Surface Water Hydrology
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Lecture 35
Synthetic Unit Hydrograph

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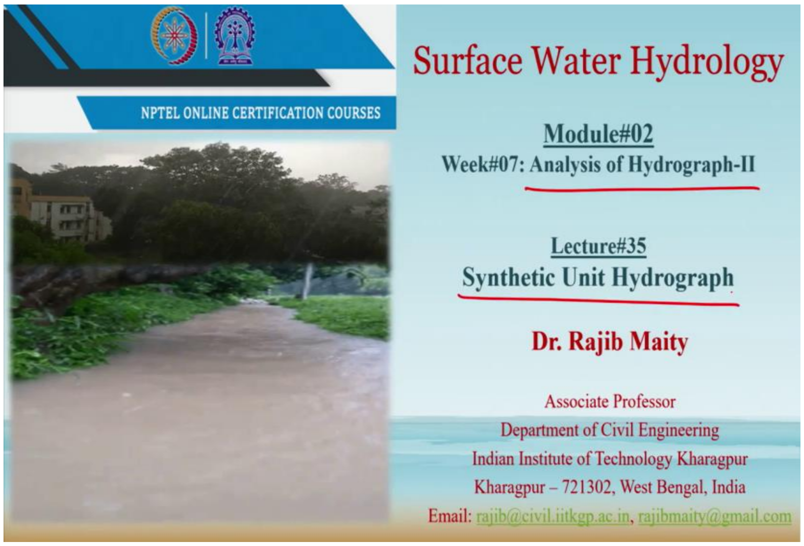

In today's lecture, we are discussing synthetic unit hydrograph.

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The concept covered is the synthetic unit hydrograph and one of the old but very popular methods is Snyder's method that we will discuss.

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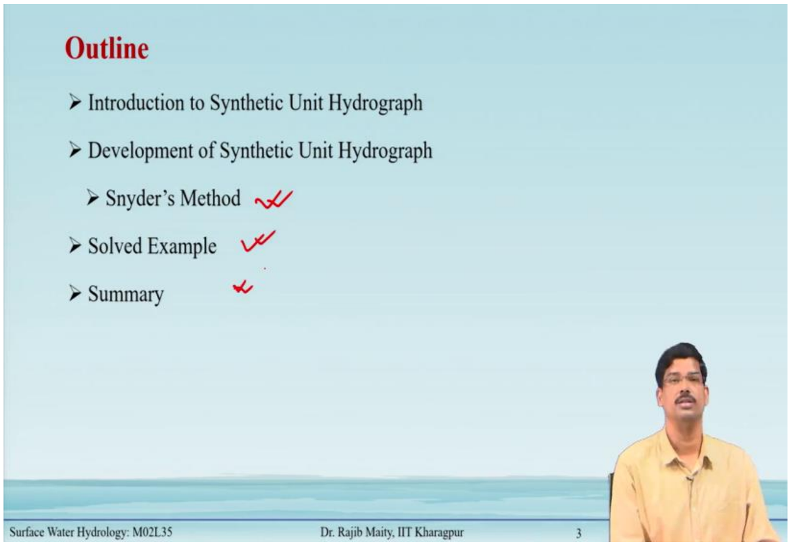

The outline goes like this, first of all, we will give an introduction to the synthetic unit hydrograph, and then we will discuss the development of synthetic unit hydrograph. And this development is through Snyder's method. We will also solve one example using this method before coming to the summary.

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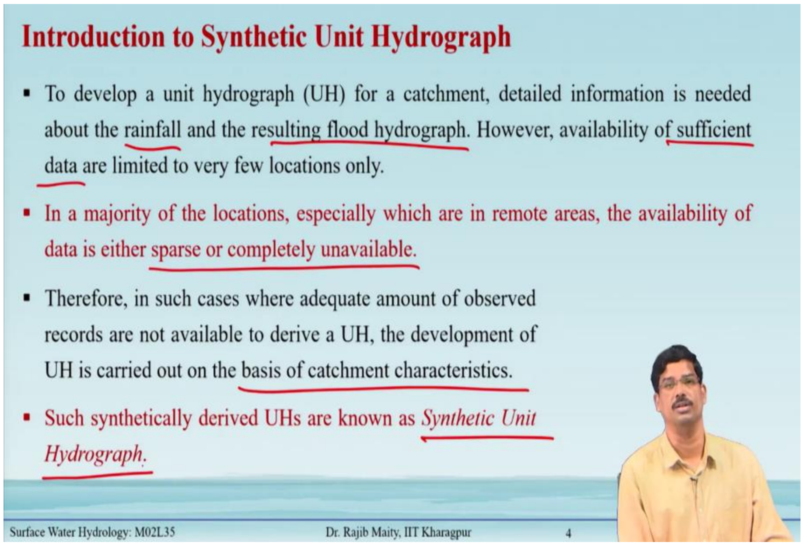

Introduction to Synthetic Unit Hydrograph

To develop a unit hydrograph (UH) for a catchment, detailed information is needed about the rainfall and the resulting flood hydrograph. However, the availability of sufficient data is limited to very few locations only.

But here the main challenge is that the availability of the sufficient data that is required for the development of unit hydrograph is limited to a few locations only, particularly in the remote areas where it is not accessible, the availability of that data is either sparse or sometimes it is completely not available. Therefore, in such cases where an adequate number of observed records are not available to derive a UH, the development of UH is carried out based on catchment characteristics. Such synthetically derived UHs are known as Synthetic Unit Hydrographs.

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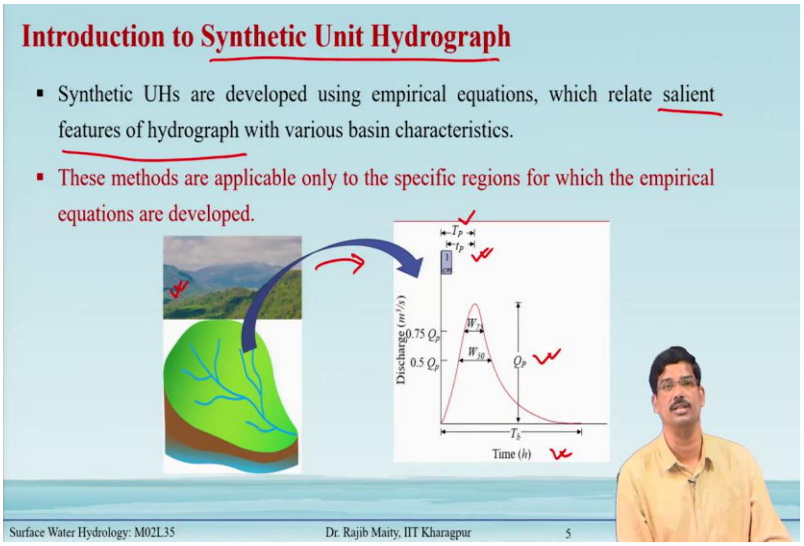

Synthetic UHs are developed using empirical equations, which relate salient features of hydrograph with various basin characteristics. So, there are different physical and geomorphological properties are there for a watershed. Using those properties, we want to relate it with the different salient features of the hydrograph, and if we can establish this relationship then establishing this relationship is the fundamental thing to develop the synthetic unit hydrograph.

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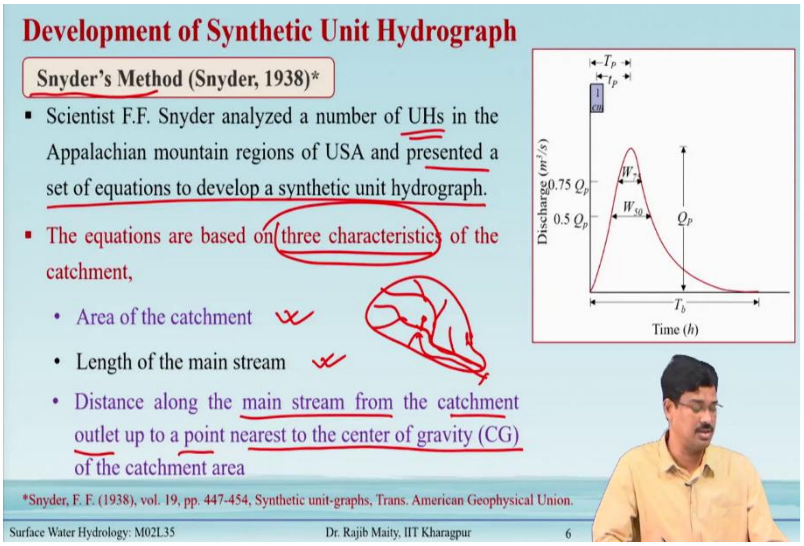

Snyder's Method (Snyder, 1938)

Scientist F.F. Snyder analyzed a number of unit hydrographs in the Appalachain mountain regions in the USA. And he presented the setup equation to develop the synthetic unit hydrograph. Again, relating the watershed property and the salient features of the hydrograph.

The three characteristics of the catchment were utilized in that case,

I. Area of the catchment

II. Length of the mainstream

III. The distance along the mainstream from the catchment outlet up to a point nearest to the center of gravity (CG) of the catchment area

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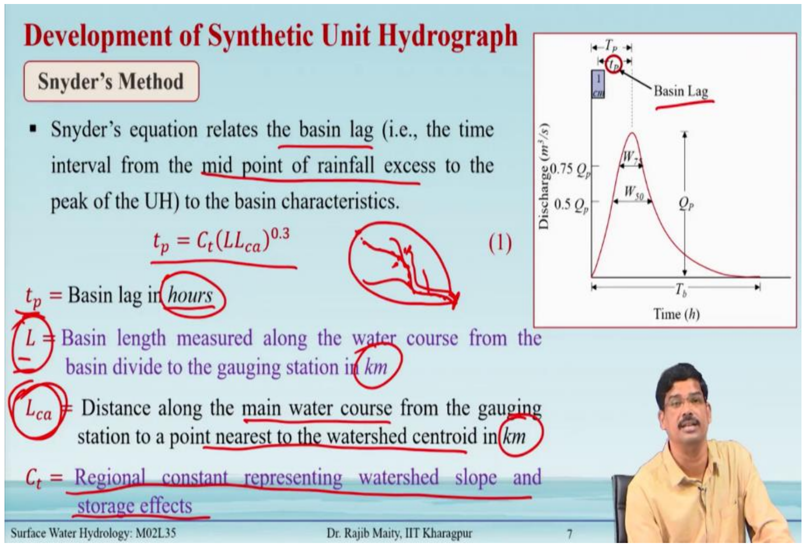

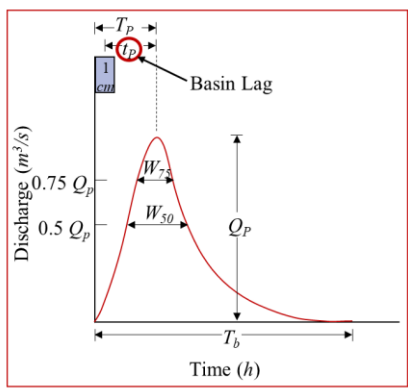

Fig.1 shows the elements of the Synthetic Unit Hydrograph

Snyder's equation relates the basin lag which is defined as the time interval from the midpoint of rainfall excess to the peak of the UH (Fig.1) to the basin characteristics.

$$t_p = C_t(LL_{ca})^{0.3} \tag{1}$$

Where t_p= Basin lag in hours

L= Basin length measured along the watercourse from the basin divide to the gauging station in km

L_{ca}= Distance along the main watercourse from the gauging station to a point nearest to the watershed centroid in km

C_t= Regional constant representing watershed slope and storage effects

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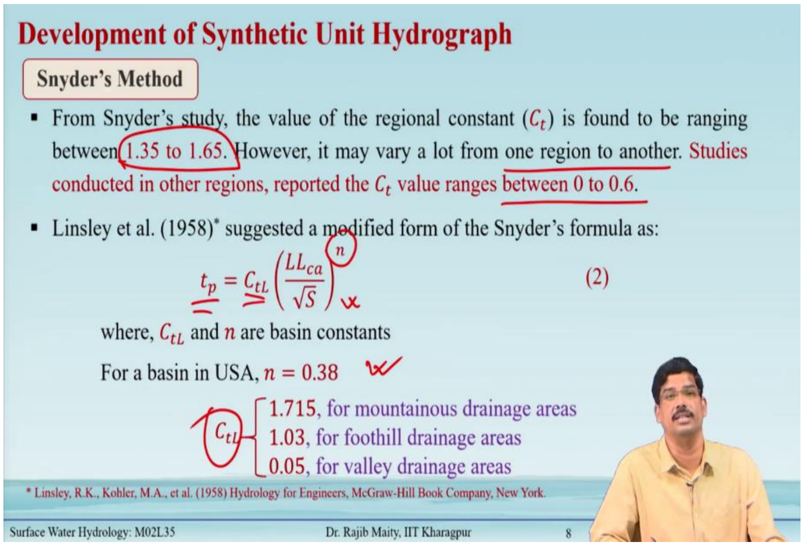

From Snyder's study, the value of the regional constant (C_t) is found to be ranging between 1.35 to 1.65. However, it may vary a lot from one region to another. Studies conducted in other regions, reported the C_t value ranges between 0 to 0.6.

Linsley et al. (1958) suggested a modified form of Snyder's formula as:

$$t_p = C_{tL}\left(\frac{LL_{ca}}{\sqrt{S}}\right)^n \qquad (2)$$

Where C_{tL} and n are basin constants

For a basin in USA, $n = 0.38$

$$C_{tL} = 1.715, \textit{ for mountainous drainage areas}$$

$$1.03, \textit{ for foothill drainage areas}$$

$$0.05, \textit{ for valley drainage areas}$$

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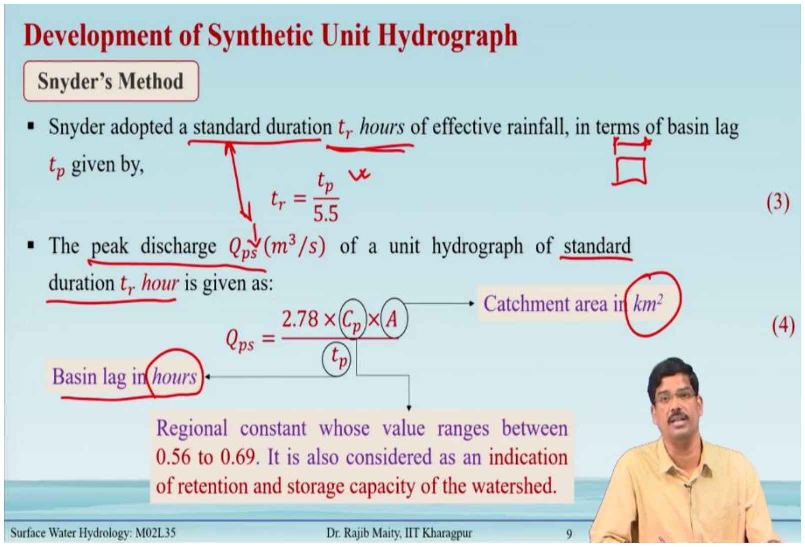

Snyder adopted a standard duration t_r hours of effective rainfall, in terms of basin lag t_p given by,

$$t_r = \frac{t_p}{5.5} \quad (3)$$

The peak discharge Q_{ps} (m^3/s) of a unit hydrograph of standard duration t_r hour is given as:

$$Q_{ps} = \frac{2.78 \times C_p \times A}{t_p} \quad (4)$$

where A is the catchment area empirical equation should come in the proper unit, it is in kilometers square, t_p is the basin lag as was discussed in the previous slide also in ours, and Cp is a regional constant whose value ranges from 0.56 to 0.69. It is also considered as an indication of the retention and storage capacity of the watershed, but again these things may vary from one region to another region

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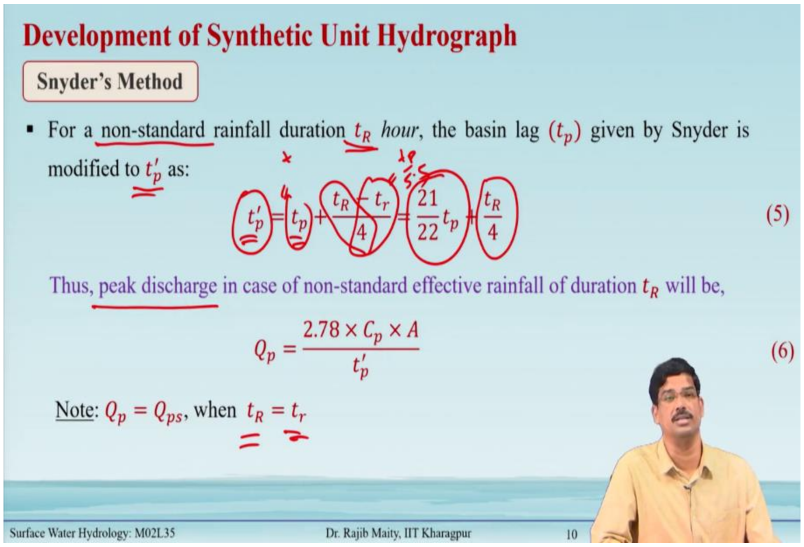

For a non-standard rainfall duration t_R hour, the basin lag (t_p) given by Snyder is modified to t_p' as:

$$t_p' = t_p + \frac{t_R - t_r}{4} = \frac{21}{22}t_p + \frac{t_R}{4} \tag{5}$$

Thus, peak discharge in case of non-standard effective rainfall of duration t_R will be,

$$Q_p = \frac{2.78 \times C_p \times A}{t_p'} \tag{6}$$

It may be noted that $Q_p = Q_{ps}$, when $t_R = t_r$

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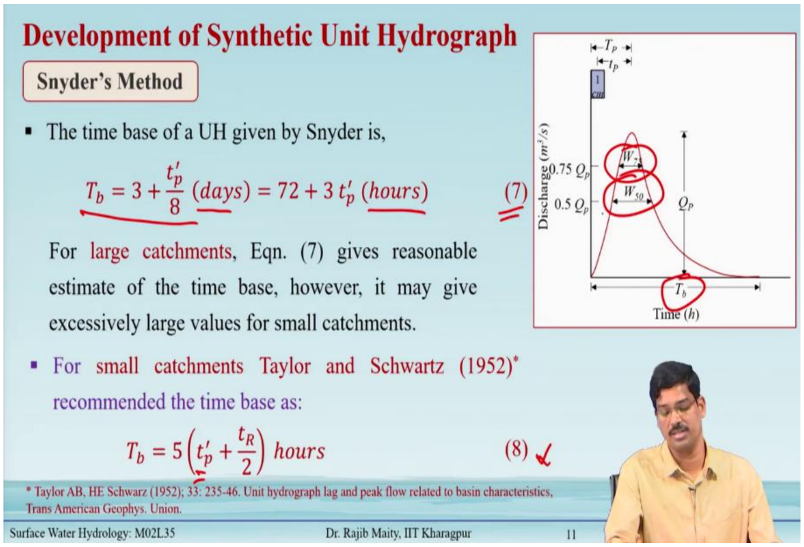


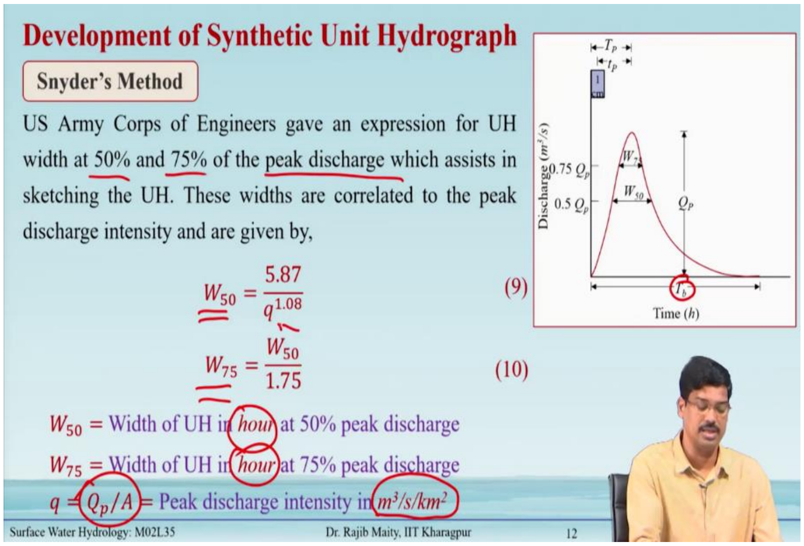
The time base of a UH given by Snyder is,

$$T_b = 3 + \frac{t_p'}{8}\ (days) = 72 + 3\ t_p'\ (hours) \tag{7}$$

For large catchments, Eqn. (7) gives a reasonable estimate of the time base, however, it may give excessively large values for small catchments.

For small catchments, Taylor and Schwartz (1952) recommended the time base as:

$$T_b = 5\left(t_p' + \frac{t_R}{2}\right)\ hours \tag{8}$$



US Army Corps of Engineers gave an expression for UH width at 50% and 75% of the peak discharge which assists in sketching the UH. These widths are correlated to the peak discharge intensity and are given by,

$$W_{50} = \frac{5.87}{q^{1.08}} \tag{9}$$

$$W_{75} = \frac{W_{50}}{1.75} \tag{10}$$

W_{50}= Width of UH in an hour at 50% peak discharge

W_{75}= Width of UH in an hour at 75% peak discharge

$q=Q_p/A$= Peak discharge intensity in $m^3/s/km^2$

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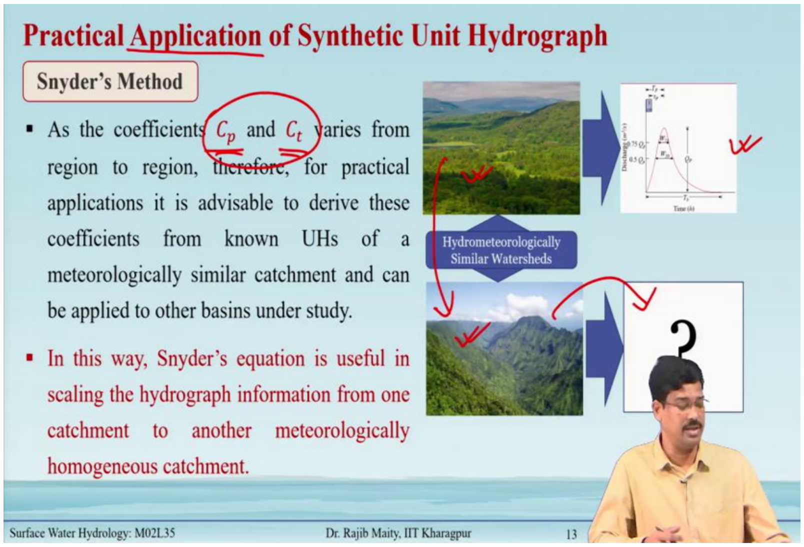

Practical Application of Synthetic Unit Hydrograph

As the coefficients C_p and C_t varies from region to region, therefore, for practical applications, it is advisable to derive these coefficients from known UHs of a meteorologically similar catchment and can be applied to other basins under study.

In this way, Snyder's equation is useful in scaling the hydrograph information from one catchment to another meteorologically homogeneous catchment.

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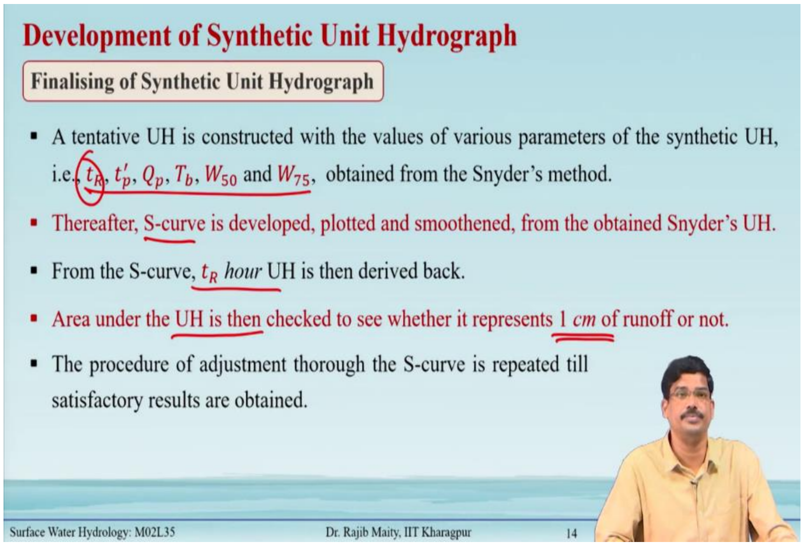

Finalizing of Synthetic Unit Hydrograph

- A tentative UH is constructed with the values of various parameters of the synthetic UH, i.e., $t_{R,} t'_{p,} Q_{p,} T_{b,} W_{50,} W_{75}$ obtained from the Snyder's method.
- Thereafter, S-curve is developed, plotted, and smoothened, from the obtained Snyder's UH.
- From the S-curve, t_R *hour* UH is then derived back.
- The area under the UH is then checked to see whether it represents 1 *cm* of runoff or not.
- The procedure of adjustment through the S-curve is repeated till satisfactory results are obtained.

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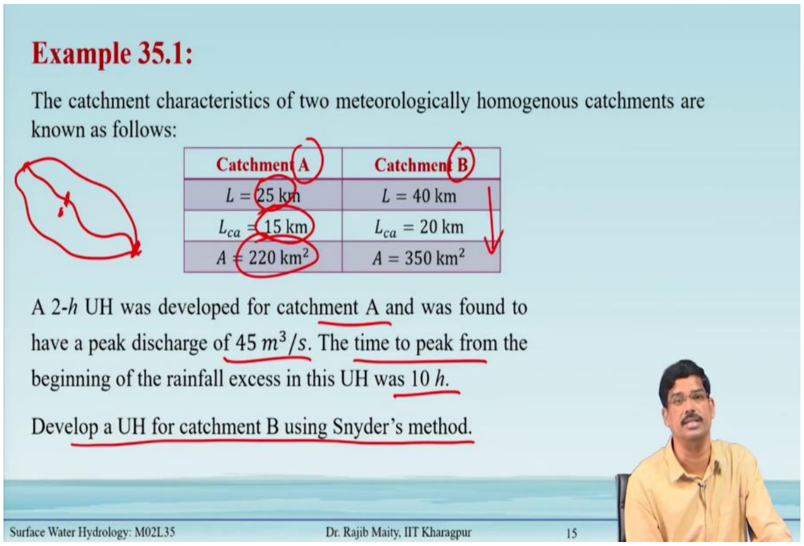

Example 35.1:

The catchment characteristics of two meteorologically homogenous catchments are known as follows:

Catchment A	Catchment B
$L = 25$ km	$L = 40$ km
$L_{ca} = 15$ km	$L_{ca} = 20$ km
$A = 220$ km^2	$A = 350$ km^2

A 2-h UH was developed for catchment A and was found to have a peak discharge of 45 m^3/s. The time to peak from the beginning of the rainfall excess in this UH was 10 h.

Develop a UH for catchment B using Snyder's method.

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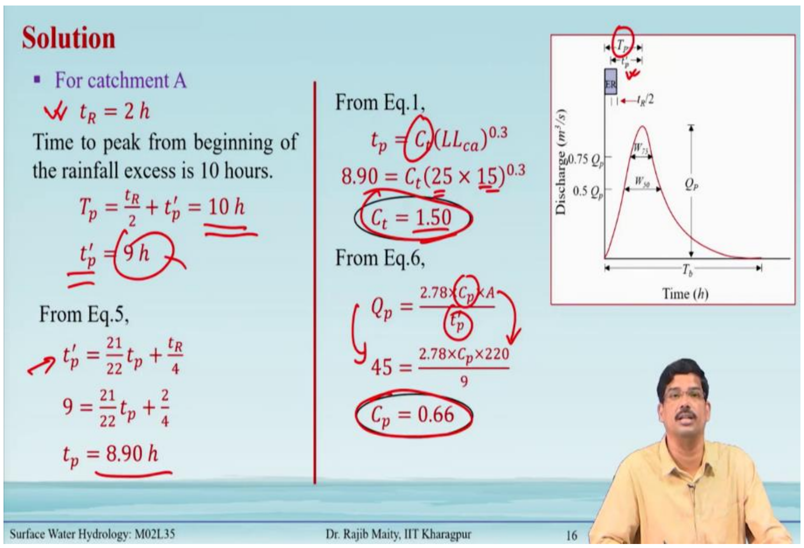

Solution

For catchment A

$$t_R = 2\,h$$

Time to peak from beginning of the rainfall excess is 10 hours.

$$T_p = \frac{t_R}{2} + t_p' = 10\,h$$

$$t_p' = 9\,h$$

From Eq.5,

$$t_p' = \frac{21}{22}t_p + \frac{t_R}{4}$$

$$9 = \frac{21}{22}t_p + \frac{2}{4}$$

$$t_p = 8.90\,h$$

From Eq.1,

$$t_p = C_t(LL_{ca})^{0.3}$$

$$8.90 = C_t(25 \times 15)^{0.3}$$

$$C_t = 1.50$$

From Eq.6,

$$Q_p = \frac{2.78 \times C_p \times A}{t'_p}$$

$$45 = \frac{2.78 \times C_p \times 220}{9}$$

$$C_p = 0.66$$

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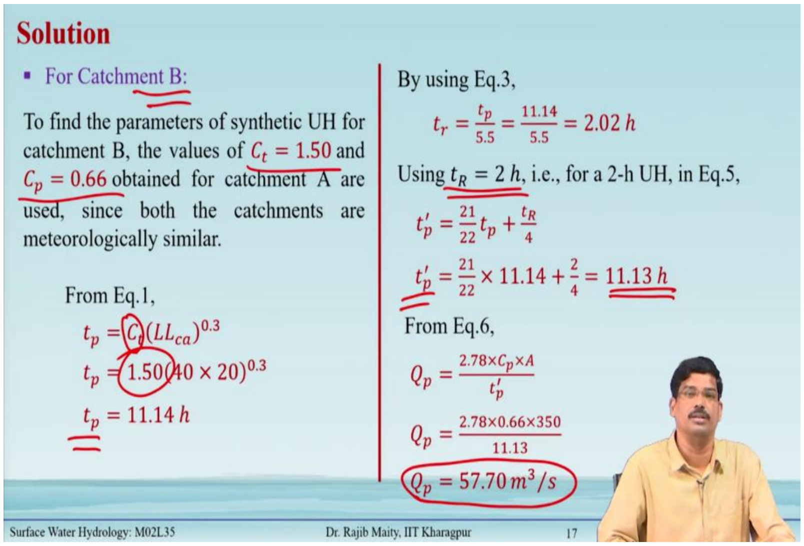

For Catchment B:

To find the parameters of synthetic UH for catchment B, the values of C_t=1.50 and C_p=0.66 obtained for catchment A are used since both the catchments are meteorologically similar.

From Eq.1,

$$t_p = C_t(LL_{ca})^{0.3}$$

$$t_p = 1.50(40 \times 20)^{0.3}$$

$$t_p = 11.14\ h$$

By using Eq.3,

$$t_r = \frac{t_p}{5.5} = \frac{11.14}{5.5} = 2.02\ h$$

Using $t_R = 2\ h$, i.e., for a 2-h UH, in Eq.5,

$$t'_p = \frac{21}{22} t_p + \frac{t_R}{4}$$

$$t'_p = \frac{21}{22} \times 11.14 + \frac{2}{4} = 11.13\ h$$

From Eq.6,

$$Q_p = \frac{2.78 \times C_p \times A}{t'_p}$$

$$Q_p = \frac{2.78 \times 0.66 \times 350}{11.13}$$

$$Q_p = 57.70\ m^3/s$$

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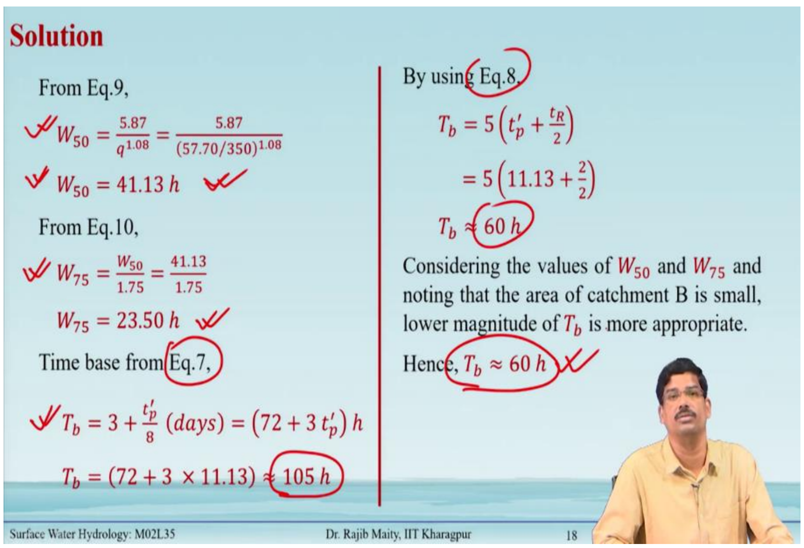

From Eq.9,

$$W_{50} = \frac{5.87}{q^{1.08}} = \frac{5.87}{(57.70/350)^{1.08}}$$

$$W_{50} = 41.13\ h$$

From Eq.10,

$$W_{75} = \frac{W_{50}}{1.75} = \frac{41.13}{1.75}$$

$$W_{75} = 23.50\ h$$

Time base from Eq.7,

$$T_b = 3 + \frac{t_p'}{8}\ (days) = \left(72 + 3\ t_p'\right)\ h$$

$$T_b = (72 + 3\ \times 11.13) \approx 105\ h$$

using Eq.8,

$$T_b = 5\left(t_p' + \frac{t_R}{2}\right)$$

$$= 5\left(11.13 + \frac{2}{2}\right)$$

$$T_b \approx 60\ h$$

Considering the values of W_{50} and W_{75} and noting that the area of catchment B is small, a lower magnitude of T_b is more appropriate.

Hence, $T_b \approx 60\ h$

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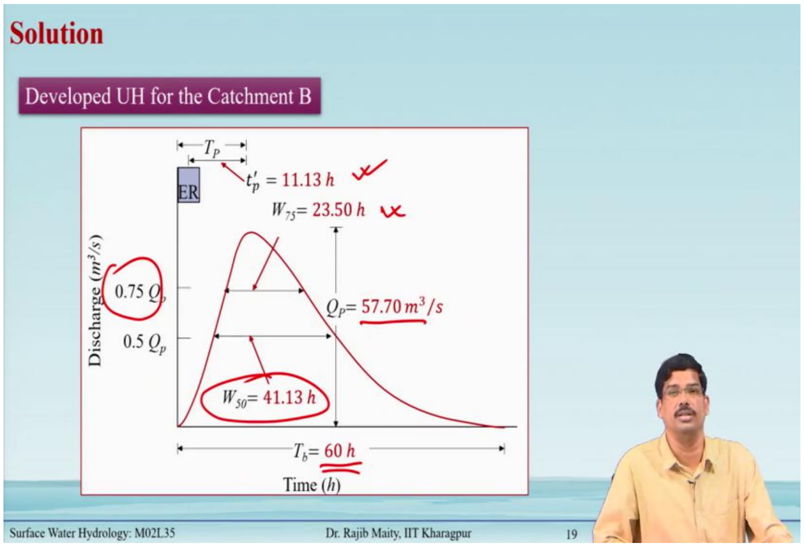

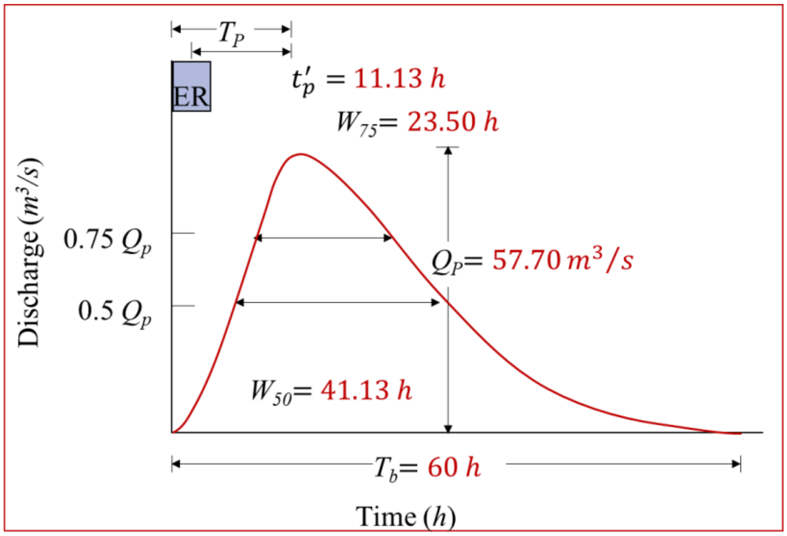

Fig.2 shows the Developed UH for the Catchment B

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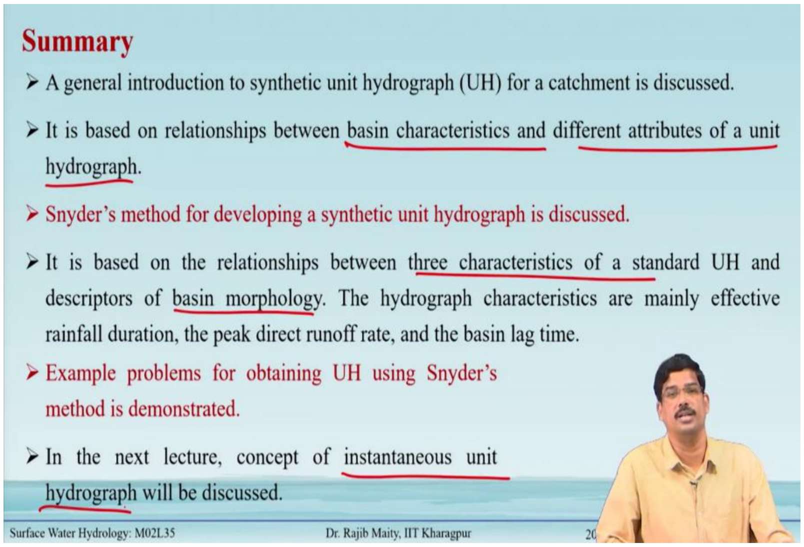

Summary

In summary, we learned the following points from this lecture:

- A general introduction to synthetic unit hydrograph (UH) for a catchment is discussed.
- It is based on relationships between basin characteristics and different attributes of a unit hydrograph.
- Snyder's method for developing a synthetic unit hydrograph is discussed.
- It is based on the relationships between three characteristics of a standard UH and descriptors of basin morphology. The hydrograph characteristics are mainly effective rainfall duration, the peak direct runoff rate, and the basin lag time.
- Example problems for obtaining UH using Snyder's method are demonstrated.
- In the next lecture, the concept of instantaneous unit hydrograph will be discussed.

References:

Linsley, R.K., Kohler, M.A., et al. (1958) Hydrology for Engineers, McGraw-Hill Book Company, New York.

Snyder, F. F. (1938), vol. 19, pp. 447-454, Synthetic unit-graphs, Trans. American Geophysical Union.

Taylor AB, HE Schwarz (1952); 33: 235-46. Unit hydrograph lag and peak flow related to basin characteristics, Trans American Geophysical Union.