**Rural Water Resources Management**
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**Week 07 - Lecture 02**
**Hydrological Water Balance - Key Parameters**

Hello everyone, welcome to the NPTEL course on Rural Water Resource Management. This is week 7, lecture 2. In this week we are looking at the hydrological water balance, how to construct it, water issues and what are the meanings of each parameter. In the previous lecture, we had an introduction to the hydrological water balance.

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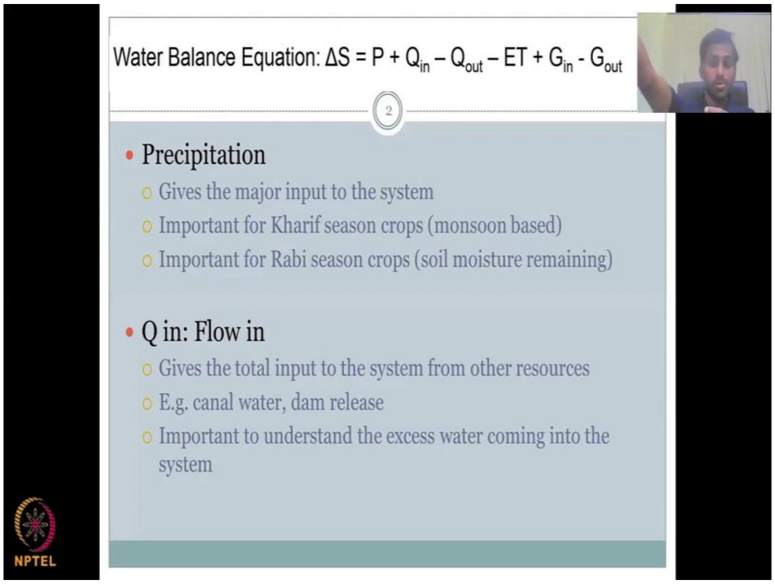


In this week in, this today's lecture two, let us look at what each parameter means. For that, let us take the same example that we use to introduce you to the water balance equation. Again, there is different names for this it could be a water budget, hydrological balance, water mass balance etcetera. And it follows the continuity equation which is mass in minus mass out is the storage.

Here are the del S is your change in storage or the actual storage is equal to P which is precipitation plus Q in minus Q out minus ET plus G in minus G out. Today, we will look at each parameter and how it applies to the overall goal of this lecture series which is rural water resource management.

Before that, some caution notes these equations can be constructed for any land use land cover, which means it can also be done for urban it could also be done for your small community area, but because this lecture is on rural water resource management, we will be looking at rural examples and what these parameters mean for rural water resource management. I also want to give another answer of which is the most important part for your water resource management, which is the goal of this lecture is del S, which is change in storage.

How can you augment, How can you increase change your storage in the positive is the key for rural water resource management. Because your precipitation cannot be at once increased or jumped, it is a very slow process for example, if you want to plant trees, specific trees and then condense etcetera, etcetera, or the seeding cloud seeding is a very costlier affair, we are not going to talk about cloud seeding and increasing your precipitation.

So, the most important part in your rural resource water management course is your del S, how are you going to preserve conserve or manage your storage for better water management is the key. Your precipitation is the first term in your water balance equation it has given as P. And remember that before I jump into the first variable, each variable can be differently used in different books, papers and by different authors.

So, it is your goal even if you want to start writing one to have an index, a key for what each variable means you will also forget it, if you do not write it. So, P could be anything from precipitation and R is also called as rainfall or recharge or runoff, you see how one term can be used different ways depending on the user and there is no universal rule that P should be precipitation, R should be runoff. So, it is your goal, it is your impetus that you need to give the reader full understanding of what it means.

But moving on, precipitation is the major input to the system because it is the one which has given you rainfall which is the big component for rural water resource management, it is the input to the system, not all lands, get water from your dams from your canal irrigation. So, precipitation is key. It is important for Kharif season. Before we discuss this point, it is important to understand what is Kharif season. In India, there are two major growing seasons.

One is Kharif and the other is Rabi. Kharif is the monsoon season, where crops are rain-fed, which means the crop does not get irrigation from groundwater, your dam water etcetera, but it looks at the sky for water. So, it wants to get more water from your precipitation. So, it is a precipitation-only based irrigation system.

There are colloquial terms for this also in various parts of India and also as I say various parts of India the monsoon season also differs. So, what is in Maharashtra for example, your monsoon season starts in June and ends around September or October whereas, your southern states let us take one for Tamil Nadu for example, your monsoon will just start in September October. So, you see how the peak monsoon season differs and also the peak monsoon cropping pattern differs. So, it is important to understand where you are located then what is your season.

Before we also continue expanding the call, understand what unit you are going to use, I have mentioned this in the previous lecture when we define the unit of analysis, which is watershed, basin, plot, etcetera. For our study for this lecture, we will look at watershed as the base unit for analysis. It can also be a plot scale if you are doing a plot where in some variables will not come into the picture.

So, this equation is very important and precipitation gives the important input for Kharif season it is also important for the Rabi season. So, Rabi season is a non-monsoon cropping, which means it is a fully irrigated crop. Irrigation means you have to apply water, is it manual, through technology, groundwater drip irrigation anything all these constitute irrigation, and Rabi is the non-monsoon pack.

So, sometimes you have Kharif winter and Rabi. So, Rabi is kind of before your peak summer, so that is also based on rainfall how people can ask me there is no rainfall in your Rabi season. So, for example, in your Kharif season your P is big number that is the precipitation coming in and because of that others are driven.

In your Rabi season P 0, there is no input into your watershed from rainfall. However, your P would I would have influenced your del S which is your storage, it could have filled up the dam, it could have filled up your groundwater. it could have filled up the soil moisture, as I put it here.

So, it is very very important when you do an annual water balance to have that picture in mind. So, your del us you can understand how much it is.

Moving on, we have Q in, which is your discharge coming in or flow coming in. So, this gives a total water input to the system from other resources, other resources as in other water bodies, other watersheds etcetera. So, this is a water that has been taken from another watershed, and it has been funneled into your watershed through different means, it could be through a river discharge. So, the previous watershed would have taken the water cap for the water and then push it into your watershed, it could be through a pipe.

Like, for example, Pune supply some water to Mumbai. So, through a big big pipes and water is coming in. So, that is the total water inflow into your watershed from outside your basin. It is a very very important component especially the Rabi season because when the dams are built, mostly the watershed areas above and the canal system extends down to the farmers and gives you water.

So, I have given an example as example canal water dam release, etcetera. So, this is Q in coming into your watershed. Then you have it is important to understand the excess water coming into the system because sometimes your excess could be above your precipitation. And so, it is important to document it otherwise your del S, might be increasing or ET might be high than your P, which is not possible. So, you need to understand the major major inputs into your watershed, and Q in is coming from a different watershed. Please understand that if you do not have a barrier in your watershed and all the water is coming in the river, then it would eventually flow out.

Let us take the example of the Ganges. The Ganges origins somewhere and it is picking all the tributaries water and coming and flowing in. One of the biggest tributaries is the Koshi. The Koshi river which originates in Tibet, flows through Nepal, and then to Bihar and joins the Ganges. It is one of the biggest contributor of water to the Ganges.

Suppose they say, no, I am not going to give this Q out, which is my Q in, which is water coming from Tibet and Nepal. If they say no, I am going to hold my water, I am not going to give it as Q in into the Ganges in Bihar, Then the majority of your water is going to be reduced. So, my Q in, so my Q in is someone's Q out. So, think if your watershed is getting water from somewhere else, it is someone else's Q out. So, this inflow component is very important also to understand how much you can give others.

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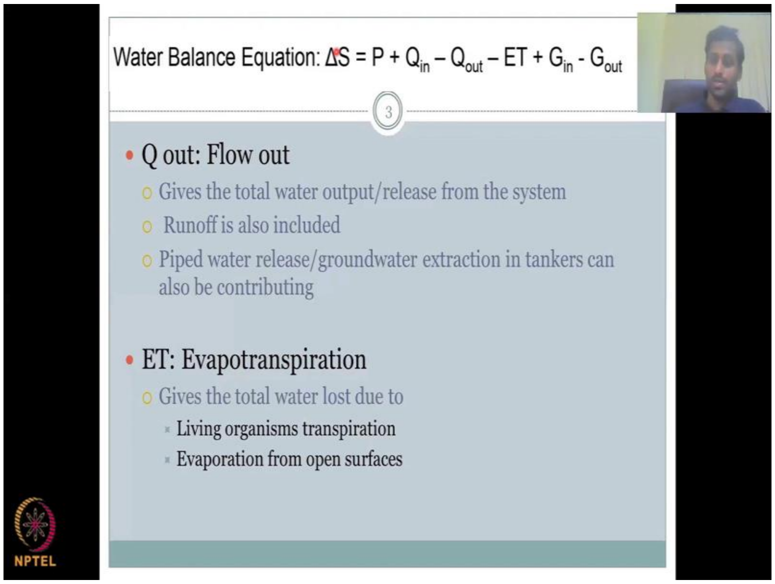


Let us continue. So, we have discussed the positives, the positive side means the input into your water. So, all positives in the del S term, if you have del S, on one side and the other side has the equation, the positives mean it is an input to your watershed and the negatives mean it is a loss to the watershed are you giving it to someone and so, the basic idea as per the continuity is, is the positive minus the negative enough to have storage still remaining. Moving on now, in this lecture, we side we will be looking at the negatives.

Q out is the flow out how much water is going out of my watershed through runoff through channels and through other means, like you taking it from a tank you put it input water into a big container or a tank or a river and then from there you are taking tankers and taking out this is a very very important Q out in terms of rural-urban periphery that area.

So, for example, if you are in Bangalore or Chennai, they will take a lot of water from outside of your urban settlements mostly in the rural areas through tankers and it is very, very difficult to quantify because not all tankers are equal in size, they do not have a log of how many times they go up and down and supply water. And we do not know the exact volume in the tankers, because most of the time when the tank does run it loses water.

So, Q flow out is the flow that is coming from your watershed to the others watershed. So, you are losing the water, so it gives the total water output release from the system. And it is also important, not all waters, you could store because it would be flooding. If you are saying no, no, I want a dam in every watershed nearly every water basin, then what would happen all the water would be holding on and you will not also get water from the previous watershed.

The other point to think about is the downstream communities, the farmers downstream also are dependent on the upstream water. So, it is very important to understand how much water is released, runoff is included which is you have a land precipitation falls and then runoff happens after infiltration, groundwater recharge. So, your runoff is also included along with the pipes that come in and the watershed previous how much water is giving into your water.

So, all this is channelized in the river channels or pipe network. So, pipe water is counted. Groundwater extraction and water extraction tankers is also contributing. The groundwater can also pull some of your Q. Let us not discuss too much about it. But think about this, for example, you are having a river flowing and right next to the river you are pulling groundwater, is the only groundwater you are going to pull you may also pull the river water so that is what I am meaning by this Q out.

ET Evapotranspiration. This gives the total water lost due to living organisms which are transpiring, giving out from the skins giving out from the leaves as water used for photosynthesis and evaporation from open surfaces. We have discussed this a lot in the evapotranspiration slide, but I am just going to stick on for another couple of minutes to explain that it is a big negative in the system. in your watershed, but when it comes to rural water resource management, can you make it 0? Can ET be 0? If it is 0 then there is no plant growing.

You can minimize the evaporation, let us say I am having no open surfaces water is all stored in the groundwater or whatever water I get. I am going to put it on to the plants through drip irrigation so no soil evaporation, but transpiration has to occur for plant life to grow. So, for example rice, sugarcane, whatever crops or food crops that India grows mostly. You cannot control the evapotranspiration to become 0, but you can lessen it by reducing it you can increase your del S. So, that is the idea how can I reduce the negatives so that I increase my del S, for the next cropping season.

I talked about the next cropping season from Kharif to monsoon to non-monsoon etcetera. But I am not supporting or not approving that every month the land has to grow. So, the idea is because this course is a rural water resource management course we assume that the fertility of the land is sustainable. And we are maximizing the waters so that the farmers can grow because discussing on soil fertility and what process are there to increase the fertility is by itself a lecture series? Is it by itself a course.

So, we will not get into that angle we are only going to focus on, is my land having enough water? If not, how can we increase and why not? Why are we not having enough water? If we have enough water we will use it for the next season that is all. So, evapotranspiration is the collective loss, it is the collective loss with evaporation which is from open surfaces land, water, road etcetera. And your transpiration is from living organisms, we had a good lecture series on that.

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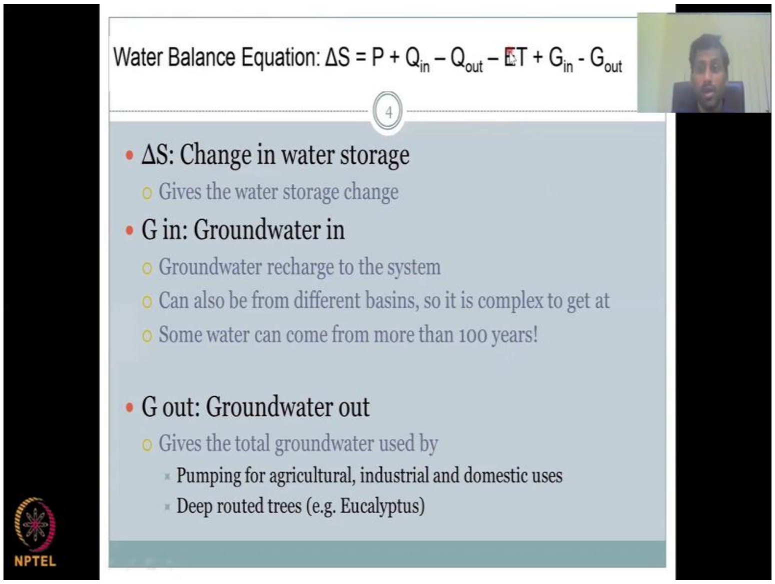


So, I am moving on to the next parameter. So, next parameter is a del S, which is the hero of this equation as per the course is concerned, and there is this change in water storage gives the total water storage change, what do I mean as total is because this component includes your soil moisture storage, it includes your surface storage, like dams, etcetera, it also includes your groundwater storage, because all these other storages are just not as a storage within the system because when you do a minus G in minus G out how much water is going you remain as a storage and where does the storage go to this equation.

Same here, we have river coming in and river going out. If my river coming in is lesser than the river going out, then I am storing some water and that could be here, it could be a check dam, it could be a large dam etcetera. So, del S, I am not breaking it yet, is the total water storage in your field in your watershed, and it has multiple components, we will get into that. So, for our course, this is the parameter that we need to maximize, we need to control, we need to manage because the others are very very difficult.

So, precipitation you cannot big manage it but you can manage how much water comes in going out which eventually goes to del S, the ET as I said most farmers are stuck with a particular crop they would like to only grow that crop sugarcane for example. You can give alternate hybrid varieties hybrid stuff but are they willing to grow it is a question. Let us take for example ET of the previous traditional food that we used to eat like millets and other things, those had very less ET value. But now almost everywhere price is the important staple food which consumes much much more water than millets.

So, are we ready to shift that? is a question. So, ET also is very hard to control right now you can control your evaporation pretty much drip irrigation etcetera. transpiration is totally dependent on the plant, you can have a hybrid plant which consumes less water. Same way groundwater in groundwater out your groundwater out is very hard to control if it goes to baseflow, but your pumping can be controlled so that you store it. So, del S is the key for this course.

The next parameter is G in which is your groundwater in, how much groundwater is coming in to the system, it could be coming in from another watershed. Because groundwater does not operate with a watershed boundary. It operates as the slope, the land, the rainfall occurring etcetera. Some water comes from 100 kilometers. There are a lot of studies and news articles on this. Please feel free to go through it. And you would be amazed that how much water can come from where and depends on your pumping if you have tremendous high-power pumps, you can pump really water beyond the state also. So, in the US, there are lawsuits on groundwater being pumped from different states within the United States.

So, coming back groundwater recharge through the system from another watershed because your precipitation is already contributing. But from the other watershed, how much is coming in? Can also be different from different basins. So, it is complex to get at, you do not know where it is coming see, unlike surface runoff, which you can visualize, I know this watershed is here, and this is the next watershed, I know the rainfall in this watershed, I know the land use, so I know how much runoff is come. But underneath what is happening is groundwater, you do not know where this basin is coming getting the water.

So, it is a very, very complex part to get at. And since it is very near and dear to me groundwater because I am a groundwater hydrologist, focusing more. And the other reason is, it is near to me is because India is the highest groundwater extractor. And it extracts more water than the next two countries, which is US and China put together. So, the combined usage of groundwater by the next two countries, which is China and US, is much much bigger than India. So, India's uses much bigger than these two countries use. So, we have to be very careful in managing groundwater.

So, coming in groundwater recharge system, some water can take more than 100 years, how do you complex, it is very complex to quantify that, how do you know how much water is coming in. So, you need to be very careful when you use this equation. G out is the groundwater out of your basin, you do that mostly by pumping so that you could estimate how much water you take out. But the other part which is very, very difficult to estimate is how much water goes out as base flow into the other watershed. So, same as I said, you may get groundwater from this watershed, this if this is your watershed, but your groundwater can flow to this watershed.

So, it is always difficult to estimate where the boundaries are. Because aquifers are wide and spread and, sometimes very random, you do not know why they stop. it is a purely geological process, so here is the total groundwater used. Pumping for agriculture is also included, industries, domestic use, deep-rooted trees, all the trees and plants that are in your watershed should be accounted for. For example, if I am having a lake that is my del S, the lake water is being stored, I am happy. But around the lakes, if I am having a very thirsty tree, which is just sucking all the water out into transpiration.

And that is your groundwater out. Because your groundwater is pulled, your lake water is pulled, and then you evaporate the lake, you finish off the lake. So, this is some of the reasons that you see in Bangalore now. More so the lakes have specific trees, which can pull water out of the system. So, groundwater out is a complex part. So, what do you see in most of these equations is if it comes to groundwater, people say, if I have 3 watersheds 1 2 3.

And if I know that groundwater is coming from the watershed to my watershed, and this is my watershed, and then groundwater can flow from my watershed to the others, what they say is normally, G in minus G out is 0, how much water groundwater is coming in, is going to go up. So, that assumption you would see and that is why some of the times you do not see this parameter, and your G out through the pumping for agriculture etcetera is accounted in the ET. So, make sure you do not double calculate it. Sometimes you are pumping water can go to some other place. So, be very careful if you have your ET, where the water is being taken.

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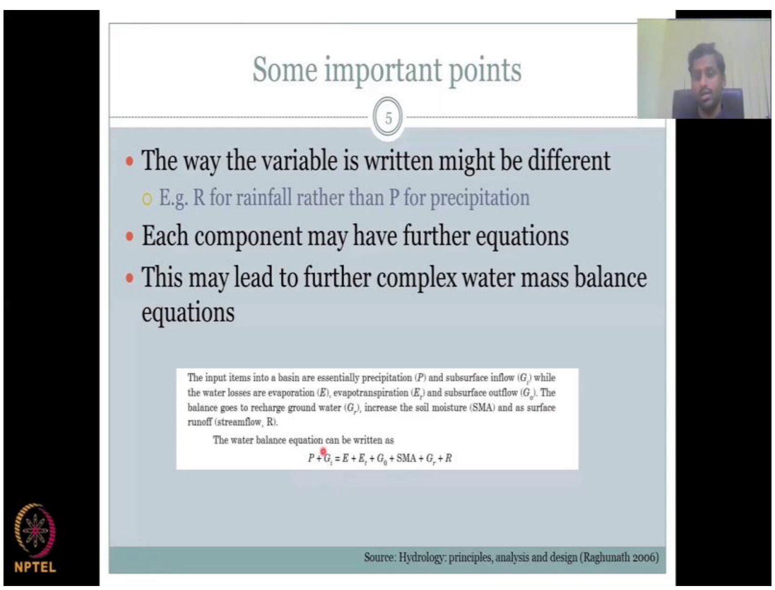


So, let us look at some more important points in this hydrological water balance. The first point very important point is the way the variable is written might be different in different books, there is no universal law that R should be rainfall, not runoff. So, even you can construct a watershed balance water balance, so it is very important to before you break down the equation, go to the author's notes on what each one means, normally, they will give a keynote at the bottom of the equation or they will give an index at the end. So, be very careful on what it means.

Along with it. The other important point is the units are all the units consistent because your rainfall could be in inches per hour, whereas your infiltration could be millimeters per second. So, make sure all normalized to one unit to one rate, rate as it is a per second per day per minute, all of them should be one-unit time. Normally, these are done as per day and then they multiply it by 365 to get the annual rates.

Each component may have further equations. So, as I said if you do not know groundwater complexities. Some people say groundwater in minus groundwater out is 0 remove the term, but most of the cases you would have to have the objective clear to rule that out. So, each component may have further equations, your del S, as I said is a storage. Storage of what water where? Is it the groundwater in the groundwater aquifer? Is it your dam water in your watershed or is it your rainwater harvesting on top of your terrace.

So, you have to be careful that there is a possibility for each parameter to be expanded. How much you want to expand is totally your objective and study area. This will lead to further complex water balance equations. So, the equation can go on elongating both sides which means the del S might be a combination of other del S, del S soil, del S groundwater, del S the rooftop etcetera etcetera. Whereas this side also you can have multiple multiple equations, precipitation, runoff, rainfall, snow, snow water, ice melt, etcetera etcetera.

So, we will have an example to show how it can be different. Let us take a small example from the book you the input items into a basin are essentially precipitation for this equation and your surface inflow. Subsurface inflow is the water that comes into the ground and then out into your rivers and discharge area.

So, P plus Gi is the input to the system while losses are E which is your evaporation, evaporation from open surfaces, evapotranspiration from your plants and the land that where the plant grows because you have the land the soil and the soil can evaporate. So, evapotranspiration is a term that could be used only for your plot, whereas evaporation can be from the lake, open-source etcetera.

So, normally it is combined together as ET but some people would differentiate as evaporation and transpiration or evaporation and ET for plot. And then your subsurface outflow as I said, as your groundwater is moving into the land, through discharge as subsurface flow, you can also get your water loss out of the system as subsurface out which is O, so the balance goes to record and recharge the groundwater Gr. Increase soil moisture SMA soil moisture A and as surface runoff streamflow R.

So, you see here, P plus Gi is the input to the watershed, which is being converted as evaporation, evapotranspiration, G out, which is your subsurface out in the previous example we saw G, as groundwater, here it is subsurface outflow. Then you have your groundwater recharge, G again coming, and then your R as runoff.

So, all these are your losses, and these are your positives. So, you need to understand the positives, negatives. And then if you bring it to this side, you bring all this to this side, the net, if it is 0, then your del S is 0, the storage is 0. So, this equation says there is no storage, except the SMA. So, the SMA could be positive or negative depending on where you put it in your equation.

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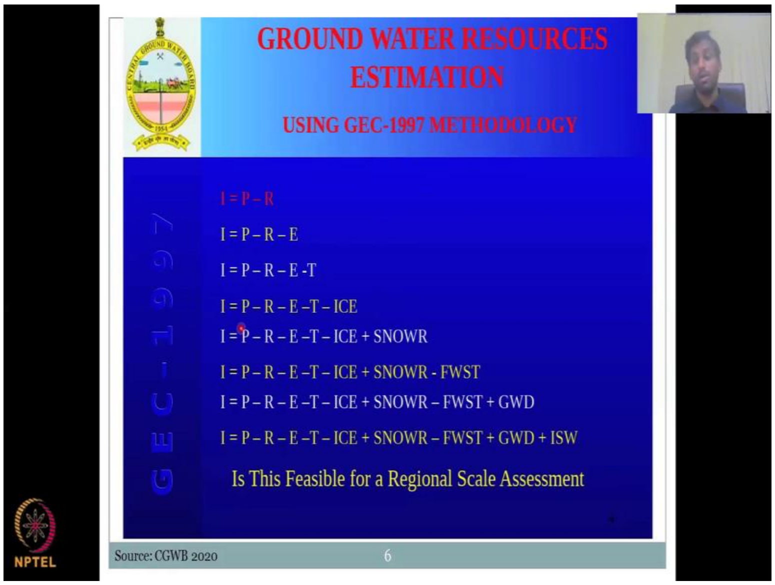

Moving on, he can become very complex or very easy. I am going to give you an example of how it is very, very simple. And this example is taken from the groundwater resource estimation book, the GEC 1997 has given this groundwater estimation committee and is still used because it is based on fundamental physics, because the fundamentals do not change. So, you can have the equations as this.

Let us take the first example equation given I is equal to P minus R. P is your precipitation, rainfall minus your runoff, I will have this equation like that. So, this is your land, you have your rainfall coming in, which is P and all of it can go as runoff with some water infiltrating. So, the infiltration is nothing but P minus runoff. So, P happens some some infiltration happens, but most of the water goes up as runoff. So, just the three variables out of which to if you know you can estimate the height.

But then let us make it more complex. So, here in the example let us visualize it would be a road. A road is there some water goes into the road on the corner as infiltration, but most of the water is going as runoff. It just goes into steam, etcetera. The next one is E. So, evaporation is happening. There is no in the top one there is no water body to evaporate. But here I is equal to P minus R minus E. So, some of the precipitation goes into your lake. So, the lake can evaporate. So, that is here.

The next equations, now I am throwing in another variable which is T, transpiration. So, the now the lake around the lake, I have some crops, so, the crops are transpiring. So, some part of your precipitation is lost because of water going to crops some part of water is lost because it goes into your lake and then the next one is I is equal to P minus R minus E minus T minus ICE, So, some of the water can become ice, if it is the cold region. So, here we are, we are including and taking more and more complex terms.

So, another one I just finished with this one is SNOWR, which is your snow water melt which is a positive so, it can add to your precipitation. So, you could see here how an infiltration a small component can be explained by simple terms or a complex of terms. So, is this feasible for regional scale assessment is your question, but it may or may not be important for your field area depending on the site that you choose.

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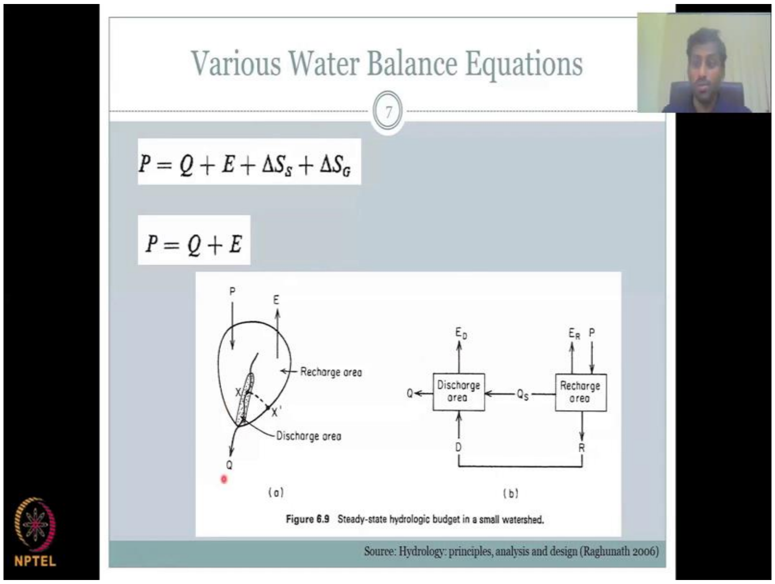


Moving on, there are various water balance equations now, we have understood from the previous example that it can be too simple, it can be complex, let us take a watershed approach and solve one. So, this is your watershed and you have the area the whole area is the recharge area and a small area along the stream. So, this is your stream as the discharge area for groundwater. So, the important component is precipitation is happening and evaporation is happening and some of the water is going into the groundwater as recharge and the recharge can also give water to the river as base flow which is discharged.

So, the first equation is a simplest one is P is equal to Q plus E. So, your precipitation is equals to Q plus your evaporation finish. I am not going to look into all these complexes. But now I will say no there is different storage is there. So, let us look at the storages. So, now P is equal to Q plus E which is the evaporation plus del Ss, which is the water stored in the soil, and del Sg which is the water stored in the groundwater.

Let us look at the steady-state hydrological budget example. So, this is your recharge area where on which your precipitation happens and there is evaporation on the recharge area. So, some water is lost, and the recharge area means water is recharging into groundwater. So, it goes into the groundwater component gets stored here, which is del Sg gets stored here on the ground surface which is your del Ss, your soil and some of the groundwater gets into the discharge area along the stream because the stream can get water from the groundwater, we saw this is the base flow example in the previous lectures.

So, that can go into the discharge area here and your Ed is the evaporation along the discharge area, which is a loss. So, the net water all these waters would combine and come out of the watershed as Q. So, you can see here how a simple equation can be explaining your watershed behavior or if we know the details, you can throw in more other variables to make it more complex.

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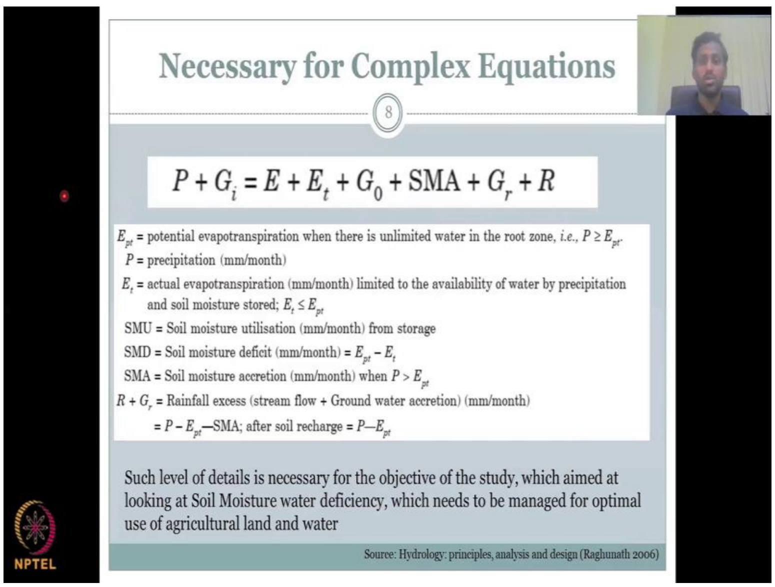


Is it necessary for complex equations? Is it necessary to have all these equations and all these indexes to explain what it is etcetera. It depends, such level of details is necessary for the objectives of the study, which aimed at looking at soil moisture water deficiency, which needs to be managed for optimal use of agricultural land and water. So, for this example, let us say P plus Gi is groundwater, subsurface inflow is equal to E plus ET plus Go the water lost out of the surface plus SMA plus Gr plus R.

We have discussed all these terms in the previous slide, but what is this equation going to give me if I know SMA, if I know how much ET is lost, then I can get at SMD as given here, which is your soil moisture deficiency, there is nothing but soil moisture deficient millimeters per month is equals to Ept minus Et. So, Ept is the potential Et of the particular plant, which means how much maximum the plant can consume if it has unlimited water supply, and if it is a healthy plant, minus the actual ET.

So, how much is it actually growing because I am giving only less water, I am not giving unlimited water, it is less water? And that is SMD. SMD is 0 during your monsoon because rainfall can give all the water. SMD is a very important concept during your early season. Because you are applying water only when the plant suffers slightly, the farmers would rush and say okay, I am going to irrigate, why would they irrigate, the plant is happy with the water. Or they know prepared that okay, every 3 days the plant will get thirsty, I will give water the third day.

So, this is the beauty of this equation. It can be as simple as possible, depending on your study area objectives. And it can become as complex as possible if you have the data and you know the objectives. The idea here is if you know that the land has groundwater recharge, for example, but you do not have groundwater recharge data, then you can put it as an limitations or concern for your study. Please do not say that there is no groundwater recharge.

If that is the case, it is fine. But if you know that these are the physical principles that are happening, but you do not have data, give the equation for what it is and then write a description saying, due to limitations of data, I do not have these for supporting my equation, so I am not going to consider it.

However, the assumption is, it is kind of supported in the del S or precipitation or ET whatever estimate you have. So, it is always good to be upfront about the limitations of your study and or your objectives have to be clear to understand what the parameters go into your water balance equation.

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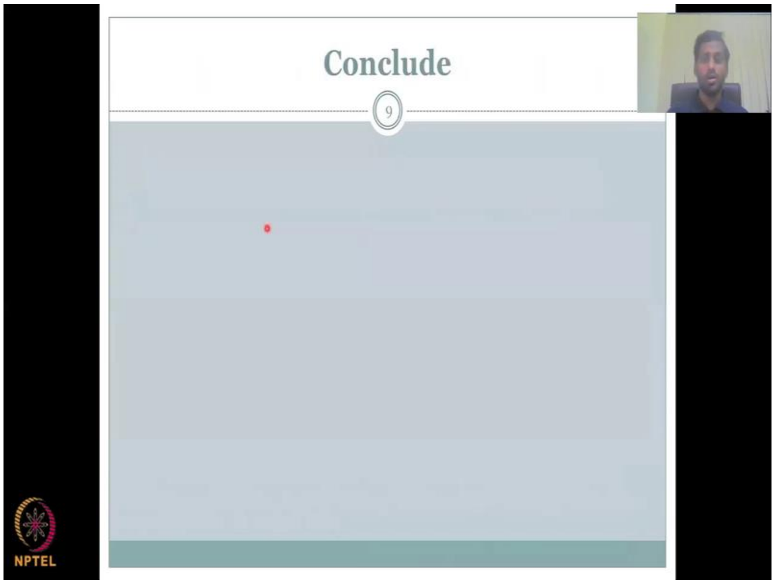


With this, I hope you understood the water balance equation, complexities and the ease of using it and what variables written, I will see you in the next class. Thank you