Rural Water Resources Management
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Week: 02 Lecture: 04
Runoff And Discharge

Hello, everyone. Welcome to NPTEL course Rural Water Resource Management, lecture 4 of week 2. In the previous lecture we looked about what are key parameters for the hydrological water balance and the parameters, we looked at three main parameters for this week. we have covered precipitation and then evapotranspiration which is are loss in the system.

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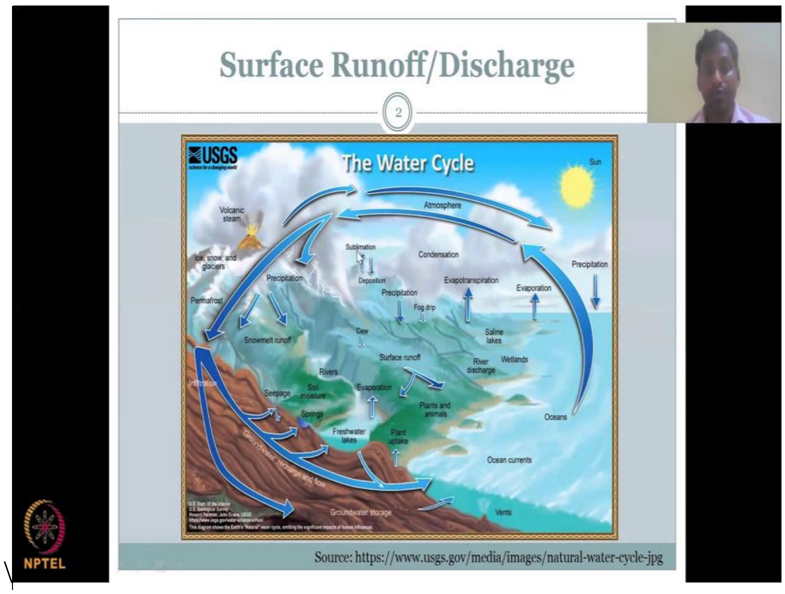

Today we will be looking at surface runoff and discharge which is also a loss for the water system in the hydrological cycle. Depending on your watershed or unit of analysis, the discharge can also be a input system, let us quickly look by going back to the water cycle, this runoff and discharge.

So, we have seen that the rainfall which comes in to the rural areas may come in from snowmelt, from precipitation and then it goes through all the drainages in the watershed and comes through rivers and lakes, oceans, et cetera. So, process of conversion of your rainfall into a drainage system constitutes runoff. Whatever precipitation does not go into groundwater, does not evaporate, is available for runoff.

So, we could see here in this image precipitation is going into river discharge, where it converts into a river network and then flows through the river network and that would be constituting your river discharge. Similarly, here your snowmelt and runoff is occurring after the snow has been melted, and then combines and flows in a particular direction.

So, when water starts to flow on the surface it is called surface runoff. If it is coming through the rivers it is called discharge and the discharge can also feed into the system. For example, if I am having a river behind your watershed, assuming this is your watershed boundary, if a river is flowing and giving water discharge, then discharge can be a positive turn in your water balance.

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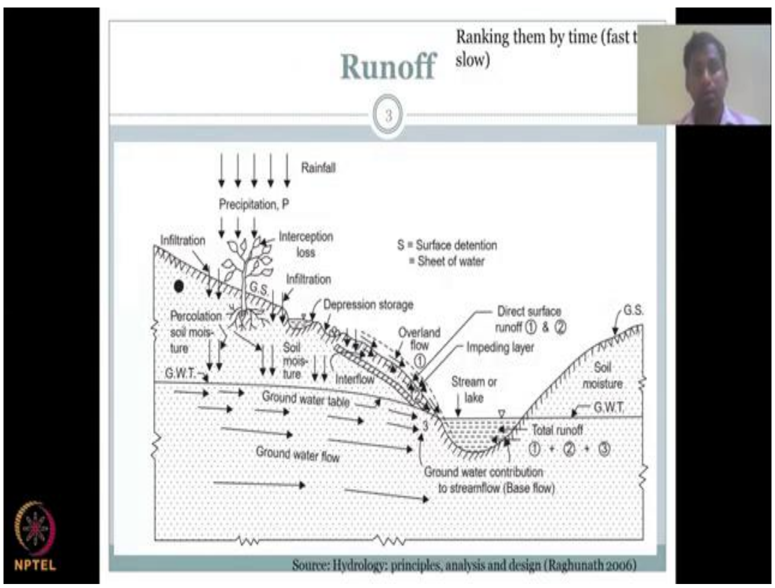

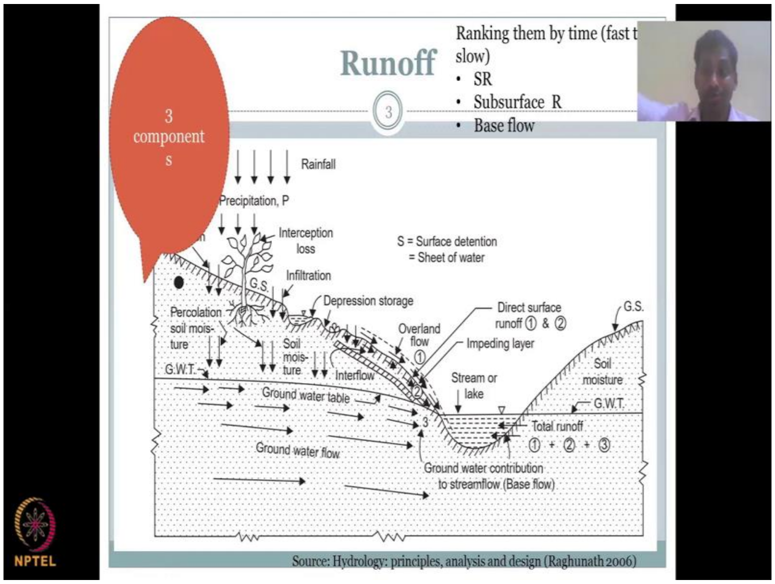

Let us take a close up scale of a rural water balance and see where runoff occurs, let us rank them. Ranking them by time. So, what we have here is an access to look at how precipitation is first converted into infiltration. So after that plant has taken up or interception losses the rainfall converts into infiltration which is once it hits the surface some water goes under the surface due to gravity.

And then further after some relocation of water through the root zone and water is taken up by the plant, further water goes in as percolation into the groundwater. So, whatever water from the precipitation which is your rainfall, whichever does not go onto the ground or is not taken up by the plants can go as overland flow, so that is the first component.

So, as the name suggests surface runoff and overland flow both are phenomena which happened on the top of the surface. So, what is needed for that a slope and a gradient, you can see there, there is a slope. So, only when there is a slope the water would run off or flow on top of the surface and then come and collect into the stream, river, lake, whatever water body we have.

What happens if the water hits a surface and there is no slope, like this, then it becomes a detention, it becomes depression storage. So, while I am explaining these, please think about how and where water can be blocked or stored in your landscape. So, that is the exercise why we have to go through all the parameters.

In most sessions you will not see a depression storage. But that could be a way to take this water from the slope, runoff and store it for future use by farmers, like a farm pond, et cetera. So, please understand how we are bringing all these concepts into a single water balance concept. So, then what constitutes your runoff, your major runoff in your stream and rivers? First is the overland flow where precipitation is converted into rainfall.

And part of your water gets stored, part of your water gets under the ground, part of your water is stored in the plants, the remaining would go and flow, so that is the first component. Then there is the second component. So, the second component is something which actually gets into the water, groundwater or your soil water and comes back out into the surface.

So, that is called a sub-surface flow. So, whatever water because of gravity has moved down still because of a gradient or slope, instead of moving further downwards, it would take a lateral movement. And water always would like to move where there is less resistance. So, if there is more resistance here because of rocks and other materials, the water would flow in a lateral position through the root zone and mix with your overland flow.

So, here we have direct surface runoff, which is component one which is the water that rainfall that falls on the surface and because of the slope gradients it comes down, that is the first component. The second component is when water moves down and percolates or infiltrates and then moves back again into the surface, because it goes down due to gravity, but if there is resistance to flow it comes up. So, that part is called direct surface runoff.

So, as I said there is something impeding here, impeding means obstruction, something that is stopping this subsurface flow. So, number 2, you could see, the subsurface flow for this area, something is stopping it and that is why the water comes and then takes the water out or it can come back into the surface into the lake.

So, that is called your sub-surface runoff. So, you have your overland runoff, your sub-surface runoff. There is another name given for subsurface runoff, it is called Ottonian flow. So, the other component which is your groundwater base component, as I said part of the water goes in as infiltration, some of the infiltrated water comes out as sub-surface runoff.

So, if you visualize like a layer of lake on the top, the water would go down, then on the first part, first layer itself, the water would go in and then there is the subsurface. There could be some other water which goes down and hits your ground water table. Your groundwater table is the level at which the groundwater is at static without any disturbance.

So, that is the level at which your ground water is available from the top of the ground. So, you could see here below this your aquifer or your ground network would have water. So, this is called the groundwater table. So, what happens if the rainfall, precipitation rainfall comes in and mixes with the groundwater, most of the groundwater could be seen here still under the ground.

But some of the water would come and mix into your lake or stream or river, whatever river body, why, because this level is at a lower potential then this one. So, your groundwater table is at a higher potential so water would move from high potential to low potential and that is what is happening here. You could see water moving and mixing into the lake.

There is also some soil moisture which can move, even though there is no precipitation, soil moisture, some of the water as we have seen in the previous lecture, some of the water which is not taken on plants, which is not absorbed or held by the soil can still move down, go to the groundwater table and if the groundwater table is at a higher potential compared to the lake.

So, you can see the level of water level. So, water would move from high potential to low potential. Here there is not much movement because it is at the same potential. So, then there is a groundwater contribution to the surface runoff and that is called the base flow. So, these are three components, number one, it is surface runoff, which is purely when water hits the surface because of a slope that flows down or because there is no infiltration.

For example, if you have a slope then water will not go in, whatever impeding surface or a non-penetrable surface water will hit and move down. So, that is your surface runoff. The second is where water would move in slowly and move laterally in and along the slope. So, it will not move vertically, but laterally along the slope and that lateral entry sometimes would come back out as a sub-surface runoff, number 2. So, these two are called direct surface runoff.

The third one is not as direct because only part of your precipitation contribution to the groundwater. So, the groundwater can be moving from your left in this image, in the left side also, some other rainfall could have contributed, so it was kind of a indirect runoff, which also contributes to your overall runoff. So, that is where water comes in goes. So, once all these three components combine and flow into your stream, it is called discharge or runoff.

So, what you see as a water flow in a stream or a river network is called runoff or discharge. So, once runoff is from the top of the surface comes and you could see it come in the stream or lake, you can call it as a discharge. So, here what is needed to be understanding is the time, how or which process is faster than the other. So, here I have ranked them as fast too slow.

And clearly you could see that the water which is from precipitation goes and hits the land surface and converts to runoff is the fastest, because it just goes through one process. You have rainfall, it hits the surface and then go, it comes down as a runoff. It is a very direct runoff. It is the fastest that comes into the stream and contributes to the discharge. So, your discharge in the stream or lake or river mostly it is a moving body.

So, it should be a stream or a river, would be from the fastest contribution it would be from the overland runoff or surface runoff. Second, or the second fastest is the water which goes in, a little bit goes into the soil and then moves laterally. So, here the water just goes through two phases, it hits the land and then goes into part of the soil and comes back. So, this is the second fastest, your subsurface runoff.

The third or slowest is the base flow, because it has to go to the groundwater and from groundwater, it has to move laterally. So, first it is vertical, then horizontal. Here if you could see why is the base flow or the groundwater flow component, which is called the base flow, why is it very slow is because it has to go through more media. Media means porous soil or rocks and then come and join the river.

So, that is why ground water contribution is very slow. But this also gives us an opportunity to slow down the water loss for the system. For example, if your precipitation comes and joins the river and lake, your rainfall goes into the river and lake, what happens, if it is a lake it is a stagnant water, but if it is a running river or a running stream, then the water is lost for the system because what flows, so if it goes through the base flow, it can delay.

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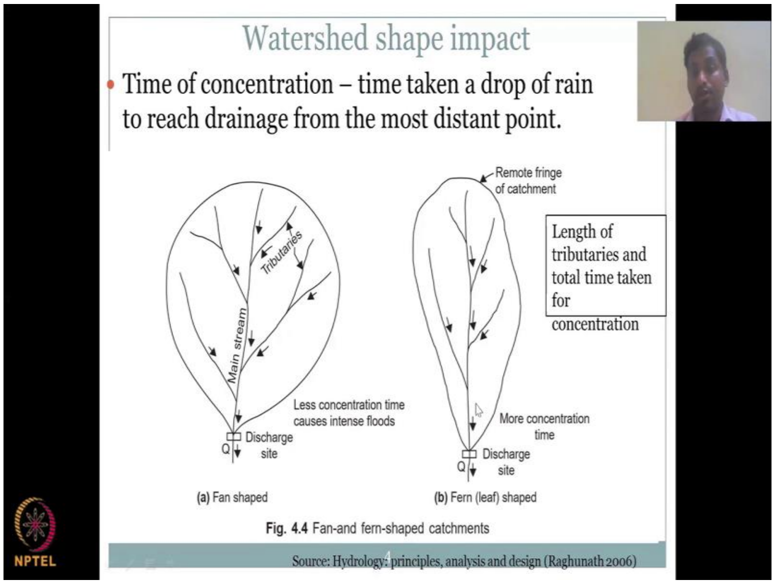

Let us have a look at it in a more, using a hydrograph approach. In this slide, what do you see is what are the key factors that contribute to runoff time. So, watershed is a very, very important, as an important impact on the rainfall. Time of concentration – Let us define what is time of concentration?

Time of concentration is the time taken by a drop of rain to reach the drainage point. Here the drainage point is the end of the watershed. So, this is your watershed and you have the end of the watershed, which is Q, from the most distant point, so not rainfall coming from here to this point it is very faster, but the farthest point, so this is the most distant point from Q.

So, what is the time taken for a drop of water, which falls on the top of your watershed or your distant point to come to your Q? So, this is called your time of concentration. So, the time of concentration affects or impacts how fast the discharge is taking place. So, what is it telling in the first one? It is a fan shaped. So, it is like a fan, the watershed and you could see your river networks more spread out across.

So, the area might be the same between the fern and the fan shaped, the fern is like a leaf, which is elongated. So, the area might be the same, but one is taller and one is stout. So, what happens here is there is less concentration time causes intense floods. Because this stout one has a very less concentration time, so whatever waterfalls on the distant point can still come to the Q point, which is your discharge point and cause intense floods.

However, when it is an elongated shape, a longer shape, where water has to go through only limited number of channels, here you have many stream networks, whereas here you have limited stream networks, then water will take longer time. The rainfall would take a longer time to come to Q and that could reduce your flood. What is a flood? When too much of rainfall is converted into runoff and runoff is stagnant, it cannot go through quickly then you have a flood.

Flood can happen only when there is some stagnation and because of that, there is the water level rises in the streets or in the rural areas. But if everything is open, for example, the Ganges, the river is flowing and water comes in then everything is fine. But if there is some blocking or the water is slowed down because of mixing into the ocean, then there is a backdrop and there is a backlog of water which would make it flooded.

So, length of tributaries and total time taken for concentration have been discussed. So, the length of the tributaries which are the networks you can see here, the stream networks. So, length of the tributaries also play a vital role, if it is very short here then water would quickly go into the network and then come out causing flooding. But then water droplets would take longer time to come.

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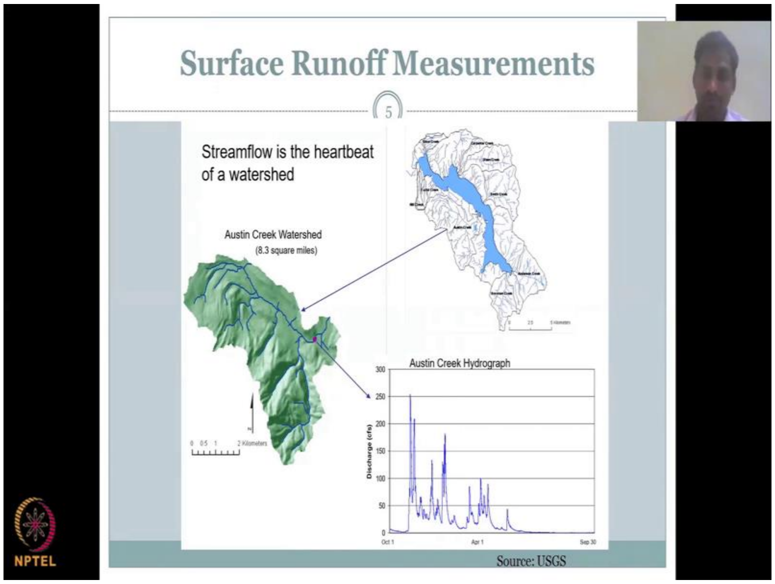

So, let us see how surface runoff measurements are made. Stream flow is their heartbeat or the river discharge is heartbeat of a watershed. Let us take American watershed example because of the data availability, source is USGS and you can see that this is the watershed, and you have the Austin Creek. Austin Creek, you do not monitor everywhere the stream flow.

But at right here they are monitoring and you could see how the other smaller rivers and stream networks are there from your DEM on a Digital Elevation Model. All of these are based on the elevations on the land. So, what you could see here is the river as a network, lot of networks and from the networks you identify the major flow path, where the water would flow and this one has a north-south dominant flow.

And also one coming from south to north and then comes out here. So, this is a Austin Creek discharge hydrograph. What is the hydrograph? It is a graph with the discharge on the y-axis and the time on the x-axis, and you could see that it was 0, 0, 0 and suddenly there could have been a rainfall. So, the discharge increased and then slowly decreases, that is a flood, so if suddenly rises and if the discharge cannot be contained in the river network, it is a flood.

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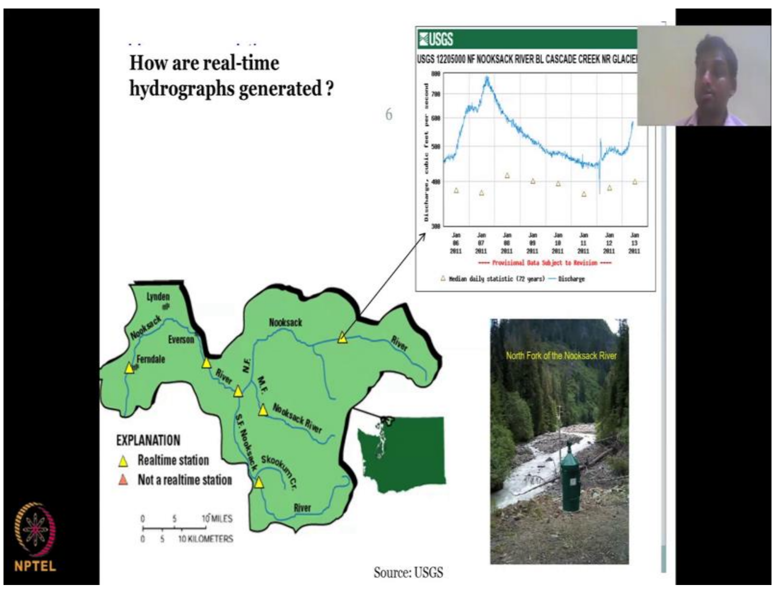

How are these measured? How these generated? So, how is the hydrographs generated? So you could see that something like a monitoring device is placed along the riverbank and it would be measuring the velocity of the water vehicles or velocity to the stream along the network. Here you could see real time station, there is 1-2-3-4-5-6 stations along this watershed and all of them are real time.

So, what do they do? Are they measuring how fast the water is moving in the stream or are they measuring a level. So, either way, it could be they could measure a level and then from the level of the streams, if you have a river which is flowing, just knowing the height of the water flowing in the river, you could estimate the discharge or the rating curve approach.

In some experiments or in some watersheds, you do have a meter, which can actually accurately measure the velocity of water in the street. And if it is too much, then you have a flood. So, here you could see the main daily static level and discharge for 72 years is around 400. So, suddenly, if there is a high discharge like this that could be leading to a flood and this is how warnings are given. So, real time how it works?

You strategically place stations along the creek, and you wait until small up gradient of the discharge is happening. And as soon as it crosses a threshold, for example, if 700 is the flood, the warning will go out at 500. Once it is 500, there will be warnings given to open the dams and gates to release the water otherwise the water would just get pointed up. So, this is how hydrographs are generated.

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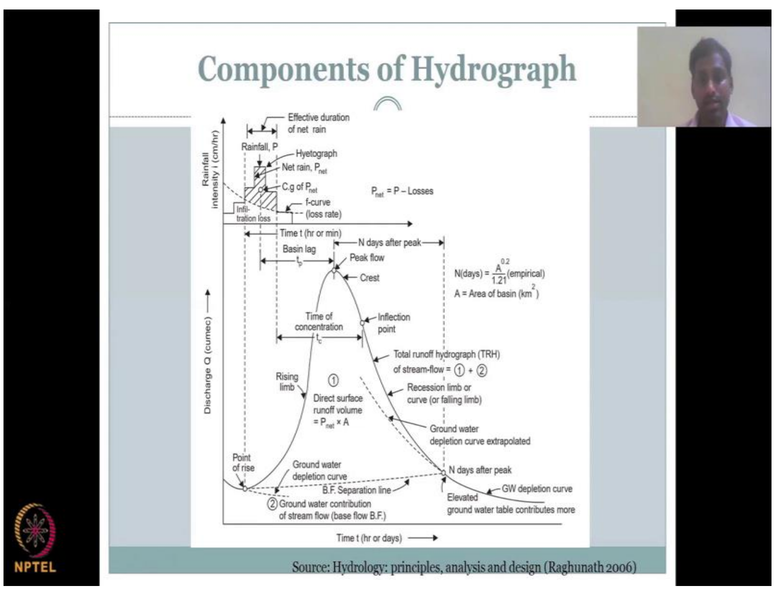

In Indian government websites, you would also see the level is being monitored and the discharge. It can be discharge or only level. So, let us look at the components of your hydrograph. This is the very-very important part, let us try understanding what are the components as you have seen what a hydrograph is which is a graph of discharge versus your time and what are the components.

So, let us first generate a hydrograph. You have the rainfall event and this river is a non-zero flowing river, which means it is a perennial river, always it is flowing. So, that is where it is not having a 0 point here. So, when the rainfall is happening, you see that as soon as some infiltration is gone. So, first water will infiltrate and after the infiltration rate or the infiltration the soil moisture is wet.

Then there is no more water going inside then it will be the first part which is your overland runoff. So, the overland runoff happens and suddenly your discharge starts to rise and this is called the rising limb. So, the rising limb and it is a peak after your rainfall depending on your rainfall intensity and et cetera. It will take time.

And at the time of concentration it would hit a peak. So, that is your peak of discharge and then it will come down which is called your, because the rainfall is stopping and as your rainfall stops your discharge also slowly, slowly, slowly it will come down. So, that is called the falling limb or the recession limb.

So, there are three parts, very-very important parts, which is your rising limb, your falling limb and your groundwater. So, because it is not zero when before the rainfall, what does that mean then that means that there is already some water which is coming into the river and that water is your groundwater input which is your part three in your surface runoff, which I discussed earlier, which is your base flow.

So, the base flow component is still here and that if you draw a line it will be like almost a straight line. So, that is how you divide a hydrograph. So, when there is zero rainfall before the rise where the point is and from there if you draw a line, it will be hitting the discharge curve at a particular point and after that it is purely because of your groundwater.

So, there is base flow and then water starts to rise because of your rainfall peaks and then comes down as a recession limb, it comes down but still this contribution is from rainfall. There is some rainfall lag and that is where it is and then it hits back at this point which is your base flow, which is your ground water.

So, this is the total area which is being given by your rainfall that is how you should understand a hydrograph and then you have your recession limb still coming down, almost equal to the before rainfall event. So, the time, total time of rainfall could be a very short period, but the lag, because of the basin lag or the lag time, the time of concentration, it takes more time for the rainfall to come into the discharge and that is why you see a peak and it comes down.

So, any hydrograph can be analyzed in this three steps to understand where it rises, where it falls down and before rising is it zero or not. If it is zero before rising then the base flow component is zero and that is the case for seasonal rivers. Seasonal rivers are rivers which do not flow without rainfall because there is no groundwater.

So, only when rainfall happens, then all the water in the basin come together and flows into the river. So, this is an example of, the one you see on the screen is an example of a river which has a base flow component. So, most probably it will be a perineal river.

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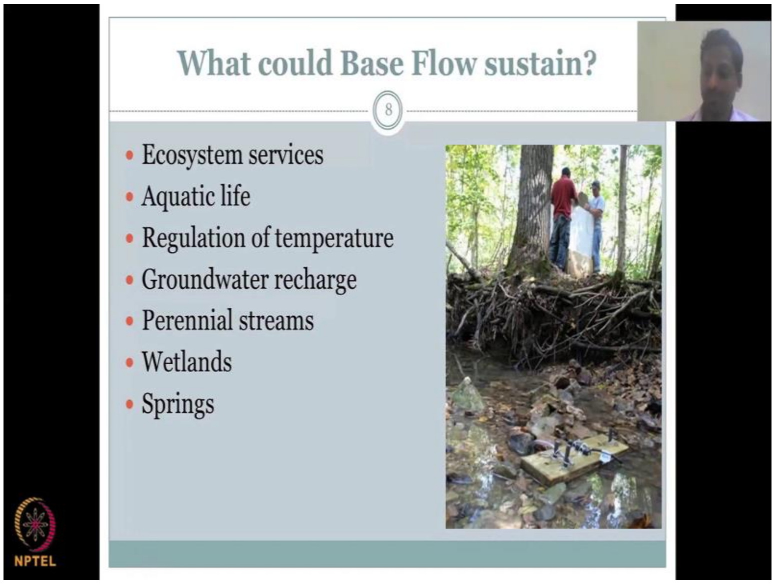

What could this base flow sustained? So, you know that now rainfall without rainfall also there could be some water in your river, due to baseflow. Why is it very important, because it can give, it can sustain ecosystem services. Ecosystem services include all the water that is needed for the operation of the ecosystem.

The ecosystem consists of living and nonliving things in your watershed, example, trees that want to grow, think about if trees only need rainfall, then what will they do without rainfall or they would need always river to flow, what would they do if there is no river flowing, then base flow can help.

Aquatic life, same here, fish are always present even if it rains or not. The water which comes into the stream from the groundwater, which is a base flow component can sustain aquatic life which is fish, insects in the water, frogs, et cetera. Regulation of temperature ground water is at a much cooler temperature compared to the surface water.

So, if you have a hot river flowing and cool groundwater mixing, then your temperature is regulated. So, this flow plays a very important role in regulation of temperature. Groundwater recharge - Your base flow is part of the groundwater recharge and by, because your base flow is going in the river, it can actually discharge or recharge areas around wherever the river flows, it can also recharge.

It is a key reason for perennial streams as I explained in the previous slide, perennial streams are streams that flow around the year and it can only flow because there is no rainfall around the year but there is base flow. River Ganges, it flows every day that is because there is snowmelt happening and when there is rainfall, there is more flow in the Ganges.

So, base flow is also component but still snowmelt is always there, but in most other rivers the flow is sustained mostly by base flow. Wetlands, wetlands are regions where all this water is present. And that is a key resource, a key resource for climate change wetlands, and that is sustained by base flow, because water would be seeping in very, very slowly and it will go into the wetlands.

Spring that you see in the mountains and hills, water which comes out of your mountains and hills, which is a byproduct of the base flows. The base flow instead of mixing into the rivers, sometimes the base flow groundwater can come out as springs. This is a clear example of our fieldwork, where you could see that there is no rainfall. And there is no big flow in the river.

But there is a very small tiny flow, and that flow is because the groundwater is giving water to the river and that is the base flow See how my meter is placed, but still the water is enough to capture. So, it is below the meter level but still this water can sustain the trees, which is your ecosystem services, then it can also sustain the small fish that can live on the water and because of the fish, insects and other things. So, this is what base flow can sustain.

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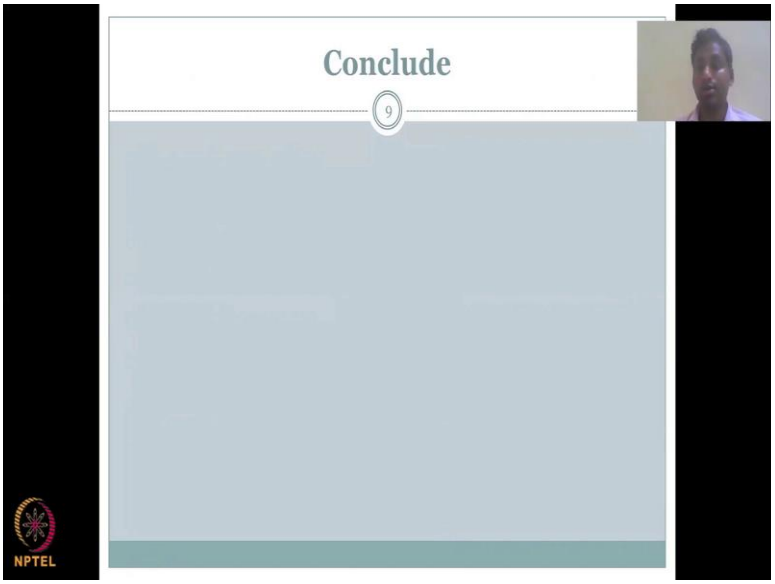

As I would like to conclude, so today we looked at another system in hydrological cycle, which is your surface runoff and discharge and of the surface runoff we looked at what are the components that are giving you more input into the system. We also looked at how to generate a hydrograph and for the hydrograph we looked at what are the components in the hydrograph which is your rising limb, recession limb and your base flow.

We also looked at where base flow is very, very important for your sustaining ecosystem. With this, the third component is done. We will see you in the next class.