Surface Water Hydrology
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Lecture – 20
Indirect Streamflow Measurement

In lecture 20, we will discuss indirect streamflow measurement techniques.

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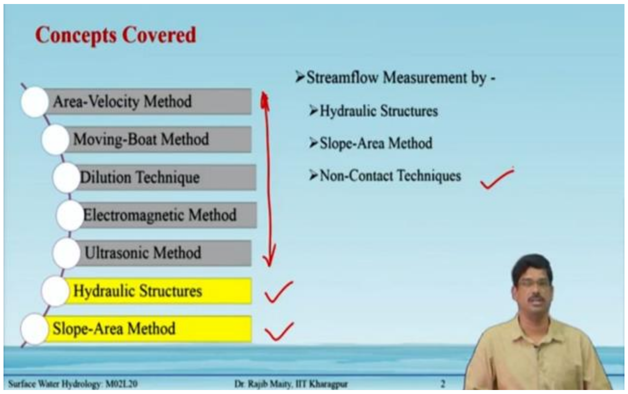

We will cover mainly the streamflow measurement, the discharge measurement through hydraulic structures, and the slope area method. Apart from this, we will also take up some non-contact techniques that are mostly used in the laboratory scale setup.

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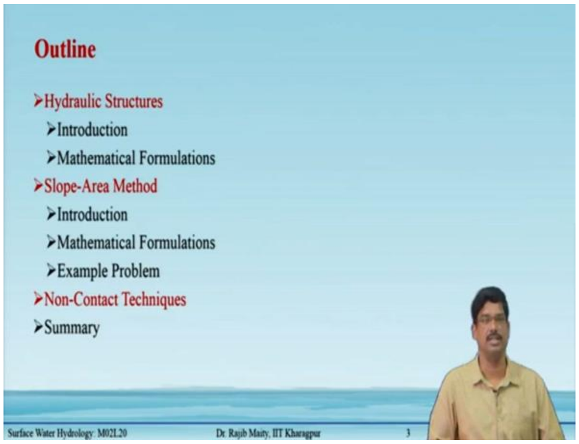

The outline of this lecture is like this. First, we will take up the hydraulic structures, its introduction to different structures; mostly we will mean confined within the introductory part; And then most important field level application method, which is slope-area method; in under that will give some introduction, then mathematical formulations and take up some example problems. And finally, we will take some non-contact techniques before we go to the summary.

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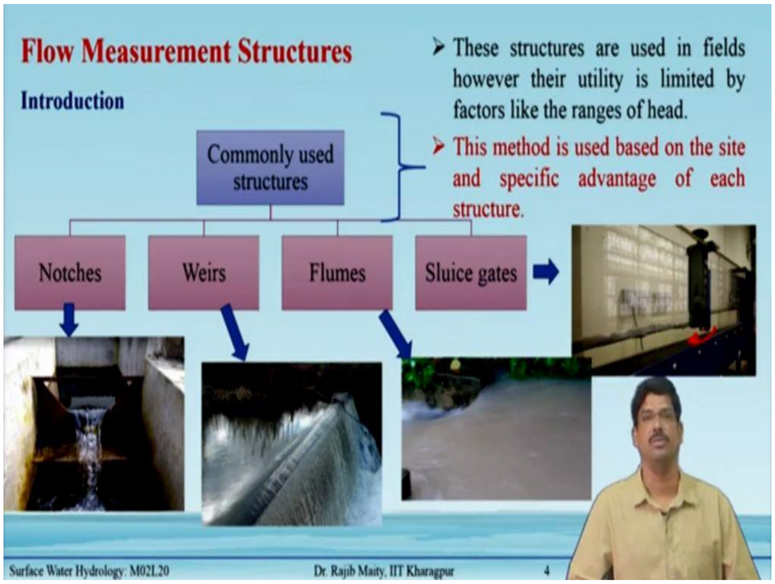

Flow Measurement Structures

The flow measurement structures there are different types of structures are possible; and the four major categories of these different structures are: The first one is the notches. Notches are basically can be of different shapes, over which the water flows. There are flumes are there, where we create some reduction in the flow area; and through that using some mathematical formulation, we can calculate the discharge.

Sluice gates, which have been seen at different places at the field level applications. In the have laboratory, when we use it for the generation of this hydraulic jump to study the hydraulic jump; this is the part below which the water comes out. And this is a typical laboratory-scale setup sluice gate.

Now, these structures are used in the field; however, their utility is limited by the factors like range of the head. It depends on which type of structure can be utilized in the field. It depends on different factors like the amount of discharge, the quality of the discharge, then different sediment load or debris loads.

So, all the structures cannot be used for a particular site condition. So, this method is used based on the site and the specific advantage of each structure that we can see; and depending on the site condition, we have to select these things.

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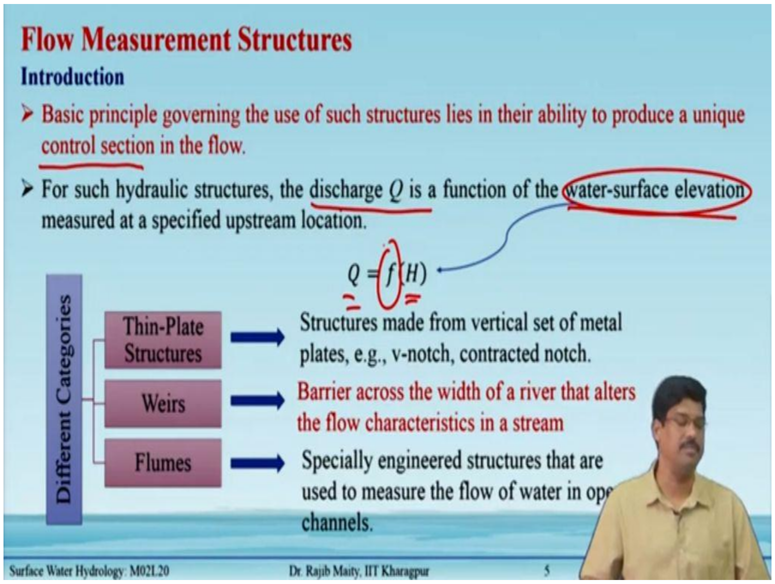

The basic principle over which this kind of structure works on are that lies in the ability to produce a unique control section. So, this is important the control section that is being created through this structure; and from there we collect some reading. And that is related to the discharge through a function.

For such hydraulic structures, the discharge Q is a function of the water-surface elevation measured at a specified upstream location.

$$Q = f(H)$$

Now, there are different categories are there, for example, some thin plate structures are there, weirs, flumes. The thin plate structures are made from a vertical set of metal plates, e.g., v-notch, contracted notch. The weirs are the barrier across the width of the river that alters the flow characteristics in the streams. And then we can measure what is the height above the crest level and that is that can be related through a function through the discharge. Coming to the flumes, it is specifically engineered structures that are used to measure the flow of the water in the open channels. And generally, it also depends on how much of the discharge, what is range of the discharge can be taken up by these different structures.

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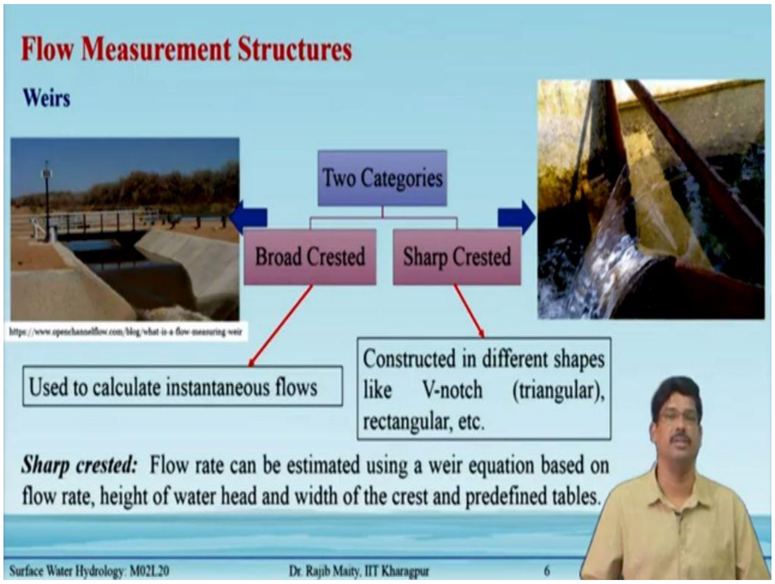

Weirs

There are two major categories are there; one is the broad crested weirs and the other one is the sharp-crested weir. And these broad crested weirs are generally used to calculate the instantaneous flow; whereas the sharp-crested weirs are constructed in different shapes like V-notch, which is triangular in shape. And it can be of the other shapes like rectangular. Then, the sharp-crested weir flow rate can be estimated using the weir equation based on the flow rate, the height of the water head, and width of the crest, and predefined tables are available. So, from there we can calculate the discharge over that structure.

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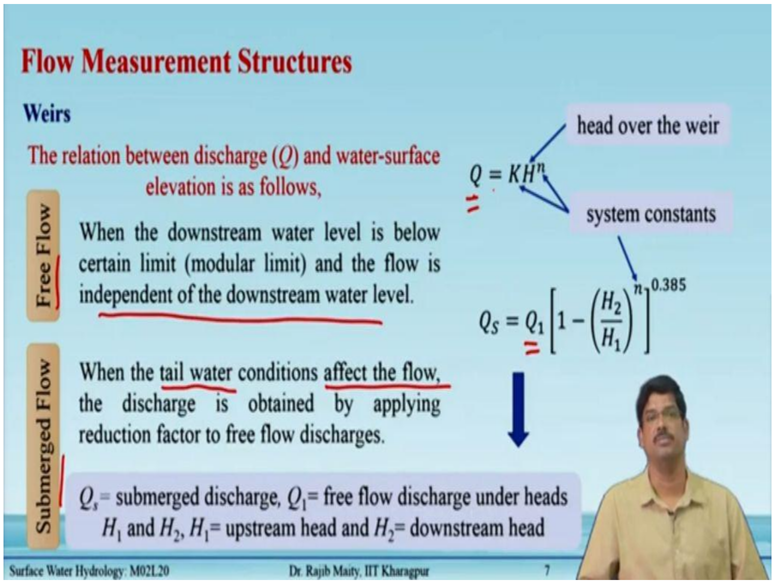

The relation between the discharge and the water surface elevation that is H are as follows.

$$Q = KH^n$$

K=System Concept

H^n=Head over the weir

When it is the free flow, when the downstream water level is below a certain limit; the modular limit; then the flow is independent of the downstream water level. On the other hand, when it is a submerged flow, the tail water condition affects the flow; and the discharge is obtained by applying the reduction factor for the free flow discharge.

So, that means when we call it a free flow, that time it is independent of the downstream water level; and when it is submerged, then the water conditions the tailwater condition that is in the downstream it affects the flow. This is the major difference between these two.

The relationship between the discharge and that head is

$$Q_S = Q_1\left[1-\left(\frac{H_2}{H_1}\right)^n\right]^{0.385}$$

Q_s= submerged discharge,

Q_1= free-flow discharge under heads H_1 and H_2,

H_1= upstream head and

H_2= downstream head

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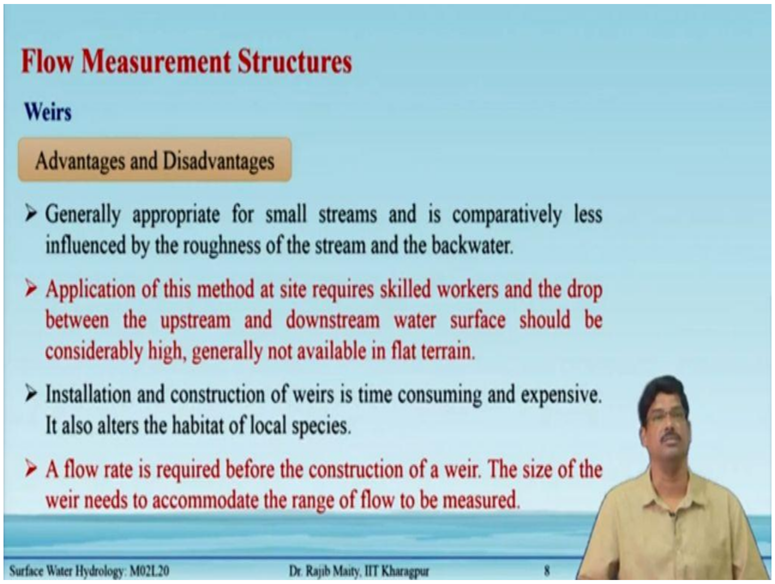

Advantages and Disadvantages

- Generally appropriate for small streams and is comparatively less influenced by the roughness of the stream and the backwater.
- Application of this method at the site requires skilled workers and the drop between the upstream and downstream water surface should be considerably high, generally not available in flat terrain.
- Installation and construction of weirs are time-consuming and expensive. It also alters the habitat of local species.
- A flow rate is required before the construction of a weir. The size of the weir needs to accommodate the range of flow to be measured.

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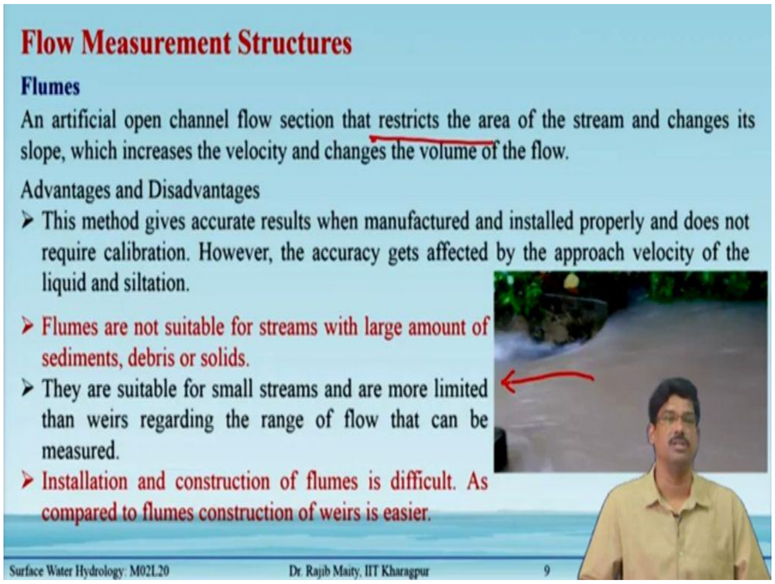

Flumes

The flumes are generally an artificial open channel flow section that restricts the area of the stream and changes its slope which increases the velocity and changes the volume of the flow. So, the important for the flume is that we restrict the area. So, once we restrict the area of the course to maintain the continuity equation, its velocity will increase. And then, all of a sudden there is a contraction, and the flow going here in this part.

Advantages and Disadvantages

- ➢ This method gives accurate results when manufactured and installed properly and does not require calibration. However, the accuracy gets affected by the approach velocity of the liquid and siltation.
- ➢ Flumes are not suitable for streams with a large amount of sediments, debris, or solids.
- ➢ They are suitable for small streams and are more limited than weirs regarding the range of flow that can be measured.
- ➢ Installation and construction of flumes are difficult. As compared to flumes construction of weirs is easier

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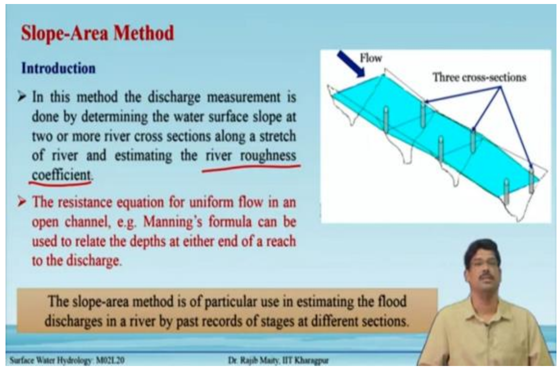

Slope-Area Method

Introduction

Another important method which is known as the slope-area method is for a very large amount of discharge can be measured particularly during flood time. And it depends on the basic principle of Bernoulli's equation. And in this method, the discharge measurement is done by determining the water surface slope at two or more river cross-sections along the stretch of the river; and estimating the river roughness coefficient. So, this river roughness coefficient is one of the important factors here just to ascertain it first. It is one of the sensitive parameters that can influence the final result. The resistance equation for the uniform flow in an open channel is Manning's formula that can be used to relate the depth at either end of the reach to measure the discharge. This slope-area method is of particular use in estimating the flood discharge in a river, by past records of the stage at different sections.

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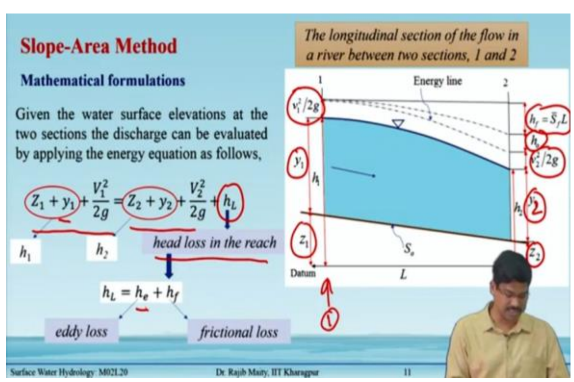

Mathematical formulations

Now, its mathematical formulation depends on Bernoulli's principle of the energy grid lines. So, we take two sections as you can see in fig.1, is section 1 and section 2. And in this part, we have seen that we generally take this total energy at this section 1 and section 2. So, that is in section 1 there are three components the Z_1, which is from the datum to the base of the river bed. Y_1 is the depth of the flow as you can see in this diagram here, and this $V_1^2/ 2g$ is the velocity head. So, this is a total head you can say in section 1. So, at section 2 now if I just see it is the Z_2, this is y_2, and this is $V_2^2/ 2g$.

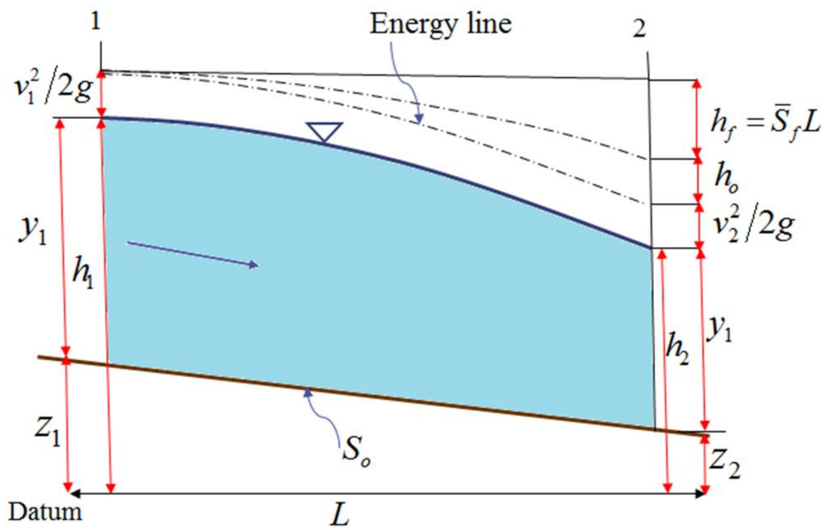

Fig.1 Slope area method

Given the water surface elevations at the two sections, the discharge can be evaluated by applying the energy equation as follows,

$$Z_1 + y_1 + \frac{V_1^2}{2g} = Z_2 + y_2 + \frac{V_2^2}{2g} + h_L$$

Where h_L= head loss in the reach = h_e+h_f

h_e= eddy loss

h_f=frictional loss

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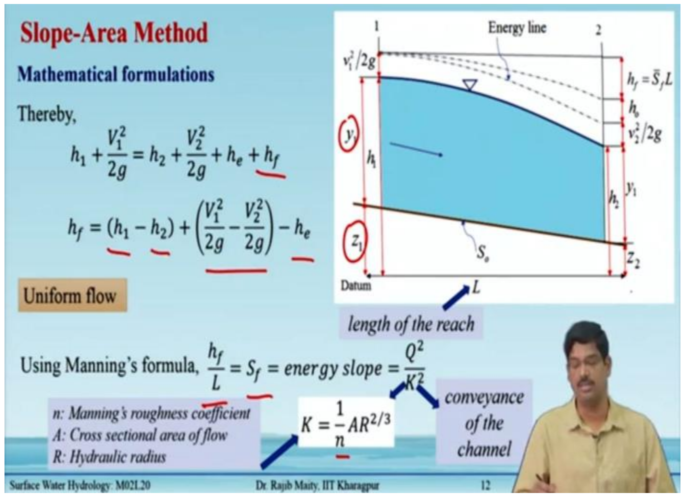

Thereby,

$$h_1 + \frac{V_1^2}{2g} = h_2 + \frac{V_2^2}{2g} + h_e + h_f$$

$$h_f = (h_1 - h_2) + \left(\frac{V_1^2}{2g} - \frac{V_2^2}{2g}\right) - h_e$$

Uniform flow

Now, using Manning's formula,

$$\frac{h_f}{L} = S_f = energy\ slope = \frac{Q^2}{K^2}$$

$$K = \frac{1}{n} AR^{2/3}$$

Where, K=conveyance of the channel

N= Manning’s roughness coefficient

A= Cross-sectional area of flow

R= Hydraulic radius

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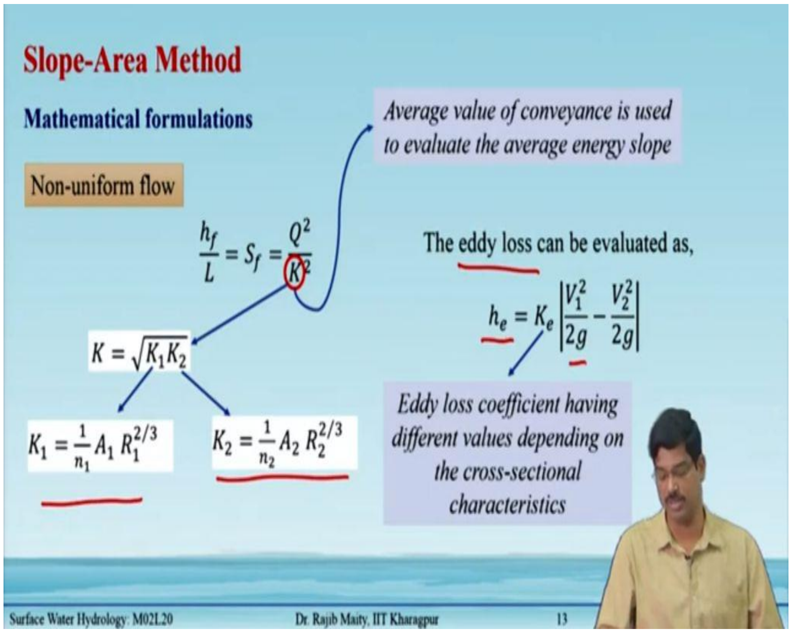

Non-uniform flow

$$\frac{h_f}{L} = S_f = \frac{Q^2}{K^2}$$

Where K= Average value of conveyance is used to evaluate the average energy slope.

$$K = \sqrt{K_1 K_2}$$

$$K_1 = \frac{1}{n_1} A_1\ R_1^{2/3} \qquad\qquad K_2 = \frac{1}{n_2} A_2\ R_2^{2/3}$$

On the other hand, when we take the eddy loss, the eddy loss can be evaluated as,

$$h_e = K_e \left| \frac{V_1^2}{2g} - \frac{V_2^2}{2g} \right|$$

Where K_e= Eddy loss coefficient has different values depending on the cross-sectional characteristics

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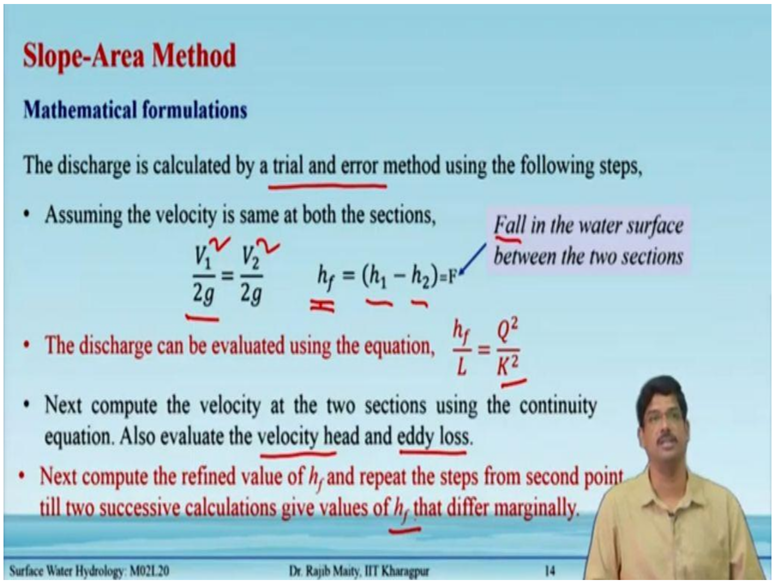

Slope-Area Method

Mathematical formulations

The Discharge is calculated by a trial-and-error method using the following steps,

- Assuming the velocity is the same at both the sections,

$$\frac{V_1}{2g} = \frac{V_2}{2g} \qquad h_f = (h_1 - h_2)\text{=F}$$

Where, F= Fall in the water surface between the two sections.

- The discharge can be evaluated using the equation,

$$\frac{h_f}{L} = \frac{Q^2}{K^2}$$

- Next, compute the velocity at the two sections using the continuity equation. Also, evaluate the velocity head and eddy loss.

- Next, compute the refined value of h_f and repeat the steps from the second point till two successive calculations give values of h_f that differ marginally.

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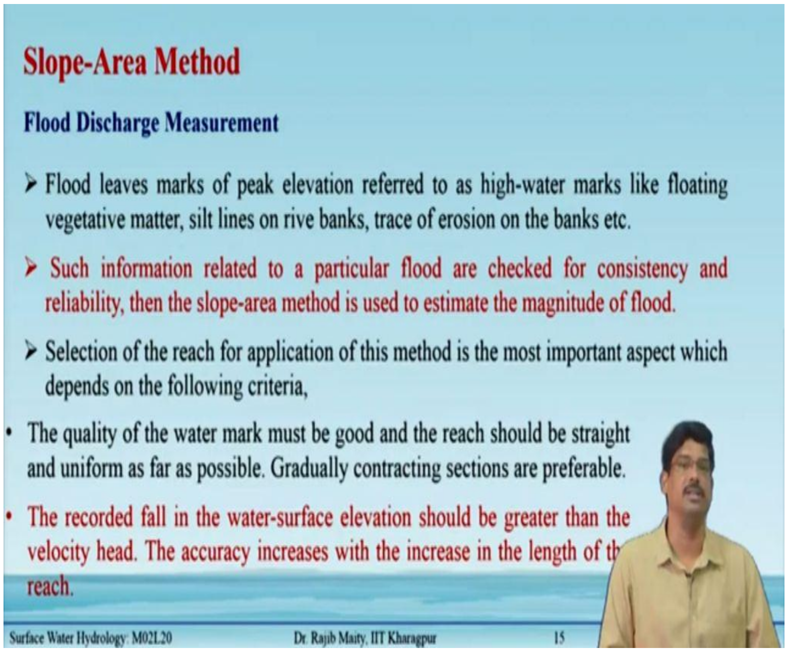

Flood Discharge Measurement

- Flood leaves marks of peak elevation are referred to as high-water marks like floating vegetative matter, silt lines on river banks, the trace of erosion on the banks, etc.
- Such information related to a particular flood is checked for consistency and reliability, then the slope-area method is used to estimate the magnitude of flood.
- Selection of the reach for application of this method is the most important aspect which depends on the following criteria,
    - The quality of the watermark must be good and the reach should be straight and uniform as far as possible. Gradually contracting sections are preferable.
    - The recorded fall in the water-surface elevation should be greater than the velocity head. The accuracy increases with the increase in the length of the reach.

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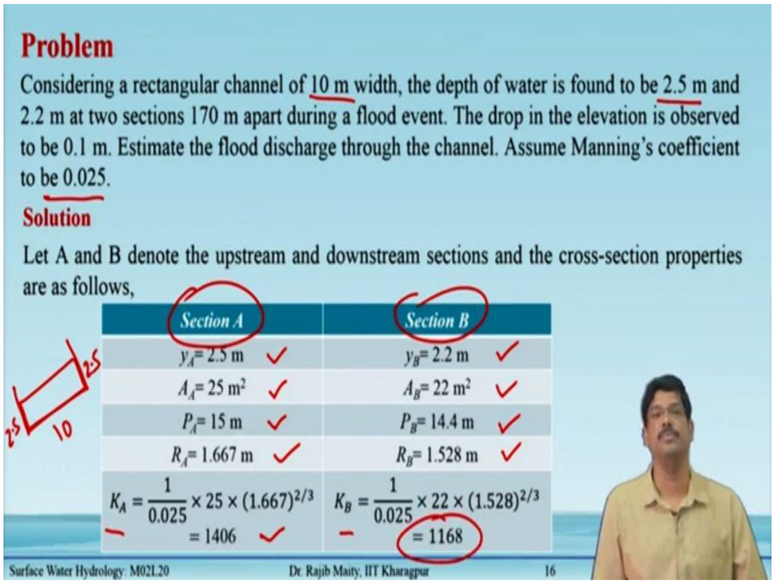

Problem

Considering a rectangular channel of 10 m width, the depth of water is found to be 2.5 m and 2.2 m at two sections 170 m apart during a flood event. The drop in the elevation is observed to be 0.1 m. Estimate the flood discharge through the channel. Assume Manning's coefficient to be 0.025.

Solution

Let A and B denote the upstream and downstream sections and the cross-section properties are as follows,

Section A	*Section B*
y_A= 2.5 m	y_B= 2.2 m
A_A= 25 m^2	A_B= 22 m^2
P_A= 15 m	P_B= 14.4 m
R_A= 1.667 m	R_B= 1.528 m
$K_A = \frac{1}{0.025} \times 25 \times (1.667)^{2/3} = 1406$	$K_B = \frac{1}{0.025} \times 22 \times (1.528)^{2/3} = 1168$

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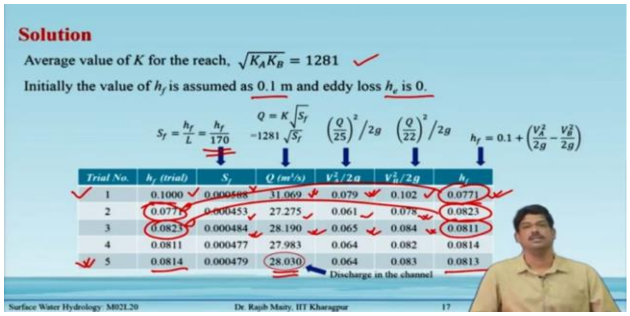

The average value of K for the reach, $\sqrt{K_A K_B} = 1281$

Initially, the value of h_f is assumed as 0.1 m, and eddy loss h_e is 0.

Trial No.	h_f *(trial)*	S_f	Q *(m³/s)*	$V_A^2/2g$	$V_B^2/2g$	h_f
1	0.1000	0.000588	31.069	0.079	0.102	0.0771
2	0.0771	0.000453	27.275	0.061	0.078	0.0823
3	0.0823	0.000484	28.190	0.065	0.084	0.0811
4	0.0811	0.000477	27.983	0.064	0.082	0.0814
5	0.0814	0.000479	28.030	0.064	0.083	0.0813

Discharge in the channel =28.030 cumec

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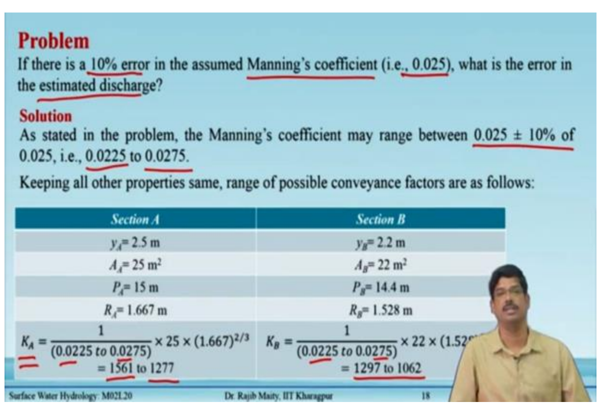

Problem

If there is a 10% error in the assumed Manning's coefficient (i.e., 0.025), what is the error in the estimated discharge?

Solution

As stated in the problem, the Manning's coefficient may range between 0.025 ± 10% of 0.025, i.e., 0.0225 to 0.0275.

Keeping all other properties the same, the range of possible conveyance factors are as follows:

Section A	*Section B*
y_A= 2.5 m	y_B= 2.2 m
A_A= 25 m^2	A_B= 22 m^2
P_A= 15 m	P_B= 14.4 m
R_A= 1.667 m	R_B= 1.528 m
$K_A = \frac{1}{(0.0225\ to\ 0.0275)} \times 25 \times (1.667)^{2/3}$ = 1561 to 1277	$K_B = \frac{1}{(0.0225\ to\ 0.0275)} \times 22 \times (1.528)^{2/3}$ = 1297 to 1062

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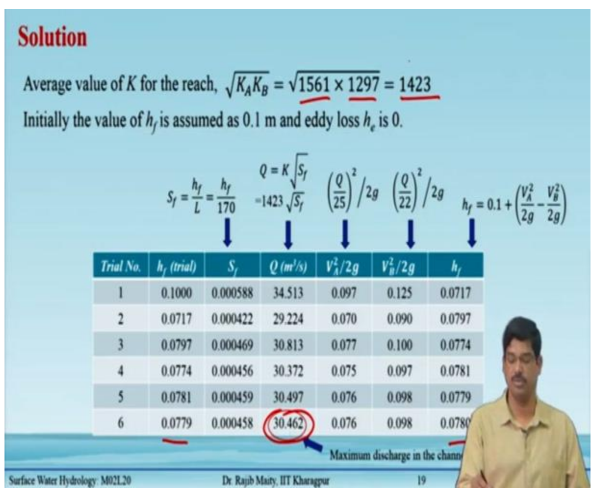

The average value of *K* for the reach

$$\sqrt{K_A K_B} = \sqrt{1561 \times 1297} = 1423$$

Initially, the value of h_f is assumed as 0.1 m, and eddy loss h_e is 0.

Trial No.	h_f (trial)	S_f	Q (m^3/s)	$V_A^2/2g$	$V_B^2/2g$	h_f
1	0.1000	0.000588	34.513	0.097	0.125	0.0717
2	0.0717	0.000422	29.224	0.070	0.090	0.0797
3	0.0797	0.000469	30.813	0.077	0.100	0.0774
4	0.0774	0.000456	30.372	0.075	0.097	0.0781
5	0.0781	0.000459	30.497	0.076	0.098	0.0779
6	0.0779	0.000458	30.462	0.076	0.098	0.0780

Maximum discharge in the channel=30.462 cumec

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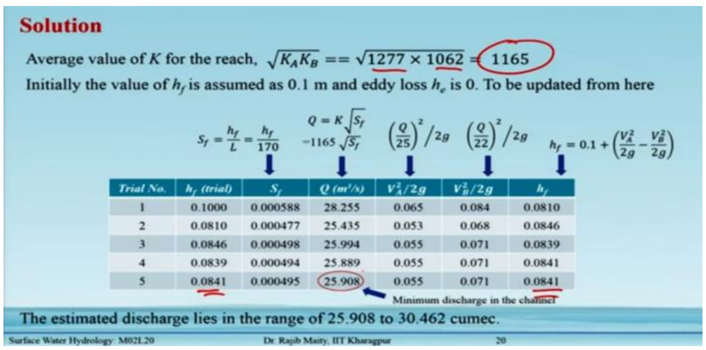

The average value of K for the reach,

$$\sqrt{K_A K_B} == \sqrt{1277 \times 1062} = 1165$$

Initially, the value of h_f is assumed as 0.1 m, and eddy loss h_e is 0. To be updated from here

Trial No.	h_f (trial)	S_f	Q (m^3/s)	$V_A^2/2g$	$V_B^2/2g$	h_f
1	0.1000	0.000588	28.255	0.065	0.084	0.0810
2	0.0810	0.000477	25.435	0.053	0.068	0.0846
3	0.0846	0.000498	25.994	0.055	0.071	0.0839
4	0.0839	0.000494	25.889	0.055	0.071	0.0841
5	0.0841	0.000495	25.908	0.055	0.071	0.0841

Minimum discharge in the channel =25.908 cumec

The estimated discharge lies in the range of 25.908 to 30.462 cumec.

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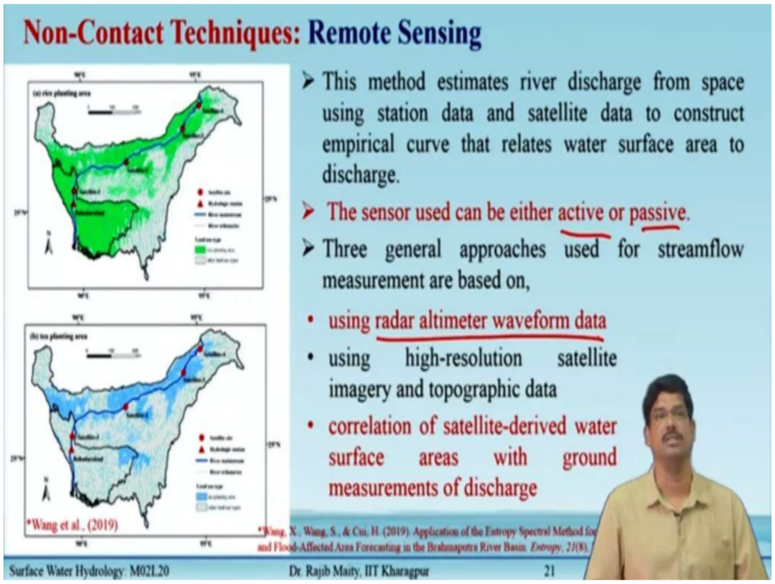

Non-Contact Techniques: Remote Sensing

Next, there are some non-contact techniques, one of the majors on most recent and important applications over a very large area is remote sensing. This method, this method estimates the river discharge from the space using the station data and the satellite data, to construct the empirical curve that deletes the water surface area to the discharge.

So, we collect the satellite imagery and we develop the relationship between the water surface elevation and the discharge of different locations. The sensor used can be either active or passive. There are two types of sensors are there are in remote sensing. One is active, the other one is passive; that uses depending on whether it generates its signal, or just received the signal from the ground.

There are three general approaches are used so far as streamflow measurements are concerned,

- The first one is the radar altimeter waveform data. This is one of the recent techniques from where we measure the discharge.
- Secondly, using the high-resolution satellite imagery and the topographic data, how the topography varies over the larger area on the ground.

➢ And thirdly, the correlation of the satellite-derived water surface areas with the ground measurement of the discharge; is called the matching with the ground truth.

So, these are the three things that we have to consider, so far as the three general approaches are considered for this non-contact technique under remote sensing.

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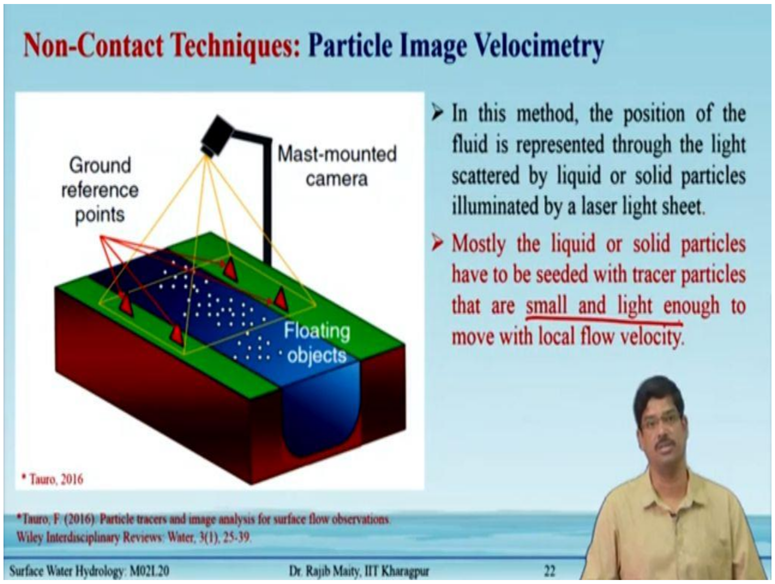

Non-Contact Techniques: Particle Image Velocimetry

Another technique that is also under the category of non-contact technique, is called particle image velocimetry. In this method, the position of the fluid is represented through the light scattered by the liquid or the solid particles illuminated by a laser light set. Mostly the liquid or the solid particle has to be seeded with the tracer particle that is small, but light enough to move with the local flow velocity.

Now, there are two requirements are there; it should be light enough and it should be small enough. So, that it the velocity with which this particle moves should be equal to the velocity of the liquid that is flowing through the channel.

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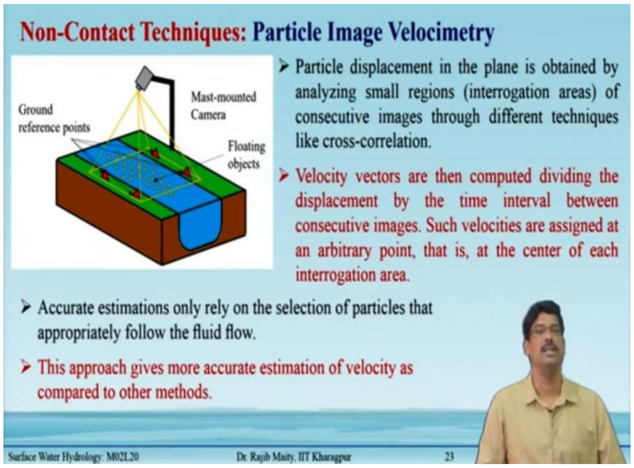

This particular displacement in the plane is obtained by analyzing the small region and the interrogating areas called the consecutive images through different techniques, like cross-correlation. Velocity vectors are then computed, dividing the displacement by the time interval between the consecutive images. And such velocities are assigned at an arbitrary point that is at the center of each interrogating area.

The accurate estimations only rely on the selection of the particles that appropriately follow the fluid flow as I mentioned in the previous slide. And this approach gives a more accurate estimation of the velocity as compared to the other methods.

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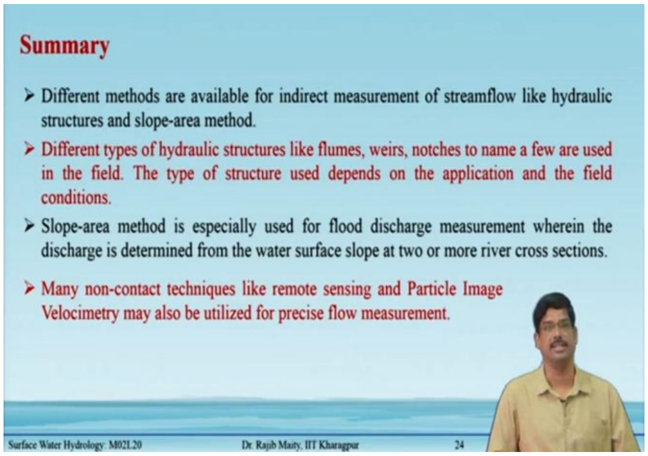

Summary

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

- Different methods are available for indirect measurement of streamflow like hydraulic structures and slope-area method.
- Different types of hydraulic structures like flumes, weirs, notches to name a few are used in the field. The type of structure used depends on the application and the field conditions.
- The Slope-area method is especially used for flood discharge measurement wherein the discharge is determined from the water surface slope at two or more river cross-sections.
- Many non-contact techniques like remote sensing and Particle Image Velocimetry may also be utilized for precise flow measurement.