Engineering Hydrology
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Module 5 - Lecture 71
Summary of Module-V

Hello, all. Welcome back. In the previous couple of lectures, we were discussing about hydrologic analysis. Mainly we were focusing on hydrograph analysis and in today's lecture, I am going to summarize the concepts which we have covered in the previous module that is the Module 5 on hydrologic analysis. We have started with the classification of hydrologic models.

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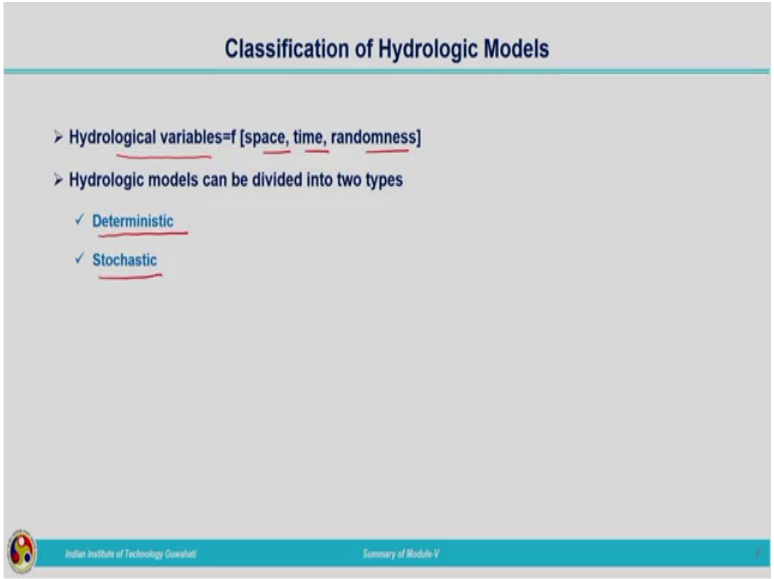

So, when we were classifying hydrologic models, we have classified hydrological variables as a function of space, time and randomness. Based on space if we are dividing, it is classified as one dimensional, two dimensional and three dimensional and with respect to time, we will be classifying it as steady, unsteady. And certain variables are there, for example, if you are considering rainfall, there are certain uncertainties involved with these variables. So, the models are classified into two categories, one is incorporating randomness and the other one is without incorporating randomness, that is, one is with incorporating uncertainties involved with the variable and the other one is without incorporating the uncertainties. So, that way we can divide hydrological models into two categories, that is deterministic model and stochastic model. Here in this course, we were discussing about deterministic model. Stochastic model, we just had the understanding what is meant by that in definition point of view. Other than that, we are not looking into the detail concepts related to stochastic hydrologic part.

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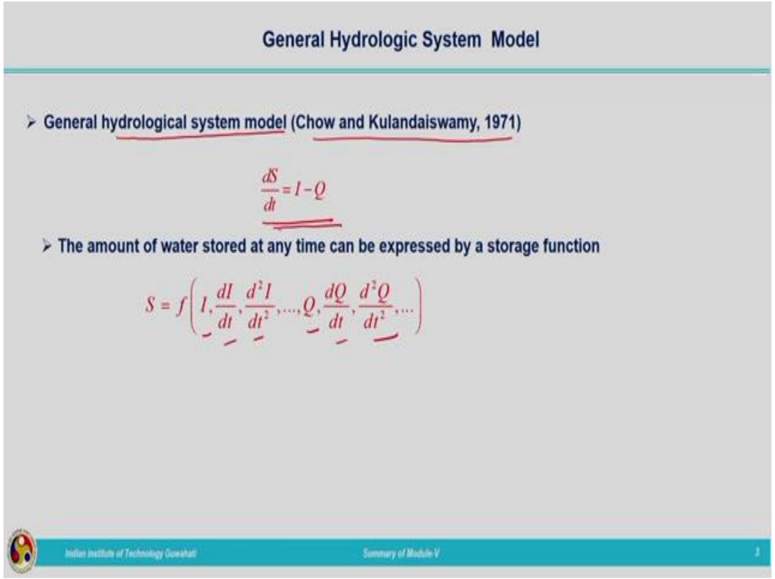

After that we have moved on to general hydrologic system model proposed by Chow and Kulandaiswamy. So, general hydrologic system model was of the form making use of continuity equation that is

$$\frac{dS}{dt} = I - Q$$

and in this the storage function S that is $\frac{dS}{dt}$ is representing the time rate of change of storage that is equal to inflow minus outflow, that is the continuity equation. According to Chow and Kulandaiswamy the storage function is considered as a function of inflow, outflow and the derivatives of inflows and outflows, i.e.,

$$S = f\left(I, \frac{dI}{dt}, \frac{d^2I}{dt^2}, ..., Q, \frac{dQ}{dt}, \frac{d^2Q}{dt^2}, ...\right)$$

So, the storage function is defined in that way that it can be expressed in terms of inflow and outflow and their derivatives. So, the quantity S can be simply of inflow and outflow or sometimes first derivatives will be incorporated or more derivatives can be incorporated depending on the property of the hydrologic system, which we are considering.

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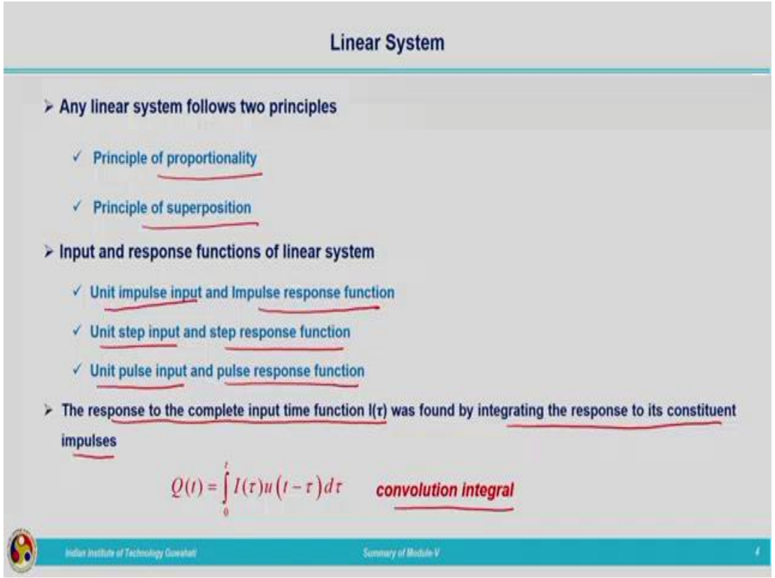

After understanding the hydrologic system model proposed by Chow and Kulandaiswamy we have moved on to linear system theory, because we have expressed our model as a linear model in this analysis. Any linear system follows two principles: principle of proportionality and principle of superposition. This we have understood what is meant by proportionality principle and superposition principles. After understanding these principles, we have discussed about different input functions and their corresponding response functions. So, different input functions which we have considered were of unit impulse input, unit step input, unit pulse input and the response from the linear system from these inputs are represented in terms of impulse response function, step response function and pulse response function. Why we have looked into these impulse input, pulse input, step input and the corresponding response functions, because we wanted to consider a hydrologic system as a linear system, and we wanted to compare our input to the input functions such as impulse, pulse and step inputs. So, if we are correlating these two things hydrologic system as a linear system, the principles followed by a linear system are applicable to hydrologic system also. In the similar way, the inputs and the response functions can be considered for the linear hydrologic system. So, that is why we had an understanding about different input functions and their response functions in the case of a linear system.

Once we understood different input and response functions, we have gone into the understanding of response to complete input time function $I(\tau)$ by integrating the response to its constituent impulses by means of convolution integral,

$$Q(t) = \int_0^t I(\tau)u\left(t-\tau\right)d\tau$$

that is impulse input is the input which is acting on the system instantaneously, and thereafter, its stops. So, the response which is coming from that instantaneous input is represented by impulse response function. Actually, in the field, for example, if we are considering the case of a watershed, watershed is experienced by means of a rainfall. Rainfall we cannot expect to happen instantaneously. It will be lasting for some time. So, what we are going to assume that this rainfall which is acted for certain duration is divided into different number of pulses. Each pulse is acting instantaneously and the response from each impulse can be summed up to get the total or the complete response from the catchment.

So, the total rainfall is considered as consisting of so many numbers of impulse inputs. So, the response from each impulse input is calculated and after summing up the individual inputs we can get the complete response of the catchment to a rainfall event which has happened for a certain period. That is what is done under convolution integral. That is the response to a complete input can be computed by making use of the convolution integral. So, this principle we have made use in the form of discrete convolution function for deriving the direct runoff hydrograph.

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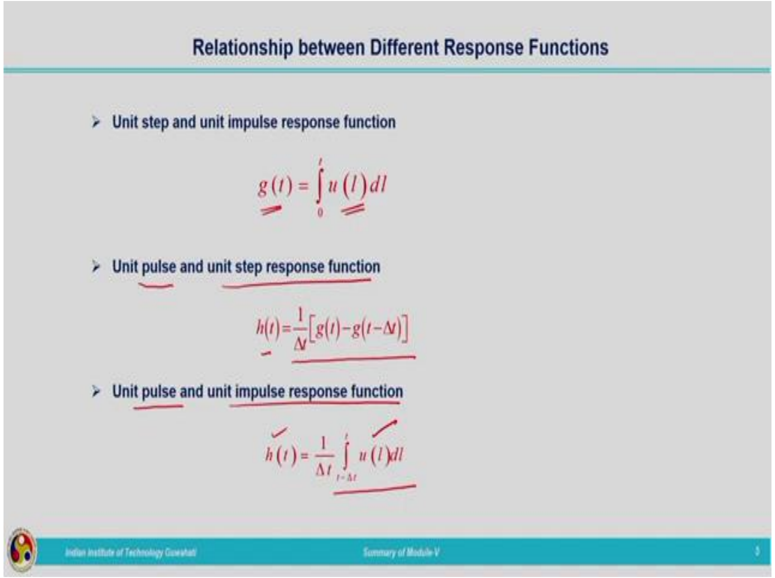

After that we have moved on to the relationship between different response functions, that is unit step and unit impulse response function if we are explaining, we can write it in this form that is *g(t)* is the step response function and *u(l)* is the impulse response function i.e.,

$$g(t) = \int_0^t u(l)\, dl$$

The step response function can be obtained by integrating the impulse response function within certain limit that is 0 to t is the limit which we usually consider and the step response function can be obtained in that way.

And in the similar way, unit pulse and unit step response function there are certain relationship that is given by

$$h(t) = \frac{1}{\Delta t}\left[g(t) - g(t - \Delta t) \right]$$

This *g(t)* and *g(t-*Δ*t)* are representing the step response function and *h(t)* is the pulse response function and the relationship between them is that the slope of these step response function will be giving you the pulse response function. *h(t)* is $\frac{1}{\Delta t}$ of difference between the ordinates of step response function.

In the similar way we can write the relationship between unit pulse and unit impulse response function. Unit pulse means the input is acting for a certain duration defined period as the duration. But in the case of impulse input, impulse input is acting on the system instantaneously. At time *t* is equal to 0, the input or the impulse input is acting on the system and after that *t* greater than 0, this input is 0. So, this is the difference between the pulse input and impulse input. Pulse input is acting on the system for a certain period of time, maybe it is *D-hour* duration or Δt hours, but impulse input is acting on the system at time *t* is equal to 0. So, the relationship between them also we have covered, i.e.,

$$h(t) = \frac{1}{\Delta t} \int_{t-\Delta t}^{t} u(l)dl$$

u(l)dl is our impulse response function and *h(t)* is the pulse response function. So, these are the interrelationships among three different response functions. If we are having one type of response function, for example, step response function is there from that we can develop the impulse response function and the pulse response function. So, by making use of these relationships, we can find out one from the other. These relationships we have utilized in the case of application related to different hydrographs. Once we understood different input functions and the corresponding response function from the linear system, we have moved on to the application of this linear system theory for a hydrologic system. Hydrologic system which we have considered is a watershed.

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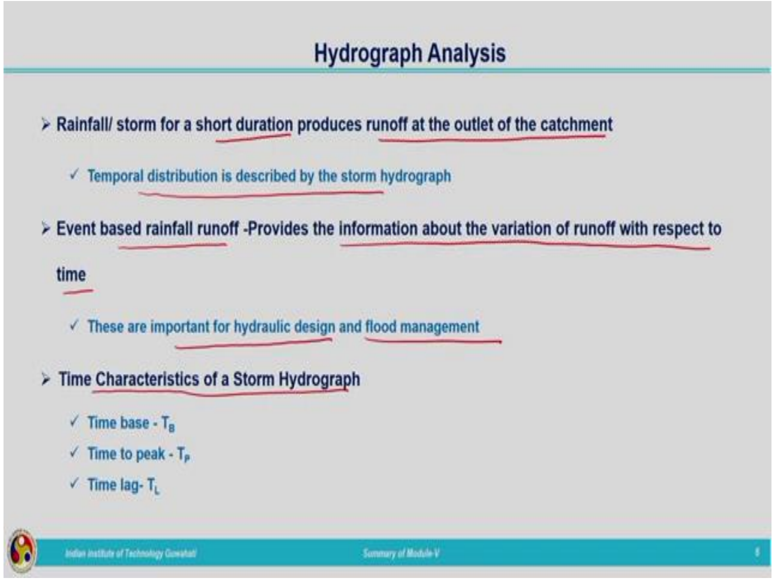

So, in the case of a watershed, if rainfall or storm is happening for a short duration, it will be producing runoff at the outlet of the catchment. The representation of the runoff with respect to time or the time distribution of the streamflow value is represented in terms of hydrograph. It is the temporal distribution of streamflow at the outlet. Event based rainfall runoff provides the information about the variation of runoff with respect to time. When we talk about runoff, it is direct runoff we are looking at. Direct runoff we will be getting after deducting the baseflow from the storm hydrograph. So, baseflow is the contribution which is coming from groundwater. That contribution will be the role throughout the year. So, that contribution has to be subtracted from the streamflow data which we are measuring at the outlet of the watershed or at a particular location in the stream. Then only we can quantify the effect of the rainfall at the impact of the rainfall at the outlet of the catchment that is in the form of runoff. So, for that we have to consider particular event-based analysis. So, these are very important for hydraulic design and flood management. Especially in the case of flooding, we need to provide certain management provisions, we need to consider certain management criteria in order to reduce the ill effects due to flooding. For that we need to go for the event-based analysis rather than making use of continuous data of rainfall.

After that we have studied the time characteristics of storm hydrograph which includes time base, time to peak and time lag. Time base is the total time when the rising limb is starting till the falling limb ends, that is the time base of the hydrograph. Then time to peak is from the starting of the runoff or the starting of the rising limb to the peak of the hydrograph and third one is the basin lag. Basin lag is representing the time between the centroid of the effective rainfall and the centroid of the runoff hydrograph. Majority of the cases it is difficult to determine the centroid of the runoff hydrograph. In such cases we will be considering the time interval between the peak of the hydrograph and the centroid of the effective rainfall hydrograph as the basin lag. These are important parameters when we carry out the hydrograph analysis.

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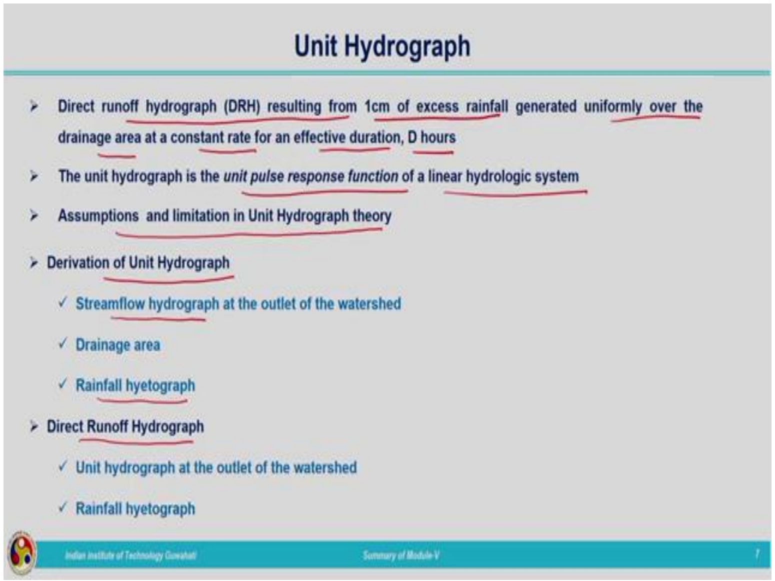

Once we understood all these concepts related to time characteristics of hydrograph and the linear system theory, we have moved on to the study related to hydrograph. First, we have started with the unit hydrograph. Unit hydrograph is the direct runoff hydrograph resulting from 1 centimeter of excess rainfall generated uniformly over the drainage area at a constant rate for an effective duration *D* hour. This is very important. This is the direct runoff hydrograph resulting from 1 centimeter of effective rainfall which has occurred for a duration of capital *D* hours. Certain specified duration we are considering, within that duration the rainfall is uniform and that rainfall is uniformly occurred over the entire catchment, then what is the runoff or the direct runoff produced at the outlet of the catchment that is the unit hydrograph. Actually, this can be considered as the unit pulse response function of a linear hydrologic system. When we are comparing the catchment behaviour with that of a linear system, we can tell that unit hydrograph is equivalent to that of a pulse response function in the case of a linear system theory, because the input 1 centimeter of rainfall is acting for a specified duration that is equivalent to a pulse input.

Then we have looked into the assumptions and limitations in unit hydrograph theory. As far as we are talking about the assumptions, the time invariance and the linearity principle these two are very important assumptions. After that we had discussed about the limitations of unit hydrograph theory and then we have moved on to the derivation of unit hydrograph. For deriving unit hydrograph, we need to have certain data related to streamflow hydrograph at the outlet of the watershed, total drainage area and the rainfall hyetograph. Rainfall hyetograph means it should represent the effective rainfall. If it is not giving the effective rainfall we need to calculate the effective rainfall based on the methods which we have discussed earlier in previous module.

So, streamflow hydrograph is there, baseflow separation we have done, after that we will be getting the direct runoff hydrograph and by dividing the total area under the curve which represents the total volume of runoff by the drainage area it will be giving us the direct runoff depth at the outlet. By dividing the ordinate of the direct runoff hydrograph by this direct runoff depth, we will get the ordinates of the unit hydrograph or if we are having the effective rainfall depth, by dividing the ordinates of the direct runoff hydrograph by this effective rainfall depth we will get the ordinates of the unit hydrograph. And we have discussed about the derivation of direct runoff hydrograph if we are having the unit hydrograph and the effective rainfall corresponding to that particular duration we can derive the direct runoff hydrograph.

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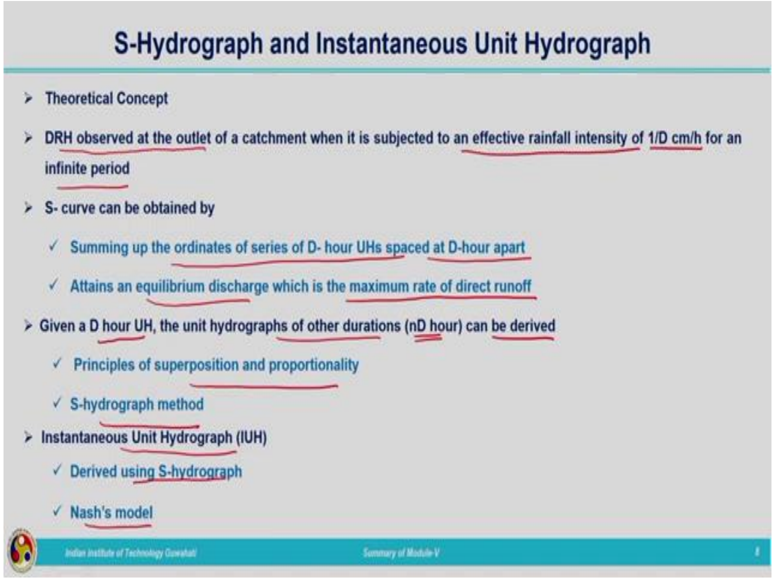

After understanding unit hydrograph and DRH direct runoff hydrograph we have moved on to S hydrograph and instantaneous unit hydrograph. S hydrograph is a theoretical concept, that is the direct runoff hydrograph observed at the outlet of the catchment when it is subjected to an effective rainfall intensity of $\frac{1}{D}$ centimeters per hour for an infinite period. In actual watershed or catchment, we cannot expect rainfall for an infinite time period. It will be for a specific period. So, the unit hydrograph is the actual concept. When we are talking about the S hydrograph this is a theoretical concept. S curve is obtained by summing up the coordinates of series of D hour unit hydrograph spaced at D hour apart. We have discussed these things in detail and we have solved some of the numerical examples for understanding this concept. In the case of S hydrograph, it attains an equilibrium discharge that is the maximum rate of direct runoff. That equilibrium discharge is attained by the S hydrograph when it reaches a time period equivalent to the time base of the unit hydrograph from which it is derived. So, that much about what we have covered related to S hydrograph and then we have moved on to the derivation of unit hydrographs having different durations, that is if we are having a D hour unit hydrograph, unit hydrographs of other durations such as nD hour was derived by making use of the principle of superposition and proportionality and S hydrograph method. Principle of superposition and proportionality is utilized for deriving unit hydrographs having the duration which are integral multiples of the duration of the given unit hydrograph or the known unit hydrographs. Sometimes the unit hydrograph which has to be derived will be having a duration which is not an integral multiple of the duration of the known hydrograph. For example, if you are having a 2-hour unit hydrograph we need to derive 3-hour unit hydrograph from that. Then we cannot make use of the principle of superposition and principle of proportionality, we have to go for S hydrograph principle. That is in the case of n value is a fraction we have to make use of S hydrograph principle for deriving the unit hydrograph. Once we have seen the derivation of nD hour unit hydrograph by making use of these principles, we have found that it is difficult to get a particular unit hydrograph having certain duration and the corresponding effective rainfall which is uniformly occurred for that particular duration. Then the discussion related to a hydrograph in which the duration is not important has come.

In that way we have discussed about instantaneous unit hydrograph for which the duration is not of importance. Because in the case of instantaneous unit hydrograph, the input is acted on the catchment at an instant or at time t is equal to 0, this is similar to that of an impulse input. In the actual condition this is a fictitious concept, because rainfall cannot occur at an instant of time. It will be acting for a certain duration of time. But this principle of instantaneous unit hydrograph can be utilized for deriving unit hydrograph of any duration. So, that is why we have discussed about instantaneous unit hydrograph and we have seen how it can be derived. It can be derived using S hydrograph concept and by making use of Nash model we have derived instantaneous unit hydrograph. Nash model was assuming the catchment is behaving like a linear reservoir. What is so particular about linear reservoir? In the case of linear reservoir, the storage is proportional to the outflow that is $S = KQ$, K is the storage coefficient and Q is representing the outflow which is occurring at the outlet of the catchment. So, the linear reservoir principle is very simple that is incorporated in the case of Nash model which is utilized for the derivation of instantaneous unit hydrograph. So, these principles can be utilized for catchments which are having data. After discussing about the concepts related to unit hydrograph, S hydrograph and instantaneous unit hydrograph, we have moved on to the topic of synthetic unit hydrograph.

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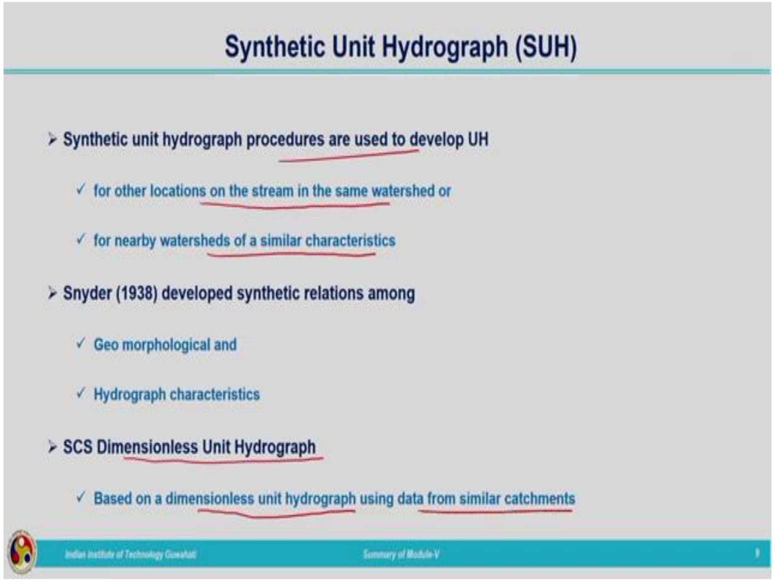

Synthetic unit hydrograph principles are utilized for deriving unit hydrographs for ungauged catchments. Unit hydrographs for ungauged catchments are required for carrying out any planning or management study related to water resources in the ungauged catchments. But if the unit hydrograph is not available, we cannot go for any of such studies in ungauged catchments. In such cases, what we will be doing, we will be making use of the data available to the neighboring catchments which are hydrologically and climatically similar to the ungauged catchment. By making use of the data from the gauged catchment, we can derive the unit hydrograph for the ungauged catchments.

So, synthetic unit hydrograph procedures are used to develop unit hydrographs for other locations on the stream in the same watershed or for nearby watersheds of similar catchments. Two different methods we have discussed, one is proposed by Snyder. Snyder developed the synthetic unit hydrograph by making use of the relationship among geomorphological and hydrograph characteristics. Geomorphological characteristics of the gauged catchment and ungauged catchments are required and also the hydrograph characteristics from the gauged catchment is required. By making use of these characteristics, synthetic unit hydrograph is derived for ungauged catchment. The second one was SCS dimensionless unit hydrograph. In this the dimensionless unit hydrograph proposed by SCS is utilized for deriving the unit hydrograph for the ungauged catchment, that is, it is based on the dimensionless unit hydrograph using data from similar catchments. One condition is that the ungauged catchment and the gauged catchment should be having similar characteristics.

After discussing the concepts related to hydrograph, we have moved on to the application of hydrograph theory in the field that is hydrograph routing topics we have discussed. Mainly the topic is termed as flow routing. Flow routing is the procedure utilized for determining the flow characteristics such as outflow details, water level characteristics at downstream locations of the streams or rivers by making use of the measured data at the upstream location. In this case, we will be having the knowledge of hydrograph at the upstream location, by making use of those known data, we can find out the hydrograph characteristics, water level characteristics at the downstream location at the required point.

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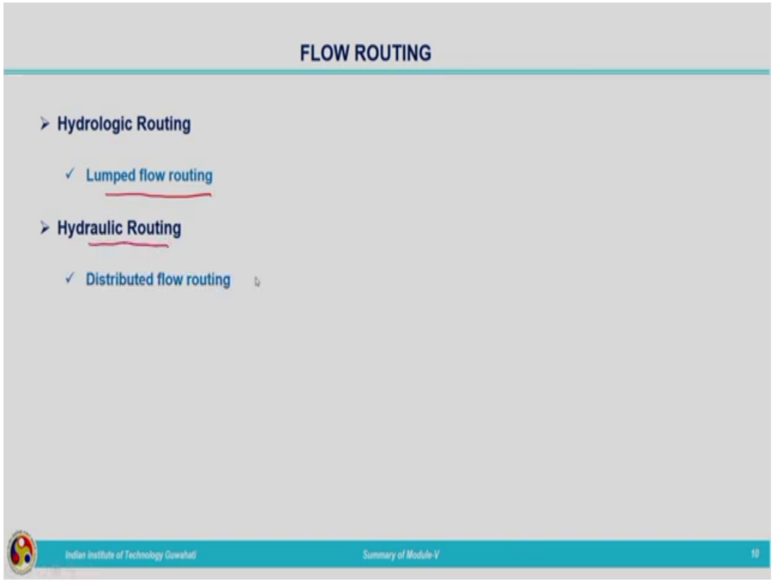

It can be of two types: hydrologic routing that is also termed as lumped flow routing, and the second one is the hydraulic routing, it is termed as distributed flow routing. From the terms lumped and distributed it is very clear that hydrologic routing is giving us the details of flow with respect to time that is temporal variation only considered in the case of hydrologic routing. But in the case of hydraulic routing, spatiotemporal variation is considered and we can get the outflow hydrograph by incorporating the temporal as well as spatial variations which are taking place in the flow characteristics. Hydrologic routing is carried out by making use of the continuity equation. Along with the continuity equation we will be making use of some particular relationship related to storage also. But in the case of hydraulic routing, we will be making use of both the continuity and momentum equations. Here in this course, we have discussed only about the hydrologic routing and hydrologic routing in terms of presence of reservoir and also simply in the case of channels we have considered.

In the case of reservoir by knowing the storage water level details and the upstream inflow hydrograph, we can find out the outflow hydrograph that is termed as the reservoir routing. In the case of channels by knowing the storage function and also the inflow hydrograph at the upstream location, we can find out the flow characteristics at the downstream location, that is termed as the channel routing. These two concepts that is reservoir routing and channel routing we have discussed in detail.

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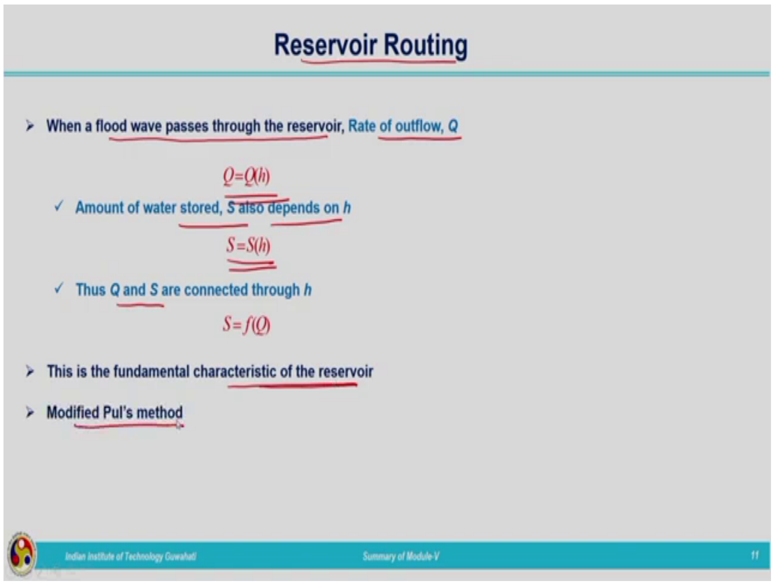

So, for carrying out the routing, we should have some understanding about different storage functions that we have understood in terms of variable storage function and invariable storage function. Variable storage function is the one in which the storage is a function of inflow and outflow and invariable storage function is the one in which it is similar to that of a linear reservoir that is storage as a function of outflow alone. In the case of reservoir routing, we have made use of the invariable storage function and in the case of channel routing, we have made use of the variable storage function.

So, while coming to reservoir routing, it is the process by which when a flood wave passes through the reservoir we are finding out the rate of outflow. Outflow hydrograph we are finding out and outflow is a function of depth of water in the reservoir i.e., $Q = Q(h)$ and at the same storage also depends on depth of water in the reservoir that is S can be represented as a function of h, i.e., $S = S(h)$. So, we can relate Q and S as related to h. So, indirectly we can relate Q and S because Q is a function of h, S is also a function of h. So, based on that relationship we can derive a relationship between storage and discharge, i.e., $S = f(Q)$. So, this is the fundamental relationship which is used while carrying out reservoir routing. And in this case, we have made use of the storage function $S = f(Q)$ for carrying out reservoir routing. And one single method we have discussed for reservoir routing which is termed as the level pool routing or the modified Pul's method.

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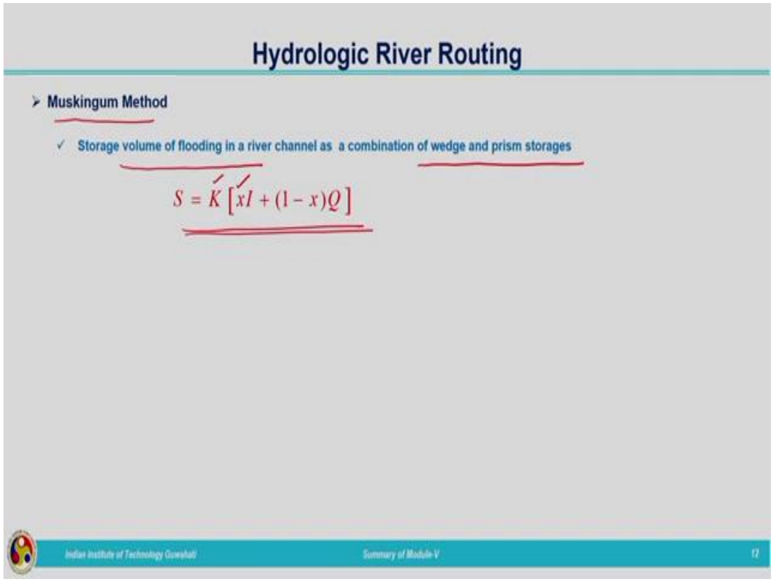

After that we have moved on to hydrologic river routing. This is also termed as the channel routing, lumped flow routing in channels. Different terms are utilized for representing channel routing. So, channel routing we have discussed with the help of Muskingum method. This is the hydrologic channel routing technique. In this case, we have made use of storage volume of flooding in river as a combination of wedge and prism storage. What is meant by wedge storage and what is meant by prism storage we have clearly understood. Prism storage is the storage in the channel when we are considering the flow to be uniform, that is, it can be considered as similar to that of a storage in the case of reservoir routing that is S is a function of Q. But whenever if flood is entering the channel reach, the uniform flow condition is getting changed to gradually varied flow condition. Sometimes it can be rapidly varied flow condition also, but we have discussed about the gradually varied flow condition. In that case, the storage cannot be assumed as a function of outflow alone, storage will be a function of both inflow and outflow. When we are representing storage as a function of outflow alone, it is termed as prism storage. If we are representing it as a function of inflow and outflow that is represented by the wedge storage. Schematically we have understood these concepts. So, in the case of channel routing, we are considering the variable storage function in which storage is a function of inflow and outflow.

So, in the Muskingum method storage is represented by this function, i.e.,

$$S = K\left[xI + (1-x)Q\right]$$

In that we are having certain coefficients represented by K and x and x was taking a range within 0 and 0.5. How to determine these values of x and K we have seen with the help of an example and once x and K are known to us, we can determine the outflow hydrograph by making use of Muskingum routing technique. But this Muskingum routing technique is a hydrologic routing technique. It gives the temporal distribution of the outflow at the required downstream point. If we want to understand the variation or changes taking place in the hydrologic characteristics or hydrograph characteristics spatially, then we may have to go for hydraulic routing. Hydraulic routing is more accurate compared to hydrologic routing.

So, here we have completed our Module 5 on hydrologic analysis. This much about the summary of Module 5. Now, in the next lecture we will move on to Module 6 related to hydrologic statistics. So, here I am winding up this lecture. Thank you.