space and comes down. Sometimes if it cannot move down due to gravity and still water is coming, it moves laterally, horizontally and we will see what that constitutes.

So let us take an example from the hydrogeology book, principles and practice. You could see very clearly there are multiple types of porosity with relation to the rock and solid type. The first one a, is a well sorted sedimentary deposit. An introduction in geology for sediment means it is transported by a medium, the medium could be air or water. So, wind can blow sediments but mostly we are talking about water like rivers, streams, glacial melt so water will bring the sediments and gets deposited.

While it gets deposited as sedimentary rocks, they have high porosity because you expose it to air, there is some space and then another layer comes with water, another layer comes with water. So, there is good amount of space in between the pore space, which is a, and then it is well sorted, which means the size is almost more or less the same. And that is called a well sorted medium. Then we have the poorly sorted sedimentary deposit b, which has a low porosity compared to a.

So, why does this have a very low porosity? Or what do you mean by low sorted, poorly sorted sediment? You could see that the size is not the same of the solid materials, and there are smaller materials present inside the pore space, which actually prevents water from entering, it occupies a volume which is not good for groundwater. So, those kind of material are called poorly sorted and poor porosity materials.

Then we come to c, c is similar to a which you can see that what is the commonality. a and c is well sorted, almost the size is same. So, that gives you extra pore space in between the rocks. But the important factor in c is, c surface of the rock or the material also has pore spaces. And those have extra space for water to be stored. So, it adds up the volume, it might be a drop but all the drops add up for ground water. Similar, like a flood, surface water flood, you have rain coming only by drops but then it adds up and then you have flood. Same way here all these small tiny, tiny water particles would add up to constitute the groundwater aquifer.

So now, if you ask me, would a have more water or c have more water, if both are same, sorted same material etcetera, c would have more because on the surface you still have some water, it is not only between the rock materials but also on the rock materials you have water particles which are available for other uses evaporation, transportation, plant extraction and groundwater flow.

So, well sorted sedimentary deposit consisting of pebbles that are themselves porous, so the whole deposit has a very high porosity. So, the whole deposit or the sedimentary layer, that layer has more porosity than a. Then we go to d, well sorted look at the size, it is well sorted sedimentary deposit, whose porosity has been reduced by the deposition of mineral matter, which means in between the material it is well sorted, the sizes are almost same but in between there is a cementation, a fluid material that of the mineral material that actually gels them together.

So, in fact, there has been a porosity but the porosity is occupied already by the mineral matter itself, so the porosity is reduced. So, from a it is reduced because the black material is filled, which is a formation process of the rock and mineral. So, that mineral content would actually deplete your porosity.

Moving on to e, it is a soluble rock made porous by solution. So, initially it was a rock so, this is a material which is initially a rock but slowly water or other chemical substances started to dissolve the rock and flow through, thicker like chalk, this simple experiment you can do at home. If you have a chalk and then you pour water it can actually put a hole through the chalk and then you come out, same way here this material in the real-life scenario would be limestone in the caves and mountains you see this.

So, limestone is a big rock, but when water goes in through the rock and formation it will cut through it and cut through it and that causes porosity. Yes, the water was occupied but while it cuts it also goes out of the system. So, after that there is space for the water to get stored. And so thereby increasing the porosity.

And many, many caves like that in India but mostly outside the world it is called cast geology, wherein, a mountain or a small hill stations and etcetera under that would be cut through water. Batu caves in Malaysia is very famous too and known for it. Where the water will just carve the inside of the mountain and the hills and then it comes out. So, you have a big hole. It is like tunnel, it is like tunneling but not through mechanical means, by natural means.

Then we have f type which is a crystalline rock made porous by fracture. So, the rock is there, the same like e, the rock is there. But the rock did not crack because of water alone but here there is weathering also, fracturing is a process in weathering, where the rock breaks. The rock would break by elements, the weather elements like heat sunlight's heat and movement of rocks, and also water that can enter through the rock can crack it. So, in the cold time the water expands and cracks the rock. So those fractures are porous space, once you fracture it there is space.

So, think like this is your rock and there is no space in between but then you fracture it, so now the water can be stored in between. So, what is the difference between this f porosity and e porosity? f porosity once the fracture is made, the most it can do is maybe the size of the fractures can be a little bit more increased because water goes in itself, but it is not soluble. Whereas e, it is soluble, it just dissolves the rock. So, it is if it had five fractures as water and other elements move it can dissolve the fractures into a massive one fracture.

So, all these tunnels and you underground rivers that you see are made by this movement of water, and those are big porous space so, that is a porosity but very, very big. The rivers that you see under the ground. But f is mostly the cracks and that is why you see even though it is similar to e, it is in a connected, more connected and fracture kind of a pattern. This is a starting point for characteristic the fluid flow through porous media according to Darcy's law.

We will get into Darcy's law and experiments and slowly we will look at the equations for unconfined and confined aquifers. We looked at the unit of analysis as an aquifer in the previous lectures, here we will get into the sub components in the aquifers and the first property that we saw, the aquifer is the porosity. How much pore space is there in my aquifer is very important to understand so that I can store the water.

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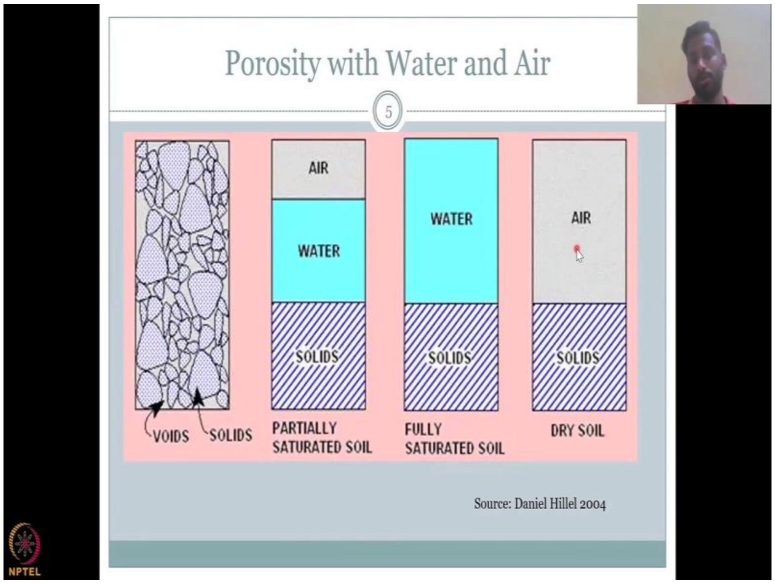


Let us look at some more graphical representations. So, the first material you see is the actual soil or rock matrix, the arrangement of rock soil materials. What you see it is a kind of a well sorted, [technical difficulty] particles in between there is good solid particles and also there is inter space between the particles.

So, these solids are represented as the dotted and dark lined circles, whereas the voids are in gray color. So now if we shift it as just partitioning it into three components, you can look it as the material as a partially saturated soil, wherein there is solids, the blue things are the solids and there is a mixture of water and air, which means the pore space, this space can be occupied by water and some of the space can be occupied by air.

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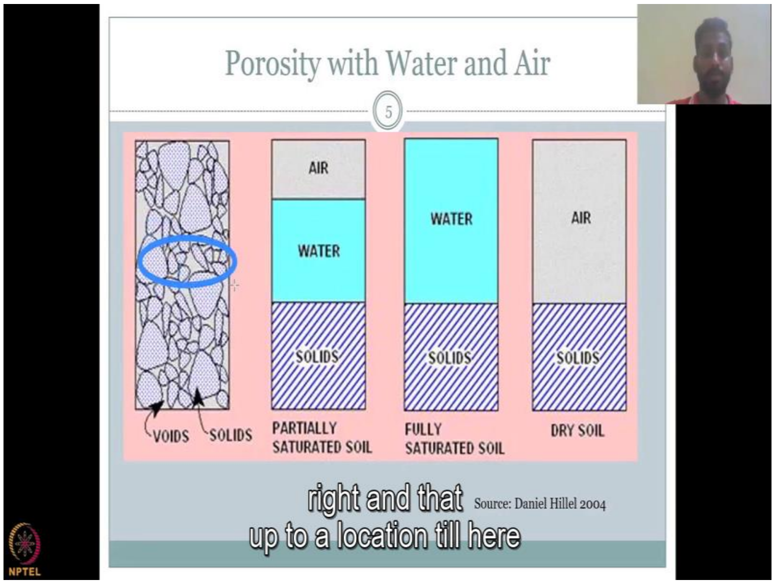


In a normal scenario it might be like this so, you will have water entering in up to a location till here and that location would actually mean that is the water table as we saw in the previous lectures. Basically, you would have water until here so which means all this pore space would be full of water.

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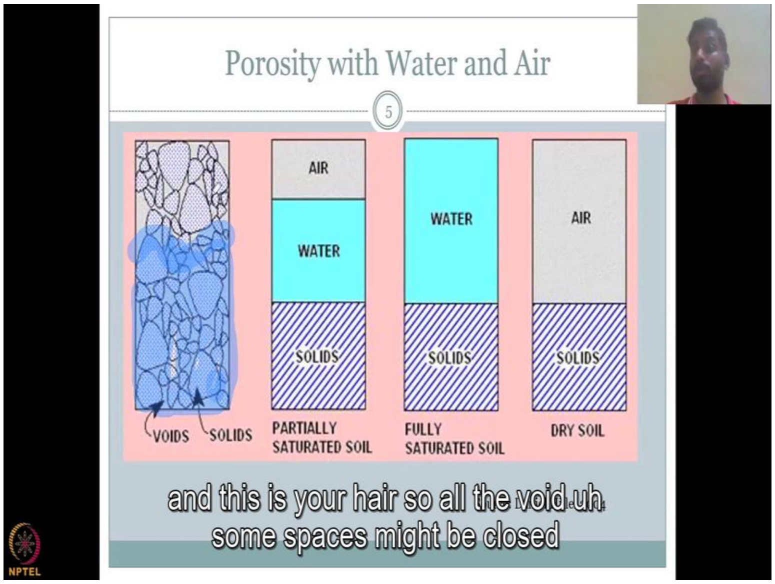

Some spaces might be closed, most of it is water. And this is your air, so all the void particles here are filled with air along with the solid. So, the solid is there, air is there on the top, in the bottom it is solid and water, if you take the volumes it would look like this, your solids and other things.

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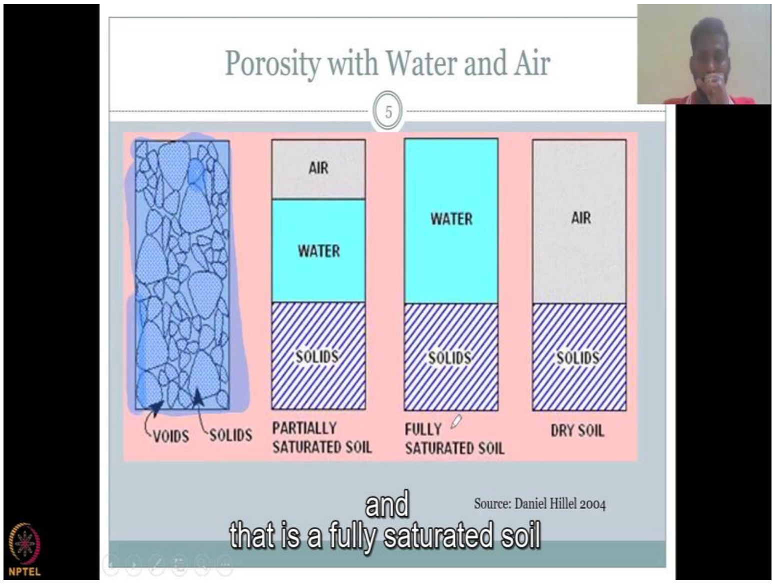


So, you have a mixture of air, water and solids but in a fully watered system. So, I apply full water into the soil which you do during your irrigation practice. You apply full water cycle and when you apply so much water, what happens is the air goes to almost zero level, negligible air is present. So how this look like? It will be looking like a solid like this, it is full of water, all this area is covered with water and that would be driving out, all the air out. So now you have a system where all of this is water and that is a fully saturated soil.

So, the partially some area was not saturated with water on the top but in a fully saturated, all the air spaces are driven out. So now your farmer is happy, you start with the system where there is air and water, there are plants and then you put water more so that the plants can take water, that is how water moves right, water will go down and push the air out in the ground water.

Now it is fully saturated soil, slowly the plants are taking it out and the sun is evaporating the water on the surface of the soil and soon all the water is lost, and at that time there is zero water in your solid material. And thereby, you only have air and solids, air in the void space, the black gray space and then you have solid materials as rock materials.

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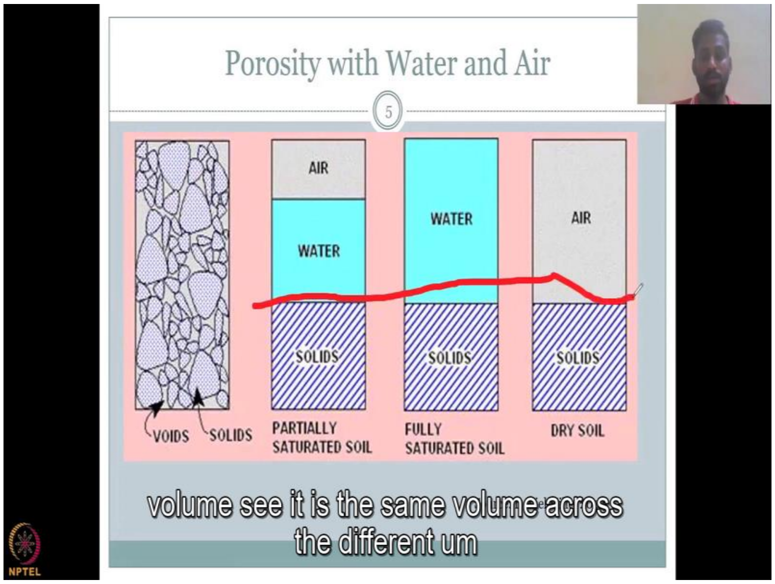


So, what happens is the volume of void is the same but the composition of water and air will change, the solid is the same, look at it, the solid volume is almost the same, it does not change. So do not assume or think that the solid material would change, it is the same volume, see it is the same volume across the different types, dry soil, fully saturated soil and a partially saturated soil.

What actually happens is because of the application of water or extraction of water the void space, the space where air and water [Technical difficulty] changes. The space changes as in [Technical Difficulty] water which is fully saturated or with air and water mixture of air and water which is partially saturated or only air which is a dry soil, and this is a danger for your farmer because he or she has to start irrigating. So, this air is not conducive for farming.

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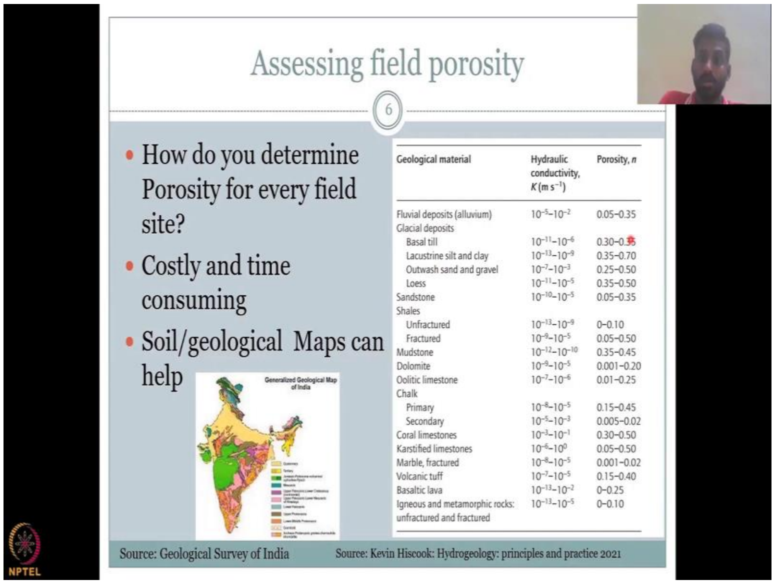


We will look at the porosity and how it is estimated in the field. How do you determine porosity for every site? Is it possible like every farmer can they actually do a test, test is done by taking the sample to the lab and when the sample is taking, a mass is taken or it is a volume is taken in a measured container and then you take it to the lab and crush it so, when you crush it and powder it all the voids would become less, why?

Because you are, you are changing the structure, the matrix of the solid and actually you are converting it into a fine, fine solid, when you do a fine solid all the pore spaces come down. So, you crush it and then you push it in so that the volume is reduced. Now if you know the volume before and after crushing, you can estimate the porosity. How do you drive the water out?

You actually throw these solid into a oven and heat it for at least two to three days, 100 degrees centigrade thereby driving the water out. So, the oven would be on for two or three days because it is very hard to get all the water out, it will be stuck inside the solid and they will do it slowly, it is a very slow process. So once you take it out the water is removed then you crush the solid to remove the air inside and then you estimate the volume, so you have a volume before and the volume after.

Now the question is can you do that for every field, every village in India? And it is very, very costly and time consuming. Therefore, if you know the type of the solid material and the geological map, you can estimate how much would be the porosity. And for that there is a lot of books and materials. So, the book I used here is the Hydrogeology, principles and practice, version 2021 year.

And you can see the type of geological material, sediments, sandstone, shale, cast, limestone etcetera, and you could see how the hydraulic conductivity and velocity changes. We will come to hydraulic conductivity later, but the porosity varies as you could see here 0.05 to 0.35, sometimes it is represented as a percentage so 5 percent to 35 percent is volume of air space as per, as per this number.

So just visually thinking which ones would have the biggest value? So, the biggest values would be in the fractures. The fractures have a good amount of porous space because it is cracked and the cracks could be joined so that is 50 percent approximately, but also your lacustrine which is your along the rivers and oceans, silt and clay deposits, the deposits as I said in the early slide will have the high values for porosity. And in fact, that is the biggest porosity on the list.

The limestones and cast, as I said it is a big porous space but sooner or later all the pore space would be gone which means the solid material would be dissolved all of it and so the solid material will crush down. So, you could estimate it up to a particular level which is 0.5 but after 0.5 the water will just eat through the system.

So, in your agricultural related work it will be fluvial deposits, glacial deposits, sandstone and mudstone especially in India it will be your sandstones, silt and clay fluvial deposits and some more or less shale and fractured, so more most of them are the fractured network. So, if you know the solid, if you know the type of geology in a particular location, you can estimate porosity. How do you get at the geology? You can use the geological map of India by survey of India and geological survey of India.

So, these maps are very handy, which give you the geological setting in India and this is a stationary setting, you cannot change the geology overnight. It has been a big long process and so these maps even though they are old are very informative in giving what type of rock is present under the ground and based on the rock the porosity can be estimated.

For example, the Ganges plain you have all these deposits from lacustrine and silt and clay and fluvial deposits. So, fluvial deposits are more alluvium and so the range you could say is 0.05 to 0.35 or 5 to 35 percentage. So, someone can ask me sir why do you have such a range? The range could be due to the use of the soil and the maintenance of the soil tilling and other things and what plants are growing in, so always there is a range, there is no one value associated with porosity.

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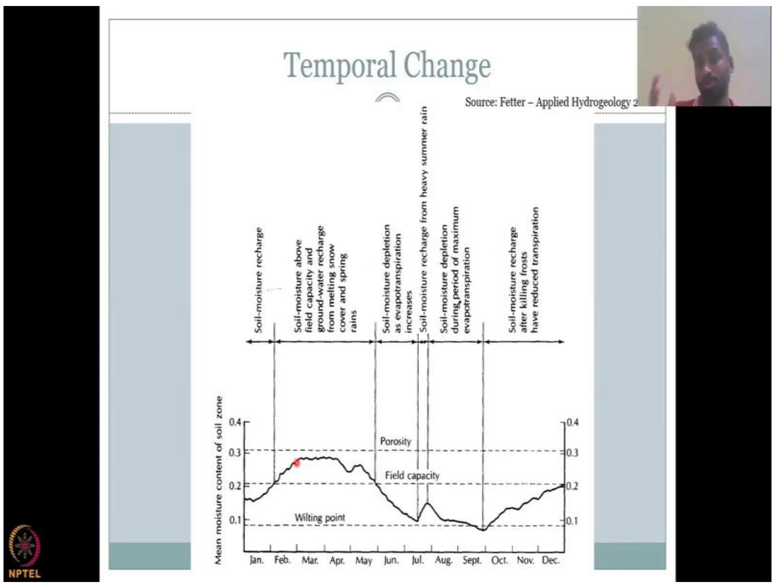


Moving on, the porosity space and the amount of water that enters into the soil is not stationary. As I explained in the previous differentiation between partially filled, fully saturated soil the amount of water inside the soil would change. Let us take a calendar year Jan to December in a system where you have good monsoon in Feb, March, April and then summer would kick in June, peak summer in June July.

So, what happens is you have, initially you start in Jan where you come from winter you have some water coming into the system. So, the soil moisture is okay above 0.1 and wilting point is the line and below which if soil moisture comes down you have to irrigate the field at once, it is very very important to irrigate the field after wilting point.

So, this is on the x-axis it is the amount of water content in the soil, how much water is present and your porosity is the maximum. So, this is the maximum pore space above which water cannot exist, so there is pore space is so much and you can fill it until the porosity is reached which is fully saturated soil.

So now you start with the system, there is some water in the pore space, and then the water increases, the water increases above the field capacity. The field capacity is the best amount of water which is needed by the plant to survive. If you go above and too much above then plants can suffocate. So, you have to be careful in watering after this. There is ground water recharge from melting snow and springs as I said Jan Feb be the time when spring comes so all the water would melt and the melted water can go into the ground water so you have an increase and then there is some rain and et cetera.

Then your summer starts, so soil moisture is depleted as evaporation, the summer pulls the water out through evaporation and plants, plants are taking the water and transpiring. So, there is transpiration. Then you come down, the soil moisture comes down in the pore space and it comes below the field capacity. So, at this point it is very very important for the plants to get water to survive.

So, what do you do? You actually start irrigating the field by other resources otherwise what would happen is there is a small rain. So here you can see summer rain is there, a small heavy rain happens but most of the soil moisture is depleted because of the summer and plant activity and then it goes below field capacity, wilting point when it goes below wilting point it has to be recharged either by rainfall or by other means.

So otherwise, you should stop planting the crops, so once you plant the stop planting the crops the soil moisture starts to raise again because your transpiration is coming down and also your snow and other rain are coming up. So, this is a system in the cold weather, snow climate season site and that site clearly shows that it is going up and down.

In the next lecture, we will also see how this can be compared to a system in India in the tropical or even the central parts of India, where you have mostly summer and winter, winter no snow but a very low amount of rainfall and also a long summer followed by a monsoon. So, with this I would like to conclude the first week lecture, day 1, on your ground water porosity and other aspects.