Surface Water Hydrology
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Lecture – 22
Introduction and Catchment Characteristics

In this lecture we will give some introduction and the catchment characteristics; those are responsible for different runoff processes

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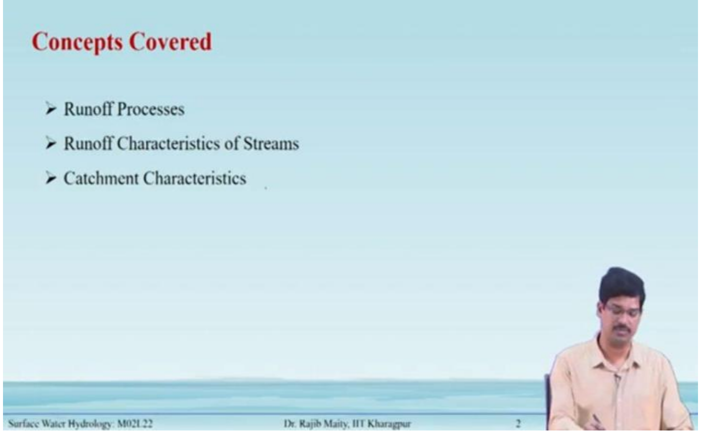

The concepts covered should be the runoff processes, runoff characteristics of streams, and catchment characteristics.

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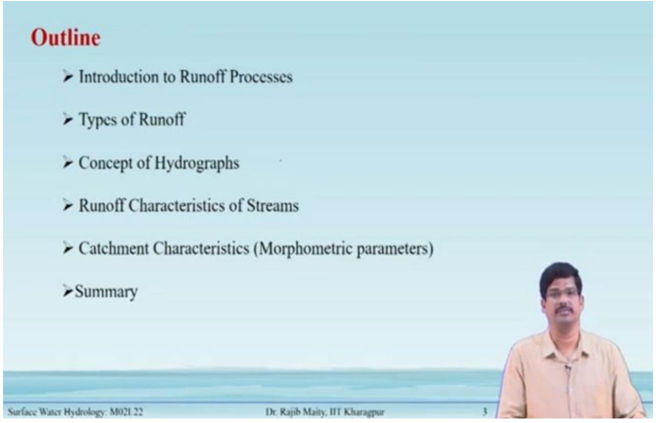

The outline goes like this introduction to runoff processes, types of runoff, the concept of hydrographs, runoff characteristics of storms, streams, and catchment characteristics and these are mostly the morphometric parameters; and finally, the summary.

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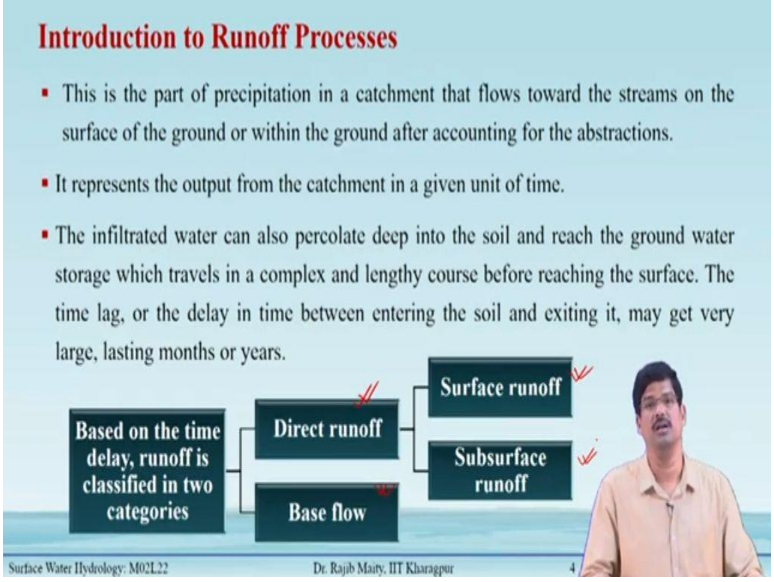

Introduction to Runoff Process

This is the part of precipitation in a catchment that flows towards the stream on the surface of the ground, or within the ground after accounting for the abstraction. So, once all those abstractions are met, the remaining amount of the precipitation goes through different processes over a catchment and is ultimately joined in the stream.

This represents the output from the catchment in a given unit of time. The infiltrated water can also percolate deep into the soil and reach the groundwater storage which travels in a complex and lengthy course before reaching the surface. The time lag, or the delay in time between entering the soil and exiting it, may get very large, lasting months or years.

It may vary from the few minutes; and if it is delayed, then it can be from months to years also. So, based on the time delay it can be categorized into two parts. One is called the direct runoff part and the other one is called the base flow part.

Direct runoff part means it comes and almost promptly it is coming out, and base property basically goes down and joins to the groundwater flow, and then there is slowly after a significant amount of time, it comes out and constitutes the base flow. Under this direct runoff, again there are two components; one is the surface runoff that never goes below the ground, and the subsurface runoff means it flows just below the ground almost in a parallel path of the topography of the catchment.

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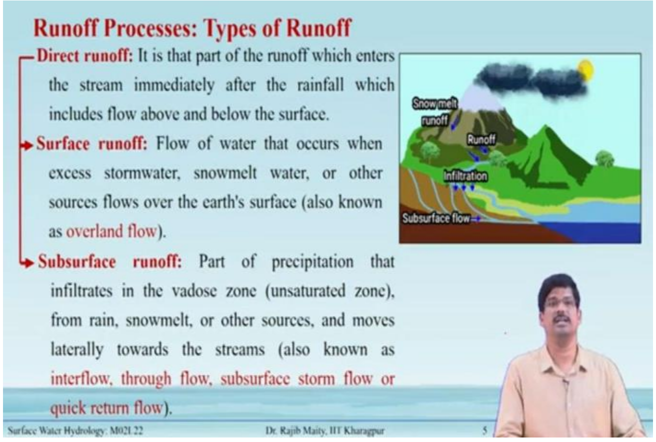

Runoff Processes: Types of Runoff

Depending on the time delay, there are different types of runoffs are there –

Direct runoff: It is that part of the runoff which enters the stream immediately after the rainfall which includes flow above and below the surface.

Surface runoff: Flow of water that occurs when excess stormwater, snowmelt water, or other sources flows over the earth's surface (also known as overland flow).

Subsurface runoff: Part of precipitation that infiltrates in the vadose zone (unsaturated zone), from rain, snowmelt, or other sources, and moves laterally towards the streams (also known as interflow, through flow, subsurface storm flow, or quick return flow).

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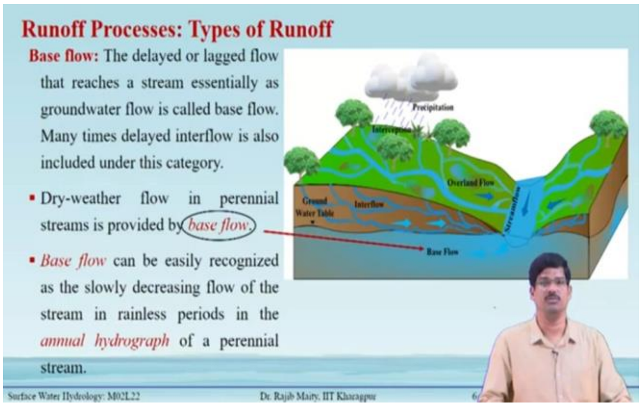

Base flow: The delayed or lagged flow that reaches a stream essentially as groundwater flow is called base flow. Many times, delayed interflow is also included under this category.

Dry-weather flow in perennial streams is provided by the base flow. Base flow can be easily recognized as the slowly decreasing flow of the stream in rainless periods in the annual hydrograph of a perennial stream.

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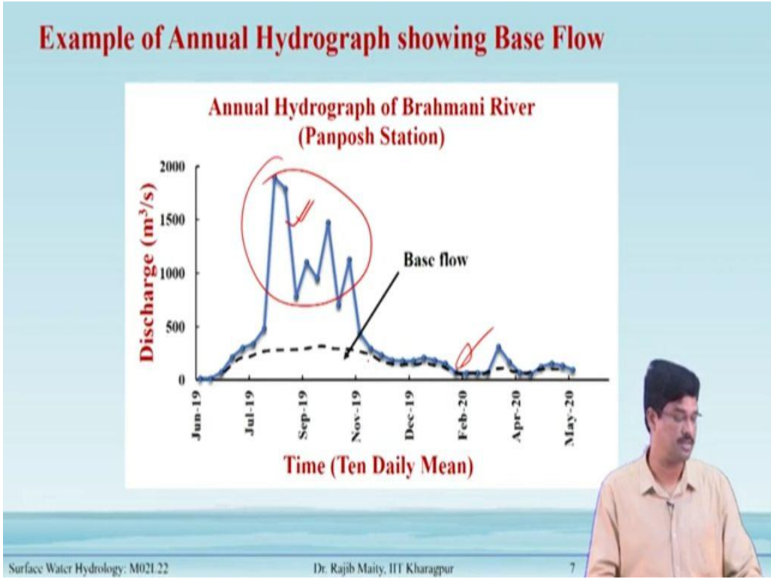

Some rivers flow almost throughout the year; even when there is no rain. And one such typical diagram of the time series is shown in fig.1. of discharge vs. time; here the time is the 10 daily mean of the one river that name is Brahmani River, it in this data is taken from the Panposh station. And in the figure, the blue line is showing the hydrograph and how it is varying over this time.

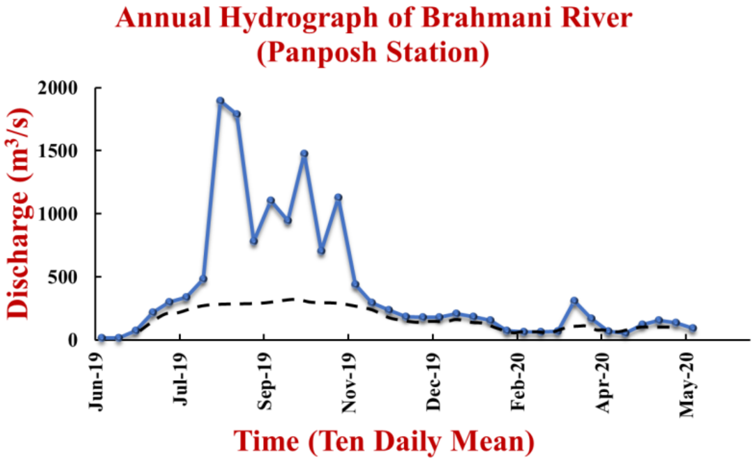

Fig.1 shows the annual hydrograph of the Brahmani River

When there is a high flow time, it is during monsoon time. But, during the non-monsoon time also, there are some flows are there; almost throughout the year, it is flowing. So, this dotted line is showing that the base flow that contributes to this one. So, how to separate this base flow and how to get this one that we will discuss when we are discussing the hydrograph analysis in detail later on.

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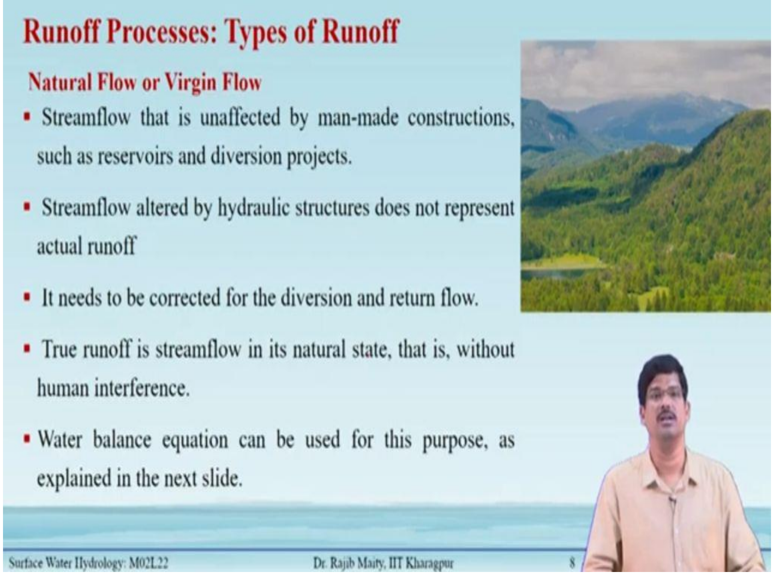

Natural Flow or Virgin Flow

Some catchments are free from any manmade structure, any man-made obstruction; the flow that is coming out of that catchment that we call a natural flow. The stream flow altered by the hydraulic structure does not represent the actual runoff, and it needs to be corrected for the diversion and the return flow.

The true runoff is stream flow in its natural state that is without any human interface. So, sometimes even if there are some structures are there, we need to calculate what should be the natural flow or the virgin flow. There we generally use the water balance equation to calculate the natural flow or the virgin flow.

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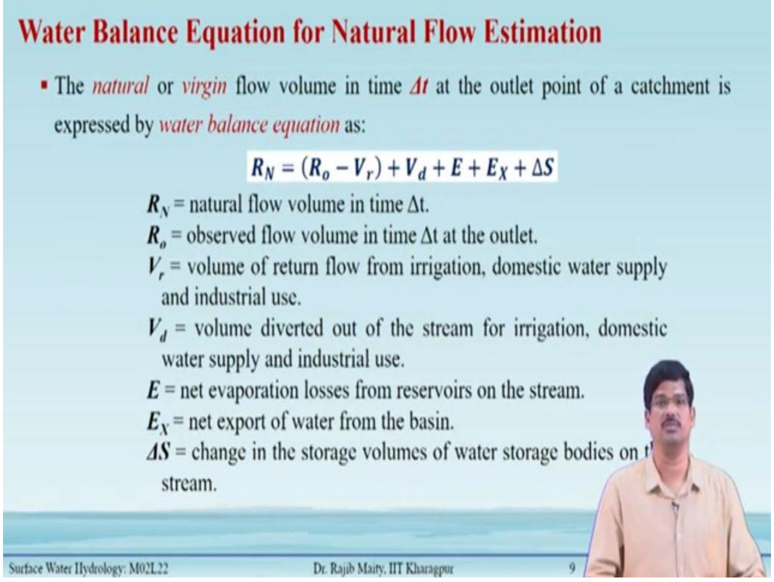

The natural or virgin flow volume in time Δt at the outlet point of a catchment is expressed by the water balance equation as:

$$R_N = (R_o - V_r) + V_d + E + E_X + \Delta S$$

R_N = natural flow volume in time Δt.

R_o = observed flow volume in time Δt at the outlet.

V_r = volume of return flow from irrigation, domestic water supply, and industrial use.

V_d = volume diverted out of the stream for irrigation, domestic water supply, and industrial use.

E = net evaporation losses from reservoirs on the stream.

E_X = net export of water from the basin.

ΔS = change in the storage volumes of water storage bodies on the stream.

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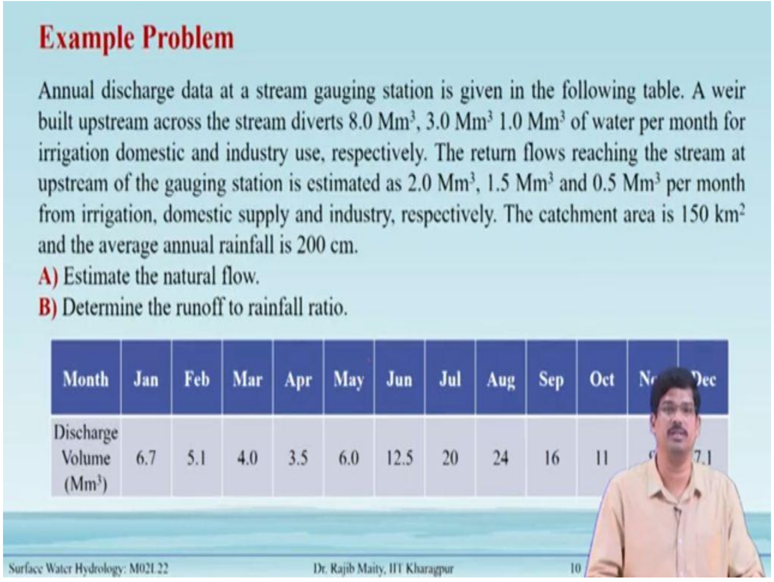

Example Problem

Annual discharge data at a stream gauging station is given in the following table. A weir built upstream across the stream diverts 8.0 Mm^3, 3.0 Mm^3 1.0 Mm^3 of water per month for irrigation domestic and industrial use, respectively. The return flows reaching the stream upstream of the gauging station are estimated as 2.0 Mm^3, 1.5 $Mm^{3,}$ and 0.5 Mm^3 per month from irrigation, domestic supply, and industry, respectively. The catchment area is 150 km^2 and the average annual rainfall is 200 cm.

A) Estimate the natural flow.

B) Determine the runoff to rainfall ratio.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Discharge Volume (Mm^3)	6.7	5.1	4.0	3.5	6.0	12.5	20	24	16	11	9	7.1

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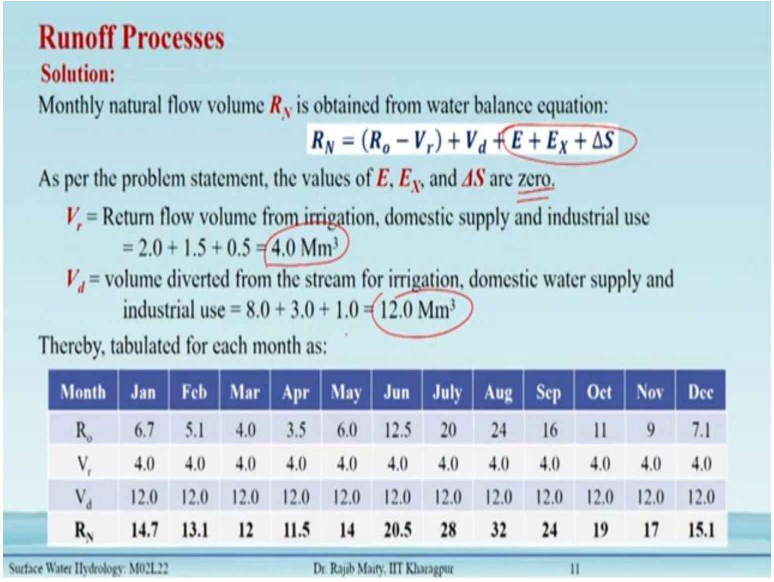

Solution:

Monthly natural flow volume R_N is obtained from the water balance equation:

$$R_N = (R_o - V_r) + V_d + E + E_X + \Delta S$$

As per the problem statement, the values of E, E_X, and ΔS are zero.

V_r = Return flow volume from irrigation, domestic supply and industrial use

= 2.0 + 1.5 + 0.5 = 4.0 Mm^3

V_d = volume diverted from the stream for irrigation, domestic water supply and industrial use = 8.0 + 3.0 + 1.0 = 12.0 Mm^3

Thereby, tabulated for each month as:

Month	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
R_o	6.7	5.1	4.0	3.5	6.0	12.5	20	24	16	11	9	7.1
V_r	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
V_d	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
R_N	**14.7**	**13.1**	**12**	**11.5**	**14**	**20.5**	**28**	**32**	**24**	**19**	**17**	**15.1**

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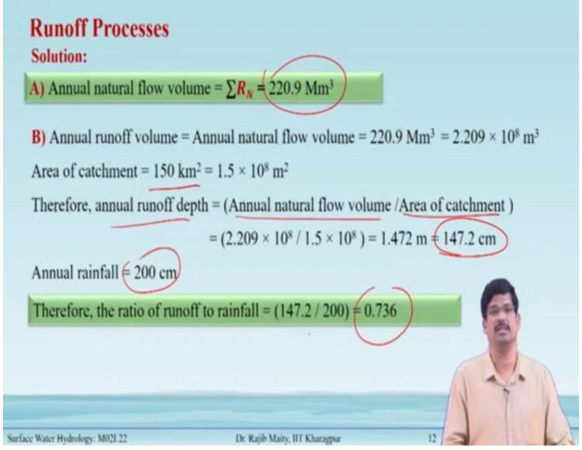

Solution:

A) Annual natural flow volume = $\sum \boldsymbol{R_N}$ = 220.9 Mm^3

B) Annual runoff volume = Annual natural flow volume = 220.9 Mm^3 = 2.209 × 10^8 m^3

Area of catchment = 150 km^2 = 1.5 × 10^8 m^2

Therefore, annual runoff depth = (Annual natural flow volume /Area of catchment)

= (2.209 × 10^8 / 1.5 × 10^8) = 1.472 m = 147.2 cm

Annual rainfall = 200 cm

Therefore, the ratio of runoff to rainfall = (147.2 / 200) = 0.736

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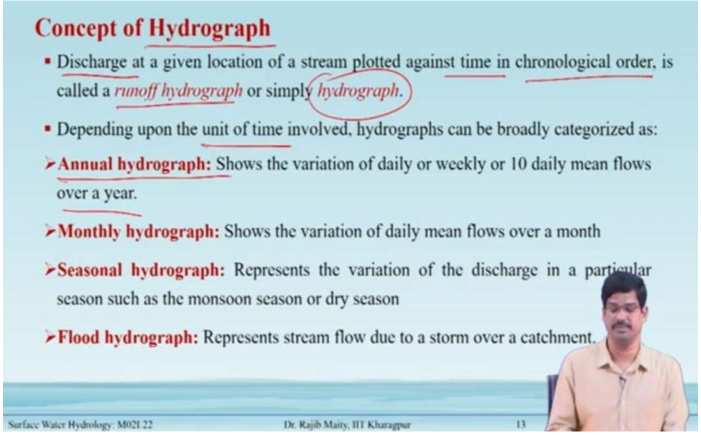

Concept of Hydrograph

Discharge at a given location of a stream plotted against time in chronological order is called a runoff hydrograph or simply hydrograph.

Depending upon the unit of time involved, hydrographs can be broadly categorized as:

Annual hydrograph: This shows the variation of daily or weekly or 10 daily mean flows over a year.

Monthly hydrograph: Shows the variation of daily mean flows over a month

Seasonal hydrograph: Represents the variation of the discharge in a particular season such as the monsoon season or dry season

Flood hydrograph: Represents stream flow due to a storm over a catchment.

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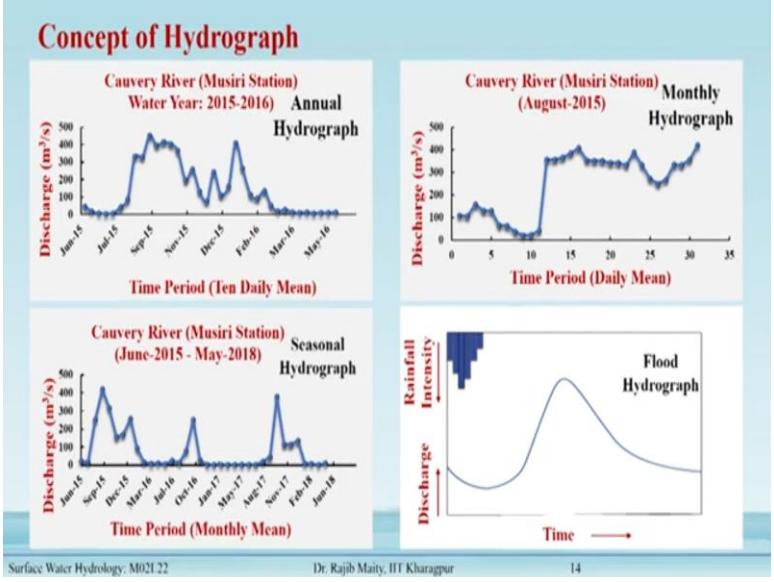

Some of the examples are shown in fig.2. The first one is taken from the Kaveri River, which is showing an annual hydrograph for the water year for 2015-16. This is again the same river the monthly hydrograph for the month of August, and then the seasonal hydrograph is also shown in fig2. from June to May. And then, this is the one typical example of the flood hydrograph, where the rainfall intensity and discharges are shown on the same plot.

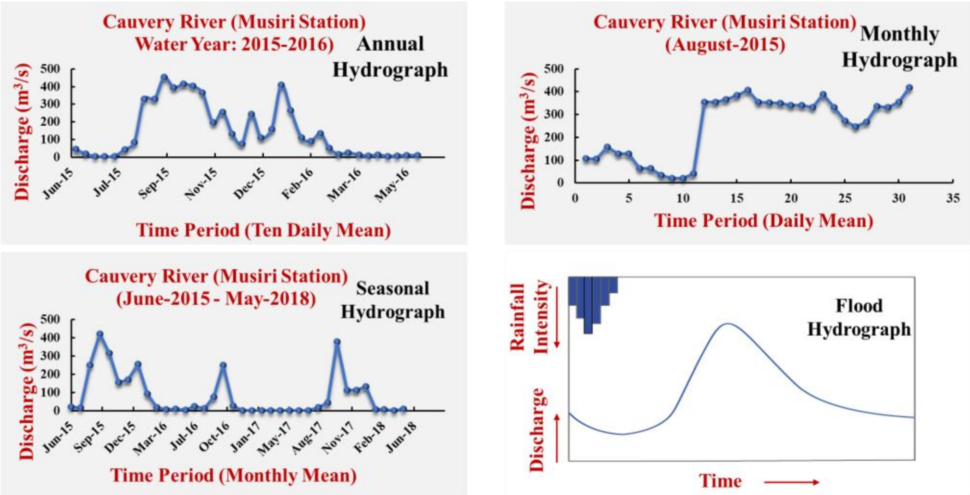

Fig.2 shows the annual and seasonal hydrograph of the Cauvery River

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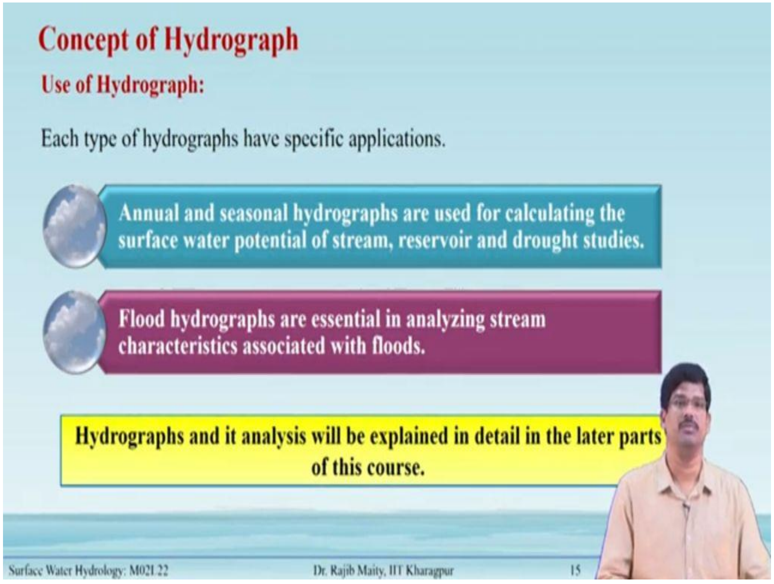

Concept of Hydrograph

Use of Hydrograph:

There are two major-specific applications is there.

i. Annual and seasonal hydrographs are used for calculating the surface water potential of the stream reservoir, and the drought studies.

ii. A flood hydrograph is essential in analyzing the stream characteristics associated with floods.

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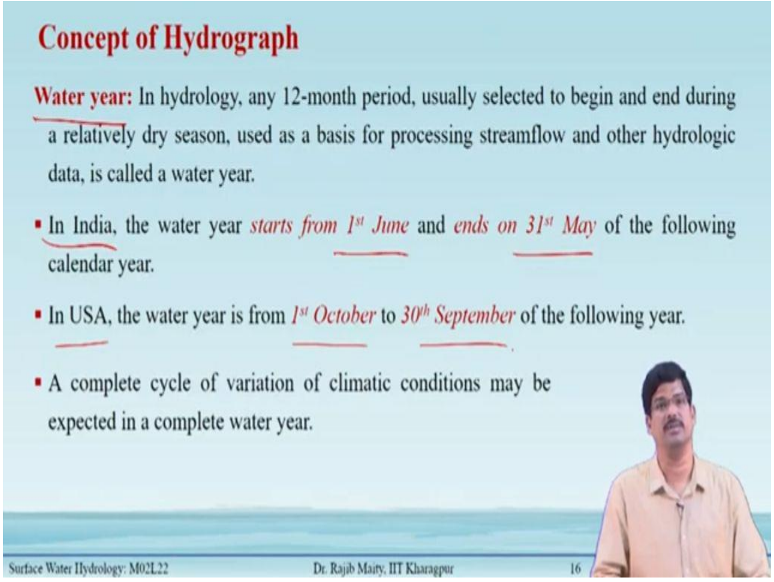

Water year: In hydrology, any 12 months, usually selected to begin and end during a relatively dry season, used as a basis for processing streamflow and other hydrologic data, is called a water year.

In India, the water year starts from 1st June and ends on 31st May of the following calendar year. In the USA, the water year is from 1st October to 30th September of the following year.

So, this generally gives a complete cycle of the variation of climatic conditions over the region that can be expected in a complete water year.

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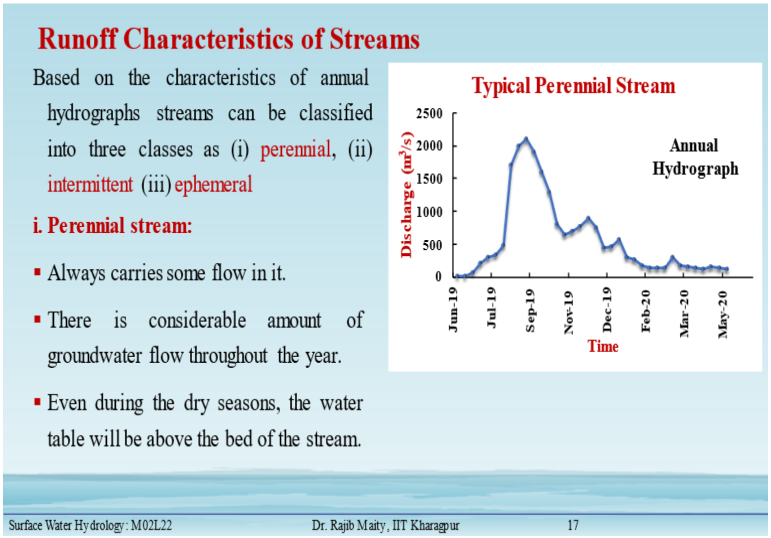

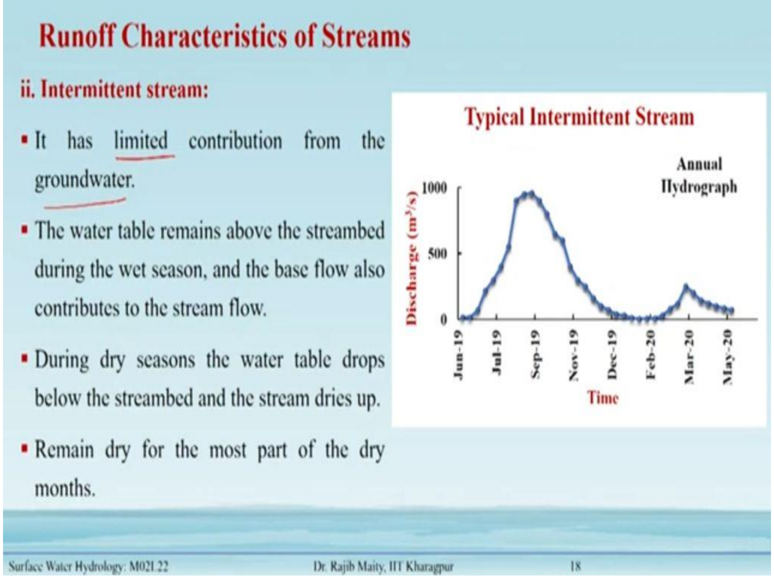

Based on the characteristics of the annual hydrograph, the streams can be classified into three different classes. One is the perennial, then intermittent, and then ephemeral.

i. **Perennial stream:**

It is always carrying some flow into it. So, there is a considerable amount of groundwater flow throughout the year. Even during the dry season, the water table will be above the bed of the stream; so that comes from the groundwater contribution.

ii. **Intermittent stream:**

It has limited contribution from the groundwater; limited means we cannot say that completely 0. But there are some times some contribution we get from the groundwater also. The water table remains above the streambed during the wet season particularly, and the base flow also contributes to the streamflow. And during the dry season, the water table drops below; and that time there is no contribution from the groundwater, and it remains dry for most of the part during the dry months.

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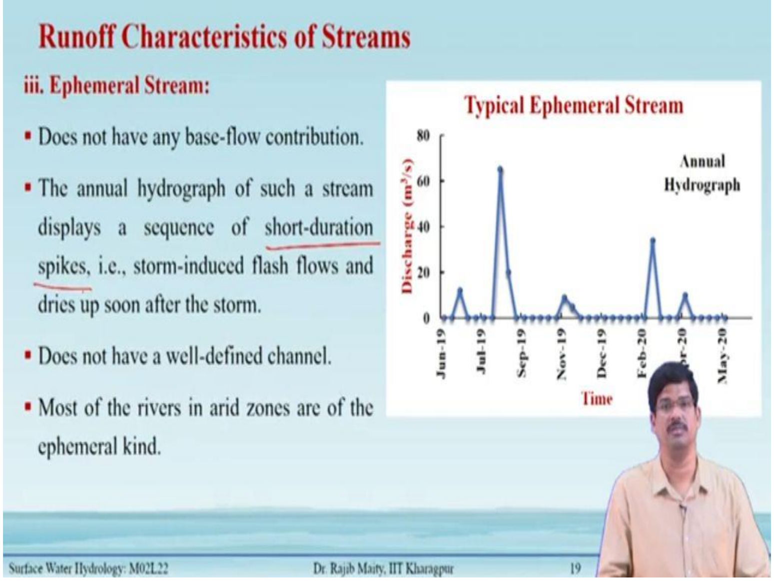

iii. Ephemeral Stream:

It has no contribution from the base flow. So, the annual hydrograph of such streams displays a sequence of short-duration spikes. So, short duration spikes are the characteristics, so far as the ephemeral streams are concerned; and these spikes are generally the storm-induced flash flows and dry up soon after the storm. It does not have a well-defined channel; most of the rivers in the arid zones are of the ephemeral kind.

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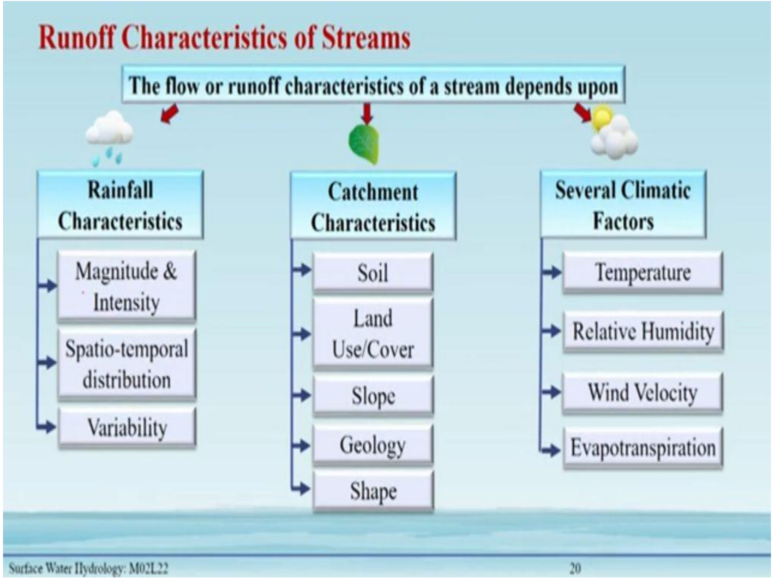

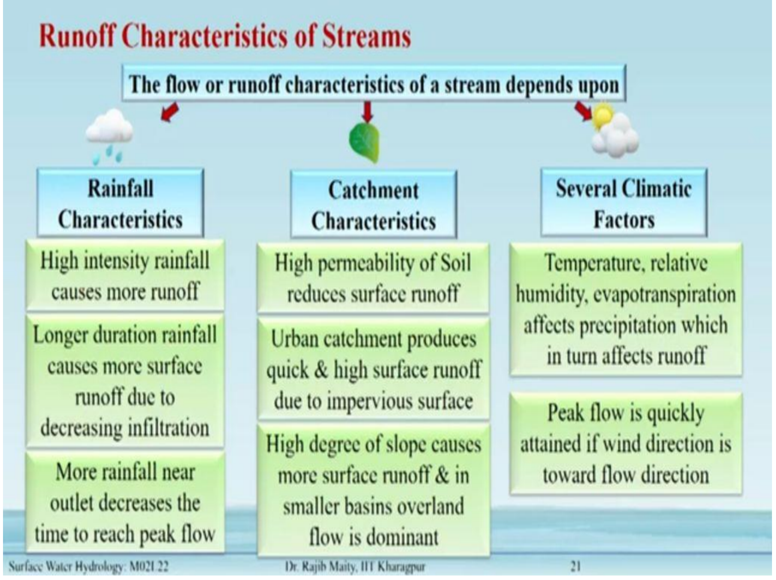

There are different characteristics of the stream; the flow of the runoff characteristics into the stream depends upon three different major categories. The first one is the rainfall characteristics, then catchment characteristics; and finally, the several climatic factors also influence this.

Under the category of rainfall characteristics, the magnitude and intensity of the rainfall, Spatio-temporal distribution of the rainfall; and variability of the time variability of the rainfall that matters how much runoff should be generated.

Under the category of the catchment characteristics, it comes from the soil properties, land use/land cover, slope of the catchment, geology, geomorphology, and shape of that of the catchment.

Finally, the several climatic factors that are also there; include temperature, relative humidity, wind velocity, evapotranspiration, etc; which also influence the total runoff from the catchment.

Under the rainfall characteristics, the high-intensity rainfall causes more runoff, duration of longer duration of rainfall causes more surface runoff due to the decreasing infiltration. More rainfall near the outlet areas time to peak flows has become less; so, it depends on this. For example, the last point is giving some Spatio-temporal variation of the rainfall characteristics; how the shape of the runoff or the hydrograph runoff hydrograph changes.

Similarly, under the catchment characteristics, the high permeability of the soil reduces the surface runoff. And urban catchment produces a quick and high surface runoff due to the impervious nature of the surface there. And the high degree of the slope causes more surface runoff in the smaller basins, overland flow is dominated there.

And under climatic conditions that temperature, relative humidity, evapotranspiration these things affect the precipitation, which in turn affect the runoff. And peak flow is quickly attained if the wind direction towards the flow direction is there.

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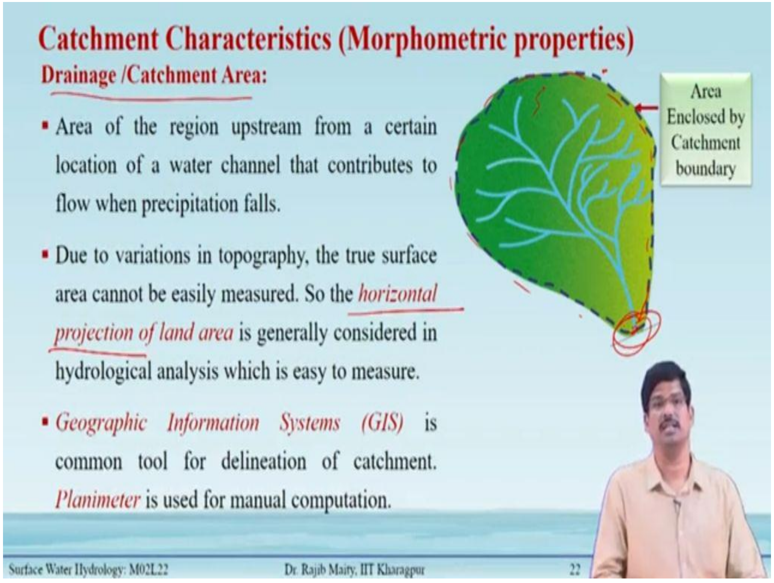

Catchment Characteristics (Morphometric properties)

Drainage /Catchment Area:

Now, we will discuss the morphometric properties of the catchment. The area of the region upstream of a certain location of the water channel contributes to the flow when the precipitation falls. So, this is the outlet of the catchment in the adjoining diagram.

Any drop of rainfall that falls inside the catchment eventually will follow some path and come to this outlet. And it will find some other path to go some other point. Now, due to the variation in the topography, the true surface area cannot be easily measured. So, the horizontal projection of land area is generally considered in hydrological analysis which is easy to measure. Geographic Information Systems (GIS) is a common tool for the delineation of the catchment. Planimeter is used for manual computation.

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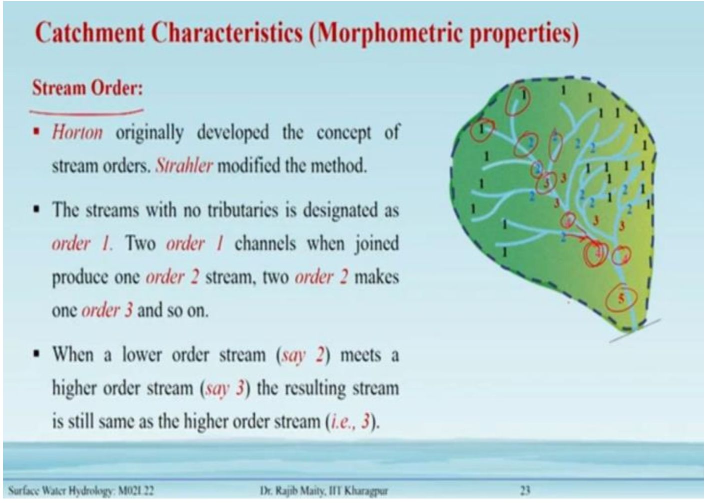

Stream Order:

Horton originally developed the concept of the stream order, and Strahler modified this method. It generally goes like this the stream with no tributaries is designated as order 1. For example, this is an odd-order 1 stream; this is also another order 1 stream. Now, when two orders 1 stream joins, produce one order 2 streams, two order 2 makes one order 3, and so on.

When a lower order stream (say 2) meets a higher order stream (say 3) the resulting stream is still the same as the higher-order stream (i.e., 3).

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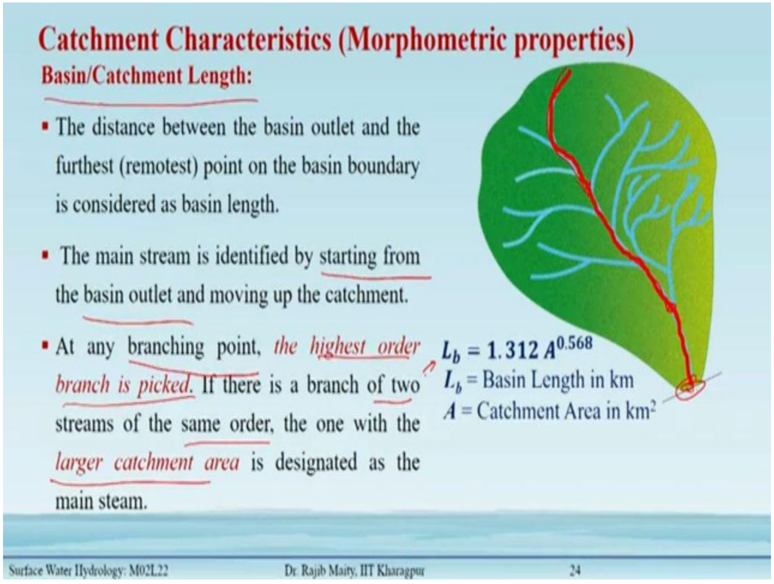

Basin/Catchment Length:

The distance between the basin outlet and the furthest (remotest) point on the basin boundary is considered basin length. The mainstream is identified by starting from the basin outlet and moving up the catchment.

At any branching point, the highest order branch is picked. If there is a branch of two streams of the same order, the one with the larger catchment area is designated as the main steam.

There are some empirical relations are there.

$$L_b = 1.312\ A^{0.568}$$

where L_b is the basin length in kilometers, A is the catchment area in kilometer square.

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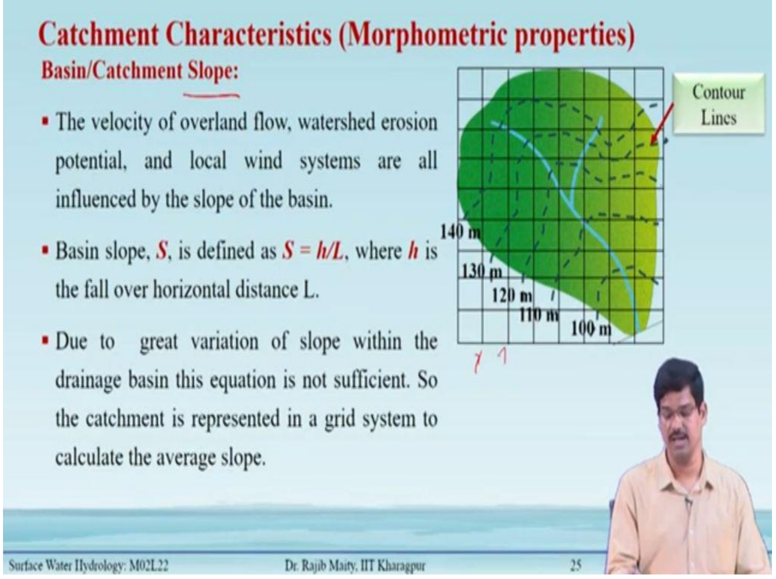

Basin/Catchment Slope:

The velocity of overland flow, watershed erosion potential, and local wind systems are all influenced by the slope of the basin.

Basin slope, S, is defined as S = h/L, where h is the fall over horizontal distance L.

Due to the great variation of slope within the drainage basin, this equation is not sufficient. So, the catchment is represented in a grid system to calculate the average slope.

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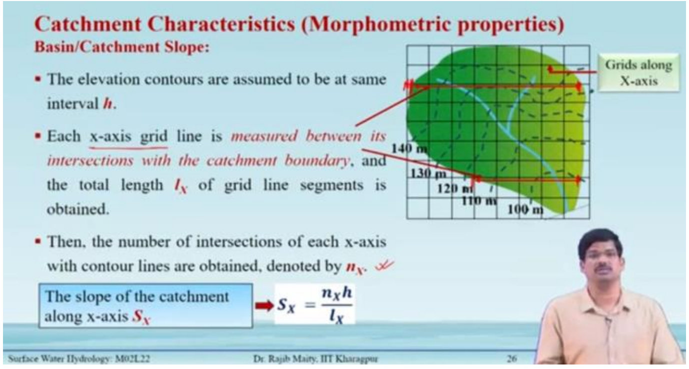

Basin/Catchment Slope:

To get the catchment slope mathematically, the elevation of the contours is assumed to be the same interval as h. Each x-axis grid line is measured between its intersections with the catchment boundary, and the total length I_X of grid line segments is obtained.

.Now, then the number of intersections of the x-axis with the contour lines are obtained and denoted as n_X. Now, the slope of the catchment along the x-axis S_X

$$S_X = \frac{n_X h}{l_X}$$

The l_X is the total of this length that is shown here.

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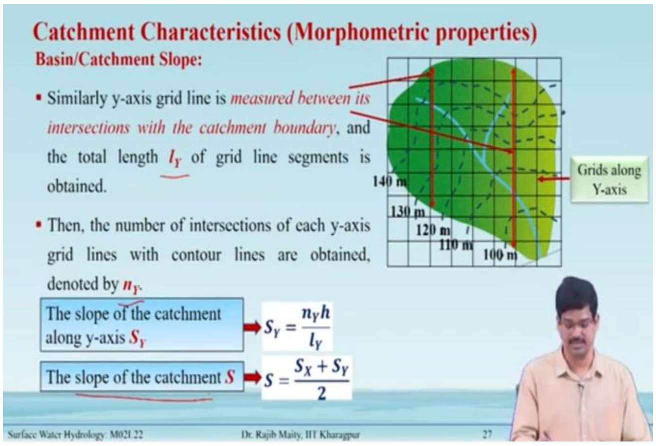

Similarly, the y-axis grid line is measured between its intersections with the catchment boundary, and the total length l_Y of grid line segments is obtained. Then, the number of intersections of each y-axis grid line with contour lines are obtained, denoted by n_Y.

The slope of the catchment along the y-axis S_Y

$$S_X = \frac{n_X h}{l_X}$$

The slope of the catchment S

$$S = \frac{S_X + S_Y}{2}$$

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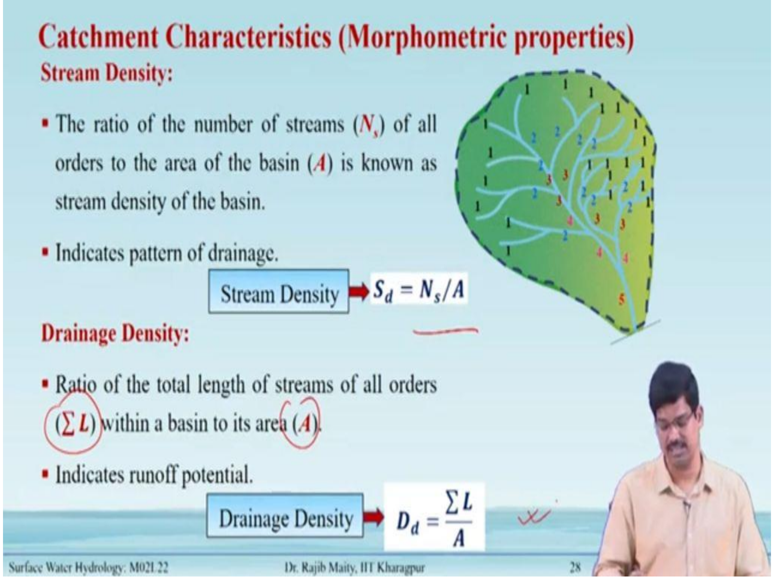

Stream Density:

The ratio of the number of streams (N_s) of all orders to the area of the basin (A) is known as the stream density of the basin. This indicates the pattern of the drainage.

The stream density $S_d = N_s/A$

Drainage Density:

The ratio of the total length of streams of all orders ($\sum \boldsymbol{L}$) within a basin to its area (A). This indicates the runoff potential.

The drainage density $D_d = \sum \boldsymbol{L} / A$

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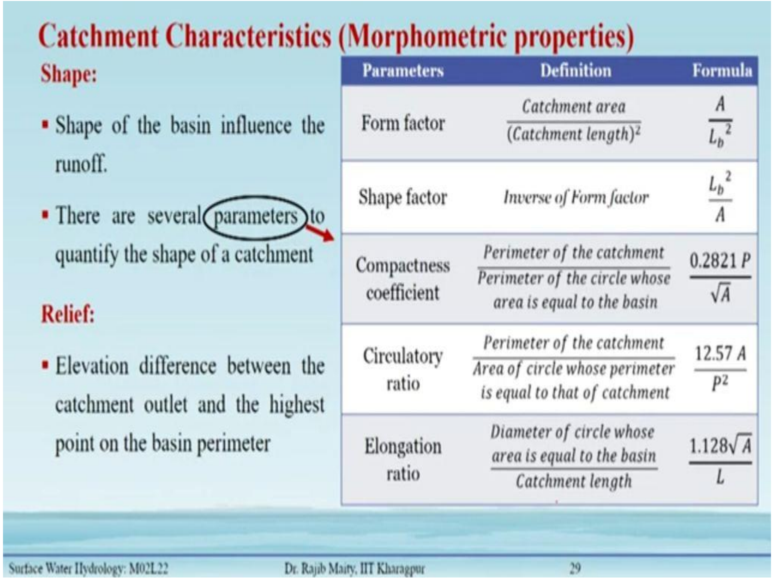

Shape: The shape of the basin influences the runoff, and several parameters are there to quantify the shape of a catchment. For example, the form factor, shape factor, compactness coefficient, circulatory ratio, elongation ratio, and their definitions are also shown in Table 1.

Table 1 shows the parameters that quantify the shape of the catchment

Parameters	Definition	Formula
Form factor	$\frac{Catchment\ area}{(Catchment\ length)^2}$	$\frac{A}{{L_b}^2}$
Shape factor	$Inverse\ of\ Form\ factor$	$\frac{{L_b}^2}{A}$
Compactness coefficient	$\frac{Perimeter\ of\ the\ catchment}{Perimeter\ of\ the\ circle\ whose\ area\ is\ equal\ to\ the\ basin}$	$\frac{0.2821\ P}{\sqrt{A}}$
Circulatory ratio	$\frac{Perimeter\ of\ the\ catchment}{Area\ of\ circle\ whose\ perimeter\ is\ equal\ to\ that\ of\ catchment}$	$\frac{12.57\ A}{P^2}$
Elongation ratio	$\frac{Diameter\ of\ circle\ whose\ area\ is\ equal\ to\ the\ basin}{Catchment\ length}$	$\frac{1.128\sqrt{A}}{L}$

Relief: Relief is the elevation difference between the lowest point to the highest point of a particular catchment.

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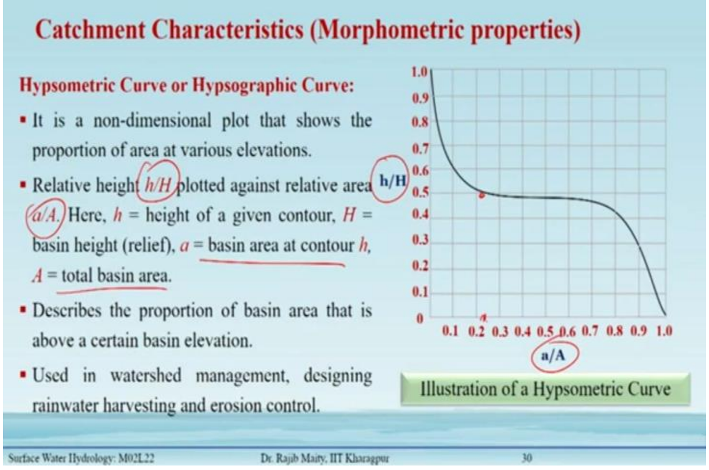

Hypsometric Curve or Hypsographic Curve:

It is a non-dimensional plot that shows the proportion of the area at various elevations.

Relative height *h/H* plotted against relative area *a/A*. Here, *h* = height of a given contour, *H* = basin height (relief), *a* = basin area at contour *h*, *A* = total basin area.

The hypsometric curve describes the proportion of basin area that is above a certain basin elevation. And it is used in watershed management, designing rainwater harvesting, and erosion control.

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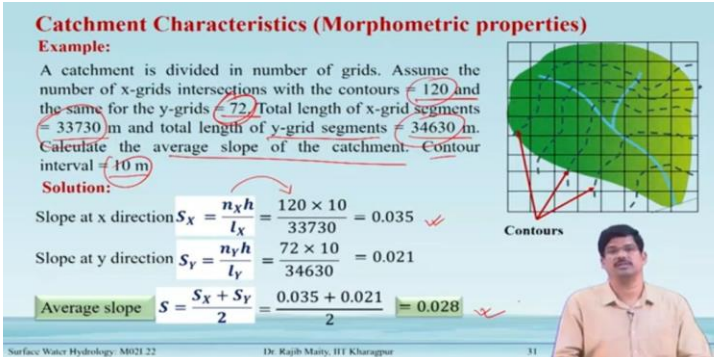

Example:

A catchment is divided into number of grids. Assume the number of x-grids intersections with the contours = 120 and the same for the y-grids = 72. Total length of x-grid segments =

33730 m and total length of y-grid segments = 34630 m. Calculate the average slope of the catchment. Contour interval = 10 m

Solution:

The slope at x-direction

$$S_X = \frac{n_X h}{l_X} \quad =(120\times10)/33730 =0.035$$

Slope in y-direction

$$S_Y = \frac{n_Y h}{l_Y} \quad =(72\times10)/34630=0.021$$

Average slope

$$S = \frac{S_X + S_Y}{2} \quad =(0.035+0.021)/2=0.028$$

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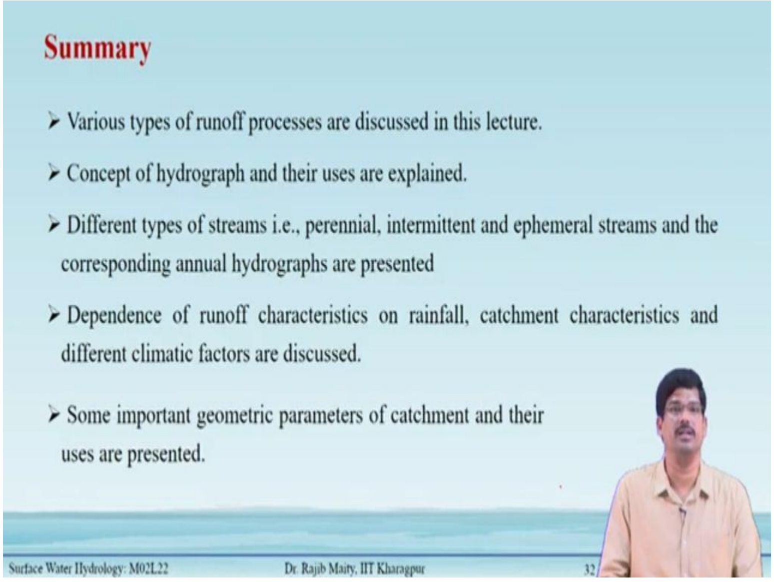

Summary

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

- ➢ Various types of runoff processes are discussed in this lecture.
- ➢ The concept of hydrographs and their uses are explained.
- ➢ Different types of streams i.e., perennial, intermittent, and ephemeral streams and the corresponding annual hydrographs are presented

- Dependence of runoff characteristics on rainfall, catchment characteristics, and different climatic factors are discussed.
- Some important geometric parameters of catchment and their uses are presented.