Course Name: Watershed Hydrology

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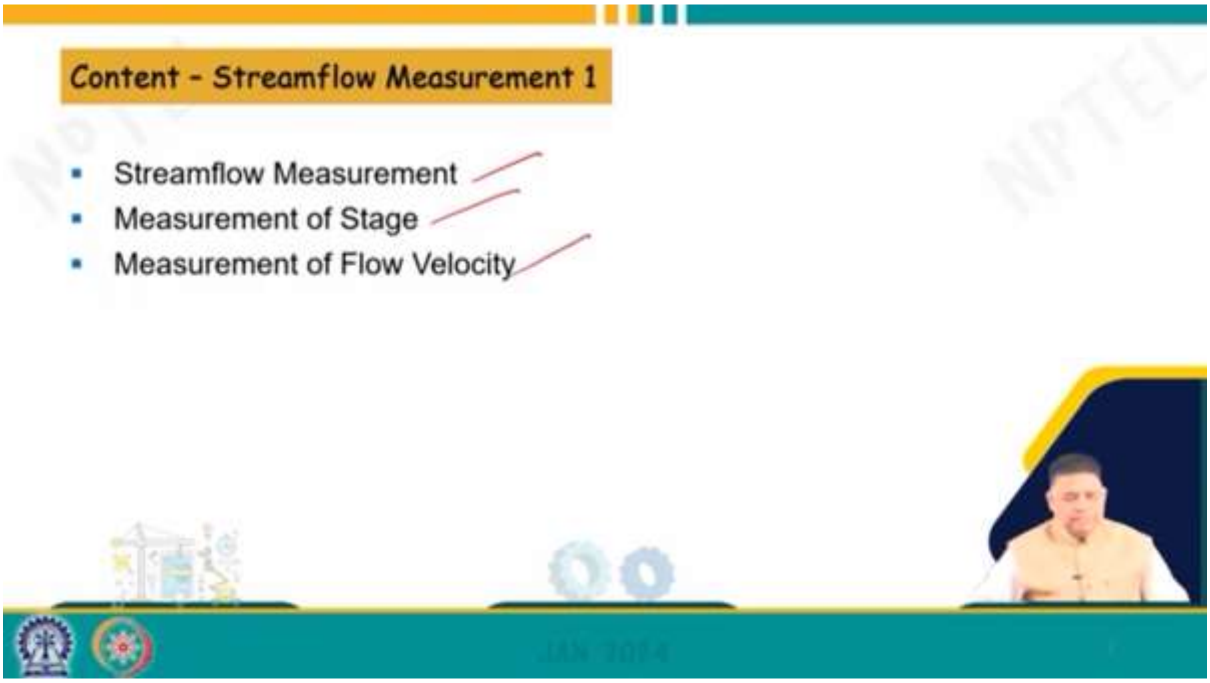
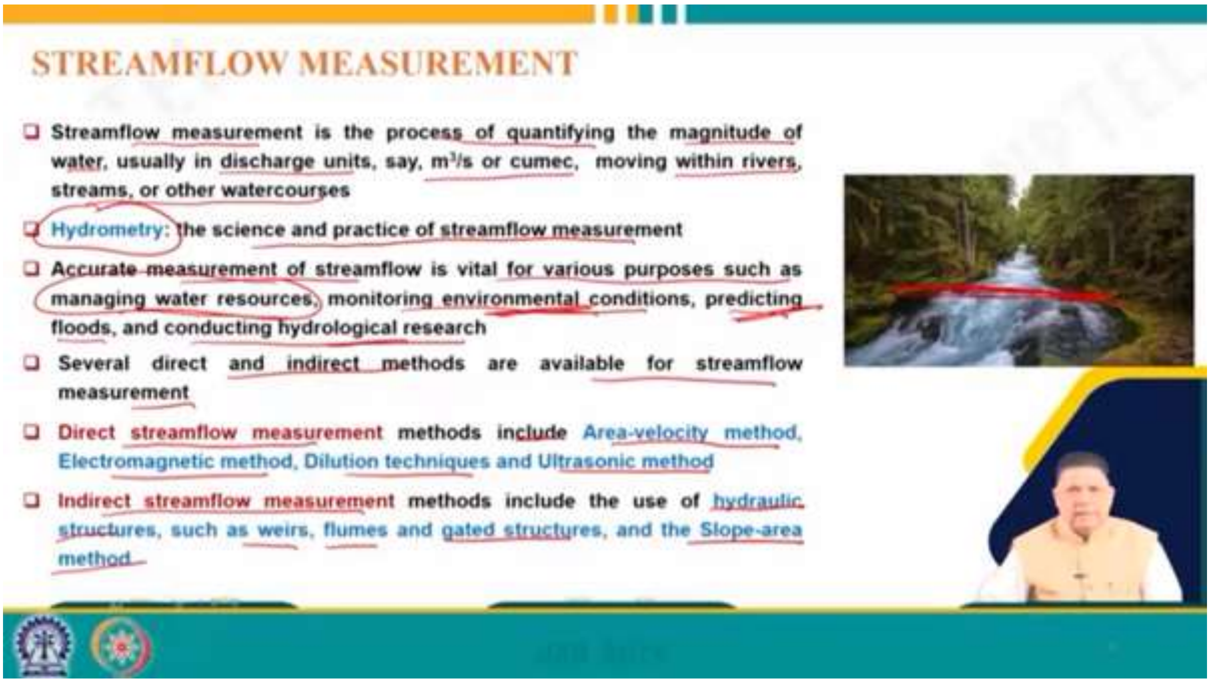
Week: 01

Lecture 12: Streamflow Measurement 1

Hello friends, welcome back to this online certification course on water sheet hydrology. I am Rajendra Singh, a professor in the Department of Agriculture and Food Engineering at the Indian Institute of Technology Kharagpur. We are in module 3, this is lecture 2, and this is entitled "Stream Flow Measurement Part 1."



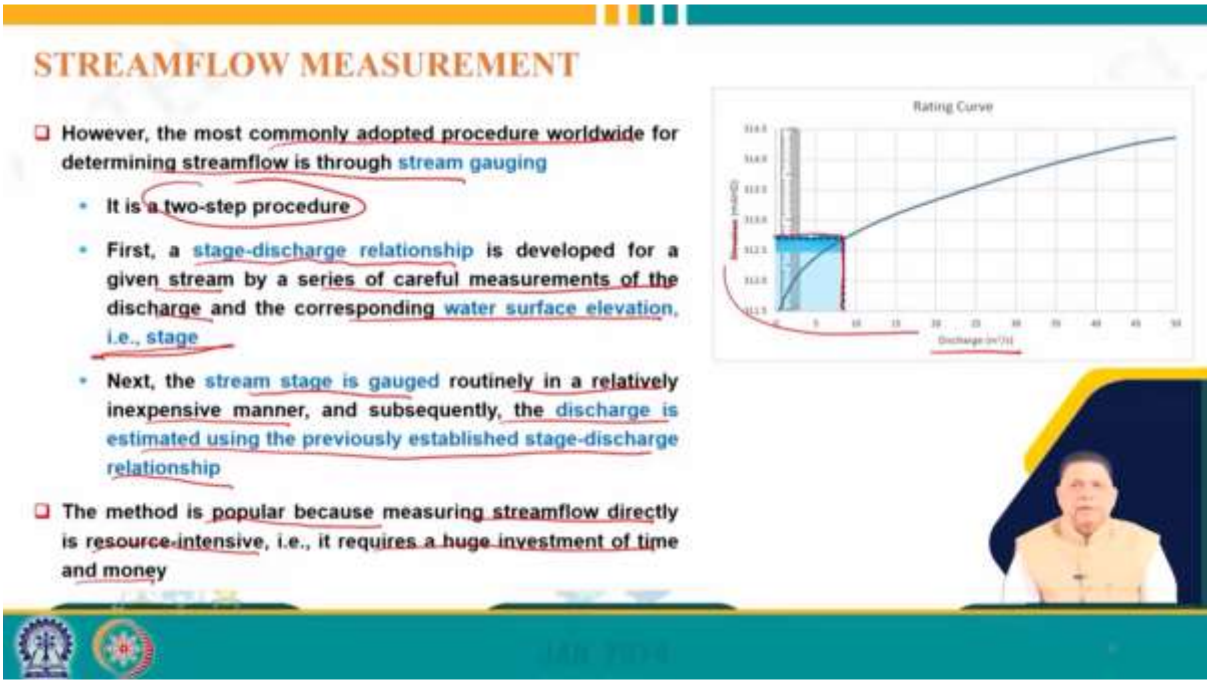
In this lecture, we will discuss stream flow measurement, measurement of stage, and measurement of flow velocity.



Now, we have already seen the stream flow process in the previous lecture, and we know that stream flow is the flow occurring in the cross-section of a river stream or a watercourse. So, stream flow measurement is the process of quantifying the magnitude of water, usually in discharge units such as cubic meters per second or cumecs, moving within rivers, streams, or other watercourses.

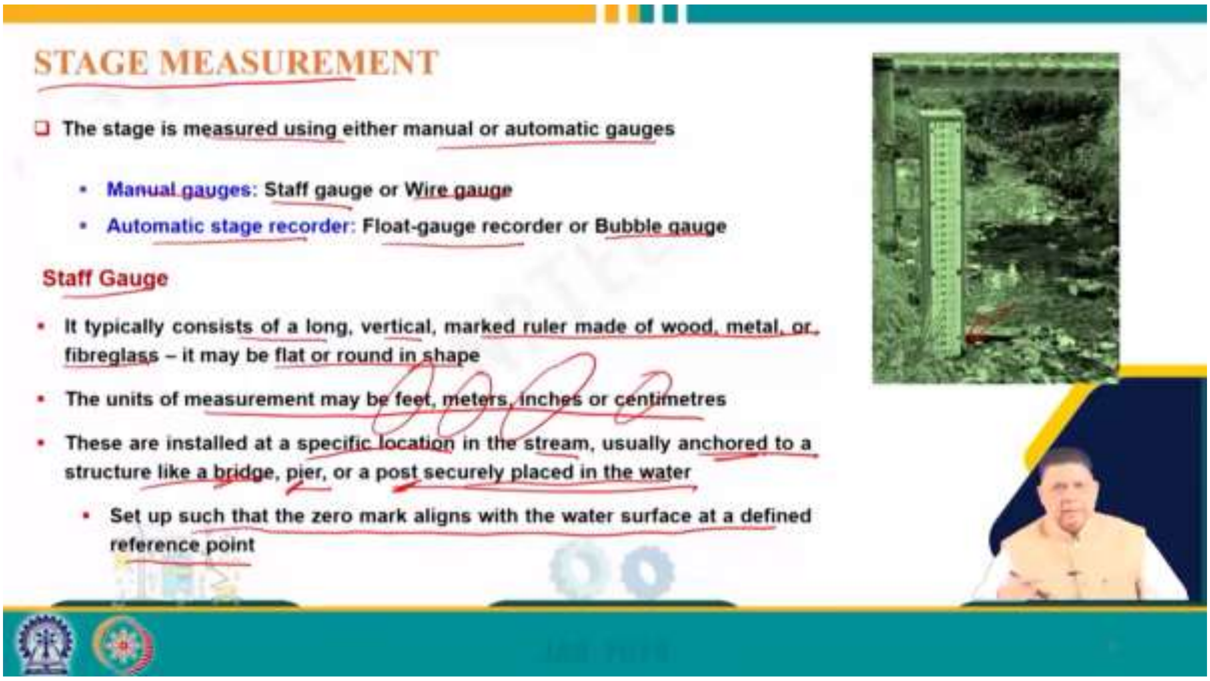
So, we saw that at any cross-section, if you measure the flow, that is the stream flow, and if you quantify that in terms of discharge units such as cubic meters per second or cumecs, that is nothing but measuring discharges stream flow measurement. And basically, the science and practice of stream flow measurement are referred to as hydrometry. So, that means, anytime we are trying to quantify a major flow, we are dealing with hydrometry. The accurate measurement of stream flow is vital for various purposes such as managing water resources, monitoring environmental conditions, predicting floods, and conducting hydrological research.

So, obviously, if you want to manage water resources of a region, a place, or a country, then obviously, you must know how much water is available. And of course, because streams and rivers carry most of the water, obviously, you have to have a good idea about how much flow is taking place in those streams, and that can only be known through stream flow measurement. And of course, as you remember in the initial introductory lecture, I also gave you information on the water resources of the country because we must know how much water is available. And then only can we think about managing it; we can predict floods in case of higher flows, or we can monitor environmental conditions based on if flows are low. And of course, for carrying out any kind of hydrological research, you require stream flow. Now, several direct and indirect methods are available for stream flow measurement. Direct flow stream flow measurements include the area velocity method, electromagnetic method, dilation techniques, and the ultrasonic method. Indirect stream flow measurement methods include the use of hydraulic structures such as weirs, flumes, gated structures, and of course, the slope area method. During our next today's lecture and the next two more lectures, we will talk about various methods, all these various methods of finding out or measuring stream flow.



Now, though there are multiple direct and indirect methods of stream flow measurement, the most commonly adopted procedure worldwide for determining slow stream flow is through stream gauging. So, what happens is that in this, it is a two-step procedure. First, what we do is we develop a stage-discharge relationship for a given stream by a series of careful measurements of the discharge and the corresponding water surface elevation or stage. So, what is done is that elevation versus discharge, we try to develop a relationship, and that is a stage-discharge relationship.

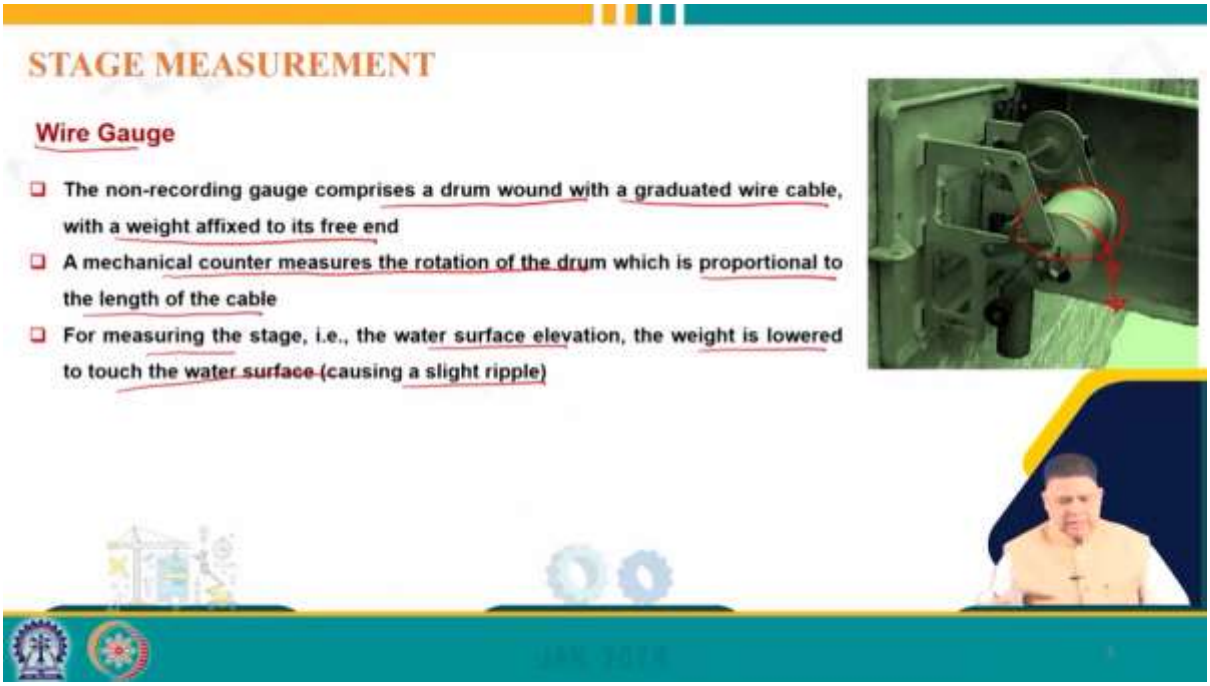
As I already mentioned, such data can come only from measurements, that is, measurements of stream flow at various elevations with respect to a datum, and then you have the relationship. Next, the stream gauge is staged routinely in a relatively inexpensive manner, and subsequently, the discharge is estimated using the previously established stage relationship. So, the first thing we do is develop this relationship, the stage-discharge relationship, and then we measure only the stage or elevation. Knowing the stage or elevation, as shown here, we can find out how much flow is taking place in the stream. The method is popular because measuring stream flow directly is resource-intensive and requires a huge investment of time and money. So, if you want to measure it, many of the methods we have seen, if you want to measure stream flow, then obviously, it is a very expensive procedure because it involves an investment in time and money. That is why this inexpensive way of just measuring the stage and then using the stage-discharge relationship is the most popular or most commonly adopted procedure worldwide for estimating discharge.



Now, as we have seen, stage measurement is a major activity in the case of stream flow measurement, and the stage could be measured using either manual or automatic gauges. The manual gauges could be of staff gauge type or wire gauge, while automatic stage recorders could be float-gauge recorders or bubble gauges, and we will see one by one. Coming to the staff gauge, it typically consists of a long, vertical, marked ruler made of wood, metal, or fiberglass. It may be flat or round, similar to a ruler we use in our daily life for measuring. The units of measurement may be feet, meters, inches, or centimetres, similar to the units on typical rulers we use in our day-to-day life, which have inches, feet, centimetres, and meters.

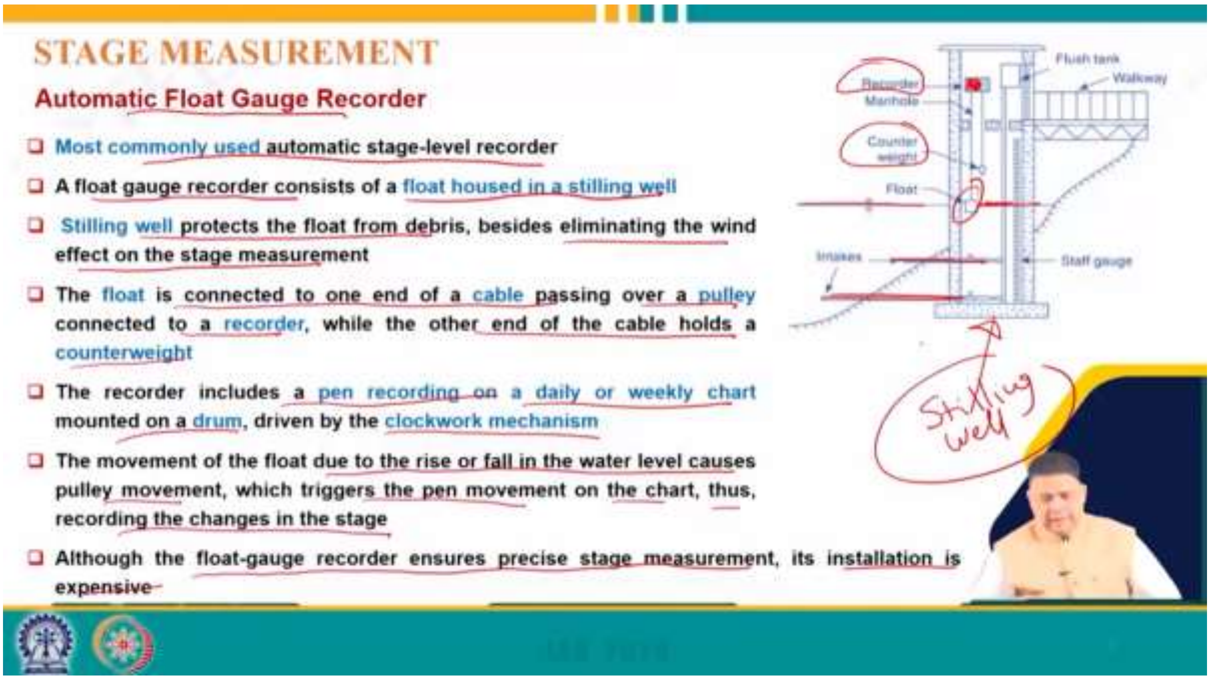
So, a similar procedure could be made here in the staff gauge. These are installed at a specific location in the stream, usually attached to a structure like a bridge, pier, or post securely placed in water. So, of course, they should be very stable for correct measurement of the stage. That is why they are always attached to a stable structure like a bridge or piers, and if the depth of water is not too much, then, of course, a post could be securely placed in the water, and then this scale could be fixed. They are such that the zero mark aligns with the water surface at a defined difference point, because we already have a stage-discharge relationship which we intend to use after measuring this stage.

Obviously, the reference point or the datum which we use here is very important because that datum should correspond to the datum that has been used for developing this stage-discharge relationship. And of course, when you cross major bridges, you might have noticed that several times the walls of the bridge itself are marked for different stages or water levels. Also, during flood times, you might hear in the news or newspapers or on television news that a river is flowing above the danger mark, and many times, we can visualize that danger mark near a river, near a bridge, or a pier because the scales are marked on the wall there.



Another type of non-recording gauge could be a wire gauge, which comprises a drum wound with a graduated wire cable with a weight affixed to the free end. So, you can see here there is a drum here on which this wire cable is wound, and of course, at the loose end, we fix a weight.

And a mechanical counter measures the rotation of the drum, which is proportional to the length of the cable. So, the measurement could be in two ways. One, the cable itself could have a measurement, or the rotation of the drum could also be measured in order to know how much cable has been lowered for reaching the water level. For measuring the stage, the water surface elevation, the weight is lowered to touch the water surface, causing a slight ripple. So, we simply lower this cable, and then when it touches the ground, water surface just touches, and then a ripple, then we stop, and that gives us the water surface elevation or the stage, and that, of course, we have to use the datum which we have used earlier as mentioned.



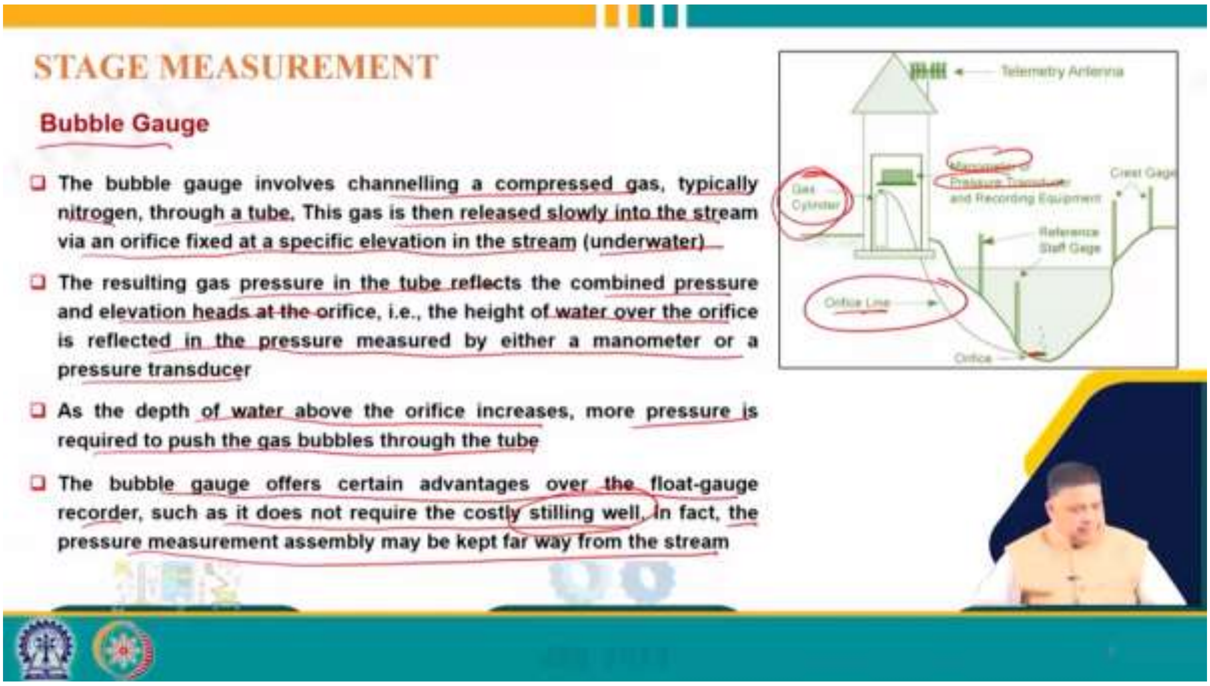
Then we can talk about automatic float gauge recorder, which is the most commonly used automatic stage level recorder. Basically, a float gauge recorder consists of a float housed in a stilling well. So, a major requirement of fixing up or installing an automated float gauge recorder is that we should have a stilling basin constructed just near the stream. This steeling wheel protects the float from debris, besides eliminating the wind effect on the stage measurement. So, obviously, what happens is that there are inlet pipes from the stream just at the bottom of the stilling well and a little up also, and in such a way that the water level in the stream and in the stilling well are maintained at the same level. And, of course, because of the protected area, debris, etcetera, cannot enter this stilling well.

Also, if we make the measurement outside, then of course, the surface of the water will be affected because of winds and all, but because the steering wheel is protected, there is no wind effect. So, we get the correct measurement of the stage. The float is connected to one end of a cable passing over a pulley connected to a recorder, while the other end of the cable holds a counterweight. So, here you can see this is basically a pulley kind of thing, and this is your float, and the other side, the free end of this cable has a counterweight.

The recorder includes a pen recording on a daily or weekly chart mounted on a drum driven by a clockwork mechanism. So, of course, linked to this pulley is a recording mechanism very similar to what we discussed in a recording type of rain gauge, say siphon type of rain gauge or weighing bucket type of rain gauge. So, what happens is that whenever the water level changes, this float level will change, and that will make a movement in the pen, and that will make a recording. So, the movement of the float due to the rise and fall in the water level causes pulley movement, which triggers the pen movement on the chart, thus recording the changes in the stage. So, as we saw in the case of rain gauges, there is a drum on which the chart is placed, and which is basically runs based on a clockwork mechanism, that is, along the clock.

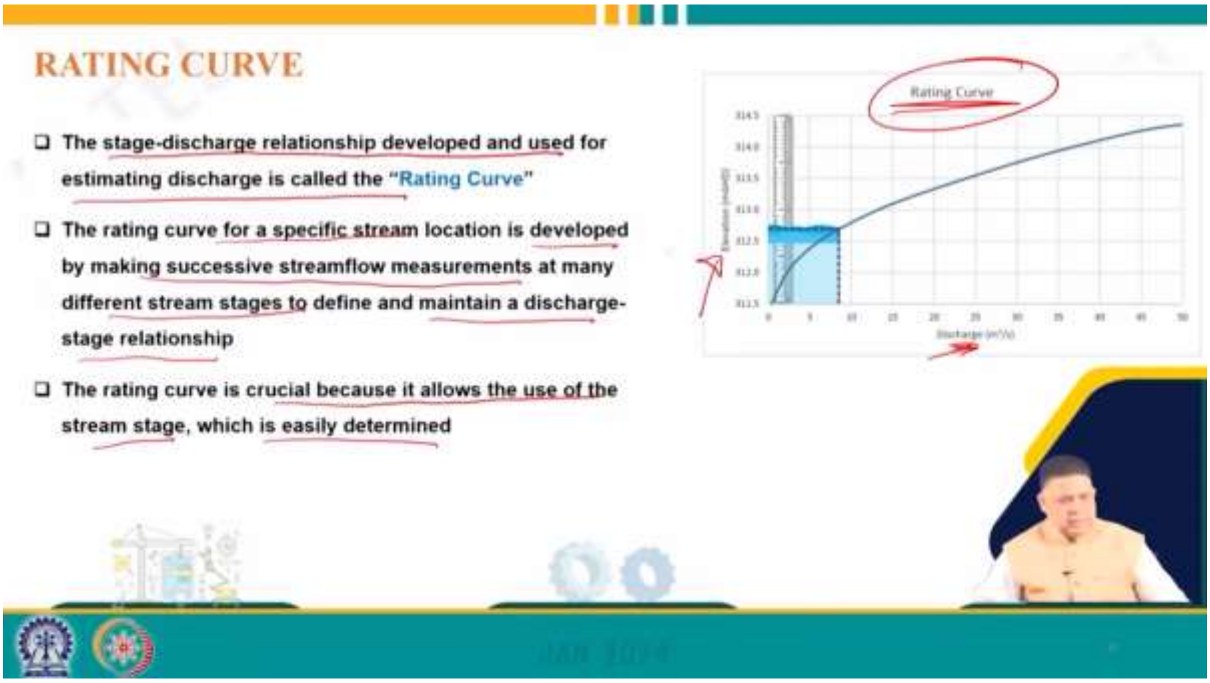
So, obviously, when there is no change in water level, we will get a horizontal line, but whenever there is a change in the water level, in the stream water level or water level in the stilling well, here the float will rise or fall, and that will be recorded by the pen movement.

Although the float gauge recorder ensures precise stage measurement, its installation is expensive, and that is primarily because we require this stilling well. So, the stilling well forms the most expensive part besides the equipment, of course, of this installation.



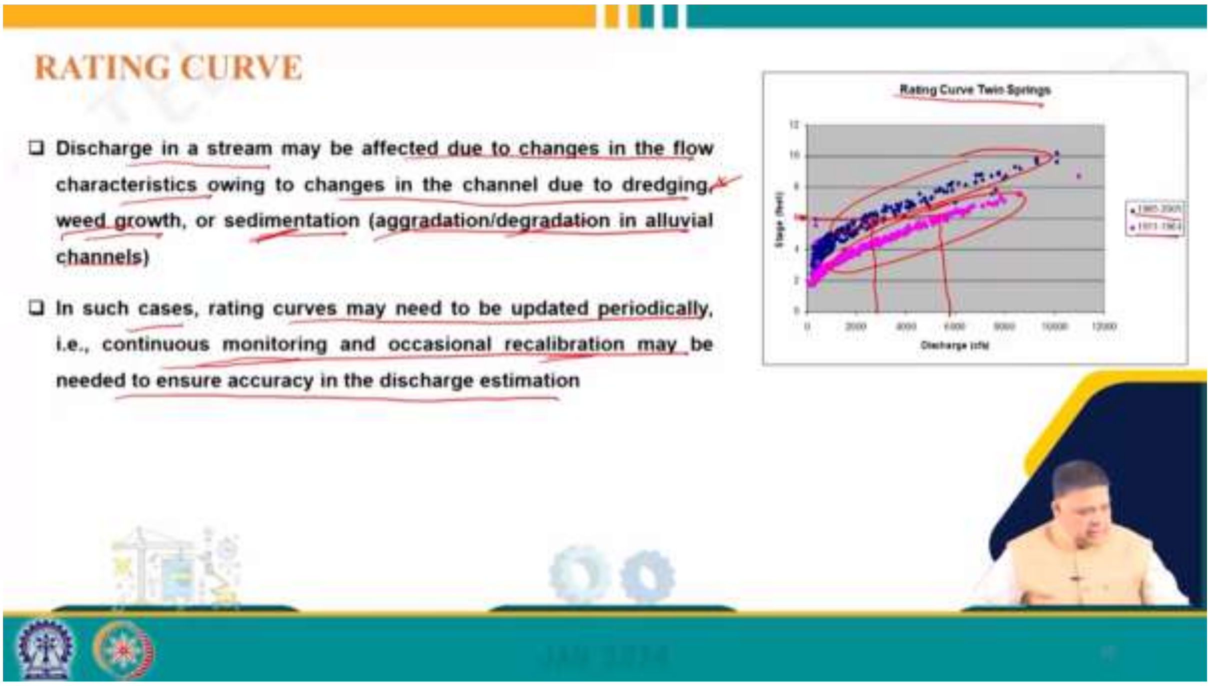
The other automatic measurement is through a bubble gauge, which involves channelling compressed gas, typically nitrogen, through a tube. This gas is then released slowly into the stream via an orifice fixed at a specific location in the stream underwater. So, as you can see here, this is a chamber and a gas cylinder here, and through a tube, this is the orifice line, this orifice is placed at the bottom under the water. So, this is the orifice, and then gas is released into the stream through this gas cylinder. The resulting gas pressure in the tube reflects the combined pressure and elevation hits at the orifice, that is, the height of water over the orifice is reflected in the pressure measured by either a manometer or a pressure transducer. So, here, linked to a gas cylinder, we have a manometer or pressure transducer that records the pressure, and that pressure will include not only the pressure of the gas but also the water level changes. As the depth of water above the orifice increases, more pressure is required to push the gas bubbles through the tube.

So, that means, any change in the water level we require will change the pressure on the gas cylinder for releasing the gas here, and that will be recorded by the manometer or the pressure transducer. The bubble gauge offers certain advantages over the fluid gauge recorder, such as it does not require the costly. In fact, the pressure measurement assembly may be kept far away from the stream. So, as we saw in the case of an automatic stage level recorder, we have to have a, and because we know that the water level is maintained at the same level in the stream as well as in the, obviously, that cannot be too far off from the stream because the pipes are inserted from the stream to take the water to stilling well. But here, in this case, it is only an orifice line or a simple tube that is taking gas to this orifice below the water, below the stream level, and that is why this particular arrangement could be far off because only a pipe has to go. So, that is why it is much less expensive compared to a stage level recorder.



But, of course, coming back, we have already seen that the most commonly used way is to use this rating curve, and this rating curve is nothing but the stage-discharge relationship developed and used for estimating discharge. So, earlier we talked about the elevation-discharge relationship which we developed, and that is referred to as a rating curve. Basically, once we have a rating curve for a specific stream location, then if we measure the stage using either the manual, that is, a staff gauge or the wire gauge, or the automatic stage level recorder, or the bubble gauge, if we know the stage, then, of course, that stage can be converted into discharge quite easily.

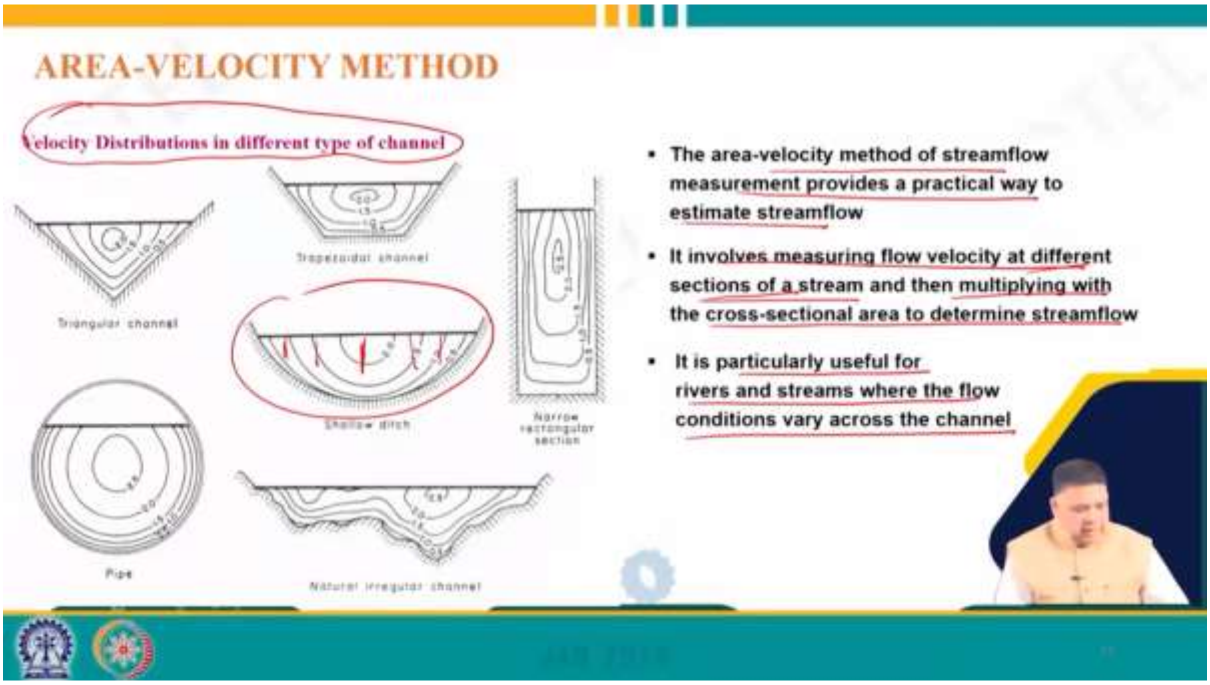
The rating curve for a specific stream location is developed by making successive stream flow measurements at many stream stages to define and maintain a discharge-stage relationship that we already discussed earlier also that, of course, we have to conduct experiments or flow major flow at different stages in order to be able to develop the stage-discharge curve or rating curve, and it is crucial because it allows the use of the stream stage which is easily determined. So, just now we discussed that we measure the stage and using the rating curve, we can find out what is the stream flow in a given river.



And the problem is that the discharge stream may be affected due to changes in the flow characteristics going to change in the channel due to dredging, weed growth, or sedimentation that is both a gradation or degradation in a lube wheel channel. So, obviously, we just now discussed that what we do is carry experiment at a particular cross-section of the river in order to develop the stage-discharge relationship, but if the cross-section of the river or stream gets affected. So, for example, if there is sand mining dredging, so obviously, the cross-section will go up if there is weed growth the cross-section will reduce, and similarly, due to sedimentation whether it is a gradation or degradation.

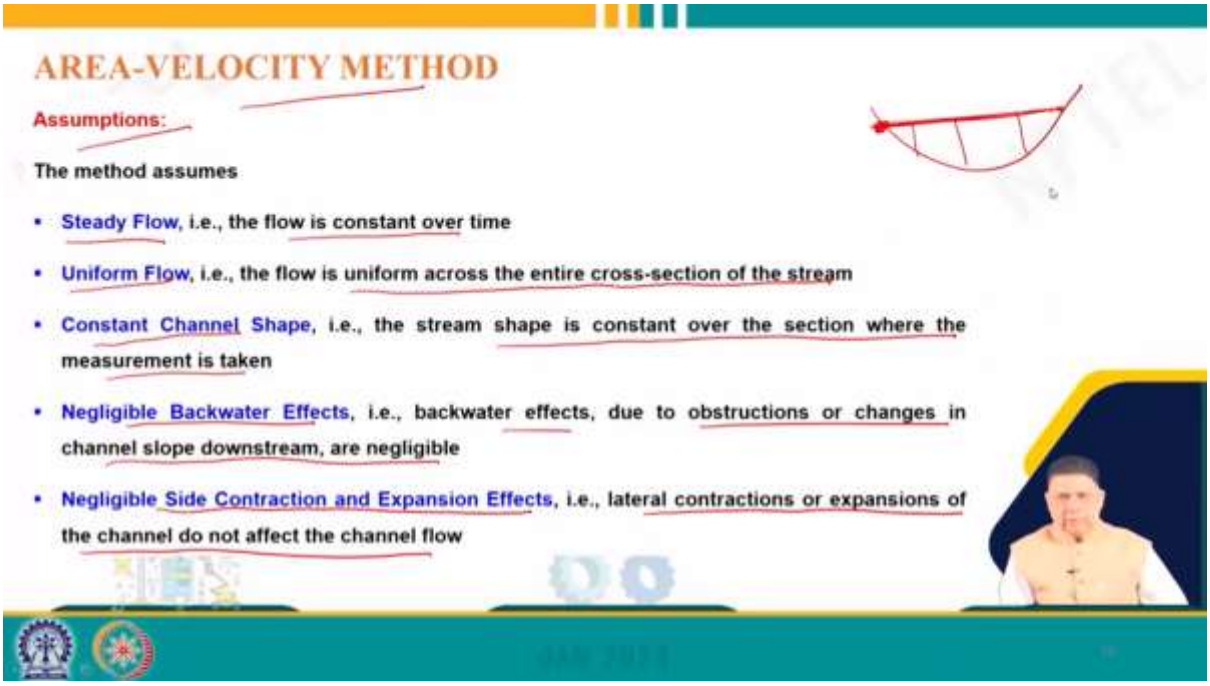
A gradation means the silt is getting deposited at that cross-section, and degradation means the silt is being taken away from that cross-section. So, there will be cross-sectional changes, and if that happens, then obviously, the rating curve which we have developed will be affected. And in such cases, rating curves may need to be updated periodically, that is, continuous monitoring and occasional recalibration may be needed to ensure accuracy in the discharge relationship. Because we are depending on that stage-discharge relationship for converting the stage into discharge, so obviously, that stage-discharge relationship has to remain true for a given period of time where we want to use. For example, here, for a particular rating curve in Twin Springs, this two-page stage-discharge relationship is shown.

So, between 1965 and 2005, this is the blue colour, whereas between 1911 and 1964, the pink colour. So, as you can see here, there is a change in the stage level relationship. So, if you continue to use the same old stage level recorder, for the same stage, you will be getting a much different result. For example, if the stage is 6 and you are using the old rating curve, then your flow will be very close to 6000 cubic feet per second, whereas if you are using the new one, then your flow will be only 3000. So, obviously, as you can see, there is just a 100 percent change in the stream flow because of the change in the characteristics of the rating curve. So, that is why it is important that we continuously monitor the developed rating curve and we keep on recalibrating that in order to see that the stream cross-section remains true.



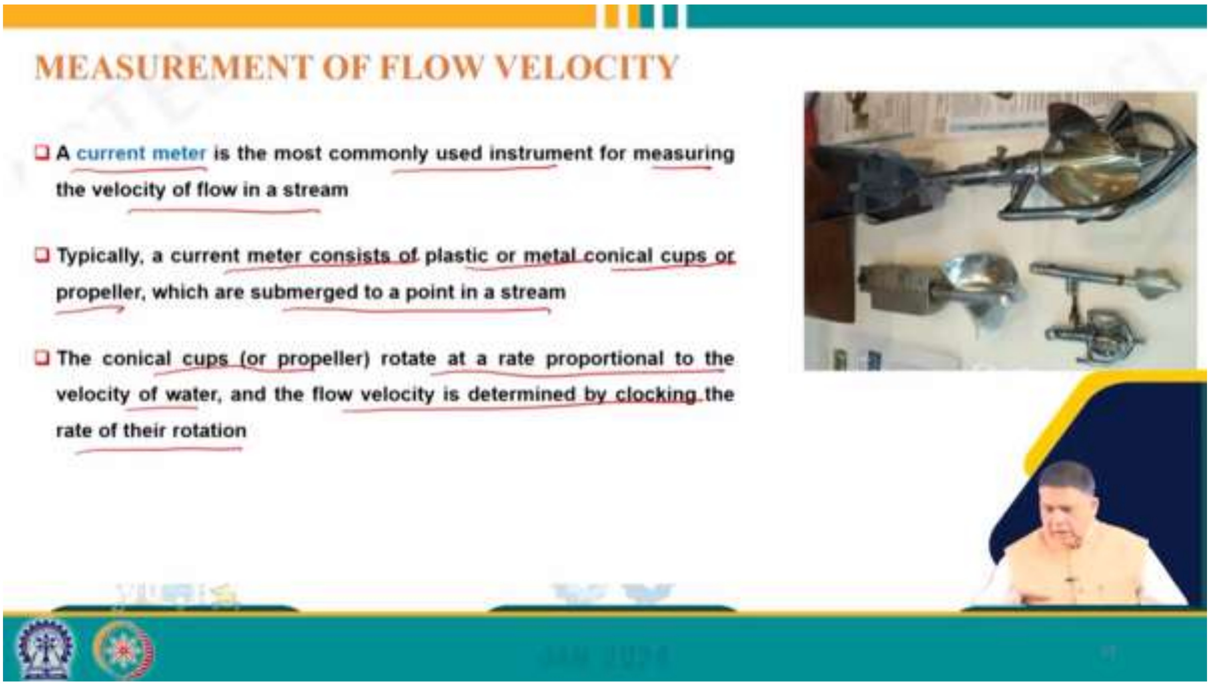
Then we come to the area velocity method, and the area velocity method of stream flow measurement provides a practical way to estimate stream flow. It involves measuring flow velocity at different sections of the stream and then multiplying with the cross-sectional area to determine the stream flow. So, it is also a two-stage process; we measure velocity and then we determine the cross-section and multiply the cross-section with the velocity to get the stream flow. It is practically useful for rivers and streams where the flow conditions vary across the channel.

So, obviously, you can understand by looking at the velocity distribution in different types of channels. As you can see here, the velocity distribution changes drastically, and that is why we cannot have just a single measurement of velocity at one section; we have to have, because if you consider this kind of thing. So, if you measure velocity here and the cross-section here, probably you will get a wrong picture because the velocity of flow is very different at different sections. So, that is why we make several measurements or measurement of flow velocity at different sections of the stream and then multiply that with the cross-section in order to get the correct value of stream flow.

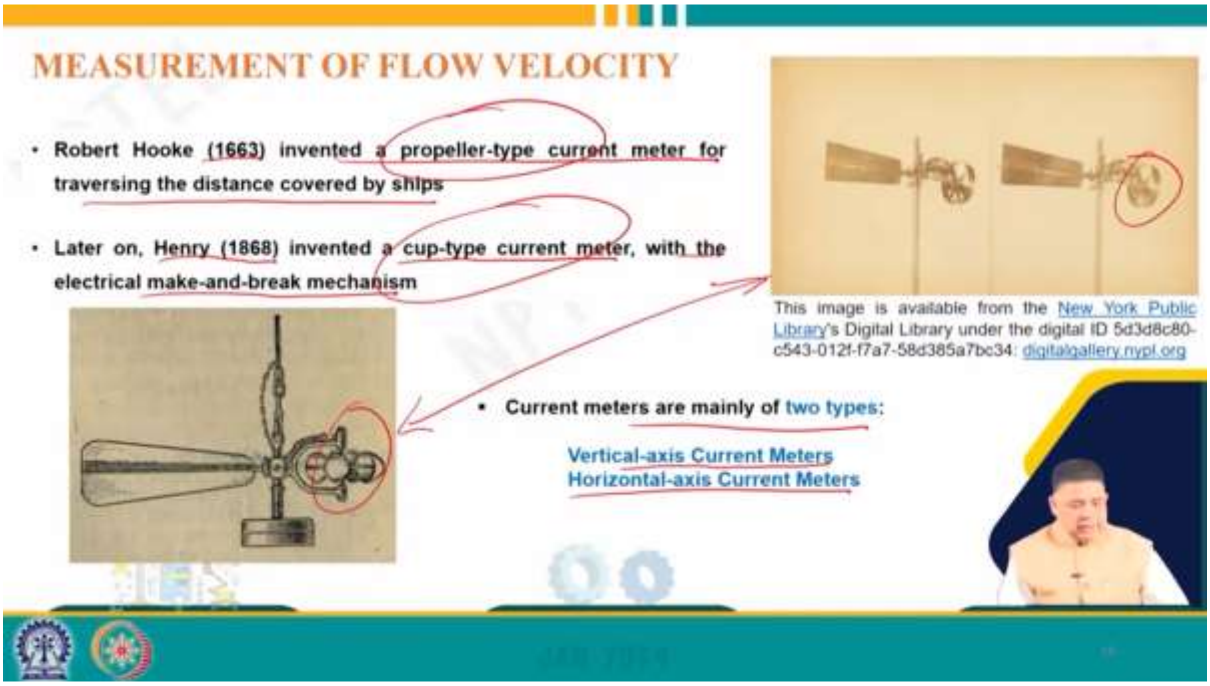


Now, this area velocity method has certain assumptions behind it. It assumes that the flow is steady, that is, the flow is constant over time, during the experimentation there is no change in the flow. Then the flow is uniform, that is, the flow is uniform across the entire cross-section of the stream. So, you have a cross-section of the stream, so flow does not vary from one section to the other. Then constant channel shape, the stream shape is constant over the section where the measurement is taking place. So, that means, there are no sudden changes in the cross-section.

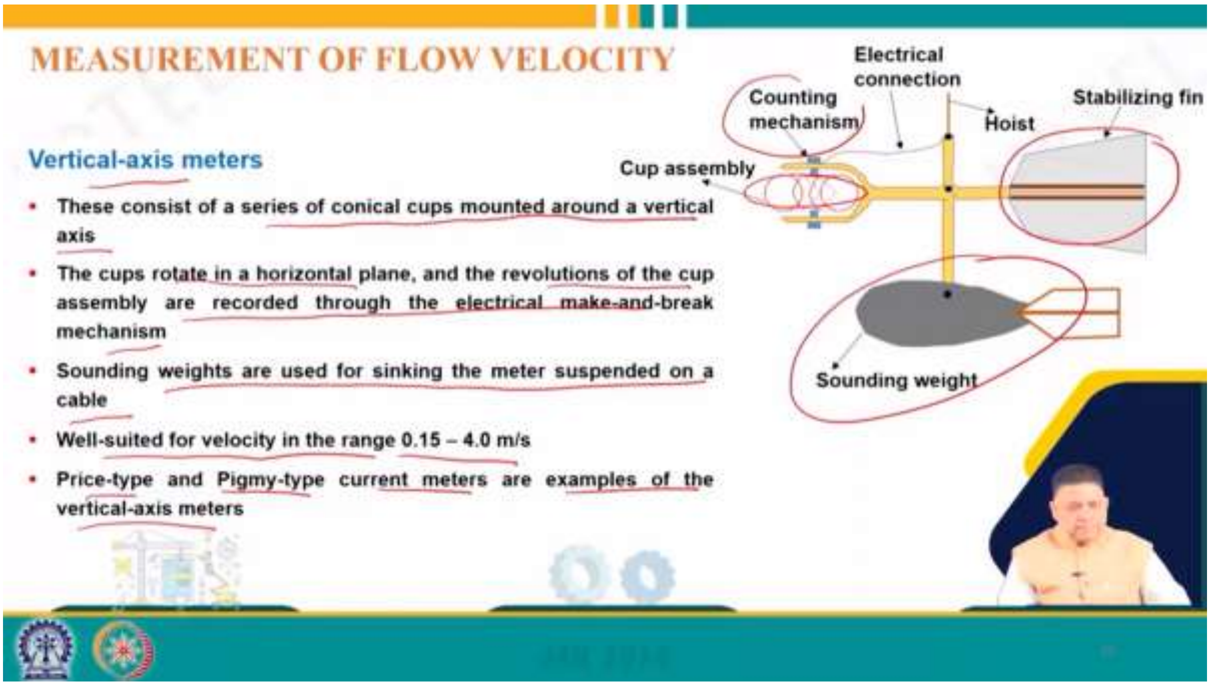
Negligible backwater effects, that is, backwater effects due to obstruction or changes in channel slope downstream, are negligible. So, that is why if there is a say a dam or some kind of obstruction just downstream or upstream, then obviously, the flow patterns will be very different at a given cross-section. So, we assume that there is a negligible backwater effect and there is a negligible side contraction or expansion effect, that is, the lateral contractions or expansions on the channel do not affect the channel flow. So, that means, if there are any contractions or expansions at the sides, that will not affect the flow. These are the kind of assumptions we make here.



Now, coming to the measurement of velocity, typically, equipment called a current meter is most commonly used for measuring the velocity of flow in a stream. Typically, a current meter consists of plastic or metal conical cups or a propeller which are submerged to a point in a stream, and then thus, we measure the velocity. And the conical cups or propeller rotate at a rate proportional to the velocity of water, and the flow velocity is determined by clocking the rate of their rotation. So, a current meter has either conical cups or a propeller. It is immersed in the water, and because of the flow velocity, the either conical cups or propeller they rotate, and we simply measure the rotation, and from there, we determine the flow velocity, that the simple procedure which we use.

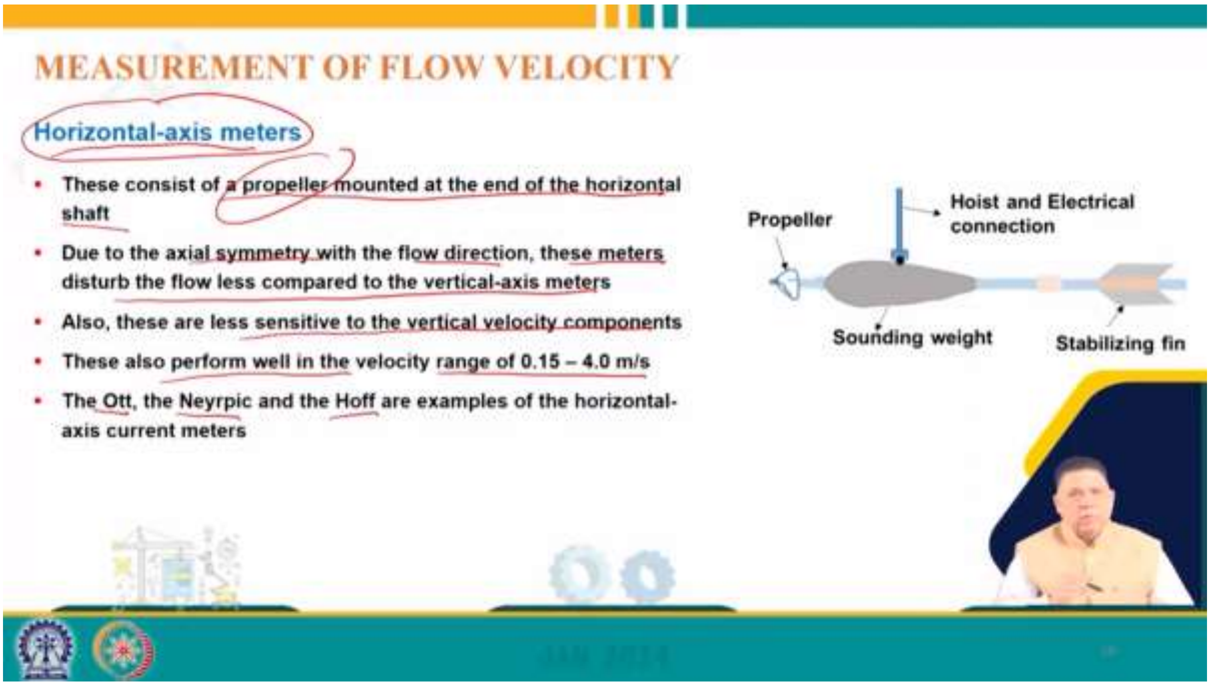


Now, Robert Hooke in 1663 invented a propeller-type current meter for traversing the distance covered by a ship. So, the first current meter was developed way back in 1663, that means, almost 400-450 years or 460 years back. And later on, Henry in 1868 invented a cup-type current meter with the electrical make and break mechanism. So, I mean so, if we talk about the propeller type which is here or a cup type of current meter, they came into existence long back, 450 years almost in the case of propeller type and almost 250 years in the type of a cup type current meters. And current meters are mainly of two types, vertical axis current meters, and horizontal axis current meters. And of course, when we come to discuss this, you will realize that basically these are the two types of current meters we are talking about when we talk about vertical axis meters or the horizontal axis meters.



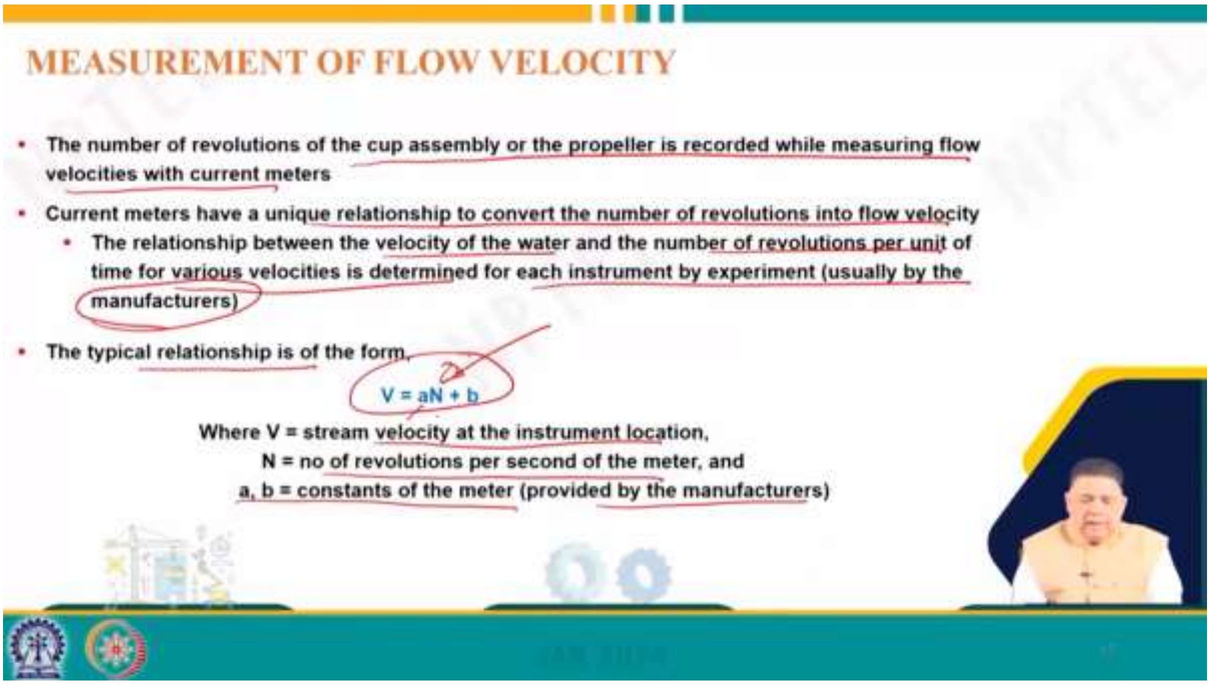
Coming to vertical axis meters, these consist of a series of conical cups mounted around a vertical axis. So, as you can see here, there is a vertical axis, and you have a series of conical cups or a cup assembly. The cups rotate in a horizontal plane, and the revolutions of the cup assembly are recorded through the electrical make and break mechanism. So, here there is an electrical connection and the counting mechanism, and then this rotation is recorded. Sounding weights are used for sinking the meter suspended on a cable. So, there is a see this sounding weight is lowered for sinking this current meter and also to keep it stable vertically.

In order to keep it stable horizontally, there is a stabilizing fin on the other side. Such current meters are well-suited for velocity in the range of 0.15 to 4 meters per second. Price type and pygmy type current meters are examples of the vertical axis current meter, that is, that means, they have these conical cups mounted around a vertical axis.



Then the other category we have horizontal axis meters. These consist of a propeller mounted at the end of a horizontal shaft. So, obviously, as we discussed earlier, the vertical axis meters have conical cups whereas in the horizontal axis meters, we have propeller type. They are propeller type at the end of a horizontal shaft. Due to axial symmetry with the flow direction, these meters disturb the flow less compared to the vertical axis meter. So, in this case, as you saw, if you look at the design of the two, here there is a significant ah component which might disturb the flow whereas it is just a propeller which rotates.

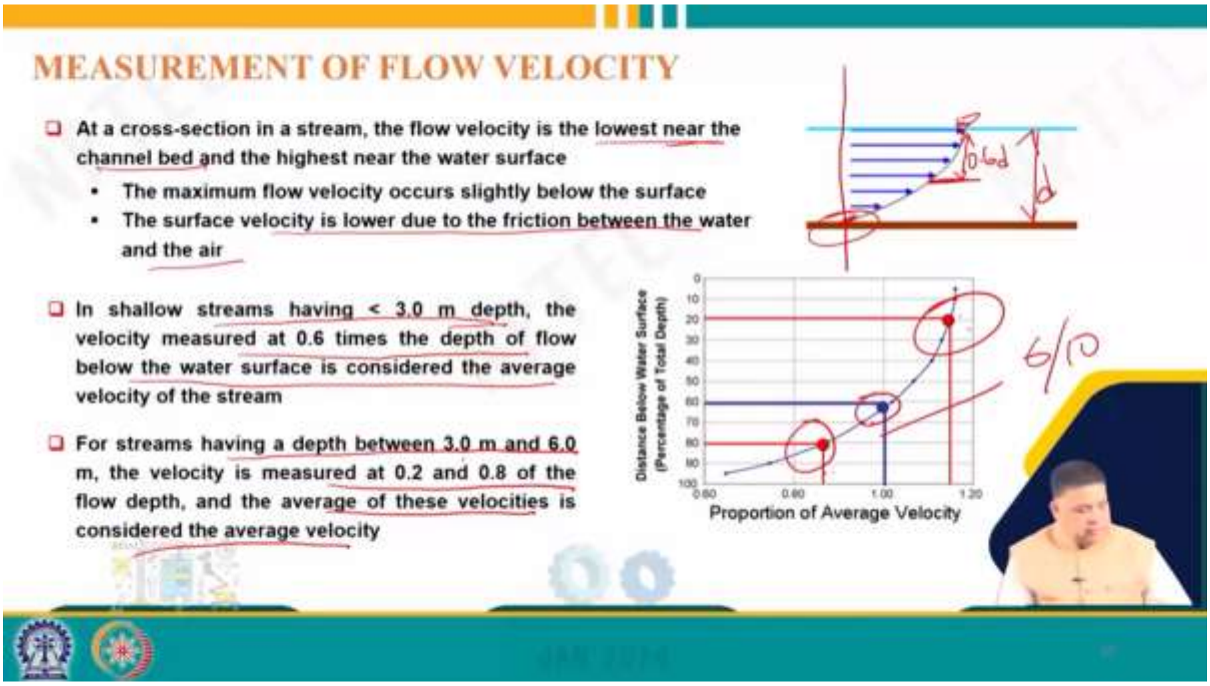
Also, these are less sensitive to the vertical velocity component because, in this case, there is no vertical disturbance. So, there is no vertical velocity component in this case. And these also perform well in the velocity range of 0.15 to 4 meters per second. That means, as far as velocity range is concerned, both vertical and horizontal axis current meters are similar in nature. The typical examples of horizontal axis current meters are the Ott type, the nephric type, or the huff type of current meters, and they originate from different countries like Ott comes from Germany, basically.



The number of revolutions of the cup assembly or the prop is recorded while measuring flow velocity with a current meter. So, basically, as we discussed earlier, we measure the number of revolutions, and each current meter comes up with a unique relationship to convert the number of revolutions into flow velocity. The relationship between the velocity of water and the number of revolutions per unit of time for various velocities is determined for each instrument by experiments, and basically, it is provided by the manufacturer. So, typically, when we buy a current meter, it comes with a relationship of this form:

$$V = aN + b,$$

where V is the stream velocity at the instrument location and N is the number of revolutions per second of the meter, and a and b are constants of the meter provided by the manufacturer. So, that simply means when we immerse this current meter into the stream, this is what N we measure, and a and b are the constants of the meter that is provided by the manufacturer.



At a cross-section in a stream, basically, we have seen that across the cross-section, velocity varies. But also, if you take a vertical cross-section, then velocity varies significantly from top to the bottom. The maximum flow velocity occurs somewhere near to the surface, and the surface velocity is lower due to friction between the water and the surface. The flow velocity is lowest near the channel bed because of the drag, etcetera. The friction and the drag result in the lowest velocity at the bottom. Though with this graph, it appears that the velocity is highest at the top, but it is not so because of the resistance; it is slightly below the surface where the velocity is highest. So, that is why we have to be careful where we measure, at what depth we measure the velocity.

So, in shallow streams having less than 3 meters depth, the velocity is measured at 0.6 times the depth of flow below the water surface. That is, for example, if this is the total depth d, then from the top, we measure 0.6d, which is this point here where we measure the velocity. For streams having a depth between 3 to 6 meters, slightly deeper ones, velocity is measured at two locations at 0.2d and 0.8d, and the average of these velocities is considered the average velocity. So, in deeper streams, we make two measurements: one at 0.2d and one at 0.8d, and then we take the average of these two. We have to be careful that if it is up to 3 meters depth stream, then we use the 6th-tenth rule, but if it is more than 3 meters, then we make measurements at 2 points, 0.2d and 0.8d, and take the average velocity, the mean velocity of the stream.

Measuring velocity in a large stream is also challenging and can be done through current meters. In that case, we use a ropeway, which offers a practical means of measuring velocity in large streams, allowing for the assessment of flow characteristics at different points and depths across the stream width. So, as you can see, there is a cableway, a ropeway, and a cable which may carry a person or could be automated. Then, at different locations, which are already known or prefixed points, the current meter is lowered. Then, the velocity is measured at different cross sections across the cross section of the large streams, and then, knowing the area, we can find out the stream flow. Here, in this lecture, we have started looking at various methods of stream flow measurement. As I said, we will continue because we saw that there are various direct and indirect ways of estimating or measuring stream flow. So, we will continue to discuss in the next lectures also. So, with this, thank you very much. Please give your feedback and also raise questions or doubts, which can be answered on the forum. Thank you very much.