Surface Water Hydrology
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Lecture – 31
Derivation of Unit Hydrograph

The derivation of unit hydrograph from the field data that we should discuss in this particular lecture.

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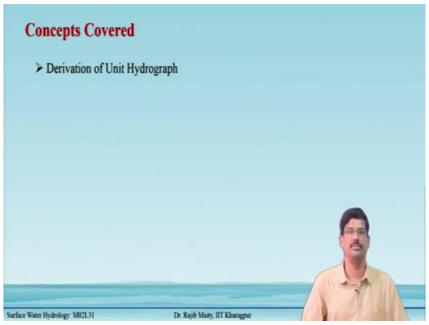

In the concept cover, we are discussing the derivation of unit hydrograph in this particular thing. But there are two parts one we can it can be from the isolated storm or it can be from the complex storm also.

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The outline of this lecture goes like this first some introductions. Derivation of the unit hydrograph is possible from the isolated storm and the complex storm also, and we will see some of the example problems before going to the summary.

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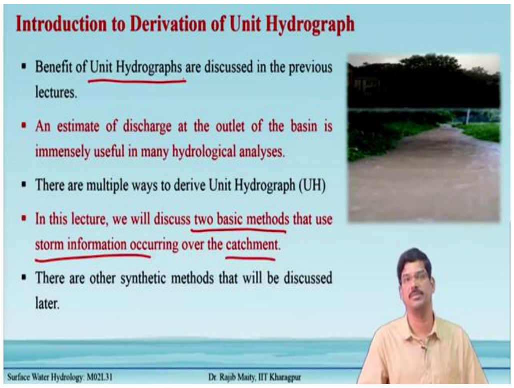

Introduction to Derivation of Unit Hydrograph

The benefit of the unit hydrograph is discussed in the previous lecture. An estimate of the discharge of the outlet of the basin is immensely useful as you know for different hydrological analyses.

And there are multiple ways to derive this unit hydrograph. And in this lecture, we will discuss two basic methods, two basic methods will be discussed in this one from is that uses the storm information occurring over the catchment. And there are other synthetic methods are also there.

So, here whatever is there are some rainfalls when it occurs some catchment gets one runoff hydrograph at the outlet. Now, every time the nature, magnitude, duration, and intensity of the rainfall will change, depending on that get the different types of hydrographs at the outlet.

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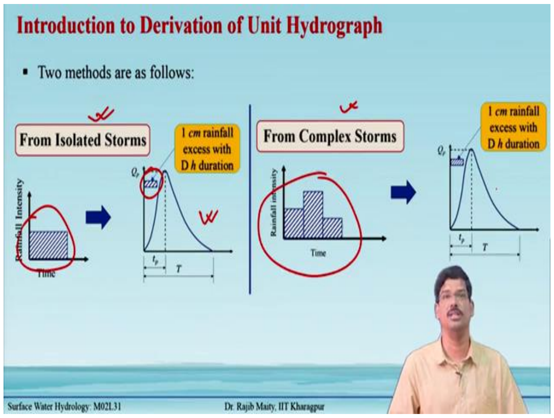

There are two basic methods, that will be utilized here and both are from the field data. Field data comes in the, either it can be the field data of the isolated storms or the field data from the complex storms. So, in the isolated storm over time the rainfall intensity is constant.

The rainfall excess information is available from the raw field data and we have to deduct that initial loss and then get unit hydrograph information. Similarly, for a complex storm also sometimes may not get that isolated storm, we can get the storms in this nature. From here also we can reach a unit hydrograph which is up to D hour unit hydrograph.

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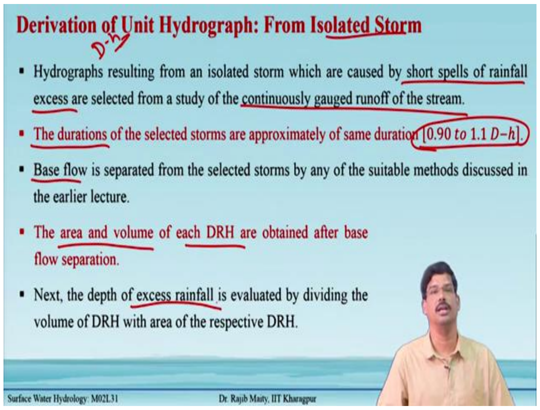

The hydrographs resulting from an isolated storm are caused by short spells of the rainfall excess that are selected from, for the from a study of the continuously gazed, continuously grazed runoff of a storm. So, there are, there are different such events are there, so, we just picked out that information.

So, when we picked out that information of the isolated storms, that time we have to be, because the duration of this every selected storm should be more or less same, more or less equal duration we can maximum allow that 10 percent of the variation. So, 0.9 D to 1.1 D is how the variations should be. So basically, we are targeting to develop 1 D our unit hydrograph.

Next, the base flow is separated from the selected storms by any of the suitable methods, the base flow separation method, there are three methods out there. So, using any one of them separate the base flow. So, after separating the base flow get the direct runoff hydrograph from there.

So, the area and the volume of each direct runoff hydrograph are obtained after the base flow separation is done. Next, the depth of the excess rainfall is evaluated by dividing the volume of the direct runoff hydrograph by the area of the respective DRH.

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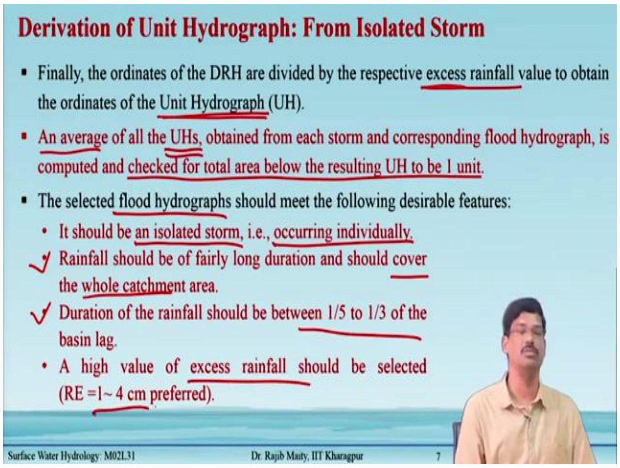

Finally, the ordinates of the DRH are divided by the respective excess rainfall value to obtain the ordinates of the Unit Hydrograph (UH).

An average of all the UHs, obtained from each storm and corresponding flood hydrograph, is computed and checked for the total area below the resulting UH to be 1 unit.

The selected flood hydrographs should meet the following desirable features:

- It should be an isolated storm, i.e., occurring individually.
- Rainfall should be of fairly long duration and should cover the whole catchment area.
- The duration of the rainfall should be between 1/5 to 1/3 of the basin lag.
- A high value of excess rainfall should be selected (RE =1~ 4 cm preferred).

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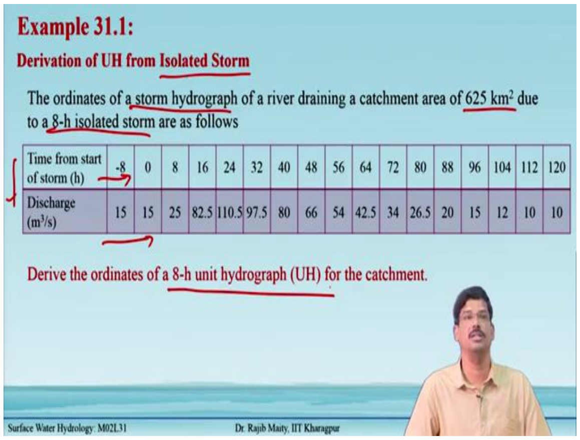

Example 31.1:

Derivation of UH from Isolated Storm

The ordinates of a storm hydrograph of a river draining a catchment area of 625 km^2 due to an 8-h isolated storm are as follows

Time from start of storm (h)	-8	0	8	16	24	32	40	48	56	64	72	80	88	96	104	112	120
Discharge (m^3/s)	15	15	25	82.5	110.5	97.5	80	66	54	42.5	34	26.5	20	15	12	10	10

Derive the ordinates of an 8-h unit hydrograph (UH) for the catchment.

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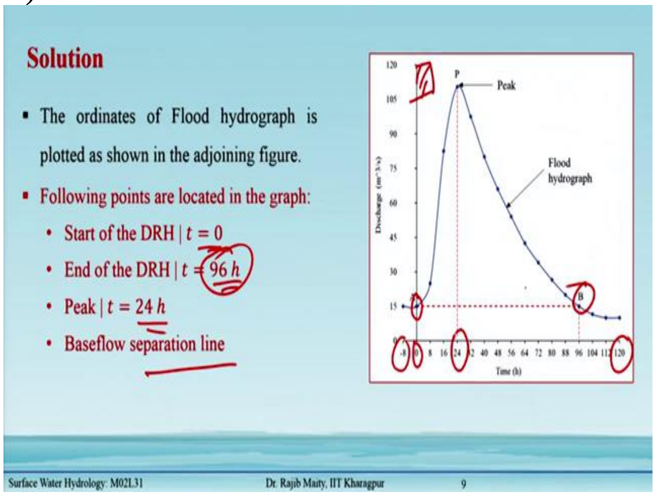

Solution

The ordinates of the Flood hydrograph are plotted as shown in the figure 1.

The following points are located in the graph:

Start of the DRH | t=0

End of the DRH | t=96 h

Peak | t=24 h

Baseflow separation line

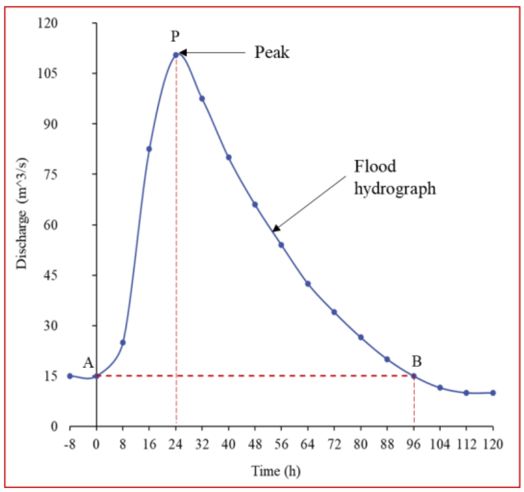

Fig.1 shows the derivation of UH from isolated storm of example 31.1

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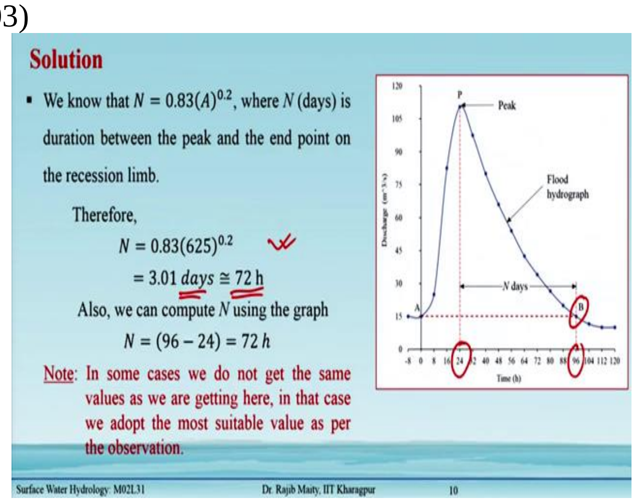

We know that $N=0.83(A)^{0.2}$, where N (days) is the duration between the peak and the endpoint on the recession limb.

Therefore,

$$N=0.83(625)^{0.2}$$

$$=3.01\ days \cong 72\ \text{h}$$

Also, we can compute N using the graph

$$N=(96-24)=72\ h$$

It may be noted that in some cases we do not get the same values as we are getting here, in that case, we adopt the most suitable value as per the observation.

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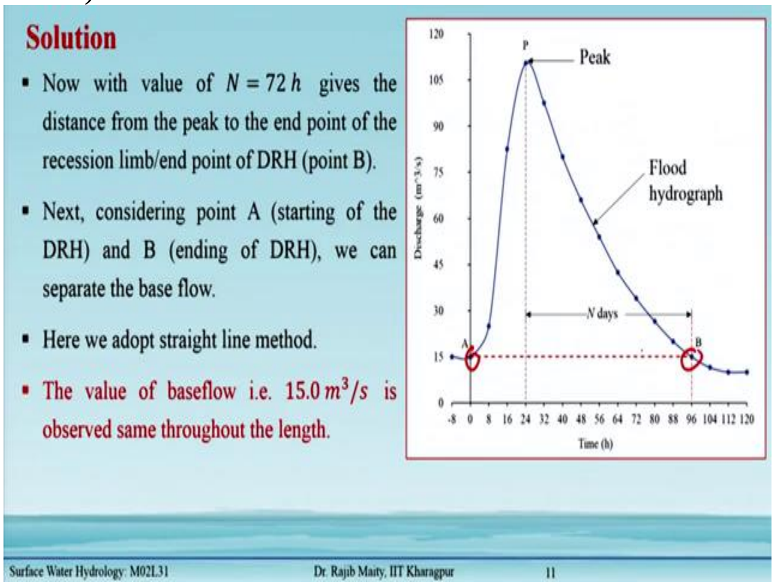

Now with the value of $N=72\ h$ gives the distance from the peak to the endpoint of the recession limb/endpoint of DRH (point B).

Next, considering points A (starting of the DRH) and B (ending of DRH), we can separate the base flow.

Here we adopt the straight-line method.

The value of baseflow i.e. 15.0 m^3/s is observed the same throughout the length.

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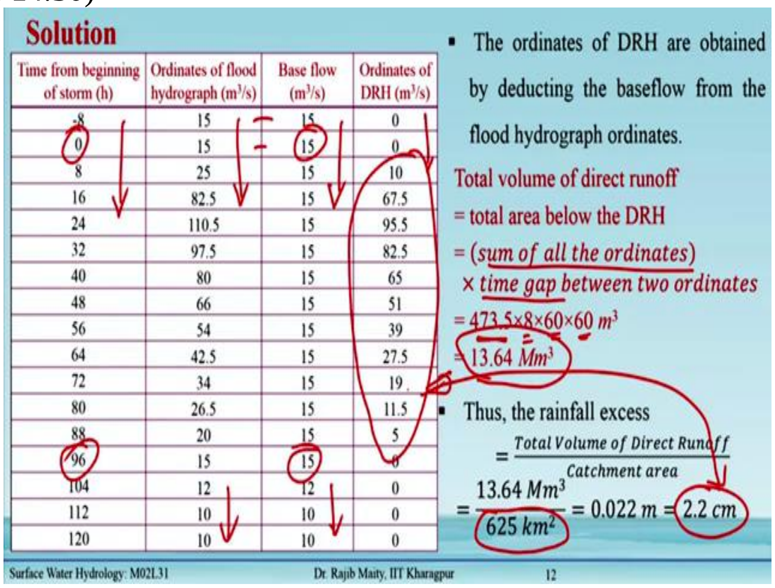

Time from beginning of storm (h)	Ordinates of flood hydrograph (m^3/s)	Base flow (m^3/s)	Ordinates of DRH (m^3/s)
-8	15	15	0
0	15	15	0
8	25	15	10
16	82.5	15	67.5
24	110.5	15	95.5
32	97.5	15	82.5
40	80	15	65
48	66	15	51
56	54	15	39
64	42.5	15	27.5
72	34	15	19
80	26.5	15	11.5
88	20	15	5
96	15	15	0
104	12	12	0
112	10	10	0
120	10	10	0

The ordinates of DRH are obtained by deducting the baseflow from the flood hydrograph ordinates’

The total volume of direct runoff

= total area below the DRH = $(sum\ of\ all\ the\ ordinates) \times time\ gap\ between\ two\ ordinates$

= 473.5×8×60×60 m^3

= 13.64 Mm^3

Thus, the rainfall excess

= $(Total\ Volume\ of\ Direct\ Runoff)$ / $(Catchment\ area)$

= (13.64 Mm^3) / (625 km^2)=0.022 m=2.2 cm

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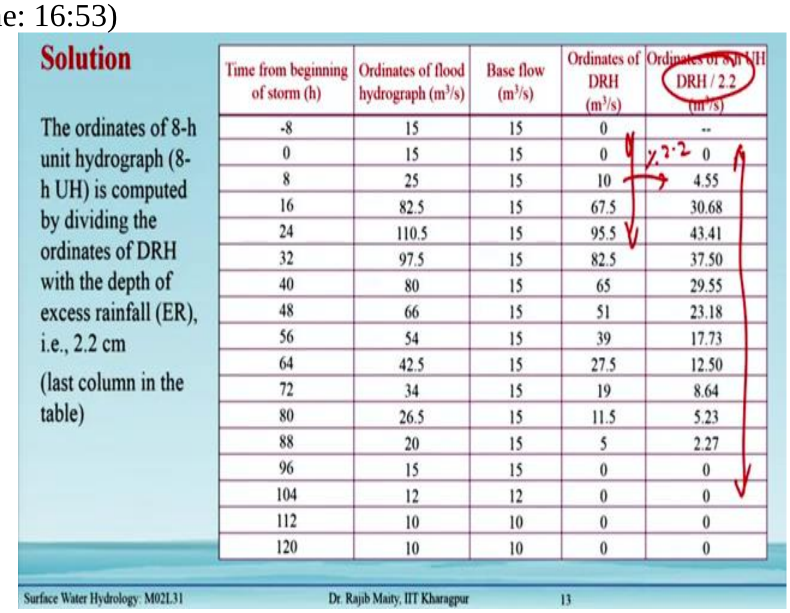

Time from beginning of storm (h)	Ordinates of flood hydrograph (m^3/s)	Base flow (m^3/s)	Ordinates of DRH (m^3/s)	Ordinates of 8-h UH DRH / 2.2 (m^3/s)
-8	15	15	0	--
0	15	15	0	0
8	25	15	10	4.55
16	82.5	15	67.5	30.68
24	110.5	15	95.5	43.41
32	97.5	15	82.5	37.50
40	80	15	65	29.55
48	66	15	51	23.18
56	54	15	39	17.73
64	42.5	15	27.5	12.50
72	34	15	19	8.64
80	26.5	15	11.5	5.23
88	20	15	5	2.27
96	15	15	0	0
104	12	12	0	0
112	10	10	0	0
120	10	10	0	0

The ordinates of the 8-h unit hydrograph (8-h UH) is computed by dividing the ordinates of DRH with the depth of excess rainfall (ER), i.e., 2.2 cm (last column in the table)

Time from beginning of storm (h)	Ordinates of flood hydrograph (m^3/s)	Base flow (m^3/s)	Ordinates of DRH (m^3/s)	Ordinates of 8-h UH DRH / 2.2 (m^3/s)
-8	15	15	0	--
0	15	15	0	0
8	25	15	10	4.55
16	82.5	15	67.5	30.68
24	110.5	15	95.5	43.41
32	97.5	15	82.5	37.50
40	80	15	65	29.55
48	66	15	51	23.18
56	54	15	39	17.73
64	42.5	15	27.5	12.50
72	34	15	19	8.64
80	26.5	15	11.5	5.23
88	20	15	5	2.27
96	15	15	0	0
104	12	12	0	0
112	10	10	0	0
120	10	10	0	0

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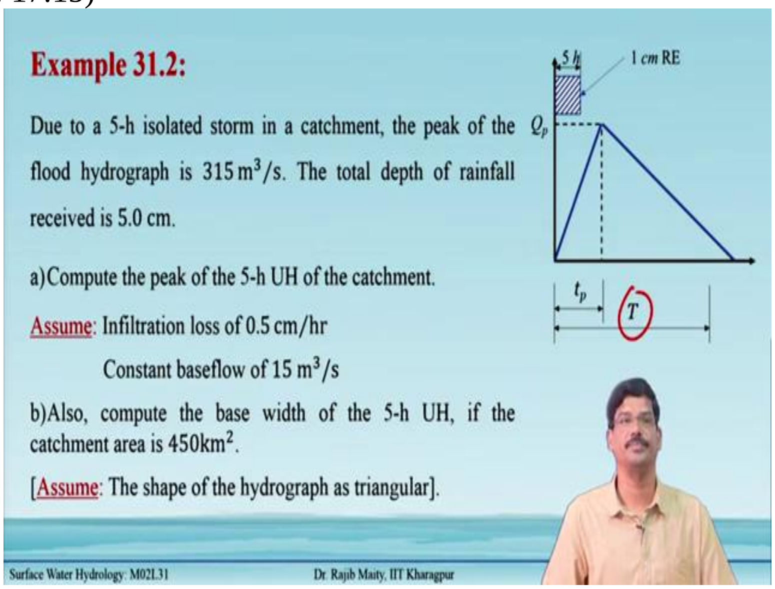
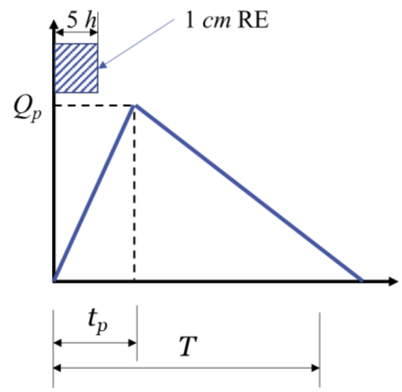


Example 31.2:

Due to a 5-h isolated storm in a catchment, the peak of the flood hydrograph is 315 m^3/s. The total depth of rainfall received is 5.0 cm.



a) Compute the peak of the 5-h UH of the catchment.

Assume: Infiltration loss of 0.5 cm/hr

Constant baseflow of 15 m^3/s

b) Also, compute the base width of the 5-h UH, if the catchment area is 450km^2.

[Assume: The shape of the hydrograph as triangular].

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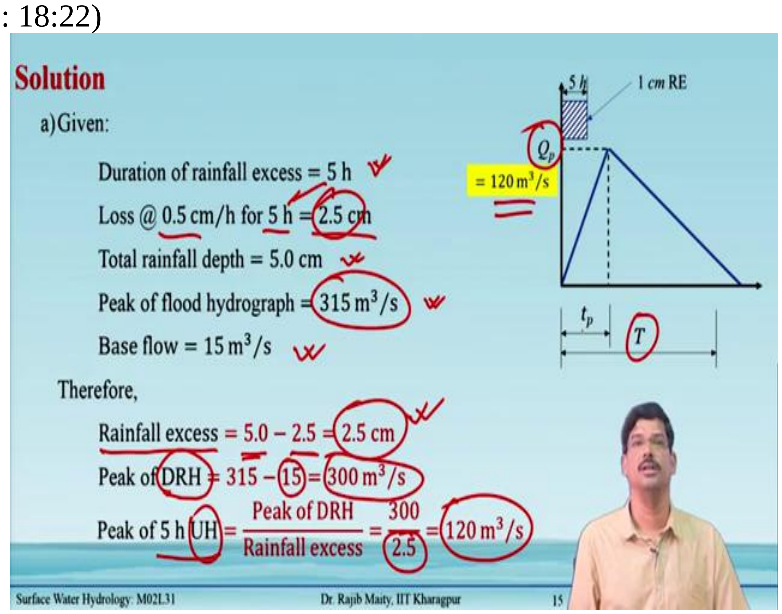

a) Given:

Duration of rainfall excess =5 h

Loss @ 0.5 cm/h for 5 h=2.5 cm

Total rainfall depth =5.0 cm

Peak of flood hydrograph =315 m^3/s

Base flow=15 m^3/s

Therefore,

Rainfall excess=5.0−2.5=2.5 cm

Peak of DRH =315−15=300 m^3/s

"Peak of " 5 h" UH"=(Peak of DRH)/(Rainfall excess)=300/2.5=120 m^3/s

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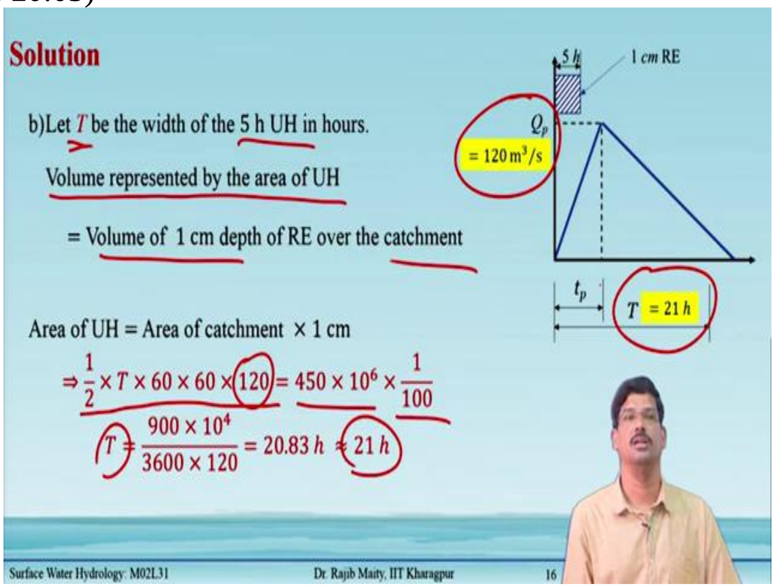

b) Let T be the width of the 5 h UH in hours.

The volume represented by the area of UH

= Volume of 1 cm depth of RE over the catchment

Area of UH = Area of catchment × 1 cm

$$\Rightarrow \frac{1}{2} \times T \times 60 \times 60 \times 120 = 450 \times 10^6 \times \frac{1}{100}$$

$$T = \frac{900 \times 10^4}{3600 \times 120} = 20.83\ h\ \approx 21\ h$$

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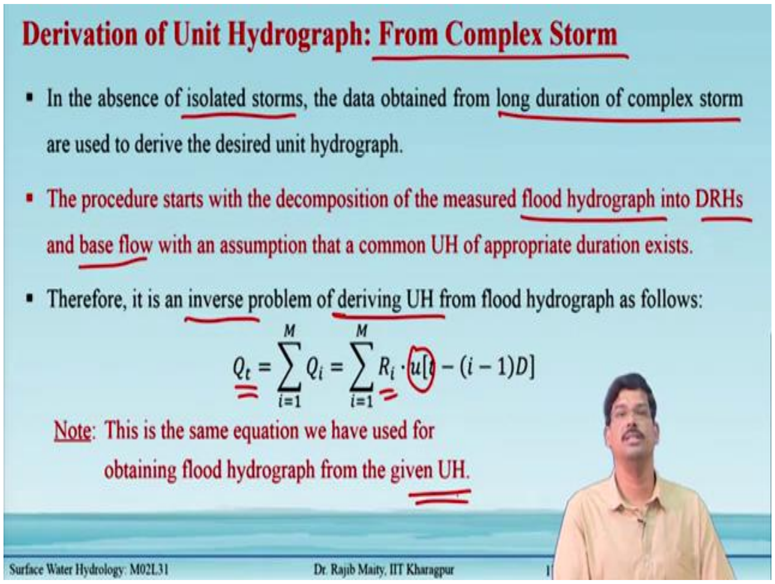

Derivation of Unit Hydrograph: From Complex Storm

the absence of isolated storms, the data obtained from the long duration of the complex storm are used to derive the desired unit hydrograph.

The procedure starts with the decomposition of the measured flood hydrograph into DRHs and base flow with an assumption that a common UH of appropriate duration exists.

Therefore, it is an inverse problem of deriving UH from flood hydrograph as follows:

$$Q_t = \sum_{i=1}^{M} Q_i = \sum_{i=1}^{M} R_i \cdot u[t - (i-1)D]$$

It may be noted that this is the same equation we have used for obtaining flood hydrograph from the given UH.

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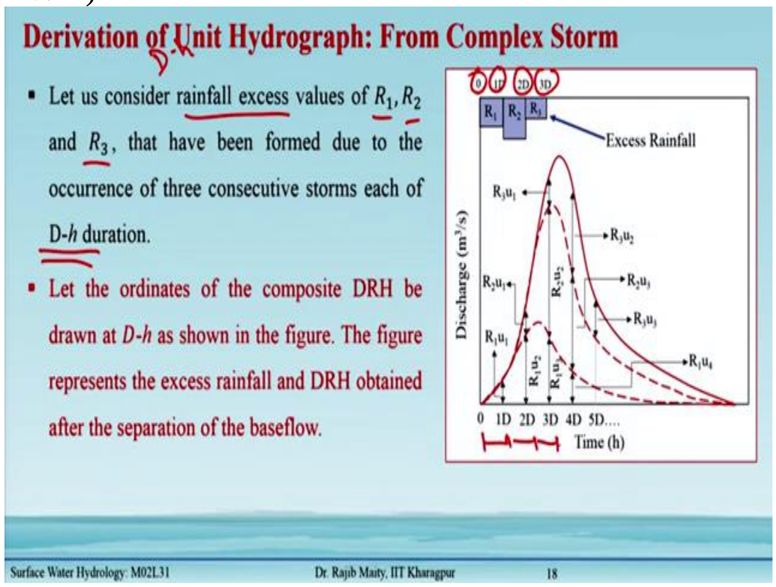

Let us consider rainfall excess values of R_1, R_2 and R_3, that have been formed due to the occurrence of three consecutive storms each of D-h duration as shown in fig.2.

Let the ordinates of the composite DRH be drawn at *D*-h as shown in the figure2.

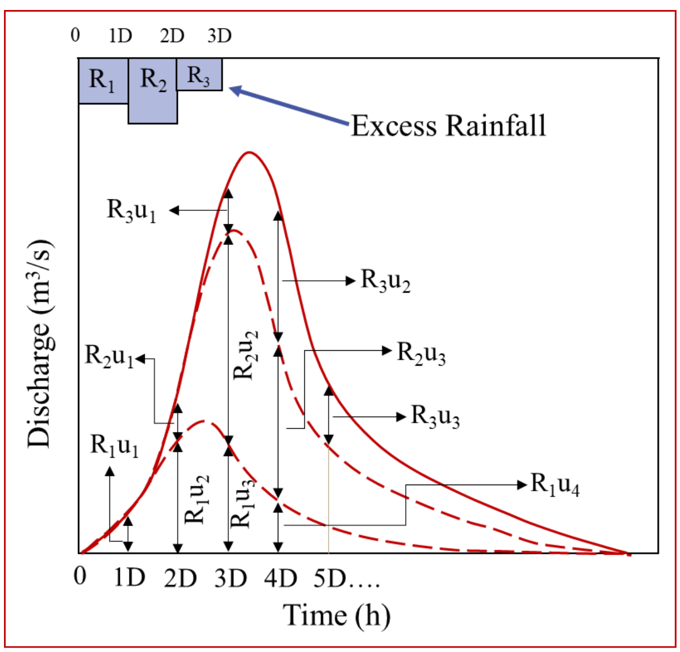

Fig.2 represents the excess rainfall and DRH obtained after the separation of the baseflow.

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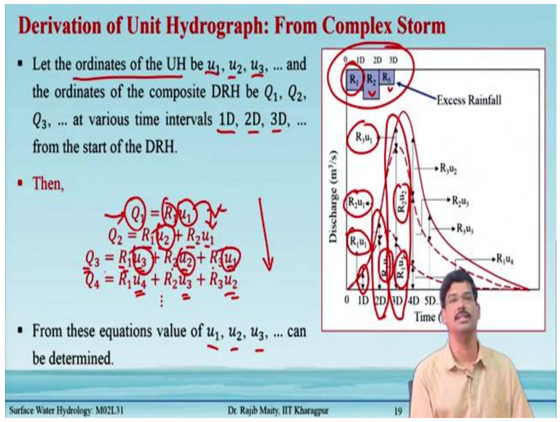

Let the ordinates of the UH be u_1, u_2, u_3, … and the ordinates of the composite DRH be Q_1, Q_2, Q_3, … at various time intervals 1D, 2D, 3D, … from the start of the DRH.

Then

$$
\begin{aligned}
Q_1 &= R_1u_1\\
Q_2 &= R_1u_2 + R_2u_1\\
Q_3 &= R_1u_3 + R_2u_2 + R_3u_1\\
Q_4 &= R_1u_4 + R_2u_3 + R_3u_2\\
&\vdots
\end{aligned}
$$

From these equations value of u_1, u_2, u_3, … can be determined.

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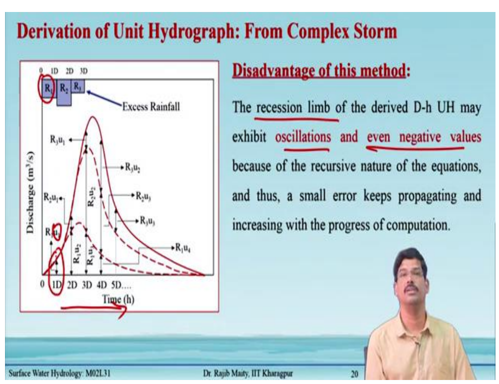

The disadvantage of this method:

The recession limb of the derived D-h UH may exhibit oscillations and even negative values because of the recursive nature of the equations, and thus, a small error keeps propagating and increasing with the progress of computation.

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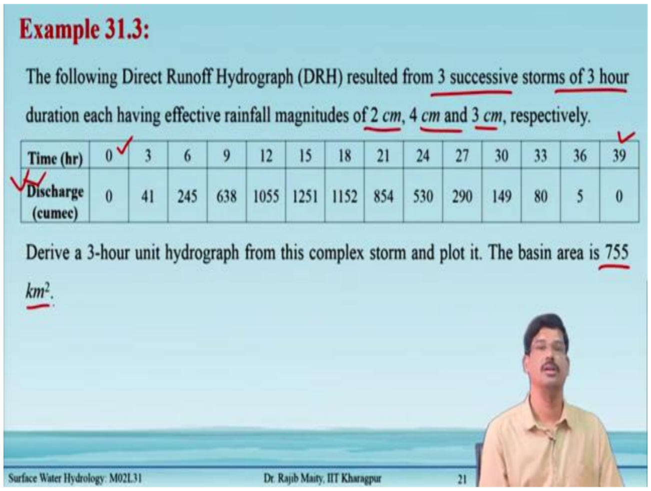

Example 31.3:

The following Direct Runoff Hydrograph (DRH) resulted from 3 successive storms of 3-hour duration each having effective rainfall magnitudes of 2 *cm*, 4 *cm*, and 3 *cm*, respectively.

Time (hr)	0	3	6	9	12	15	18	21	24	27	30	33	36	39
Discharge (cumec)	0	41	245	638	1055	1251	1152	854	530	290	149	80	5	0

Derive a 3-hour unit hydrograph from this complex storm and plot it. The basin area is 755 km^2.

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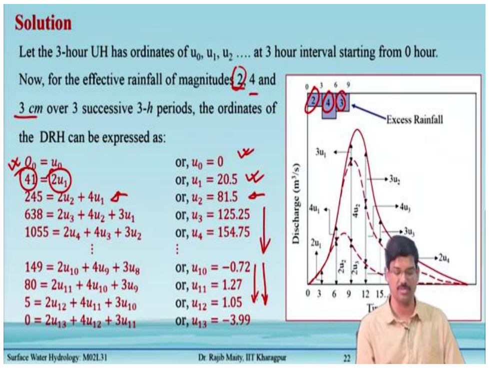

Solution

Let the 3-hour UH have ordinates of u_0, u_1, u_2 …. at a 3-hour interval starting from 0 hours.

Now, for the effective rainfall of magnitudes 2, 4, and 3 *cm* over 3 successive 3-*h* periods, the ordinates of the DRH can be expressed as:

$$
\begin{array}{ll}
Q_0 = u_0 & \text{or, } u_0 = 0 \\
41 = 2u_1 & \text{or, } u_1 = 20.5 \\
245 = 2u_2 + 4u_1 & \text{or, } u_2 = 81.5 \\
638 = 2u_3 + 4u_2 + 3u_1 & \text{or, } u_3 = 125.25 \\
1055 = 2u_4 + 4u_3 + 3u_2 & \text{or, } u_4 = 154.75 \\
\vdots & \vdots \\
149 = 2u_{10} + 4u_9 + 3u_8 & \text{or, } u_{10} = -0.72 \\
80 = 2u_{11} + 4u_{10} + 3u_9 & \text{or, } u_{11} = 1.27 \\
5 = 2u_{12} + 4u_{11} + 3u_{10} & \text{or, } u_{12} = 1.05 \\
0 = 2u_{13} + 4u_{12} + 3u_{11} & \text{or, } u_{13} = -3.99
\end{array}
$$

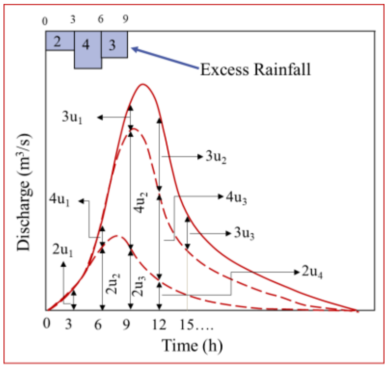

Fig.3 shows the ordinate of the DRH of example 31.3

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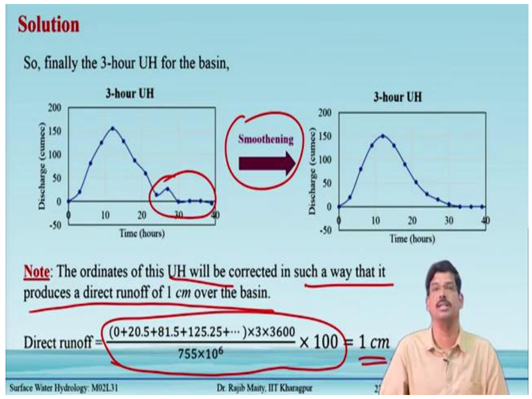

So, finally, the 3-hour UH for the basin,

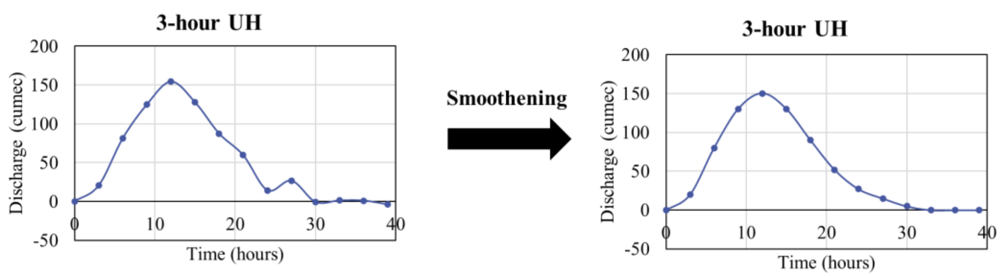

Fig.4 shows the 3h UH of example 31.3

It may be noted that the ordinates of this UH will be corrected in such a way that it produces a direct runoff of 1 *cm* over the basin.

$$\text{Direct runoff} = \frac{(0+20.5+81.5+125.25+\cdots)\times 3\times 3600}{755\times 10^{6}} \times 100 = 1\ cm$$

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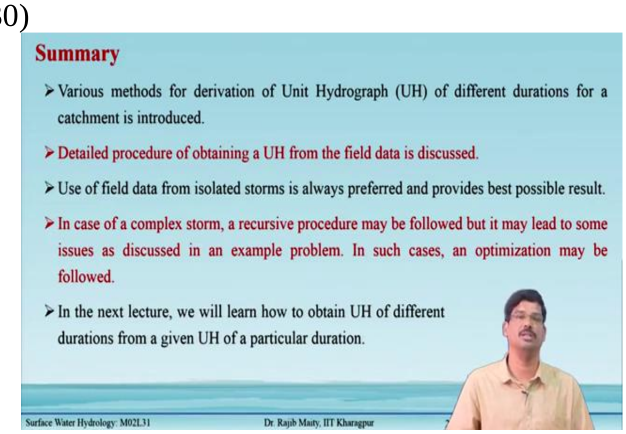

Summary

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

- Various methods for the derivation of Unit Hydrograph (UH) of different durations for a catchment is introduced.
- Detailed procedure of obtaining a UH from the field data is discussed.
- The use of field data from isolated storms is always preferred and provides the best possible result.
- In the case of a complex storm, a recursive procedure may be followed but it may lead to some issues as discussed in an example problem. In such cases, an optimization may be followed.
- In the next lecture, we will learn how to obtain UH of different durations from a given UH of a particular duration.