Rural Water Resources Management
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Week 07 – Lecture 05
Data and tools for watershed delineation

Hello everyone, welcome to NPTEL course on Rural Water Resources Management. This is week 7, lecture 5. This whole week we will be looking at the watershed water balance approach, we will look at the important units and parameters. And we have looked at a manual method how you could designate it, where to get data for watershed and why watershed approach is more important. We will wrap up today with a recap and also a specific example to show how a watershed balanced approach will be very important.

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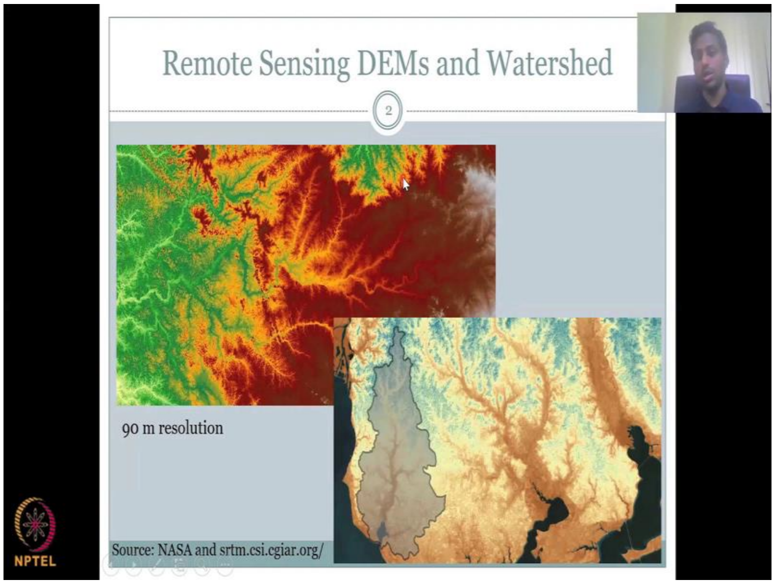

Moving on I did promise that I would show you some new data for Watershed delineation and that is from remote sensing and satellite images and what we see here is DEM, a Digital Elevation Model. I have given this full form in the previous lecture what they will give you is a 90-meter resolution which is spatial. So, each pixel if you zoom in each pixel on the image is 90-meter resolution which means within 90 meters the elevation is taken.

So, this is at a much higher spatial resolution than the manual maps, as I said the manual maps they would fire stand far away and then take an image and then see how the elevation is or using instruments differential GPS, differential elevation meters etcetera. But there are a lot of errors because of manual etcetera.

Whereas this is a very spatially based experiment using satellites. The other reason for using more satellite products is because it is a new one. So, with technologies, you have better-updated resolution. So, initially it was more than 300 meters now it has come to 90 30 meters and ISRO satellites have also with one-meter resolution. So, you can range anywhere you want.

The second thing is those maps, manual maps have been taken very very long like 1916s as I said through the Britishers when they were ruling India and they do not change much because elevation is elevation, maybe you taken off a hill by terracing it or blasting for granite. So, that piece gone, that is different, but most of the land elevation is the same.

There has been some Earthquake disturbances some subsistence because you pull water too much then the land comes down those have been there sinking of land etcetera. But overall the topographic maps are still good whereas these remote sensing data captured every 3 to 4 years so that you have an updated version.

So, these are very colorful and only give you elevation. So, each pixel only gives you the elevation or the data and you could see clearly that the stream network is captured. what is a stream network? A stream network is a low elevation in your land because it is low water comes there and then flows out.

Stream, rivers, etcetera lakes, ponds all are having water, water flows into it because they are at a lower resolution with lower height. So, this low altitude is because they are the formed in depressions and those depressions are at a substantially lower altitude lower potential than other points in your watershed.

Remember, when we did the watershed, we picked points along the boundary where high elevation is there and from there we went towards the stream to see how water moves to the stream. So, this is an example of a remote sensing image especially DEM and which has given you the elevations. So, using this, you could delineate your watershed you could see this watershed which has been delineated. And this is your outlet point.

So, clearly you start with the outlet point, and then you go on marking the elevation points across. How do we know this is accurate? Because if you look at it, no other stream comes into it. So, the watershed has a very well developed one major river with some stream networks. And that outlet is fed by only one river, you could have this river coming from here, which means the watershed boundary would come along this side. But your watershed is truncated here because this stream just do not go beyond a point. And elevation would stop it from breaching over. A stream cannot climb and go over an elevation.

So, across the elevation, this side is one stream across the elevation, the other side is one stream. So, you could see how leaf shape a fern shape that we discussed in lectures four, five, we saw how watershed shape can influence the flow into the rivers, all this can be now well understood, because those are the shape are determined by your elevation points. And the outer point where you want your outlet.

So, here is the outlet. And then you move across and see how high elevations are there. The coloring is given us in this image, blue is high elevation, brown is low elevation, just two colors. So, you do see that you have high elevation which is blue, all the water comes down, and then goes into the brown and goes out of the system. Here, the red is medium elevation, whereas your brown is high elevation, you could see snow and other things.

And then from here, the network starts all these would feed into the network, and you have your watershed point here, outlet, and it has two rivers coming in. And this river would stop here, because it is a well-demarcated watershed boundary, whereas this green will go to the other watershed boundary.

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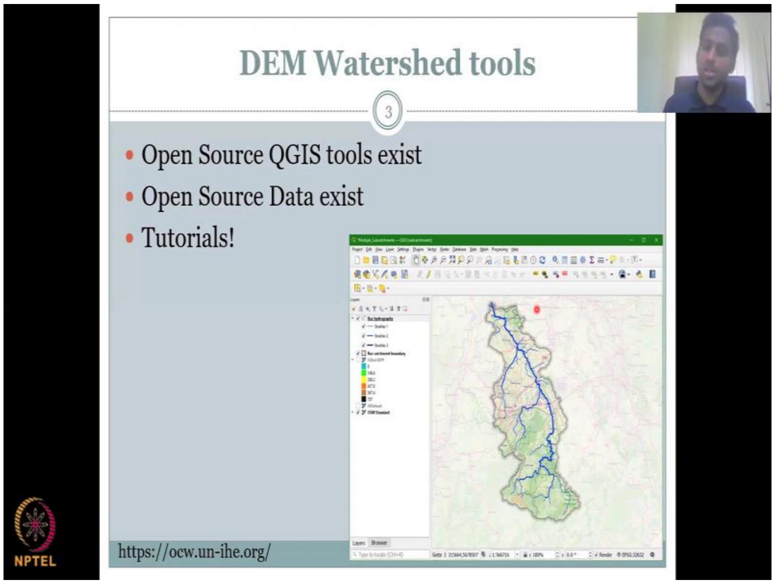

So, this is how you should do it. But you do not have to visually or manually when you have a digital data. When you have a digital data, you can then just go to tools for the DEM watershed, delineation and analysis. The lot of open source GIS tools that exist in particular QGIS. QGIS has been one of the world leaders in open source free GIS tools, even governments are using QGIS tools, for example, in Switzerland, France, etcetera. So, it is very important to shift towards this phase, because you have everyone using it, if it is proprietary software, expensive software, not everyone can use it.

And there is a good forum to help you understand the tools. So, now we have open-source framework where you can put the data and then delete the watershed, but you need the data. So, where do you go, there are open source data that exists. The previous slide I showed you is from NASA and SRTM CGIR where these are open source archived data, anyone can access this.

Some data need to be cleaned, some data need to be error-checked. And that is what the CGIR has done. They have taken the NASA data, they do not have satellites by themselves. They have taken NASA Data and they have cleaned the errors they have cleaned the image so that it is at a better resolution and better quality. They use some algorithms tools, mostly codes and or inspections on the ground, and remember that a satellite accesses a different data and converts it to something that you need. For example, it is a proxy system or a secondary system.

So, how do you know this is correct? You have to send people to check if the elevation from the satellite is the same elevation here. So, either way, you would still go back to your Topo sheet maps and then see how these two maps agree. And topo sheets are very low-density points where this is high-density points. So, you could actually if you use your topo sheet to calibrate validate this model, then you can use this and also some people send surveys based on the DEM map into the field to collect data and check these maps.

Once it is checked is free available you can use it on QGIS software, you can use it on open source, multiple data sets, archives that are available and there are tutorials to learn so it is free. Open to all and multilingual for example IIT Bombay's, fosse and spoken tutorial programs leads QGIS in terms of the number of avenues it has created, and also multiple languages it has created so you can listen to these tutorials. They give you example data which is open source and they train you on an open-source platform QGIS.

So, you have a tutorial to self-learn, you have a platform which has to be put on a computer and the software that you can run and the data. So, once you know all these, you could actually use these tutorials. One, another international tutorial is given by the UNIG so the United Nations the hydrology program has a lot of tutorials available for a lot of different regions, it can be region specific in terms of language, but most importantly the tools are in English and most of the tools you could understand So, if you have the data and if you know the physics behind it that water flows from high potential to low potential and you need an outlet point then all these boundaries can be easily created, however big however small.

So, that is the other beauty of using open source data, you could have global scales or even smaller scales. The smallest you can go as I said is one meter from cartostat and it is expensive that data some high-resolution data is expensive, but for your village for your research area, you could use a 30-meter resolution which is free of cost.

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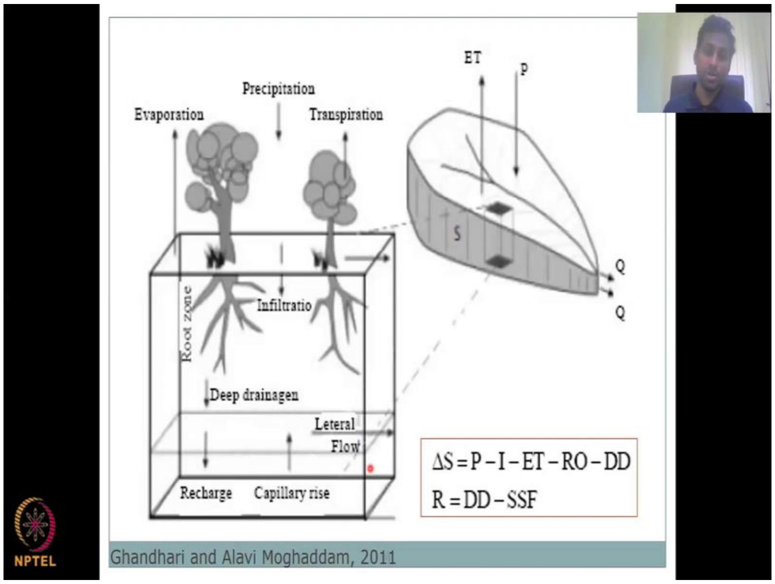

Once you have the watershed, it does not stop there then what you do is you put in your hydrological parameters. So, now I have this watershed boundary, what do I do next and I have the stream network which is delineated along with a watershed. So, if you go back to these images, you could see that if I know that this is the outlet and this is my boundary or the boundary created here, I also get to know where are the streams the small drainage that go into my river. And so, similarly you could see here that the water can come across your watershed and go into the smaller streams and major rivers.

So, those are delineated when you delineate your watershed boundary, as I said, most probably it will be like a leaf shape fern shape object and you could then collect data just for that watershed, you do not have to collect data from other regions, it may not be necessary. So, you could collect data and then establish your water balance equation. For example, I am putting precipitation I know by the crop, how much evaporation and transpiration happens the type of soil etcetera I know then based on this I know how much water is going to be stored and how much water is going to go out of the system as runoff.

So, let us take a small area of interest within your watershed it could be a pixel it could be a plot. So, this plot has been taken out and you could do a micro analysis micro watershed analysis here or water balance analysis here let me show you how. So, if you take a small pixel out or a small unit of land, and then you could see that what type of tree is there what type of tree of crop is there you understand the transpiration rate.

So, I can put a transpiration value and for that block I know that precipitation because I know the overall precipitation and if it is the homogeneous precipitation across a small area homogeneous means same precipitation I can put the same precipitation here and then knowing the soil type, if I know the soil type, the soil texture, the dominant trees etcetera in the region, I could estimate the infiltration, we went through infiltration percolation in the previous classes, where we do find that it helps you to get the water through the soil profile, these infiltration, percolation and gravity.

So, those things can be estimated using your soil rock profile and then either by the type of tree can also give you the root zone and knowing the layers in the soil you can know how much deep groundwater aquifer goes in and how much recharge goes in and at the end how much goes as subsurface flow which is small Sq and bottom base flow which is Qb and on the top you have just the Q or runoff. So, all these small components you can put in and models are run like this, they divide the entire watershed into small areas and then estimate how one area goes to the other in terms of water balance.

Now, as I said you could set up a smaller water balance del S is equals to precipitation minus your infiltration minus ET minus your RO and minus DD. So, the deep drainage, etcetera, etcetera. So, you have R and then you can also estimate, which is your groundwater recharge is actually your deep drainage minus your subsurface flow, how much lateral flow is going on.

So, if you know how much is water coming in, you know how much recharge is, you can estimate how much the lateral flow is, which is your base flow, or if you know your base flow from your stream, you can get back to your recharge, which is the key ingredient in your analysis. So, with this, I think a clear picture has been given on how to set up the watershed and within the watershed, you can have a smaller water balance equation.

And also, you could look at the application. So, now I know all these values, how can I apply for rural water resource management? Where can I apply I know the recharge, fine. I have estimated it, I know that del S which is the change in storage, functional precipitation, infiltration, evapotranspiration, runoff, and your deep drainage or drip recharge.

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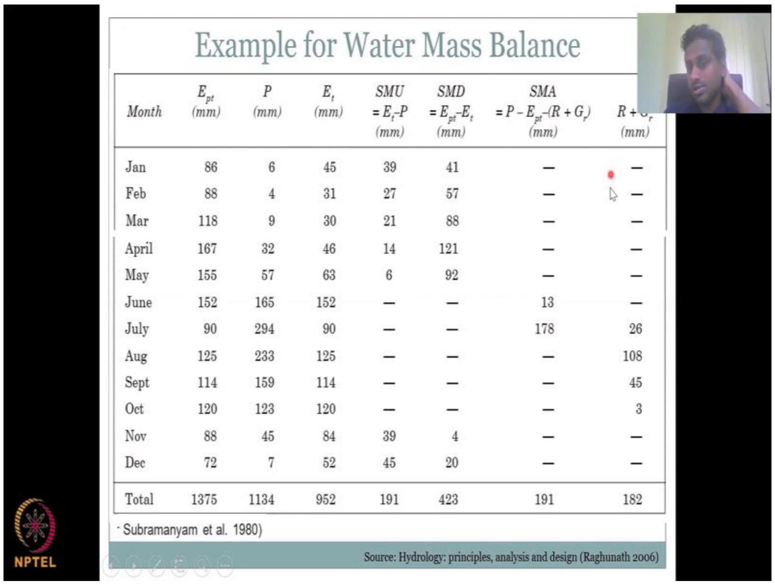
Example for Water Mass Balance

Month	E_{pt} (mm)	P (mm)	E_t (mm)	SMU $= E_t - P$ (mm)	SMD $= E_{pt} - E_t$ (mm)	SMA $= P - E_{pt} - (R + G_r)$ (mm)	$R + G_r$ (mm)
Jan	86	6	45	39	41	—	—
Feb	88	4	31	27	57	—	—
Mar	118	9	30	21	88	—	—
April	167	32	46	14	121	—	—
May	155	57	63	6	92	—	—
June	152	165	152	—	—	13	—
July	90	294	90	—	—	178	26
Aug	125	233	125	—	—	—	108
Sept	114	159	114	—	—	—	45
Oct	120	123	120	—	—	—	3
Nov	88	45	84	39	4	—	—
Dec	72	7	52	45	20	—	—
Total	1375	1134	952	191	423	191	182

* Subramanyam et al. 1980)

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

Let us do an example. I am going to put in values and show you an example. And we will use the same book that has been prescribed and the same water balance equation and data that has been given in the previous lectures. So, it is a monthly timescale water balance, and at an annual scale, we will be looking at the total.

So, the Ept I will go through the units and parameters and the Ept is your evapotranspiration potential, which means that is the maximum for the type of plant. So, before this, I have the watershed boundary, and I have the land use type, which means what crops are growing in the area, this is the two information.

I have and then all these data are collected. So, Ept based on the crop type, I can estimate the growing curve, and how much water it needs per month based on the crop type. Here this crop is using a little bit water in the initiation stage, then it grows, peaks and then comes down a little bit, and then peaks and then comes down. there is a small peaking period. Or it is a two-crop period one crop dies here and another crop is put.

So, it is evapotranspiration potential which means, excess water is available or unlimited water is available. So, the plant can grow as it pleases as much as it can consume because there is a maximum of water that a plant can consume and that is given as Etg. P is the precipitation rainfall and you can see the seasonal rainfall. So, mostly the season starts in June and then comes down in November, and then you have your ET which is your actual ET, which means there is no unlimited water there is only limited water.

And how the plant grows depending on the plant growth you have a good growing season and the rainfall or recharge water is being used. For example, let us look at here if your ET is very close or as good as your rainfall, which is 165 is the rainfall the plant needs only 152 potential then the potential and your actual ET are same because the available water is more excess off your growing potential.

SMU is when soil moisture is utilized, you could see here is the soil moisture is utilized when your rainfall is lesser than the amount of water the plant needs. So, this can be looked at the maximum or the good amount of water the plant needs and the precipitation is sometimes limited. So, when the precipitation is limited, you can go to the soil moisture utilization and soil moisture deficit. You want to utilize it but there is no soil moisture. So, that is a deficit and then the soil moisture recharge which is basically a groundwater recharge component going in and your Ept which is your potential evapotranspiration taken out. And your R plus G which is your groundwater recharge.

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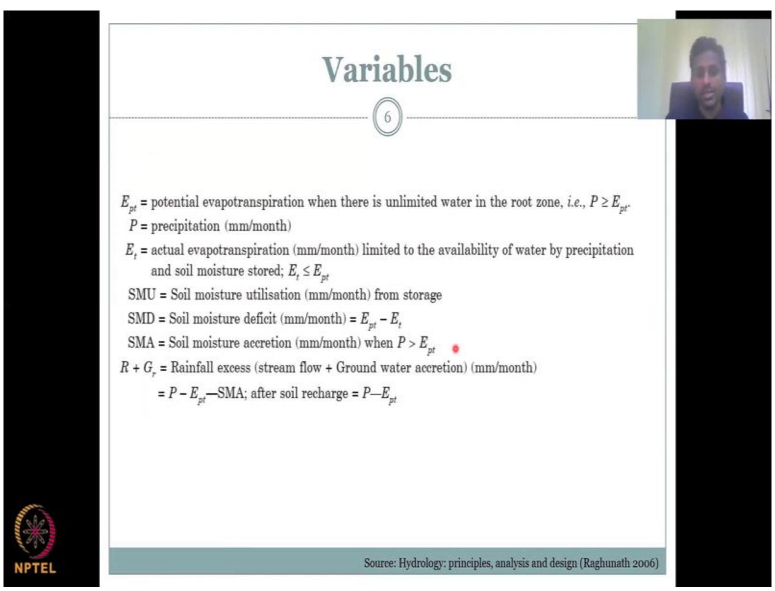

Let us look at the variables again potential evapotranspiration, precipitation, actual evapotranspiration all are in millimeters per month and your soil moisture utilization, soil moisture deficit, soil moisture accretion when P is greater than Ept, which means your water is in excess so, the plants can take it and even then there is more water which can go into the groundwater and R plus Gr is the rainfall excess that is available.

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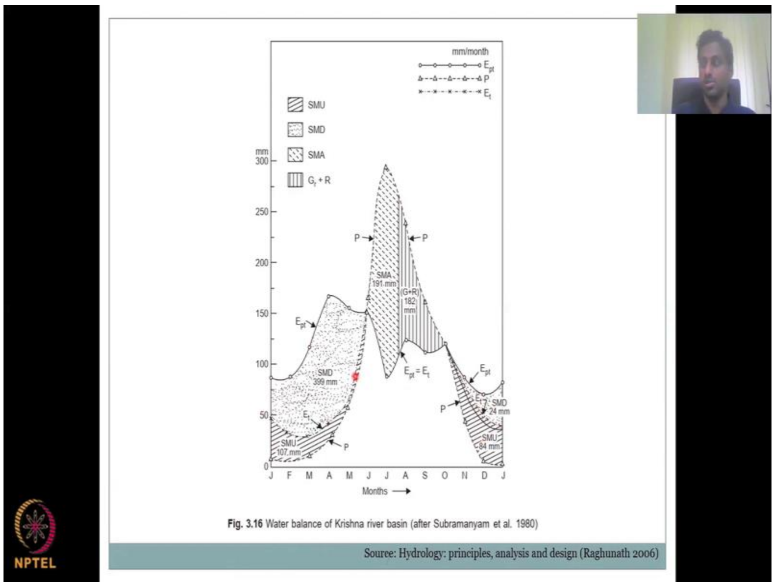

Now, this is what you find after you plot that it in a table you cannot see what is exactly happening but if you can put it in a graphical format here it is a graph. You could see how these different quantities are very important. So, let us start with your growing crop Ept. So, Ept is the good water that the plant would need amount of water for full growth, but sometimes it is stressed which means it has lesser water.

So, it has to be irrigated or it takes water from the soil. So, it is starts in Jan there is one crop as I said and then another crop there is one crop which goes down and then another crop and then it comes down again. So, which is given dot dot dots in the graph, comes like this Ept but what is your actual ET, which means it is suppressed it is lower than the potential ET because there is no water available for the plant and it is growing like this in the x-axis.

So, what is happening is, is this soil moisture if available could have been given to the plant to attain the Ept, but it is not available. So, it is called as soil moisture deficit there is no water and when does it come it comes in the summer season or before the summer season which is the Rabi season.

So, in the Rabi season, if you are using that crop, you should understand that you have to supply water from other resources like your groundwater, your tankers, etcetera or channels of water because the soil moisture is not available it is deficit. Then what you have is SMU, Soil Moisture Utilization. So, your since your ET is low, it is low not fully down to the precipitation level because it is using from soil moisture.

So, some soil moisture usage is there but still you cannot push your plant growth to Ept and that balance is called your soil motion deficit. Now, your precipitation starts to rise the ones with the triangle when it starts to rise and peak during your monsoon June July, what happens is there is more water than what is needed for your plant which is your Ept. So, Ept is equal to ET, so, under the peak rainfall monsoon season your potential ET is equal to the actual ET, which is what is going to say.

Your Ept the potential ET is on the book and your actual ET is what the plant consumers in real life. So, what happens now, because there is excess rainfall some of the rainfall goes into the soil because the soil has been depleted it is almost nil because all the soil moisture has been used which is which can be accessed and that is why there is a deficit. So, now the excess rainfall after the plant is taken up can go into soil moisture acquisition, but that happens through proper network and that is the base of this course rural water resource management.

The next is some water goes into groundwater as recharge and you can see that here that some of the precipitation is broken in given into the aquifer as recharge and then you do have soil moisture utilization again during the end of the monsoon because sometimes the monsoon water quickly finishes or the monsoon stops before the crop has peaked or ready to harvest for which you need to supply soil moisture.

So, what happens is all the soil moisture and groundwater that has been stored during the monsoon is slowly started to be used in the post-monsoon season this is the post-monsoon rainfall is coming down. So, now what happens to sustain the growth of the plant the SMU the soil moisture is utilized but still there is a slight soil moisture deficit SMB is very low here you have a high soil moisture deficit because it is pre-monsoon which is a summer season.

But here you have still a little bit of soil moisture deficit because the plant the water does not get stored in the basin and maybe this basin did not have a storage to store these water components. And then your precipitation comes down in the end of the monsoon, but the farmer is still interested in the crop. So, if suppose the farmer had one crop and that one crop is correctly spaced in the precipitation season, then what happens your soil moisture deficit is 0.

Your ET is equal to your actual ET is equal to your potential ET and the groundwater recharge can happen without a problem. But because as coming back to the first slide, because the population is growing, because there is a need to sustain the livelihoods of farmers which is because India is an agrarian nation they go into groundwater extraction.

So, moving on, you have these water resources used for the growing of the crop or completion of the crop and this SMU comes to this point which means that is where your soil moisture has been depleted and then more is depleted leading into the pre-monsoon big deficit happens and your next monsoon comes. So, a water balance has helped us to understand which part is the best part to grow a plant which is under your precipitation and if I need to change the crop because my soil moisture if it is too much I cannot control the soil moisture I cannot augment it through groundwater.

So, I should change the crop to bring down this curve and Et can be somewhere normalized. So, the selection of crop the timing of the crop, which went to grow the season and the number of crops can be aligned to your water balance and you could see where it aligns itself. Because what would happen is you could push your crop growing calendar until or under the precipitation curve, and then you could also move your or lessen your soil moisture deficit and soil moisture utilization, you can utilize it for small parts, but it cannot sustain a full growth period. That is what this graph is showing.

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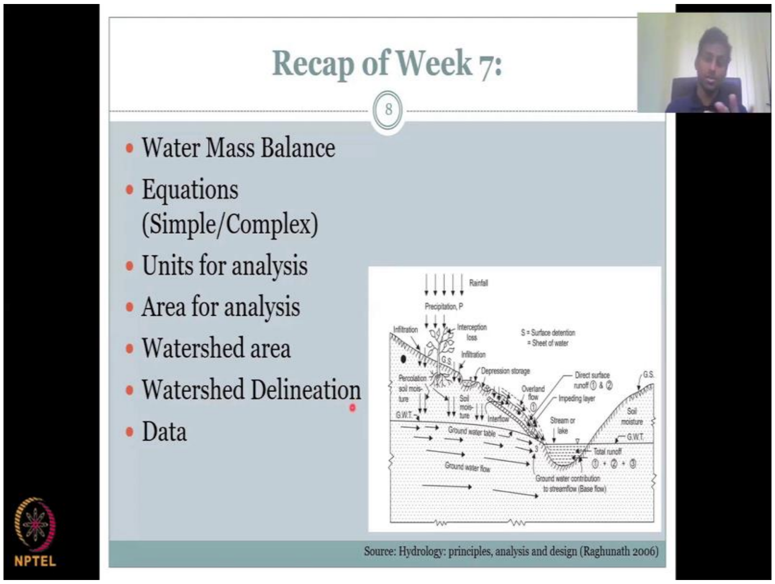

With this I just run through the recap of week 7, we have looked into a watershed approach for the hydrological balance, we understood the hydrology and hydrological balance in terms of what are the key parameters, where do this water flow etcetera in the previous class, but in this week, we have looked at the water balance, now we know the hydrological cycle.

How do you convert it into a water balance? What are the parameters that are important? What are the units for parameters, we gave some equations which could range from very simple, which is like precipitation is equal to your runoff plus your storage or your storage is equal to precipitation minus runoff. And you can also be very complex that we saw when you throw in groundwater, you throw an infiltration catchment of water in the plants as interception losses, and then ET evapotranspiration, those kinds of things. So, it can be very simple and it can be complex.

We understood that there has to be a unit for analysis, both the spatial and the unit in the parameter. And then we also looked at what type of time unit you have to keep for your units, for example, is it millimeters per month or millimeters per year. And most importantly, there are differences of units when you go to different parameters. So, you need to normalize it convert it to 1 unit. And the unit of analysis in terms of area should also be defined, which means you have to set up a watershed boundary or for which you need the outlet point. And also, you need to delineate the watershed using different tools.

The watershed area was discussed, it could be as small as a stream network, or as big as a big basin with multiple rivers coming in. We also looked at different methods to do it both manually using the topo sheets that have been given by the Britishers or even the Americans who did the surveys. And or you could use the recent ones which are driven by remote sensing data through satellites through planes. And we saw that data exists in open source platforms, which can be put on a open source software like QGIS.

And there are tutorials to do the watershed analysis. So, please do not think that it might be too difficult to for you to understand and do it. And there are good NPTEL courses on GIS which I will not discuss in detail. So, here you would actually understand that which data has to go in? Why do you need a watershed? So, those parts and then you could shift to the other courses on how to bring water into the watershed component, your precipitation, groundwater components, etcetera. And then you close the water balance by understanding how much water comes out of the system. All this data is also available for Indian regions. I have given you the links and you could also get the delineated watershed through your open source software's.

So, what is the delineation is a very important thing. We also looked at the free open source data sources especially for India and the different scales or temporal resolution spatial-temporal resolutions that are available. Your spatial resolution starts anywhere from 90 meters for free to 1 meters in some region, but most regions you can get it for 30 meter resolution. So, with this I would like to conclude today's lecture and the lecture series on the water balance equation. See the other side of the next week. Thank you