Surface Water Hydrology
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Lecture – 19
Dilution Technique, Electromagnetic and Ultrasonic Methods

In lecture number 19 we will discuss three methods. The first one is the dilution technique, then the electromagnetic method, and then the ultrasonic method.

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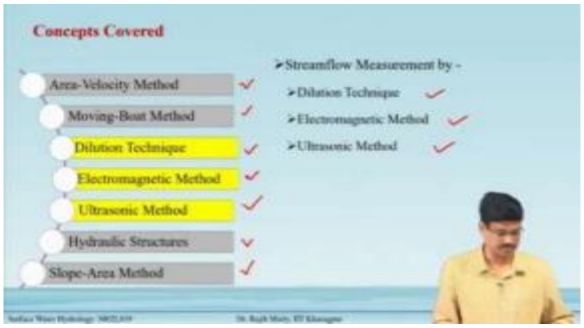

Today we will cover the concept of streamflow measurement by dilution technique, an electromagnetic method, an ultrasonic method.

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In every technique, we will see some introduction, their mathematical formulations; and then some example problems wherever applicable before coming to the summary at the end.

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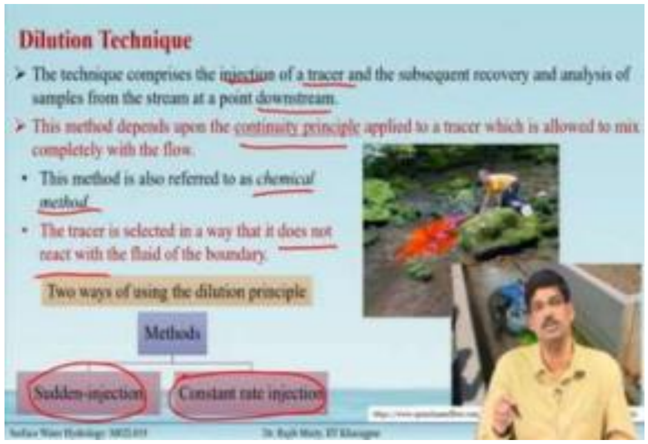

Dilution Technique

This technique comprises the injection of a tracer and the subsequent recovery, and analysis of the sample from a stream at a point downstream. So, three things are important; one is the tracer. In tracer, there are two sections, where inject it that the section; and then at some downstream section we take the sample, and evaluate it. And then there are some mathematical formulations are there to calculate the discharge.

This method depends on the continuity principle. To maintain this one to ensure this particular principle, the method is also methods should be the tracer that will utilize; it should have some properties. The first important thing is that it should not react with the fluid of the boundary, and it should not settle or it should not be lost in any of this course of this water flow. So, we are utilizing some tracers, which is also sometimes known as the chemical method, also is that some other alternative names.

There are two ways now to where inject the tracer. one is called the sudden-injection method and the second one is the constant rate injection method. So, the sudden-injection method means just putting it once at a time at a particular location. Then wait in the downstream location to collect the size and collect the sample. And the constant rate injection means upstream section wherever we are putting the tracer, it has to be with a constant rate are just adding it.

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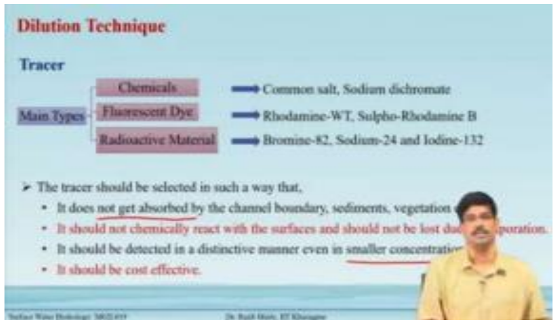

There are different types of tracers are available; three main categories we can talk about. The first one is the is different types of chemicals, and the common salt the sodium chloride or sodium dichromate; these are the things that are utilized as chemicals. There are some fluorescent dyes are also there and there are some radioactive materials are also there. And it is basically which one to utilize, it depends on how much accuracy we finally get. For example, when we use the common salt, we get about 1 percent accuracy; we can measure it at the downstream location.

The tracer should be selected in such a way that,

- It does not get absorbed by the channel boundary, sediments, vegetation, etc.
- It should not chemically react with the surfaces and should not be lost due to evaporation.
- It should be detected distinctively even in smaller concentrations.
- It should be cost-effective.

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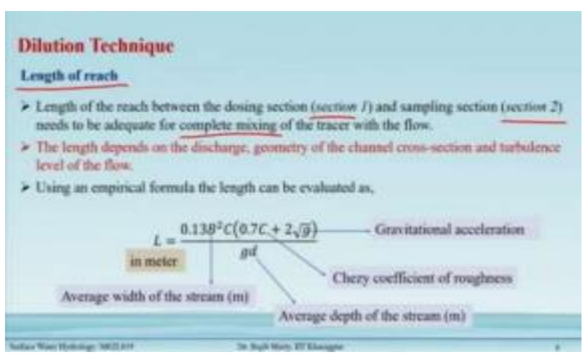

Length of reach

These are the different conditions when you select the tracer and the second thing that we select is the length of the reach.

- The length of the reach between the dosing section (*section 1*) and sampling section (*section 2*) needs to be adequate for the complete mixing of the tracer with the flow.
- The length depends on the discharge, geometry of the channel cross-section, and turbulence level of the flow.
- Using an empirical formula, the length can be evaluated as,

$$L = \frac{0.13B^2C\left(0.7C + 2\sqrt{g}\right)}{gd}$$

in meter

Gravitational acceleration

Chezy coefficient of roughness

Average width of the stream (m)

Average depth of the stream (m)

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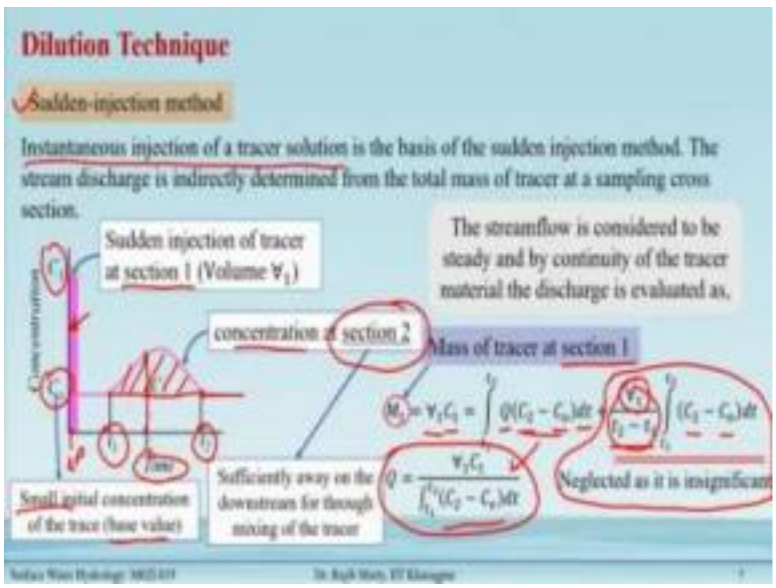

Sudden-injection method

Instantaneous injection of a tracer solution is the basis of the sudden injection method. The stream discharge is indirectly determined from the total mass of the tracer at a sampling cross-section. In fig.1 this x-axis is the time axis, as you see them over the time we see; and the particular pink bar shown in fig.1, this is at section 1. So, that means it is just the instantaneous time, where the time starts counting t equals 0. Here we just put some concentration there; that concentration is denoted as C_1 and just to stop.

So, since we are putting as a sudden and then stop, there is no other thing. Now, the continuous curve in fig.1 is the concentration variation in section 2. So, concentration variation and section 2 means this is maintaining some background concentration. Then, due to the injection of this upstream, there is some concentration was put there as a sudden; so, it will gradually increase. It is not increased abruptly, and it will go to a peak, and gradually it will come down and again joined to the background concentration.

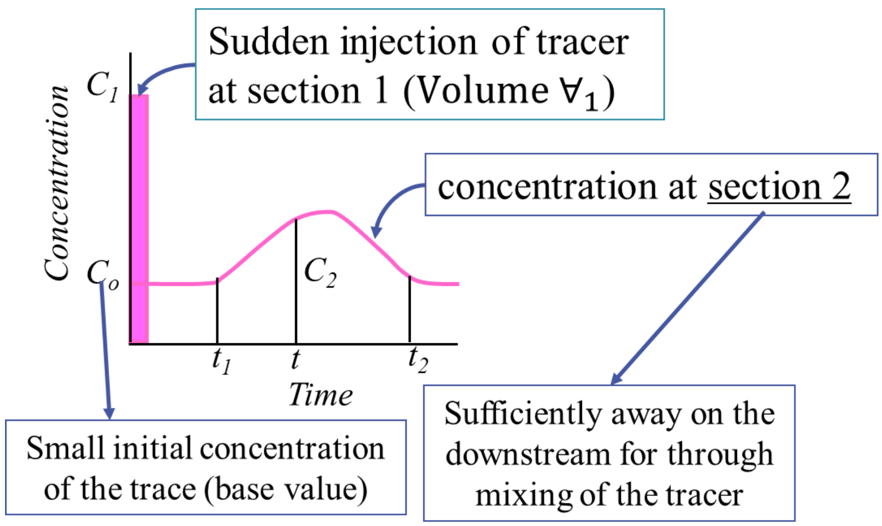

Fig.1 shows the sudden injection method

The C_0 is called the background concentration that whatever the tracer that is already present in the water with a certain quantity may or may not be. So, it may be very small, but if it is there, we have to consider that and that is what is called the base value. So, that means the basic principle here is that whatever this quantity that we have added in section 1, if we maintain the continuity, then this area that is above this background concentration; so, these areas should match with this total mass.

So, these two masses in section 1 and section 2, should match; then we can calculate based on after equating these things, we can calculate the discharge; this is the basic principle.

The streamflow is considered to be steady and by continuity of the tracer material the discharge is evaluated as

$$M_1 = \forall_1 C_1 = \int_{t_1}^{t_2} Q(C_2 - C_o)dt + \frac{\forall_1}{t_2 - t_1} \int_{t_1}^{t_2} (C_2 - C_o)dt$$

$$Q = \frac{\forall_1 C_1}{\int_{t_1}^{t_2} (C_2 - C_o)dt}$$

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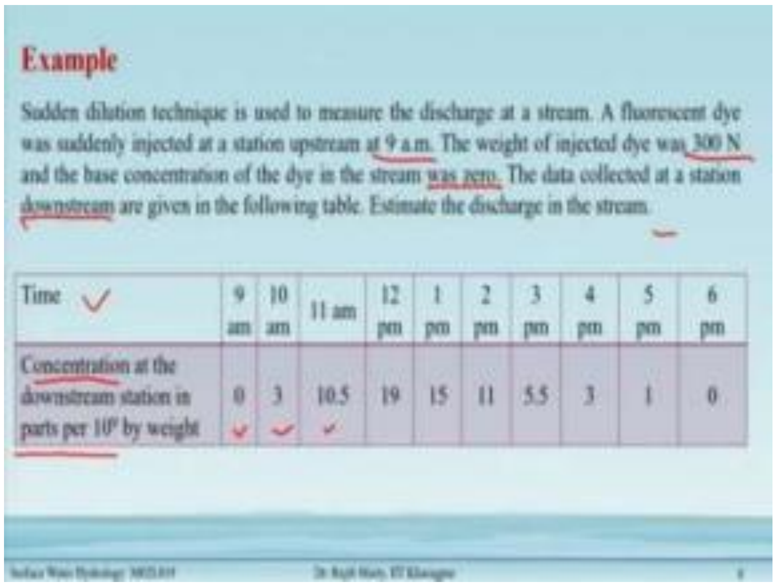

Example

The sudden dilution technique is used to measure the discharge at a stream. A fluorescent dye was suddenly injected at a station upstream at 9 a.m. The weight of injected dye was 300 N and the base concentration of the dye in the stream was zero. The data collected at a station downstream are given in the following table. Estimate the discharge in the stream.

Time	9 am	10 am	11 am	12 pm	1 pm	2 pm	3 pm	4 pm	5 pm	6 pm
Concentration at the downstream station in parts per 10^9 by weight	0	3	10.5	19	15	11	5.5	3	1	0

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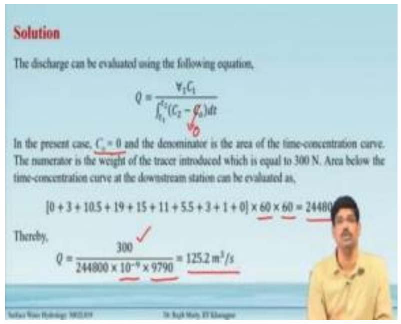


Solution

The discharge can be evaluated using the following equation,

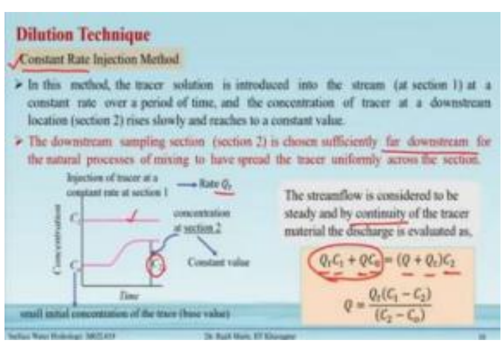
$$Q = \frac{\forall_1 C_1}{\int_{t_1}^{t_2} (C_2 - C_o) dt}$$

In the present case, $C_o = 0$ and the denominator is the area of the time-concentration curve. The numerator is the weight of the tracer introduced which is equal to 300 N. Area below the time-concentration curve at the downstream station can be evaluated as,

$$[0 + 3 + 10.5 + 19 + 15 + 11 + 5.5 + 3 + 1 + 0] \times 60 \times 60 = 244800\ ppb$$

Thereby,

$$Q = \frac{300}{244800 \times 10^{-9} \times 9790} = 125.2\ m^3/s$$



Constant Rate Injection Method

In this method, the tracer solution is introduced into the stream (at section 1) at a constant rate over a period of time, and the concentration of tracer at a downstream location (section 2) rises slowly and reaches a constant value as shown in fig.2.

The downstream sampling section was chosen sufficiently far downstream for far downstream, in such a way that the natural process of mixing to have the spread the tracer uniformly across this across the section.

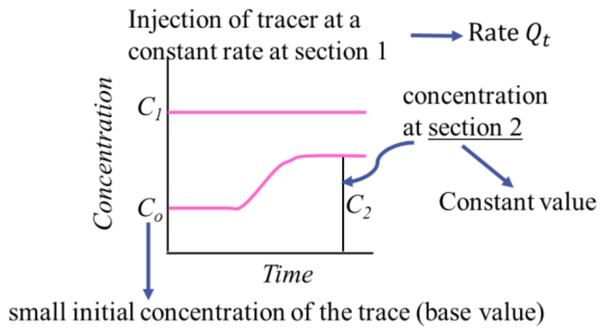


Fig.2 shows the constant rate injection method

The streamflow is considered to be steady and by continuity of the tracer material the discharge is evaluated as,

$$Q_t C_1 + Q C_0 = (Q + Q_t) C_2$$

$$Q = \frac{Q_t (C_1 - C_2)}{(C_2 - C_o)}$$

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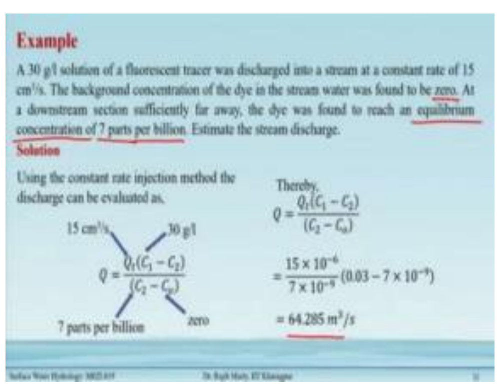

Example

A 30 g/l solution of a fluorescent tracer was discharged into a stream at a constant rate of 15 cm^3/s.

The background concentration of the dye in the stream water was found to be zero. At a downstream section sufficiently far away, the dye was found to reach an equilibrium concentration of 7 parts per billion. Estimate the stream discharge.

Solution

Using the constant rate injection method, the discharge can be evaluated as,

15 cm³/s → Q_t; 30 g/l → C_1

$$Q = \frac{Q_t(C_1 - C_2)}{(C_2 - C_o)}$$

7 parts per billion → C_2; zero → C_o

Thereby,

$$Q = \frac{Q_t(C_1 - C_2)}{(C_2 - C_o)}$$

$$= \frac{15 \times 10^{-6}}{7 \times 10^{-9}}(0.03 - 7 \times 10^{-9})$$

$$= 64.285\ m^3/s$$

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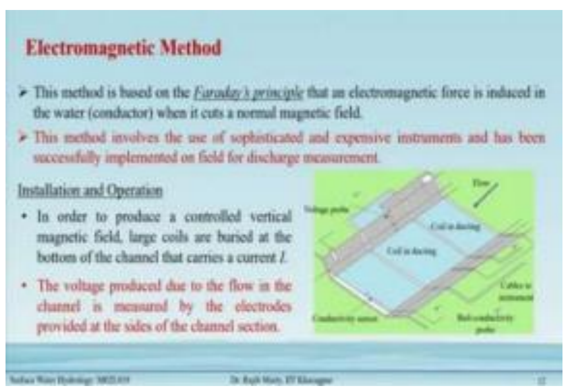

Electromagnetic Method

This method is based on Faraday's principle that an electromagnetic force is induced in the water (conductor) when it cuts a normal magnetic field. This method involves the use of sophisticated and expensive instruments and has been successfully implemented in the field for discharge measurement.

Installation and Operation

- To produce a controlled vertical magnetic field, large coils are buried at the bottom of the channel that carries a current *I*.
- The voltage produced due to the flow in the channel is measured by the electrodes provided at the sides of the channel section.

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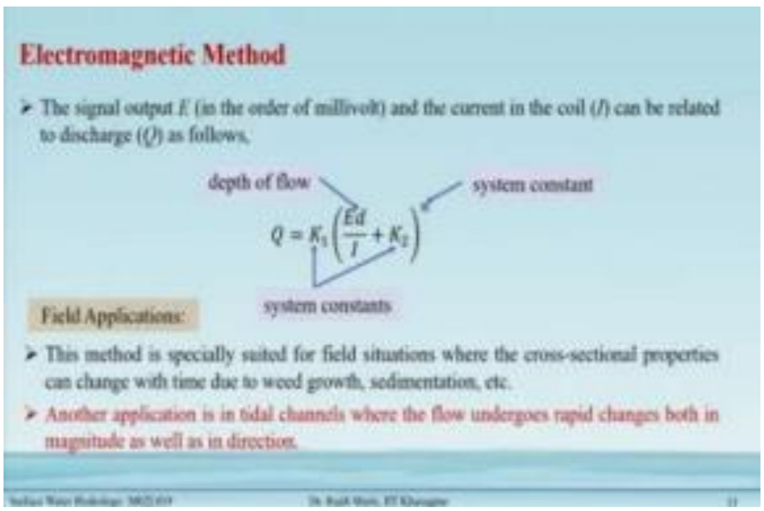
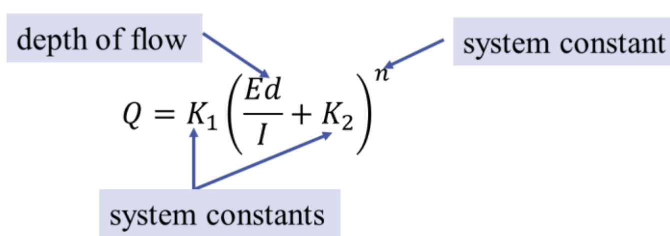


The signal output E (in the order of millivolt) and the current in the coil (I) can be related to discharge (Q) as follows,



$$Q = K_1 \left(\frac{Ed}{I} + K_2 \right)^n$$

Field Applications:

- This method is especially suited for field situations where the cross-sectional properties can change with time due to weed growth, sedimentation, etc.
- Another application is in tidal channels where the flow undergoes rapid changes both in magnitude as well as in direction.

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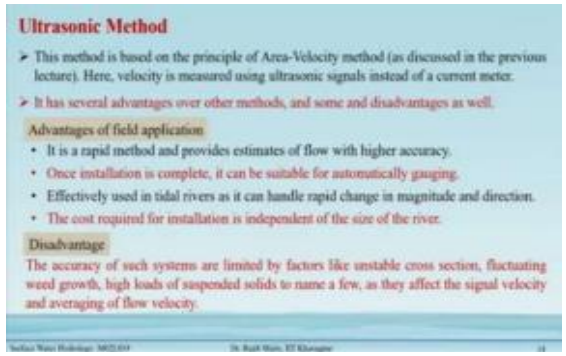

Ultrasonic Method

This method is based on the principle of the Area-Velocity method (as discussed in the previous lecture). Here, velocity is measured using ultrasonic signals instead of a current meter.

It has several advantages over other methods, and some disadvantages as well.

Advantages of field application

- ➢ It is a rapid method and provides estimates of flow with higher accuracy.
- ➢ Once installation is complete, it can be suitable for automatically gauging.
- ➢ Effectively used in tidal rivers as it can handle the rapid change in magnitude and direction.
- ➢ The cost required for installation is independent of the size of the river.

Disadvantage

The accuracy of such systems is limited by factors like unstable cross-section, fluctuating weed growth, high loads of suspended solids to name a few, as they affect the signal velocity and averaging of flow velocity.

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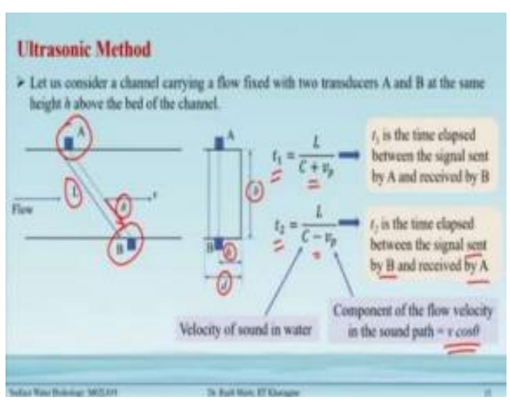

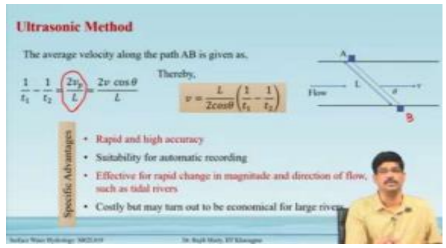

Let us consider a channel carrying a flow fixed between two (trans) transducers A and B, as shown in fig.3 and their length is L between these two, and there is an angle with respect to the velocity of the flow is θ. The bottom width is B of the channel, and the height over which it is placed in the h, and the total depth of the flow is d as shown in fig.3.

The t_1 and t_2 are the two times; t_1 is the time elapsed between the signals sent by A and received by B. So if one signal comes from the A and it is received by the B; so, this time gap is we said t_1. And t_2 is just the reverse when the signal is sent by B, and it is received by A. While, these two times are different, this is because of the flow velocity that is v_p; the component of the flow velocity in the sound part that is vcos θ.

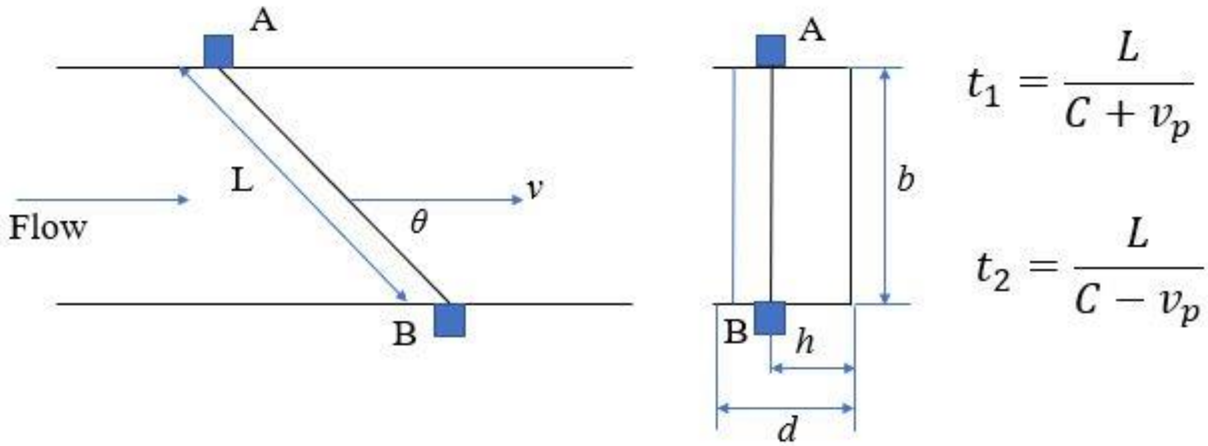

Fig.3 shows the ultrasonic method

If we take the V as the velocity of the flow, then this component along this line is the v cos θ. So, C is the velocity of the sound in the water. Now, it is when it comes from the A to B, it is added; and when it is going from B to A, it is subtracted to get the relative velocity. So that is why there is a difference between t_1 and t_2.

From the expression, if we can somehow eliminate C; C is the velocity of the sound in the water.

Then, we will get an expression that comes as

$$\frac{1}{t_1} - \frac{1}{t_2} = \frac{2v_p}{L} = \frac{2v\ \cos\theta}{L}$$

Thereby,

$$v = \frac{L}{2cos\theta}\left(\frac{1}{t_1} - \frac{1}{t_2}\right)$$

Specific Advantages

- Rapid and high accuracy
- Suitability for automatic recording
- Effective for rapid change in magnitude and direction of flow, such as tidal rivers
- Costly but may turn out to be economical for large rivers

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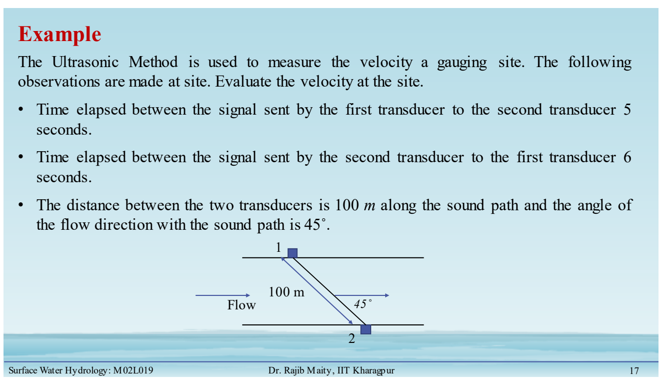
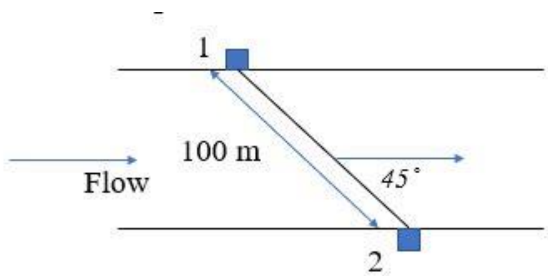


Example

The Ultrasonic Method is used to measure the velocity of a gauging site. The following observations are made at the site. Evaluate the velocity at the site.

- Time elapsed between the signal sent by the first transducer to the second transducer 5 seconds.
- Time elapsed between the signal sent by the second transducer to the first transducer 6 seconds.
- The distance between the two transducers is 100 *m* along the sound path and the angle of the flow direction with the sound path is 45˚.



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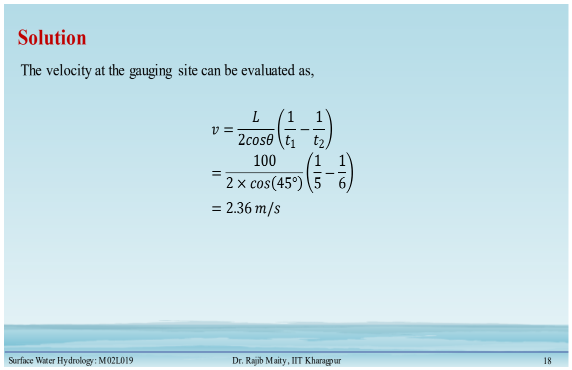

Solution

The velocity at the gauging site can be evaluated as,

$$v = \frac{L}{2cos\theta}\left(\frac{1}{t_1} - \frac{1}{t_2}\right) = \frac{100}{2 \times cos(45°)}\left(\frac{1}{5} - \frac{1}{6}\right)$$

$$= 2.36\, m/s$$

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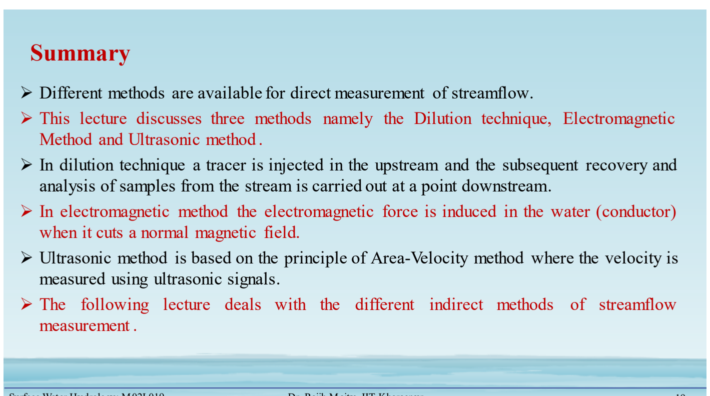

Summary

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

- Different methods are available for the direct measurement of streamflow.
- This lecture discusses three methods namely the Dilution technique, Electromagnetic Method, and Ultrasonic method.
- In the dilution technique, a tracer is injected upstream and the subsequent recovery and analysis of samples from the stream are carried out at a point downstream.
- In an electromagnetic method, the electromagnetic force is induced in the water (conductor) when it cuts a normal magnetic field.
- The ultrasonic method is based on the principle of the Area-Velocity method where the velocity is measured using ultrasonic signals.
- The following lecture deals with the different indirect methods of streamflow measurement.