Rural Water Resources Management
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Week 07 - Lecture 03
Hydrological Water Balance - Units

Hello, everyone welcome to Rural Water Resource Management course, which is the NPTEL course focusing on rural water issues and how to manage them. This is week 7, and we are at lecture 3. In this week, we have been looking at the water balance equation, how to construct one, what are the data that gets into the equation. And today, we will be looking at more specifics on how to solve issues and concerns using a water balance equation. Also, some important concepts to be discussed.

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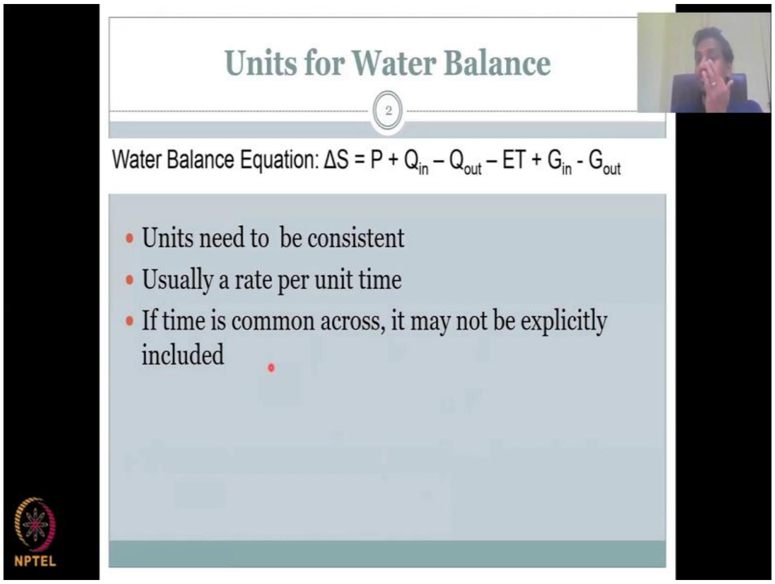

The first one is, of course, the units for water balance. Because most of the time, the complex equation would have different water resources, for example, groundwater, rainfall, infiltration, etcetera. These units might be procured, or a sum assumed or estimated from a different entity. For example, ET, we take the crop growth and then using the crop growth crop coefficient, we understand how much water is needed. And these might trigger a difference in units. So, you need to be very careful to normalize across the equation with a single unit.

Let us take our example for today. The water balance equation that we have been seeing, which is del S the storage or change in storage, the P which is your precipitation, here we are only looking at rainfall to keep it simple. Q's are the runoff, discharge coming in, and discharge going out. Your ET, which is the plan consumption, the groundwater in and groundwater out which is given by G.

The units need to be consistent. Otherwise, we will be comparing apples and oranges. Which means if the units are different, your del S might be too small, minuscule, or too big, which cannot happen. We have seen a lot of works that have not normalized and by that time the data has been published. So, be very careful to have the exact units across not only the quantity of the unit but also the time, which means what is the unit of time that has been discussed.

When I said del S, del S across what? Is it a day, is that an hour, or is it a month or annual. So, you can pick any day, any time that goes into your equation, but keep that time consistent. Just between seconds and a year. Just between seconds and an hour. You see the unit can change your magnitude can change multiple times if you use the wrong word.

Usually a rate per unit time, but it is not explicitly given here. For example, when you write it, most people would write del S, as millimeters, precipitation as millimeters, Q in millimeters Q out millimeters, ET, G in G out millimeters because when we define the water balance equation somewhere, the author would have defined it as water balance, annual or daily water balance. So, sometimes your unit of time is implicit. It is not as explicit as your parameters.

P is rainfall millimeters or inches, so be careful to understand the unit when you have seen the water balance equation. So, it is always good to go back and check are they doing it correctly, is it correctly what you want. If time is common across, it may not be explicitly included. As I mentioned, if time is the only unit across, they will not put millimeters per year, because annually they have defined.

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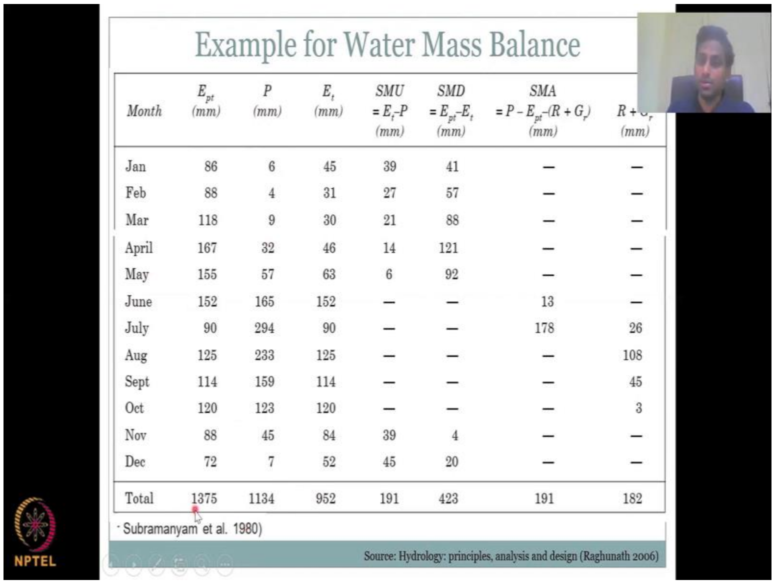

Example for Water Mass Balance

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 take an example for water balance. Here where is the time it is implicit, which means you have the time here as months? So, you have a total of 12 months for a particular year. So, you have a particular year and you are taking 12 months and monthly these are the parameters values. And for our equation. We have EPT which is your evapotranspiration together with potential. And then your P which is your rainfall, which is ET, which is your actual evapotranspiration, and then SMU we had it as soil moisture deficit with SMD and soil moisture utilization with SMU, actual soil moisture or storage etcetera etcetera.

We will not get into the units of these what they actually mean because this is for showing the example of how the units are the same across the ET which is a measure of water getting into the plant and transpiring consumption which converts into a gaseous phase and goes up is in millimeters. So, think about this the phase will also change. The precipitation which is your rainfall is in millimeters you have a tube you can measure it but your ET which is in a gaseous phase is also measured as the thickness millimeters, not as a volume.

Similarly, your ice for example, if it is a solid you say, soil water coming from your snowmelt, which is actually initially was a small thickness. So, you have millimeter of small thickness which converts to runoff which converts to soil moisture. So, to keep that flow uniform the unit has been kept uniform across the table, and as I said you will not have a unit explicitly mentioned if it is a common unit. Here it is month a quick question is what was this unit for time if you think about it, the months have been totaled which means added so, all the months have been summed up so, this is the sum of all the EPT and sum of all your rainfall you actual ET etcetera etcetera.

What you see here is, the total is an annual timestep which means a unit time is annual per year. It is not per month as you see here. So, let it keep it across and then we will see how things rearrange etcetera. Just for the quick analysis let us do a quick seeing what this actually means this water balance, so you have total 1375 millimeters per year which is the total water a plant needs in a hygienic or good condition which is like unlimited water supply for good growth.

But the actual precipitation is only 1134 and out of the 1134 which is lesser than your plant requirement, not all water has been taken up because some runoff some go to evaporation on the site etcetera etcetera. So, you have only 952, so 952 minus P gives you your actual SMU which is soil moisture utilization, how much unused are kept in it, and the deficit.

So, coming back deficit is just these two numbers because you have the potential medium, which is the highest, but actual ET is much lesser. So, you could now use a what balance approach to identify what is the soil moisture use? What is the soil moisture deficit? How much should I augment? Or how much water should my groundwater be supplied? This exercise could have been only possible by first normalizing your parameters on a specific unit and also normalizing it on-time unit. You cannot have January for monthly for EPT.

And for this example, January and then keep it annual for precipitation, it cannot be done. If you have only an annual what do you do? Like the least common denominator approach? You just come back here and say, what is the smallest time that is across the series, which is same. For here if you say presentation is in annual, then you have to sum everything and only look at this column and row. Here only the total column and row should be taken up.

Because presentation is an annual, but here we have the division so we kept it if you do not have it, in some cases you may not have it. So, be careful on just using the annual so you can sum it up but do not divide your rainfall by 12 and put it here it is not correct because for January you cannot put an average rainfall which is divided from your total rainfall. So, keep your rainfall, look at it. It starts very low and then goes up and comes down. All these are tied to the plant growth and the circulation of climate. So, here keep it at annual scale if that is the least common timeframe that agrees across your parameters.

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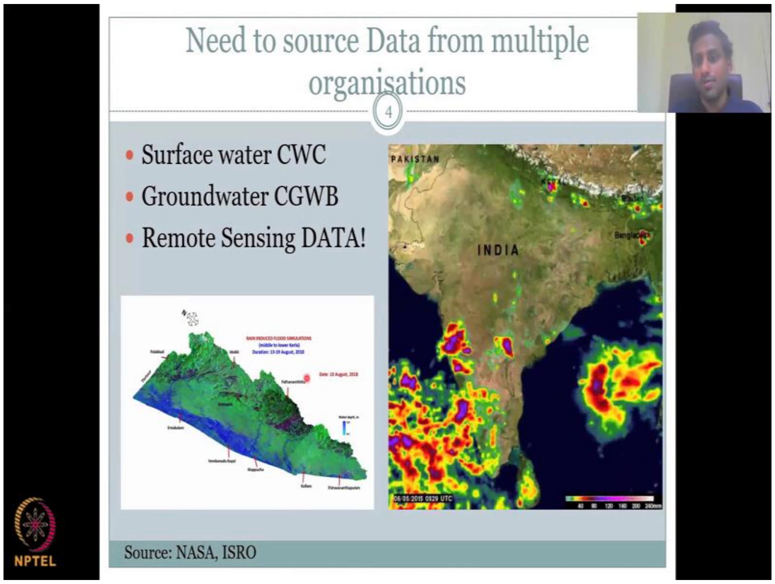

Moving on need to source data from multiple organization this is another issue or concern. Based on the equation's complexity, you may have to get data from different organizations. This happens across the world, it is not only in India or rural sectors, wherever you go, you will have different agencies monitoring different data. To bring them together, we need to work on some mechanisms or the user has to maintain a table of data and source and pick each source of data and reorganize the units both the time and the actual quantities parameters unit.

Let us take an example for Indian case. The surface water which is your discharge runoff is monitored by the Central Water Commission, so this is CWC. However, the groundwater is meant monitored by the CGWB, Central Ground Water Board. In some cases, we have the government data. So, IMD is monitoring your rainfall data, which is also common for all the government agencies. And then there is a government agency which monitors remote sensing data and remote sensing can be of groundwater, of surface water, rainfall, ET. You can name it. I am only naming the parameters for your water balance equation.

So, it is very important to understand these units and understand the source, there could be some errors in the source which you need to incorporate especially for remote sensing data, they will give you some parameters that you need to incorporate to get the final output. So, that is also important to read about the data before you incorporate into your water balance equation read the source the methodology, how the data is collected the units for the actual quantity as in millimeters or inches or foot and the timeframe which was collected the timestamp temporal resolution we call is it per day, per hour, per month, etcetera.

For example, rainfalls can be collected per day. So, what you should do is I am reporter when you download the data, you should say no I want it as a monthly so that it automatically sums it and gives it to you. Otherwise, you will have to do it by downloading the data and then making sure you use your tables to sum it up to the least common timeframe. Remote sensing data can be one single entity but multiple data.

So, what you saw in surface water, groundwater, and also the state water department which is the PWD as we call it India, have data in focused parameters. For example, CWC is surface water, CGWB is groundwater, but remote sensing units like NASA for the global and US regions and ISRO for mostly Indian regions, you would find that the data of multiple parameters is kept as an archive in the database, would it be able to replace the observation data? Not possible, but you can work it together. So, my point is, make your equation try to see if you can get observation data.

Otherwise, try to see if you can go to the field and collect data. The final step is if you cannot get the data from an organization if you cannot go collect the data, maybe it is costly time consuming, etcetera, use remote sensing data. All these are accepted norms in the government because ISRO is a government data board. And you can see here how for example, a climatic event progresses per day. So, this is at very hourly or even sub-minute levels, it runs the time runs and then you have rainfall pattern emerging.

So, where the higher rainfall and millimeters look at the units all of them are given in your remote sensing data. You have a ledger which gives you the unit is which is millimeters, the color gives red means, for example, is around 40 to 60 millimeters and the unit is given here. So, normally what do you take it as an annual stamp daily stamp or three hours the stamp and do your calculations.

Here you see the flooding which is your surface water drainage water, or your discharge water. And you put that in your equation for R, you remember R we used runoff that is this data if it comes too much it is flooding. And so, this data was taken for the August 2018 floods in Kerala, which was very devastating floods 100-year flood in Kerala, and you can see the water level depth as meters. So, look here very carefully, it is in meters, we need to convert to millimeters. If you find it very hard, I will give you some tricks how to do conversions, etcetera.

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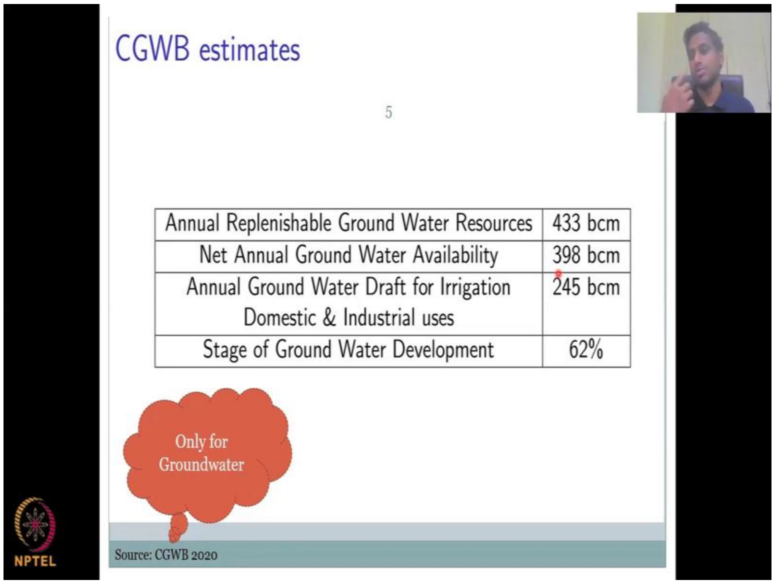

Let us look at some central groundwater board estimate type of water balance equation you have the annual replenishable groundwater resources 433 billion cubic meters. So, in a millimeter you have and now this is a volume, so you have a thickness and you have a volume, the thickness can be converted to a volume by just multiplying across the area. They will have some different methods, please look at the source and see how they estimated.

So, the net annual groundwater availability is 398 billion cubic meters. Annual groundwater draft for irrigation domestic is 245 billion cubic meters, which is one of the biggest in the world. And it is the biggest ranked number one highest consumption of groundwater. Stage of groundwater development is 62 percent. So, here if the three variables are enough to set up a good groundwater water balance, you have your annual 433, on one side, and then you have your net groundwater availability 398 and the use is 245.

So, what is the storage? 390 minus 245 could be the storage and that is what gives you the 62 percent, and you can also understand from 433 only 398. So, approximately 35 million cubic meters is not available, but it gets replenished and so that would be the water that goes into the base flow, river discharge etcetera.

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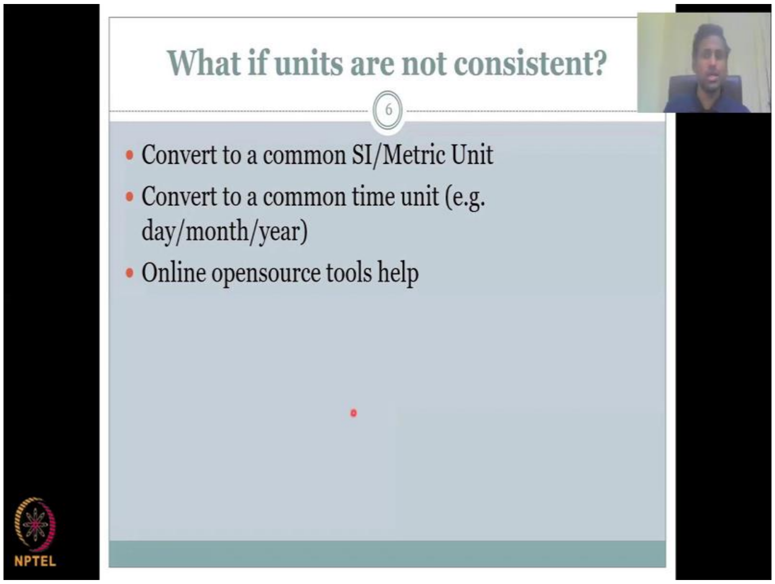

So, these do give a clear picture. What if the units are not consistent? As I promised I will give you that fix, go back and convert to a common unit, I will stick to SI metric units so that it is more commonly used than the gallons and foot by those kinds of conversions. Convert to a common timing example day, month, year, most of these parameters are done monthly and then annually.

From the month you can take the seasonal so which is very smart. You cannot do a year and then come back to seasonal, because the seasons what is important, your Rabi, your Kharif, which is your monsoon season, the Rabi which is your non-monsoon and then you enter the winter crops. Sometimes the winter crops is clubbed with the Rabis. So, you can add the two key ones for water irrigation as Kharif and Rabi season.

If you cannot convert it manually, and all through your tabular format, like Excel, open-source, LIDAR, Open Office, etcetera, what you could do is use online open-source tools. Just type it in

Google meters, to foot, kilometers to foot data, it will do it automatically to just check it out. But most of the time it is accurate.

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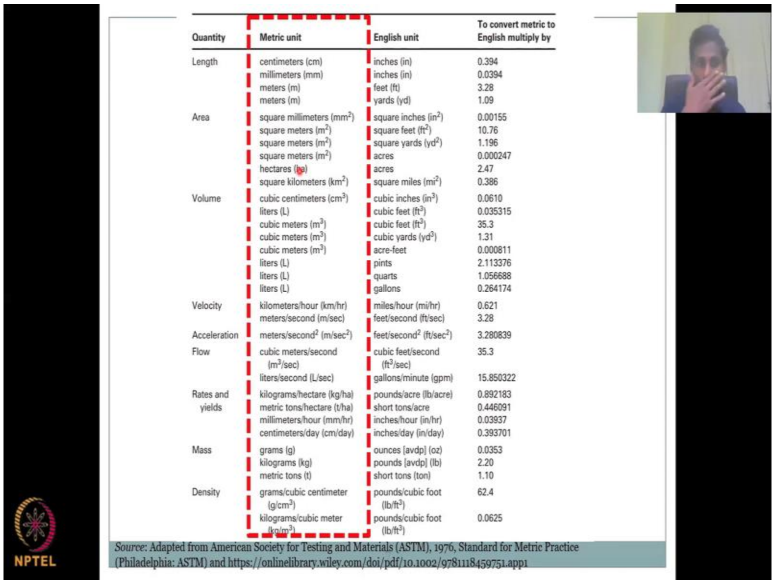

Quantity	Metric unit	English unit	To convert metric to English multiply by
Length	centimeters (cm)	inches (in)	0.394
	millimeters (mm)	inches (in)	0.0394
	meters (m)	feet (ft)	3.28
	meters (m)	yards (yd)	1.09
Area	square millimeters (mm^2)	square inches (in^2)	0.00155
	square meters (m^2)	square feet (ft^2)	10.76
	square meters (m^2)	square yards (yd^2)	1.196
	square meters (m^2)	acres	0.000247
	hectares (ha)	acres	2.47
	square kilometers (km^2)	square miles (mi^2)	0.386
Volume	cubic centimeters (cm^3)	cubic inches (in^3)	0.0610
	liters (L)	cubic feet (ft^3)	0.035315
	cubic meters (m^3)	cubic feet (ft^3)	35.3
	cubic meters (m^3)	cubic yards (yd^3)	1.31
	cubic meters (m^3)	acre-feet	0.000811
	liters (L)	pints	2.113376
	liters (L)	quarts	1.056688
	liters (L)	gallons	0.264174
Velocity	kilometers/hour (km/hr)	miles/hour (mi/hr)	0.621
	meters/second (m/sec)	feet/second (ft/sec)	3.28
Acceleration	meters/second^2 (m/sec^2)	feet/second^2 (ft/sec^2)	3.280839
Flow	cubic meters/second (m^3/sec)	cubic feet/second (ft^3/sec)	35.3
	liters/second (L/sec)	gallons/minute (gpm)	15.850322
Rates and yields	kilograms/hectare (kg/ha)	pounds/acre (lb/acre)	0.892183
	metric tons/hectare (t/ha)	short tons/acre	0.446091
	millimeters/hour (mm/hr)	inches/hour (in/hr)	0.03937
	centimeters/day (cm/day)	inches/day (in/day)	0.393701
Mass	grams (g)	ounces [avdp] (oz)	0.0353
	kilograms (kg)	pounds [avdp] (lb)	2.20
	metric tons (t)	short tons (ton)	1.10
Density	grams/cubic centimeter (g/cm^3)	pounds/cubic foot (lb/ft^3)	62.4
	kilograms/cubic meter (kg/m^3)	pounds/cubic foot (lb/ft^3)	0.0625

Source: Adapted from American Society for Testing and Materials (ASTM), 1976, Standard for Metric Practice (Philadelphia: ASTM) and https://onlinelibrary.wiley.com/doi/pdf/10.1002/9781118459751.app1

So, do it. And this kind of handbooks are something that could be stuck on your reading room. When you are doing these calculations. These conversions do help you arithmetically to think about these numbers, how they have been sourced. But most importantly, you should not be waste putting too much time on each and every conversion because sometimes you can do a small mistake. For example, you say to convert just multiply from centimeters to inches 0.394. If you just put point 0.0394 in your computer, Excel, for example, then the whole table is gone.

So, be careful with these changes, double-check your work. And always compare randomly test one variable, put it in Google and say, for example, 50 millimeters into inches, test what it is and then double-check it, always double-check. And it is better use metric units, not English units, because most of the data that you get from online open source is metric not English. I will tell you, for example, Cricket is in yards.

But our road length and time to get this in kilometers. So, you see how it is confusing if you just keep it in meters, we do not call 22 meters or 10 meters. For the cricket pitch, we say yards, we say in feet, foot for the height we could have just kept it in meters and centimeters like they use it for selection committees. So, like that, just keep it in one, which is very, very important for your water balance.

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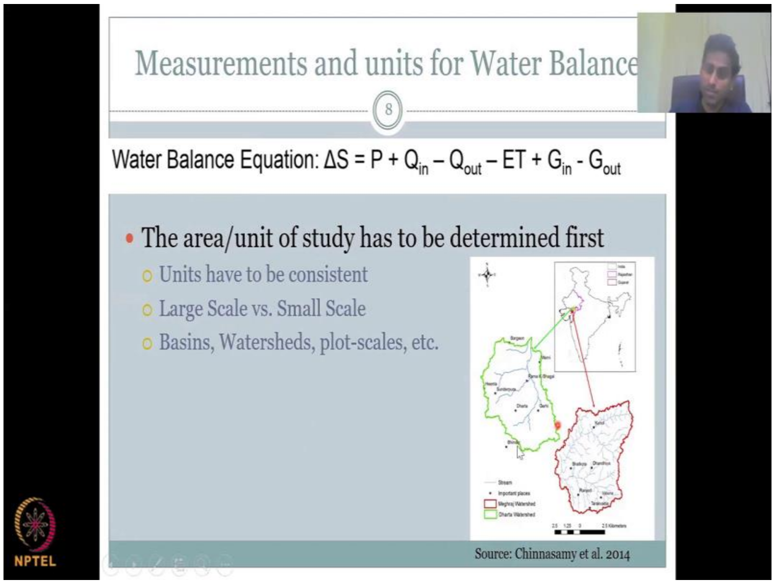

Moving on measurements units for water balance. Let us take our example again, when you do this example, it is as important to also identify the area and unit of study, this has to be the first that you should be doing. Then you look at your data availability units, etcetera. Why did I bring it after this so that to give a clear picture of your units, availabilities, etcetera, and pan, your area, you could check. For example, I am going to do it in Chennai, and I would like to see what data sources are available in Tamil Nadu and the government so that I could check the data's available.

So, that is why I started with the units. But then when you focus on your study area, make sure the unit is taken first. Sometimes you have your area and you have different points of observation later not in your center for example, this part is your area of interest, but the data is only available here and down.

So, what normally people do is interpolate the data for example IMB rainfall data. So, it is good to understand the data the units and then come back to your area of interest and this area should be very, very carefully determined. Units have to be consistent again the units the area has to come commensurate with your area and your water balance, which you should go back here and check if you are using metric for length like meters, centimeters use your areas for as per your metric also, which is square meters, square kilometers etcetera.

Do not jump back and forth square yards square feet, you do use acres, in irrigation, you see suddenly acres coming up and then hectares on one side. So, do not jump back and forth, I normally use meters, millimeters, centimeters, kilometers for length and then jump into kilometer square meters square millimeters per cubic meters by area and volume respectively. Volumes I use cubic meters, Area I use meter square and length meters.

Velocity acceleration all meters to keep it uniformly consistent, then you can easily divide or multiply by 10 magnitude orders to get into the other units. The area of unit has to be determined and units have to be consistent, large scale with small scale, please understand that if you go larger scale, the probability of getting the data for your experiment is high, you will have more options to get the data.

However, if you have a smaller area, it might limit your probability. So, make sure that if you are okay for the small area, and less data by interpolating or assuming from other data, for example, there is no rainfall here and there is no rainfall here. You are not going to have rainfall here, like some kind of assumptions that you can make. Depending on the distance, you cannot have kilometers, but I am saying there is a 100 meters this side of your area, 100 meters this side of your area, you have observation for rainfall, you can carefully assume that this can also be 0.

So, those kinds of assumptions. Basins, watersheds, plot scales etcetera. We did discuss about basins, what is the basin? What is the watershed catchment? Are you going to those scales are you doing a plot scale analysis. Be very careful and do make these maps, GIS is a very good open-source tool to make these maps for your study areas and then collect the data. But I would I would very carefully taking these examples from notebooks on. If the data is available, if so, where is the data and then my watershed area can be mapped out.

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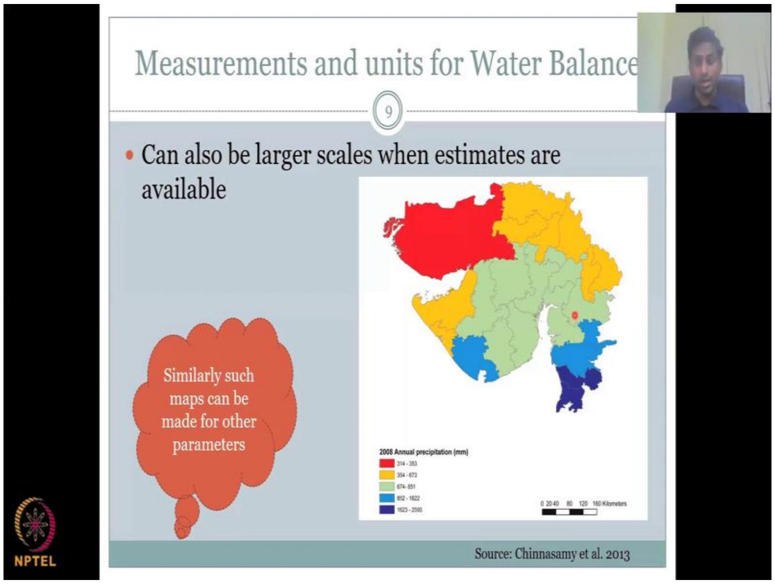

Measurements and units, let us continue can also be larger scales when estimates are available, it can also show a bigger and clearer picture. However, if you do not have the data, then most probably people go about scale. For example, this is an annual precipitation map for 2008 that we prepared and within your district, some places do not have rain gauge.

For example, I may not have a gauge here, I may not have a rain gauge here, but it can be extrapolated into the district boundary, which IMD also does to get an assumption of the rainfall. And you could see clearly a pattern, this region is getting rainfall around 674 to 851, whereas this is the driest with 340 to 353 and then yellows and blues etcetera.

So, your estimates if they are available, if the data is available, you can go to larger scale. If it is very focused and you are doing a field study, it is better to locate a smaller watershed area for your study and data units. Similarly, such maps can be made for other parameters to visualize See, this visualization is a very important technique to understand your water balance.

So, if I see a map, which is a spatial representation of the data rather than an equation, I could quickly say that this is the driest region, and around this driest region is also having less rainfall. So, somewhere here that less rainfall, but higher rainfall is on the south of Gujarat. So, I can throw these estimates or comments saying that South Gujarat has better rainfall, because I visualized your data, then I can do multiple data sets together to estimate the water balance and storage competence.

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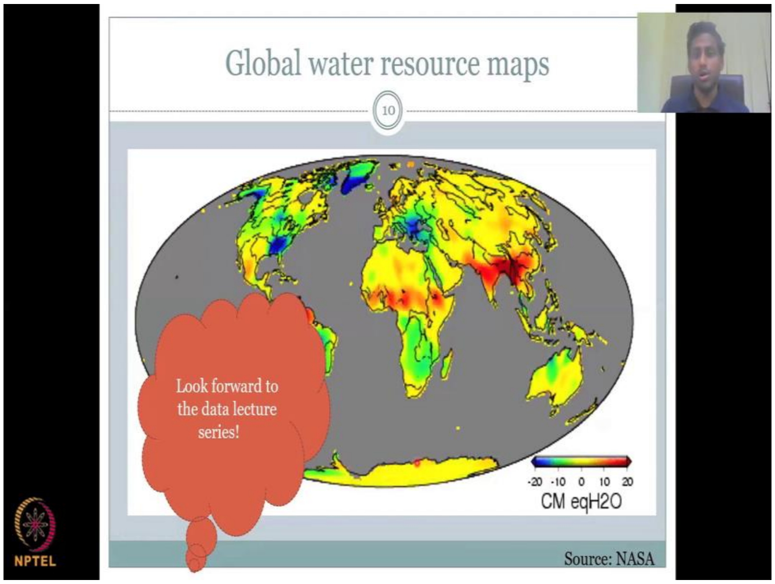

You can also do Global Water Resource Maps, for example, this map has been done by NASA to show how the groundwater availability changes across the world. And you could see, based on the beige, areas, the basins, they have done these maps and you could see a centimeter equivalent of H2O and you can see how it changes per month or annual availabilities of groundwater resources and you can see that red is mostly here and that is where it is more dangerous the Water Resources etcetera.

So, you could club these with your other estimates be it observation data, be it your water availability data to get an estimate a clear estimate of where you want to take your water balance, how do you estimate unknown parameters and also if it is at one length you cannot estimate the unknown parameters are you okay to dismiss them as negligible? One such parameters groundwater in versus groundwater out.

Mainly equations you would see that groundwater in is assumed to be the groundwater out so both of them can cancel. If it is the groundwater study. do not do that. Because groundwater study is to estimate how much groundwater you are pumping and then looking at it in detail. So, be careful with what your estimates are and what is your objective of your study.

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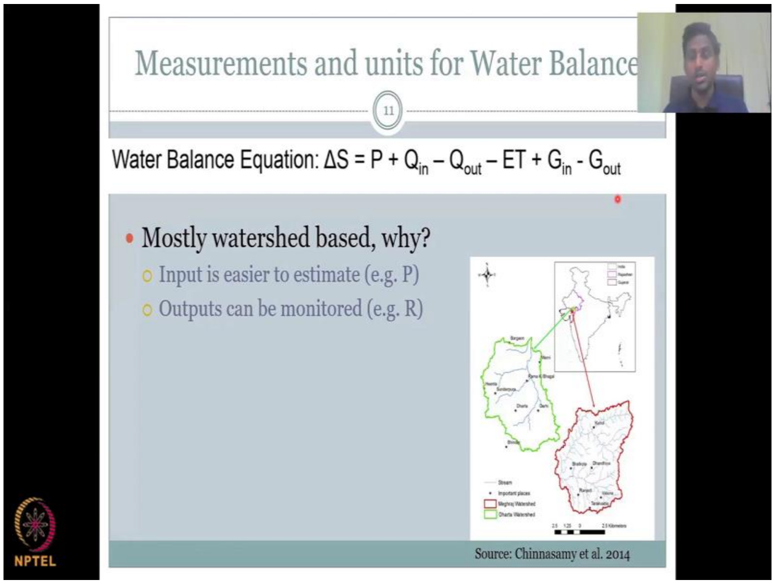

So, measurements and units also the a unit for the area is always kept as a watershed. So, most studies would keep the watershed boundary because it is easier for estimating the input. Let us say example rainfall, in this equation, you will see rainfall can be estimated very accurately, and how the rainfall combines into discharge very accurately through a watershed approach, if you do not have a watershed approach, it may be difficult because the conversion of rainfall to runoff is based on elevations which also gives you the boundary of your watershed, basin, catchment.

So, understand the hydrology flows through the physics equations and also the principle of water flows from high potential to low potential, and here a watershed boundary captures that dynamics from a high potential to low potential. So, all this could be managed within your watershed if you know these physics principles and these are driving your watershed boundaries and area etcetera.

So, with this I would like to conclude today's lecture and stress on the fact that units are very important for water balance there are concerns that sometimes you may not have all the data for your water balance equations. For example, B Q etcetera etcetera. So, you are allowed to assume some values for your input or output variables, but clearly mentioned that, so that another study person or a researcher can understand how you got these values and is it credible, depending on your limitations. Also, it is important to finalize a unit area for the study. And normally it is a watershed approach or if you have more data it go for state district, national subcontinent, global etcetera.

And when you grow above a particular level, like for example, from watershed to nation, some of these parameters can cancel out. And most of the time you will not have all the data. So, be careful between the unit for your study area and then based on the units also make sure you have all the data that is available for your study area and what are the parameter units available and from the parameter units, try to estimate what is the time unit and keep the time common across, keep the parameter unit common across. So, that you have something to compare and estimate your change in storage.

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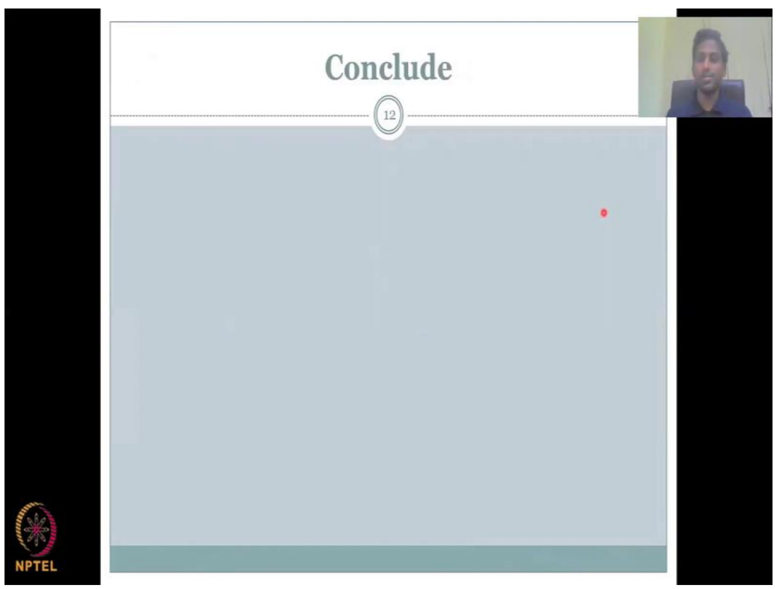

So, we have taken all these points and I would like to conclude with this lecture for important points on setting up a watershed water balance. Thank you