Surface Water Hydrology
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Lecture: 38
Flood Peak Discharge and Catchment Characteristics

This is the second lecture of this week, lecture 38, where we will discuss the flood peak discharge and catchment characteristics.

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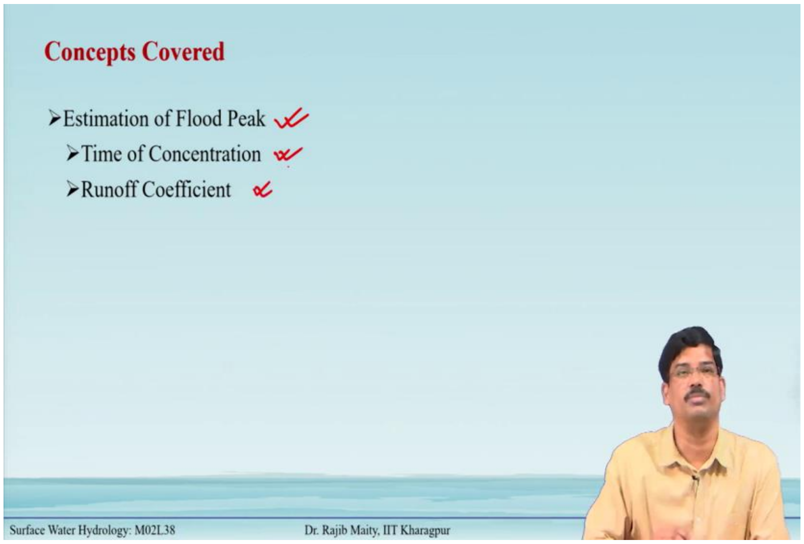

Under this concept covered, we are now learning this estimation of flood peak and within this one those two characteristics of this basin the time of concentration and runoff coefficient, these two things will be discussed in this lecture.

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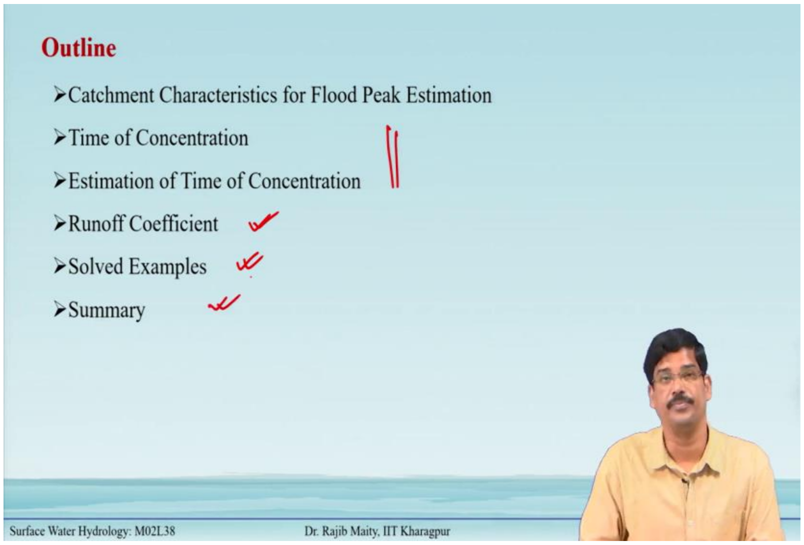

The outline of this lecture goes like this the catchment characteristics for the flood peak estimation. And within this the time of concentration and estimation of time of concentration using different methods. And after that, we will discuss something about the runoff coefficient. And using this, we will use some examples. And then we will go to the summary of this lecture.

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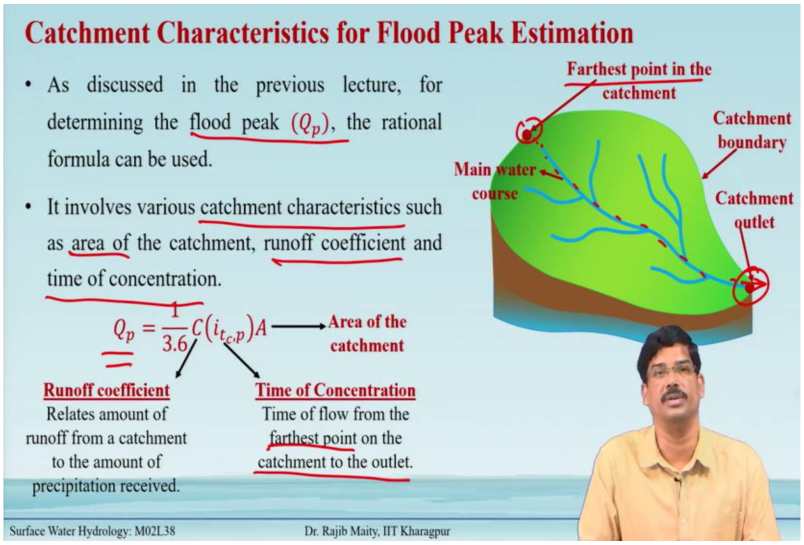

Catchment Characteristics for Flood Peak Estimation

For determining the flood peak the rational formula can be used and there are other formulas are also there. But, the general thing so, far as the any this kind of equation, that utilize the different catchment characteristics, they try to link these catchment characteristics to that to the peak flood.

It involves various catchment characteristics such as area of the catchment, runoff coefficient, and time of concentration.

$$Q_p = \frac{1}{3.6} C\left(i_{t_c,p}\right) A$$

where the C is the runoff coefficient that relates the amount of runoff from a catchment to the amount of precipitation that is received over the entire catchment; t_c is the time of concentration and that is the time of flow from the farthest point on the catchment to the outlet of this basin; A is the area of the catchment.

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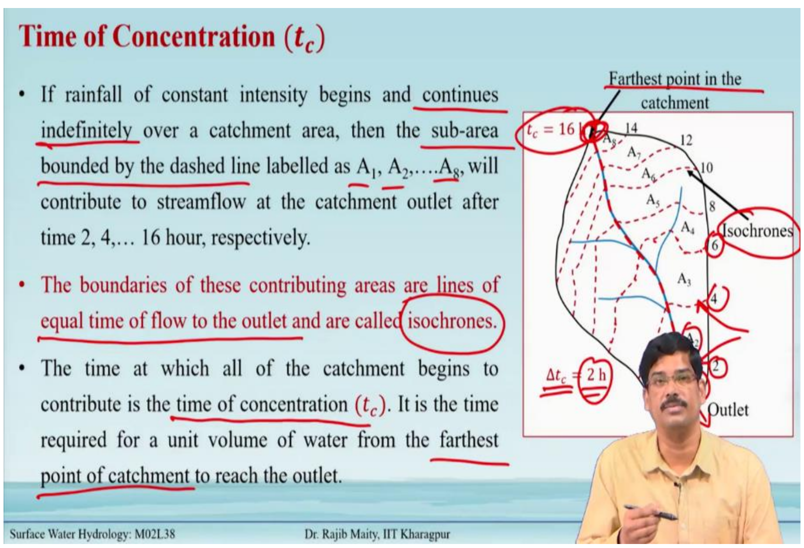

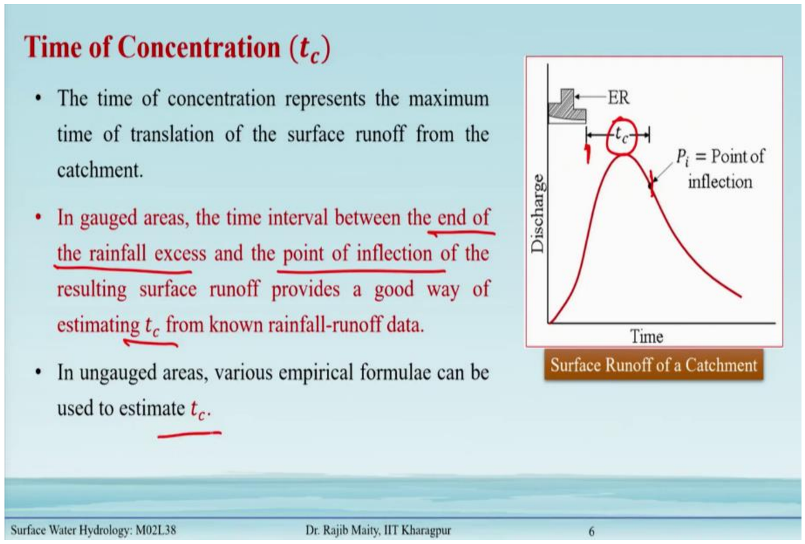

Time of Concentration (t_c)

If the rainfall of the constant intensity begins and continues indefinitely then over a catchment area then just divide the center catchment into different sub-areas, which are bounded by the dashed line as shown in fig.1.

So, if it is bounded by this one and the respective areas are A_1, A_2. So, in this particular example, it is shown up to A_8 so, these areas are shown here in fig.1. And this is a specific example where the Δt_c that is we divide the entire time of concentration into smaller parts which are 2 hours and in the diagram, this dashed line is the line of the equal time that the flow takes to reach the outlet. So, from any point on a particular dashed line, if just consider, then that meaning is that from any point the time taken by your water volume to reach the outlet are same.

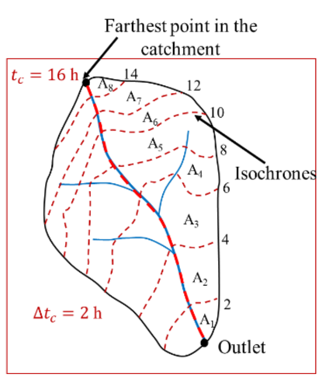

Fig.1 shows the schematic sketch of catchment of a river

The equal time of flow to the outlet is shown by this red dashed line and it has a special name this name is called the isochrones. So, isochrones as shown here for this a specific watershed and here there are these isochrones are shown in the gap of 2 hours that means, from this point where it is marked as 2 marks as 4 marks as 6, so, it takes that hour from that particular point for that particular line to reach to the or reach to the outlet. For the enter catchment, it will take a total of 16 hours to reach the outlet of the basin. So, the time of concentration for this basin we can say that 16 hours.

So, the time at which all the catchment begins to contribute is the time of concentration. So, it is a time required for the unit volume of the water from the farthest point of the catchment to reach the outlet.

So, in the hydrograph, the time of concentration represents the maximum time of the translation of the surface runoff from the catchment in the gauged areas that time interval between the end of the rainfall excess, between the end of the rainfall excess, and the point of the inflection of the resulting surface runoff on the recess and limb, provides a good way of estimating the t_c. In the ungauged area, the various empirical formula, and formulae are there that we can use to estimate the time of concentration.

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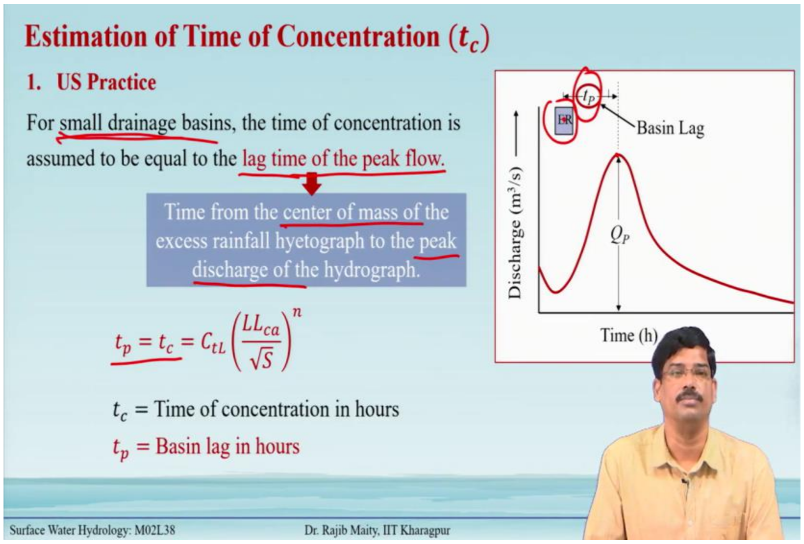

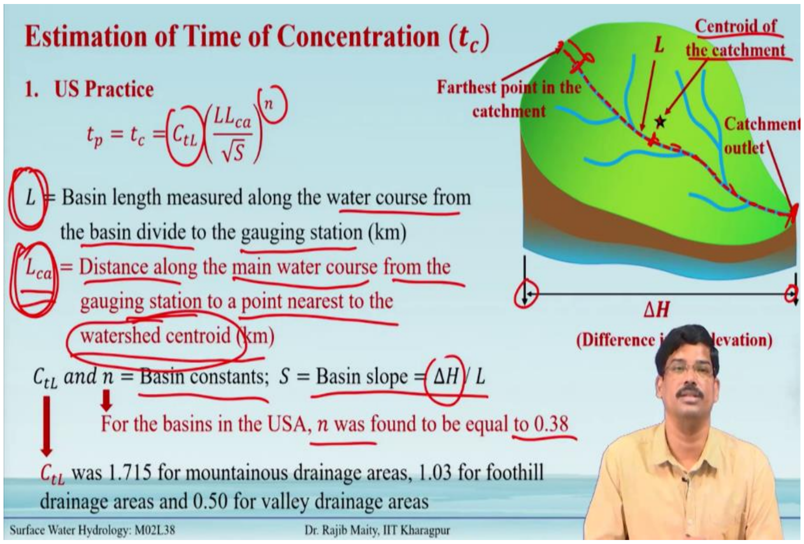

Estimation of Time of Concentration (t_c)

1. **US Practice**

For small drainage basins, the time of concentration is assumed to be equal to the lag time (Time from the center of mass of the excess rainfall hyetograph to the peak discharge of the hydrograph) of the peak flow.

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

Where,

t_c= Time of concentration in hours

t_p= Basin lag in hours

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

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

C_{tL} *and* n= Basin constants; S= Basin slope =ΔH / L

It is noted that for the basins in the USA, n was found to be equal to 0.38 and C_{tL} was 1.715 for mountainous drainage areas, 1.03 for foothill drainage areas, and 0.50 for valley drainage areas.

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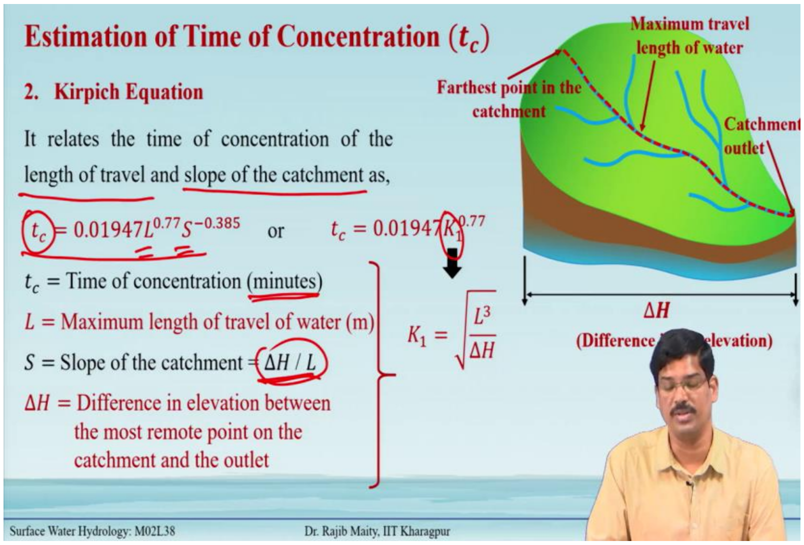

2. **Kirpich Equation**

There is another popular empirical equation which is known as a Kirpich Equation, it relates the time of concentration of the length of travel and the slope of the catchment. So, two things we are considering in this equation are the length of travel which is the L, and the slope of the catchment S.

$$t_c = 0.01947L^{0.77}S^{-0.385} \quad \text{or} \quad t_c = 0.01947K_1^{0.77}$$

Where

$$K_1 = \sqrt{\frac{L^3}{\Delta H}}$$

t_c= Time of concentration (minutes)

L= Maximum length of travel of water (m)

S= Slope of the catchment = ΔH / L

ΔH= Difference in elevation between the most remote point on the catchment and the outlet

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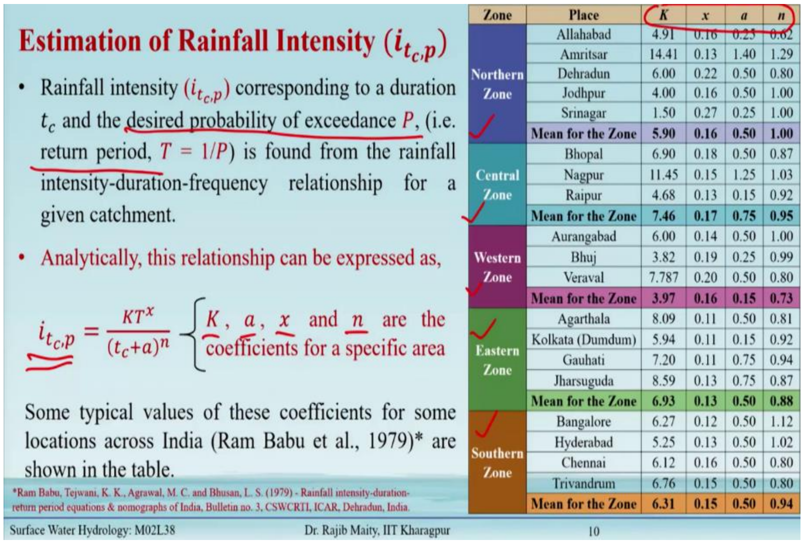

Zone	Place	K	x	a	n
Northern Zone	Allahabad	4.91	0.16	0.25	0.62
	Amritsar	14.41	0.13	1.40	1.29
	Dehradun	6.00	0.22	0.50	0.80
	Jodhpur	4.00	0.16	0.50	1.00
	Srinagar	1.50	0.27	0.25	1.00
	Mean for the Zone	**5.90**	**0.16**	**0.50**	**1.00**
Central Zone	Bhopal	6.90	0.18	0.50	0.87
	Nagpur	11.45	0.15	1.25	1.03
	Raipur	4.68	0.13	0.15	0.92
	Mean for the Zone	**7.46**	**0.17**	**0.75**	**0.95**
Western Zone	Aurangabad	6.00	0.14	0.50	1.00
	Bhuj	3.82	0.19	0.25	0.99
	Veraval	7.787	0.20	0.50	0.80
	Mean for the Zone	**3.97**	**0.16**	**0.15**	**0.73**
Eastern Zone	Agarthala	8.09	0.11	0.50	0.81
	Kolkata (Dumdum)	5.94	0.11	0.15	0.92
	Gauhati	7.20	0.11	0.75	0.94
	Jharsuguda	8.59	0.13	0.75	0.87
	Mean for the Zone	**6.93**	**0.13**	**0.50**	**0.88**
Southern Zone	Bangalore	6.27	0.12	0.50	1.12
	Hyderabad	5.25	0.13	0.50	1.02
	Chennai	6.12	0.16	0.50	0.80
	Trivandrum	6.76	0.15	0.50	0.80
	Mean for the Zone	**6.31**	**0.15**	**0.50**	**0.94**

Estimation of Rainfall Intensity (i_{tc},)

Rainfall intensity (i_{tc},) corresponding to a duration t_c and the desired probability of exceedance P, (i.e. return period, T = 1/P) is found from the rainfall intensity-duration-frequency relationship for a given catchment.

Analytically, this relationship can be expressed as,

$$i_{t_c,p} = \frac{KT^x}{(t_c+a)^n} \quad \left\{ \begin{array}{l} K\text{, } a\text{, } x \text{ and } n \text{ are the} \\ \text{coefficients for a specific area} \end{array} \right.$$

Some typical values of these coefficients for some locations across India (Ram Babu et al., 1979) are shown in the table.

Zone	Place	*K*	*x*	*a*	*n*
Northern Zone	Allahabad	4.91	0.16	0.25	0.62
	Amritsar	14.41	0.13	1.40	1.29
	Dehradun	6.00	0.22	0.50	0.80
	Jodhpur	4.00	0.16	0.50	1.00
	Srinagar	1.50	0.27	0.25	1.00
	Mean for the Zone	**5.90**	**0.16**	**0.50**	**1.00**
Central Zone	Bhopal	6.90	0.18	0.50	0.87
	Nagpur	11.45	0.15	1.25	1.03
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	Mean for the Zone	**7.46**	**0.17**	**0.75**	**0.95**
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	Veraval	7.787	0.20	0.50	0.80
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Southern Zone	Bangalore	6.27	0.12	0.50	1.12
	Hyderabad	5.25	0.13	0.50	1.02
	Chennai	6.12	0.16	0.50	0.80
	Trivandrum	6.76	0.15	0.50	0.80
	Mean for the Zone	**6.31**	**0.15**	**0.50**	**0.94**

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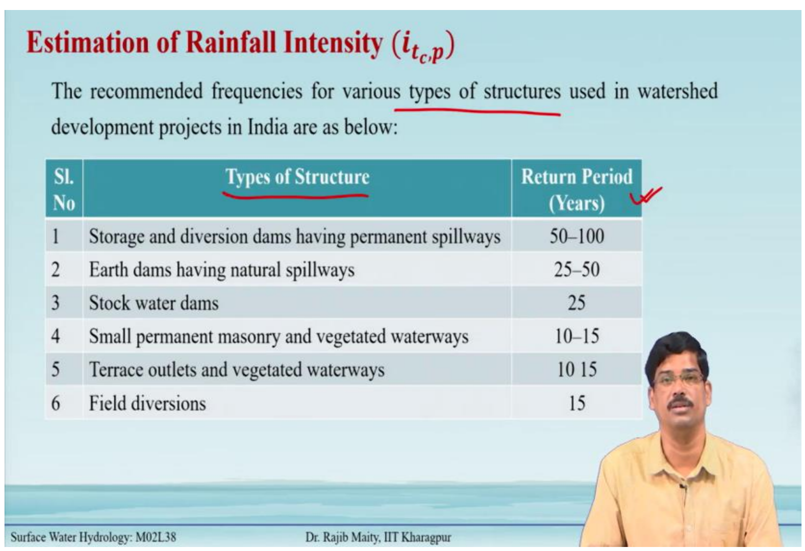

The recommended frequencies for various types of structures used in watershed development projects in India are as below:

Sl. No	Types of Structure	Return Period (Years)
1	Storage and diversion dams having permanent spillways	50–100
2	Earth dams having natural spillways	25–50
3	Stock water dams	25
4	Small permanent masonry and vegetated waterways	10–15
5	Terrace outlets and vegetated waterways	10 15
6	Field diversions	15

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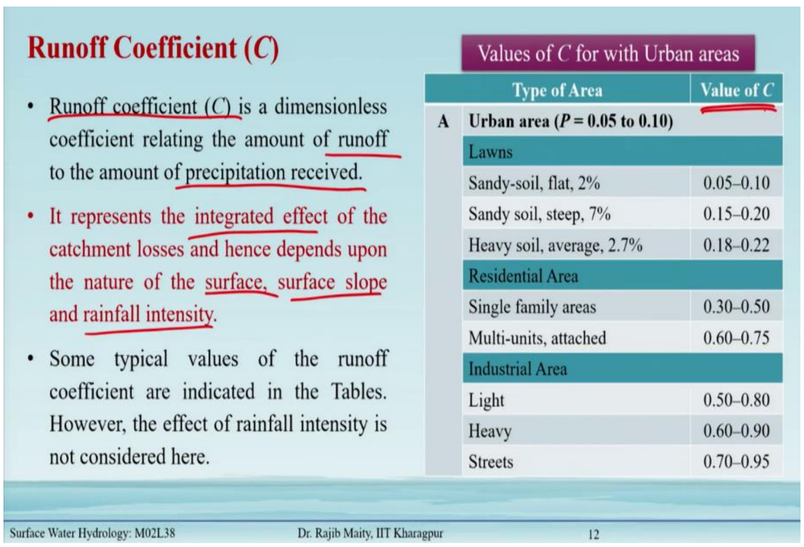

Runoff Coefficient (*C*)

The runoff coefficient (C) is a dimensionless coefficient relating the amount of runoff to the amount of precipitation received.

It represents the integrated effect of the catchment losses and hence depends upon the nature of the surface, surface slope, and rainfall intensity.

Some typical values of the runoff coefficient are indicated in the Tables. However, the effect of rainfall intensity is not considered here.

Values of *C* for Urban areas

	Type of Area	Value of *C*
A	**Urban area (*P* = 0.05 to 0.10)**	
	Lawns	
	Sandy-soil, flat, 2%	0.05–0.10
	Sandy soil, steep, 7%	0.15–0.20
	Heavy soil, average, 2.7%	0.18–0.22
	Residential Area	
	Single family areas	0.30–0.50
	Multi-units, attached	0.60–0.75
	Industrial Area	
	Light	0.50–0.80
	Heavy	0.60–0.90
	Streets	0.70–0.95

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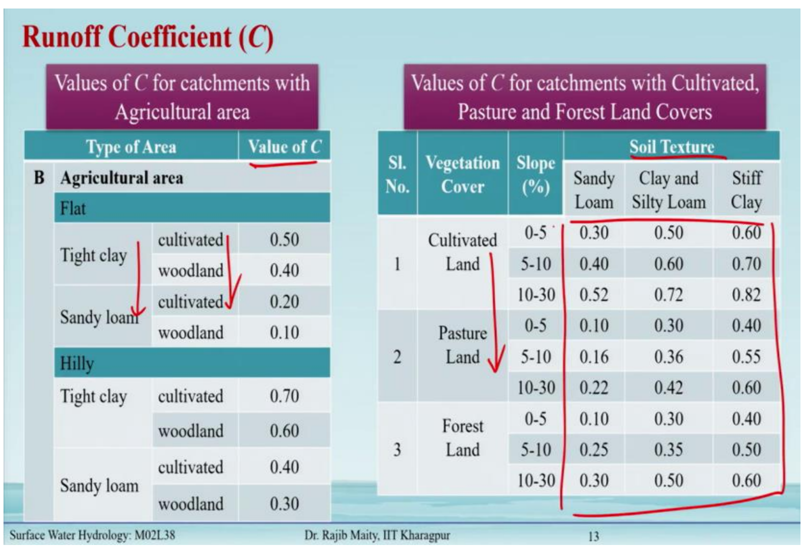

	Type of Area		Value of *C*
B	**Agricultural area**		
	Flat		
	Tight clay	cultivated	0.50
		woodland	0.40
	Sandy loam	cultivated	0.20
		woodland	0.10
	Hilly		
	Tight clay	cultivated	0.70
		woodland	0.60
	Sandy loam	cultivated	0.40
		woodland	0.30

Sl. No.	Vegetation Cover	Slope (%)	Soil Texture: Sandy Loam	Soil Texture: Clay and Silty Loam	Soil Texture: Stiff Clay
1	Cultivated Land	0-5	0.30	0.50	0.60
		5-10	0.40	0.60	0.70
		10-30	0.52	0.72	0.82
2	Pasture Land	0-5	0.10	0.30	0.40
		5-10	0.16	0.36	0.55
		10-30	0.22	0.42	0.60
3	Forest Land	0-5	0.10	0.30	0.40
		5-10	0.25	0.35	0.50
		10-30	0.30	0.50	0.60

Values of *C* for catchments with Agricultural area

Type of Area				Value of *C*
B	**Agricultural area**			
	Flat			
		Tight clay	cultivated	0.50
			woodland	0.40
		Sandy loam	cultivated	0.20
			woodland	0.10
	Hilly			
		Tight clay	cultivated	0.70
			woodland	0.60
		Sandy loam	cultivated	0.40
			woodland	0.30

Values of *C* for catchments with Cultivated, Pasture, and Forest Land Covers

Sl. No.	Vegetation Cover	Slope (%)	Soil Texture		
			Sandy Loam	Clay and Silty Loam	Stiff Clay
1	Cultivated Land	0-5	0.30	0.50	0.60
		5-10	0.40	0.60	0.70
		10-30	0.52	0.72	0.82
2	Pasture Land	0-5	0.10	0.30	0.40
		5-10	0.16	0.36	0.55
		10-30	0.22	0.42	0.60
3	Forest Land	0-5	0.10	0.30	0.40
		5-10	0.25	0.35	0.50
		10-30	0.30	0.50	0.60

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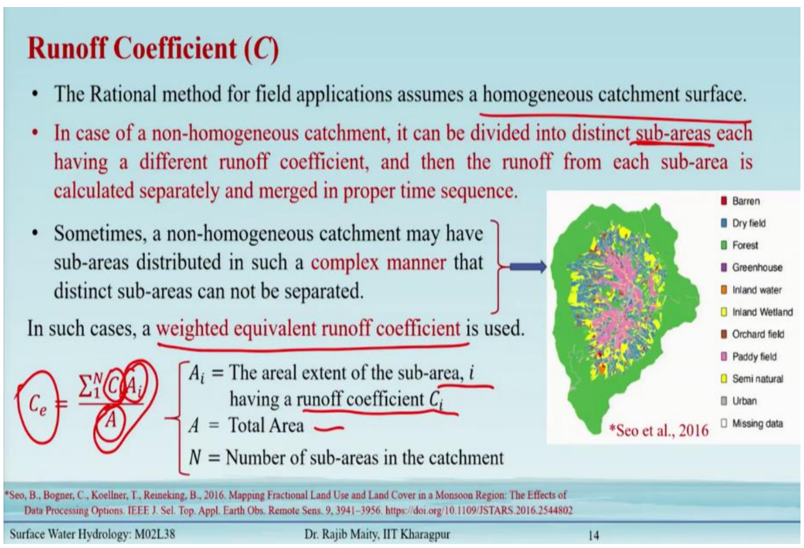

The Rational method for the field application assumes a homogeneous catchment surface this is one of the important background assumptions to apply this rational method however, it is in the reality the catchment may not be homogeneous for whatever even if the small catchments also for the different areas can have different C factors.

Depending on that sometimes we can divide the center catchment into different sub-areas, sub-areas of different runoff coefficients, and then the runoff from each sub-area can be calculated separately and merged in the proper time sequences. So, sometimes a non-homogeneous catchment may have sub-areas distributed in such a complex manner that the distinct sub-areas cannot be even separated. In such cases, a weighted equivalent runoff coefficient is used

$$C_e = \frac{\sum_1^N C_i A_i}{A}$$

Where A_i is the areal extent of the sub-area I that is having the runoff coefficient Ci, A is the total area and N is the total number of sub-areas in the catchment.

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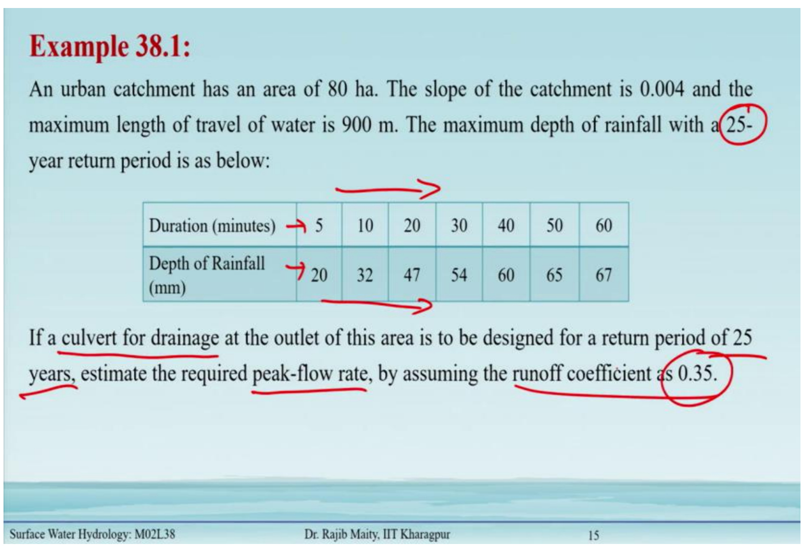

Example 38.1:

An urban catchment has an area of 80 ha. The slope of the catchment is 0.004 and the maximum length of travel of water is 900 m. The maximum depth of rainfall with a 25-year return period is as below:

Duration (minutes)	5	10	20	30	40	50	60
Depth of Rainfall (mm)	20	32	47	54	60	65	67

If a culvert for drainage at the outlet of this area is to be designed for a return period of 25 years, estimate the required peak-flow rate, by assuming the runoff coefficient as 0.35.

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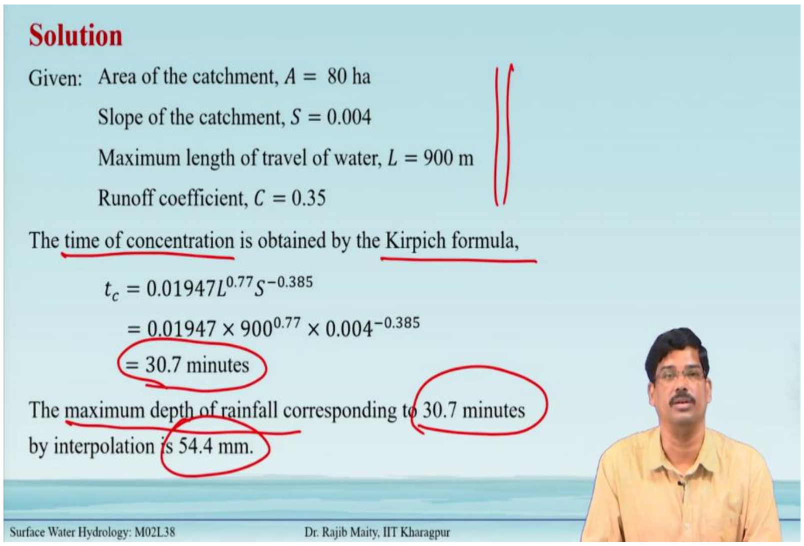

Solution

Given: Area of the catchment, A= 80 ha

The slope of the catchment, S= 0.004

The maximum length of travel of water, L= 900 m

Runoff coefficient, C= 0.35

The time of concentration is obtained by the Kirpich formula,

$$\begin{aligned} t_c &= 0.01947 L^{0.77} S^{-0.385} \\ &= 0.01947 \times 900^{0.77} \times 0.004^{-0.385} \\ &= 30.7 \text{ minutes} \end{aligned}$$

The maximum depth of rainfall corresponding to 30.7 minutes by interpolation is 54.4 mm.

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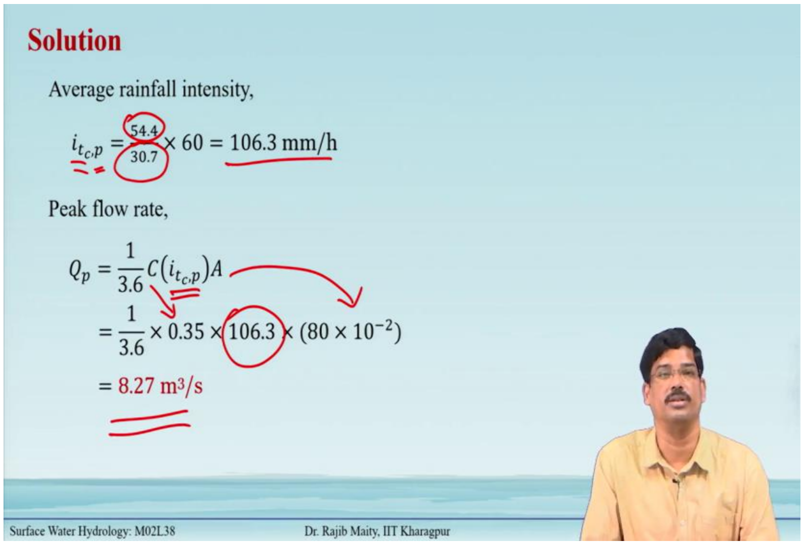

Average rainfall intensity,

$$i_{t_c,p} = \frac{54.4}{30.7} \times 60 = 106.3 \text{ mm/h}$$

Peak flow rate,

$$Q_p = \frac{1}{3.6} C(i_{t_c,p}) A$$

$$= \frac{1}{3.6} \times 0.35 \times 106.3 \times (80 \times 10^{-2})$$

$$= 8.27 \text{ m}^3\text{/s}$$

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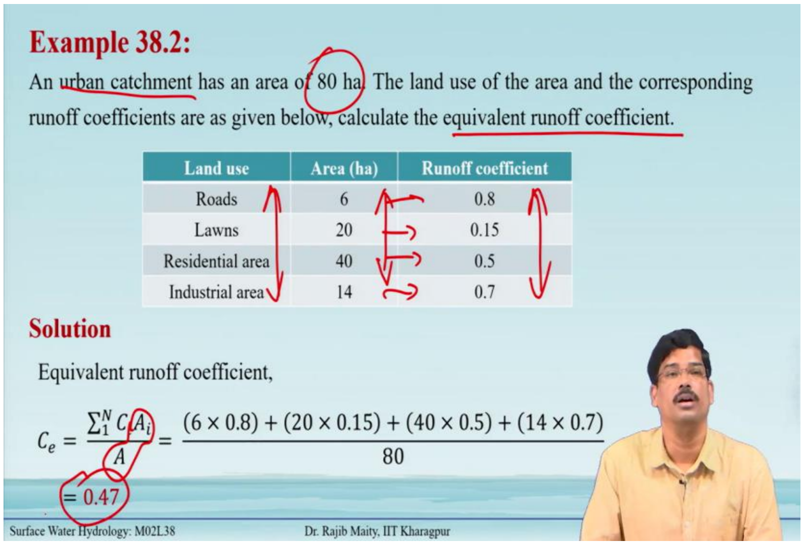

Example 38.2:

An urban catchment has an area of 80 ha. The land use of the area and the corresponding runoff coefficients are as given below, calculate the equivalent runoff coefficient.

Land use	Area (ha)	Runoff coefficient
Roads	6	0.8
Lawns	20	0.15
Residential area	40	0.5
Industrial area	14	0.7

Solution

Equivalent runoff coefficient,

$$C_e = \frac{\sum_1^N C_i A_i}{A} = \frac{(6 \times 0.8) + (20 \times 0.15) + (40 \times 0.5) + (14 \times 0.7)}{80}$$

=0.47

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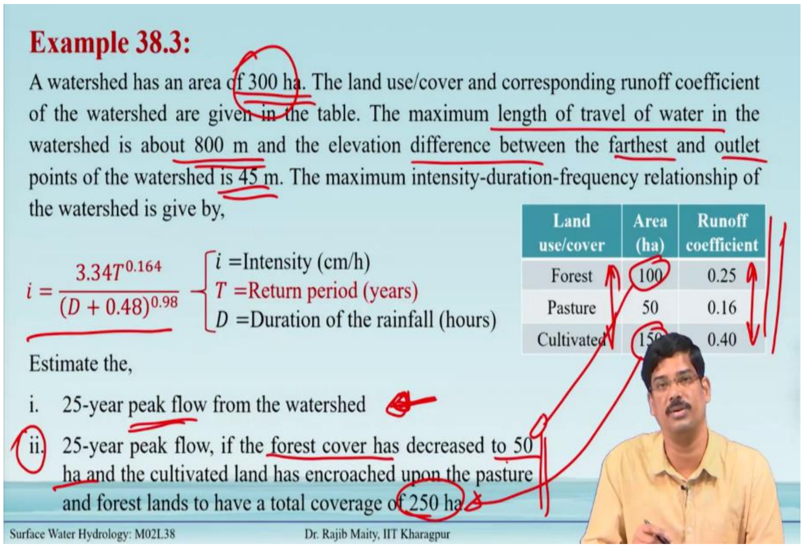

Example 38.3:

A watershed has an area of 300 ha. The land use/cover and corresponding runoff coefficient of the watershed are given in the table. The maximum length of travel of water in the watershed is about 800 m and the elevation difference between the farthest and outlet points of the watershed is 45 m. The maximum intensity-duration-frequency relationship of the watershed is given by,

$$i = \frac{3.34T^{0.164}}{(D + 0.48)^{0.98}} \quad \begin{cases} i = \text{Intensity (cm/h)} \\ T = \text{Return period (years)} \\ D = \text{Duration of the rainfall (hours)} \end{cases}$$

Land use/cover	Area (ha)	Runoff coefficient
Forest	100	0.25
Pasture	50	0.16
Cultivated	150	0.40

Estimate the,

i. 25-year peak flow from the watershed

ii. 25-year peak flow, if the forest cover has decreased to 50 ha and the cultivated land has encroached upon the pasture and forest lands to have total coverage of 250 ha.

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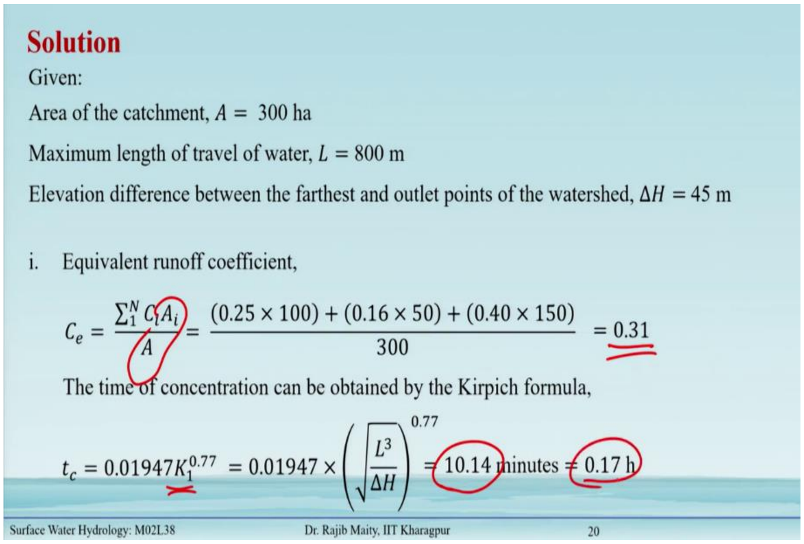

Solution

Given:

Area of the catchment, A= 300 ha

The maximum length of travel of water, L= 800 m

The elevation difference between the farthest and outlet points of the watershed, ΔH= 45 m

i. Equivalent runoff coefficient,

$$C_e = \frac{\sum_1^N C_i A_i}{A} = \frac{(0.25 \times 100) + (0.16 \times 50) + (0.40 \times 150)}{300}$$

$$= 0.31$$

The time of concentration can be obtained by the Kirpich formula,

$$t_c = 0.01947K_1^{0.77} = 0.01947 \times \left(\sqrt{\frac{L^3}{\Delta H}}\right)^{0.77} = 10.14 \text{ minutes} = 0.17 \text{ h}$$

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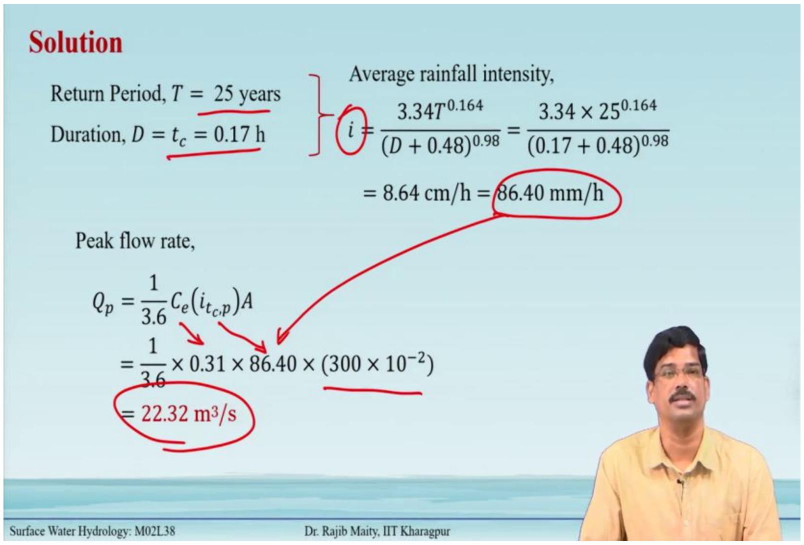

i. Return Period, $T = 25$ years; Duration, $D = t_c = 0.17$ h

Average rainfall intensity,

$$i = \frac{3.34T^{0.164}}{(D+0.48)^{0.98}} = \frac{3.34 \times 25^{0.164}}{(0.17+0.48)^{0.98}}$$

Peak flow rate,

$$Q_p = \frac{1}{3.6} C_e\left(i_{t_c,p}\right)A$$

$$= \frac{1}{3.6} \times 0.31 \times 86.40 \times (300 \times 10^{-2})$$

$$= 22.32 \text{ m}^3/\text{s}$$

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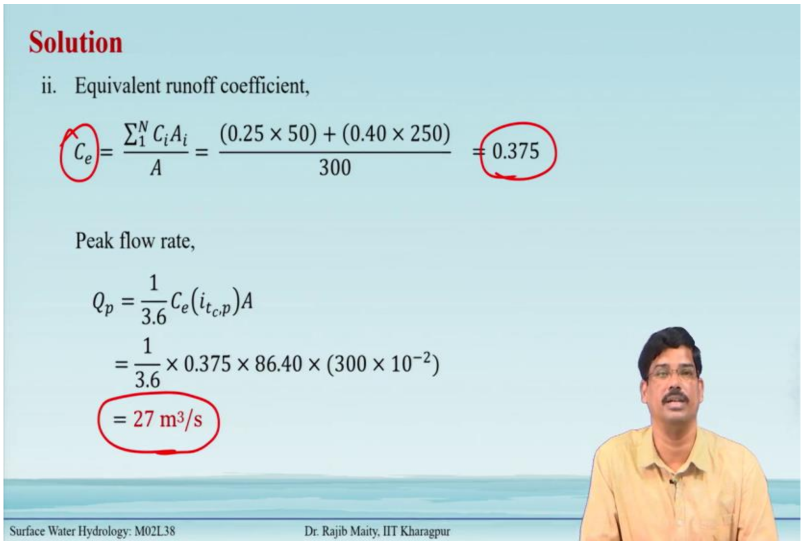

So, now if we come to the second part of this problem, so where the land use land cover has changed, so there also we can first of all, as you see there are only two types of this one is the cultivated land and the forest land so we can calculate this first this equivalent runoff coefficient which you can see that now it has increased 2.375.

Other things remain the same we have considered that only the land use land cover has changed. So, this intensity has not changed. So, here we can see that this peak discharge has also increased due to the change in this land use land cover pattern, this is one of the small examples to show how the peak flow rate can change due to the change in this land use land cover.

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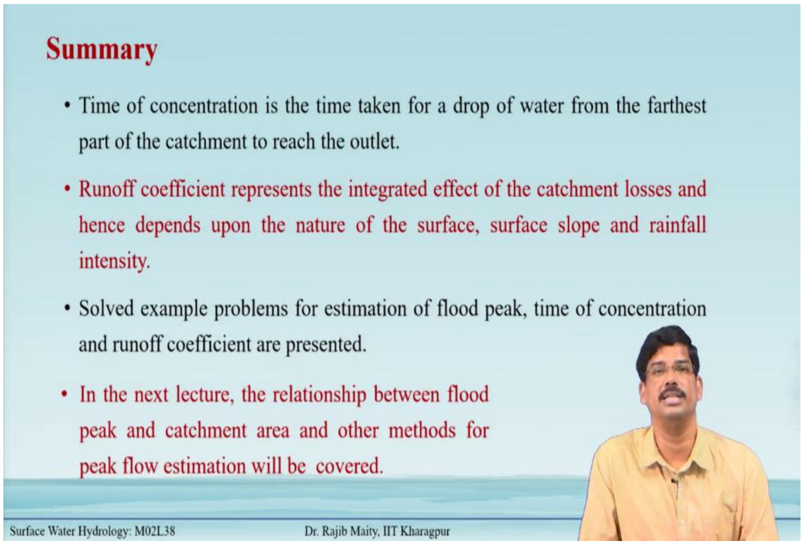

Summary

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

- Time of concentration is the time taken for a drop of water from the farthest part of the catchment to reach the outlet.
- The runoff coefficient represents the integrated effect of the catchment losses and hence depends upon the nature of the surface, surface slope, and rainfall intensity.
- Solved example problems for estimation of flood peak, time of concentration, and runoff coefficient are presented.
- In the next lecture, the relationship between flood peak and catchment area and other methods for peak flow estimation will be covered.

References

- Ram B., Tejwani, K. K., Agrawal, M. C. and Bhusan, L. S. (1979) Rainfall intensity-duration-return period equations & nomographs of India, Bulletin no. 3, CSWCRTI, ICAR, Dehradun, India.
- Seo, B., Bogner, C., Koellner, T., Reineking, B., 2016. Mapping Fractional Land Use and Land Cover in a Monsoon Region: The Effects of Data Processing Options. IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens. 9, 3941–3956. https://doi.org/10.1109/JSTARS.2016.2544802