Engineering Hydrology
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Module - 5
Lecture-64
SCS Dimensionless Synthetic Unit Hydrograph

Hello all, welcome back. In the previous lecture, we have discussed about the synthetic unit hydrograph proposed by Snyder. Detail steps we have discussed related to Snyder's synthetic unit hydrograph. Today, let us move on to the synthetic unit hydrograph based on category II, that is the dimensionless synthetic unit hydrograph. So, here we are going to discuss about SCS dimensionless synthetic unit hydrograph.

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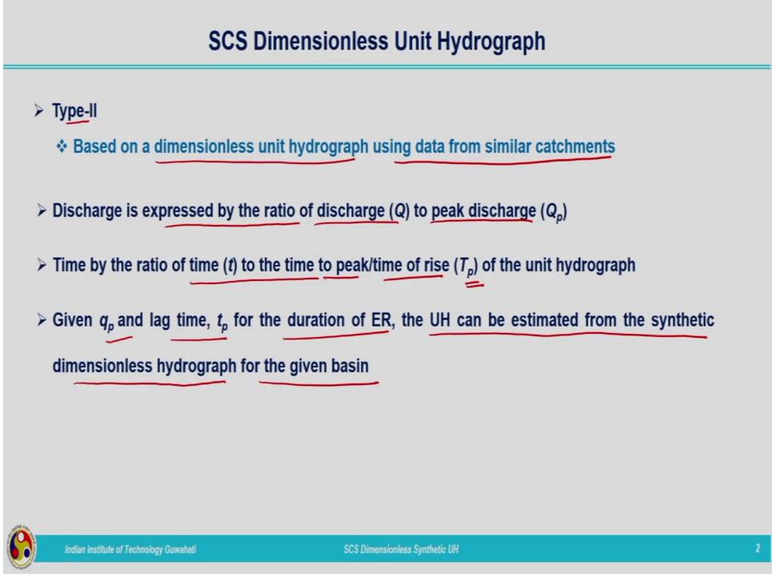

This is coming under the category of type-II that is based on a dimensionless unit hydrograph using data from similar catchments. This method is also developed in the US that is from different catchments, different unit hydrographs have been developed and an average unit hydrograph is proposed, and based on that a dimensionless unit hydrograph is derived and corresponding to that the hydrograph is also given and also corresponding data also given in all the textbooks which are explaining this topic.

So, here in this method the discharge is expressed by the ratio of discharge Q to peak discharge. From that itself it is clear why this hydrograph is having the name called dimensionless, here we are not directly plotting the discharge, we are plotting discharge divided by peak discharge, $\frac{Q}{Q_p}$ and also along the x axis the time is plotted by the ratio of time to the time to peak or time of rise, which is represented by T_p. In this case, we are plotting the dimensionless discharged with the dimensionless time. Dimensionless discharge is $\frac{Q}{Q_p}$ and dimensionless time is $\frac{t}{T_p}$, capital T_p is representing the time to peak, it is not the basin lag which we have discussed in the previous slide, it is the time from the starting of the runoff to the peak runoff, time to peak is considered as T_p. Now, given Q_p and lag time T_p for the duration of effective rainfall, the unit hydrograph can be estimated from the synthetic dimensionless hydrograph for the given basin.

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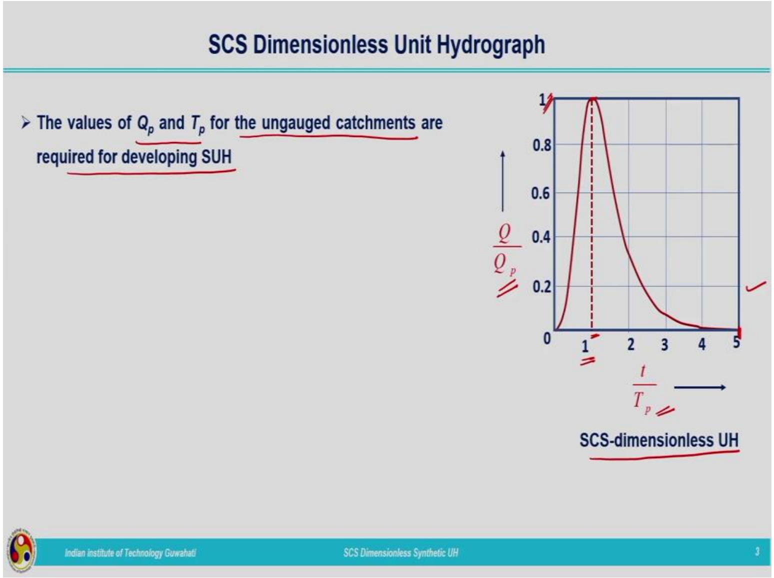

We need to develop a synthetic unit hydrograph for a particular basin for an effective rainfall having a duration T_p. Based on SCS dimensionless unit hydrograph we can refer to the unit hydrograph provided by them and also corresponding data table. The values of Q_p and T_p for the ungauged catchments are required for developing synthetic unit hydrograph, that we already know, for developing the synthetic unit hydrograph we need to know, what is the peak discharge for the corresponding catchment, and also what is the time to peak? Then only we can clearly draw that curve. Otherwise where is Q_p will be marked, time to peak is also important, then only we can exactly get the value corresponding to that particular point Q_p. This is the dimensionless synthetic unit hydrograph provided by SCS, SCS dimensionless unit hydrograph. Here you can observe along the y axis we are having $\frac{Q}{Q_p}$ and along the x axis we are having $\frac{t}{T_p}$, since it is dimensionless number, when it reaches the peak value the ordinate value is 1, because at the peak value Q will be equal to Q_p, $\frac{Q}{Q_p}$ is equal to 1. And as far as the x axis is concerned, we are not taking the value corresponding to this point for making it dimensionless, we are considering T_p value, that is corresponding to the peak discharge value. So, we will be getting a value of 1 corresponding to the peak discharge, along the x axis we will be having 1 corresponding to the peak discharge value, that is corresponding to peak discharge we are having the time Tp. So, $\frac{T_p}{T_p}$ will be equal to 1.

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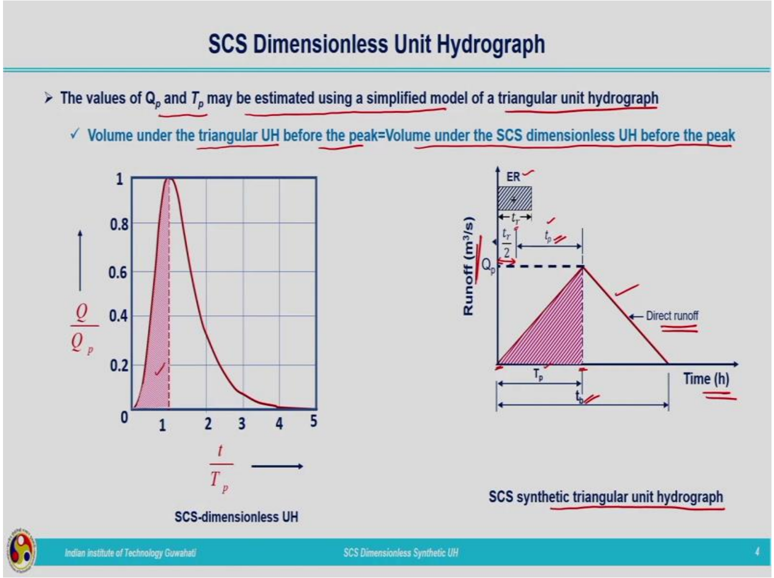

Now, the values of Q_p and T_p may be estimated using a simplified model of a triangular unit hydrograph. Here we are going to assume the unit hydrograph is having a triangular shape, that is time base is there, peak is represented by that particular point that can be drawn with the help of a triangle. This is our SCS dimensionless unit hydrograph. This is approximated by means of a SCS synthetic triangular unit hydrograph, that can be plotted like this. Here we are plotting the runoff in meter cube per second, runoff or streamflow in meter cube per second along the y axis and time along the x axis. In the SCS dimensionless unit hydrograph we were having the dimensionless discharge along the y axis and dimensionless time along the x axis. This has been approximated by means of a triangular unit hydrograph, in this along the y axis the discharge is plotted and along the x axis time, it is not dimensionless.

We are having an effective rainfall which is having a duration t_r , and this will be producing a runoff, which is represented by means of a triangle, this is our direct runoff corresponding to an effective rainfall having duration t_r. This effective rainfall is 1-centimeter rainfall only. So, that is why the direction of hydrograph produced will be a unit hydrograph, only thing is that it is simplified by means of a triangular shape and the peak discharge can be marked by capital Q_p and the basin lag is marked by t_p small t_p, basin lag is the difference in time between the centroid of the effective rainfall and the peak of the direct runoff hydrograph. So, that is marked over here as t_p. Now, this particular distance can be marked as $\frac{t_r}{2}$ because t_p is starting from the centroid of effective rainfall hyetograph. So, remaining distance towards the left will be $\frac{t_r}{2}$ and the base time is represented by small t_b. These are the characteristics of the triangular unit hydrograph and time to peak is the time starting from the beginning of the direct runoff to the peak of the unit hydrograph, that is represented by capital T_p. Do not get confused with small t_p and capital T_p, capital T_p is the time starting from the beginning of the runoff to the peak of the runoff or the time of rise, this can be called as time of rise also. Small t_p is representing the basin lag, that is the distance between or time elapsed between the centroid of the effective rainfall hyetograph and the centroid of the direct runoff hydrograph or the unit hydrograph instead of centroid of the unit hydrograph we will approximate it to happen at the peak runoff that is why the basin lag is represented by the difference of time between time to the peak and the centroid of the effective rainfall hyetograph.

Now, the volume under the triangular unit hydrograph before the peak is equal to volume under the SCS dimensionless unit hydrograph before the peak. What we are assuming here that by making it as approximating it by the triangular shape, the volume of water or the volume under the triangular unit hydrograph before the peak is equal to the volume before the peak in the SCS dimensionless unit hydrograph, that can be represented like this. This is the volume under the triangular unit hydrograph before the peak and corresponding volume under the SCS dimensionless unit hydrograph is marked over here, these two are equal, with this we are going to develop the relationship. So, the area of this triangle, area under this curve is representing the volume of water or the volume of runoff. So, we can calculate the volume of water at the outlet of the catchment by calculating the area of this triangular unit hydrograph. For this we need to have the idea about the base time of this triangular unit hydrograph. So, how can we get that?

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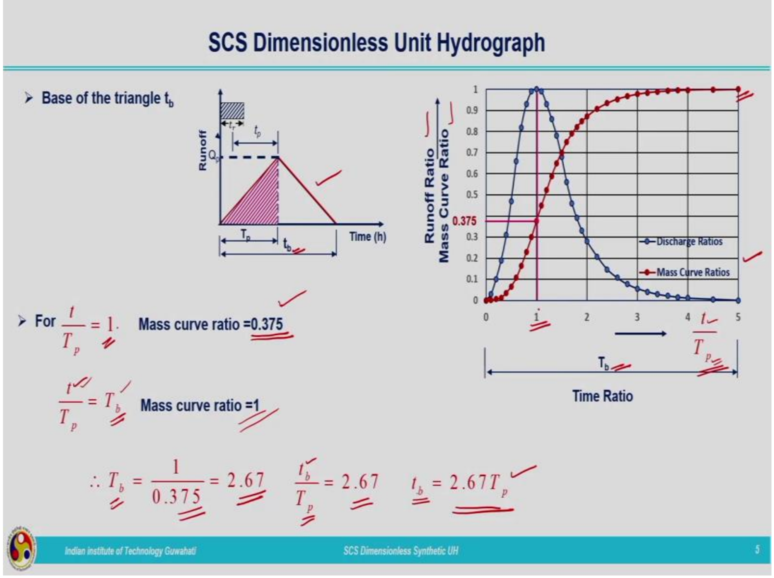

For that, I have plotted both the triangular unit hydrograph and the dimensionless SCS unit hydrograph. This is the same unit hydrograph which is shown as the dimensionless SCS unit hydrograph before, but this is to scale I have drawn, that is the along the *y* axis we are having runoff ratio that is $\frac{Q}{Q_p}$ and also mass curve ratio, mass curve you already know, that is cumulative discharge value calculated, that also made to be dimensionless with a peak discharge, that is represented by the mass curve ratio and along the *x* axis we are having the dimensionless time, $\frac{t}{T_p}$, T_p is representing the time of rise or time elapsed between the beginning of the runoff to the peak runoff. So, this is plotted according to the data given in the table, that data table I have not given over here, you can refer to any of the textbook which is explaining this SCS dimensionless unit hydrograph for getting the data table.

So, here we are making use of this dimensionless unit hydrograph for getting the ordinate of the time base of the triangular unit hydrograph. You can observe this curve related to SCS dimensionless unit hydrograph, here you can see time corresponding to $\frac{t}{T_p} = 1$, corresponding to that from the mass curve we can observe that the value is coming out to be 0.375. Mass curve ratio is equal to 0.375 corresponding $\frac{t}{T_p} = 1$. Now, corresponding to the time base T_b, capital T_b, time ratio will be $\frac{t}{T_p} = T_b$, corresponding to that we are having the mass curve ratio 1, and by making use of this relationship that is $\frac{t}{T_p} = 1$, mass curve ratio of 0.375 and $\frac{t}{T_p} = T_b$, mass curve ratio is equal to 1. So, we can write T_b is equal to

$$T_b = \frac{1}{0.375} = 2.67$$

But what is T_b? T_b is

$$T_b = \frac{t_b}{T_p} = 2.67$$

So, we can write

$$t_b = 2.67 T_p$$

So, you look at this curve triangular unit hydrograph, in that you can see t_b is representing the base of the triangle. Here in the case of SCS dimensionless unit hydrograph we are having capital T_b represented by the base of the unit hydrograph, capital Tb is nothing but

$$T_b = \frac{t}{T_p},$$

that is what we have used over here, i.e., $\frac{t}{T_p}$ and that is $\frac{t_b}{T_p} = 2.67$. Time base of the triangular unit hydrograph can be calculated by using this relationship, that is 2.67 T_p. This is derived based on the concept of mass curve, that is corresponding to peak runoff, peak discharge of the unit hydrograph that is when $\frac{t}{T_p} = 1$, we have taken the volume corresponding to that unit hydrograph, that is taken from the mass curve ratio, that mass curve ratio value corresponding to $\frac{t}{T_p} = 1$ was taken from the table or you can take it from the curve that is coming out to be 0.375. Based on that we have found out the value corresponding to that time base of the triangle t_b. So, we can understand that $t_b = 2.67T_p$, this is obtained from the SCS dimensionless unit hydrograph.

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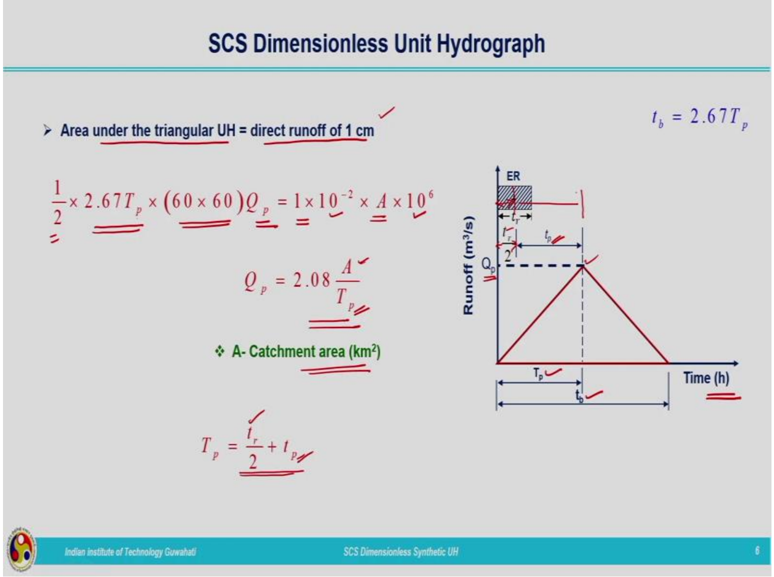

Now, we are going to make use of the principle of unit hydrograph, that is area under the triangular unit hydrograph is equivalent to direct runoff of 1 centimeter, because 1 centimeter of effective rainfall for the particular duration t_r, that is producing this triangular unit hydrograph, that is our assumption. So, if that is the case, area under the triangular unit hydrograph will be equal to direct runoff of 1 centimeter.

Here we are having the idea about time base of the triangle and we need to determine peak discharge. For determining that peak discharge we are going to make use of this relationship, that is area under this triangular unit hydrograph is representing the total volume at the outlet of the catchment due to 1 centimeter of rainfall. So, by making use of this relationship and substituting the, in the proper units, we can get the value corresponding to peak discharge Q_p. So, how can we write the area under the triangular unit hydrograph? It can be, it is half base into height. What is base? t_b and t_b is given by

$$t_b = 2.67T_p$$

Where T_p is nothing but the time to peak or time of rise, time from the beginning to the peak runoff and our Q_p is in meter cube per second and

$$\frac{1}{2}\times 2.67T_p\times(60\times 60)Q_p = 1\times 10^{-2}\times A\times 10^{6}$$

Here in this case time is marked in hours. So, we need to convert T_p into hours that is why we are multiplying with a factor of conversion of hours to seconds. And coming to the right-hand side, it is due to 1 centimeter of rainfall uniformly occurring over a catchment area of capital A kilometer square. So, 1 centimeter is converted to meter and capital A kilometer square is converted to meter square, and this can be simplified to

$$Q_p = 2.08\frac{A}{T_p}$$

So, by making use of this formula, we can calculate the peak discharge. This is very simple, that is we will be having the idea about the catchment area and the equation also very simple, $Q_p = 2.08\frac{A}{T_p}$.

But you look at the equation A can be obtained, catchment area from the topographic map we can calculate, but what about T_p ? Where we will go for getting the value corresponding to T_p ? This is T_p , that is T_p is from the beginning of the runoff to the peak of the hydrograph. A is the catchment area and now, we need to have some method to get the value corresponding to T_p . So, how can we represent T_p ? So, here you look at the figure we are having the basin lag represented by small t_p and capital T_p can be written as

$$T_p = \frac{t_r}{2} + t_p$$

because small t_p is the difference in time between the centroid of effective rainfall and the peak of the unit hydrograph and towards this side we are having a time of $\frac{t_r}{2}$.

So, $T_p = \frac{t_r}{2} + t_p$. Here t_r is known to us, t_r is the effective rainfall of required duration, we are going to develop a synthetic unit hydrograph corresponding to an effective rainfall having certain duration t_r, so, that t_r we are having. Now, what about t_p? t_p is the basin lag, how to calculate that?

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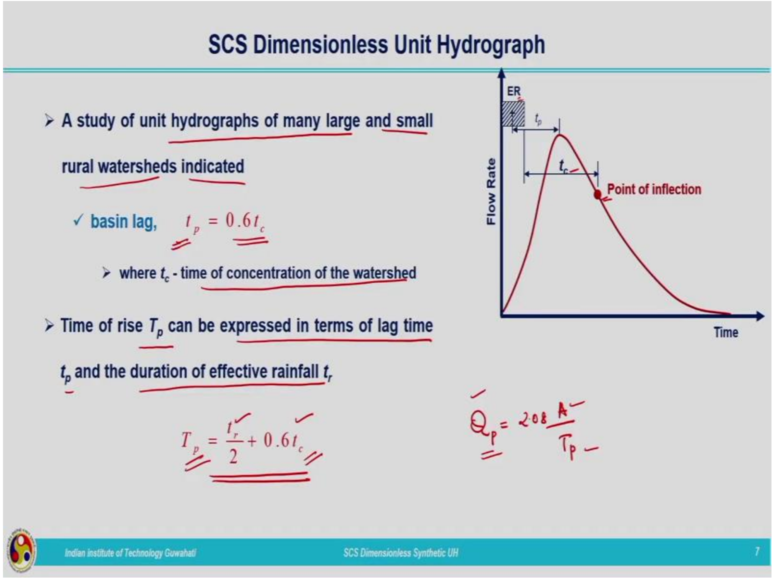

That is represented in terms of time of concentration, that is a study of unit hydrographs of many large and small rural watersheds indicated that, t_p can be written in terms of time of concentration. So, what is time of concentration then? Time of concentration is the time taken by water to reach from the remotest point to the outlet of the catchment. So, that is the time of concentration, that is at time of concentration the entire catchment will be contributing to runoff, that is the point. So, that point which we are marking in the hydrograph by means of point of inflection. Let me draw it again and then we are going to draw the unit hydrograph corresponding to an effective rainfall ER. Let this be the unit hydrograph and we are having the point of inflection represented by this particular point. So, what is point of inflection? It is the point corresponding to the entire catchment is contributing to the runoff. After that what will happen? Base flow recession will be starting.

So, this can be marked by means of time of concentration, that is just after the effective rainfall has stopped to the point of inflection that is represented by time of concentration t_c. Now, our t_p is from the centroid of ER is to the peak of the hydrograph. From this study it is found that the basin lag can be approximated by t_p is equal

$$t_p = 0.6t_c$$

i.e., if time of concentration is known to us basin lag can be approximated by taking this factor of time of concentration, that is $t_p = 0.6t_c$, t_c is nothing but the time of concentration of the watershed and time of rise T_p can be expressed in terms of lag time t_p and the duration of effective rainfall t_r that as we have already seen

$$T_p = \frac{t_r}{2} + t_p$$

that can be written as

$$T_p = \frac{t_r}{2} + 0.6t_c$$

Where t_r is the duration of the effective rainfall and t_c is the time of concentration.

So, getting time concentration is not a difficult task. So, many numbers of empirical equations have been proposed for calculating time of concentration. So, here SCS method itself there are different methods for calculating. So, any of the equations can be utilized for calculating time of concentration that I will be explaining later on in one of the lectures. So, those equations can be utilized for calculating time of concentration.

By making use of the empirical equations provided for time of concentration, we can calculate T_p. Once T_p is calculated, we can get Q_p as

$$Q_p = 2.08\frac{A}{T_p}$$

So, A is the catchment area, T_p we can use by making use of the time of concentration, Q_p is obtained. So, we are having Q_p and we are having the time to peak and also time base. So, we can plot the triangular unit hydrograph by making use of this technique. So, this is very commonly utilized for developing the synthetic dimensionless unit hydrograph.

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So, here I am winding up this lecture, these are the references related to this topic of dimensionless unit hydrograph. Thank you.