Groundwater Hydrology and Management
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Lecture: 28
Groundwater recharge estimation methods-I

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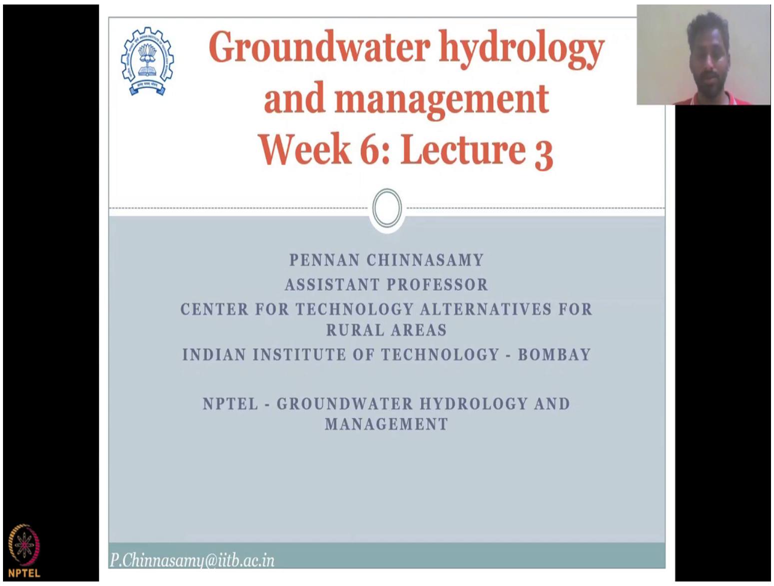

Hello everyone, welcome to NPTEL course on groundwater hydrology management. This is week six, lecture three. In this week, we are looking at the important definitions for recharge and discharge, how groundwater enters the aquifer and groundwater storage through recharge, and how to estimate them. The previous classes, we looked at certain concepts for groundwater recharge, what are the key methods physical, numerical, tracing methods etcetera.

Now, we will get into some of the actual methods that are used by the government of Indian agencies, especially the GEC groundwater estimation committee and the central groundwater board. These are very important to understand because these equations and methods are used throughout India as a baseline. So, it is important to understand these two make sure what these recharges are made under assumptions and how to tabulate them.

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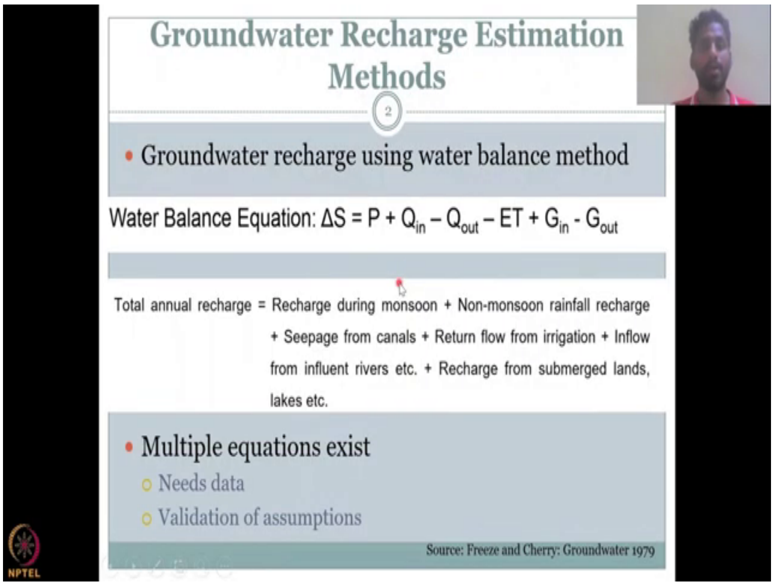

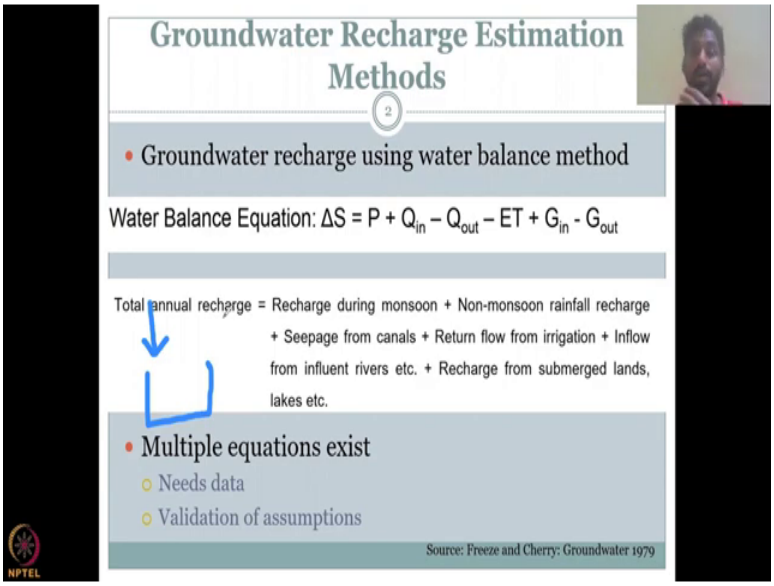

Groundwater Recharge Estimation Methods

2

- Groundwater recharge using water balance method

Water Balance Equation: $\Delta S = P + Q_{in} - Q_{out} - ET + G_{in} - G_{out}$

Total annual recharge = Recharge during monsoon + Non-monsoon rainfall recharge + Seepage from canals + Return flow from irrigation + Inflow from influent rivers etc. + Recharge from submerged lands, lakes etc.

- Multiple equations exist
  - Needs data
  - Validation of assumptions

Source: Freeze and Cherry: Groundwater 1979

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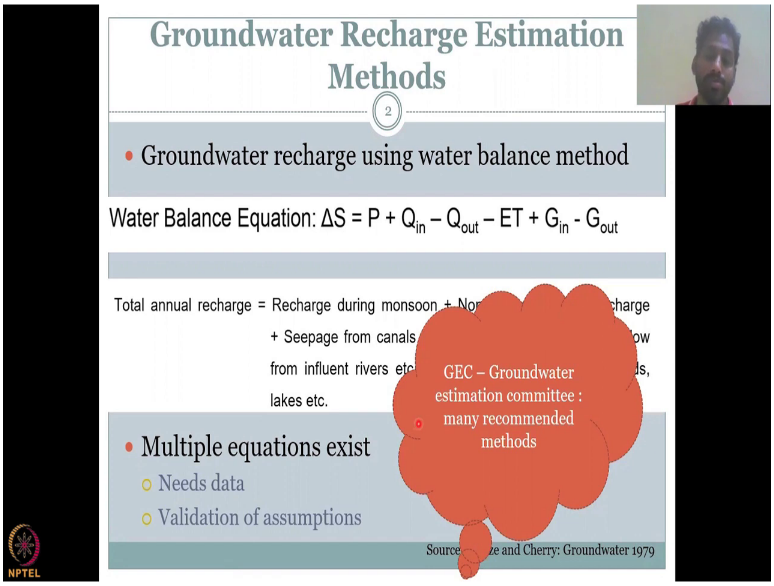

Let us move on. So, the first method is the groundwater recharge estimation method using the groundwater balance method. I will not dwell much on this slide, because we have introduced the groundwater balance a lot in this lecture. The water balance method or groundwater balance method is the same method. But, in groundwater balance method it is a more focused on groundwater but it can be also called as a water budgeting method.

So, these terms can be interchanged, the first equation as you saw was an overall general equation, for the base in our watershed and del s is a change in storage which is nothing but your precipitation, your Q in your surface runoff in's and then surface runoff out is subtracted from the total, your ED is subtracted from the total and your groundwater in minus groundwater out.

So, the net is your del s change in storage. The storage can be multiple storages, is one is your tree plant inception storage, one is your surface water storage, one is your soil storage and then your groundwater storage. So, it depends on where you use this equation and this equation can be used for overall hydrology and also getting in groundwater recharge.

The next one is your specific water balance method for groundwater, it is called total annual recharge, in the left hand side which is your what do you want to find, you want to find the groundwater recharge and the total recharge is equal to the summation of the recharge during monsoon, your non monsoon rainfall recharge.

The seepage from Canals plus return flow from irrigation plus inflow from influent rivers etcetera, plus recharge from submerged lands lakes etcetera. So, your net recharge, let us take a well and in this well where are the water going to come. So, as they say first the recharge through rainfall, the rainfall can get into the ground and then come as groundwater flow, during monsoon. So, there is some rainfall during monsoon and then there is non-monsoon rainfall, off season rainfall also sometimes happens that also recharges.

So, we are looking at the total annual recharge on the left hand side. This one seepage from Canals as I said when the dam water is filled up during monsoon, some of the water is channelized to these irrigation fields, the irrigation fields along the way will not have cement line and those canals would give recharge.

Then return flow from irrigation you take the water from the canals you take the water from your dam or even ground water you apply water to the ground. So, let us say you are applying water to the field, you apply water into the field what happens is the plants take the water yes. Some soil moisture is taken yes, but you apply more, so, then the water will eventually go down to the groundwater aquifer.

This is called return flow very important term in groundwater recharge also irrigation they will ask you how efficient is irrigation most efficient irrigation would reduce the return flow. So if you look at sprinklers and or direct irrigation techniques where the drip irrigation is used only to the root zone only to the particular plant then the return flow is very very less. Inflow from influent rivers etcetera.

When rivers flow the water can be lost to the groundwater we saw this losing stream gaining stream concepts etcetera which has formed submerged lands, lakes etcetera. So, all these water bodies that are inside the land can also give groundwater discharge. So all this can be estimated using a mass balance approach. In this first mass balance it is looking at the hydrology of the entire watershed.

Whereas in the second it is total annual recharge, which is summation of the individual recharges. Some of these can be calculated using data some of these could be estimated, but it is good to have data for everything. So multiple equations exist, the drawback, you can make it as big as you want or as small as you want. And then you can keep on adding terms.

For example, let us add one more term here. So you have your total annual recharge and then rainfall is happening etcetera etcetera, then I will say that the water is being brought to the houses using pipes. What if the pipe is leaking, then there is recharge to groundwater, because inside inside the ground, so you have to think about how. For example, this is a ground and this is your big water pipe connection.

There should be some water leakage. And that can also contribute to groundwater recharge, so this systems contribute to groundwater recharge, it is bad quality, but quantity yes it increases. So countries like Nepal have a lot of these old water supply schemes. And there is always leakages in. Multiple equations exist for water balance, which means you can bring it make it big or small as and as big as needed. But all of this need they do not have data they will say it is negligible, or they will not put the component on the equation.

So lot of data is needed and validations of assumptions is very very important. For example, if you say that there is no return flow in my recharge equation, that means you should make sure that this irrigation compound is now there. For example, in urban area full of buildings, no agriculture, so return flow will zero, you will not have any return flow.

For example, there is canals, see this goes to zero. So all these assumptions have to be validated by certain logic. If there is no rainfall, then there is no rainfall recharge. So that is flow is zero. So all this is very, very important while making these equations for water balance. So GEC groundwater estimation committee has recommended many methods and the methods are based on particular sites, particular use of water. For example, urban versus rural water, and also canals and non-canal regions, etcetera.

This book, I have put it there, GEC 9097. Just Google it, you will find it. There is a PDF from the groundwater board central groundwater board, it is a government of India, approved agencies government of India's agency. So they give you all these equations and different methods. So when you want to propose something to a village or understand if the village or area is doing good groundwater activities, you could look at this by the estimation method.

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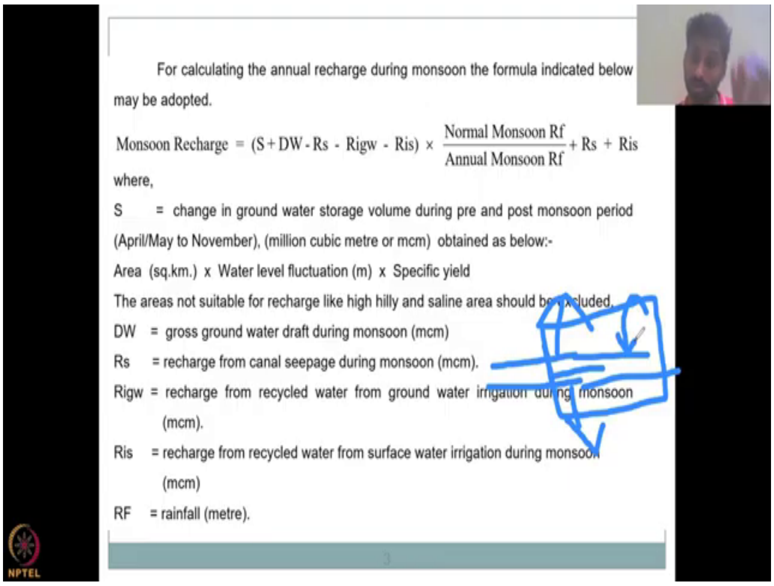

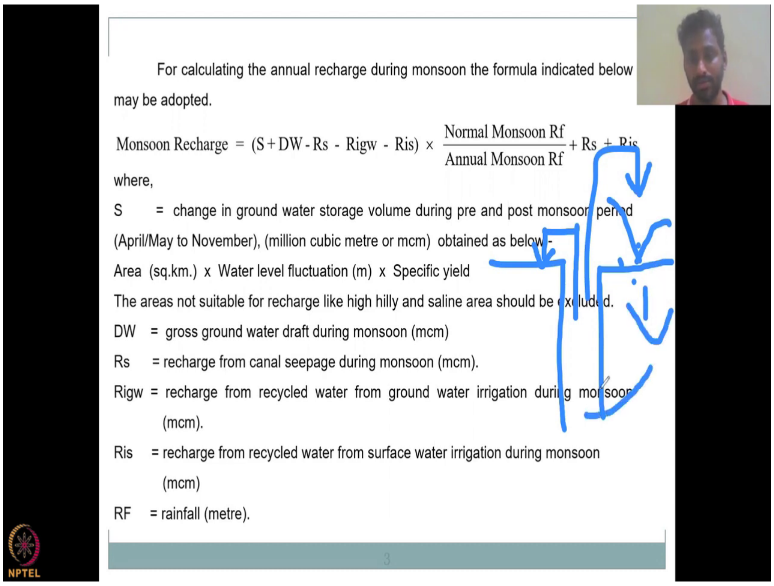

Let us look at some. For calculating I am just taking one example from the book for curbing recharges during monsoon the formula indicated below maybe adopted and this is only annual recharge during monsoon. So, this is only the monsoon recharge if you look at the previous equation we have total annual recharge is including our monsoon recharge. So, let us look at how monsoon recharge is done.

So, as I said each component itself will have a water budget. So, here monsoon recharges S plus DW minus Rs, but S is given as changing groundwater storage volume during pre and post monsoon period April/May to November. So, that is April-May is your pre monsoon, this is the typical monsoon period the JJAS, the June, July, August, September rainfall and then post monsoon is November. So, you have the April/May as a pre monsoon on the summertime. So, what is the change between the pre monsoon and post monsoon.

So, pre monsoon the groundwater level is low post monsoon the groundwater level will be high because rainfall recharge etcetera happened the subtraction of this is not only the recharge because there is the component of the soil to allow the recharge to happen. So, that is the coming as a specific key we will come to that. Then we the newness of million cubic metres or mcm, obtained as below.

The S is appeared as below, it is the area times water level fluctuation what is the difference in water level times your specific yield. So you have an area and then the thickness so the water so that is how the volume comes specific yield is a percentage. The area is not suitable recharge like high hilly and certain areas should be excluded because they are not going to anyway calculate the recharge in these hilly area saline areas because there is no use for the groundwater saline areas.

If you recharge the water the waters going to be salty. What is the use of salty water nothing. Same when hilly regions people do not get wells inside. So you do not even look at the recharge. So monsoon recharge has given us S plus DW plus certain other factors in negative which is minus Rs minus Rigw minus Ris which is given us recharge from canal seepage during monsoon Rs canal seepage Rigw is recharged from recycled water for from groundwater irrigation during monsoon.

So from ground water irrigation please know the terms GW irrigation groundwater. So there could be some irrigation using surface water which is given us Ris. So as I said you have a field and this plot can have a canal which which brings in water and because of that there is recharge. So there is recharge happening from the canal, so this is a canal and also there is a groundwater which is being pumped and then put on the feet and that water can also get down into the groundwater recharge. I will show you well diagram.

So for example, you have this assumed well. This is your field, so you have crops growing here when you pull water and put it now, which is you are pumping water and you are recharging your area, but most importantly you are supplying water to the plant. In water and supplying water to the plant. After the plant has taken by enough water, water will still move down and then recharge back.

So, this is the Rigw which is recharged from recycled water it is recycled from ground water irrigation during monsoon. So, all this is important to understand the different components coming within your equation. So, Rigw is a negative because you need to remove that Ris is a recharge from canal seepage you need to remove that because all it say is double calculating Ris is recharged from recycled water from surface water irrigation during monsoon because what do you want to do with the left the left you have only monsoon recharge which is a recharge coming from rainfall.

So it is very important not to double calculate your recharge. So if you are doing recharge estimation here and another recharge of saying seepage here, so you are double calculating this seepage, so very very carefully do it. If only monsoon recharge should only look at Monson recharge, which is your water level how it fluctuates times your specifically times your area, but make sure to remove your DW is also added but after you add DW remove Rs Rigw.

What is DW? Gross groundwater draft during monsoon because you have your recharge which is affecting your fluctuation, but you are also pumping so when rainfall recharge is happening you are also pumping that water is also added to the recharge because only recharge water you are pumping as annoying so take the monsoon water put it into the groundwater as recharge, but while you are putting the groundwater is recharged you are also extracting water and that water combines with the recharge to get net recharge.

So, S plus DW is net and then you have your removing your double calculations Rs Rigw Ris times your normal monsoon rainfall by your annual monsoon rainfall plus Rs plus Ris. So, all this is given as your monsoon recharge. What is RF? It is your rainfall in metres. So, this is subtraction time is your thickness plus thickness thickness. So, all this will be your thickness plus all these volumes and all this is very very important to understand how you calculate your specific recharges.

Because in this equation, you saw multiple recharges happening, but you should not double calculate. And you have to be very careful making this water balance equation. I recommend you to go through the book to identify other other methods. It is very very informative and we can pick up a whole two weeks of lectures based on this book because each and every one method given very specific directions and values.

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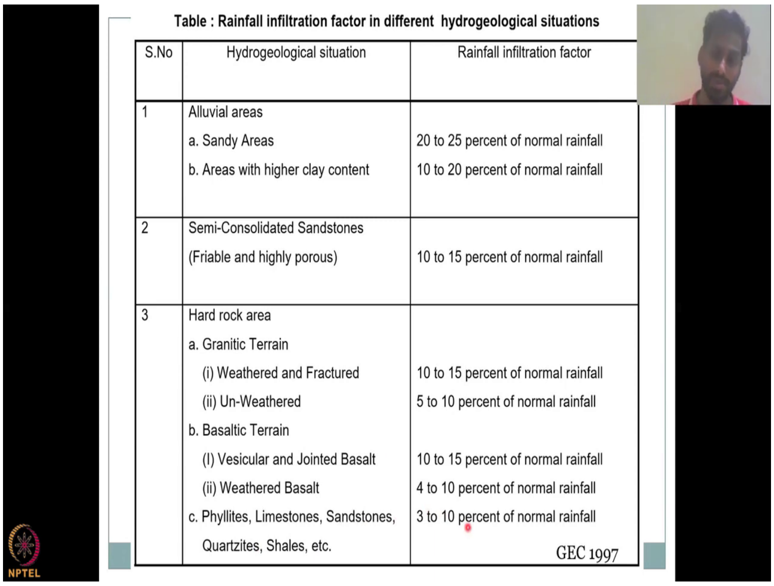

Table : Rainfall infiltration factor in different hydrogeological situations

S.No	Hydrogeological situation	Rainfall infiltration factor
1	Alluvial areas	
	a. Sandy Areas	20 to 25 percent of normal rainfall
	b. Areas with higher clay content	10 to 20 percent of normal rainfall
2	Semi-Consolidated Sandstones (Friable and highly porous)	10 to 15 percent of normal rainfall
3	Hard rock area	
	a. Granitic Terrain	
	(i) Weathered and Fractured	10 to 15 percent of normal rainfall
	(ii) Un-Weathered	5 to 10 percent of normal rainfall
	b. Basaltic Terrain	
	(I) Vesicular and Jointed Basalt	10 to 15 percent of normal rainfall
	(ii) Weathered Basalt	4 to 10 percent of normal rainfall
	c. Phyllites, Limestones, Sandstones, Quartzites, Shales, etc.	3 to 10 percent of normal rainfall

GEC 1997

I think some in this lecture for example. Let us look at it rainfall infiltration factor in different hydrogeological situations. What is the hydrogeological situation? Hydro geology not only geology, when it is geology, it is only rock sedimentary those kind of things, but when you call talk about hydro geological, then water is also part of it hydro. So rainfall infiltration is very important to understand these recharge factors if you go back to the previous entity.

You say that oh how much is recharge happening? What is the change in the groundwater storage etcetera etcetera. But if you do not understand the hydrogeological condition, you cannot do it and this is where you can estimate based on GEC recommendations, what is the rainfall that can go in because you do not you may not know have data.

Again if all these equations need data if you do not have the data and then GEC has given you recommendations. If your area does not have data simply analyze what type of geological situation it is. Let us take alluvial areas. Where are alluvial areas? We have that in the Ganges basin. For example, those areas are sandy soil, formations or sandy areas and areas with higher clay content.

So, the rainfall infiltration factor, which is how much here it is given us how much percentage of the rainfall goes into your aquifer through rainfall infiltration is calculated and it is given as a percentage 20 to 25, 10 to 20 percentage of normal rainfall. So, we have our for example 100 mm of rainfall around 20 to 25 percentage. So, 25 mm can get into the ground as infiltration.

This is not directly going to the aquifer, it goes as infiltration. After infiltration, it can be taken up by the plants it can be stored in the soil or go into the groundwater. Moving on the semi consolidated sand stones which are mostly found in the northern regions, along the western East northern regions you have some semi consolidated sand stones, which are less having infiltration capacity compared to alluvial areas because it is only 10 to 15 percentage.

Then we come to the most predominant aquifer system in India which is the hard rock area aquifer system where the rock is hard the porous space fractured and sometimes the fractures are not connected so water is not shared. So, in that type of area we have dramatic terrain weathered and fractured on weather rocks. So we have 10 to 15 percentage of rainfall infiltrates and goes into these kind of Soil formations. Please note that it says 10 to 15 from weathered which means broken un-weathered rock.

But when it is unweathered when it is still fresh rock we call or a rock which is not weathered due to conditions then we just five to 10 percentage of rainfall. So, the percentages help to differentiate the type of hard rock aquifer and then if it is ballistic terrain it is again 10 to 15 if it is a jointed basalt whether Basalt is four to 10. Jointed means it has more connections into intertwining each other and that makes the water to flow and store.

So, you can see from here that the GEC has given you a set of equations if you can have data fine, but if you do not, do not worry here are the other estimates that you can put into the groundwater equation or groundwater water balance. So, you have Phylites, limestones, sandstones, Quartzites, shales etcetera which are 3 to 10 percentage very, very less and unfortunately, this is the hard rock aquifer system in most of India.

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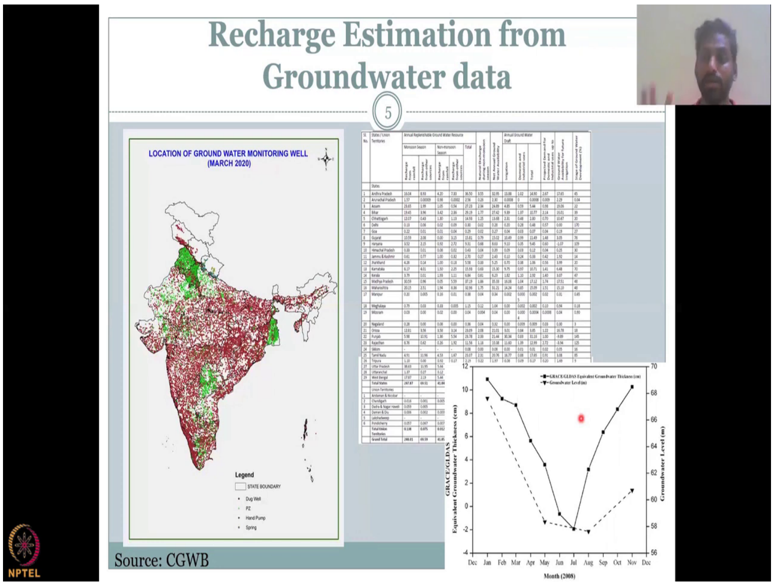

Moving on recent groundwater data , so let us look at some recharge estimation methods based on groundwater data the previous was the hydrogeological condition, the rainfall, etcetera. Now, we are going to look at only the groundwater data and how recharge happens. The good thing about this is we have a lot of data from the Government of India especially Central Water Board, which is well locations around 15,000 wells.

And all of them are given us data as state wise, district wise, and block wise, you can go into these data sets from online or the GCGWB quarter book the handbook they call every year annual book they release and it is very very informative of giving the situation of groundwater in India. Sometimes it is published once in two years, but sometimes annually also.

And the groundwater year book has all these details of how many wells how many wells are monitored, which are the locations turning critical those kinds of things. And it can be used with other data to also look at how the groundwater situation is going down as it is showing here the four points which is just coming down.

So, the groundwater board data is collected four times in a year, it is the pre monsoon, post monsoon, and then you have a winter and then a summer. So, somewhere else in between the monsoon also the season can be taken. So, all these four months are very, very important and it depends on where you are, if it is south of India, it has a different calendar. But at the end, it takes four times.

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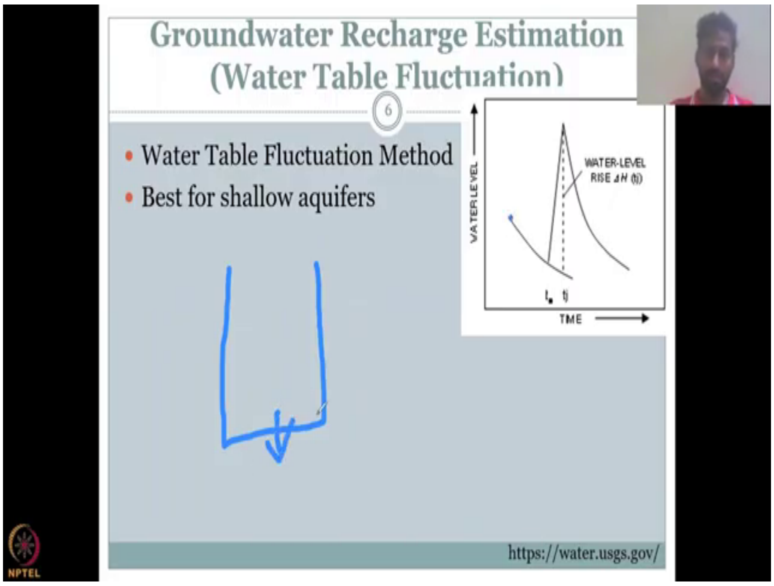

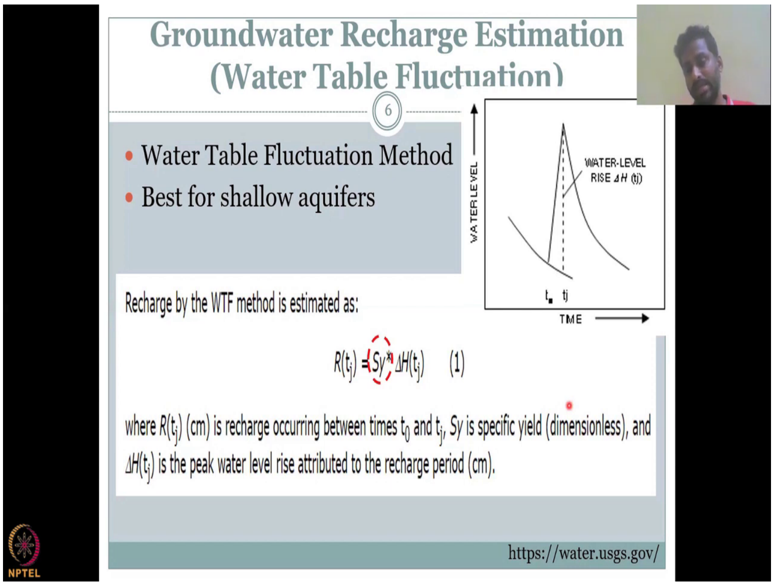

And they give you the month of which they take. So let us see how we could use this data to estimate groundwater recharge. So this is a very, very widely used method. I am taking the notes from the USGS, US Geological Survey. And you could see that the water table fluctuation is best for shallow aquifers not deep aquifers, because it readily depicts how the solid material will let water flow like this specifically yield is one of the parameters.

So, all you have here is, you are have your water level on your y axis and time on your x axis, the groundwater level is down and it is called discharge or pumping that is happening. So we are worried about it, we are worried about the recharge. So suddenly there is a recharge and maybe water rainfall occurs and a lot of recharge is happening. So the water level rises. So this is the water level in the well.

So think about a well and this is point A, it is not going down, down, it is going down and then suddenly after some time point B happens. So the water level is rising. So now you need to calculate what is the recharge which is our objective. How to do that? You take time t equal to zero to time t equal to tj. So where it actually starts here and where the peak is taken. That is a two time or whatever time frame you are going to look at for the recharge so you have a zero stop and then what time are you want it can be daily can be hourly, etcetera.

So Rtj, which is the recharge occurring between two times t0 and tj is nothing but the specific yield of the material, of the soil, of the rock times your change the hydraulic head. So, you have the time t0 and tj and the peak water level rise attribute to the change point. So, from here the peak level is tj, at tj the peak levels h j were we call del hj.

So, that difference that difference in the head from t0 to tj is called as del h. See the symbol del it is like a triangle that means change, the change in head hydraulic head or water level because of recharge during a short time period is called del h and that time period the water is raised to here it is delta h which is nothing but this minus this one.

And you just multiply by the specific yield, you get the recharge because a specific yield is a function of the liquid and the rock material it lets the it tells about how much water can actually flow through gravity and the remaining water actually is available for water for plants and stuff. So, here the most important factor is not only groundwater data because you need to have lot of data accumulated over time.

And sometimes you do have metres which are monitoring these data at a longer time interval, the most important factor is a specific yield is very hard to estimate expensive.

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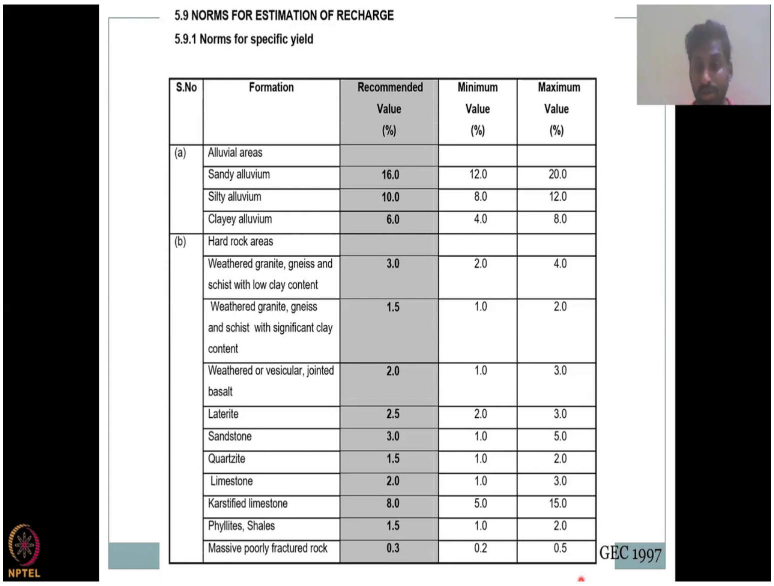

5.9 NORMS FOR ESTIMATION OF RECHARGE

5.9.1 Norms for specific yield

S.No	Formation	Recommended Value (%)	Minimum Value (%)	Maximum Value (%)
(a)	Alluvial areas			
	Sandy alluvium	16.0	12.0	20.0
	Silty alluvium	10.0	8.0	12.0
	Clayey alluvium	6.0	4.0	8.0
(b)	Hard rock areas			
	Weathered granite, gneiss and schist with low clay content	3.0	2.0	4.0
	Weathered granite, gneiss and schist with significant clay content	1.5	1.0	2.0
	Weathered or vesicular, jointed basalt	2.0	1.0	3.0
	Laterite	2.5	2.0	3.0
	Sandstone	3.0	1.0	5.0
	Quartzite	1.5	1.0	2.0
	Limestone	2.0	1.0	3.0
	Karstified limestone	8.0	5.0	15.0
	Phyllites, Shales	1.5	1.0	2.0
	Massive poorly fractured rock	0.3	0.2	0.5

So, what the GEC has done, it has given you all the different types of formations or solids or rock material or however you want to call it sand the soil type etcetera the formation and the recommended value then there is a range minimum and maximum learning. So, in Indian terms these are the recommended values in the international terms and globally this could be the range and these understand that these are rock materials weathered rock materials under the ground so it does not have boundaries of national climate etcetera.

It is just how bad the rock is whether or how young the rock is it determines the connections the pore space etcetera etcetera. So, let us look at the most important factors here. We have the formations alluvial, Sandy, silt, clay all having 16 percent, 10 percent, 6 percent, pretty high. So in the Alluvial, we can say it is pretty high. Then the next is your hard rock aquifers.

So again, the Indian government, the GEC committee has just divided into two types A and B is where the alluvial and high yielding aquifers are. Whereas B is more the Hard rock, the central India part where groundwater is really really scars. So you have all these having specific yield around the range of 3 1 percent, 1.24 percent etcetera. So it is really really low except the karst limestone, which is all these caves and rocks, which is not much in India. So, most of the areas are Hard Rock.

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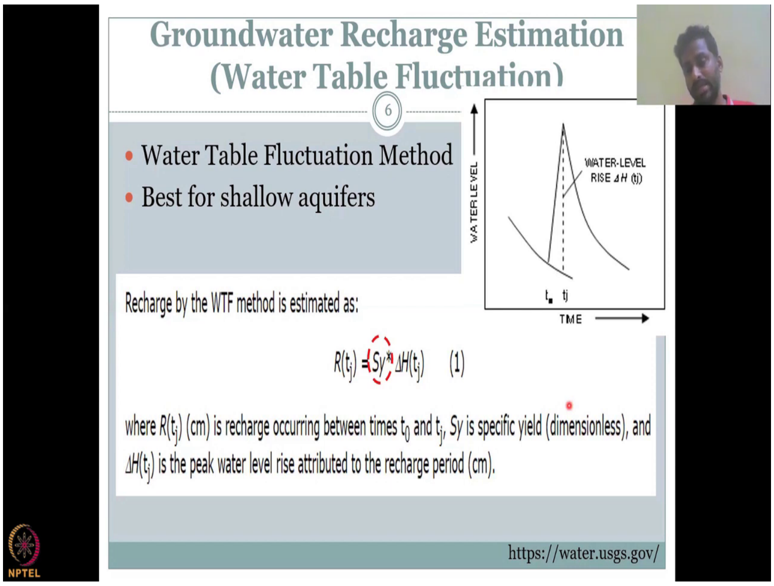

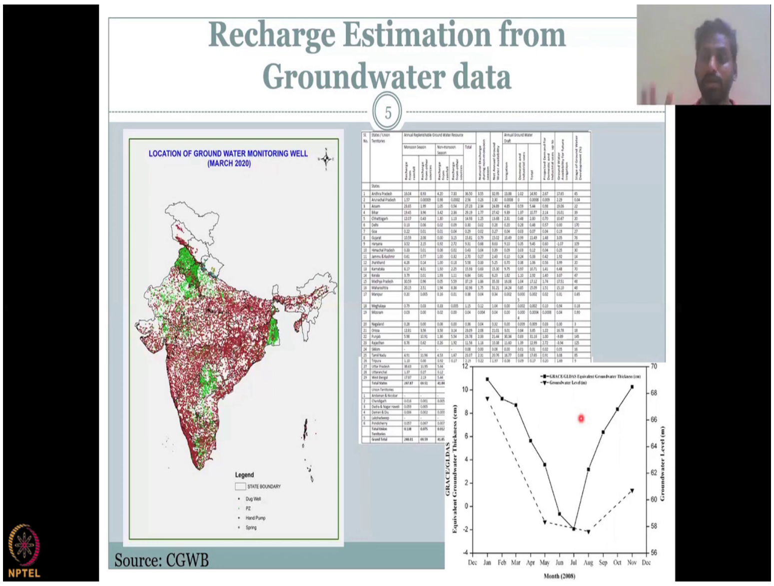

So, this is the value that you should put in this equation. You can take the data this data was from here. So I am giving you a method based on the GEC and the data where you can take and do these equations, you can go to GECs website or something on water website download the data for your particular area and for that particular area, the CEG WB handbook gives you what type of rock it is, then you go back to this equation.

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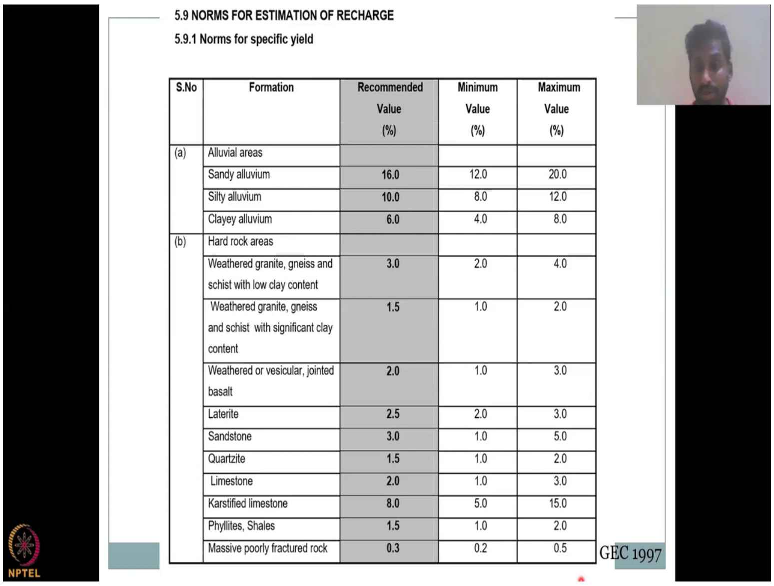

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	Weathered granite, gneiss and schist with low clay content	3.0	2.0	4.0
	Weathered granite, gneiss and schist with significant clay content	1.5	1.0	2.0
	Weathered or vesicular, jointed basalt	2.0	1.0	3.0
	Laterite	2.5	2.0	3.0
	Sandstone	3.0	1.0	5.0
	Quartzite	1.5	1.0	2.0
	Limestone	2.0	1.0	3.0
	Karstified limestone	8.0	5.0	15.0
	Phyllites, Shales	1.5	1.0	2.0
	Massive poorly fractured rock	0.3	0.2	0.5

Put up the specific yield from this table you have already the water level difference between the pre and the post monsoon. The pre is summer and after the summer the monsoon comes so, if you take the reading between the pre and the post monsoon then you can know how much water level has changed. So what are we going to calculate is the recharge for three months because pre and post is three months.

The time between the pre monsoon and post monsoon is three months. So this is how you would use the GEC estimation method with the groundwater data and a specific yield to estimate groundwater recharge. I hope you understood the principles of this most importantly the estimation methods. I will see you in the next class where we will look at a couple of more equations and also this is the same thing to do discharge.

Please understand that recharge is a process from low groundwater level to high groundwater level, water level goes in for water goes in groundwater recharge happens, the water level is pushed up that is recharge. What is discharge? Your groundwater is at high, it is pumped out. So what water is lost it comes down or it can naturally come down because it is discharging.

So you can use the same or similar methods because the data is the same and that is why the Central groundwater Board collects data four times a year, beautifully capturing the pre to post which is your recharge and the post monsoon to the next pre monsoon, which is your discharge, how much water you have taken out. With this I conclude today's lecture, I will see you in the next lecture. Thank you.