Rural Water Resources Management
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Week 07 – Lecture 01
Hydrological Water Balance- Intro

Hello everyone, welcome to Rural Water Resource Management, NPTEL course. This is week 7, lecture 1, we are covering the syllabus as given in the website. And if there is any questions feel free to type the TA through the group.

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Let us do the recap of week 6 ending to week 7. In week 6, we looked at surface water hydrology equation and also how surface water is being stored across India with some special focus on rural water surface storage structures. These structures are predominantly used for rural water irrigation schemes or programs. Some of them are run by the government some of them are run by the state agencies and some local panchayats etcetera. There are some ad hoc surface water hydrology structures which are made by the individuals it may be legal or not, but it is a kind of obstructing the flow and holding it for their personal use.

What we saw that is if surface water hydrology is developed like this through tanks and command areas, there could be some issues in the downstream farmers community. So, for example, you have upstream farmers, they can store the water in lakes, dams, ponds, manmade ponds, etcetera. However, if it is not released eventually to downstream communities, then there is a risk of having a downstream starvation for water.

So, it has to be balanced not only for farmers, but also for other living things which constitute the ecosystem. And we looked upon ecosystem services concept. Moving on, let us come to the week seven where we combine the previous week lectures like for example groundwater precipitation, etcetera into the hydrological water balance and see where the understanding takes us. We also jump into the consumption model framework.

Where in you use your hydrological water balance understanding then you collect data reflecting your water balance and you input them in conceptual models to understand the performance of different structures to understand the need of water, which is the demand side and to understand the supply sides scenario and this gives insights for better managing by having alternative methods for demand side management and for supply side management.

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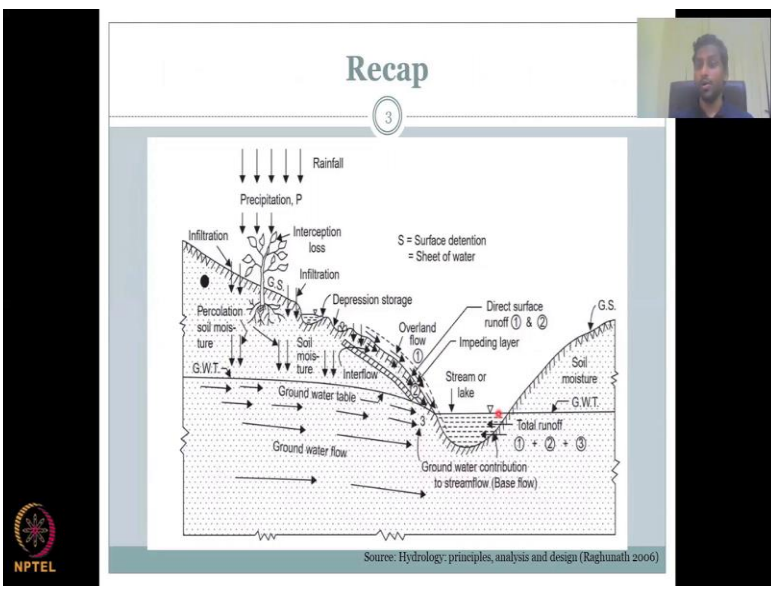

With this introduction, let us do a recap of your hydrological cycle with groundwater and hydrology for surface water. You have different types of surface runoff based on your precipitation input. So, you have precipitation, which will go as overland flow into the rivers lakes or streams, this becomes a discharge, then you can have water to go into the soil profile and then come out as subsurface flow, then you can have deeper groundwater infiltration as groundwater and come out as base flow. So, all of these come back to one point where you can monitor and measure it as discharge.

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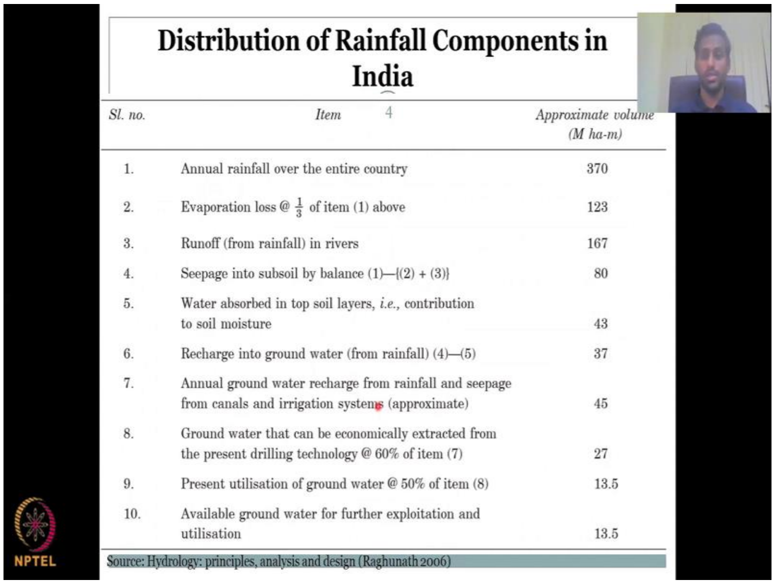

Distribution of Rainfall Components in India

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1.	Annual rainfall over the entire country	370
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4.	Seepage into subsoil by balance (1)—{(2) + (3)}	80
5.	Water absorbed in top soil layers, *i.e.*, contribution to soil moisture	43
6.	Recharge into ground water (from rainfall) (4)—(5)	37
7.	Annual ground water recharge from rainfall and seepage from canals and irrigation systems (approximate)	45
8.	Ground water that can be economically extracted from the present drilling technology @ 60% of item (7)	27
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10.	Available ground water for further exploitation and utilisation	13.5

Source: Hydrology: principles, analysis and design (Raghunath 2006)

Moving on, let us look at the distribution of rainfall components in India. So, like breaking the rainfall, so this is an attempt to do a water balance, but let us go through the exercise from Raghunath's book 2006. So, the annual rainfall over the entire country for which the author has taken a timeframe is 370 million-hectare meters. Evaporation loss at one third of the item above. So, one third is also kind of empirical, but it could be based on statistical information which is giving you 123 So, the 1 third of 370 is 123.

Then runoff from rainfall in rivers also could be an empirical estimate, not a discharge estimate because not all data is coming together. So, this is an entire India scale. So, these kinds of assumptions kind of smoothens out, it is not noisy to create big disturbance, but it can smooth out, we will see how it is. So, runoff from rainfall in rivers in rivers is 167, which is what the remaining component so if you add both, what do we get? You get 0929. So, there is evaporation loss, there is a runoff loss and you have an annual rainfall.

So, what are the other components seepage into subsoil for which the remaining water can go into the groundwater? So, you have 290 units of water which goes 1 third of it goes as evaporation loss and then the there is another fraction which goes as runoff loss and the remaining 80 goes as seepage into soil, how did we call it as infiltration. So, there are other aspects as I said, interception losses, there could be soil evaporation, plant evaporation and even drinking it, but all those kind of are negligible when compared to these big big units of evaporation and runoff. So, for India scale, they have taken it as a average.

Water absorbed in topsoil. So, of the 80 Now, we are going to break the 80. So, here we stop and now we go into the ground, seepage is going into ground infiltration, water observed in topsoil ie contribution to soil moisture, so, when water moves through gravity, the first part of your soil is going to get the water and it can increase the soil moisture, then you have your groundwater component under the soil moisture.

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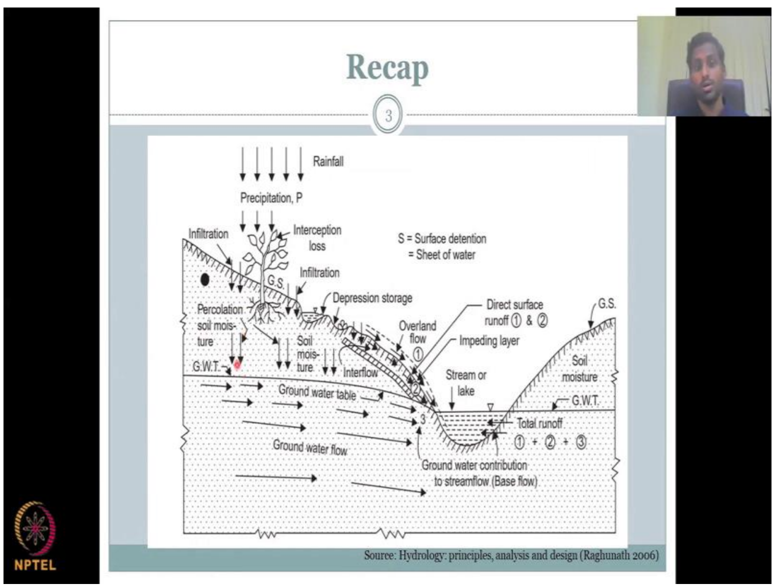

Remember soil moisture is the component where it supplies water to the plants. And whereas the further movement of ground water or water through the soil profile would be eventually contributing to groundwater flow and run groundwater table. So, now we have been divided. So, 43 goes to approximate 43 approximately 50 percent goes to water in the soil. So, it is not going to release it and the field capacity concept that we looked at in previous lectures. So, where in water is going to be held by the soil.

The remaining what happens through percolation it goes down further into the recharge into groundwater. So, it is just basically 4 minus 5 the seepage minus the water is stored in the topsoil. Now, this component is full 80 has been divided into soil moisture component and your deep groundwater component. Groundwater that can be economically extracted from the present drilling technology at 60 percent of items 7, which means all the water cannot be extracted out as I have been telling in the groundwater hydrology concept slides.

You cannot extract all the groundwater out because some would be going into the deep deep aquifers, some the energy is too expensive to even extract and some water will be attached to the materials of the soil or the rock. So, assuming at 60 percent efficiency, we will remove the water, so 60 percent of items 7, which is 45 is 27 percent utilization of groundwater at 50 percent of item 8.

So, not all the water which is extracted or which could be economically extracted please note the word economically you cannot spend a lakh rupees on water to irrigate a field which is going to be 50,000 rupees profit you understand the concept. So, economically it has to be viable for the farmer or they will try it and then they just abandoned.

So, let us assume an estimation of 50 percent of item 8, that could be used for groundwater. So, available groundwater for further exploitation and utilization is another 50 percent. So, not all groundwater can be used and off the groundwater only 50 percent 60 percent can be economically use but out of the 60 percent, 50 percent is present current, the current status of utilization. The remaining 50 percent can be utilized by further exploration, utilization, improved Pumping Efficiency, economic cost etcetera etcetera.

So, this can be evaluated only if you have all the parameters on the top. For example, I want to start with groundwater. I say no, I want to understand what is number 10. You cannot come to number 10 without going through 1 2 3 4. You cannot say 30 percent of the rainfall can come into groundwater, let us jump into groundwater because it might be misleading.

So, for your plot scale, you have to go through the cycle of hydrology to fit in the numbers as much as possible. If you do not know, then you have to discuss it and make sure it is negligible to remove it, for example, interception loss is not put here, you can club it and wrap a transpiration and remove it. Let us get back to this slide. So, let us take a hypothetical field.

In hypothetical field, you should know the input of the water coming in, let us remove the lakeside, you are not going to look at the lake you are not looking at the stream only your field. So, from here up to the overland flow number 1 2 3. So, you should know the precipitation level which is coming in, which is why people are striving to say we need more rainfall gauges, we need to understand the rainfall variation.

So, you need more rainfall gauges to catch the precipitation rate, then as I said, you will not have proper estimates of interception loss or we can say whatever water is the intercept it falls down back into the land. For example, I was shot crop like spinach and spinach leaves are broad, waterfalls on the Spanish but it can drip down. So, assuming that this intersection loss is negligible. So, we are going to not estimate it, knowing your soil profile you could estimate the infiltration and your runoff.

So, only two components, now precipitation is falling it is dividing into infiltration versus runoff. And the infiltration is going to give you some evaporation and transpiration loss because we have plants the plants have a consumption rate we looked at this in the FAO method. We looked at KC value so the plant will just take the water and evaporated evapotranspiration, so transpiration also occurs. So, ET is the term.

So, we started with precipitation, we went to seepage, we went to evapotranspiration, what is not being used was to runoff. So, every land has a runoff potential based on the land use land cover, for example, if it is cement row 100 percent, rainfall would go into your runoff, maybe 98 percent, because 2 percent can be better than evaporated. So, there is no transpiration, there is no seepage, let us say 98 percent goes into runoff, well it be 100 percent If rainfall falls on an open water body.

Let us say River, ocean Lake, all of that goes into the runoff, there is no seepage, there is nothing it just goes into the water which is actually a runoff. So, like this based on your field area, where you want to do the conceptual model or the water management practice, you should be identify the parameters that are more important and you should neglect those you cannot feel it is important and or if there is not sufficient data you have to mark it that there is no sufficient data.

Let us go through the field exercise now. So, precipitation I monitor, then knowing the land use land cover let us say I have an agricultural field, 70 percent of the water is infiltrated 30 percent is gone as runoff for example for that particular crop. So, 30 percent I know the remaining 70 percent goes into seepage and out of the seepage some part goes into evapotranspiration most of it. So, now the seepage is then or infiltrated water is then allocated into two compartments, one is your soil moisture and then the other is your groundwater.

Soil Moisture holding capacity is taken from your SR value, if you remember it is your specific retention and specific gained values. So, if you know your specific yield, you can know your porosity, you can know your specific retention. So, the amount of water that is held up by the soil can be estimated and then multiply to get the volume.

So, now you have the groundwater, of the groundwater, how much water can you take out? And that depends on your economic analysis and you can say approximately 30 percent 50 percent You do not know about the groundwater aquifer, let us say I do not know about my groundwater aquifer, a good estimate is 20 percent is lost.

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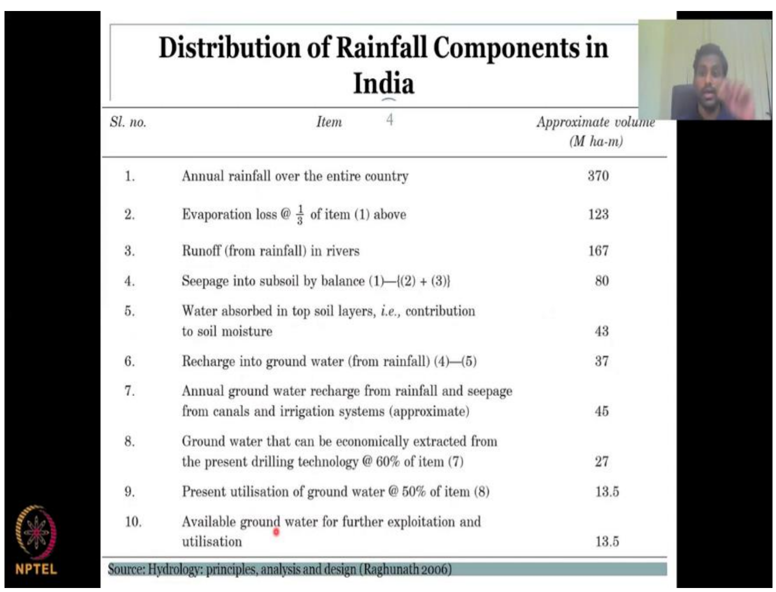

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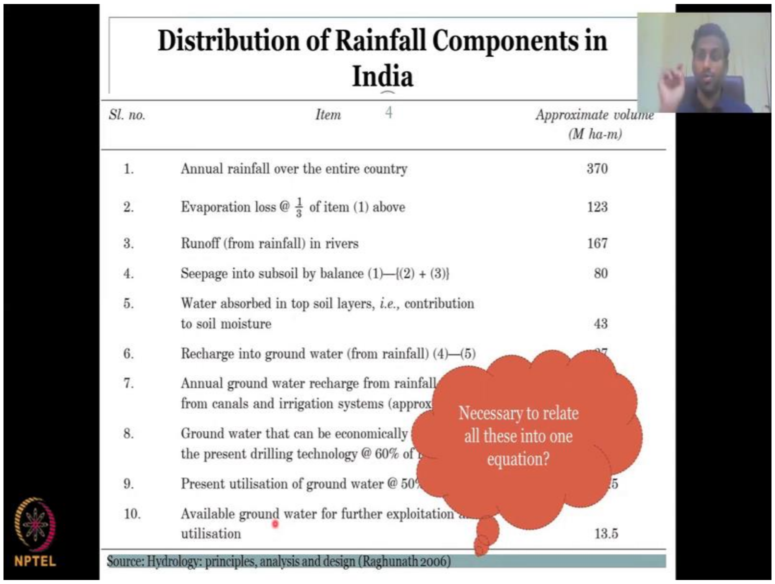

So, that is what this author has also done. it is a beautifully setup equation, which equates out so if you add all these relevant features it should come to 370. There should not be extra than 370, you get my point. But when you use a pump, groundwater, there might be some old water that is present. Same way your soil moisture can have some old water which is also Evaporating. So, somewhere you need to adjust these values to come to the exact PPT or the precipitation that has entered into the soil.

It is necessary to relate all those into one equation, do not you think so. So, because somewhere you say, out of 370 one third, then out of 1 third, I am taking subtracting to get to see pitch. So, it is necessary to collate them into one equation so that a user can go to the field and use that equation to populate it for his or her own study area.

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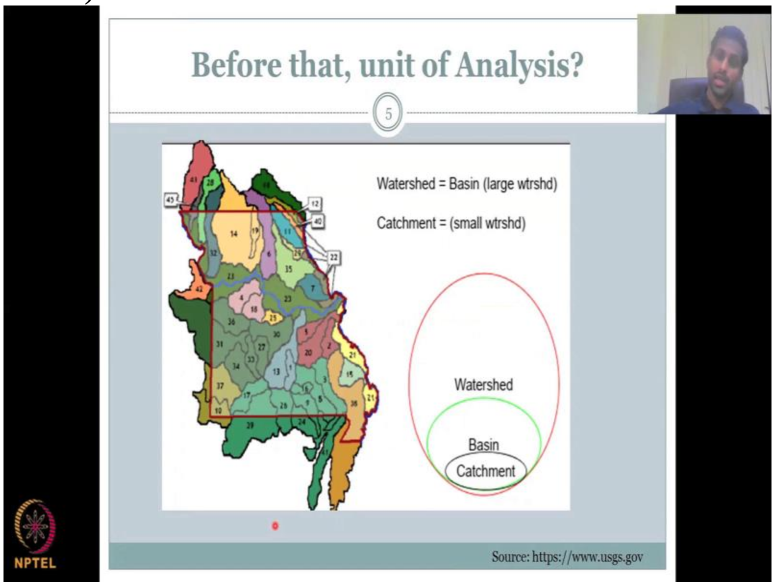

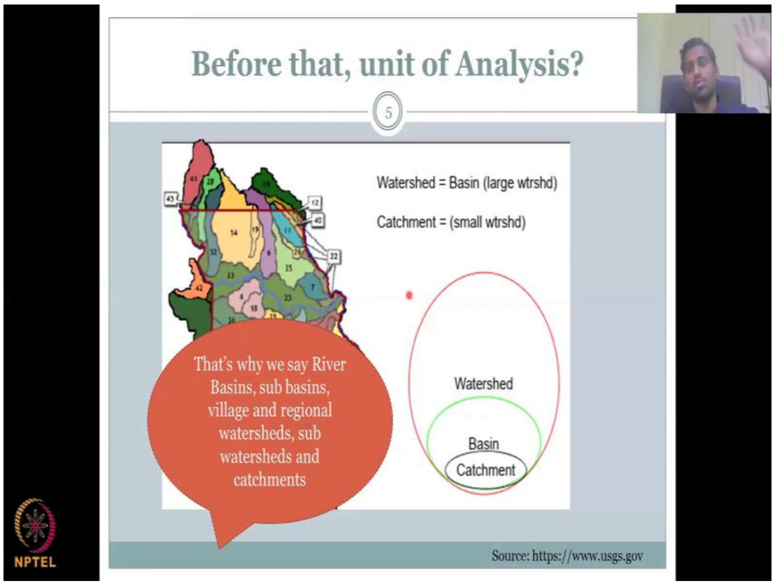

And that can be done only when you arrest a size for your analysis. So, before that, what is your unit of analysis? I have been telling in my previous example, that I would like to do it from my field. So, I will not talk about the lakes, I will not talk about the rivers, I only focus on my land, which is a one-acre plot of sugar cane, for example, or I like turmeric, so I would be putting turmeric.

So, coming back that size has to be first setup before you get into your water balance concept. In the previous example, what was the water balance done for it was done for India. So, India the whole boundary was taken as a unit of analysis. So, you are free to take as much on big or small size depending on the availability of your data.

So, let us come back to this discussion. We have different hydrological terms for unit of analysis. Normally, we do not do plot scale, we do not say I am going to do India scale at all, there is a hydrological unit of analysis and it is called watershed size, basin size or catchment. I will explain them now.

So, what is a catchment? It is a small watershed and a watershed would be a basin, which is a large watershed. So, you see the size could be different depending on which notes you use. In India, sometimes you say Ganges basin, which is a big watershed and within that you can have smaller watershed Koshi watershed, for example, koshi watershed leads into the Ganges basin. So, you can have it. So, this can be interchange in the US so, that is why I have kept it two different formats, one is a watershed can be bigger than your basin or your large watershed can be called as a base. So, let us define each term the size can come later.

Catchment, what is the catchment? If you look at the term and this is good that all these terms have the meaning within them, Catchment what is the mean catch, so, you catch rainfall. So, this is a catchment the name is given because rainfall is coming and I catch the rainfall, I catch it and it is a small size because it does not give the water out it holds it within the area it is called a catchment. So, your land your plot can be looked at as a small catchment.

Where do we use it in hydrological terms? We use a dam catchment area. So, when you want to construct a dam or you discuss a dams potential, you put a dam and above that or upstream of that is called the catchment Command Area. And all the water catching in that will come to your dam so it is catching.

Now, coming to watershed, let us do the Indian term. So, in India catchment is the smallest then is the watershed and then it is the basin, this this one. So, what is a watershed? Let us break them in watershed. A shed is not a shed that you put for your scooter or your car. But shed means giving off a tree sheds the leaves, right so there is a tree and during autumn season or fall season we call it sheds the leaves in falls down and the new leaves come upright and that is called shedding. So, now combined watershed so it catches the water and sheds it, it gives it out and that is a true concept inland.

What happens is let us say for this figure, this is the state of Missouri you have water coming into the land, the land catches the water because it is made up of smaller watersheds is also called a catchment. So, water is first caught in a catchment and then it sheds so it brings all the small catchments together all the water comes to one point and then it sheds it out which means it gives out the water.

The same thing is happening here. You have water from the some small watersheds it catches the water and then gives it out. Let us take the Ganges, the Ganges has smaller smaller catchments, all the catchments give water for Ganges to flow and the Ganges is flowing, if it is not flowing it is not a watershed. So, water is let go of the system. So, naturally waters will flow from high potential to low potential, and because of that it is called a watershed, it is not storing the water, it is leaving the water. So, watershed is taken from that concept. So, watershed is something that catches the water and combines it to one point or concentrates the water to one point and from there it leaves it.

I hope you remember when we discussed about the fern shape watershed, elongated watershed leaf shaped watershed what does it do? It takes the water and puts it in the stream channels and brings it to one point out as discharge, when we discussed about discharge, we discussed about this watershed concept.

Now, coming to basin, what is the basin? Everyone has a basin in their house, you have a kitchen basin, you have a sink basin in your washroom. So, something that catches the water catches it does not spill it out within the boundary of the basin and goes into the drainage. So, here you can look at basin as a large-scale catching land, it catches the water and it also sheds like a watershed. So, the shedding part is still there, the Ganges basin is there, it takes all the water from starting from Tibet flowing into Nepal and then India then goes into Bangladesh and then sheds it into the ocean through the sea. Goes to Bay of Bengal and then the Indian Ocean.

So, all this is shed from a point where the rainfall occurs or precipitation occurs and then it goes through a small watershed or a catchment. Normally catchments keep the water but if it is connected together it becomes a large watershed. And as the name suggests, watersheds will shed the water and so watershed all combined to a big basin and then comes up Kaveri basin, Krishna basin, Ganges basin.

We go to the western countries watershed is bigger, the basins is small. So, you can discuss that where you are, but for our class, let us keep basin as a main, and how do you know by going to government reports and how do they call the Ganges? Ganges river and the river basin not a River watershed. The Koshi which is a tributary to the Ganges can be called as a sub-basin or a watershed.

So, sub-basin is also another term that is being used, which is also a smaller watershed than the basin. This is not the catchment. So, catchment is always the same catchment is the smallest. So, now we have the unit of analysis, it could be a catchment, it could be a watershed, it could be a basin, it could be a plot depending on where you are, if you want to do your farm, it is a plot. That is why we say river basins, sub-basins, village, and regional watersheds, sub-watersheds and catchments.

So, sub-word can be used for small size basin sub-basin and then watershed sub watershed and then catchments. It does not differ when you interchange in models you should understand what you put as a watershed, but the same process is there, catches the water stores it and if it is combined together it sheds the water.

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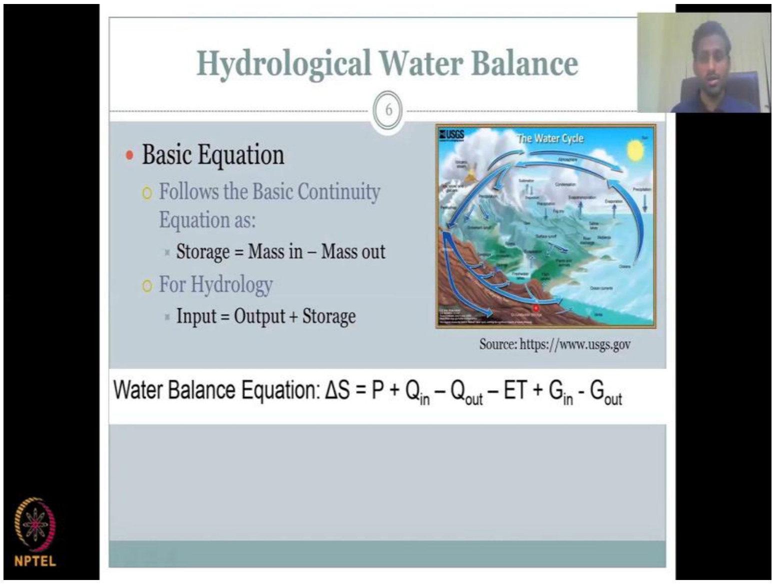

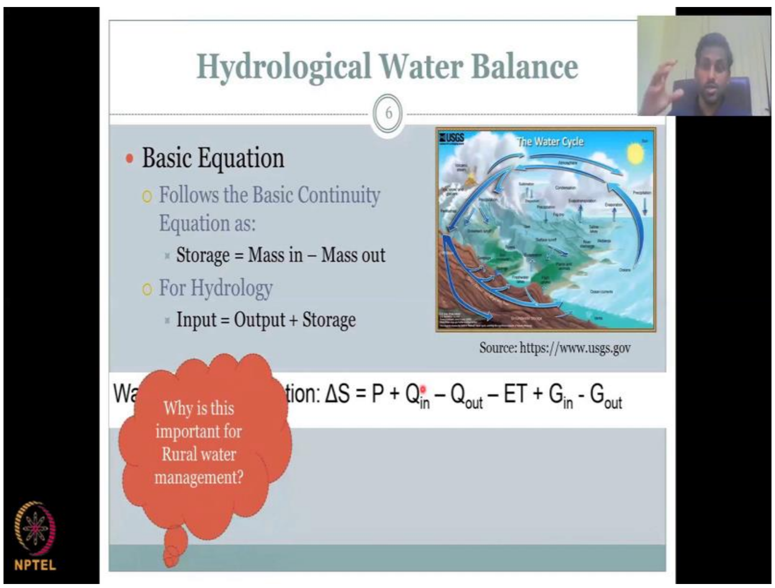

So, let us come to the hydrological water balance. We have the hydrological components most of them we have discussed in class in the previous lectures, let us do the basic hydrological water balance equation which is the objective of the lecture. It follows the basic continuity equation as storage is mass in minus mass out what is the basic continuity say that if you have a mass which is coming in and you have a mass which is going out, the storage what remains in your storage is your mass in minus mass out.

If your mass in and mass out, are same, it is 0, storage is zero. So, you are not saving anything. Think like a bank account. If you have 100 rupees coming in and you are taking 100 rupees there is no storage, if you have 100 rupees coming in and you take 80 rupees 20 rupees is your storage. So, that is the basic continuity equation. So, water balance equation can be kept as simple as possible or as complex as possible depending on the number of variables. For hydrology. We put it as the following. It is input is equal to output plus storage, So, you can rearrange it to bring it out the real meaning.

Why do we put input in one side, so, we actually rearrange the storage mass in my mass out. So, we keep the storage on the side, we take the negative in front of the mass out to the other side, which is the output and then you get input is equal to output plus storage. So, that we have a better understanding of the input, which is your precipitation. So, precipitation is equal to output, which is your losses plus storage. So, now all this combined to your input, remember the example we saw 370 is the total rainfall units, and that if you add all the other components it should come to 370.

So, now let us discuss the water balance equation, which I pulled out based on these estimations. So, your del s which is your storage, or your change in storage, in some books, that is called change in storage, because it is a changing term in some books just as just storage is equal to p which is your precipitation, you can take it from here, plus Q in minus Q out, which is your surface water coming in minus your surface water going out minus your ET plus groundwater in minus groundwater out. So, let us look at this equation here. Your storage or here also is your mass in or your volume in which is precipitation.

And your Q in is also your precipitation coming in or your mass coming in, your groundwater in is a positive because it is coming into the system minus mass out which is all your outputs. So, Q out is a loss. So, that is a minus sign minus ET evapotranspiration is a loss. So, you take it out as a loss, and then you also have G out which is another negative, you take it out because it is leaving the system.

So, all that is coming into the system is a positive if you have storage on one side, the water that is coming into your system will have a prefix positive. So, P, Q in G in are positives. Groundwater in. So, let us say this is my storage structure. And I am trying to see how much storage is changing, your precipitation is positive, it is coming in the top, your Q in the river is discharging. So, Q in is positive, Q out is negative.

So, somewhere another way the water is leaking out. So, this is groundwater, let us take this way here. So, water would may be flowing out to the ocean, so that is Q out minus ET, Evaporation is happening plant is taking. So, ET is loss, that arrow mark is up, plus G in, groundwater is coming into the lake. So, it is positive. And G out is negative because groundwater is losing to the system.

So, you could actually visualize this equation, as I have done now, in this image, I always use this image because most of the components are reflected. And if I do not have that problem, I can strike it up. You say strike it out, say negligible or 0. Good. So, why is this important for rural water management? This question should always lag because this is a rural water resource management course. And it is very important to understand why we learn these concepts. So, if I know the storage change, and if I know the key dominant losses in my system, can I better manage my resource, that is the idea.

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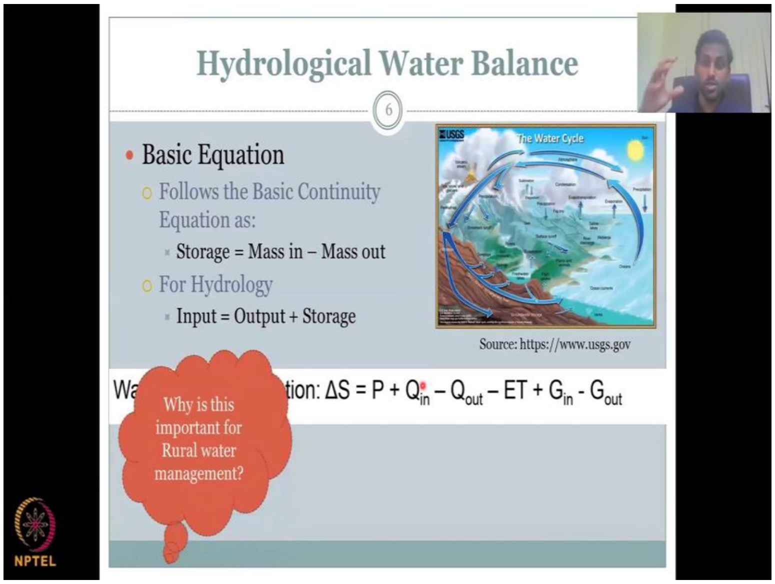

So, better management scenarios can be produced from your water balance exercise, supply side management, which is your water coming in. Because precipitation is the same even before or after the management I am saying but now you can store the precipitation and give it as a storage, you can store the precipitation as in a river and then bring it as Q in, that is a supply side. Also, you could arrest your Q out. So, how much water leaves your system you can close it let us take a plot. In my plot. If I have water coming in, if I make bunds across the plot, then all the water stays right. I am arresting the water from going out.

So, Q out is 0 Q in I will have higher potential water coming in through a pipe. So, I can put more water in. So, supply side I am managing. Understanding water availability knowing the precipitation cutting down the losses I now know better how much water is available for plants. Storage requirements. So, if there is excess water even all these bunds I have created, but what was overflowing from my plot or my area Watershed? What do I need to do? I need to arrest the water. How do I arrest it? By increasing storage structures.

One such storage structures is a check dam. We will be discussing this in future, but check dams are good to catch the water and store it in your local area. You can have rainwater harvesting systems to push more groundwater storage by pushing rainwater into the rainwater harvesting, then goes into the groundwater storage and then green infrastructures where they could slow down the water so that your plot can have more water.

So, think about your equation again, going back. So, here you have increased your Q in by supplying more water, you decrease your Q out in the supply side by raising bunds and preventing the water from going out or having a storage structure. You have also increase your groundwater in by recharging and then using it again and reduce the groundwater out. So, that is your supply side management. Better supply systems, which is your pumps, your drip irrigation, those kind of things you could evolve now knowing that you have X amount of water. So, now if we know your water, you can have better supply systems.

Let us do the demand-side management. But I also wanted to mention that in your supply system, you can have a drip, you can also have a channelized water only for some parts, you can arrest the top of your land, you have seen strawberry farms, they put plastic sheet in the empty land. So, along the plants, there is a whole water is taken. But on the other part of the land, there is a plastic sheet which prevents the water from evaporation which means your E part in the ET is slashed down. So, all this is better supply and management systems.

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Other management system which is important is your demand-side management. If I know that the water is not enough based on my equation, can I not reduce the transpiration which is a loss? Or do I reduce the transpiration? Yes, by changing the type of crop because crops transpire your plants and animals and trees transpire. So, how do you reduce it by changing the type of crop or plant but options for crops can be given diversification of crops or also area that the crop is going to take can be.

Controlling cropping acreage, the better options could also include better types of crops. For example, if you have rice, there are some less water-intensive rice that you could use for growing your crops. Crop diversification means changing it totally. For example, I have a plot, I have water coming in from a sugar cane.

Now, I know that my groundwater is less so groundwater in component is going to go less my storage is going down. So, what do I do, I change it for this year, I say no, I am going to diversify my crop, I am not going to put sugarcane I am going to put turmeric. So, then or millets then I grow a much more different crop with less water requirement thereby increasing my storage for the next sugarcane crop. So, it is about long-term vision not short-term this vision. If you just showing no I want to get my sugar cane this year, then you boom you do it, but your water is gone. So, you have to be very careful about it.

Then you have control cropping acreage, knowing the water now you could tell how much water acreage crop can be used. So, if I have 1000 millimeters of total storage, then I can choose ET crop which is much much lesser than 1000. So, then the acreage can be increased. Better crop irrigation facilities which is also a supply-side and a demand-side management with example drip irrigation, those kind of things. So, you have to pick a crop which is suited for drip irrigation. That is why I am putting it in the demand side, the supply side every crop can be used for drip irrigation, but then the demand side you have to pick the crop for suitable drip irrigation methods.

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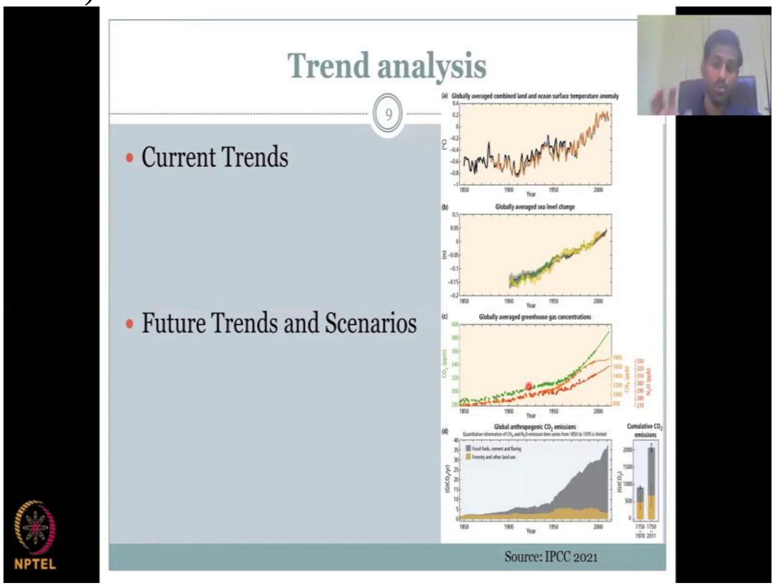

Trend analysis you could look at climate change trends, and understand from your water balance. Are you following the current trends? Or have you taken future trends and scenarios in your analysis like as I said long-term vision. You have taken them in your analysis and thought about your storage which can change in the years to come.

So, in the current trends, I only know the current rainfall pattern, my current rainfall pattern I put in my water balance equation I estimate what is the ET, what is the losses, then I pick a crop, here you can also use future trends and scenarios and then pick a precipitation and based on that you now play with your storage play with your groundwater in groundwater out Q in, Q out to arrive at which crops can be grown for optimum ET. Your ET should not go above then the water you have, which is your precipitation and storage.

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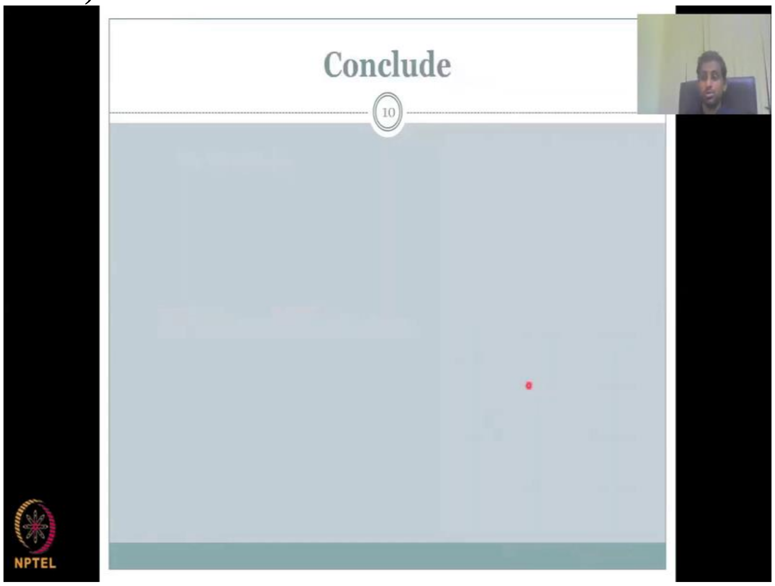

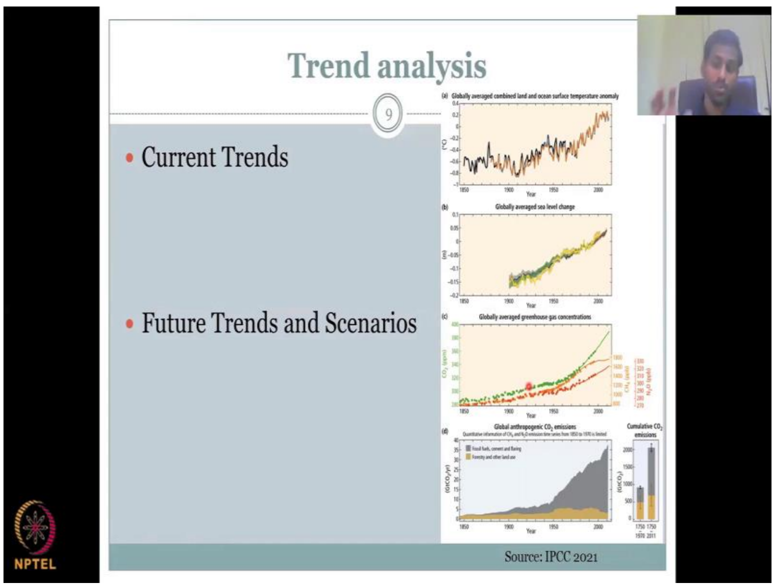

So, today we have covered a very broad topic of the need of a water balance equation. Even what a water balance means, the name water balance can be differently given as water budgets water mass balance and hydrological balance. We have multiple other names this is all based on the continuity equation of storage is equal to mass in minus mass out. And we have also seen how we could use it for a India scale example from the book and also a short pilot-scale or a field-scale analysis by the equations we did.

And we also saw how that understanding can be used for better management in the demand side and supply side. We also thought about trend analysis given the climate change projections and trends, how can you better manage water. So, with this, I would like to conclude today's lecture on water balance components. I look forward to the next discussion in the next class which would go further in developing these water balance equations and developing the conceptual model at different scales sizes which could aid your analysis. Until then, see you. Thank you.