Surface Water Hydrology
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Lecture 16
Infiltration Indices

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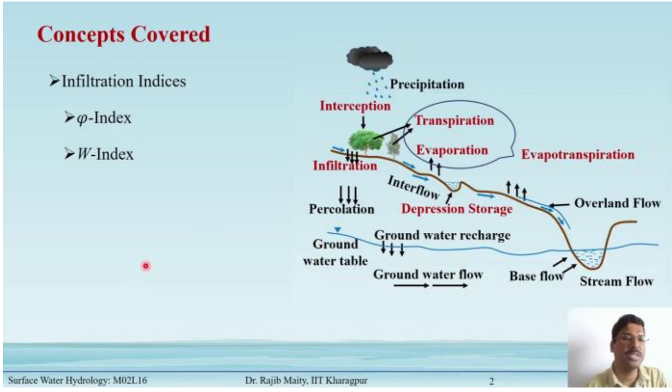

In this specific lecture, we will discuss the infiltration indices. So, under this concept cover, two important concepts that will be covered one is **φ** index and W-index.

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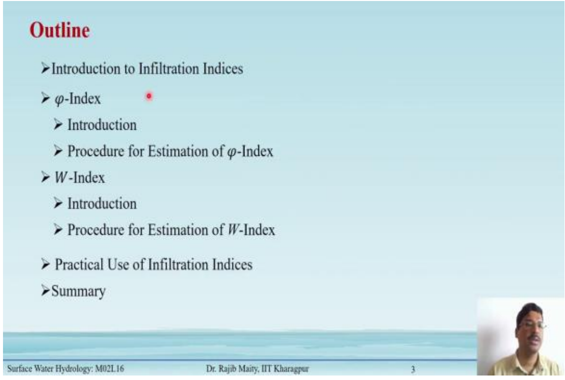

The outline of this lecture goes as follows an introduction to Infiltration indices and then we take **φ** index and W-index one after another and we will also give their introduction then the procedure to estimation of **φ** index and W-index will be discussed one after another. Then some brief discussion on the practical use of Infiltration indices before we proceed to summary.

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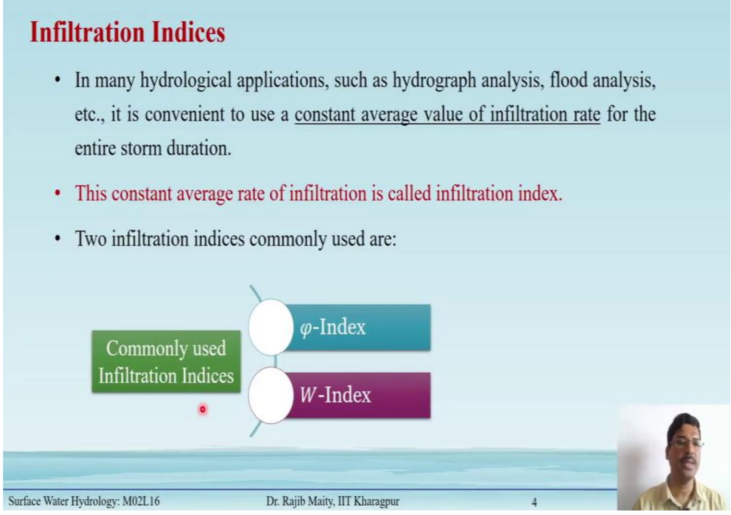

Infiltration Indices

In many hydrological applications, such as hydrograph analysis, flood analysis, etc., it is convenient to use a constant average value of infiltration rate for the entire storm duration. This constant average rate of infiltration is called the infiltration index. So, there are two commonly used indices are as follows, one is $\boldsymbol{\varphi}$ index and the other one is W-index.

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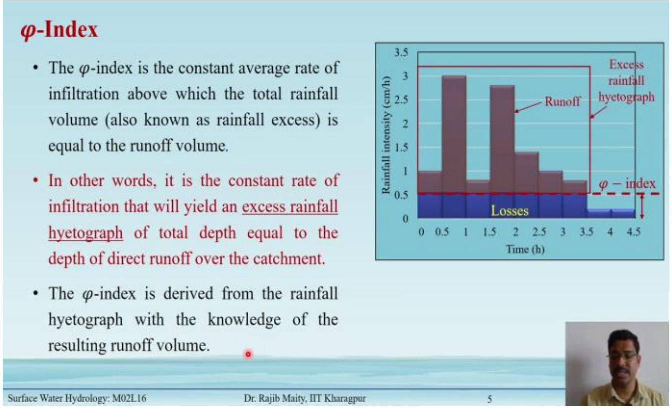

$\boldsymbol{\varphi}$-Index

The φ-index is the constant average rate of infiltration above which the total rainfall volume (also known as rainfall excess) is equal to the runoff volume. In other words, it is the constant rate of infiltration that will yield an excess rainfall hyetograph of total depth equal to the depth of direct runoff over the catchment. The φ-index is derived from the rainfall hyetograph with the knowledge of the resulting runoff volume.

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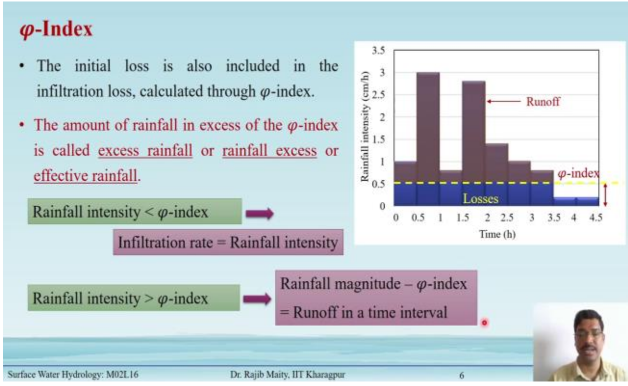

The initial loss is also included in the infiltration loss, calculated through φ-index. The amount of rainfall in excess of the φ-index is called excess rainfall or rainfall excess of effective rainfall.

Rainfall intensity < φ-index

Infiltration rate = Rainfall intensity

Rainfall intensity > φ-index

Rainfall magnitude – φ-index = Runoff in a time interval

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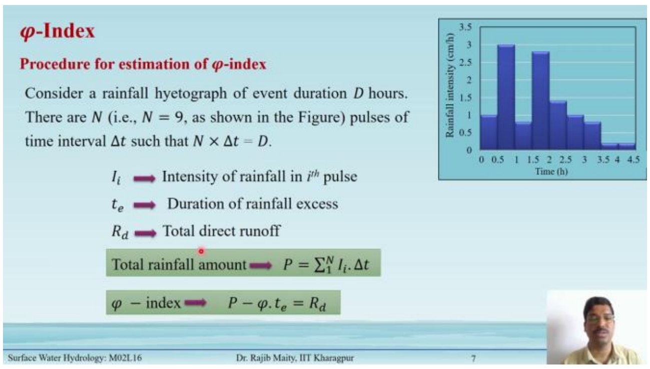

Procedure for estimation of $\boldsymbol{\varphi}$-index

Consider a rainfall hyetograph of event duration D hours. There are N (i.e., N=9, as shown in Fig. 1) pulses of time interval Δt such that $N \times \Delta t = D$.

I_i = Intensity of rainfall in i^{th} pulse

t_e = Duration of rainfall excess

R_d=Total direct runoff,

Total rainfall amount $\quad P = \sum_1^N I_i . \Delta t$

$$\varphi - \text{index} \qquad P - \varphi . t_e = R_d$$

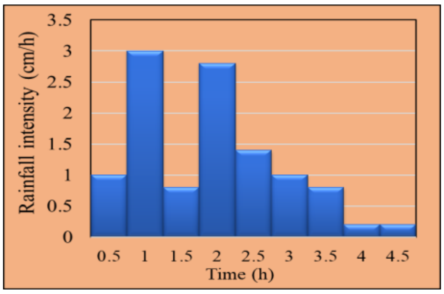

Fig.1 shows the φ index

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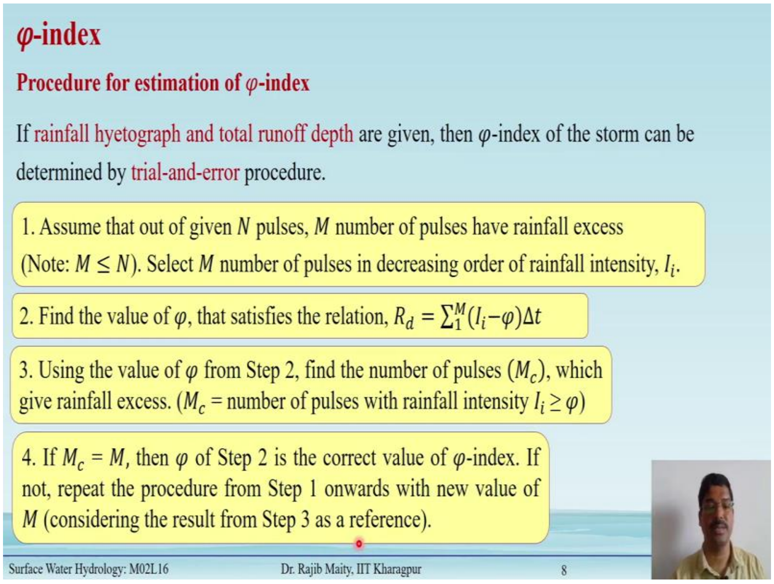

If rainfall hyetograph and total runoff depth are given, then φ-index of the storm can be determined by trial-and-error procedure.

1. Assume that out of given N pulses, M number of pulses have rainfall excess.

(Note: $M \leq N$). Select M number of pulses in decreasing order of rainfall intensity, I_i.

$$R_d = \sum_1^M (I_i - \varphi)\Delta t$$

2. Find the value of φ, that satisfies the

3. Using the value of φ from Step 2, find the number of pulses (M_c), which give rainfall excess. (M_c = number of pulses with rainfall intensity $I_i \geq \varphi$)

4. If $M_c = M$, then φ of Step 2 is the correct value of φ-index. If not, repeat the procedure from Step 1 onwards with the new value of M (considering the result from Step 3 as a reference).

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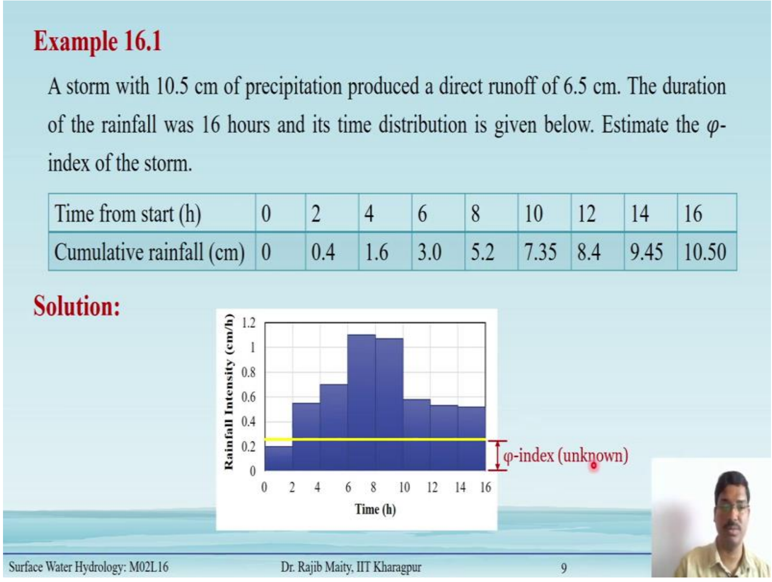

Example 16.1

A storm with 10.5 cm of precipitation produced a direct runoff of 6.5 cm. The duration of the rainfall was 16 hours and its time distribution is given below. Estimate the φ-index of the storm.

Time from start (h)	0	2	4	6	8	10	12	14	16
Cumulative rainfall (cm)	0	0.4	1.6	3.0	5.2	7.35	8.4	9.45	10.50

Solution

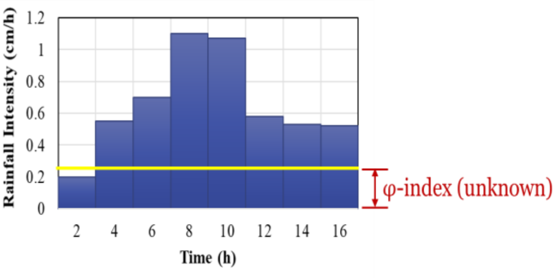

Fig.2 shows the φ index -Example 16.1

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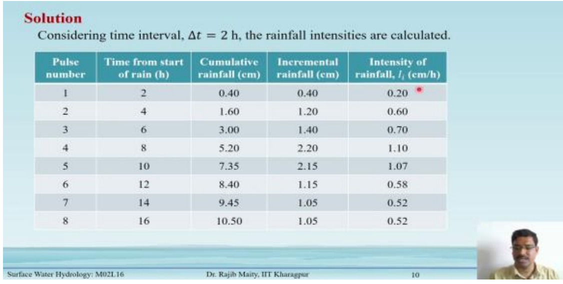

Solution

Considering time interval, Δt = 2 h, the rainfall intensities are calculated.

Pulse number	Time from start of rain (h)	Cumulative rainfall (cm)	Incremental rainfall (cm)	Intensity of rainfall, I_i (cm/h)
1	2	0.40	0.40	0.20
2	4	1.60	1.20	0.60
3	6	3.00	1.40	0.70
4	8	5.20	2.20	1.10
5	10	7.35	2.15	1.07
6	12	8.40	1.15	0.58
7	14	9.45	1.05	0.52
8	16	10.50	1.05	0.52

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Considering time interval, Δt=2 h, the rainfall intensities are calculated

Pulse number	Time from start of rain (h)	Cumulative rainfall (cm)	Incremental rainfall (cm)	Intensity of rainfall, I_i (cm/h)
1	2	0.40	0.40	0.20
2	4	1.60	1.20	0.60
3	6	3.00	1.40	0.70
4	8	5.20	2.20	1.10
5	10	7.35	2.15	1.07
6	12	8.40	1.15	0.58
7	14	9.45	1.05	0.52
8	16	10.50	1.05	0.52

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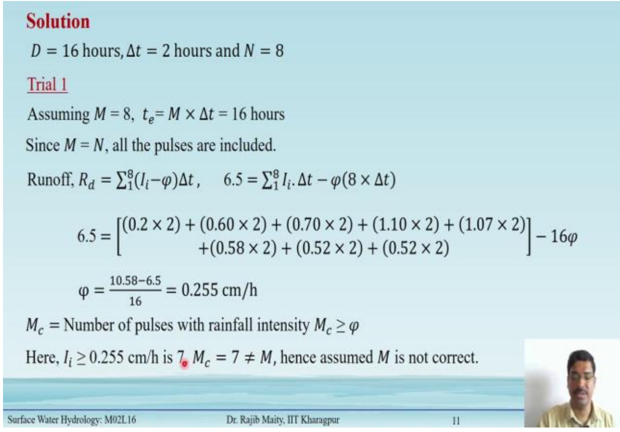

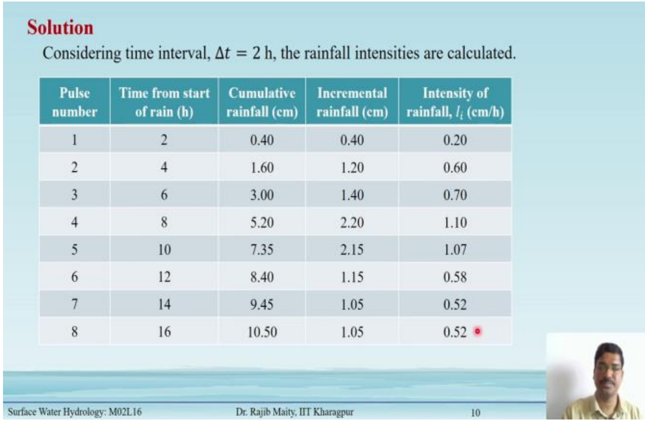

D=16 hours, Δt=2 hours and N=8

<u>Trial 1</u>

Assuming M = 8, t_e= $M \times \Delta t$ = 16 hours

Since M = N, all the pulses are included.

$$\text{Runoff, } R_d = \sum_1^8 (I_i - \varphi)\Delta t, \quad 6.5 = \sum_1^8 I_i.\Delta t - \varphi(8 \times \Delta t)$$

6.5 = [(0.2×2) + (0.60×2) + (0.70×2) + (1.10×2) + (1.07×2) + (0.58×2) + (0.52×2) + (0.52×2)] −16φ

Φ = (10.58−6.5)/16=0.255 cm/h

M_c= Number of pulses with rainfall intensity $M_c \geq \varphi$

Here, $I_i \geq 0.255$ cm/h is 7, M_c=7≠M, hence assumed M is not correct.

Thus, a new value of M =7 in the next trial.

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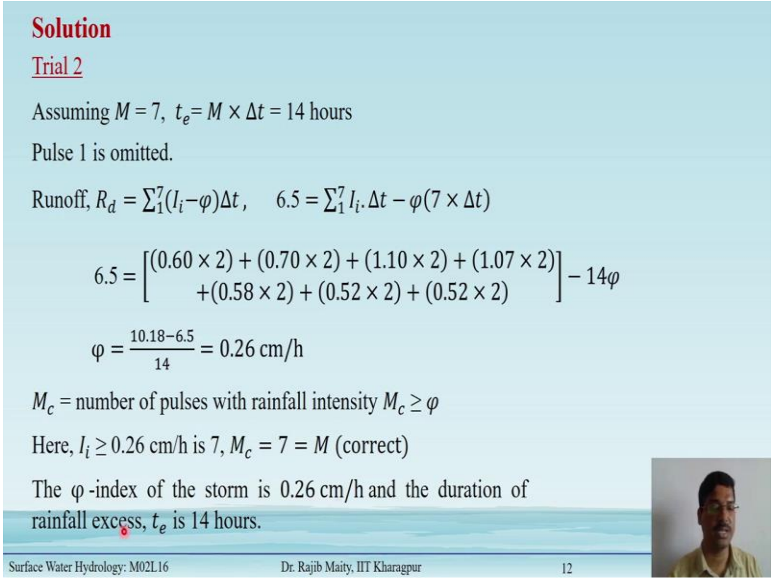

<u>Trial 2</u>

Assuming M = 7, te= M×Δt = 14

Pulse 1 is omitted.

Runoff, $R_d = \sum_1^7 (I_i - \varphi)\Delta t$, $6.5 = \sum_1^7 I_i.\Delta t - \varphi(7 \times \Delta t)$

6.5 = [(0.60×2) + (0.70×2) + (1.10×2) + (1.07×2) + (0.58×2) + (0.52×2) + (0.52×2)] −14φ

φ= (10.18−6.5)/14=0.26 cm/h

M_c = number of pulses with rainfall intensity $M_c \geq \varphi$

Here, $I_i \geq 0.26$ cm/h is 7, M_c=7=M (correct)

The φ -index of the storm is 0.26 cm/h and the duration of rainfall excess, t_e is 14 hours.

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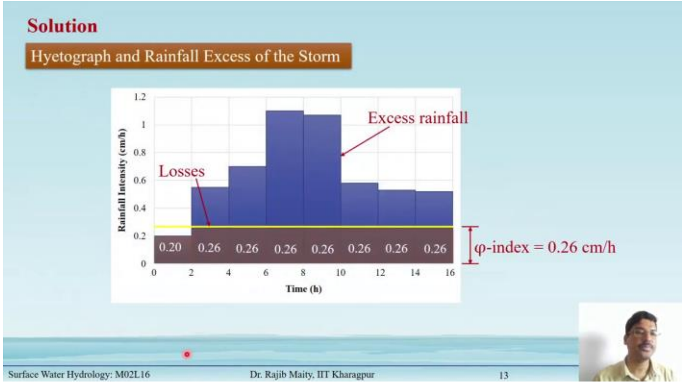

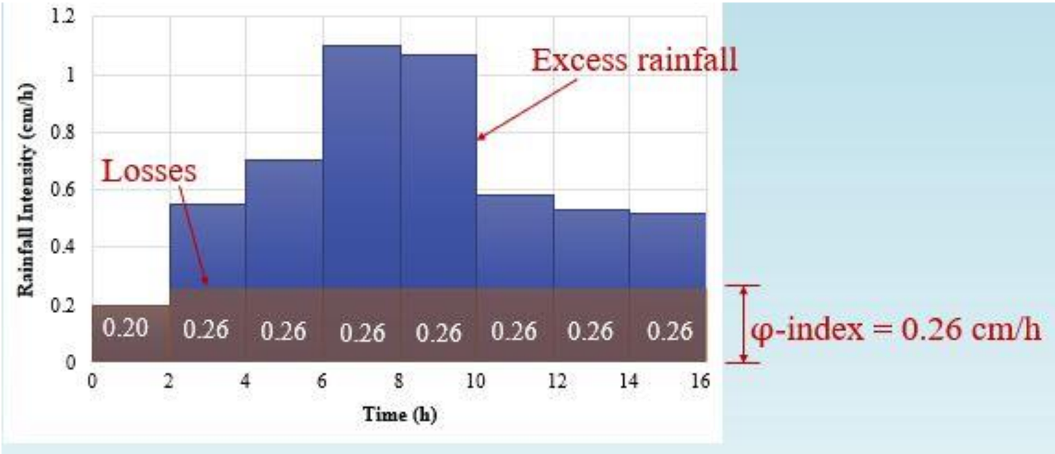

Fig.3 shows the Hyetograph and Rainfall Excess of the storm- Example 16.1

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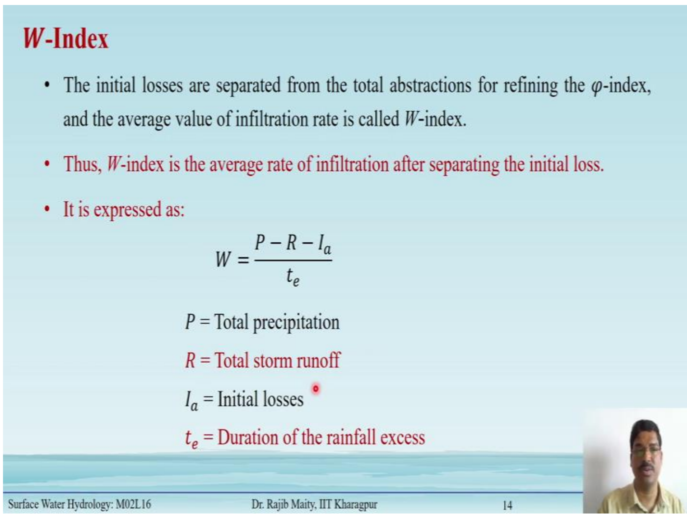

W-Index

The initial losses are separated from the total abstractions for refining the φ-index, and the average value of infiltration rate is called W-index. Thus, W-index is the average rate of infiltration after separating the initial loss.

$$W = \frac{P - R - I_a}{t_e}$$

Where, P = Total precipitation

R = Total storm runoff

I_a = Initial losses

t_e = Duration of the rainfall excess

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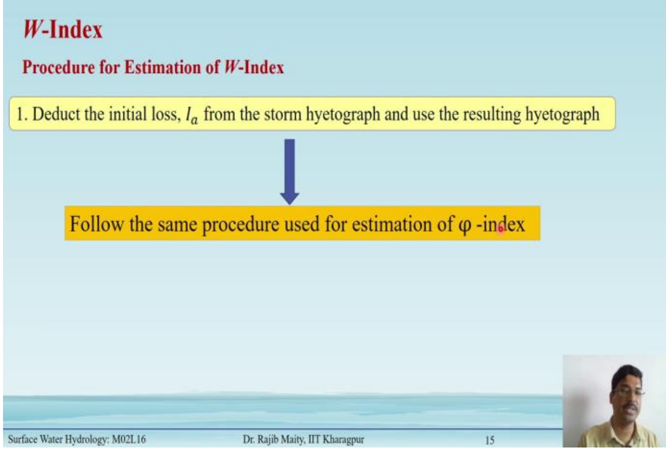

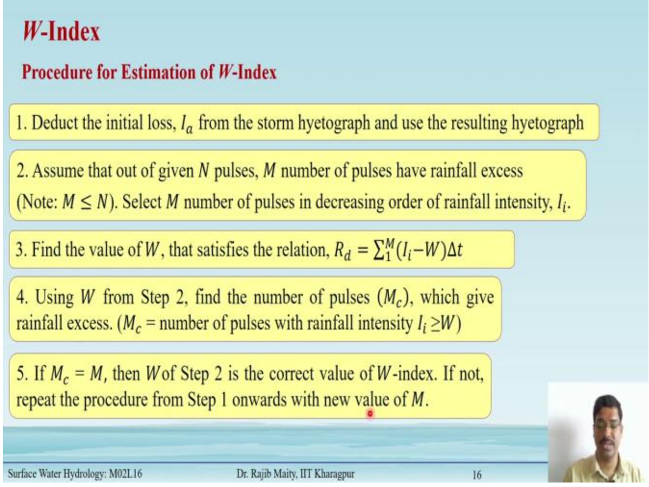

Procedure for Estimation of W-Index

1. Deduct the initial loss, I_a from the storm hyetograph, and use the resulting hyetograph.

2. Assume that out of given N pulses, M number of pulses have rainfall excess

(Note: $M \leq N$). Select M number of pulses in decreasing order of rainfall intensity, I_i.

3. Find the value of W, that satisfies the relation $R_d = \sum_{1}^{M} (I_i - W)\Delta t$

4. Using W from Step 2, find the number of pulses (M_c), which give rainfall excess. (M_c = number of pulses with rainfall intensity $I_i \geq W$)

5. If $M_c = M$, then $W$of Step 2 is the correct value of W-index. If not, repeat the procedure from Step 1 onwards with the new value of M.

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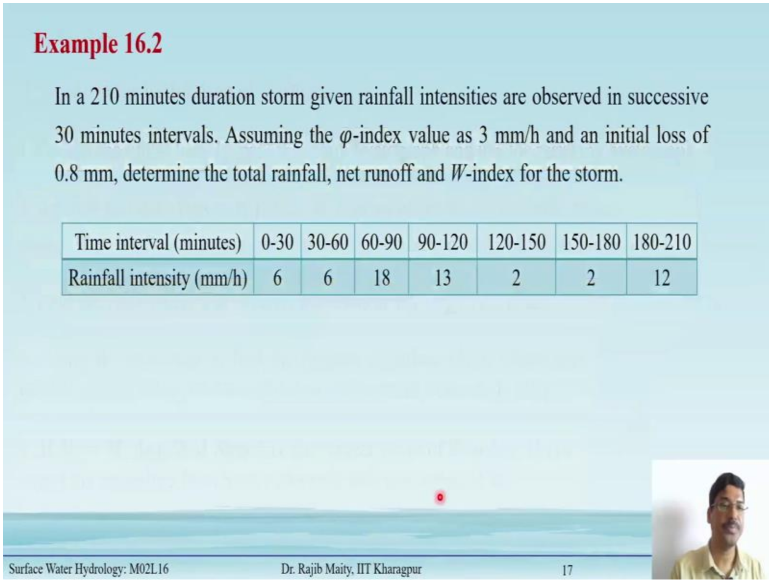

Example 16.2

In 210 minutes, duration storm given rainfall intensities is observed in successive 30 minutes intervals. Assuming the φ-index value as 3 mm/h and an initial loss of 0.8 mm, determine the total rainfall, net runoff, and W-index for the storm.

Time interval (minutes)	0-30	30-60	60-90	90-120	120-150	150-180	180-210
Rainfall intensity (mm/h)	6	6	18	13	2	2	12

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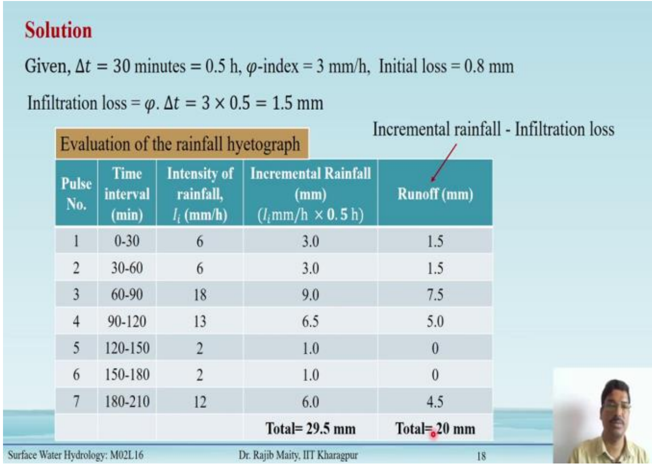

Solution

Given, Δt=30 minutes = 0.5 h, φ-index = 3 mm/h, Initial loss = 0.8 mm

Infiltration loss = φ. Δt=3×0.5=1.5 mm

Pulse No.	Time interval (min)	Intensity of rainfall, I_i (mm/h)	Incremental Rainfall (mm) ($I_i$mm/h $\times$ **0.5** h)	Runoff (mm)
1	0-30	6	3.0	1.5
2	30-60	6	3.0	1.5
3	60-90	18	9.0	7.5
4	90-120	13	6.5	5.0
5	120-150	2	1.0	0
6	150-180	2	1.0	0
7	180-210	12	6.0	4.5
			Total= 29.5 mm	**Total= 20 mm**

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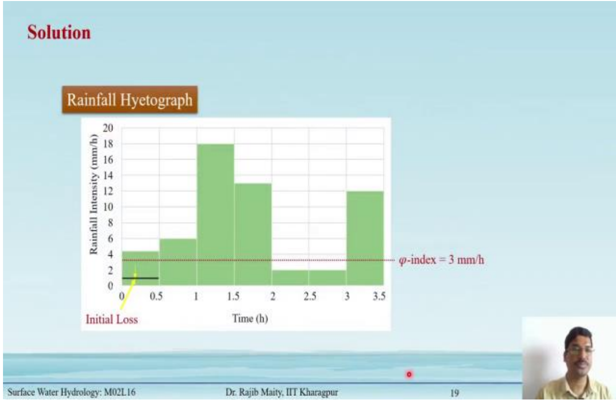

In fig.4 you see that difference in this plot that the initial first part, the initial loss is designated here and this phi index is given as a 3 mm per hour.

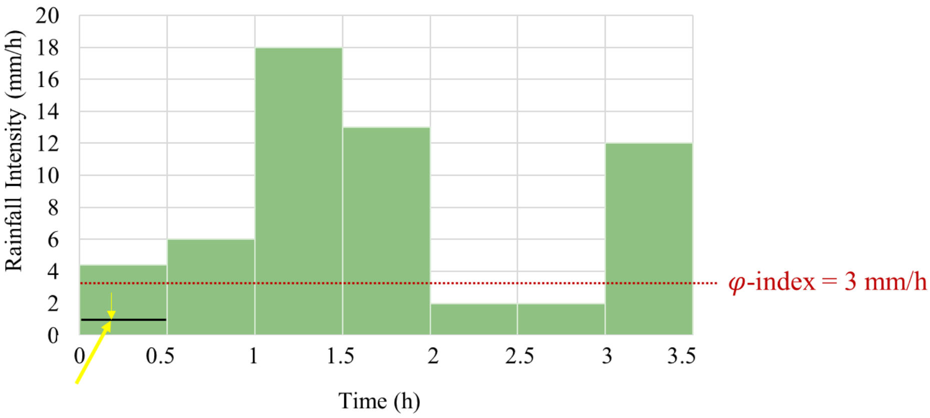

Fig.4 shows the Hyetograph and Rainfall Excess of the storm- Example 16.2

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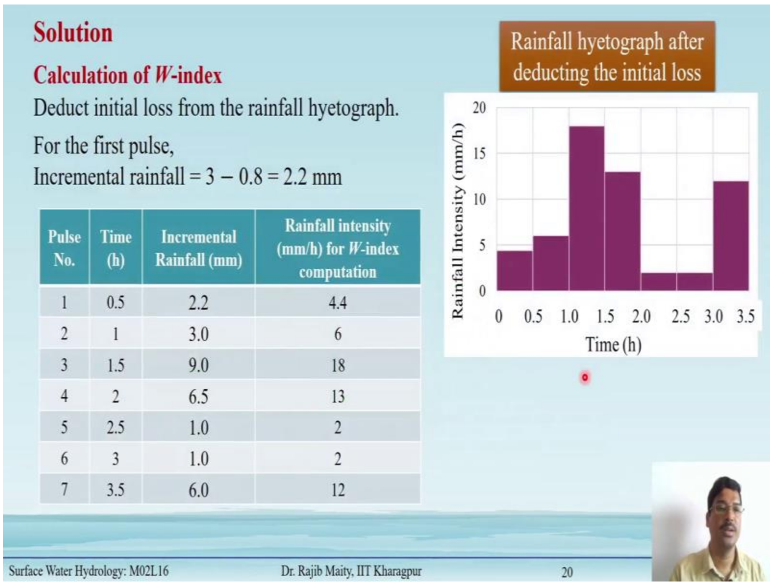

Calculation of *W*-index

Deduct initial loss from the rainfall hyetograph.

For the first pulse,

Incremental rainfall = 3 − 0.8 = 2.2 mm

Pulse No.	Time (h)	Incremental Rainfall (mm)	Rainfall intensity (mm/h) for *W*-index computation
1	0.5	2.2	4.4
2	1	3.0	6
3	1.5	9.0	18
4	2	6.5	13
5	2.5	1.0	2
6	3	1.0	2
7	3.5	6.0	12

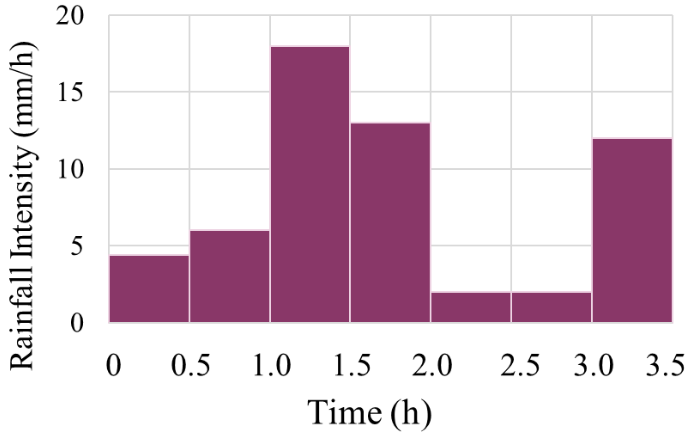

Fig5. Shows the rainfall hyetograph after deducting the initial loss

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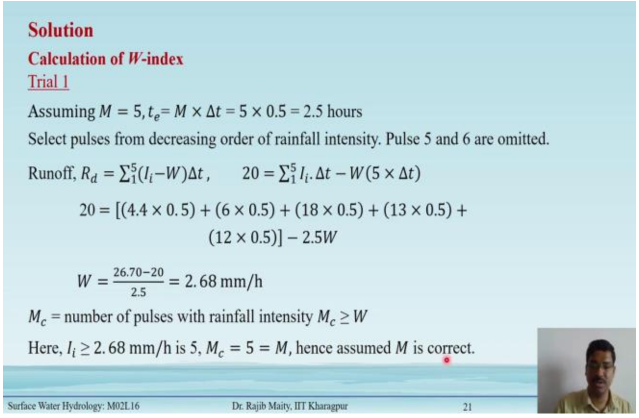

Calculation of W-index

<u>Trial 1</u>

Assuming M=5, t_e= M×Δt = 5×0.5 = 2.5 hours

Select pulses from decreasing order of rainfall intensity. Pulse 5 and 6 are omitted.

$$\text{Runoff,}\ R_d = \Sigma_1^5 (I_i - W)\Delta t, \qquad 20 = \Sigma_1^5 I_i.\Delta t - W(5\times\Delta t)$$

20 = [(4.4×0. 5)+(6×0.5) +(18×0.5) +(13×0.5) +(12×0.5)] −2.5W

W= (26.70−20)/2.5=2. 68 mm/h

M_c = number of pulses with rainfall intensity $M_c \geq W$

Here, $I_i \geq$ 2. 68 mm/h is 5, M_c=5=M, hence assumed M is correct.

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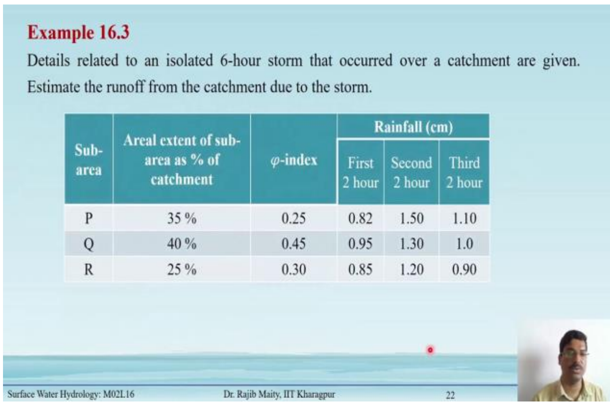

Example 16.3

Details related to an isolated 6-hour storm that occurred over a catchment are given. Estimate the runoff from the catchment due to the storm.

Sub-area	Areal extent of sub-area as % of catchment	φ-index	Rainfall (cm)		
			First 2 hour	Second 2 hour	Third 2 hour
P	35 %	0.25	0.82	1.50	1.10
Q	40 %	0.45	0.95	1.30	1.0
R	25 %	0.30	0.85	1.20	0.90

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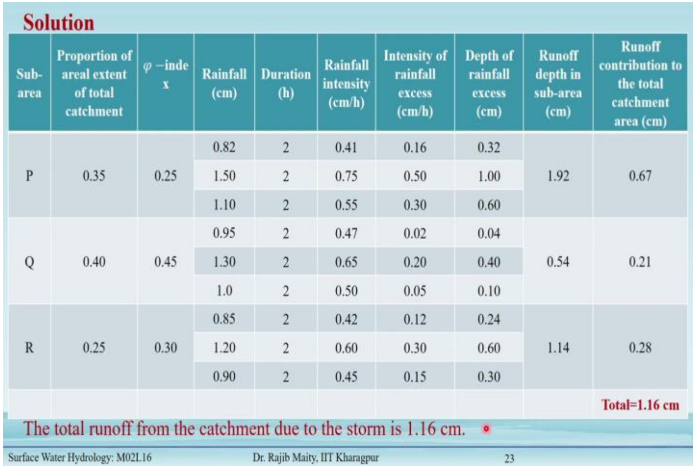

Solution

Sub-area	Proportion of areal extent of total catchment	φ −index	Rainfall (cm)	Duration (h)	Rainfall intensity (cm/h)	Intensity of rainfall excess (cm/h)	Depth of rainfall excess (cm)	Runoff depth in sub-area (cm)	Runoff contribution to the total catchment area (cm)
P	0.35	Solution 0.25	0.82	2	0.41	0.16	0.32	1.92	0.67
			1.50	2	0.75	0.50	1.00		
			1.10	2	0.55	0.30	0.60		
Q	0.40	0.45	0.95	2	0.47	0.02	0.04	0.54	0.21
			1.30	2	0.65	0.20	0.40		
			1.0	2	0.50	0.05	0.10		
R	0.25	0.30	0.85	2	0.42	0.12	0.24	1.14	0.28
			1.20	2	0.60	0.30	0.60		
			0.90	2	0.45	0.15	0.30		
									Total=1.16 cm

The total runoff from the catchment due to the storm is 1.16 cm.

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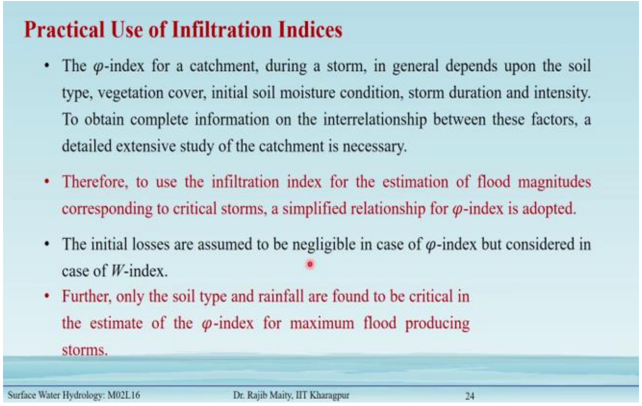

Practical Use of Infiltration Indices

- The φ-index for a catchment, during a storm, in general, depends upon the soil type, vegetation cover, initial soil moisture condition, storm duration, and intensity. To obtain complete information on the interrelationship between these factors, a detailed extensive study of the catchment is necessary.
- Therefore, to use the infiltration index for the estimation of flood magnitudes corresponding to critical storms, a simplified relationship for φ-index is adopted.
- The initial losses are assumed to be negligible in the case of φ-index but considered in the case of W-index.
- Further, only the soil type and rainfall are found to be critical in the estimate of the φ-index for maximum flood-producing storms.

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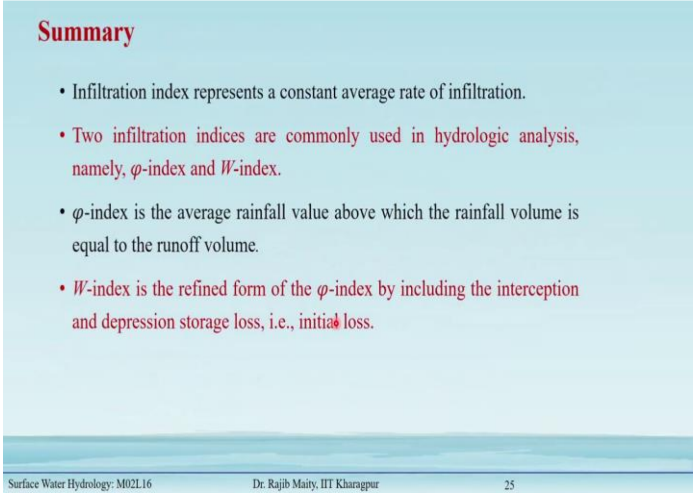

Summary

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

- The infiltration index represents a constant average rate of infiltration.
- Two infiltration indices are commonly used in the hydrologic analysis, namely, φ-index and W-index.
- φ-index is the average rainfall value above which the rainfall volume is equal to the runoff volume.
- W-index is the refined form of the φ-index by including the interception and depression storage loss, i.e., initial loss.