River Flow Measurements

Introduction

Flow measurement technology has evolved rapidly in recent decades. Physical phenomena discovered centuries ago have been the starting point for many variable flow measuring devices. In recent years technical development in other fields namely in optics, acoustics and electromagnetism have resulted not only in improved sensitive designs but also in new flow measuring concepts.

Why measurements?

The measurement of river flow is required for river management purposes including water resources planning, pollution prevention, and, flood control. Existing method of river flow measurements consists mainly of the velocity area method and the use of weirs and flumes. In velocity area method, the river is divided into segments and the discharge through each segment is computed by multiplying the average velocity in each segment by the segment area. The sum of the products of area velocity for each segment gives the discharge. Velocity is measured by means of a rated current meter and area is measured using soundings, measurements of distances from a fixed reference point on the riverbank. In the measurement of discharge by means of hydraulic structure constructed in the river a well-established relationship of head and discharge is utilized which can be determined empirically in the laboratory and checked as necessary. Both the methods have certain limitations and are not applicable in all the circumstances. The former method requires condition, which produce a stable stage discharge relationship and the later is confined, generally, to small rivers where sufficient head is available and where a constriction in the river is acceptable. Very often, these conditions are difficult to find especially in the lower reaches of the river. This has necessitated the new methods for river gauging.

Following are some of the reasons why this may arise:

(i) The river is too large.

(ii) There is no stable stage discharge relationship.

(iii) A measuring structure would be unsuitable and unacceptable.
In large rivers having width say more than 300 m, the conventional method of velocity-area measurement is both costly and tedious especially during floods or unsteady flow conditions. The unsteady flow may be caused by releases from dams, barrages, navigational locks, and in such circumstances, there would be no stable stage discharge relationship. Also the mobile bed, growth of weeds will cause unsteady flow. In tidal rivers and particularly in estuaries, there is no satisfactory conventional method of measurement because the problem caused by reversal of flow and navigational requirements.

Theoretically, there is no limit to the length of measuring structure. However, practically such structures can not be constructed on the rivers that are being used for inland navigation, river crafting etc. Also, on the rivers where sufficient efflux is not available. Further, the cost alone decides the installations of measuring structures in rivers of width greater than 50 m.

Some of the new methods for measuring the river flow are:


The most popular method in India even now is the **Velocity Area Method** and **Radio active Tracer Technique**.

**Historical Data Requirements**

The planning, design, and development of water resource require predictions of amounts, the variability and quality of water in a variety of river and stream. The parameters measured usually describe processes that develop in time, generally the quantities determined exhibit random fluctuations such that their values can be predicted only in a statistical sense. In such cases, the properties of the time series are estimated from records of historical data and the longer the series the better are the estimates of parameters describing the design of the processes. Historical data or the data that is observed only once as opposed to experimental data, which are repeatable. Thus, the ability to predict hydrologic processes, stream flow, for example: is linked closely to the available length of records. Records of river stages and river discharges extend far back in time.
Errors

One of the important aspects of river flow measurements is the recording of stage. The accuracy of the computed discharge entirely depends on the accuracy of record of stage produced at the station, and a prime requirement is that the instrumentation used for this purposes operates efficiently and within the tolerance limits of the specification. An inspection and maintenance routine for the stable design should be established and any installation operation and maintaining instruction provided by the manufacturer and the gauging authority should be followed carefully. Field personnel responsible for operation of the recorder, should be trained to recognize recording errors, and be able to identify the source of such errors and carry out any necessary adjustments.

In order to maintain accuracy and continuity of the record it is important that errors originating from sources other than the recorder should be anticipated and prevented. A typical example in the errors is caused by the float, system can result from various combinations of other sources of errors. These faults may cause a lag both in the response of the floats with changing water levels and in the response of the recording head to changes in float position.

Nature of Errors

Basically, there are three types of errors, which must be considered are:

1. Spurious errors (instrument malfunctioning, human mistakes).
2. Random errors (experimental and reading errors).
3. Systematic errors (which may be either constant or variable).

The usefulness of the flow rate measurement is greatly enhanced if true flow rate which is calculated from the measured water level (upstream head) with the aid of an appropriate head discharge equation and would be accurate. It is not relevant to give an absolute upper bound to be exceeded to the value of the error. Considering this, it is better to give a range, which is expected to cover the true value of the measured quantity with high degree of probability. This range is termed the "uncertainty" of measurement and the "confidence levels" associated with it indicate the probability that
the range quoted will include the value of the quantity being measured. Generally probability of 95% is adopted as the confidence level for all errors.

Possible sources of Errors for Discharge Measurement Structures are
1) Internal friction of recording system.
2) Inertia of indication mechanism.
3) Instrumentation errors.
4) Zero setting.
5) Setting or tilting side ways of the structure with time.
6) The crest height being level or other construction faults not included & the dimensional measurements of weir. e.g.: The width of the weir or the weir (notch) angle.
7) Improper maintenance of the structure (which can cause an extra error in the product of \( C_v \) and \( C_d \))
8) Reading errors.

One has to be very careful about identifying whether the error is random or systematic. Some sources can cause either systematic or random errors depending on circumstances.

**Propagation of Errors**

The overall error in flow discharge is the result of various contributory errors which themselves can be contributory errors. The propagation of errors is based on the standard deviation of the errors. For practical purposes, it is assumed that the distribution of the errors in a set of measurements under steady conditions can be sufficiently, closely approximated by a normal distribution.

To determine the magnitude of the composite errors the standard deviation has to be used. It is to be noted that while considering the composite standard deviation only factors with uncorrelated errors can be introduced. If the flow is modular, submerged flow reduction factor is constant and is not subject to error. The combination of a sufficiently large number of errors not having normal distribution tends to a composite error having a normal distribution. Thus in error analysis, estimation of certain errors (standard deviation) will often be used. There is a general tendency to under estimate errors. In some cases, they may even be overlooked.
Some of the common items that contribute to the Errors in Measurement of head are
1. Insufficient depth of foundation of the structures or the measurement devices or both can cause errors in zero setting.
2. Several errors that are introduced when a float operator recorder used in combination with a stilling well are
   (a) Lag errors due to imperfection in the stilling well.
   (b) Instrumental errors due to imperfection in the recorder due to internal friction of the recorder, zero setting, backlash, in the mechanism.
The magnitude of the errors that may occur in automatic recorder depends on the diameter of the float (inversely proportional to the square of the float diameter). Reduction scale for the working mechanism also contributes the errors. In case of the digital reading recorders, systematic errors are negligible but random errors occur, which is due to the falling or rising of stages between two successive readings. The wave dampening by the stilling well introduces a systematic error.

**Coefficient Errors**
The maintenance of the structures is very important in order to obtain the expected accuracy. Sediment, debris, algal growth must be removed regularly to keep the structures free of weed, and fungicides can be used. It must be realized that algal growth on broad crested weirs increases the friction and the crest.

**Velocity Measuring Devices**
One of the earlier developments in the measurements of the velocity using current meter was attempted by Revy in 1870. Continuous development of the current meter over 300 years has resulted in the general adoption, for river flow measurements of an instrument with an underwater unit in which a rotating element operates an electric or make and break switch. Basically there are two types of current meters.
1. Propeller Type
2. Cup Type
Miniature current meters have been developed for river flow measurements. Some of the standard methods used for measuring discharge in river are classified under two categories.

1. Continuous measurements
2. Occasional and calibration methods.

<table>
<thead>
<tr>
<th>Continuous method</th>
<th>Occasional and calibration method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Stage-Discharge Method</td>
<td>1. Velocity-area method</td>
</tr>
<tr>
<td>2. Slope-Stage Discharge Method</td>
<td>2. Slope-Area method</td>
</tr>
<tr>
<td>(rise or fall)</td>
<td></td>
</tr>
<tr>
<td>3. Weirs</td>
<td>3. Dilution Method</td>
</tr>
<tr>
<td>4. Flumes</td>
<td>4. Existing facilities</td>
</tr>
<tr>
<td>5. Ultrasonic</td>
<td></td>
</tr>
<tr>
<td>6. Electromagnetic Method</td>
<td></td>
</tr>
<tr>
<td>7. Using the existing facilities</td>
<td></td>
</tr>
</tbody>
</table>

There have been ranges of equipment to measure the velocity such as horizontal axis propeller type current meters, vertical axis cup type current meters, optical current meter, and deep-water isotope current meter in addition to the other devices.

Normally meters with a propeller with a horizontal axis are not commonly used, Compared to meters with series of 6 conical cups rotating about a vertical axis. Approximately ratio of 1:3 in India.

The diameter of common propeller current meter is about 100 mm. Many smaller versions are available in the market. The conical cup type also ranges from mini type to normal size. These current meters are usually made of metal and some times the propeller type is made using FRP or plastics, (which are neutrally buoyant in water). These are cheaper to produce but their main advantage is that they respond very quickly to the changes in the velocity. Such current meters are very useful in rivers where fluctuations are present. Such propellers improve the accuracy of measurement of flow particularly in low velocity. Some types of horizontal axis current meters have additional facility of indicating the direction of flow and as well as speed. These types of sensors would be more useful in coastal region such as in estuaries. Some of these modern current meters could be coupled to the recording current meters, strip chart
recorder or digital recorders which could be connected to data acquisition and storage systems.

Some of the major advantages of having multiple sensors are to obtain the continuous record. However, in such cases an undetected instrument failure could result in the loss of a part of the record.

Small current meter on rod with support and counter has normally nickel plated brass, with built-in electrical contacts fitted to non-corroding metal with telescopic extensions of normally 9 mm dia. The propellers are made using anodized aluminum alloy, without any brackets in front.

Current meter is fitted with battery operated counters. Propeller diameter range from 30 mm to 50 mm, with a pitch ranging from 0.05 m to 0.5 m. As the Pitch increases the velocity range also increases. Some of these current meters can be used from 0.5 m/s to 5.0 m/s. The speed of rotation vary from 6 rev/sec to 60 rev/sec. Large size propellers are with sturdy blades with diameter ranging between 80 - 125 mm, with a pitch of 0.12 m to 1.0 m.

### The Types of Signaling Devices

Most electromagnetic pulse counters are unable to deal reliably with signal rates greater than about 10 Hz, which for many current meters limit the flow measurement to speeds not more than about 2.5 m/s. At the same time, at low speeds the signal rate is so low that a long observation period is advisable for accuracy. In order to have suitable signal frequency, sometimes in the current meter either variable gearing or a range of propellers of different pitch, or in the indicating unit, some range of selecting devices is used. All these possibilities give rise to the misinterpretation of observations. Electro digital counters are the recent advances, which promise to overcome some of these difficulties. All devices generally, electric pulse require a means of timing the number of pulses in a given period which may either be contained in the indicator unit as a built in electronic unit or be a mechanism linkage from the electrical on off switch to a normal stop watch.
Reasons for Calibrating the Current Meters

Reasons for calibrating the current meters are to establish the variation of characteristics, from meter to meter during the production. The accuracy of calculation depends on (a) the repeatability of calculated measurements. (b) The closeness of its calibrated equation and the speed of the results when group calibrations are made using number of calibration of similar pattern.

In view of the cost of calibration being high either individual or group calibrations are done. The calibration is to be repeated after the use, if wear is appreciable and the meter has been damaged or the standard of maintenance is low.

The repeatability has three meanings.
1. It can refer to the extent of agreement between more than one measurement at given speed.
2. It may refer to the agreement between a pair of measurements the second measurement being made after the meter has been dismantled and reassembled.
3. It also refers some time to the agreement between the calibration made in the working life of a meter.

The first two items above reflect the precision of the calibrated measurements and depend on the quality of the measuring equipment, where as the third refers to the durability of the meter, the use to which it has been subject to and efficiency of the maintenance.

Epper Effect

While calibration is being done, "Epper effect" must be taken into account. When towing a meter through still water in a tank a wave may develop ahead of the meter. The speed at which this wave occurs related to the depth of water in the tank and \( v = \sqrt{gd} \).

Measurements in the vicinity of this speed should be avoided as the wave affect comes into picture. The rotation of the meter causing appreciable deviation, often as high as 15% from the expected values. The different tanks will provide different calibration and the error may vary between 0.7 % to 1.5 %.
**Accuracy**

The trend in the calibration of the current meter is greatly affected by conditions in which it is used and by the standard of maintenance. But after some of use the effective pitch tends to become slightly shorten-then onwards the deviation from the rated characteristics is minimum and does not exceed the accuracy of the instruments used for calibration. Although the meters appear to maintain their characteristics within acceptable limits but care is necessary in the operation of some direct reading instruments where alteration of the controls can introduce error of the order of 40%. Therefore, the meters, which are easier to maintain and to calibrate, maintain their calibrations better than those, which require most difficult adjustments, do. Baring accidental damages the characteristics of current meters show only small variation with use, particularly with higher velocities.

Meters must be always checked and maintained carefully immediately after the use. Ill-maintained meters show large differences between the calibration characteristics before and after overhaul and repair. The threshold speed depends upon type, make, but generally, propeller type meters have threshold speeds of 0.025 m/s to 0.035 m/s. The spread of results near this threshold value is about 20% and at higher speeds the spread is within 1% range. In general, the spread of results at higher speeds is less for propeller type meters than for cup type meters. Although meters rotate about near the threshold values it is not recommended to use the current meters in this range for field measurements. International standards recommend that the minimum operation speed not be less than 0.15 m/s.

Weights are used for suspending the current meters in the field. The shapes of the weights vary. The commonest form is the bomb shape. Some weights are elliptical in cross section. In such cases the downward force is then a combination of the submerged weights and the hydrodynamic force caused by the flow of water past this body.
The meters must be calibrated by suspending in the same manner in which in the field, as the method of suspension and sinker weight affect the calibration characteristics. The difference between the readings of the meter suspended by cable and held by the rod is nearly 1%. The cable mounted current meters tend to run faster than when mounted on the rod. The deviation also depends upon the distance between the meter and the weight when suspended. If the distance is 200 mm or less the propeller may rotate about 2% faster than when mounted on rod, on the other hand when the current meter is mounted on nose of a large sinker weight, the propeller may be rotated 0.5% more slowly. In case of vertical axis meters the differences between the rods mounted meters may reach about 9%. This being lesser for cable mounted meters. When meters are suspended from the cable oscillations may occur. The effect of such oscillations may not be much on the rotation but however they may affect the bearing, in turn the calibration. Effect of depth of immersion ranges between 0.25% to 1%. Therefore, the current meters must be fixed at least at a depth below the surface of not less than twice the impeller diameter.

Measurements of the velocity in river can be done by either suspending from a static boat or by a moving boat. The later method is suitable for wide rivers.

The details of electromagnetic method, ultrasonic methods are available in Reference 1, 5 and 6.

Conclusion

Selection of the instruments and the methodology for flow measurement is to be done carefully and depends on the individual situation and site conditions.

**Calibration of Current Meters**

1. Recording current meters (self contained instruments for recording speed direction, temperature, pressure, and conducting. These are the vector ranging recording current meters employed fully encapsulated solid state electronic and memory). Aanderaa instruments, Norway.

2. Doppler current sensors, (which can be used with the buoy in the ocean, can be mounted at the bed monitoring flow velocities and direction at the surface and at
selected depths. This can measure water surface variations. Price type current meter, Gurley precision instruments, Pigmy meters.

**BIS Codes**

Indian standard specification for current meter (for cup type for water flow measurements, IS 3910, 1966, printed 1967) gives the basic details of the current meters. The ratings of the current meter is also described.

1. A minimum observation length of 30 m for automatic recording of current meter, revolutions, time and distance travelled are to be provided on the trolley.
2. Range of speed to be covered 0.05 m/s to 6 m/s.

It is mentioned that current meters shall be checked and re-rated after 300 working hours or a period of 6 months which ever is earlier.

[According to IS 3918 code of practice for the use of cup type current meter water flow measurements, (jun 1980)] some of the factors affecting the accuracy of the current meters are state of flow, angle of current, effect of wind, aquatic growth, temperature effects of boundary, low velocity.

References: