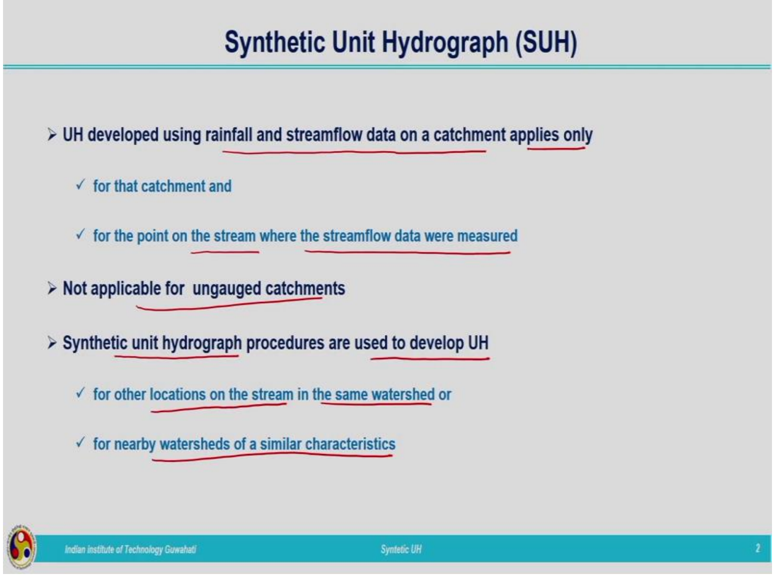
Engineering Hydrology
Dr. Sreeja Pekkat
Department of Civil Engineering
Indian Institute of Technology, Guwahati
Module: 5
Lecture 63
Synthetic Unit Hydrograph

Hello all, welcome back. Till now , we were discussing about different types of hydrographs. We have discussed about unit hydrograph, direct runoff hydrograph, S-hydrograph and also instantaneous unit hydrograph. Today we are going to look into synthetic unit hydrograph. From the name itself it is clear that it is the unit hydrograph which is artificially constructed. So, why do we want to go for synthetic unit hydrographs. Let us look into that.

(Refer Slide Time: 1:15)

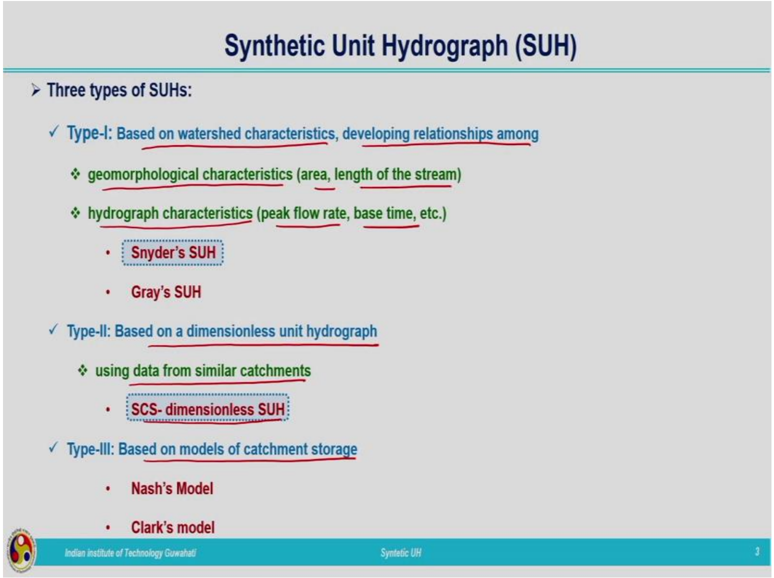


Unit hydrograph developed using rainfall and streamflow data on a catchment applies only to that particular catchment and also for the point on the stream where the streamflow data were measured. While we were designing the unit hydrograph, we have seen that we need to have the effective rainfall having a particular duration and also corresponding streamflow from the gauging station. So, the way in which we were developing the unit hydrograph needed rainfall data and the streamflow data. So, the unit hydrograph thus derived will be applicable to that particular location only. Sometimes we will be having data at different locations, but in majority of the cases we will not be having streamflow data for all the locations corresponding to different points in a stream or river. In such cases, we have to make use of the data which is available to us or sometimes the entire catchment will be ungauged. So, we will be considering the data from the neighboring station, which is hydrologically and climatically similar to this particular catchment.

So, these kinds of unit hydrograph developed by using rainfall and streamflow data from a particular gauging station will not be applicable to other locations that is it is not applicable for ungauged catchments. In such cases, we can opt for synthetic unit hydrograph. There are different procedures for developing synthetic unit hydrographs. So, those procedures can be utilized for constructing the unit hydrograph for the ungauged catchment that is for other locations on the stream in the same watershed or for nearby watersheds of a similar characteristics.

What we are going to do? We are going to make use of the principle of synthetic unit hydrograph approach for developing unit hydrographs for the ungauged catchments or in the same catchment where the streamflow data is not available.

(Refer Slide Time: 3:32)



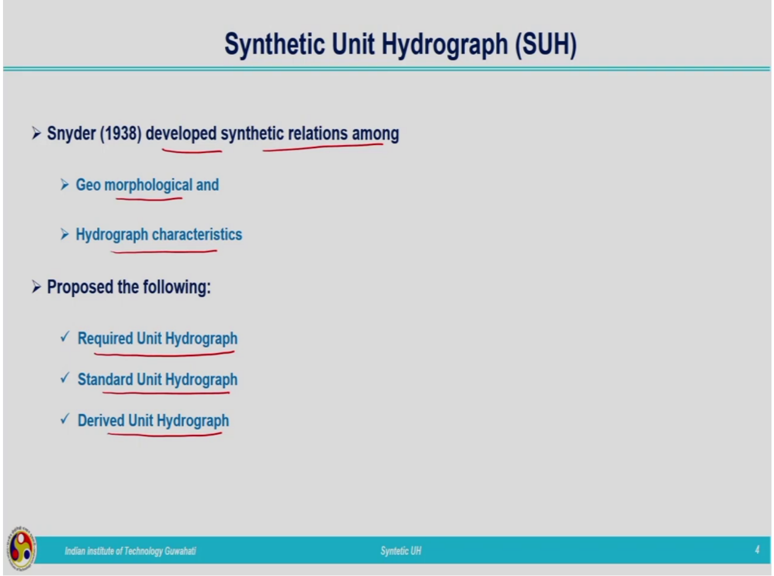
There are different methods to develop synthetic unit hydrographs, those are classified into three types. Type I is based on watershed characteristics and developing relationships among geomorphology characteristics and hydrograph characteristics that is for a particular catchment we will be having different types of stream networks and also based on the hydrology characteristics, we will be getting different types of hydrographs at the outlet of the catchment. So, here in this type I approach, we are going to develop the relationship between the geomorphology characteristics and the hydrograph characteristics. Because when we were discussing about the streamflow hydrograph that time itself it is explained that the shape of the hydrograph depends on the shape of the catchment, characteristics of the catchment. Depending on the characteristics of the catchment, we will be having the hydrograph with the sharp peak or flat peak, all those depends on the characteristics of the catchment. So, here in this type I approach for the construction of synthetic unit hydrograph, we are going to make use of the geomorphological characteristics and the hydrograph characteristics. Geomorphology characteristics includes area, length of the stream, etcetera. Different geomorphology characteristics we have already discussed while discussing about stream networks: drainage density, stream density, etcetera comes under that and coming to hydrograph characteristics we will make use of peak flow rate, base time, time to peak, all these characteristics can be incorporated. There are different synthetic unit hydrographs developed based on this principle. Some examples are Snyder's synthetic unit hydrograph and Gray's synthetic unit hydrograph.

Now, coming to type II, it is based on dimensionless unit hydrograph that is by using data from similar catchments. We are having an ungauged catchment for which we need to develop the unit hydrograph. So, here we are going to develop some kind of dimensionless relationships by making use of the data from the neighboring catchment for which the streamflow and rainfall data are available. The example for this type II synthetic unit hydrograph is SCS dimensionless synthetic unit hydrograph.

Now, coming to type III, it is based on models of catchment storage. We know whenever a storm is occurring different storage components needs to be satisfied after that only we will be getting the runoff at the outlet of the catchment. So, here in type III, we are making use of the catchment storage concepts and the examples related to these are Nash's model and Clark's model.

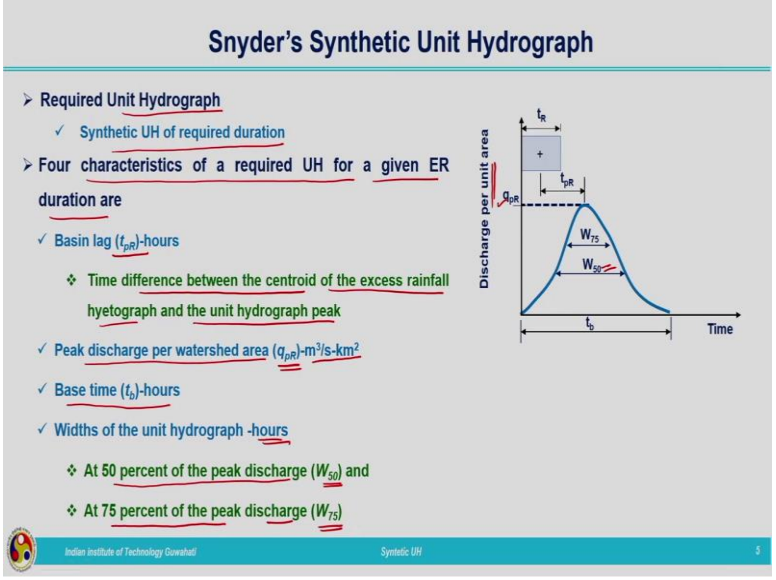
So, here in this course, we are going to discuss about Snyder's synthetic unit hydrograph and SCS dimensionless synthetic unit hydrograph. In this lecture, we will look into Snyder's synthetic unit hydrograph and in the next lecture, we will move on to the SCS dimensionless unit hydrograph.

(Refer Slide Time: 7:14)



So, let us start with the type I synthetic unit hydrograph that is Snyder's synthetic unit hydrograph. Snyder developed synthetic relations among geomorphological characteristics and hydrograph characteristics. We know already that while explaining in the previous slide, that is the type I category deals with the development of relationship between the geomorphology characteristics and the hydrograph characteristics. So, Snyder's method is based on that and he proposed the following concepts that is under this topic, we need to have idea about three types of unit hydrograph. The first one is required unit hydrograph, then standard unit hydrograph and derived unit hydrograph. Three types of unit hydrographs are proposed here: required unit hydrograph, standard unit hydrograph and derived unit hydrograph all are unit hydrographs only, but, depending on the requirements different names have been given.

(Refer Slide Time: 8:13)



First one is required unit hydrograph, as the name indicates, this is the synthetic unit hydrograph required for that particular location of specific duration. This is the synthetic unit hydrograph of required duration and related to required unit hydrograph four characteristics of a unit hydrograph for a given effective rainfall duration are considered. Snyder considered four different characteristics of the unit hydrograph and based on that this synthetic unit hydrograph has been derived. The synthetic unit hydrograph which is going to derive for an ungauged catchment is known as the required unit hydrograph. The four characteristics which are considered, we can explain with the help of the figure, we are going to plot the unit hydrograph here, here in this case you need to understand the *y* axis is not discharge, it is discharged per unit area and along the *x* axis we are having the time and we are going to consider an effective rainfall pulse which is having a duration of *t* subscript capital *R*. Whenever we are going to develop a unit hydrograph, we use to consider an effective rainfall which is having a specific duration capital *D* that duration we are considering or we are denoting as t_R, capital *R* is representing the required unit hydrograph. Corresponding to this effective rainfall with duration t_R, we will be having a response from the catchment. Since 1-centimeter rainfall is considered this is a unit hydrograph.

Out of the four different characteristics, first one is basin lag represented by t_{pR}. Basin lag is the time difference between the centroid of the excess rainfall hyetograph and the unit hydrograph peak. So, this definition of basin lag we have already discussed earlier while discussing the components of hydrograph. Basin lag is nothing but the time difference between the centroid of the effective rainfall hydrograph and the centroid of the direct runoff hydrograph. But it is very difficult to determine the centroid of hydrograph that is why majority of cases we will be considering the basin lag as the difference between the centroid of the effective rainfall hyetograph and the peak of the runoff hydrograph, that is here in this case peak of the unit hydrograph. That can be marked like this we are considering the centroid of the effective rainfall hyetograph and the peak of the unit hydrograph. This is represented by t_{pR}, t_p is the notation used for basin lag and subscript R is representing corresponding to required unit hydrograph.

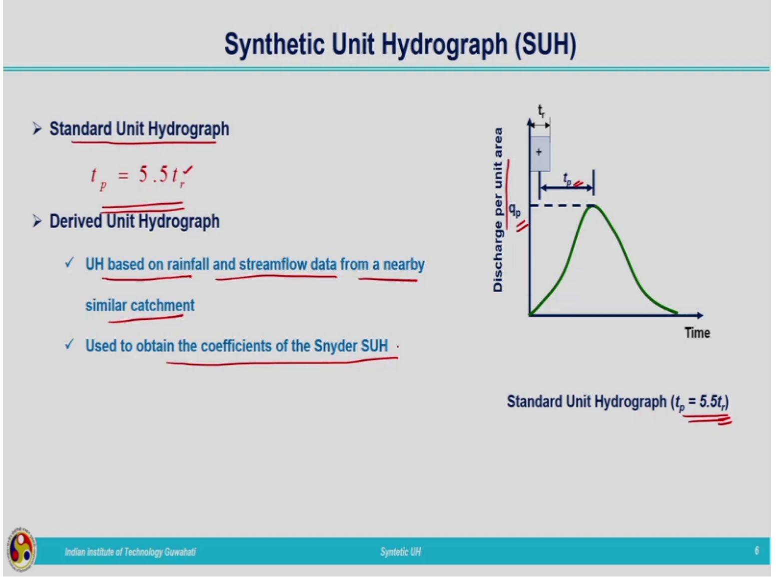
Second characteristic is that peak discharge per watershed area that is small q_{pR}. We are not talking about the capital Q, small q_{pR} is the value corresponding to discharge per unit area that is capital Q divided by the area of the catchment. So, the unit corresponding to that will be meter cube per second kilometer square, meter cube per second is a unit of discharge per area of the catchment it will be kilometer square. So, the unit of small q which we are considering is meter cube per second kilometer square, that is what we are plotting along the y axis. That can be marked in the figure, this is our q_{pR}.

Third characteristic is that base time t_b in hours. Base time is considered as the time elapsed between the beginning of the runoff and the cessation of the runoff that can be marked in the graph this is our time base or base time represented by small t subscript b.

Then one more characteristic is there that is related to width, width of the unit hydrograph. This is also in hours, two widths we are considering that is corresponding to 50 percentage of the peak discharge which is represented by W_{50}. So, we are having q_{pR} here corresponding to 50 percentage of that we will be having a width represented by W_{50} and corresponding to 75 percentage of the peak discharge that is represented by W_{75}. These are the four characteristics which are considered while deriving the required unit hydrograph by Snyder's method.

First one is the basin lag that is the time difference between the effective rainfall hyetograph and the peak of the hydrograph, then peak discharge per unit area, third one is the base time and the fourth one is the widths corresponding to 50 percentage of the peak discharge and also 75 percentage of the peak discharge. If we are having all these characteristics we can construct the unit hydrograph. So, our main idea is to find out expression for these parameters.

(Refer Slide Time: 13:55)



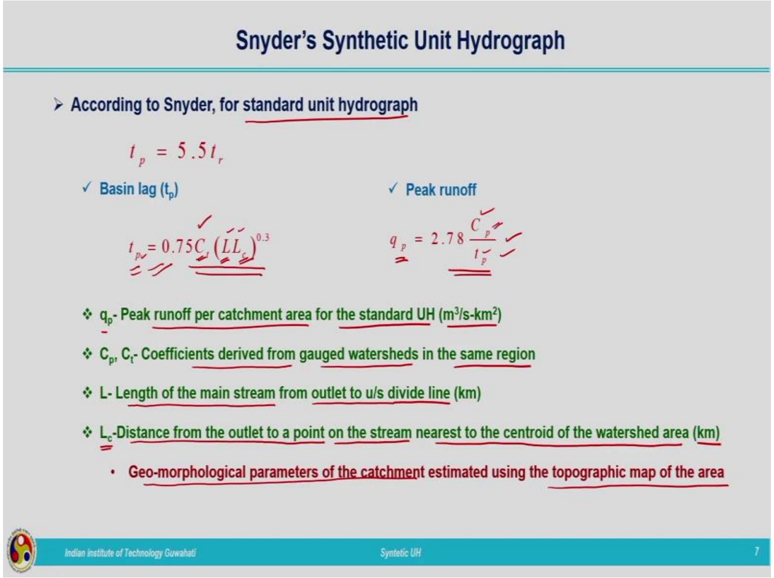
The second terminology related to hydrograph which Snyder has proposed is standard unit hydrograph. Standard unit hydrograph is the one in which

$$t_p = 5.5t_r$$

Where t_r is the duration of the effective rainfall which we are considering and t_p is the basin lag. So, for a standard unit hydrograph this relationship should be satisfied. In a particular unit hydrograph if basin lag is equal to 5.5 times the effective rainfall duration then it can be considered as a standard unit hydrograph. We can represent it graphically that is the standard unit hydrograph having basin lag $t_p = 5.5t_r$. So, here we are plotting in the similar way as that of required unit hydrograph. Discharge per unit area is plotted along the *y* axis and time along the *x* axis and we are having the effective rainfall pulse which is having the duration given by t_r. So, t_r is the duration of the effective rainfall we are considering and the response from the catchment is represented by the unit hydrograph and the peak is q_p and the basin lag can be represented by t_p and this hydrograph will be a standard unit hydrograph if it follows the relationship $t_p = 5.5t_r$.

Now, the third concept is derived unit hydrograph, as the name indicates this is the unit hydrograph based on rainfall in streamflow data from a nearby similar catchment. Nearby similar catchment means the catchment which is having hydrologically and climatically similar characteristics as that of the ungauged catchment and the data corresponding to rainfall and streamflow will be used to construct a unit hydrograph for that gauged catchment and that will be utilized for developing the coefficients of the Snyder synthetic unit hydrograph.

(Refer Slide Time: 16:05)



So, now, let us move on to Snyder's method of synthetic unit hydrograph. According to Snyder for standard unit hydrograph

$$t_p = 5.5 t_r$$

Snyder conducted so many studies in different types of watersheds in the US and the areas of the watersheds were varying from 25-kilometre square to 25,000-kilometre square. Small catchments to larger catchments the study has been conducted and based on this study certain relationships have been formulated in the form of equations.

So, for basin lag t_p Snyder suggested an equation

$$t_p = 0.75 C_t (LL_c)^{0.3}$$

and for peak runoff the proposed equation is

$$q_p = 2.78 \frac{C_p}{t_p}$$

In this q_p is the peak runoff per catchment area for the standard unit hydrograph. So, this peak runoff per catchment area we have already seen before it is having the unit of meter cube per second kilometer square. Now, C_p, C_t here we are having coefficient C_t and C_p, C_t is the coefficient corresponding to time and C_p is the coefficient corresponding to peak runoff. So, these coefficients are derived from the gauged watersheds in the same region.

For developing these synthetic unit hydrograph, we need to have a gauged catchment, which is having the similar characteristics of the ungauged catchment for which we are going to develop the synthetic unit hydrograph. Here we are having a term corresponding to capital L, L is representing the length of the mainstream from outlet to upstream divide line, that is the length of the mainstream in kilometers that is represented by capital L that is from the upstream point from where the mainstream is starting to the outlet of the catchment that is the length of the mainstream starting from the watershed divide at the upstream point to the outlet point, that is capital L.

Another term L_c is there. L_c is present in the equation corresponding to t_p that is representing the distance from the outlet to a point on the stream nearest to the centroid of the watershed area in kilometer. For a watershed, we can find out which is the point corresponding to the centroid of the watershed. So, that centroidal point may not be on the mainstream. So, from that centroidal point, closest point on the main stream that is the closest point near to the centroidal point will be selected which is on the stream and the distance from that particular point to the outlet of the catchment is considered as L_c. These L and L_c are the geomorphological parameters of the catchment estimated using the topographic map of the area. For the catchments which we are considering that is gauged catchment and also ungauged catchment we should have the topographic map. So, if topographic map is available to us, we can calculate different geomorphological characteristics. Nowadays it is very easy by making use of GIS software's and from that we can calculate the values corresponding to L and L_c in kilometers. So, here you can look at the equations corresponding to t_p and q_p again,

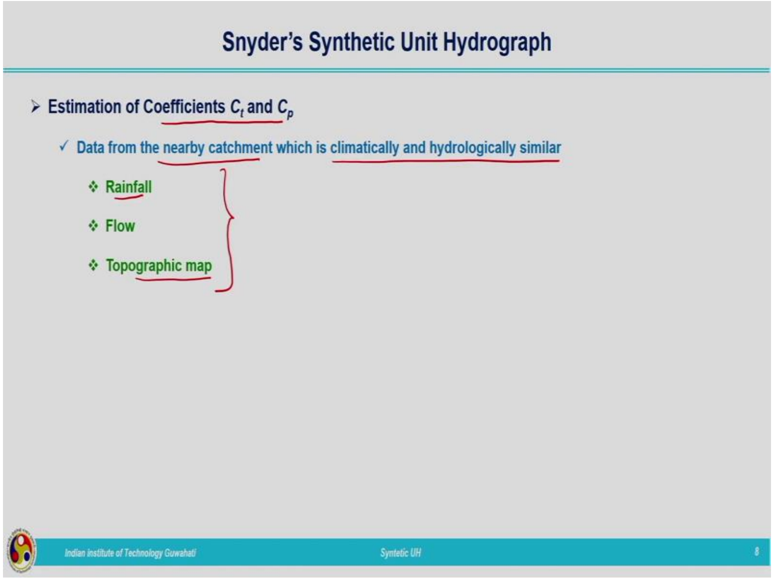
$$t_p = 0.75 C_t \left(L L_c \right)^{0.3}$$

L and L_c we can get from the topographic map and coming to q_p can be calculated by using this formula

$$q_p = 2.78 \frac{C_p}{t_p}$$

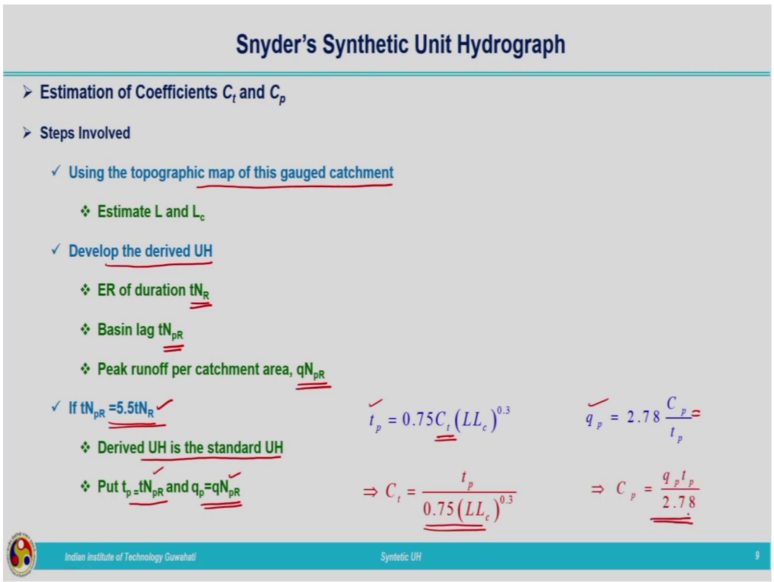
We need to have the value corresponding to coefficient C_p. So, next step is to determine the different coefficients C_p and C_t.

(Refer Slide Time: 20:22)



Estimation of coefficients C_p and C_t. We are having data from the nearby catchment versus climatically and hydrologically similar to the ungauged catchments. These data include: rainfall data, streamflow data and also topographic map. So, different data required from the gauged catchment are given over here. Rainfall data with particular duration, corresponding streamflow data and the topographic map corresponding to the gauged catchment.

(Refer Slide Time: 20:54)



Now, coming to different steps involved in this, using the topographic map of this gauged catchment we can calculate the length such as L and L_c. After that we can go for developing the derived unit hydrograph. Derived unit hydrograph is the unit hydrograph which is derived for the gauged catchment. We have the rainfall data and also streamflow data and based on the methods which we have discussed in previous lectures, we can develop the unit hydrograph corresponding to this gauged catchment by making use of the rainfall and streamflow data.

Let the effective rainfall duration of the gauged catchment, tN_R, basin lag represented by tN_{pR} that is t_p is the term which is used for representing basin lag. So, here this is for the gauged catchment that is why we are having extra *N* and *R* is representing the required one. So, for the gauged catchment basin lag is represented by tN_{pR} and peak runoff per catchment area is represented by qN_{pR}. Now, if this derived unit hydrograph is representing a standard unit hydrograph then it will be following the equation

$$tN_{pR} = 5.5tN_R$$

Once the unit hydrograph is developed, that is the derived unit hydrograph is there with us, we can check how much is the basin lag for that particular catchment that is $tN_{pR} = 5.5tN_R$. If we are calculating the basin lag to be 5.5 times the effective rainfall duration then it can be considered as a standard unit hydrograph. So, this derived unit hydrograph can be considered as standard unit hydrograph if it follows this relationship. So, directly we can make use of the relationship for t_p and q_p for developing the synthetic unit hydrograph. What we have to do? We have to put $t_p = tN_{pR}$ and $q_p = qN_{pR}$ and t_p we are having represented by tN_{pR} and q_p is represented by qN_{pR}. This is from the derived unit hydrograph if it follows the relationship related to standard unit hydrograph. So, here in this equation we know t_p i.e., $t_p = 0.75C_t\left(LL_c\right)^{0.3}$ and q_p i.e., $q_p = 2.78\frac{C_p}{t_p}$ then we can calculate the coefficient C_t and C_p

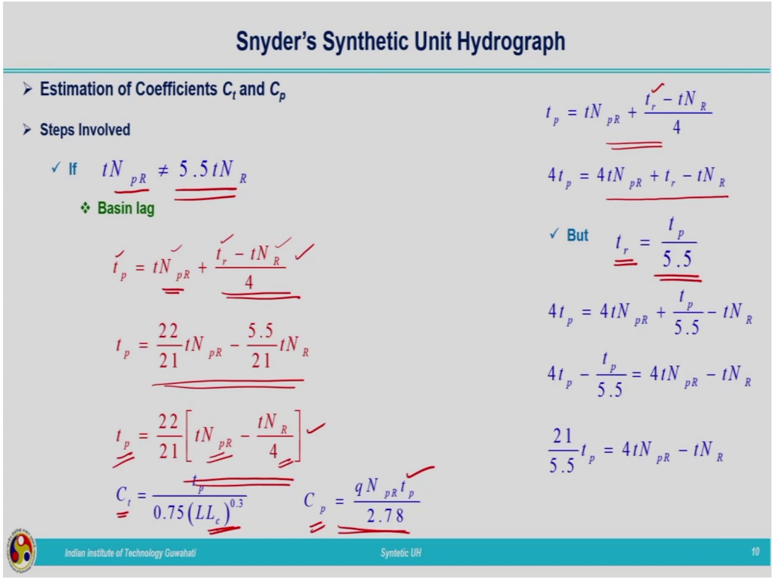
$$C_t = \frac{t_p}{0.75\left(LL_c\right)^{0.3}}$$

and

$$C_p = \frac{q_p t_p}{2.78}$$

If the derived unit hydrograph is following the relationship corresponding to standard unit hydrograph, we can directly make use of that formula to get the coefficients. But always it will not be following that particular relationship that is $t_p \neq 5.5t_r$.

(Refer Slide Time: 24:05)



Then what we can do? If $tN_{pR} \neq 5.5tN_R$ then Snyder has proposed another equation for calculating basin lag given by

$$t_p = tN_{pR} + \frac{t_r - tN_R}{4}$$

tN_{pR} is known to us and tN_R is also known to us. We do not know t_p and t_r. So, this can be modified a little bit by assuming that this relationship t_p follows the relationship of $t_p = 5.5t_r$. Based on this we are going to modify the equation slight rearrangements of the terms we are doing. So,

$$4t_p = 4tN_{pR} + t_r - tN_R$$

and if this is following the standard unit hydrograph equation then we can write

$$t_r = \frac{t_p}{5.5}$$

The unit hydrograph which is derived with the known data that is for the gauged catchment is not behaving as a standard unit hydrograph. So, we need to derive the standard unit hydrograph first. So, for that from the studies conducted in different catchments, Snyder has proposed a formula, if it is not following that particular relationship we can make use of this formula then it will be becoming standard unit hydrograph. In that case $t_r = \frac{t_p}{5.5}$. So, that we are going to substitute over here for t_r i.e.,

$$t_p = tN_{pR} + \frac{t_r - tN_R}{4}$$

and we will be simplifying the equation

$$4t_p = 4tN_{pR} + \frac{t_p}{5.5} - tN_R$$

$$4t_p - \frac{t_p}{5.5} = 4tN_{pR} - tN_R$$

$$\frac{21}{5.5}t_p = 4tN_{pR} - tN_R$$

and the equation takes the form

$$t_p = \frac{22}{21}tN_{pR} - \frac{5.5}{21}tN_R$$

and again, it can be simplified to

$$t_p = \frac{22}{21}\left[tN_{pR} - \frac{tN_R}{4}\right]$$

So, this equation can be utilized for calculating t_p that is for the derived unit hydrograph we are having the value corresponding to tN_{pR} and tN_R. This is nothing but the t_r, required duration of the effective rainfall and t_{pR} is representing the basin lag. By making use of this formula we can calculate the basin lag corresponding to standard unit hydrograph and if t_p is calculated by using this formula we can calculate C_t by making use of this formula

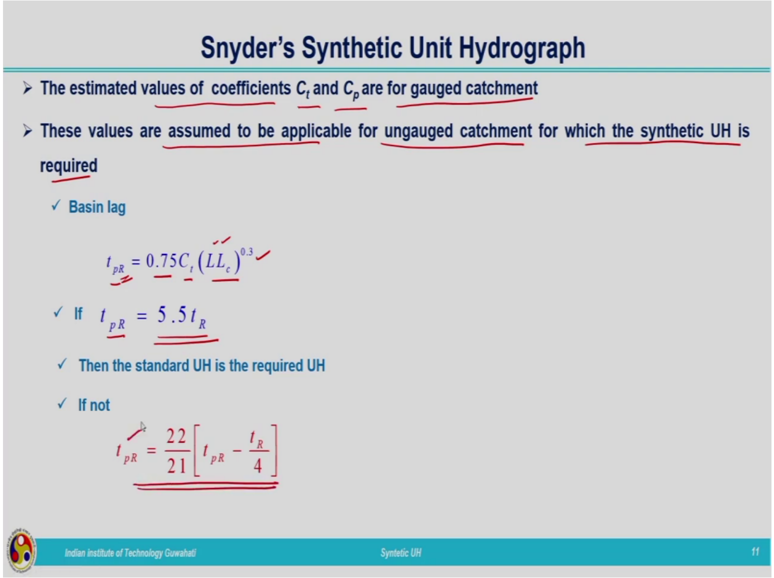
$$C_t = \frac{t_p}{0.75\left(LL_c\right)^{0.3}}$$

which we have already discussed and C_p can be obtained after calculating t_p as,

$$C_p = \frac{qN_{pR}t_p}{2.78}$$

So, if the derived unit hydrograph is following that particular equation for standard unit hydrograph that is $t_p = 5.5t_r$, then we can assume that the derive unit hydrograph is the standard unit hydrograph. But in majority of the cases it will not be behaving like that, it will not be satisfying that formula. In such cases, we have to make use of this equation which is provided by Snyder for calculating the basin lag. Once the basin lag is calculated we can calculate the coefficient corresponding to time that is C_t and we are having t_p, we can make use of the other formula for C_p to get the coefficient corresponding to peak discharge.

(Refer Slide Time: 27:30)

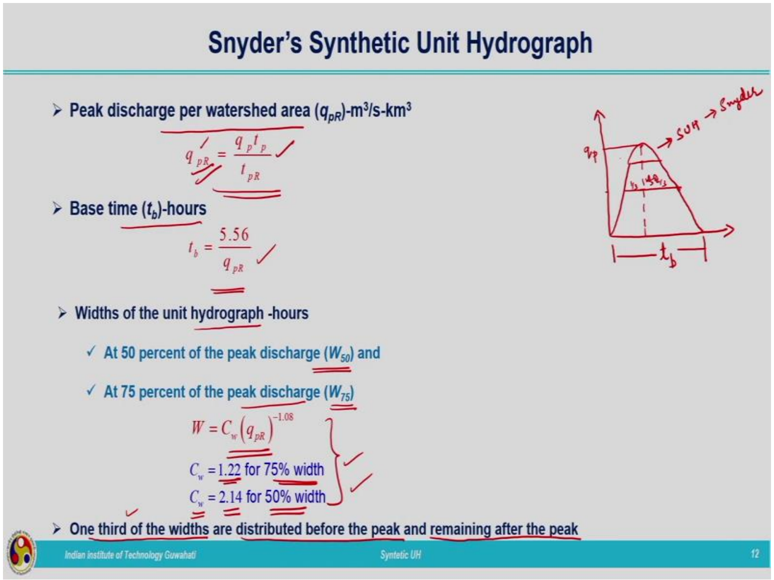


Now, the estimated values of coefficient C_t and C_p for the gauged catchments are there with us. These values are assumed to be applicable for ungauged catchment, for which we need to derive the synthetic unit hydrograph. By the principles which are discussed till now, we got the values corresponding to C_t and C_p. Those C_t and C_p are derived based on the hydrograph characteristics and also geomorphology characteristics of the gauged catchment. What we are going to assume that since these two catchments are having similar characteristics climatically and also hydrologically, we can assume that these coefficients can be applicable to ungauged catchment also. So, the basin lag corresponding to the ungauged catchment can be calculated by

$$t_{pR} = 0.75C_t\left(LL_c\right)^{0.3}$$

Here L and L_c, we will be getting from the topographic map of the ungauged catchment. C_t, we have already calculated based on the data from the gauged catchment that C_t the value will be utilized and the length values L and L_c will be calculated from the topographic map of the gauged catchment. So, if $t_{pR} = 5.5t_R$, that is the effective rainfall is having a duration of t subscript capital R, if this t_p calculated by using the characteristics from the gauged catchment that follows this particular relationship this thing can be considered as the standard unit hydrograph. So, the standard unit hydrograph is the required unit hydrograph. If it is not following that relationship we need to make use of this formula for $t_{pR} = \frac{22}{21}\left[t_{pR} - \frac{t_R}{4}\right]$.

(Refer Slide Time: 29:28)



Once t_{pR} is calculated we can get the values corresponding to peak discharge per watershed area that is q_{pR} by using this formula,

$$q_{pR} = \frac{q_p t_p}{t_{pR}}$$

and base time t_p in hours can be calculated by using

$$t_b = \frac{5.56}{q_{pR}}$$

Now, other two characteristics which are considered are width of the unit hydrograph in hours, that is at 50 percentage of the peak discharge that is represented by W_{50} and 75 percentage of the peak discharged represented by W_{75} can be calculated by using this formula given by W is equal to

$$W = C_w \left(q_{pR} \right)^{-1.08}$$

Same formula only the difference is in the coefficient of C_w,

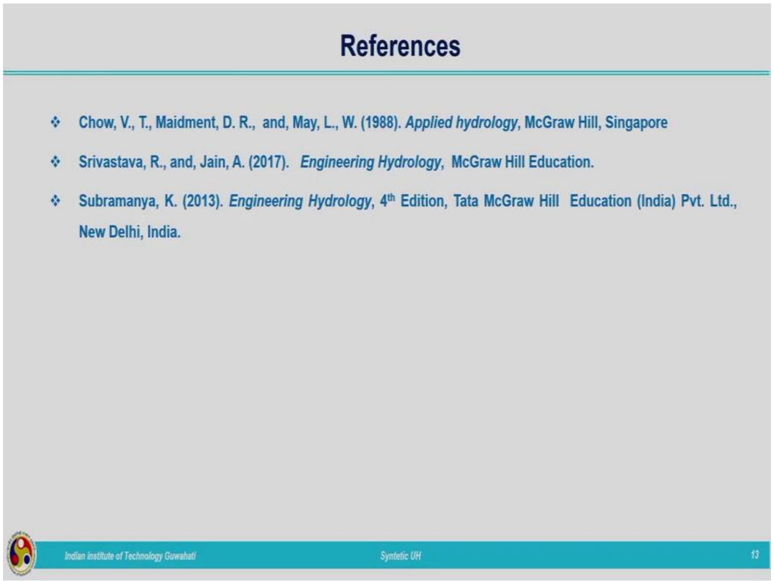
$C_w = 1.22$ for 75% width
$C_w = 2.14$ for 50% width

Width we are calculating corresponding to 75 percentage of the peak discharge and also 50 percentage of the peak discharge corresponding to these separate coefficients have been given. So, the four characteristics which are considered by Snyder, we are having expressions to calculate that for the required unit hydrograph. In order to reach that step, we have to make use of the data corresponding to the gauged catchment. Here we are having the values corresponding to basin lag, then peak discharge per unit area, then comes the width corresponding to 75 percentage and 50 percentage of the peak discharge and base time t_b. Once these data are available to us, we can plot the synthetic unit hydrograph. One thing you need to make sure that after getting the width calculation by using this formula, it should be arranged in such a way that one third of the widths are distributed before the peak and remaining two thirds is drawn after the peak has occurred.

Once we calculate the values corresponding to basin lag q_{pR}, base time and the widths corresponding to 50 and 75 percentage of the peak discharge, we can construct these synthetic unit hydrograph. So, let me plot this, we are having that base time t_b, let me mark that first. t_b is marked along the x axis and we can consider the value corresponding to peak discharge that can be marked in this plane, this is representing our q_p. Now, we will drop a perpendicular from this point to the x axis, and then only we can draw the widths corresponding to these discharges. How to draw these widths? It should be drawn in such a way that one third of the width should be before the peak and two thirds should come after the peak. So, W_{50} I can mark at this point, this is corresponding to 50 percentage of q_p and the width is marked in such a way that one third of W will be coming over here and two third will be coming after the peak has occurred and this is representing our W_{50}. Now, coming to W_{75}, similar way we will mark one third before the peak and two third after the peak. Now, we will join these points with a smooth curve like this and this is our synthetic unit hydrograph proposed by Snyder.

So, this is the way in which we will be developing the synthetic unit hydrograph based on the type I category that is finding out the relationship between the geomorphology characteristics and the hydrograph characteristics, that is you could have understood the concept. In this case from the gauged catchment we have derived the unit hydrograph and also, we were having the topographic map of the gauged catchment. Based on those data the coefficients C_p and C_t determined. That C_p and C_t applied to the gauged catchment assuming that these two catchments are hydrologically and climatically having the similar characteristics. After that the steps which we have explained here can be followed and we can find out different characteristics or the four different characteristics which are proposed by Snyder can be calculated and it can be plotted to obtain the synthetic unit hydrograph Snyder's synthetic unit hydrograph. So, here I am winding up this topic of Snyder's synthetic unit hydrograph.

(Refer Slide Time: 34:50)



The reference related to this topic is given over here. Thank you.