Surface Water Hydrology
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Lecture – 27
Basics of Hydrographs

In this sixth week, we will discuss the analysis of hydrograph. And in lecture number 27, we will talk about some basics of hydrographs.

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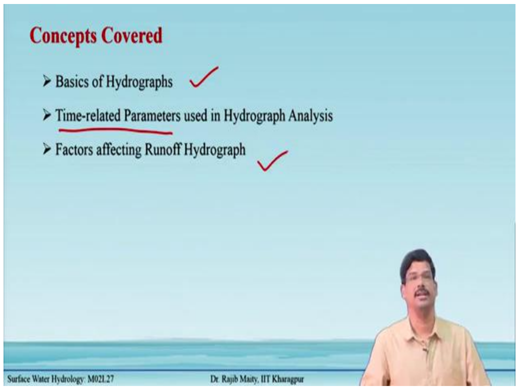

Under the concept covered, we will talk about the basics of hydrographs, then there are some time-related parameters are there, that are frequently and very importantly used in the hydrograph analysis. And finally, we will also cover the factor that affects the runoff hydrograph and we will see the details about it.

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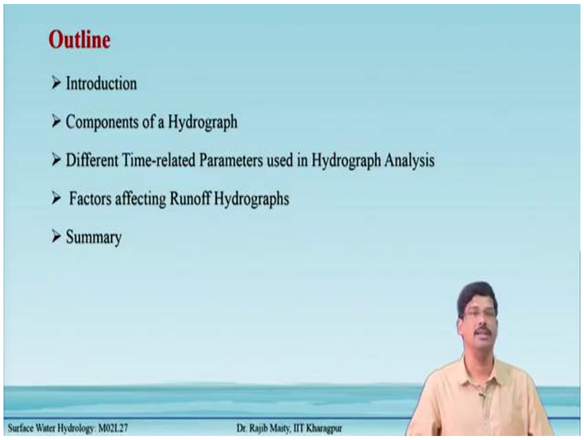

The outline of this lecture goes like this first some basic introduction, then we will talk about the components of a hydrograph and then different time-related parameters that are frequently used in hydrograph analysis, then factors affecting the runoff hydrograph, and then finally, a summary.

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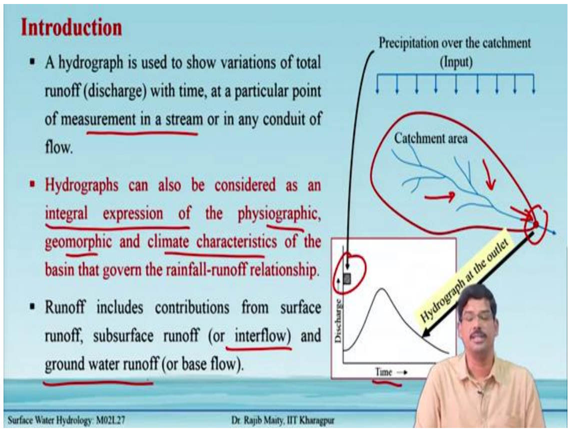

Introduction

A hydrograph is used to show variations of total runoff (discharge) with time, at a particular point of measurement in a stream or any conduit of flow.

In a catchment when some precipitation comes into it, there are different processes in this entire catchment before it reaches different channels and after that, it goes to the outlet. Now, after the rainfall occurs over time, the discharge gradually increases reach to some time and again it comes down. These things bear the signature of whatever the physical property of the catchment, physical as well as geomorphic properties there are some climate characteristics are also there that controls how a catchment will respond to precipitation that comes as an input process internally and that comes out at the outlet in the in terms of one hydrograph.

A hydrograph is an integral expression of the physiographic geomorphic and climate characteristics of the basin that governs the rainfall-runoff relationship. So, the runoff is two types one is that surface runoff and subsurface runoff which we call that interflow also. And also, there is a delayed response through the groundwater runoff which comes as a base flow.

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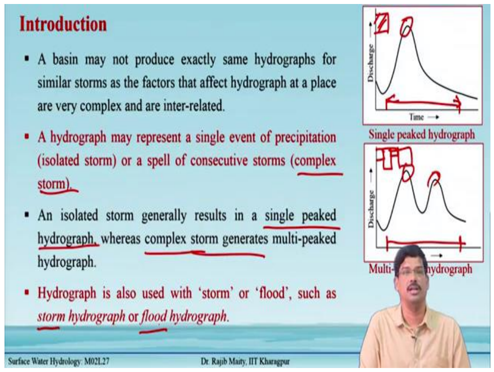

A basin may not produce the same hydrographs for similar storms as the factors that affect the hydrograph at a place are very complex and are interrelated. This relationship between this rainfall and runoff is complex and various factors are interrelated and that is the reason we can identify the relationship in terms of the hydrograph analysis.

If some storms come, whether it is in the form of an isolated storm or the complex storm, then the response of the basin in terms of various factors can find out. So, various factors may be how much is the peak or how many peaks can be there, or what will be the total duration over which the high flow can occur.

A hydrograph may represent a single event of precipitation (isolated storm) or a spell of consecutive storms (complex storm). An Isolated storm generates one single peaked hydrograph and the complex storm generates a multi-peaked hydrograph.

Hydrograph may also know as the storm hydrograph or flood hydrograph or sometimes even the runoff hydrograph is also referred too.

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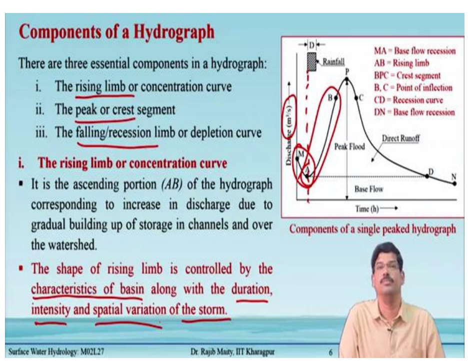

Components of a Hydrograph

There are three essential components in a hydrograph:

i. The rising limb or concentration curve

ii. The peak or crest segment

iii. The falling/recession limb or depletion curve

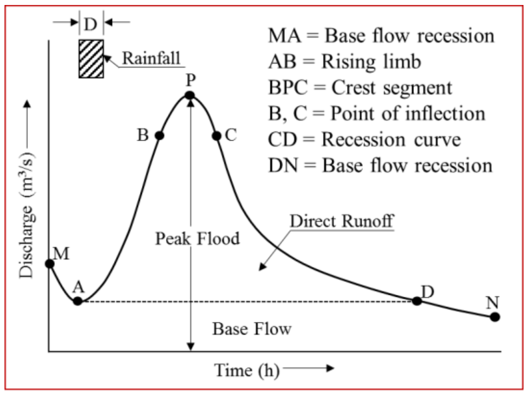

Fig.1 shows the component of the hydrograph

In fig.1, the MA part is a continuous measurement of the streamflow. MA shows the base flow recession from the previous storms or previous events.

i. **The rising limb or concentration curve**

It is the ascending portion *(AB)* of the hydrograph corresponding to an increase in discharge due to the gradual building up of storage in channels and over the watershed. The shape of the rising limb is controlled by the characteristics of the basin along with the duration, intensity, and spatial variation of the storm.

There are different physical and geomorphic characteristics of the basin that controls how it will go up means further the slope of this rising limb will be very high or flat, which is controlled by the characteristics of the basing as well as the type of storm. The type of the storms, how long the storm occurs.

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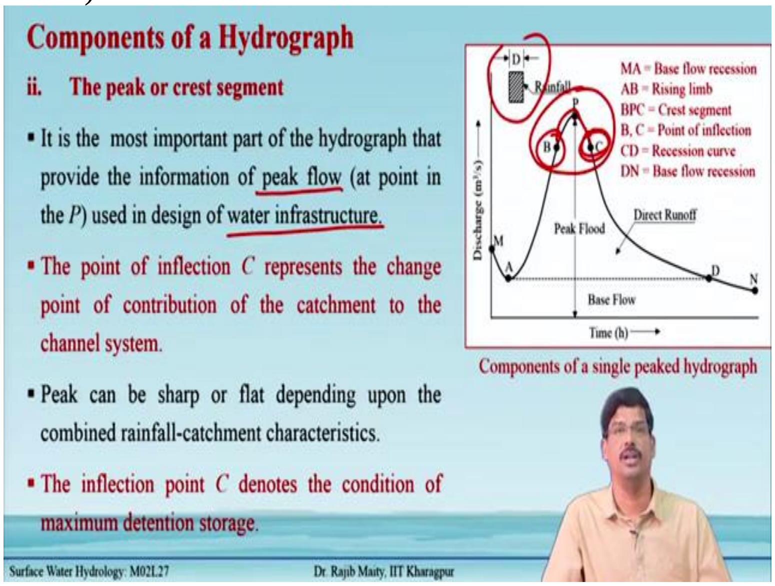

ii. **The peak or crest segment**

The second part is the big component that is BPC, this curve is shown in fig.1. It is called the crest segment and it is the most important part of the hydrograph that provides the information of peak flow (at the point in the P) used in the design of water infrastructure.

It is very important for any analysis because it gives the peak flow of a particular rainfall event. So, for a specific rainfall event if I want to know that this much maximum flow needs to pass through a particular section. So, that information is very much important for any water infrastructure. So, that is why the peak of this hydrograph is important in this considering this aspect. Now, there are two points B and point C here these are called the point of inflection. When the slope changes, B is showing the ending of this rising limb and C is showing the starting of the falling limb. So, in between this one, the P denotes the maximum distance.

The point of inflection C represents the change point of the contribution of the catchment to the channel system. So, earlier what happens all this contribution comes from A point to B point up to P and C. So, it goes and the contribution comes from this overland flow and the entire watershed. Now, this peak can be served for the flat depending upon again the combination of the rainfall and the catchment characteristics.

And next comes that inflection point C denotes the condition of the maximum detention storage. So, at this point in the watershed, we can say that the detention storage due to the occurrence of the rainfall was maximum at that point after that it starts falling.

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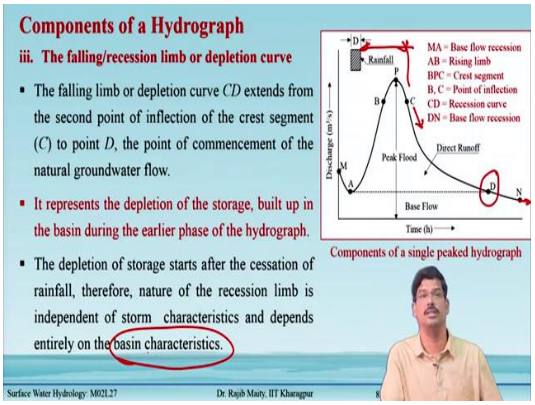

iii. **The falling/recession limb or depletion curve**

The falling limb or depletion curve CD extends from the second point of inflection of the crest segment (C) to point D, the point of commencement of the natural groundwater flow.

This falling limb represents the depletion of the storage that was built up in the basin in the early phase during the rainfall has occurred. Now, gradually the depletion of the storage starts after the cessation of rainfall therefore, the nature of the recession limb is independent of the storm characteristics and it depends entirely on the basin characteristics.

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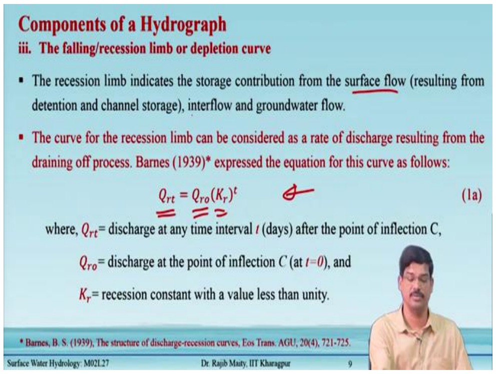

The recession limb indicates the storage contribution from the surface flow (resulting from detention and channel storage), interflow, and groundwater flow.

The curve for the recession limb can be considered as a rate of discharge resulting from the draining off process. Barnes (1939)* expressed the equation for this curve as follows:

$$Q_{rt} = Q_{ro}(K_r)^t \quad (1a)$$

Where, Q_{rt}= discharge at any time interval t (days) after the point of inflection C,

Q_{ro}= discharge at the point of inflection C (at t=0), and

K_r= recession constant with a value less than unity.

* Barnes, B. S. (1939), The structure of discharge-recession curves, Eos Trans. AGU, 20(4), 721-725.

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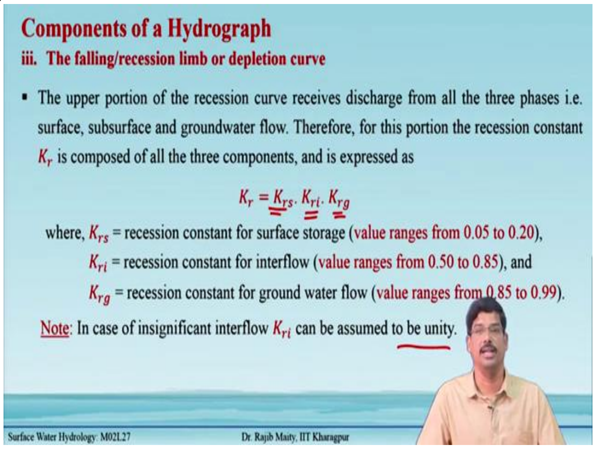

The upper portion of the recession curve receives the discharge from all three phases i.e. surface, subsurface, and groundwater flow. Therefore, for this portion, the recession constant K_r is composed of all the three components and is expressed as

$$K_r = K_{rs}.\ K_{ri}.\ K_{rg}$$

Where, K_{rs} = recession constant for surface storage (value ranges from 0.05 to 0.20),

K_{ri} = recession constant for interflow (value ranges from 0.50 to 0.85), and

K_{rg} = recession constant for groundwater flow (value ranges from 0.85 to 0.99).

It may be noted that in case of insignificant interflow K_ri can be assumed to be unity.

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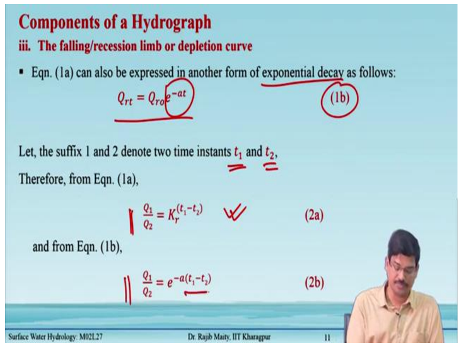

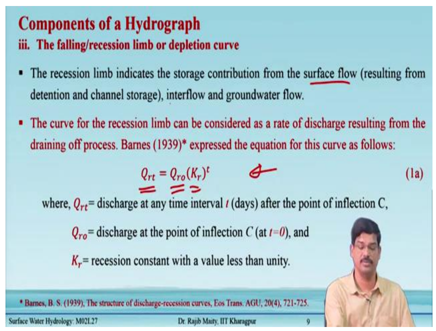

Eqn. (1a) can also be expressed in another form of exponential decay as follows:

$$Q_{rt} = Q_{ro}e^{-at} \qquad (1b)$$

Let, the suffix 1 and 2 denote two-time instants t_1 and t_2,

Therefore, from Eqn. (1a),

$$\frac{Q_1}{Q_2} = K_r^{(t_1-t_2)} \qquad (2a)$$

and from Eqn. (1b),

$$\frac{Q_1}{Q_2} = e^{-a(t_1-t_2)} \qquad (2b)$$

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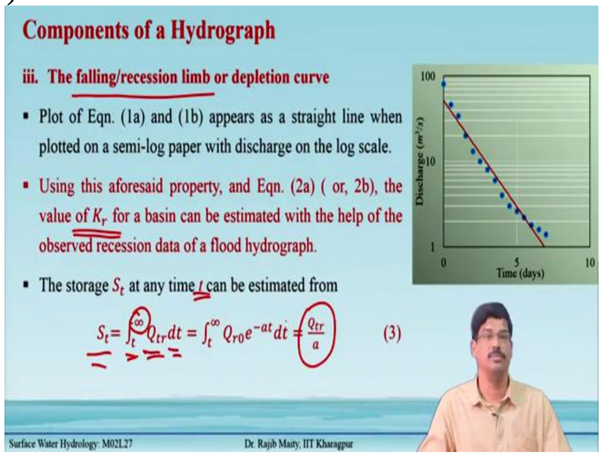

If take a logarithm of this equation 1(a) and 1(b), then on a similar paper if plot the equation 1(a), 1(b) it appears as a straight line as shown in fig.2. So, this one this property, which is approximately straight in the appearance of the straight line on this one Using this aforesaid property, and Eqn. (2a) (or, 2b), the value of K_r for a basin can be estimated with the help of the observed recession data of a flood hydrograph.

The storage S_t at any time t can be estimated from

$$S_t = \int_t^\infty Q_{tr} dt = \int_t^\infty Q_{r0} e^{-at} dt = \frac{Q_{tr}}{a} \quad (3)$$

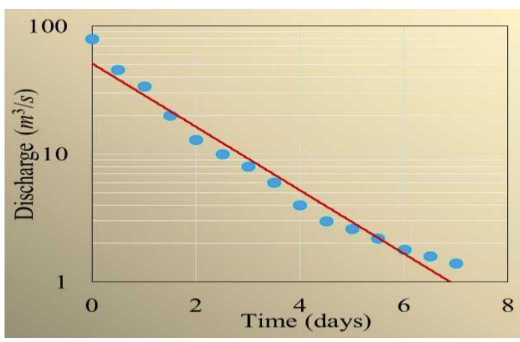

Fig.2 shows the storage recession curve

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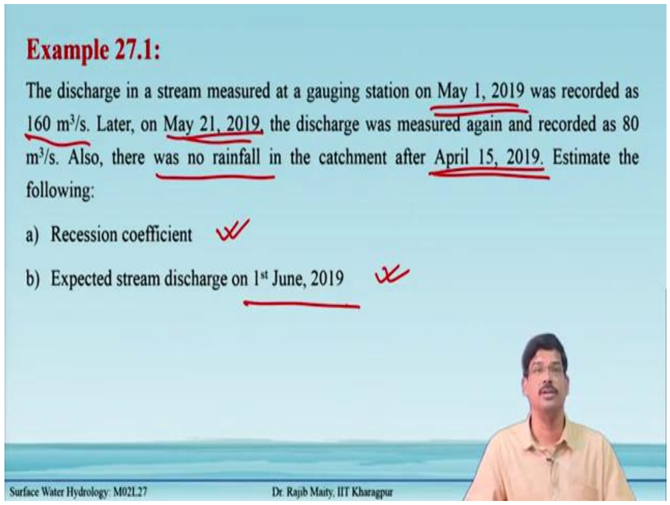

Example 27.1:

The discharge in a stream measured at a gauging station on May 1, 2019 was recorded as 160 m^3/s. Later, on May 21, 2019, the discharge was measured again and recorded as 80 m^3/s. Also, there was no rainfall in the catchment after April 15, 2019. Estimate the following:

a) Recession coefficient

b) Expected stream discharge on 1st June, 2019

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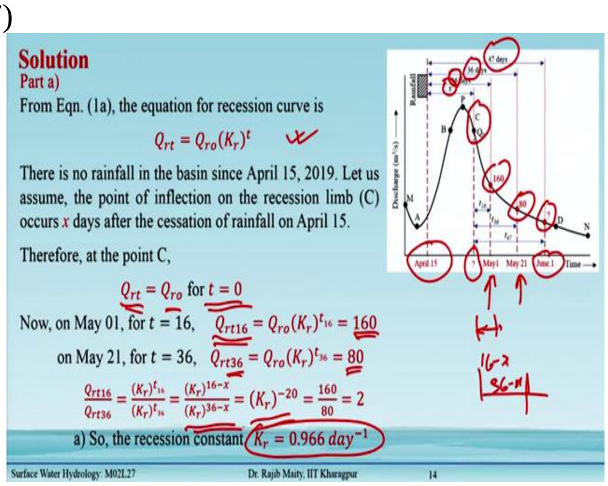

Solution

Part a)

From Eqn. (1a), the equation for recession curve is

$$Q_{rt} = Q_{ro}(K_r)^t$$

There is no rainfall in the basin since April 15, 2019. Let us assume, the point of inflection on the recession limb (C) occurs *x* days after the cessation of rainfall on April 15.

Therefore, at the point C,

$$Q_{rt} = Q_{ro} \text{ for } t = 0$$

$$\text{Now, on May 01, for } t = 16, \quad Q_{rt16} = Q_{ro}(K_r)^{t_{16}} = 160$$

$$\text{on May 21, for } t = 36, \quad Q_{rt36} = Q_{ro}(K_r)^{t_{36}} = 80$$

$$\frac{Q_{rt16}}{Q_{rt36}} = \frac{(K_r)^{t_{16}}}{(K_r)^{t_{36}}} = \frac{(K_r)^{16-x}}{(K_r)^{36-x}} = (K_r)^{-20} = \frac{160}{80} = 2$$

a) So, the recession constant, Kr = 0.966 day^{-1}

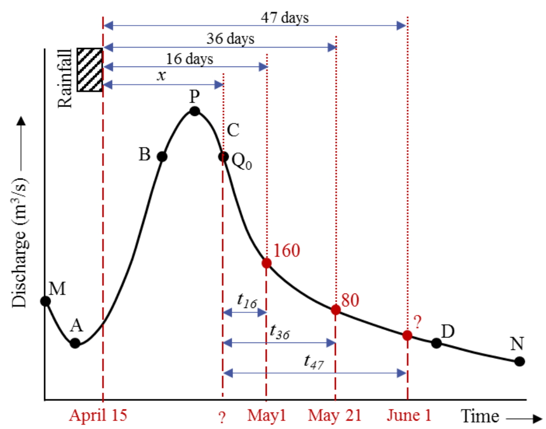

Fig.3 shows the discharge hydrograph of example 27.1

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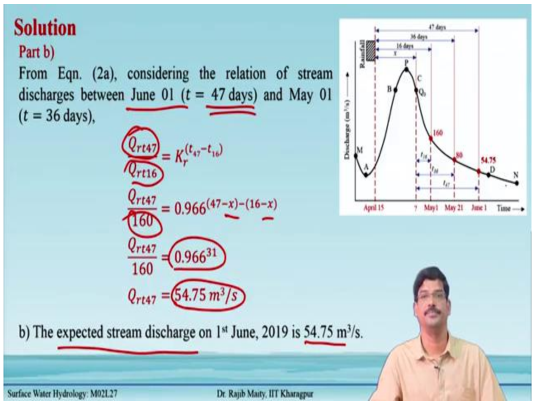

Part b)

From Eqn. (2a), considering the relation of stream discharges between June 01 (t= 47 days) and May 01 (t=36 days),

$$\frac{Q_{rt47}}{Q_{rt16}} = K_r^{(t_{47}-t_{16})}$$

$$\frac{Q_{rt47}}{160} = 0.966^{(47-x)-(16-x)}$$

$$\frac{Q_{rt47}}{160} = 0.966^{31}$$

$$Q_{rt47} = 54.75\ m^3/s$$

b) The expected stream discharge on 1st June, 2019 is 54.75 m^3/s.

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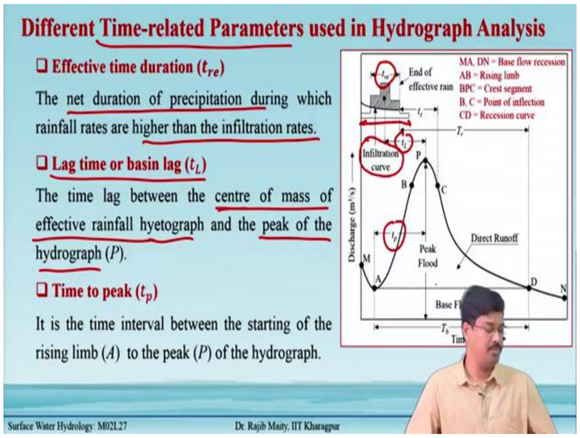

Different Time-related Parameters used in Hydrograph Analysis

The rainfall hydrograph and there is a line of this infiltration curve is also shown in fig.4. Above the infiltration curve whatever the rainfall is, call as rainfall excess and the duration of the rainfall excess is the total duration of rainfall.

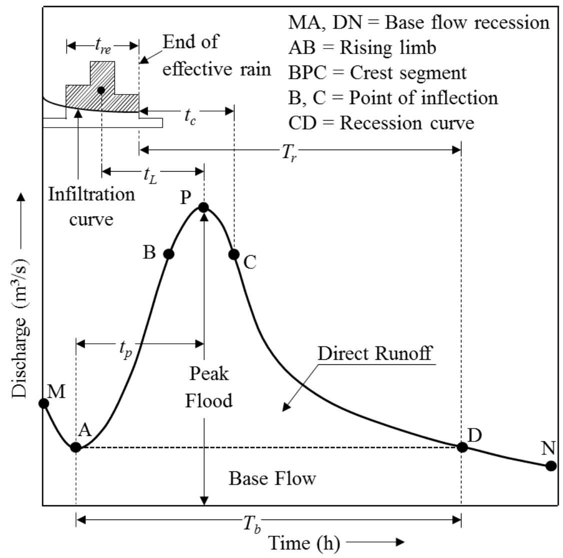

Fig.4 shows the elements of the flood hydrograph

Effective time duration (t_{re})

The net duration of precipitation during which rainfall rates are higher than the infiltration rates.

Lag time or basin lag (t_L)

The time lag between the center of mass of effective rainfall hyetograph and the peak of the hydrograph (P).

Time to peak (t_p)

It is the time interval between the starting of the rising limb (A) to the peak (P) of the hydrograph.

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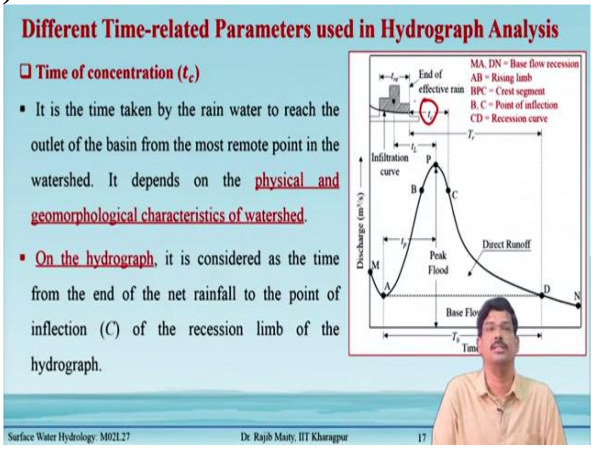

Time of concentration (t_c)

It is the time taken by the rainwater to reach the outlet of the basin from the most remote point in the watershed. It depends on the physical and geomorphological characteristics of the watershed.

On the hydrograph, it is considered as the time from the end of the net rainfall to the point of inflection (C) of the recession limb of the hydrograph.

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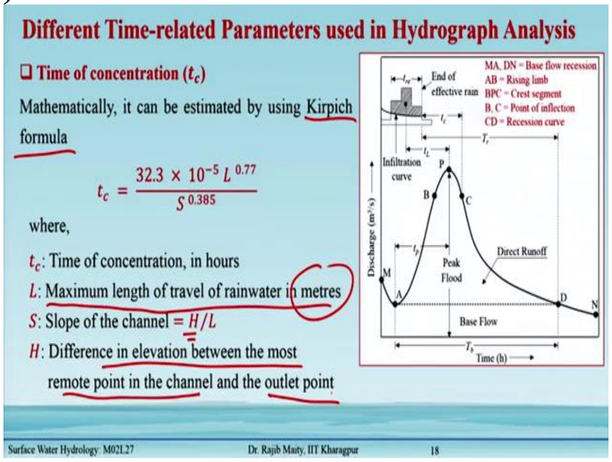

Time of concentration (t_c)

Mathematically, it can be estimated by using the Kirpich formula

$$t_c = \frac{32.3 \times 10^{-5} L^{0.77}}{S^{0.385}}$$

Where,

t_c: Time of concentration, in hours

L: Maximum length of travel of rainwater in meters

S: Slope of the channel $=H/L$

H: Difference in elevation between the most remote point in the channel and the outlet point

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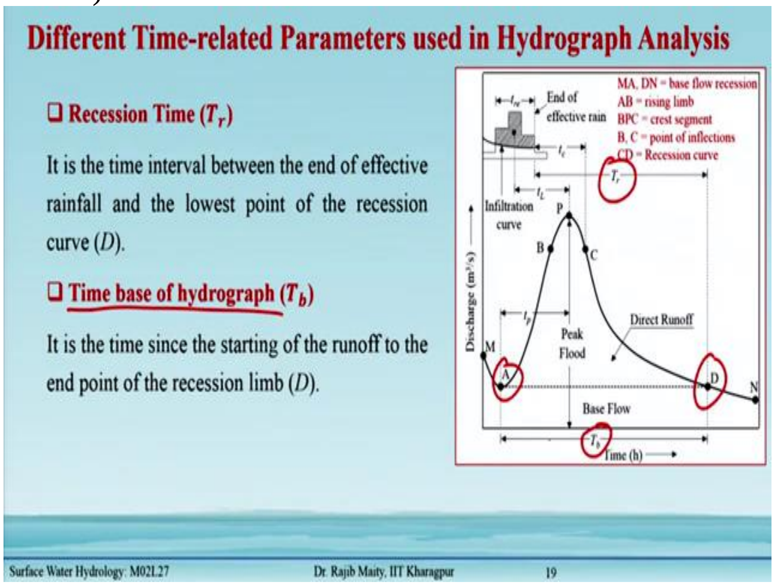

Recession Time (T_r)

It is the time interval between the end of effective rainfall and the lowest point of the recession curve (D).

Time base of hydrograph (T_b)

It is the time from the starting of the runoff to the endpoint of the recession limb (D).

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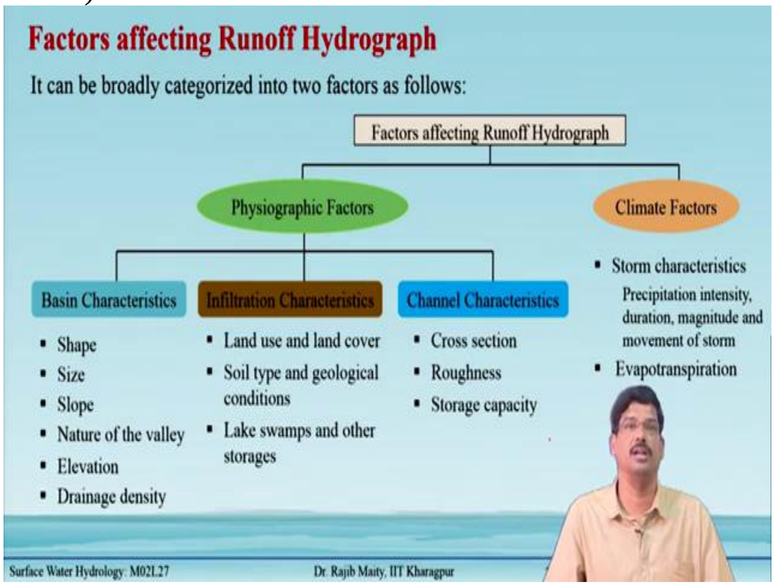

Factors affecting Runoff Hydrograph

There are different factors are there that affect the runoff hydrograph and this can be broadly categorized into two parts first one is a physiographic factor second one is climatic factors. Now, under this physiographic factor again it can be categorized into three parts basin characteristics, infiltration characteristics, and channel characteristics.

Under the basin characteristics, the shape of the basin size of the basin slope, their nature of the valley means in terms of its land use land cover, elevation, drainage density, these are the some of the things that influence this one.

Under the infiltration characteristics, it comes to the land use land cover over the entire basin soil type geological conditions, and then Lake Swamps and other stores are there. So, those causes an effect on the runoff hydrograph under the channel characteristic, the cross-sections of the channels the roughness, and the storage capacity of the channels, these are the controlling factors, then coming up to the climate factors, this is the storm characteristics.

Now, under the climatic factors the precipitation, intensity, duration, and, magnitude and even the movement of the storm whether it is moving from the downstream to upstream or upstream to downstream, evapotranspiration also affects the shape of the hydrograph.

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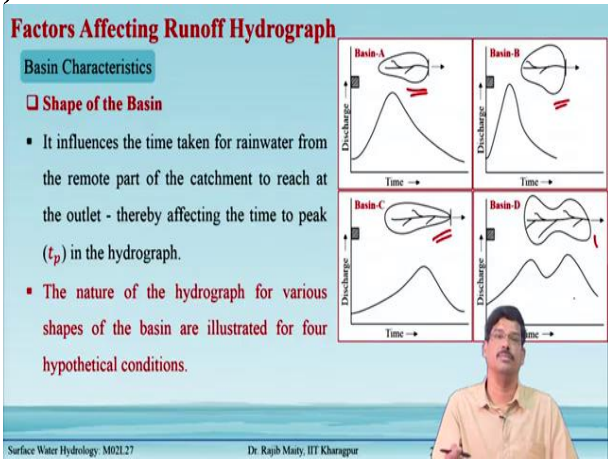

Basin Characteristics

i. The shape of the Basin

It influences the time taken for rainwater from the remote part of the catchment to reach the outlet - thereby affecting the time to peak (t_p) in the hydrograph.

The nature of the hydrograph for various shapes of the basin is illustrated for four hypothetical conditions which are shown in fig.5. So, when the watershed is wider towards the end or it can be narrower towards the end. So, depending on these two the peak may be earlier or the peak may be delayed.

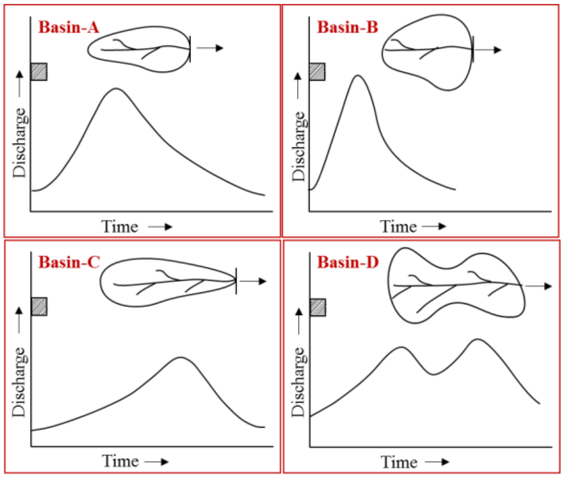

Fig.5 shows the effect of catchment shape on the hydrograph

For a basin where the circularity ratio is less compact, then it is the early pick can be observed, and then if there are some, it may two times that peak may arrive at the end so, that can result in a multi-peak hydrograph at the outlet. So, it the controls by the time that takes from the remote place to the outlet. So, thereby it is affecting the time to the peak to the hydrograph.

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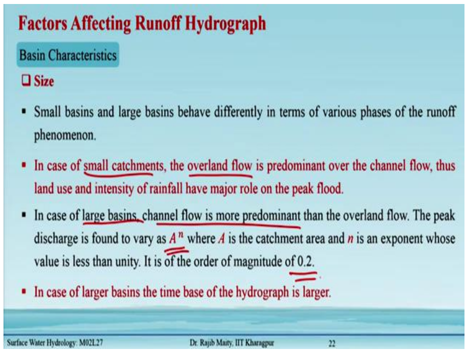

ii. Size

Small basins and large basins behave differently in terms of various phases of the runoff phenomenon. In the case of small catchments, the overland flow is predominant over the channel flow, thus land use and intensity of rainfall have a major role in the peak flood.

In the case of large basins, channel flow is more predominant than the overland flow. The peak discharge is found to vary as A^n where A is the catchment area and n is an exponent whose value is less than unity. It is of the order of magnitude of 0.2. In the case of larger basins, the time base of the hydrograph is larger.

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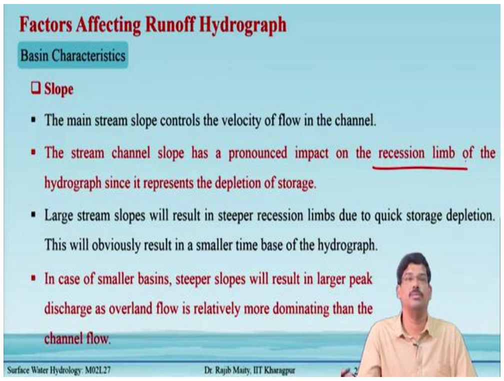

iii. Slope

Then come slope from the mainstream slope controls the velocity of the channel as it can be understood clearly. So, if the slope is more the velocity is more so, it will drain out quickly. So, the stream channel slope has a pronounced impact on the recession limb of this. So, how quickly it drains out. So, a large stream slope will result in the steeper recession limb due to the quick storage depletion and this will result in a smaller time base in the hydrograph. In the case of the smaller basin, the steeper slope will result in the larger peak discharge as overland flow is relatively more dominating than the channel flow.

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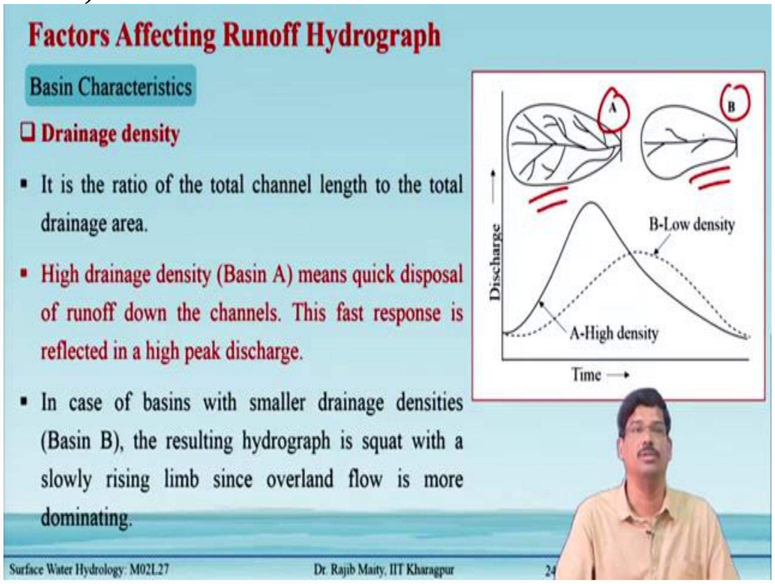

iv. Drainage density

In fig.6 drainage density for basin A is more than basin B and here the basin B is peak will be less and for basin A the peak will be high. And peak will be the time to peak will be quicker in case of basin A and the time to peak will be less for the basin B. Simply because here it will be more dominated by the channel flow which is which helps to drain out the basin quickly and in case of the second one it is the drainage density is less. So, other processes that prevent bass flow will dominate. So, it will take more time to reach the peak.

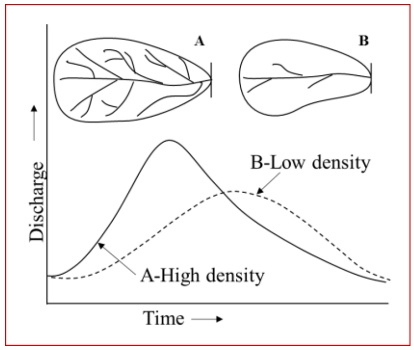

Fig.6 shows the role of drainage density on the hydrograph

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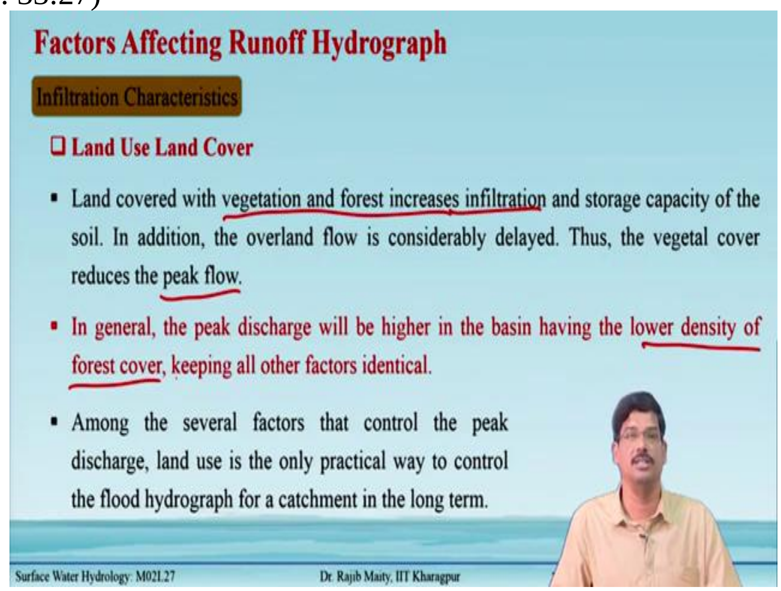

v. Land Use Land Cover

Land covered with vegetation and forest increases the infiltration and storage capacity of the soil. In addition, the overland flow is considerably delayed. Thus, the vegetal cover reduces the peak flow. In general, the peak discharge will be higher in the basin having the lower density of forest cover, keeping all other factors identical.

Among the several factors that control the peak discharge, land use is the only practical way to control the flood hydrograph for a catchment in the long term.

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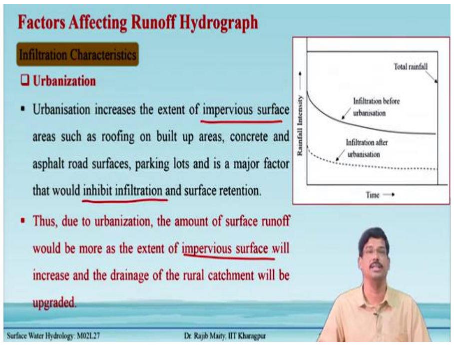

vi. urbanization

Urbanization increases the extent of impervious surface areas such as roofing on built-up areas, concrete and asphalt road surfaces, and parking lots and is a major factor that would inhibit infiltration and surface retention.

Thus, due to urbanization, the amount of surface runoff would be more as the extent of impervious surface will increase and the drainage of the rural catchment will be upgraded.

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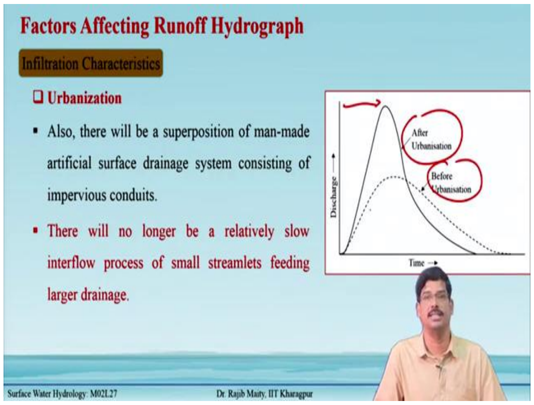

There will be a superposition of manmade artificial surface drainage system also consisting of impervious conduits and there will be no longer be a relatively slow interflow process of the small streamlets feeding the large drainage. So, the overall effect will be that after the urbanization the peak will be very high and quick whereas, before the urbanization, it was delayed and less.

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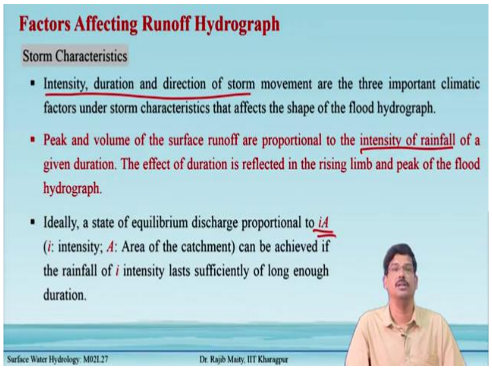

vii. Storm Characteristics

Intensity, duration, and direction of storm movement are the three important climatic factors under storm characteristics that affect the shape of the flood hydrograph. The peak and volume of the surface runoff are proportional to the intensity of rainfall of a given duration. The effect of duration is reflected in the rising limb and peak of the flood hydrograph.

Ideally, a state of equilibrium discharge proportional to iA (i: intensity; A: Area of the catchment) can be achieved if the rainfall of i intensity lasts sufficiently of long enough duration.

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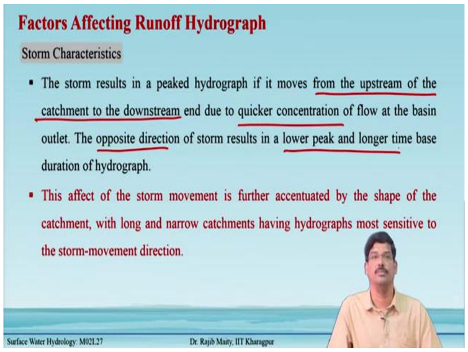

The storm results in a peaked hydrograph if it moves from the upstream of the catchment to the downstream end due to a quicker concentration of flow at the basin outlet. The opposite direction of the storm results in a lower peak and longer time base duration of the hydrograph.

This effect of the storm movement is further accentuated by the shape of the catchment, with long and narrow catchments having hydrographs most sensitive to the storm-movement direction.

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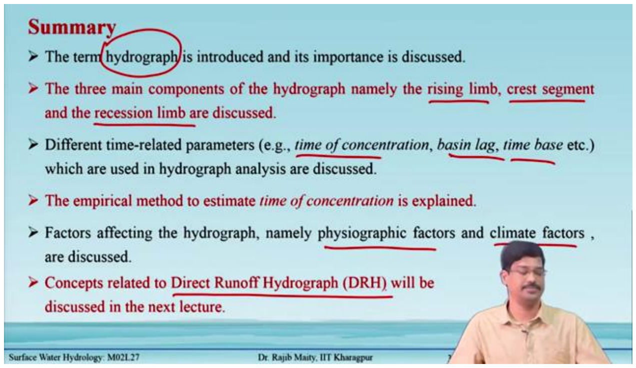

Summary

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

- The term hydrograph is introduced and its importance is discussed.
- The three main components of the hydrograph namely the rising limb, crest segment, and the recession limb are discussed.
- Different time-related parameters (e.g., time of concentration, basin lag, time base, etc.) which are used in hydrograph analysis are discussed.
- The empirical method to estimate the time of concentration is explained.
- Factors affecting the hydrograph, namely physiographic factors and climate factors, are discussed.
- Concepts related to Direct Runoff Hydrograph (DRH) will be discussed in the next lecture.