Surface Water Hydrology
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Lecture – 28
Base Flow Separation, DRH and ERH

In today's particular lecture we are considering the base flow separation DRH and ERH.

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The three major things we will learn in this first one is base flow separation second one is direct runoff hydrograph which is abbreviated as DRH and the last one is effective rainfall hydrograph which is ERH.

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The outline of this lecture goes like this the introduction to the base flow and there are different methods of the base floor separation will be discussed three methods, straight-line method, two lines method and curve extension method. Then we will discuss the direct runoff hydrograph and its properties and its relation with this effective rainfall hyetograph there are some examples of problems that will be taken up and then a summary.

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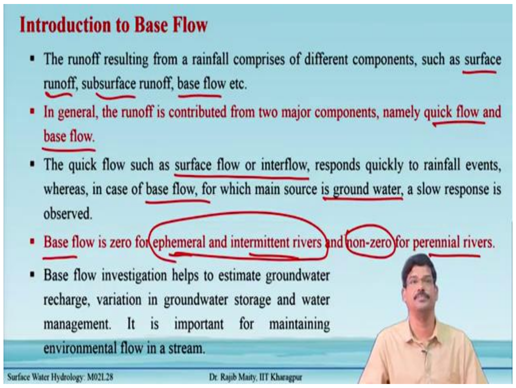

Introduction to Base Flow

Now, runoff resulting from rainfall comprises different components such as surface runoff subsurface and base flow. In general, this runoff is contributed from two major components, one is the quick flow another one is the base flow. Quick flow comes relatively faster at the outlet base flow takes a longer time.

The quick flow such as surface flow or interflow, responds quickly to rainfall events, whereas, in the case of base flow, for which the main source is groundwater, a slow response is observed. Baseflow is zero for ephemeral and intermittent rivers and non-zero for perennial rivers.

The ephemeral and intermittent rivers do not flow continuously throughout the year whereas perennial rivers flow is available throughout the year. That means the base blow is non-zero for the perennial rivers but for the ephemeral and intermittent rivers where it goes to zero sometime in the year. So, we can say that bass flow is zero.

Baseflow investigation helps to estimate the groundwater recharge in the inter catchment and the variation of the groundwater storage how it varies for the different seasons and it helps for the water management also. Secondly, it also helps to maintain the environmental flow in the stream and the importance of the environmental flow in a stream.

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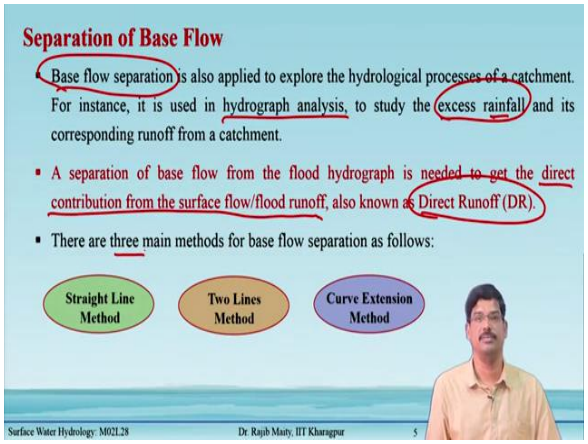

Separation of Base Flow

Baseflow separation is also applied to explore the hydrological processes of a catchment. For instance, it is used in hydrograph analysis, to study the excess rainfall and its corresponding runoff from a catchment.

Separation of base flow from the flood hydrograph is needed to get the direct contribution from the surface flow/flood runoff, also known as Direct Runoff (DR).

There are three main methods for baseflow separation as follows:

I. Straight Line Method
II. Two Lines Method
III. Curve Extension Method

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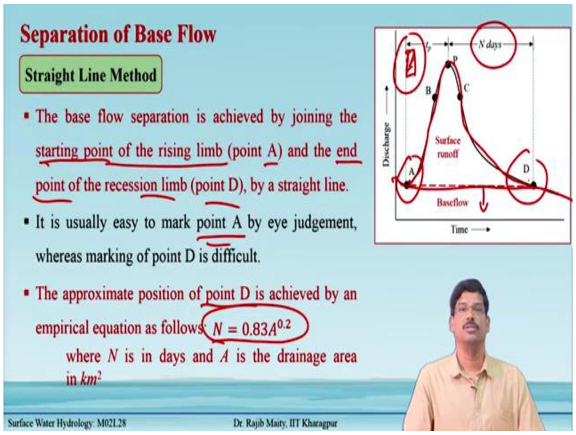

Straight Line Method

In the straight-line method, the base flow separation is achieved in this method by joining the starting point of the hydrograph or the starting point of the rising limb that points A and the ending point of the recession limb that is point D shown in fig.1. The starting point of rising limb A and ending of the rescission limb that is D, which is again identification of these two points make also some difficulties.

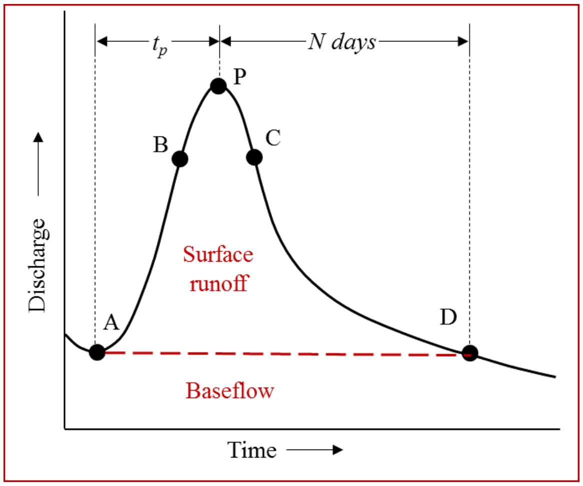

Fig.1 shows the straight-line method of base flow separation

Point A can be identified easily but sometimes it is difficult to identify where point D is and where we can say that, okay the effect of rainfall has stopped and it is now your leak coming from the groundwater contribution that is as a base flow.

The approximate position of point D is achieved by an empirical equation as follows:

$$N = 0.83A^{0.2}$$

Where N is in days and A is the drainage area in km^2

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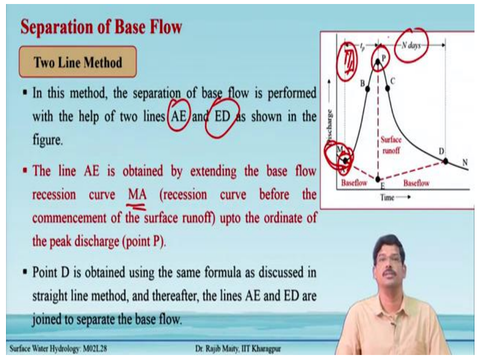

Two Line Method

In this method, the separation of base flow is performed with the help of two lines AE and ED as shown in fig.2. The line AE is obtained by extending the base flow recession curve MA (recession curve before the commencement of the surface runoff) up to the ordinate of the peak discharge (point P). Point D is obtained using the same formula as discussed in the straight-line method, and thereafter, the lines AE and ED are joined to separate the base flow.

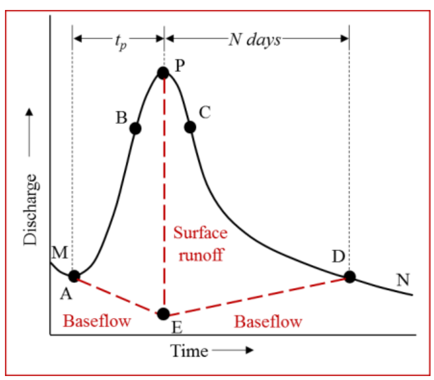

Fig.2 shows the two-line method of base flow separation

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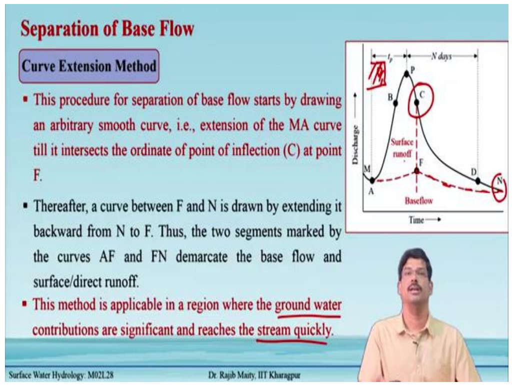

Curve Extension Method

This procedure for separation of base flow starts by drawing an arbitrary smooth curve, i.e., an extension of the MA curve till it intersects the ordinate of point of inflection (C) at point F as shown in fig.3.

Thereafter, a curve between F and N is drawn by extending it backward from N to F. Thus, the two segments marked by the curves AF and FN demarcate the base flow and surface/direct runoff. This method is applicable in a region where the groundwater contributions are significant and reach the stream quickly.

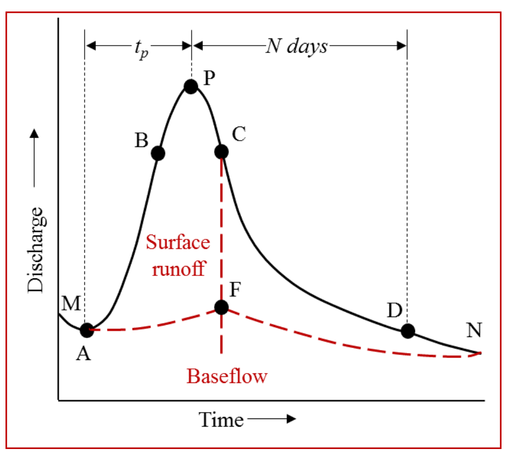

Fig.3 shows the curve extension method of base flow separation

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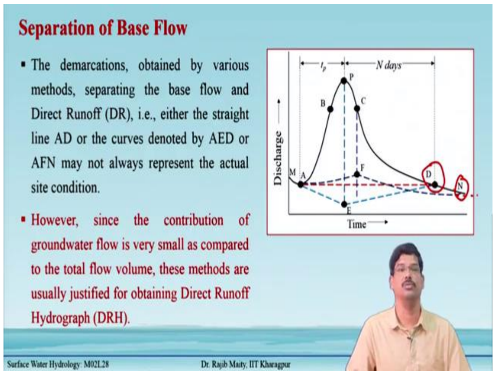

The demarcations, obtained by various methods, separating the base flow and Direct Runoff (DR), i.e., either the straight line AD or the curves denoted by AED or AFN may not always represent the actual site condition.

However, since the contribution of groundwater flow is very small as compared to the total flow volume, these methods are usually justified for obtaining a Direct Runoff Hydrograph (DRH).

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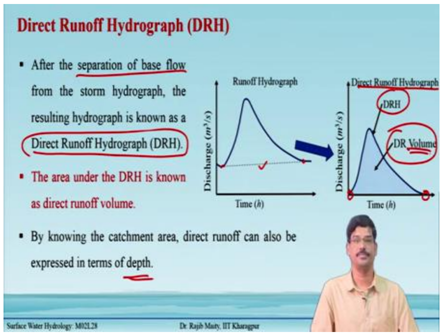

Direct Runoff Hydrograph (DRH)

After the separation of base flow from the storm hydrograph, the resulting hydrograph is known as a Direct Runoff Hydrograph (DRH). So, the total area under the DRH is indicating that how much total volume of the runoff has come out from the basin due to a storm that is what is called the direct runoff volume.

The direct runoff can also be expressed in terms of depth. If the volume is divided by the area that gets in terms of the depth also. So, runoff sometime is expressed in terms of depth as the rainfall is also expressed in terms of depth.

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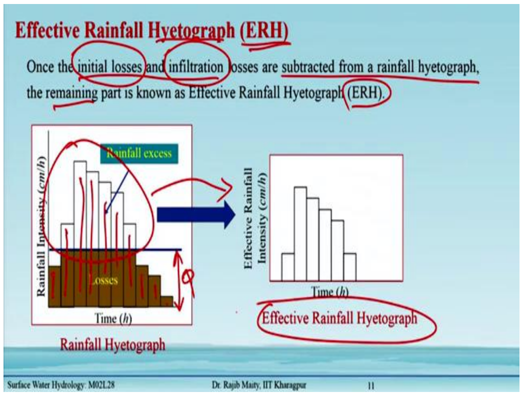

Effective Rainfall Hyetograph (ERH)

There are two such losses with respect to the runoff one is the initial loss other one is the infiltration loss. If these two things are subtracted from the rainfall hyetograph then the remaining part is known as the ERH is an effective rainfall hyetograph.

Sometimes we considered there is a constant loss in terms of the phi index or W index. So, once this rainfall hyetograph is obtained, separate the initial loss and infiltration loss which is through this sometimes the phi index, and then this remaining part is called the effective rainfall hyetograph.

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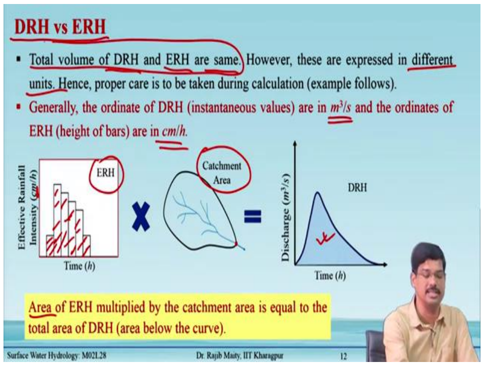

DRH vs ERH

The total volume of DRH and ERH are the same. However, these are expressed in different units. Hence, proper care is to be taken during calculation (example follows).

Generally, the ordinate of DRH (instantaneous values) are in m3/s and the ordinates of ERH (height of bars) are in cm/h. The area of ERH multiplied by the catchment area is equal to the total area of DRH (area below the curve).

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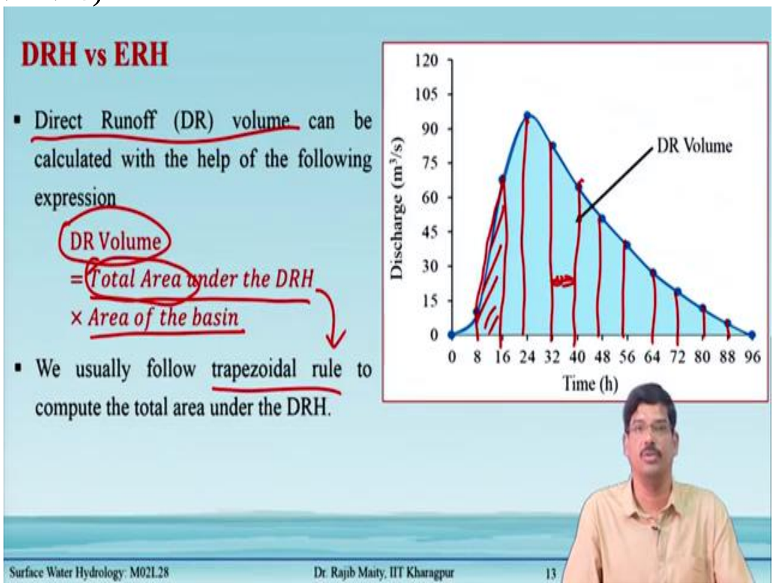

Direct Runoff (DR) volume can be calculated with the help of the following expression

DR Volume= $Total\ Area\ under\ the\ DRH \times Area\ of\ the\ basin$

We usually follow the trapezoidal rule to compute the total area under the DRH. And for that one calculation, it becomes much simpler that we can just take the ordinates at different time instances and we only add them up and then we can multiply with the time gap between two successive ordinates.

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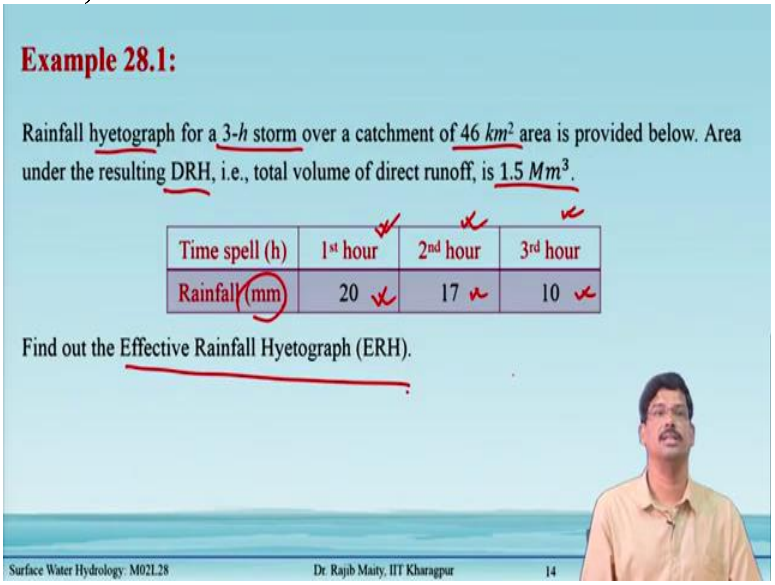

Example 28.1:

Rainfall hyetograph for a 3-h storm over a catchment of 46 km^2 area is provided below. The area under the resulting DRH, i.e., the total volume of direct runoff, is 1.5 Mm^3.

Time spell (h)	1st hour	2nd hour	3rd hour
Rainfall (mm)	20	17	10

Find out the Effective Rainfall Hyetograph (ERH).

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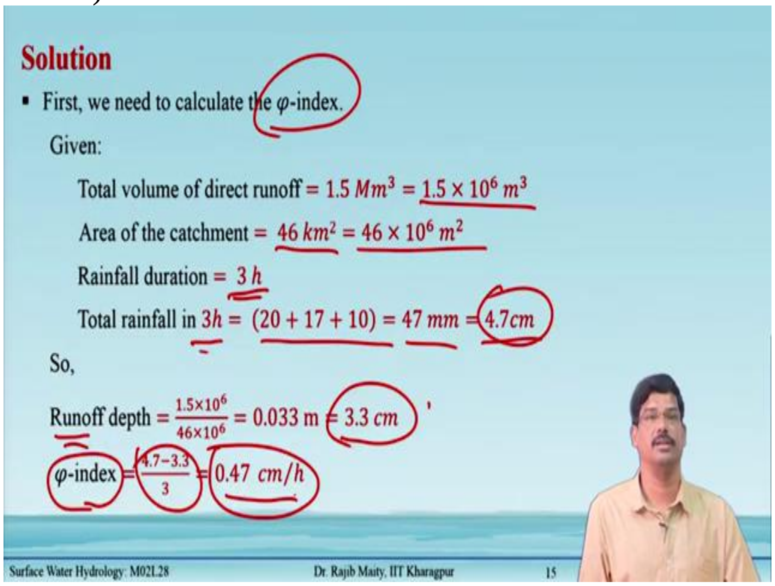

Solution

First, we need to calculate the φ-index.

Given:

Total volume of direct runoff =1.5 Mm^3=1.5×10^6 m3

Area of the catchment = 46 km^2=46× 10^6 m^2

Rainfall duration = 3 h

Total rainfall in 3h = (20+17+10) =47 mm=4.7cm

So,

$$\text{Runoff depth} = \frac{1.5\times10^6}{46\times10^6} = 0.033 \text{ m} = 3.3\ cm$$

$$\varphi\text{-index} = \frac{4.7-3.3}{3} = 0.47\ cm/h$$

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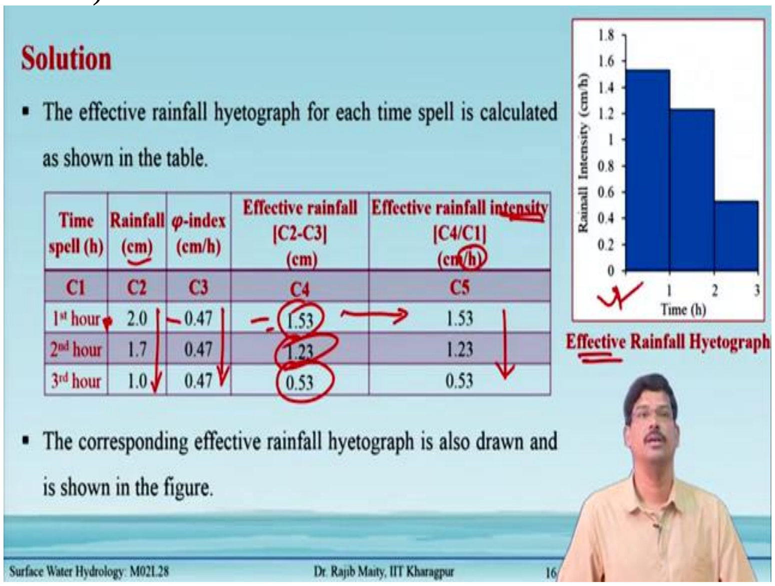

The effective rainfall hyetograph for each time spell is calculated as shown in the table.

Time spell (h)	Rainfall (cm)	φ-index (cm/h)	Effective rainfall [C2-C3] (cm)	Effective rainfall intensity [C4/C1] (cm/h)
C1	C2	C3	C4	C5
1st hour	2.0	0.47	1.53	1.53
2nd hour	1.7	0.47	1.23	1.23
3rd hour	1.0	0.47	0.53	0.53

The corresponding effective rainfall hyetograph is also drawn and is shown in figure 4.

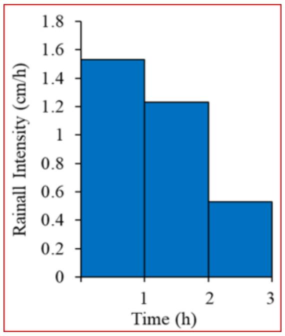

Fig.4 shows the ERH of example 28.1

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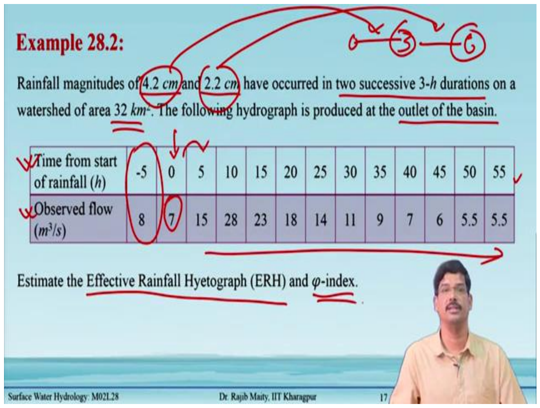

Example 28.2:

Rainfall magnitudes of 4.2 *cm* and 2.2 *cm* have occurred in two successive 3-*h* durations on a watershed of area 32 km^2. The following hydrograph is produced at the outlet of the basin.

Time from start of rainfall (h)	-5	0	5	10	15	20	25	30	35	40	45	50	55
Observed flow (m^3/s)	8	7	15	28	23	18	14	11	9	7	6	5.5	5.5

Estimate the Effective Rainfall Hyetograph (ERH) and φ-index.

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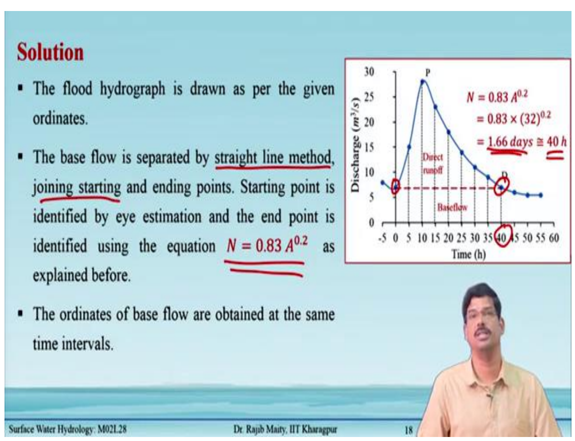

Solution

The flood hydrograph is drawn as per the given ordinates shown in fig.5.

The base flow is separated by the straight-line method, joining starting and ending points. The starting point is identified by eye estimation and the endpoint is identified using the equation N=0.8 $A^{0.2}$ as explained before.

The ordinates of baseflow are obtained at the same time intervals.

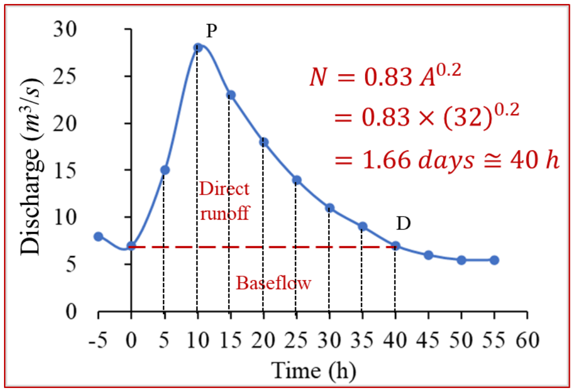

Fig.5 shows the flood hydrograph of example 28.2

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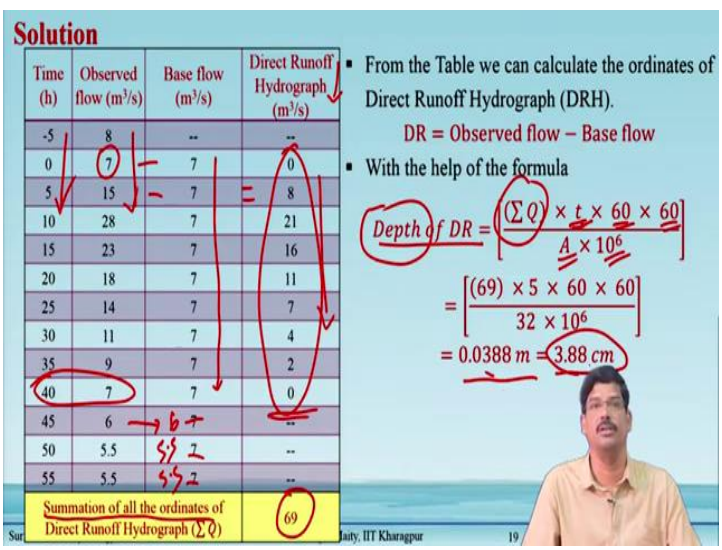

Time (h)	Observed flow (m^3/s)	Base flow (m^3/s)	Direct Runoff Hydrograph (m^3/s)
-5	8	--	--
0	7	7	0
5	15	7	8
10	28	7	21
15	23	7	16
20	18	7	11
25	14	7	7
30	11	7	4
35	9	7	2
40	7	7	0
45	6	7	--
50	5.5	7	--
55	5.5	7	--
Summation of all the ordinates of Direct Runoff Hydrograph ($\sum Q$)			69

- From the Table we can calculate the ordinates of Direct Runoff Hydrograph (DRH).

$$\text{DR} = \text{Observed flow} - \text{Base flow}$$

- With the help of the formula

$$Depth\ of\ DR = \left[\frac{(\sum Q) \times t \times 60 \times 60}{A \times 10^6}\right]$$

$$= \left[\frac{(69) \times 5 \times 60 \times 60}{32 \times 10^6}\right]$$

$$= 0.0388\ m = 3.88\ cm$$

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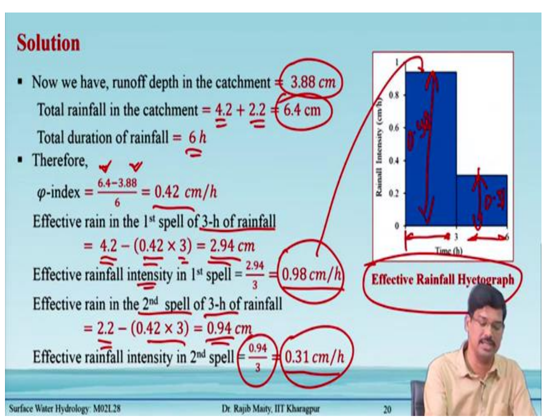

- Now we have, runoff depth in the catchment $= 3.88\ cm$

  Total rainfall in the catchment $= 4.2 + 2.2 = 6.4$ cm

  Total duration of rainfall $= 6\ h$
- Therefore,

  φ-index $= \frac{6.4-3.88}{6} = 0.42\ cm/h$

  Effective rain in the 1st spell of 3-h of rainfall

  $= 4.2 - (0.42 \times 3) = 2.94\ cm$

  Effective rainfall intensity in 1st spell $= \frac{2.94}{3} = 0.98\ cm/h$

  Effective rain in the 2nd spell of 3-h of rainfall

  $= 2.2 - (0.42 \times 3) = 0.94\ cm$

  Effective rainfall intensity in 2nd spell $= \frac{0.94}{3} = 0.31\ cm/h$

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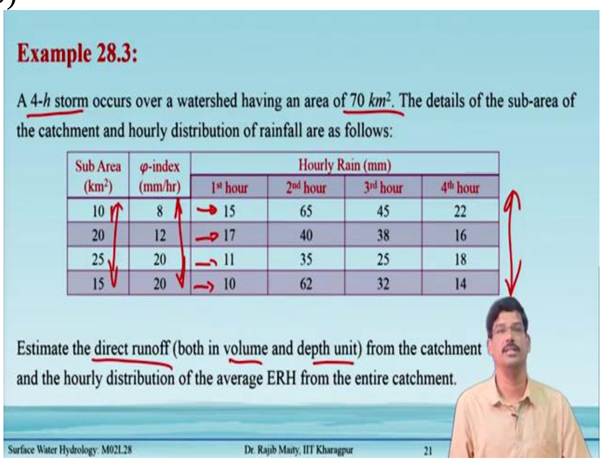

Example 28.3:

A 4-*h* storm occurs over a watershed having an area of 70 km^2. The details of the sub-area of the catchment and hourly distribution of rainfall are as follows:

Sub Area (km^2)	φ-index (mm/hr)	Hourly Rain (mm)			
		1st hour	2nd hour	3rd hour	4th hour
10	8	15	65	45	22
20	12	17	40	38	16
25	20	11	35	25	18
15	20	10	62	32	14

Estimate the direct runoff (both in volume and depth unit) from the catchment and the hourly distribution of the average ERH from the entire catchment.

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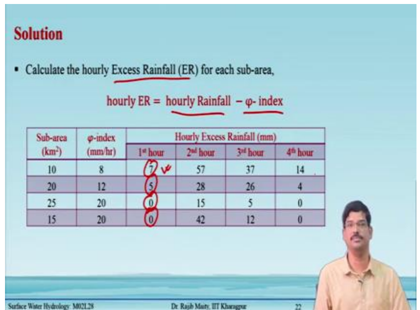

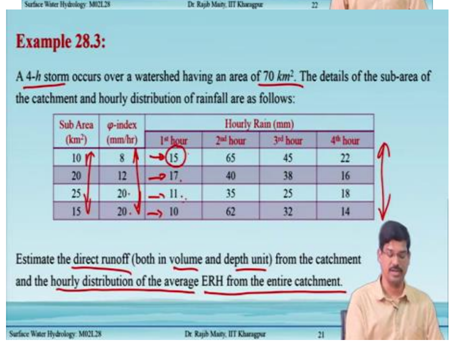

Solution

- Calculate the hourly Excess Rainfall (ER) for each sub-area,

$$\text{hourly ER} = \text{hourly Rainfall} - \varphi\text{- index}$$

Sub-area (km^2)	φ-index (mm/hr)	Hourly Excess Rainfall (mm)			
		1st hour	2nd hour	3rd hour	4th hour
10	8	7	57	37	14
20	12	5	28	26	4
25	20	0	15	5	0
15	20	0	42	12	0

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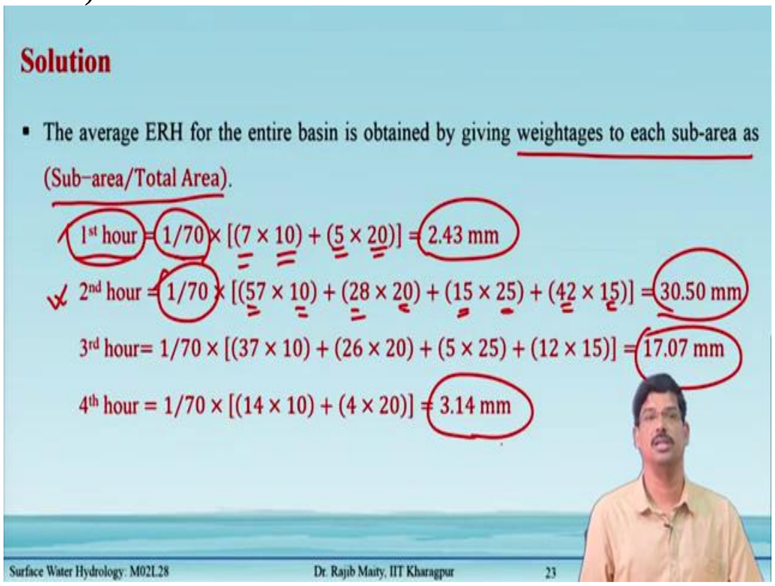

The average ERH for the entire basin is obtained by giving weightages to each sub-area as (Sub−area/Total Area).

1^{st} hour $= 1/70 \times [(7 \times 10) + (5 \times 20)] = 2.43$ mm

2^{nd} hour $= 1/70 \times [(57 \times 10) + (28 \times 20) + (15 \times 25) + (42 \times 15)] = 30.50$ mm

3^{rd} hour $= 1/70 \times [(37 \times 10) + (26 \times 20) + (5 \times 25) + (12 \times 15)] = 17.07$ mm

4^{th} hour $= 1/70 \times [(14 \times 10) + (4 \times 20)] = 3.14$ mm

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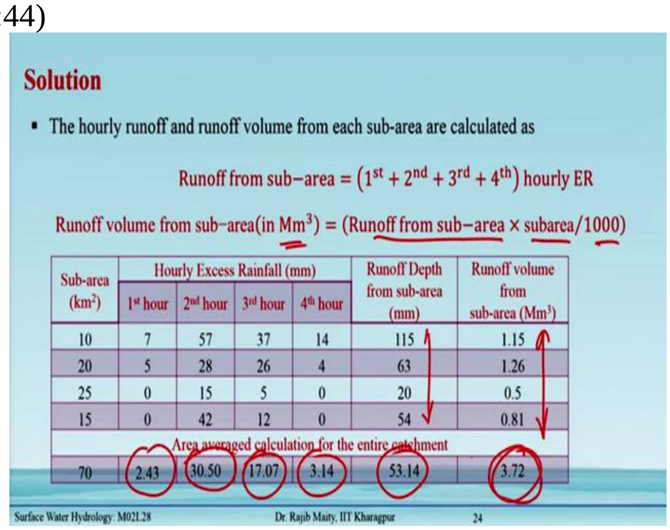

The hourly runoff and runoff volume from each sub-area are calculated as

$$\text{Runoff from sub}-\text{area} = \left(1^{st} + 2^{nd} + 3^{rd} + 4^{th}\right)\text{ hourly ER}$$

$$\text{Runoff volume from sub}-\text{area}(\text{in Mm}^3) = (\text{Runoff from sub}-\text{area} \times \text{subarea}/1000)$$

Sub-area (km^2)	Hourly Excess Rainfall (mm)				Runoff Depth from sub-area (mm)	Runoff volume from sub-area (Mm^3)
	1st hour	2nd hour	3rd hour	4th hour		
10	7	57	37	14	115	1.15
20	5	28	26	4	63	1.26
25	0	15	5	0	20	0.5
15	0	42	12	0	54	0.81
Area averaged calculation for the entire catchment						
70	2.43	30.50	17.07	3.14	53.14	3.72

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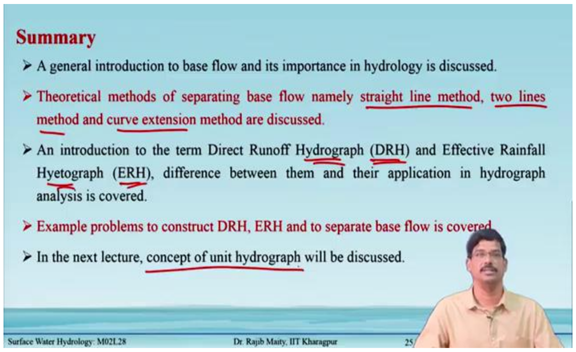

Summary

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

- A general introduction to base flow and its importance in hydrology is discussed.
- Theoretical methods of separating base flow namely the straight-line method, two lines method, and curve extension method are discussed.
- An introduction to the term Direct Runoff Hydrograph (DRH) and Effective Rainfall Hyetograph (ERH), the difference between them and their application in hydrograph analysis is covered.
- Example problems to construct DRH, ERH, and separate base flow are covered.
- In the next lecture, the concept of unit hydrograph will be discussed.