Surface Water Hydrology
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Lecture 18
Area-Velocity and Moving-Boat Methods

Today's lecture will cover two very important measuring methods one is the Area-Velocity method and the Moving-Boat method.

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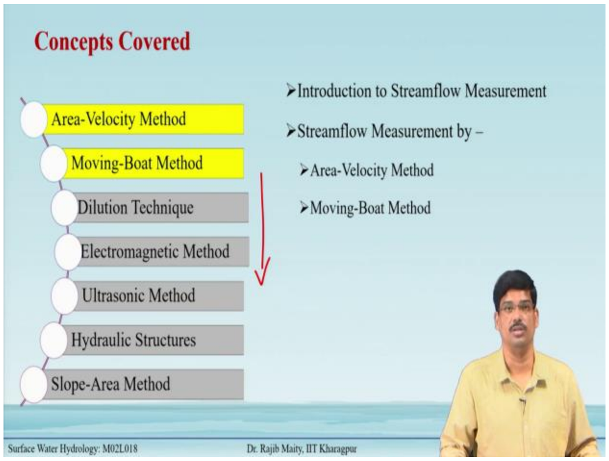

There are many methods are available for measuring the streamflow, they are as follows

- Area-Velocity Method
- Moving-Boat Method
- Dilution Technique
- Electromagnetic Method
- Ultrasonic Method
- Hydraulic Structures
- Slope-Area Method

Today's lecture will cover two methods first one is the area-velocity method, and the second one is the moving-boat method. So, before starting these methods, we will just go for a basic introduction to the streamflow measurement also.

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The outline of this lecture goes like this, the first will give a brief introduction to the streamflow measurement, and then we will take off the area of velocity method with its introduction, its mathematical formulation, and some example problem. Then we take up the moving boat method, again the same thing introduction, mathematical formulation, and example problem will take before concluding with the summary for these two methods.

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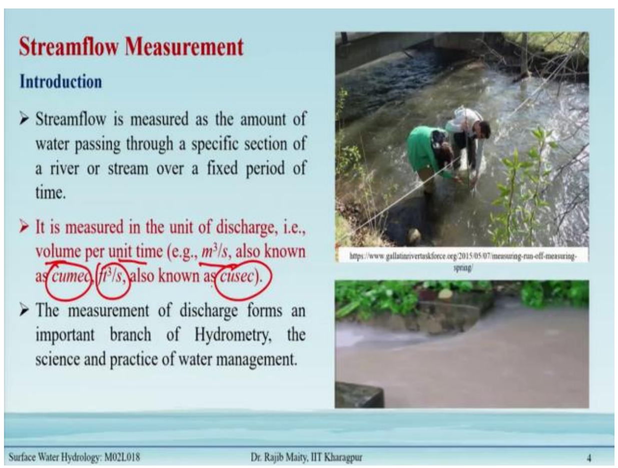

Streamflow Measurement

Introduction

Streamflow is measured as the amount of water passing through a specific section of a river or stream over a fixed period of time. It is measured in the unit of discharge, i.e., volume per unit time (e.g., m^3/s, also known as cumec, ft^3/s, also known as cusec). The measurement of discharge forms an important branch of Hydrometry, the science and practice of water management.

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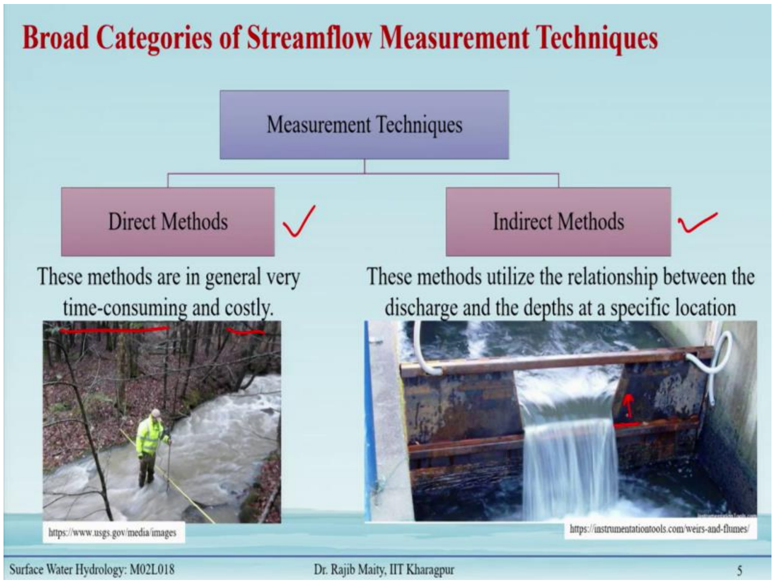

Broad Categories of Streamflow Measurement Techniques

There are two major measurement techniques are there, we can categorize into two parts one is the direct method and the other one is the indirect method. In the direct method, these are generally time-consuming and these are costly also and it depends on the site condition where we can apply it and it particularly depends on the site condition for its applicability, there are other that in the indirect method, it utilizes the relationship between the discharge and the depth at a specific location.

And the depth at a specific location is specifically designed to know where we know the relationship between the height above some level and then with respect to its discharge. So, this kind of through when it goes to some control structure, we call it as indirect method and otherwise, we go for the direct method.

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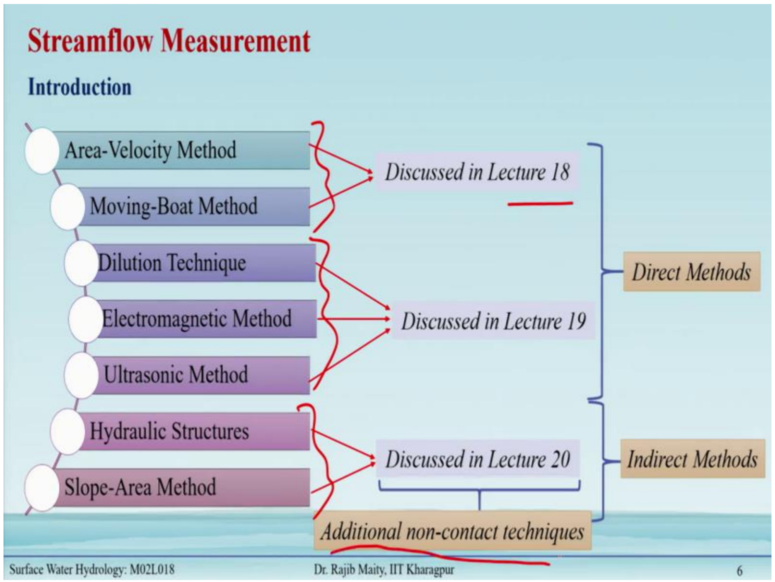

The area velocity method, moving boat method, dilution technique, an electromagnetic method, and ultrasonic method these are these come under the direct method. The hydraulic structures and the slope area method come under the indirect method.

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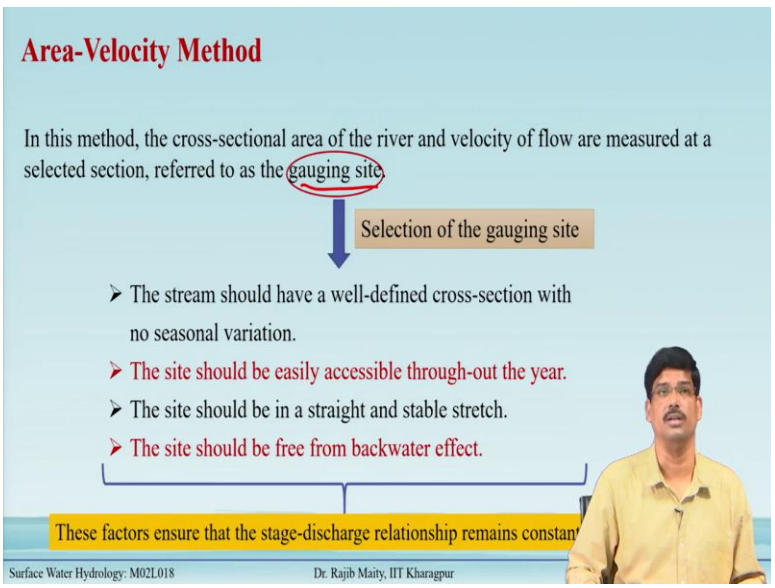

Area-Velocity Method

In this method, the cross-sectional area of the river and velocity of the flow is measured at a selected section it is referred to as its gauging site. So, wherever measured the stream flow that one called as a gauging site. Now, the selection of the gauging site depends on different condition.

- The stream should have a well-defined cross-section with no seasonal variation.
- The site should be easily accessible throughout the year.
- The site should be in a straight and stable stretch.
- The site should be free from the backwater effect.

These factors ensure that the stage discharged relationship remains constant over a long period of time. So, that is why these are the conditions that ensure the applicability of the area velocity method for a particular gauging location.

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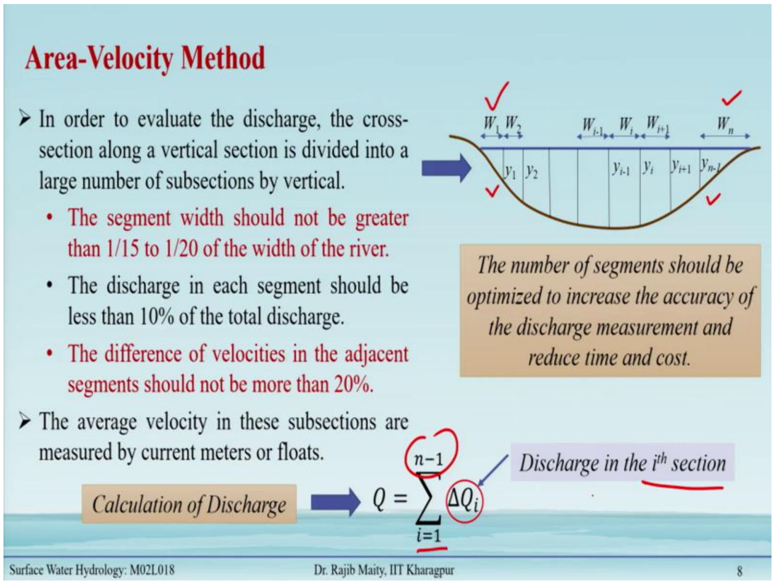

To evaluate the discharge, the cross-section along a vertical section is divided into a large number of subsections by vertical.

- The segment width should not be greater than 1/15 to 1/20 of the width of the river. The number of segments should be optimized to increase the accuracy of the discharge measurement and reduce time and cost.

- The discharge in each segment should be less than 10% of the total discharge.
- The difference of velocities in the adjacent segments should not be more than 20%.

The average velocity in these subsections are measured by the current meters or the floats and we take generally there are different techniques are there we go to the boat and at this location we stop and we measured the depth and the velocity using different instruments.

For calculation of the discharge for the entire cross-section, the following formula is used

$$Q = \sum_{i=1}^{n-1} \Delta Q_i$$

ΔQ_i = Discharge in the i^th section

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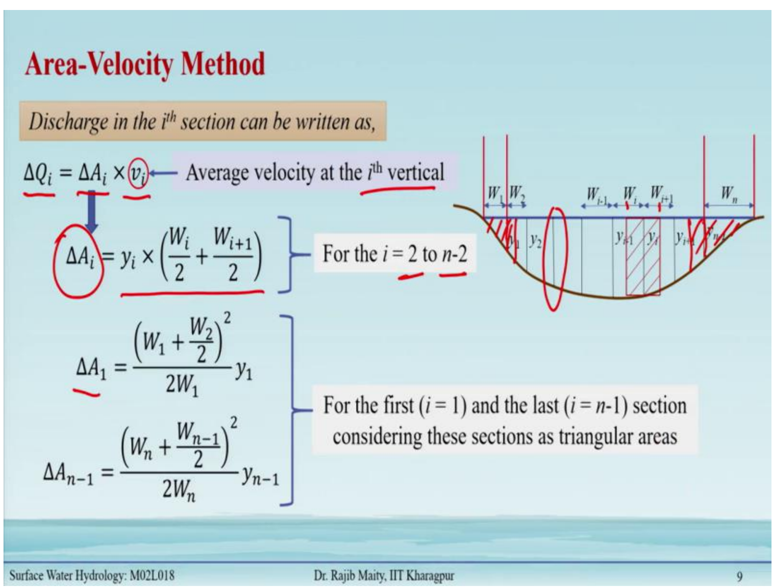

Discharge in the i^th^ section can be written as,

$$\Delta Q_i = \Delta A_i \times v_i$$

$v_{i=}$ Average velocity at the i^th^ vertical

$$\Delta A_i = y_i \times \left(\frac{W_i}{2} + \frac{W_{i+1}}{2}\right) \qquad \text{For the } i = 2 \text{ to } n\text{-}2$$

For the first (i = 1) and the last (i = n-1) section considering these sections as triangular areas

$$\Delta A_1 = \frac{\left(W_1 + \frac{W_2}{2}\right)^2}{2W_1} y_1$$

$$\Delta A_{n-1} = \frac{\left(W_n + \frac{W_{n-1}}{2}\right)^2}{2W_n} y_{n-1}$$

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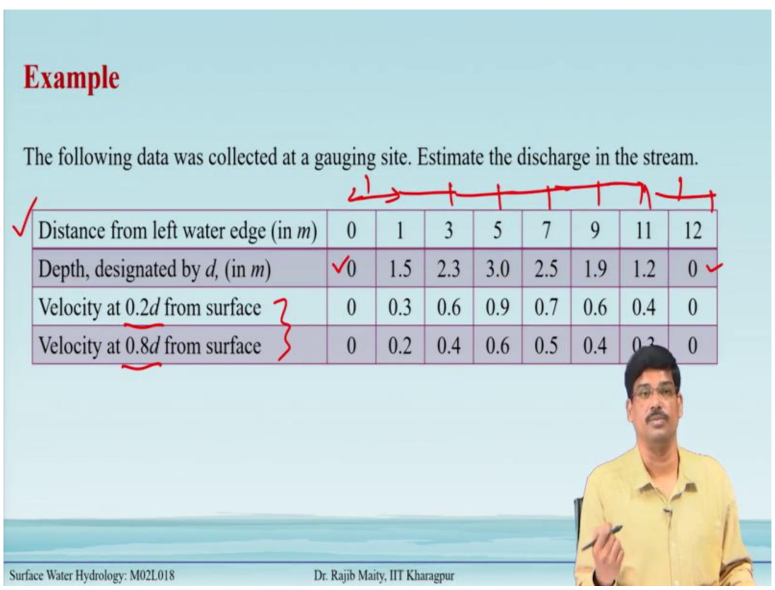

Example

The following data were collected at a gauging site. Estimate the discharge in the stream.

Distance from left water edge (in m)	0	1	3	5	7	9	11	12
Depth, designated by d, (in m)	0	1.5	2.3	3.0	2.5	1.9	1.2	0
Velocity at $0.2d$ from surface	0	0.3	0.6	0.9	0.7	0.6	0.4	0
Velocity at $0.8d$ from surface	0	0.2	0.4	0.6	0.5	0.4	0.3	0

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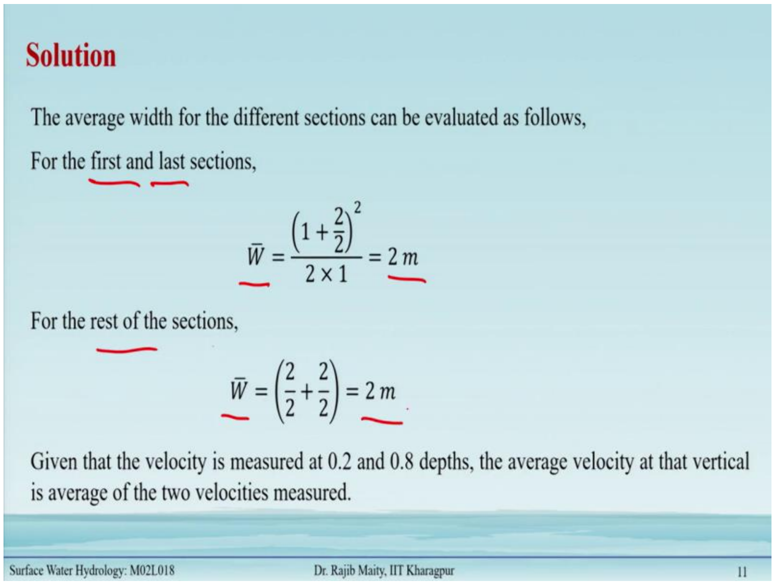

Solution

The average width for the different sections can be evaluated as follows,

For the first and last sections,

$$\bar{W} = \frac{\left(1+\frac{2}{2}\right)^2}{2\times 1} = 2\,m$$

For the rest of the sections,

$$\bar{W} = \left(\frac{2}{2}+\frac{2}{2}\right) = 2\,m$$

Given that the velocity is measured at 0.2 and 0.8 depths, the average velocity at that vertical is the average of the two velocities measured.

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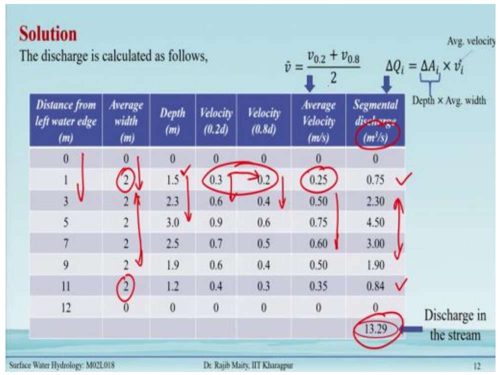

Solution

The discharge is calculated as follows,

Distance from left water edge (m)	*Average width (m)*	*Depth (m)*	*Velocity (0.2d)*	*Velocity (0.8d)*	*Average Velocity (m/s)*	*Segmental discharge (m^3/s)*
0	0	0	0	0	0	0
1	2	1.5	0.3	0.2	0.25	0.75
3	2	2.3	0.6	0.4	0.50	2.30
5	2	3.0	0.9	0.6	0.75	4.50
7	2	2.5	0.7	0.5	0.60	3.00
9	2	1.9	0.6	0.4	0.50	1.90
11	2	1.2	0.4	0.3	0.35	0.84
12	0	0	0	0	0	0
						13.29

So, the total discharge in the stream is this 13.29-meter cube per second

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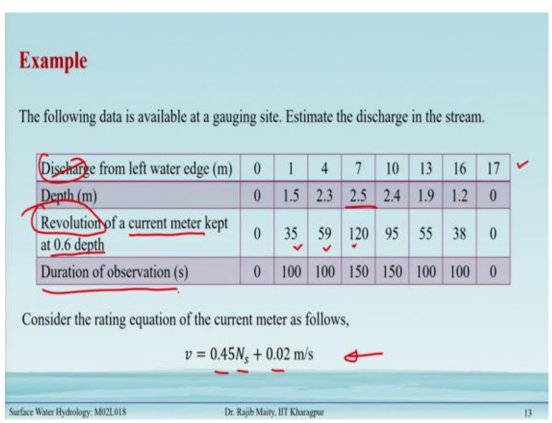

Example

The following data is available at a gauging site. Estimate the discharge in the stream.

Distance from left water edge (m)	0	1	4	7	10	13	16	17
Depth (m)	0	1.5	2.3	2.5	2.4	1.9	1.2	0
Revolution of a current meter kept at 0.6 depth	0	35	59	120	95	55	38	0
Duration of observation (s)	0	100	100	150	150	100	100	0

Consider the rating equation of the current meter as follows,

$$v = 0.45N_s + 0.02 \text{ m/s}$$

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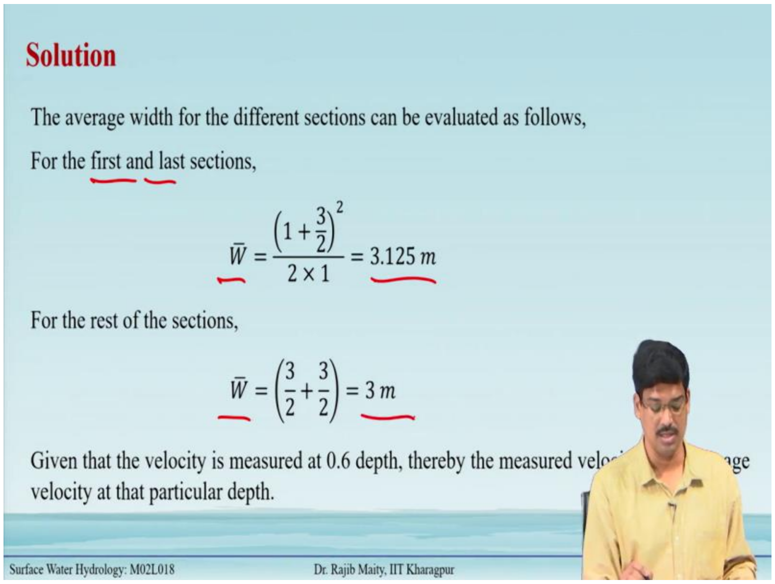

Solution

The average width for the different sections can be evaluated as follows,

For the first and last sections,

$$\bar{W} = \frac{\left(1+\frac{3}{2}\right)^2}{2\times 1} = 3.125\ m$$

For the rest of the sections,

$$\bar{W} = \left(\frac{3}{2} + \frac{3}{2}\right) = 3\ m$$

Given that the velocity is measured at 0.6 depth, thereby the measured velocity is the average velocity at that particular depth.

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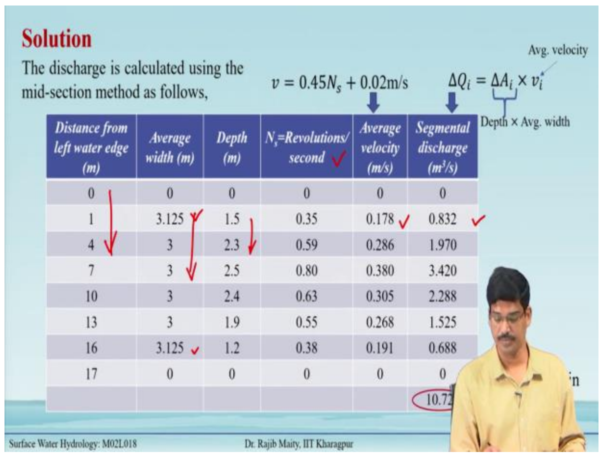

Solution

The discharge is calculated using the mid-section method as follows,

Distance from left water edge (m)	*Average width (m)*	*Depth (m)*	*N_s=Revolutions/ second*	*Average velocity (m/s)*	*Segmental discharge (m^3/s)*
0	0	0	0	0	0
1	3.125	1.5	0.35	0.178	0.832
4	3	2.3	0.59	0.286	1.970
7	3	2.5	0.80	0.380	3.420
10	3	2.4	0.63	0.305	2.288
13	3	1.9	0.55	0.268	1.525
16	3.125	1.2	0.38	0.191	0.688
17	0	0	0	0	0
					10.721

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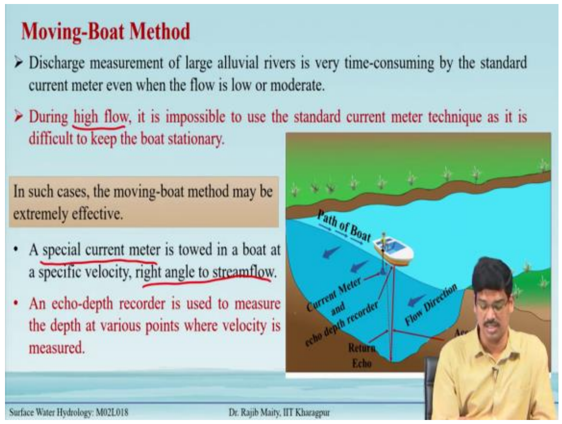

Moving-Boat Method

Discharge measurement of large alluvial rivers is very time-consuming by the standard current meter even when the flow is low or moderate. During high flow, it is impossible to use the standard current meter technique as it is difficult to keep the boat stationary.

In such cases, the moving-boat method may be extremely effective.

- A special current meter is towed in a boat at a specific velocity, right angle to streamflow.
- An echo-depth recorder is used to measure the depth at various points where velocity is measured.

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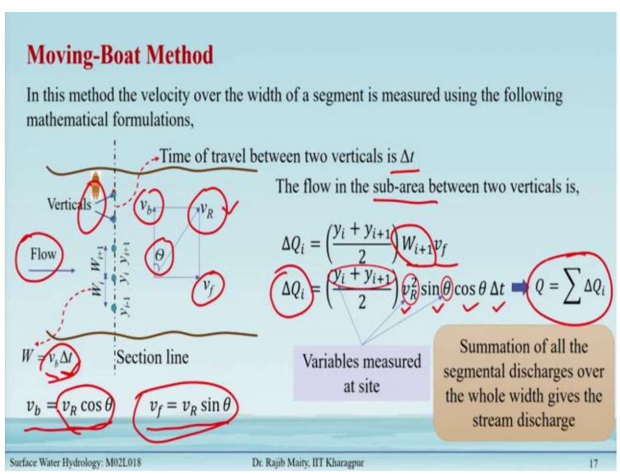

In this method, the velocity over the width of a segment is measured using the following mathematical formulations,

The flow in the sub-area between two verticals is,

$$\Delta Q_i = \left(\frac{y_i + y_{i+1}}{2}\right) W_{i+1} v_f$$
$$\Delta Q_i = \left(\frac{y_i + y_{i+1}}{2}\right) v_R^2 \sin\theta \cos\theta \, \Delta t$$

$v_b = v_R \cos\theta \qquad v_f = v_R \sin\theta$

$y_i, y_{i+1}, v_R, \theta$ are the variables measured at the site.

Summation of all the segmental discharges over the whole width gives the stream discharge

$$Q = \sum \Delta Q_i$$

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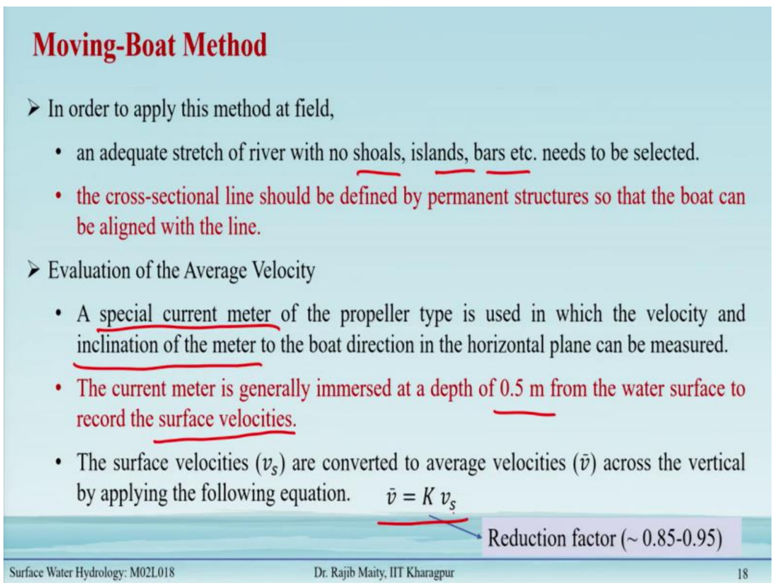

To apply this method at the field,

- ➢ An adequate stretch of river with no shoals, islands, bars, etc. needs to be selected.

- ➢ The cross-sectional line should be defined by permanent structures so that the boat can be aligned with the line.

Evaluation of the Average Velocity

- ➢ A special current meter of the propeller type is used in which the velocity and inclination of the meter to the boat direction in the horizontal plane can be measured.
- ➢ The current meter is generally immersed at a depth of 0.5 m from the water surface to record the surface velocities.
- ➢ The surface velocities (v_s) are converted to average velocities ($\bar{v}$) across the vertical by applying the following equation.

$$\bar{v} = K\, v_s$$

The reduction factor K lies between 0.85 to 0.95.

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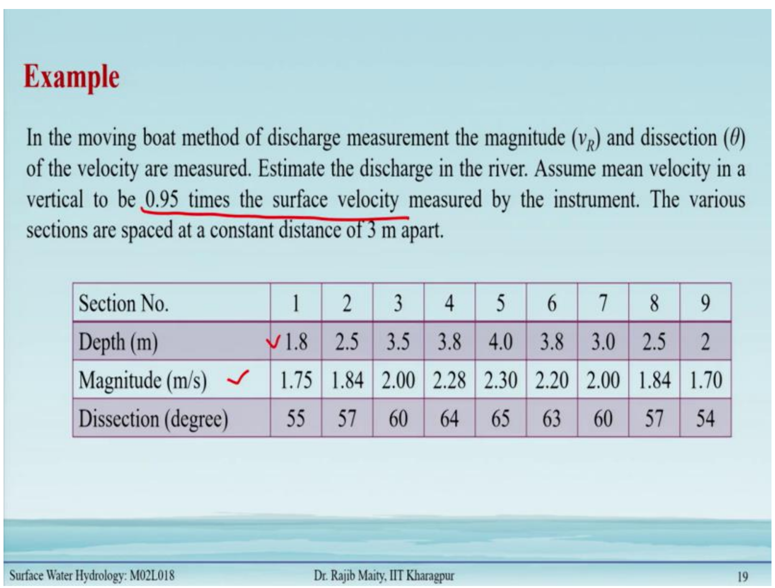

Example

In the moving boat method of discharge measurement, the magnitude of the recorded velocity (v_R) and direction (θ) of the velocity is measured. Estimate the discharge in the river. Assume mean velocity in a vertical to be 0.95 times the surface velocity measured by the instrument. The various sections are spaced at a constant distance of 3 m apart.

Section No.	1	2	3	4	5	6	7	8	9
Depth (m)	1.8	2.5	3.5	3.8	4.0	3.8	3.0	2.5	2
Recorded Velocity (m/s)	1.75	1.84	2.00	2.28	2.30	2.20	2.00	1.84	1.70
Direction (degree)	55	57	60	64	65	63	60	57	54

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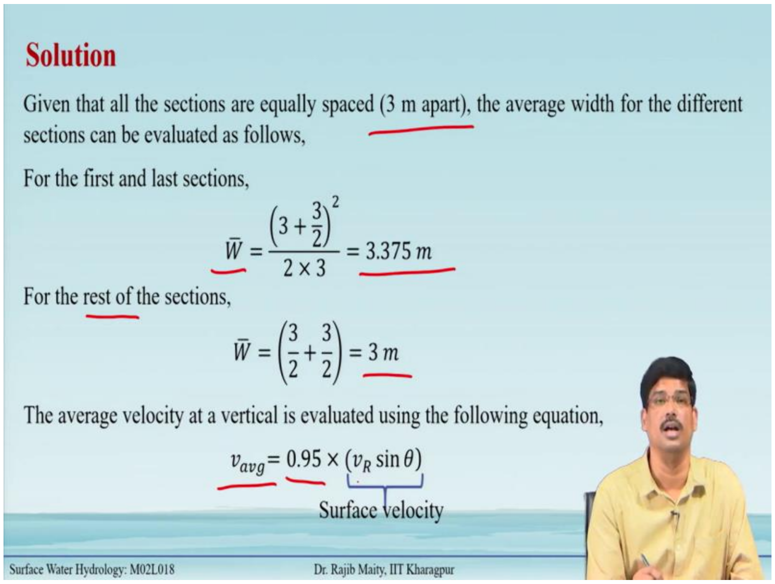

Solution

Given that all the sections are equally spaced (3 m apart), the average width for the different sections can be evaluated as follows,

For the first and last sections,

$$\bar{W} = \frac{\left(3+\frac{3}{2}\right)^2}{2\times 3} = 3.375\ m$$

For the rest of the sections,

$$\bar{W} = \left(\frac{3}{2}+\frac{3}{2}\right) = 3\ m$$

The average velocity at a vertical is evaluated using the following equation,

$$v_{avg} = 0.95 \times (v_R \sin\theta)$$

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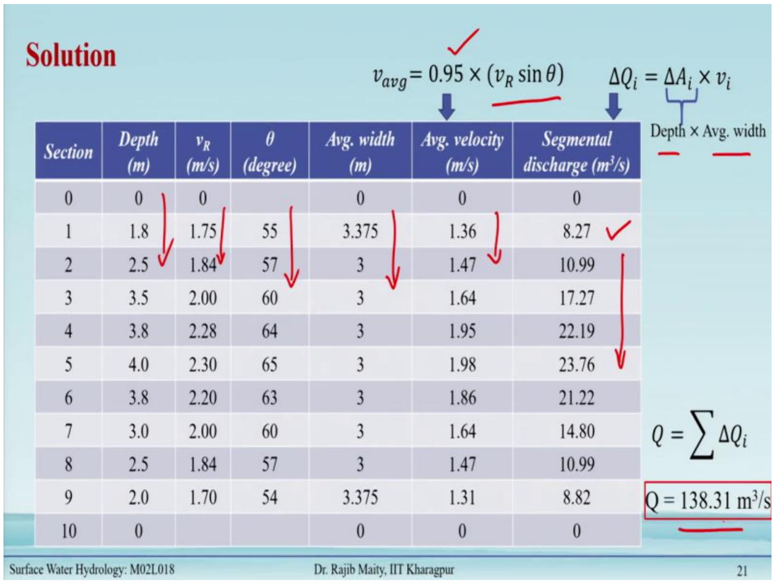

Solution

Section	Depth (m)	v_R (m/s)	θ (degree)	Avg. width (m)	Avg. velocity (m/s)	Segmental discharge (m^3/s)
0	0	0		0	0	0
1	1.8	1.75	55	3.375	1.36	8.27
2	2.5	1.84	57	3	1.47	10.99
3	3.5	2.00	60	3	1.64	17.27
4	3.8	2.28	64	3	1.95	22.19
5	4.0	2.30	65	3	1.98	23.76
6	3.8	2.20	63	3	1.86	21.22
7	3.0	2.00	60	3	1.64	14.80
8	2.5	1.84	57	3	1.47	10.99
9	2.0	1.70	54	3.375	1.31	8.82
10	0			0	0	0

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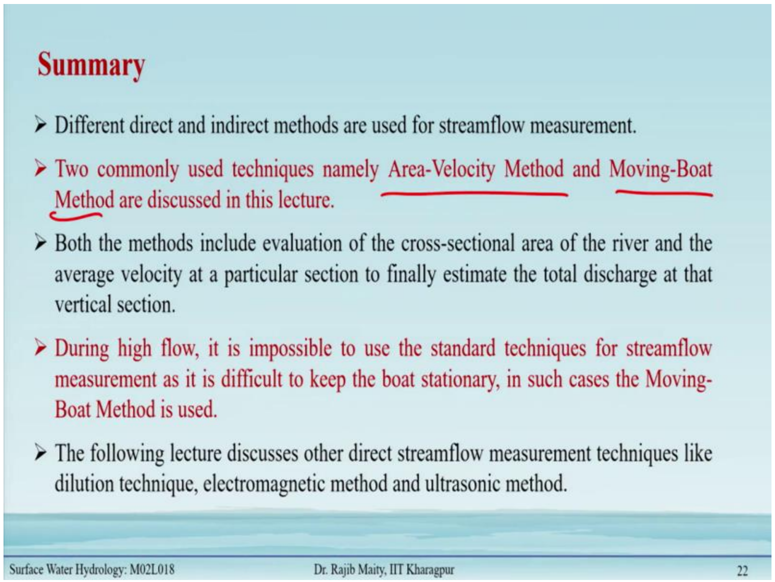

Summary

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

- ➢ Different direct and indirect methods are used for streamflow measurement.
- ➢ Two commonly used techniques namely Area-Velocity Method and Moving-Boat Method are discussed in this lecture.
- ➢ Both the methods include evaluation of the cross-sectional area of the river and the average velocity at a particular section to finally estimate the total discharge at that vertical section.
- ➢ During high flow, it is impossible to use the standard techniques for streamflow measurement as it is difficult to keep the boat stationary, in such cases the Moving-Boat Method is used.
- ➢ The following lecture discusses other direct streamflow measurement techniques like dilution technique, an electromagnetic method, an ultrasonic method.