MINISTRY OF WATER ENERGY AND MINERALS
TANZANIA

MANUAL ON PROCEDURES IN OPERATIONAL HYDROLOGY

VOLUME 3

STREAM DISCHARGE MEASUREMENTS BY CURRENT METER AND RELATIVE SALT DILUTION

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MINISTRY OF WATER
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STREAM DISCHARGE MEASUREMENTS BY CURRENT METER AND RELATIVE SALT DILUTION

ØSTEN A. TILREM

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PREFACE

This Manual on Procedures in Operational Hydrology has been prepared jointly by the Ministry of Water, Energy and Minerals of Tanzania and the Norwegian Agency for International Development (NORAD). The author is Østen A. Tilrem, senior hydrologist at the Norwegian Water Resources and Electricity Board, who for a period served as the Project Manager of the project *Hydrometeorological Survey of Western Tanzania*. The Manual consists of five Volumes dealing with

1. Establishment of Stream Gauging Stations
2. Operation of Stream Gauging Stations
3. Stream Discharge Measurements by Current Meter and Relative Salt Dilution
4. Stage-Discharge Relations at Stream Gauging Stations
5. Sediment Transport in Streams – Sampling, Analysis and Computation

The author has drawn on many sources for information contained in this Volume and is indebted to these. It is hoped that suitable acknowledgement is made in the form of references to these works. The author would like to thank his colleagues at the Water Resources and Electricity Board for kindly reading and criticising the manuscript. Special credit is due to W. Balaile, Principal Hydrologist at the Ministry of Water, Energy and Minerals of Tanzania for his review and suggestions.

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1 INTRODUCTION

The discharge of a stream is the volume of water flowing through a cross section of the stream per unit of time. Stream discharge is usually expressed in cubic metres per second (m^3/s). Discharge is the most important parameter in hydrology, its measurement usually involves consideration of both stage and velocity of flow.

When a gauging station has been set up on a stream, a continuous record of stage (i.e. gauge height) can only be observed. A continuous record of discharge is obtained by converting the gauge height readings into discharge by means of the stage-discharge relationship at the station site. To establish the relation between the stage and the volume of water flowing in the stream, a sufficient number of discharge measurements is made at various stages. The measurements are plotted on graph paper against their corresponding gauge heights to produce the stage-discharge relation, or the discharge rating curve as it is called. After having been established, the gauge height readings that have been taken at regular intervals, such as daily or more often, may be applied to the rating curve and the corresponding discharges thereby determined.

The necessity for making discharge measurements depends on the circumstances at each individual gauging station. In the case of new stations, gaugings should be done without delay in order to complete the discharge rating curve in the shortest possible time. At stations where the rating curve has already been established, regular gaugings are required to check for any changes that may have occurred in the stage-discharge relation. The first indication of any change will usually appear through the deviation of the check measurements from the established rating curve. At some stations, where the control is permanent, the initial rating curve may apply throughout the entire period of operation of the station and only check measurements will be required. Stations with poor and shifting controls usually require complete re-rating at intervals, generally after major floods.

Most discharge measurements are made by the *current-meter method*, also known at the *area-velocity method*, because it is adaptable to a wide range of flow velocities and is practically unlimited with respect to the total discharge which can be measured, provided the flow is not too turbulent. Stream discharge is by definition the product of velocity and cross-sectional area of flow and this method evaluates these two terms for a particular cross section at a particular time.

Essentially, the method consists of a) dividing the stream cross-section into a number of parts for each of which the area and the mean velocity of flow are determined separately, b) computing the discharge in each part as the product of the velocity and the area, and c) summing up the partial discharges to obtain the total. It is evident that velocity observations must be made at a sufficient number of points in order to eliminate the effect of variations in the velocity of flow across the stream.

Dilution gauging is often used as an alternative to the current-meter method at sites where excessive turbulence, high velocities and rocky or shallow sections would make the operation of a current meter difficult. The principle involved is that the discharge may be calculated from the degree of dilution by the flowing water of an added tracer solution. There are upper limits on the size of a river that may be gauged, because the injected solution must mix uniformly with the flow and the degree of dilution must be within the detectable range of the tracer.

Sodium Chloride (NaCl), i.e. common salt, has been used widely as a tracer; however, its use is limited to the smaller streams and rivers because it can not be accurately detected at concentrations lower than 1 part per million (ppm or mg/l). Thus, in large bodies of water, the quantity required would be prohibitive. Furthermore, it can only be successfully applied in *thoroughly-mixed and turbulent* waters as the salt solution generates density currents. Salt's greatest advantage is its low cost and the simple and inexpensive instrumentation required.

Fluorescent dye, as for example *Rhodamine B*, can be detected at concentrations of less than 1 part per billion (ppb). It is readily separated from naturally occurring substances, it is relatively cheap and not harmful to life. Because the dye solution can be adjusted to the same density as water by dilution with alcohol, it presents no problem regarding density currents and will mix more easily with the flow of water than the salt solution.

Radioisotopes can be applied as tracers; however, their use is limited because of their high cost and associated health-hazards. The recording instruments are also quite expensive. On the other hand, in many cases the high cost may be offset to a large degree by the extremely small concentration of a radioactive substance that can be detected.

The *slope-area method* provides an approximate estimate of the discharge in a stream and is used when gauging of the discharge by more accurate methods, like the current-meter method, is not possible. Thus, it is common to use the slope-area method to define the extreme flood-stage end of the discharge rating curve because the magnitude of extreme rare floods is often such that other methods of gauging the discharge can not be used. The slope-area method can be used with accuracy in uniform channels with stable boundaries such as rock and coarse bed material.

It is, however, not advisable to use this method in the case of very large rivers, or rivers with very flat slopes and of high sediment concentration, or channels with significant curvature. The slope-area method is described in Appendix E of this Volume.

2 THE CURRENT METER METHOD

2.1 Instruments and Equipment

Current-meter measurements are classified into four types in terms of the means the hydrographer uses to cross the stream when making the discharge measurement. The four types are: a) wading, b) cableway, c) bridge, and d) boat.

Current meters, revolution indicators, and stop watches or timers are equipment used in all the types of measurements. The other equipment used depends on the type of measurement being made. Instruments and equipment are described under the following categories in this section:

1. Current meters.
2. Sounding and suspension equipment.
3. Width measuring equipment.
4. Equipment for bridge measurements.
5. Equipment for boat measurements.
6. Equipment for cableway measurements.
7. Miscellaneous equipment.

2.1.1 Current Meters

A current meter is a device with a rotor which revolves at a speed which is a function of the local velocity of flow. By placing the current meter at a point in the stream and recording the number of revolutions over a known period of time, the velocity at that point can be determined from the revolution-velocity rating of the current meter.

The number of revolutions of the rotor is obtained by an electrical circuit through a contact which completes the circuit at a selected number of revolutions. The electrical impulse produces an audible signal in a buzzer or is registered on an electrical counter. The time is determined by a stop watch or by a timer built into the counting instrument.

There are two common types of current meters, the cup-type and the propeller-type.

The cup-type current meter consists of a rotor revolving about a vertical shaft and hub assembly, bearings, the main frame, a chamber containing the electrical contact, tail vane and means of attaching the instrument to the suspension equipment. The rotor is generally constructed of six conical cups fixed at equal angles on a ring mounted on a vertical shaft. This assembly is retained in the main frame by means of an upper shaft-bearing and a lower pivot-bearing (Figure 1).

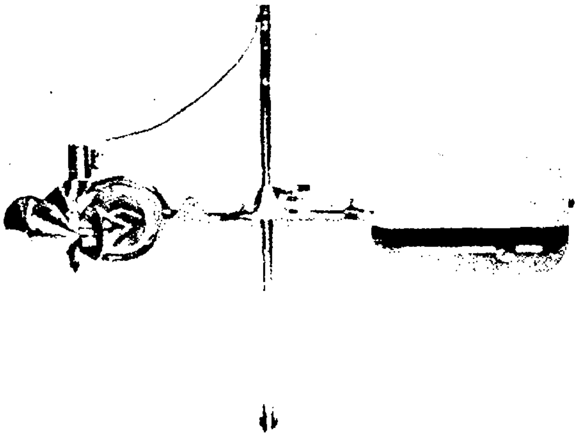


Figure 1. Vertical-shaft cup-type current meter (Price).

The propeller-type current meter consists of a propeller revolving about a horizontal shaft, two ball-bearings in an oil chamber, the current-meter body containing the electrical contact, tail-piece with vane, and means of attaching the instrument to the suspension equipment. The current meter may be provided with one or several propellers which differ in pitch and diameter. (Figure 2).

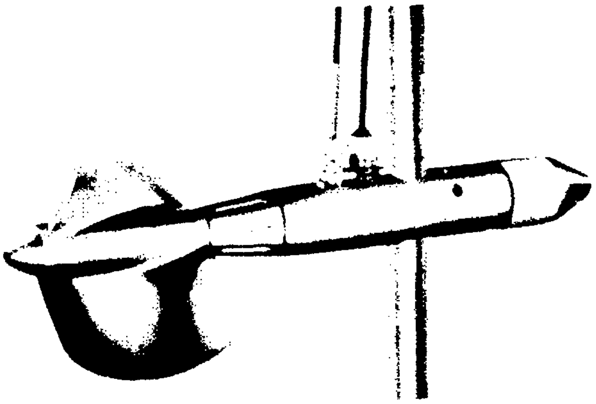


Figure 2. Horizontal-shaft propeller-type current meter (Ott).

The ideal current meter, when held rigidly at right angles to the measuring cross-section, will register the normal flow component when subjected to oblique flow. Only the propeller-type current meter can meet such a design requirement and component propellers are available which integrate flow within a range of angles varying up to 45° about the normal to the measuring cross-section.

Since the cup-type current meter is not sensitive to the flow direction, it always measures the maximum horizontal velocity regardless of whether this is normal or oblique to the measuring cross-section. Thus, it tends to over-estimate the velocity if the flow is not normal to the measuring cross-section. On the other hand, the propeller-type current meter tends to under-estimate the effect of oblique flow.

The comparative characteristics of the cup-type and the propeller-type current meter can be summarized as follows:

1. Cup-type current meter.
   a) It operates at lower velocities than the propeller-type current meter,
   b) The bearings are well-protected from silty water,
   c) A single rotor serves for the entire range of velocities,
   d) The rotor is repairable in the field without adversely affecting the rating of the current meter.
2. Propeller-type current meter.
   a) The propeller disturbs flow less than the vertical-shaft cup-type rotor,
   b) The propeller is less likely to become entangled with debris than the cup-type rotor,
   c) Bearing friction is less than for vertical-shaft rotors because any bending moment on the rotor shaft is eliminated.

2.1.1.1 Rating of Current Meters

In order to determine the velocity of the water from the revolutions of the rotor of a current meter, a relation must be established between the angular speed of the rotor and the velocity of the water which causes it to turn. The establishment of this relation is known as *rating the current meter*.

Current meters differ in their ratings principally because of slight variations in each individual rotor. Also, different sizes or shapes of weights suspended below the current meter affect the rating as do variations in the distance between the current meter and the weight. Because of these effects upon the rating, each current meter is rated individually for at least one suspension, generally the rod suspension, and coefficients based on the analysis of several comparative ratings are applied to the rod-suspension rating to obtain the rating for other suspensions.

The rating should be checked after hard usage, when the current meter has been accidentally injured and about once a year under ordinary use.

The usual method of rating a current meter is to pull it through still water and observe the time of travel and the number of revolutions made as the current meter travels a given distance. The number of revolutions per second and the corresponding velocity are then computed. When these two quantities are plotted one against the other on ordinary graph paper, a straight line will usually fit the points closely. Generally, however, there is a change in the slope of this line at a certain velocity that varies for the different current meters, so that two equations must be derived for the relationship, one for the higher velocities and the other for the lower. These equations are then solved for different velocities and a rating table made up.

Practical hints for rating current meters and an illustrative computation of the rating equations are given in Appendix D of this Volume.

2.1.1.2 Care and Maintenance of Current Meters

The so-called *spin test* is an easy method for checking the condition of the current meter. When making the test, the rotor should be protected from air currents. The rotor is then given a quick turn by hand to start it spinning and the duration of the spin is timed with a stop watch. As the rotating rotor approaches the stopping point, its motion should be carefully observed to see whether the stop is abrupt or gradual. Regardless of the duration of the spin, if the rotor comes to an abrupt stop, the reason for this should be found and corrected before the current meter is used. The normal spin time for å propeller-type current meter should be about 60 to 100 seconds; for a cup-type current meter, the spin time is considerably longer. A detailed spin test procedure is given in reference [5].

Before and after use, the current meter must be tested for proper functioning by the spin test; also, by turning the rotor slowly, the number of rotations is compared with the number indicated by the counter or audible signals. Further, the current meter should be examined for worn or damaged bearings, proper shaft alinement and for deformation of the rotor. After each discharge measurement, all bearing surfaces must be thoroughly cleaned and oiled. The oil must have the same specifications as those recommended by the manufacturer.

The manufacturer's recommendations for use and maintenance of the current meter should always be followed. A log book showing the actual details of the current meter and any changes it has undergone should be maintained for each current meter. The hours of use should also be recorded in the log book.

2.1.2 Sounding and Suspension Equipment

Sounding (determination of stream depth) is always done when making current-meter measurements. Therefore, sounding equipment as used in stream gauging serves the dual purpose of measuring the depth of water and suspending the current meter at the desired points in the gauging cross-section.

Sounding is commonly done mechanically, the equipment used depending on the type of measurement being made. The depth of water and the position of the current meter below the water surface are measured by means of a rigid rod or a sounding weight suspended on a line or cable. The line is controlled by a gauging reel.

Soundings may also be done by means of echo-sounders. The echo-sounder is an electroacoustic instrument which indicates the depth of water by measuring the time differential between the transmission of a burst of acoustic energy from just below the surface of the water and the reception of the echo from the stream bed. Echo-sounders are particularly useful for making rapid and accurate soundings in streams. Also, they are useful where the velocity is so high that other means of sounding are not practicable.

2.1.2.1 Sounding and Suspension Rods

A sounding rod, or suspension rod, is a graduated rigid rod with a base plate. The rod is used for the measurement of depths and as a support for the current meter up to depths of 4–5 m in medium velocities (about 2 m/s). The current meter is made to slide on the rod and it is fixed in position with a clamp screw. A standard rod is made of 20 mm diameter metal tubing in sections of 1 m or 2 m in length and is graduated at intervals of 10 cm. For smaller streams that can be waded, the lower 2 m portion of the rod is used only, it is then termed a wading rod.

2.1.2.2 Sounding and Suspension Lines

A sounding line, or suspension line, is used from a cableway, boat or bridge when the stream is too deep and swift for a rod to be used. A sounding line is essentially a cable to which a sounding weight or sinker is attached. The current meter is generally attached to this cable. The higher the velocity and the greater the water depth, the heavier the sounding weight required will be. For guidance in the choice of sounding weights, the following formula may be used

$$m = 5vd \qquad (2.1)$$

where

m = weight of the sounding weight (kg),
v = mean velocity (m/s),
d = depth (m).

The sounding weight should preferably be suspended below the current meter. In this way it prevents damage to the current meter when the assembly is lowered to the stream bed to determine the depth of the water. Weights are generally made in sizes of 10, 25, 50 and 100 kg and are usually made of lead. They are streamlined and furnished with tail vanes to orient them parallel to the current. The weight may be equipped with a ground contact which produces a signal when the weight touches the stream bed.

The sounding and suspension lines are controlled by means of a gauging reel or winch, or by a handline. Usually, the suspension line also serves for the transmission of the electrical impulses from the current meter to the electrical counter by an inner insulated two-conductor electrical cable.

Gauging reels consist of a drum for winding the suspension cable, a crank and ratchet for raising and lowering the current meter assembly and for holding it in any desired position, and a counting device indicating the length of line played out. (Figure 3).

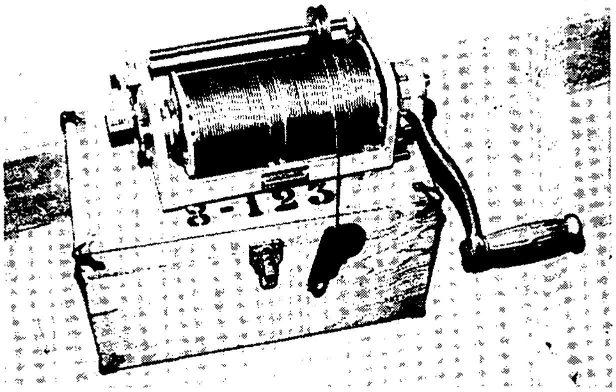


Figure 3. Gauging reel (Leupold & Stevens).

Handline suspension is a simple device operated by hand. It is used for making discharge measurements from bridges, using weights up to 20 kg and for velocities up to 2 m/s. The advantages of the handline are that it is easier to set up, eliminates the use of a gauging reel and the equipment to support the reel, and makes discharge measurements from bridges with vertical and diagonal members quicker and easier. The disadvantages of the handline are that it requires more physical exertion, especially in deep streams, and there is a greater possibility of making errors in determining the depths. A handline consists of the following parts:

1. A hand cable made up of a heavy rubber-covered two-conductor electrical cable, tagged at 0.5-metre intervals and about 10 m long.
2. Small hand reel (Figure 4).
3. A reverse-lay steel cable of diameter 2.5–3 mm with an inner insulated two-conductor electrical cable, about 12 m long.
4. Connector and plugs for current meter.
5. Plugs for electrical revolution counter.

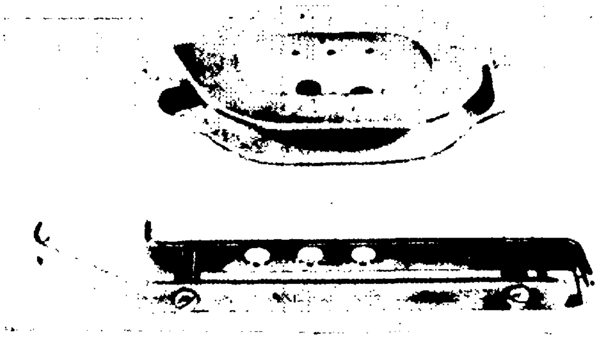


Figure 4. Handline reels (Lee-Au, and Morgan).

The hand cable is electrically connected to the steel cable at the hand reel. The connector joins the lower steel cable to the current-meter assembly. The steel cable in excess of the length needed to carry out the gauging is wound on the reel.

2.1.3 Width Measuring Equipment

The spacing of the gauging verticals in a cross section is measured from an initial point on the bank of the stream. Cableways with manned cable-car and bridges used regularly for making discharge measurements are commonly marked at 2, 5 or 10 m intervals by point marks. Spacing of verticals between the markings is measured with a rule or pocket tape. For measurements made by wading, from unmarked bridges or from boats, measuring tapes or tag lines are used.

The tag line is made of galvanized steel cable about 2 mm in diameter and brass tags at measured intervals are used to indicate the distances. The standard lengths are 25, 50 and 100 m, but other lengths can be obtained by special order. It is practical to wind the tag line on a canvas hand-reel of 20–30 cm diameter (Figure 5).

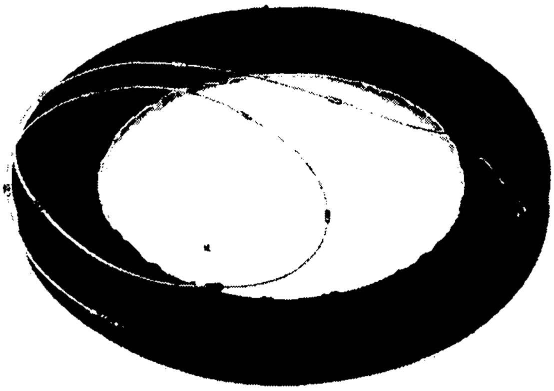


Figure 5. Tag line on canvas reel (Jobu).

2.1.4 Equipment for Bridge Measurements

The current meter and sounding weight used for measuring from a bridge can be supported by a handline or by a gauging reel mounted on a crane or on a bridge board. The handline has been described above in Section 2.1.2.2.

2.1.4.1 Bridge Cranes

Hand-operated portable cranes for bridge measurements are designed so that the superstructure can be tilted forward over the bridge rail far enough to enable the current meter and weight to clear the rail (Figure 6).

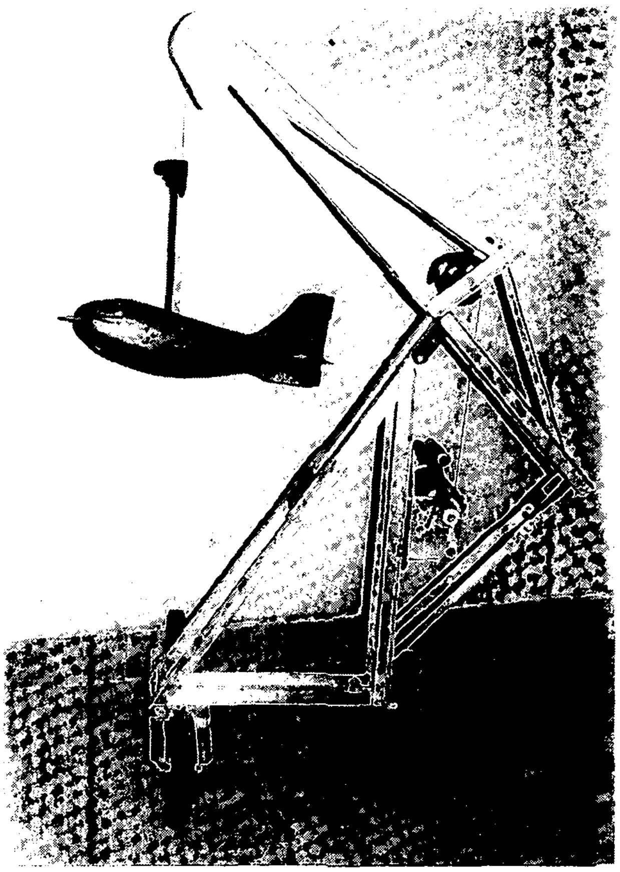


Figure 6. Bridge crane.

2.1.4.2 Bridge Boards

A bridge board is usually a plank approximately 2 m long with a sheave at one end over which the cable passes and a gauging reel mounted near the other end. The board is placed on the bridge rail during the measurement. (Figure 7.)

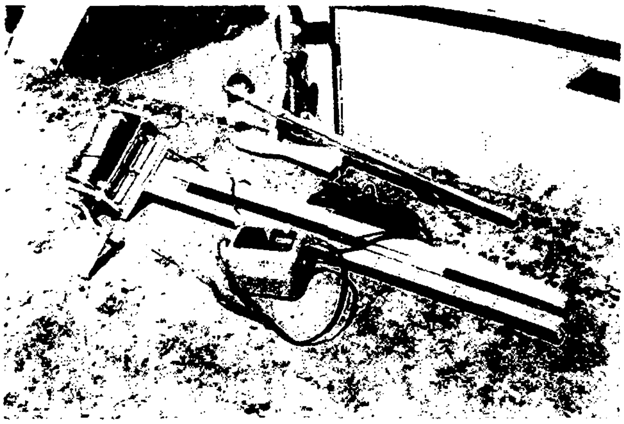


Figure 7. Bridge board.

2.1.5 Equipment for Boat Measurements

Measurements made from boats require some special equipment that is not used for any other type of measurement:

1. A boat of sufficient size to support the gauging crew and the equipment.

2. Extra large tag-line reel for use on wide streams.
3. A pair of oars.
4. A bailing device.
5. A life jacket for each crew member.
6. Outboard or inboard engine to power the boat.

An engine is required for gauging large rivers. The engine must be able to power the boat at a speed at least 25 per cent greater than the expected maximum speed of the flow. The length of the boat must be sufficient to ensure safe manoeuvrability. A simple rule for the selection of boats is

$$v = 1.3\sqrt{L} \qquad (2.2)$$

where v is the maximum relative speed of the boat in m/s and L is the waterline length of the boat in m.

Figure 8 shows a catamaran-type boat for current-meter measurements and sediment sampling on a large river. It is powered by two 18 HP outboard engines.

Figure 8. Catamaran-type boat used for current-meter measurements and sediment sampling (Karun River at Ahwas, Iran).

An engine is usually not required on small streams where the boat can be attached to a cable stretched across the river (Figure 9).

Figure 9. Current-meter measurement from boat using rod suspension (Halali River at Iyayi, Tanzania).

In a boat measurement, the current meter may be suspended on a rod or on a cable using a bridge board. Specially designed extendable boat-booms (Figure 10) or boat cranes (Figure 11) are available for boat measurements. By means of a boom, the current meter may be placed and operated so as to be unaffected by any disturbance in velocities that may be caused by the boat itself.

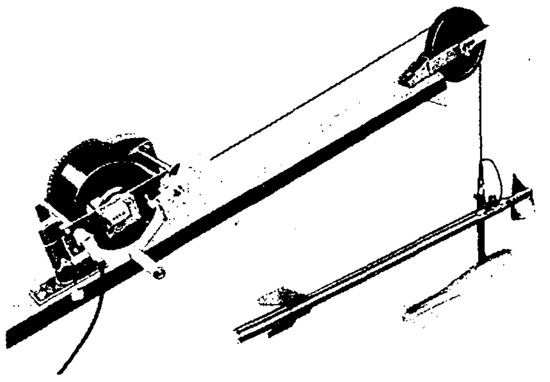


Figure 10. Boat boom for current meter measurement (Ott).

Figure 11. Boat crane used for sediment sampling (Cimanuk River at Jatiluhur Reservoir, Java, Indonesia).

2.1.6 Equipment for Cableway Measurements

Current-meter measurements can be made from a manned cable-car supported by a heavy track cable spanned across the river (Figure 12). The current meter and weight assembly are suspended on a line from a gauging reel.

A carriage from which the current meter is suspended can be used instead of a manned cable-car. The carriage is controlled by means of a winch stationed on one bank of the river (Figure 13).

For details of cableways, see Volume 1 of this Manual, *Establishment of Stream Gauging Stations*.

2.1.7 Miscellaneous Equipment

Several other items of equipment that have not been mentioned are necessary when current-meter measurements are made. These are timers, counting devices and waders.

2.1.7.1 Timers

In order to determine the velocity at a point with a current meter, it is necessary to count the revolutions of the rotor during a certain interval of time, usually 40 to 60 seconds. The velocity is then obtained from the current-meter rating table. The time interval is measured to the nearest second with a stop watch.

The stop watch commonly used is a still-movement type graduated to the fifth of a second. One complete revolution of the large hand is made in 60 seconds. A smaller dial on the face of the watch indicates the number of minutes the watch has been running up to 30 minutes. Depressing the stem of the watch starts it, a second depression of the stem will stop it, a third depression resets the watch to zero. The watches should be checked periodically to be certain they are correct and accurate. (Figure 14).

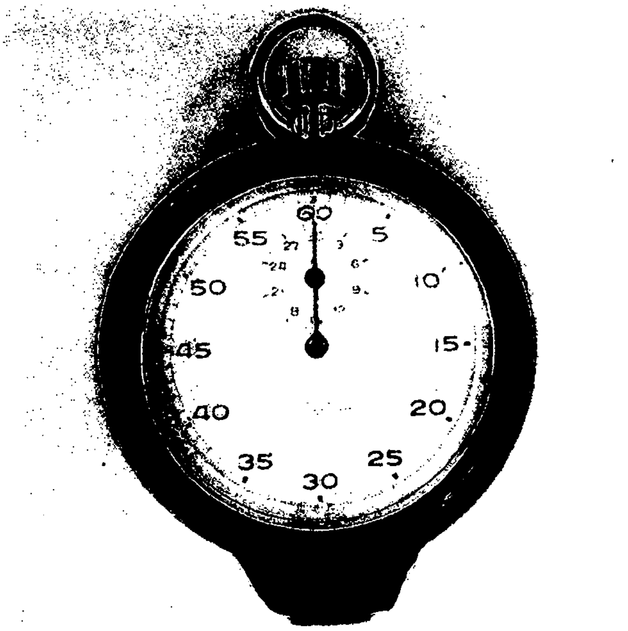


Figure 14. Stopwatch in protective rubber covering.

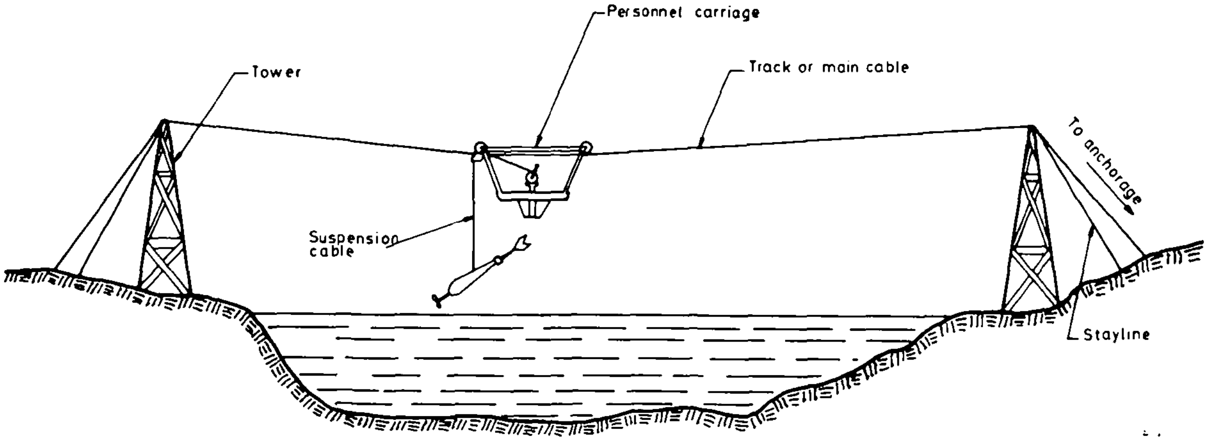


Figure 12. Cableway with personnel carriage (cable car).

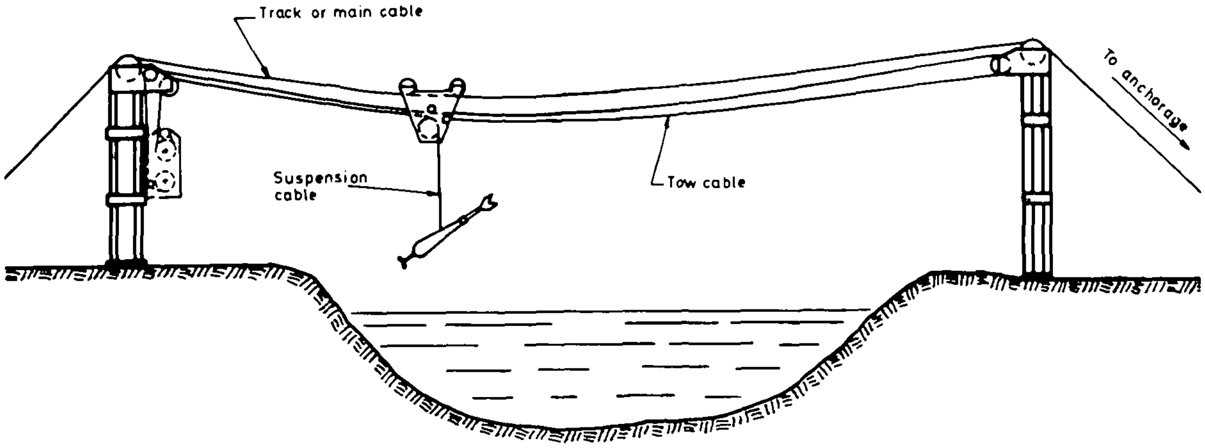


Figure 13. Cableway with instrument carriage.

2.1.7.2 Revolution Counters

The revolutions of the current-meter rotor must be counted during the observation of velocity. An electrical circuit built into the current meter closes every time the rotor of the current meter has made a set number of revolutions. An audible buzzer, or an automatic counter, is part of the electric circuit and each closure of the circuit can thus be counted or registered. Figure 15 shows a small mechanical counter for hand-operation that is very practical to use in conjunction with a buzzer. Figure 16 shows two types of electrical counters, one simple type and one type with set observation intervals.

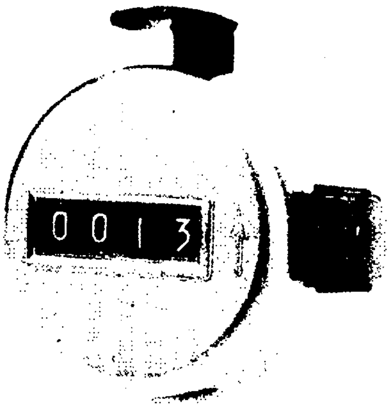


Figure 15. Small mechanical hand counter.

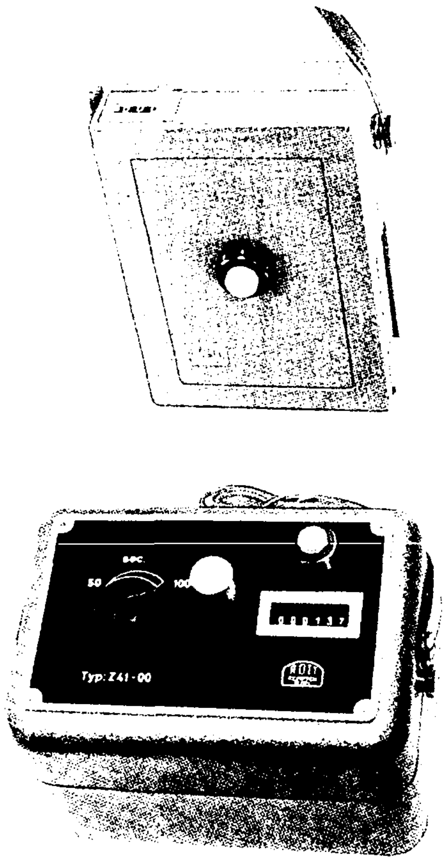


Figure 16. Battery-powered revolution counters (Ott).

2.1.7.3 Waders

Waders or high boots are needed when wading measurements are made. The waders should be loose-fitting for easy removal in an emergency.

References Section 2.1: [1], [2], [3], [4], [5], [11], [13], [14].

2.2 The Current Meter Measurement Site

A prospective gauging station location should be examined for the availability of discharge measuring sites for the various stages expected. One of the aspects of this examination is to be certain that there will be a measuring site at low flow where the velocities will be in the range where the current meter can measure them accurately. The suitability of cross sections at bridges for accurate discharge measurements at high stages and the suitability of the bridges themselves as measuring structures should be evaluated. If there are no suitable bridges, a site for a cableway or footbridge should be selected.

In the following, some characteristics of a good gauging site are discussed. It is usually impossible to satisfy them all. However, these criteria should be used and the best site available selected. Sometimes, different measuring cross-sections will be required for the different stages of flow, especially for the low-water measurements.

1. A discharge measurement is generally taken in conjunction with a water-level gauge on a stream. The measuring cross-section must therefore not be too far from the gauge. There should not be any significant inflow to or outflow from the stream between the measuring cross-section and the gauge. If this is unavoidable, corrections must be made.

   For measurements taken during rising or falling stage, the channel storage in the stream channel itself may influence the result should there be some distance between the gauge and the measuring cross-section. This is especially the case where there are pools between the two sites.
2. The stream at the gauging site should not overflow its banks and should preferably be in a single channel. If this is not possible, two straight uniform channels are preferable to one defective channel.
3. The stream channel at the gauging site should be fairly straight and of uniform cross section and slope, as far as possible, in order to avoid abnormal velocity distributions. When the length of the channel reach is restricted, the straight reach upstream from the measuring cross-section should be at least three times the width of the channel. The straight reach upstream from the measuring

cross-section should be twice that of the downstream. The channel bed and banks should be firm and stable.

4. The channel should be free from large rocks, vegetation and any other big protruding obstructions which will create turbulence.
   Where there are tendencies to the formation of eddies, boils, cross currents or backward flow, the site should not be used.
   Sites with converging, and especially with diverging flow, should be avoided, as it is difficult to allow for the systematic errors that can arise.
5. The depth should not be too shallow. For depths less than about 15 cm there will be difficulties in obtaining good measurements with the use of an ordinary current meter.
6. The velocity should be neither too low nor too high. The most reliable measurements will be obtained at velocities from 0.2 to 2.5 m/s.
7. The general direction of flow should be normal to the measuring cross-section.

A gauging site such as that described above is not always easy to find in natural streams. However, good results are obtainable even from poor gauging sites if the gauging is done carefully and if the hydrographer uses proper judgment and precautions during the measurement. Due to changes in channel conditions that often occur, all gauging sites should be inspected frequently and repaired whenever necessary. Sometimes, different measuring cross-sections will be required for the different flow conditions, especially for the low-water measurements.

References Section 2.2: [1], [2], [3], [4], [6], [10].

2.3 Current Meter Measurement Procedures

In this section, the general procedure for taking current-meter measurements will first be discussed. Details particular to each type of measurement, that is, wading, cableway, bridge or boat measurement will then follow.

A current-meter measurement is explained by reference to Figure 17 which shows a stream cross-section. At a number of verticals in the cross section, the following observations are made: a) the distance to a reference point on the bank, b) the depth of the stream, and c) the mean velocity in the vertical as measured by the current meter.

2.3.1 Measurement of Width

The distance to the verticals and the width of the stream are measured from a fixed reference point *(initial point)* on the bank of the stream. The distances are usually determined by use of a measuring tape or tag line stretched across the stream.

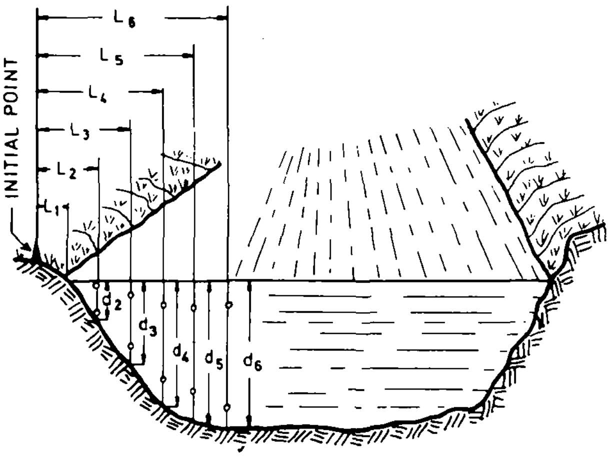


Figure 17. View of a stream cross-section showing location of the points of observation for the 0.2/0.8 method.

2.3.2 Spacing of the Measuring Verticals

The accuracy of a current-meter measurement depends largely on the number of verticals at which the observations of depth and velocities are made. The verticals should be so spaced as to disclose the real shape of the stream bed and the true mean velocity of the flowing water. Only where the velocity appears to be well-distributed and where the profile of the cross section is reasonably regular and smooth, is it desirable to space the verticals at equal intervals throughout the measuring cross-section. At two adjacent verticals, neither the depth nor the velocity should differ excessively. The interval between any two verticals should not be more than 1/20 of the total width, and the discharge between any two verticals should not be more than 10 per cent of the total discharge. Generally, the number of verticals required is between 20 and 30. For very small streams, the number can be reduced if the distance between the verticals becomes less than 30 cm.

2.3.3 Measurement of Depth

The depth of the vertical and the position of the current meter in the vertical are measured by a graduated rod on which the current meter slides, or by a sounding line on which the current meter and a streamlined sounding weight are suspended. The line is usually controlled by a gauging reel with a depth indicator.

In order to obtain accurate depths by the sounding line, the sounding weight must be equipped with an electrical bottom-contact which gives a signal when the weight touches the stream bed. If the sounding weight is not sufficiently heavy to keep the line within 5° of the perpendicular to the water surface, the angle between the sounding line and the vertical should be measured to the nearest degree with a protractor. The angle should not exceed 30°.

Methods of correcting measured depths for excessive drift of the sounding weight and the current meter in swift water are given in the following section. However, one should not rely on the possibility that corrections can be applied. The accuracy of the measurement would be improved if a sufficiently heavy weight could be used to maintain the suspension line of the current meter in an almost vertical position.

2.3.3.1 Depth Corrections

When current-meter measurements are made with a cable-suspended current meter in deep swift water, the current meter and the sounding weight will be carried downstream for a certain distance before the weight touches the bottom. This is often the case when measurements are made from a bridge or cableway which is often at a vertical distance above the water's surface. In such cases, corrections have to be applied in order to determine the correct depth of water and the depth to which the current meter should be lowered.

Figure 18 shows the position assumed by the sounding line as the weight, just off the bed of the stream, is supported by the line only. It is seen that from the length of line af, the distance ae and the difference between the lengths of ef and bc, must be deducted in order to determine the depth bc, assuming the stream bed cf is horizontal. Both these corrections are functions of the vertical angle Θ and are given in Tables 1 and 2 [13].

The values in Tables 1 and 2 are based on the assumptions that the drag force on the weight in the comparatively still water near the bottom can be neglected and that the sounding line and weight are designed to offer little resistance to the flow of water. The uncertainties in these assumptions are such that significant errors may be introduced if the vertical angle is more than 30°. If the direction of flow is not normal to the measuring cross-section, the corrections as shown in the tables will be too small.

The same conditions that cause errors in sounding the depth of the stream also cause errors in placing the current meter at the selected depths in the vertical. The correction tables are not strictly applicable to the problem of placing the current meter because of the increased drag force on the current-meter assembly caused by the higher velocities encountered as the current-meter assembly is raised from the stream bed. A current meter placed in deep swift water by the ordinary methods for observation at selected fractions of the depth will be too high in the water. The use of the correction tables will tend to eliminate this error in placing the current meter, and although not strictly applicable, its use has become general for this purpose.

The routine procedure for applying depth corrections is as follows (Figure 18):

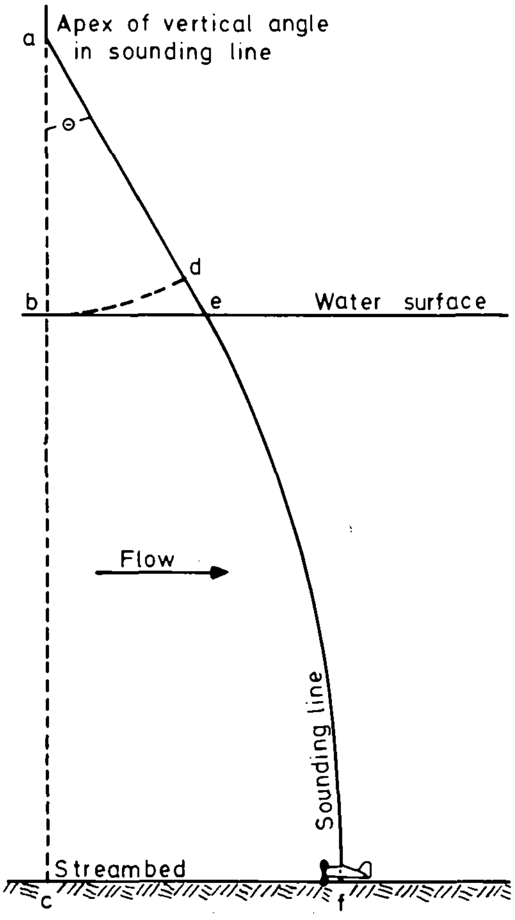


Figure 18. Position of sounding line and weight in deep swift water.

1. Measure the vertical distance ab from the guide pulley on the gauging reel to the water surface. This will give the vertical distance to be used with the air-line correction table (Table 1).
2. Place the bottom of the weight at the water surface and set the depth counter on the gauging reel to read zero.
3. Lower the sounding weight to the bed of the stream. Read and record the sounded depth df and the vertical angle Θ of the cable when the weight is at the bed of the stream, but entirely supported by the cable.
4. With the aid of the correction tables compute and record:

a) the air correction de as a percentage of ab (Table 1),
b) the wet-line depth, ef = df-de,
c) the wet-line correction as a percentage of ef (Table 2),
d) add both corrections together and subtract them from the sounded depth df, this will give the revised depth bc,
e) raise the current meter from the sounding position at the stream bed a distance equal to 0.2 of the wet-line depth ef minus the distance from the current meter to the bottom of the weight, this places the current meter approximately at the 0.8 depth position,
f) raise the current meter to the surface of the water and set the depth counter to read zero, then lower the current meter until it is at a distance equal to ae plus 0.2 of the wet-line depth ef, this places the current meter approximately at the 0.2 depth position.

Another method that may be used for approximate depth corrections is to survey the bed profile of the measuring cross-section. The bed profile is related to an auxiliary staff-gauge placed in the cross section. In this way, by reading the staff gauge, the correct depth is obtained for any position in the cross section at any stage. Depth corrections for the different points of observation in the vertical are done by multiplying the observed depth by the ratio of true depth of water to the observed depth of water.

Table 1. Air-line correction [13].

Vertical angle degrees	Correction %	Vertical angle degrees	Correction %
4	0.24	18	5.15
6	0.55	20	6.42
8	0.98	22	7.85
10	1.54	24	9.46
12	2.23	26	11.26
14	3.06	28	13.26
16	4.03	30	15.47

Table 2. Wet-line correction [13].

Vertical angle degrees	Correction %	Vertical angle degrees	Correction %
4	0.06	18	1.64
6	0.16	20	2.04
8	0.32	22	2.48
10	0.50	24	2.96
12	0.72	26	3.50
14	0.98	28	4.08
16	1.28	30	4.72

2.3.4 Measurement of Velocity

By definition, the discharge of a stream is the product of a stream cross-section and the component of the flow velocity normal to that section. Consequently, in current-meter measurements, the measuring cross-section is placed normal to the general direction of flow. This is checked either visually or by a protractor.

The velocity is measured at one or more points in the vertical by observing the number of revolutions of the current-meter rotor during a period of 40–60 seconds. Where the vertical-velocity distribution is approximately parabolic (Figure 19) and the depth is greater than about 60 cm, velocity observations are made at 0.2 and 0.8 of the depth below the surface. The average of these two observations is taken as the mean velocity in the vertical. For depths between 20 cm and 60 cm, an observation of velocity made at 0.6 of the depth below the surface is taken as the mean velocity in the vertical. For depths less than about 20 cm, an observation of velocity at 0.5 of the depth is used as the mean velocity. Should the vertical-velocity distribution be very irregular, then velocity observations are made just below the water surface, just above the stream bed and at 0.2, 0.5 and 0.8 of the depth. The current meter is supported at the desired point in the measuring vertical on a wading rod in the case of a shallow stream that can be waded, or suspended on a sounding rod or cable from a bridge, cableway or boat in the case of larger streams.

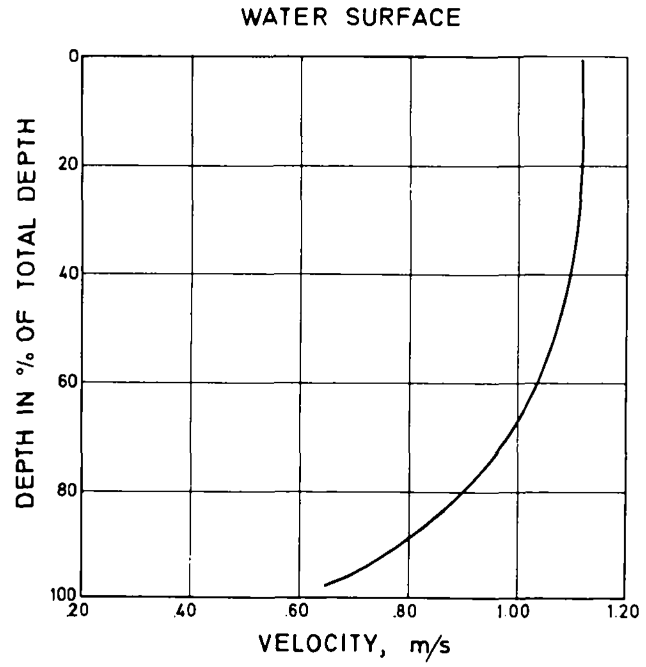


Figure 19. Normal vertical-velocity distribution curve.

2.3.4.1 Velocity Corrections

The *angle of the current*, as applied to stream-gauging, is the difference between the normal to the measuring cross-section and the angle made by the current with the measuring cross-section. To eliminate errors introduced by such angles, it is necessary to obtain the component of the velocity normal to the cross section. The method by which this angle is corrected depends on the type of current meter used. A vertical-shaft cup-type current meter, if supported on a rod, will tend to measure the full velocity in the direction in which the water is flowing and not in the direction represented by the horizontal axis of the current meter. The horizontal-shaft propeller-type current meter, when supported on a rod, tends to measure the component of the current parallel to the axis of the current meter; therefore the current meter must be held in line with the direction of flow if corrections are to be made for oblique flow. The horizontal axis of either type of current meter suspended from a cable will take the direction of the current if the flow is comparatively free from excessive turbulence.

If an oblique current is unavoidable at one or several of the measuring verticals, the velocity-component normal to the measuring cross-section must be obtained. The velocity in the direction of the current is then measured and the angle of deflection is read by a protractor. If no protractor is at hand, the angle can be measured by holding the note sheet parallel with the cross section, and with a straightedge or ruler lined up with the direction of the current, drawing a line whose angle with the normal is later measured with a protractor.

The measured velocity, when multiplied by the cosine of the angle of the current, will give the velocity-component normal to the measuring cross-section. For small angles, the correction will be negligible. When the angle is no more than 8 degrees, the correction is less than 1 per cent and may be ignored.

Propeller-type current meters with a component propeller will accurately measure the velocity component normal to the measuring cross-section in oblique flow and there will be no need for corrections, if the current meter is held rigidly at right angles to the cross section.

2.3.5 Performing the Current Meter Measurement

When the width of the measuring cross-section has been measured and the positions of the verticals in the cross section have been determined, the appropriate equipment for the current-meter measurement is assembled and the Measurement Notes are prepared in order to record the observations. See Appendix A for specimens of these forms and instructions for filling them in. For each current-meter measurement, the following information is recorded:

1. Name of the stream.
2. Name and number of the gauging station.
3. Date.
4. Time and gauge height at the start of the measurement.
5. Type and serial number of the current meter and of the rotor.
6. Spin time of the rotor before the measurement.
7. Type of measurement (wading, cableway, bridge or boat) and method of supporting the current meter (rod or cable suspension).
8. Method of velocity measurement (0.2/0.8 method, 0.6 method or method of multiple points).
9. Name of the hydrographer.
10. Other pertinent information regarding the accuracy of the discharge measurement and conditions which might affect the stage-discharge relation.

Once the equipment and the measurement notes have been prepared, the measurement is begun. Record from which bank, right bank (RB) or left bank (LB), the measurement is started and the distance from the initial point on the bank to the edge of the water. Measure and record the depth at the water's edge; in natural streams this depth is usally zero.

Move to the first measuring vertical. After the depth of the vertical has been measured and recorded, determine the method of the velocity measurement. Normally, the 0.2/0.8 method or the 0.6 method is used depending on the depth. Record the depth of observation (position of the current meter). After the current meter is placed in the right position at the correct depth, allow it to become adjusted to the current before starting the observation. The time required for such adjustments is usually a few seconds. If the velocity of flow is low or the current meter is suspended on a cable, a longer adjustment period is needed. After the current meter has become adjusted to the current, record the number of revolutions made by the rotor during a period of 40 to 60 seconds. Start the stop watch at the end of a signal (buzz) and stop it at the end of a signal if actual counting is done. Record the number of revolutions and the time interval.

If the velocity is to be observed at more than one point in the vertical, determine the current meter setting for the additional observations, time the revolutions and record the data. Move to each of the verticals and repeat the procedure: Record the distance from initial point, depth, depth of the current meter position, revolutions and time interval, until the entire cross section has been traversed.

When the measurement has been completed in this way, record the time, the gauge height and at which bank of the stream the measurement ends. The spin time of the rotor at the end of the measurement must also be checked and recorded.

During the course of a discharge measurement made when the stream stage is changing, record the time and the gauge height periodically, usually at intervals of 30 minutes. This is important, because if there is any appreciable change in stage during the measurement, these data are needed in order to determine a weighed mean gauge-height for the measurement; see Section 2.5.

2.3.5.1 Wading Measurements

Current-meter measurements by wading are preferred if the conditions permit. Wading measurements offer an advantage over measurements from bridges and cableways in that it is usually possible to select the best of several available cross sections.

In this type of current-meter measurement, the hydrographer uses either high boots or chest waders when crossing the river and doing the gauging. The first step is to check the measuring cross-section and remove any stones and debris that could affect the accuracy of the depth and velocity observations. All this work should be done before the measurement is started and nothing must be shifted or removed from the stream bed while the measurement is in progress. Selection of the measuring cross-section for wading measurements is very important, because the effects of minor irregularities in the stream channel at the lower stages, in which wading measurements are usually carried out, are relatively much greater than at the higher stages.

A tag line or tape is spanned across the measuring cross-section at right angles to the general direction of the flow. If the same measuring cross-section is used always and if it is practicable, the cross section should be defined by clearly visible markers, one on each bank, for easy identification and for holding the tag line. While placing the tag line, the hydrographer should obtain a general idea of the proper spacing of the measuring verticals by observing the total width of the cross section and the geometry of the stream bed. The first velocity observation should always be taken as close as possible to the bank.

With the current meter supported on a graduated wading rod, the velocity observations are taken at the appropriate distances along the tag line keeping the rod in a vertical position. The hydrographer should stand in a position that affects the flow of the water passing the current meter as little as possible. This position is usually obtained by standing close to the tag line on the downstream side, facing the bank with the water flowing against the side of the leg and holding the rod at the tag line at arm's length.

Avoid standing in the water if the feet and legs would occupy a considerable part of the cross section of a narrow stream. In smaller streams where the width permits, stand on a plank or other support rather than in the water.

When gauging streams with shifting bed, the hydrographer's feet can affect soundings and velocities. Generally, the current meter should be placed ahead of and upstream from the feet.

The limiting factors for wading measurements are determined by both depth and velocity and may be expressed in terms of the product of these two quantities. In general, it may be stated that even with good footing, this product should not exceed 1. For example, if the mean velocity is about 1 metre per second, measurements may ordinarily be made by wading in depths of up to 1 metre. For the lower velocities, the depth at which wading measurements may be made will be determined by the stature of the hydrographer.

When the conditions for making current-meter measurements at the gauging site are unfavourable at low water, modify the measuring cross-section, if possible, to improve the conditions. It is often possible to build small dikes in order to cut off dead water and shallow flows or to improve the cross section by removing rocks and debris within the section and from the reach immediately upstream from it. After modifying the cross section, allow the flow to stabilize before starting the current-meter measurement.

For discharge measurement of flow too small to measure with a current meter, a volumetric method or a portable parshall flume or weir plate is often used.

2.3.5.2 Cableway Measurements

Current-meter measurements are often made from a permanent heavy track cable spanned across the river where a good measuring cross-section has been located (Figure 20). The current meter is suspended from a manned cable-car running on the track cable and with capacity to carry the hydrographer and his

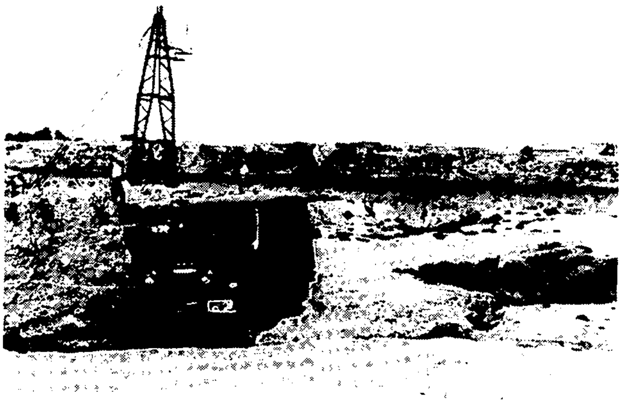


Figure 20. Heavy cableway with personnel carriage (cable car), (Karun River near Ahwas, Iran).

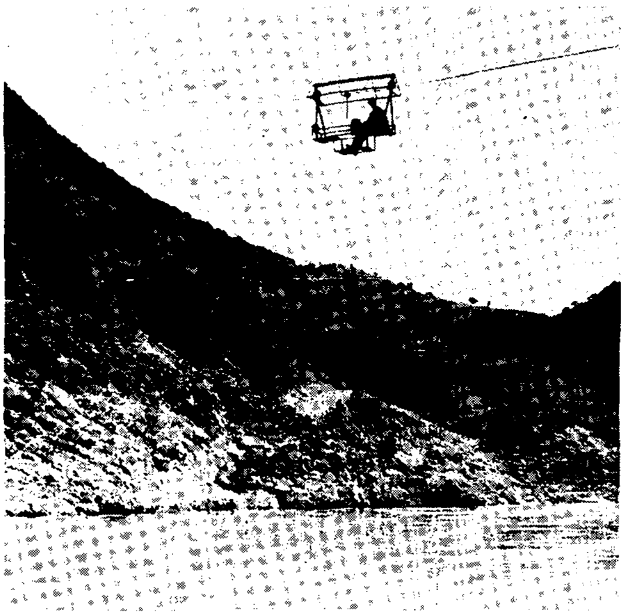


Figure 21. Current-meter measurement from cable car (Dez River at Tang-e-Panj, Iran).

equipment (Figure 21). The current meter may also be suspended from a small carriage which is operated from the bank by a gauging winch (Figure 22). Because the cableway is installed permanently, the actual measuring cross-section can not be changed, but it should be checked and, if necessary, cleared during the dry season months.

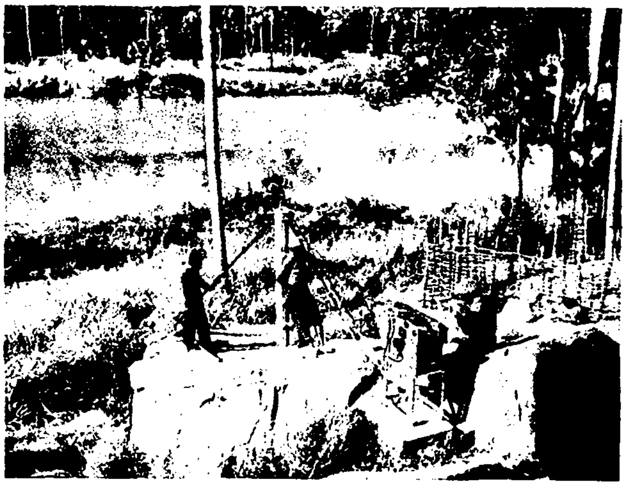


Figure 22. Cableway with instrument carriage operated by gauging winch stationed on the bank (Malagarasi River at Mbelagule, Tanzania).

Cableway with Personnel Carriage:

The manned cable-car is provided with a support for the gauging reel, a guide pulley for the suspension cable, and a protractor for reading the vertical angle (Figure 23). The gauging procedure is as follows:

1. The water's edge is identified in relation to a permanent initial point on the bank by means of a tag line or by use of the painted marks on the track cable used for spacing the measuring verticals.
2. The current meter and the weight are lowered at the first vertical until the bottom of the weight touches the water surface and then the depth counter is set to zero.
3. The current-meter assembly is then lowered until the weight touches the stream bed, the length of cable played out is read and the sounded depth is recorded.
4. If necessary, the air-line and the wet-line corrections are computed and the revised depth recorded.
5. Next, the velocities are measured at the selected depths in the vertical.
6. If there is floating drift in the stream channel, the current meter should be raised occasionally for control and cleaning. This must always be done if there is a sudden drop in the velocity as indicated by the revolution counter. The channel upstream from the gauging section should also be watched closely for any driftwood or material which could damage the current meter.

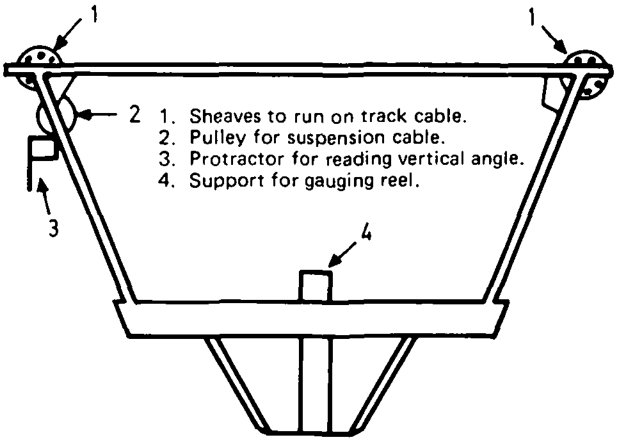


Figure 23. Two-man cable car.

It is advisable to carry a pair of cutter pliers when gauging from a cable car. If the current-meter assembly becomes caught on large floating objects and it is impossible to release it, cut the current-meter suspension cable to ensure personal safety. In some cases, it may be possible to pull the cable car to the river bank and release the drift.

One problem encountered when observing velocities from the cable car is that the moving of the car from one vertical to the next makes the car oscillate for a short time after coming to a stop. One has then to wait until the oscillations have subsided before starting the measurement.

Cableway with Instrument Carriage:

The gauging procedure with an instrument carriage is the same as that for the cable car with the exception that only the current meter and the weight are travelling on the track cable across the stream between the cable supports. The hydrographer stays on the bank and operates the gauging winch. The winch is provided with both distance and depth counters for placing the current meter at the desired positions. The electrical impulses from the current meter are returned through the core conductor of the suspension cable.

2.3.5.3 Bridge Measurements

Highway or railway bridges may often be utilized for current-meter measurements. However, measurements from bridges are usually less accurate than other types of measurements. Contracted sections, piers and other obstructions affect the distribution of the velocities and it is therefore necessary to use a larger number of verticals as well as more observation points in each vertical, especially close to bridge piers and banks. Generally, there are two types of bridge measurements using either rod or line suspension.

Rod Suspension from Bridge:
Foot bridges may sometimes be used for gauging small streams. Although the procedure for low velocities may be the same as for a wading measurement, at higher velocities it is often advisable to measure the depth in the following manner:

1. For each selected vertical, a point is established on the bridge.
2. With this point as an index, the distance to the water surface is measured by lowering the suspension rod until the base plate touches the water.
3. The rod is then lowered to the bottom of the stream and the rod reading is again noted at the index point. The difference in the readings is the depth of water at the vertical.

Measuring the depth in this manner tends to eliminate errors that may be caused by the piling up of water on the upstream face of the rod.

The natural flow of water is not disturbed when measuring from a foot bridge as is often the case when measuring from a boat or by wading.

Line Suspension from Bridge:
From higher bridges and for greater depths, the current meter and weight have to be suspended on a cable. The cable is controlled by a gauging reel mounted on a bridge crane (Figure 24) or on a bridge board (Figure 25). A handline may be used with the smaller weights. The gauging procedure is essentially the same as that for measurements from a cable car.

No set rule can be given for selecting the upstream or downstream side of a bridge for discharge measurements. The advantages of using the upstream side of the bridge are:

a) The hydraulic conditions at the upstream side of the bridge opening are usually more favourable,
b) Approaching drifts can be seen and avoided more easily,
c) The stream bed at the upstream side of the bridge is not likely to be scoured as badly as the downstream side.

The advantages of using the downstream side of the bridge are:

a) Vertical angles are easily measured on the downstream side as the sounding line will move away from the bridge,
b) The streamlines may be straightened out when passing through a bridge opening with piers.

Whether to use the upstream or the downstream side of a bridge for a current-meter measurement

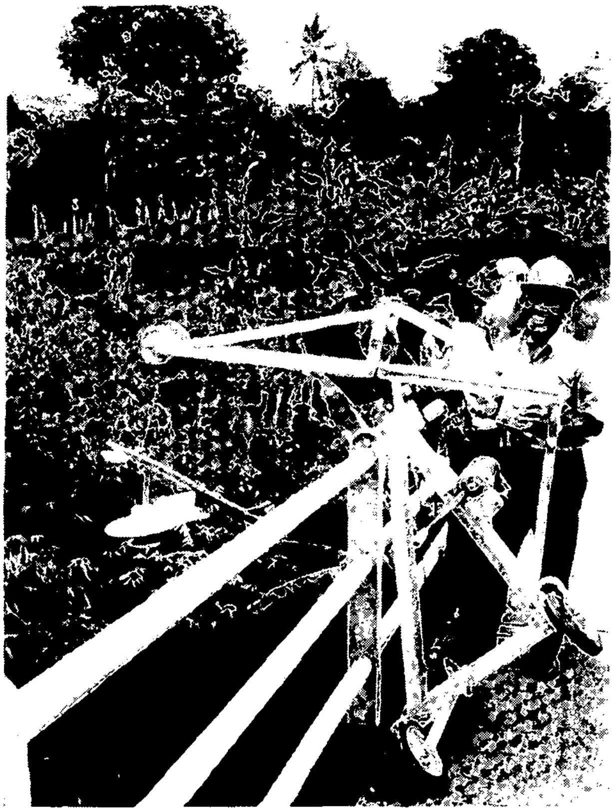


Figure 24. Curren-meter measurement from bridge using bridge crane (Citarum River at Nanjung, Java, Indonesia).

Figure 25. Current-meter measurement from bridge using brigde board (Cimanuk River at Leuwingoong, Java, Indonesia).

should be decided individually for each bridge after considering the factors mentioned above and the conditions at the bridge such as location of the walk-way and traffic hazards.

2.3.5.4 Boat Measurements

Discharge measurement taken from a boat is a common way of measuring discharges when the stream is too deep to wade. One limiting factor in the use of boats is high velocity of the water, as personal safety has to be considered.

A heavy tag line is spanned across the river at the measuring section. The tag line serves the dual purpose of holding the boat in position during the measurement, and of measuring the width of the river and positioning the measuring verticals.

The tag line is wound on a reel which is operated from the stern of the boat as the boat is propelled across the river. On the bank, the slack of the cable is taken up by means of a block and tackle attached to the reel and to an anchored support on the bank.

If there is traffic on the river, one man must be stationed on the bank to lower and raise the tag line to allow the traffic to pass. Streamers should be fixed on the tag line so that it may be seen by boat pilots.

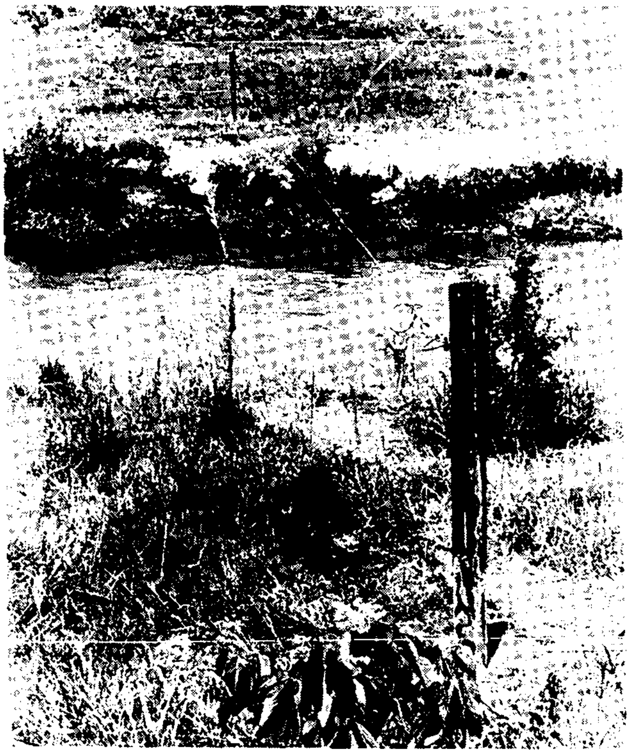


Figure 26. Permanent cable for supporting boat during gauging (Little Ruaha River at Iwawa, Tanzania).

A permanent supporting cable, spanned across the river, to which the boat is anchored during discharge measurements, will often prove advantageous. This method is less laborious and safer for the personnel performing the measurement, especially at high water conditions. A permanent cable must be erected well above the highest flood stage expected (Figure 26).

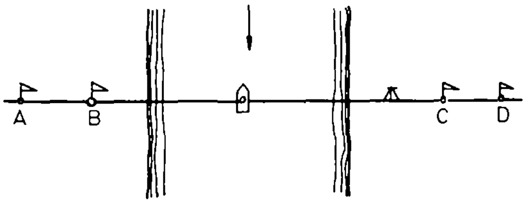


Figure 27. Survey of stream cross-section. Stadia method.

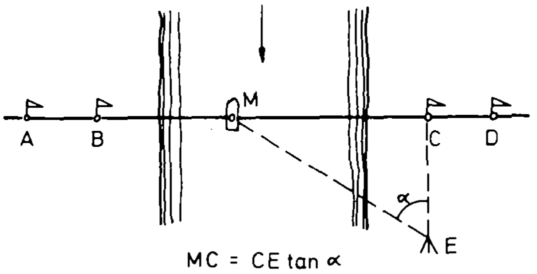


Figure 28. Survey of stream cross-section. Angular method.

If there is a continuous flow of traffic on the river or if the river is too wide to be spanned by a wire, the boat can be kept in the measuring cross-section by anchoring it up in line with flags positioned on the river banks. The position of the boat in the cross section can be read directly by means of a transit on line on shore and a stadia rod held vertically in the boat (Figure 27). The transit may also be placed in a line at right angles to the cross section some known distance from it, and by measuring the angle the boat makes with that line, the position may be calculated by triangulation (Figure 28).

References Section 2.3: [1], [2], [3], [4], [6], [7], [10].

2.4 Computation of Current Meter Measurements

The discharge should be computed either arithmetically or graphically. Choosing between these two methods depends upon the accuracy required, the nature of the stream, and the working conditions and training of the hydrographers. The arithmetical methods are more rapid and are particularly useful for computations carried out in the field. The graphical method is more laborious but increases the accuracy of the computation and gives a more comprehensive insight into the flow pattern at the gauging site.

2.4.1 The Arithmetical Mid-Section Method

The method consists essentially of: a) dividing the total area of the cross section into partial sections and determining the area and the mean velocity of each partial section separately, b) computing the discharge in each partial section as the product of the velocity and the area, and c) summing up the partial discharges to obtain the total discharge.

The mid-section method is explained in detail by reference to Figure 29 which shows a cross section of a stream channel. The discharge passing through a partial section is computed as

$$q_4 = v_4\left(\frac{(L_4 - L_3) + (L_5 - L_4)}{2}\right)d_4 = v_4\left(\frac{L_5 - L_3}{2}\right)d_4 \qquad (2.3)$$

where

q_4 = discharge through partial section 4,

v_4 = mean velocity in vertical 4,

L_3, L_4, L_5 = distance from initial point to verticals 3, 4 and 5,

d_4 = depth of water at vertical 4.

The area which is defined by this formula is that shown by the x-line around vertical No. 4 in Figure 29.

The formula for partial section 1 at the beginning of the cross section is

$$q_1 = v_1\left(\frac{L_2 - L_1}{2}\right)d_1 \qquad (2.4)$$

For the case shown in Figure 29, q_1 would be zero because the depth and therefore the velocity at vertical No. 1 is zero. However, when the cross-section boundary is vertical at the edge of the water, the depth is not zero and the velocity at the edge of the water may or may not be zero. In such cases, it is usually necessary to estimate the velocity at the end vertical as some percentage of the preceding or subsequent vertical, because it is often impossible to measure the velocity accurately, as the current meter will be affected by the closeness to the boundary and there is also the possibility of damage to the current meter. In most cases, however, the flow through the end sections may be neglected if care is taken to space the verticals so that this flow is very small in comparison with the total flow.

The summation of the discharges for all the partial sections is the total discharge of the stream. The computation procedure for the mid-section method is illustrated in Appendix B.

2.4.2 The Arithmetical Mean-Section Method

The mean-section method differs from the mid-section method in the computation procedure. Partial discharges are computed for the section between successive verticals. The velocities and depths for successive verticals are averaged, the discharge being the product of the two averages and the distance between the verticals.

The method is explained in detail by reference to Figure 30. The discharge passing through a partial section is computed as

$$q_{3-4} = \left(\frac{v_3+v_4}{2}\right)\left(\frac{d_3+d_4}{2}\right)(L_4 - L_3) \qquad (2.5)$$

where

q_{3-4} = discharge through partial section 3–4,

v_3,v_4 = mean velocity in verticals 3 and 4,

d_3,d_4 = mean depth of verticals 3 and 4,

L_3,L_4 = distance from initial point to verticals.

The computation procedure for the mean-section method is shown in Appendix C.

The mid-section method is simpler to compute and is a slightly more accurate procedure than the mean-section method.

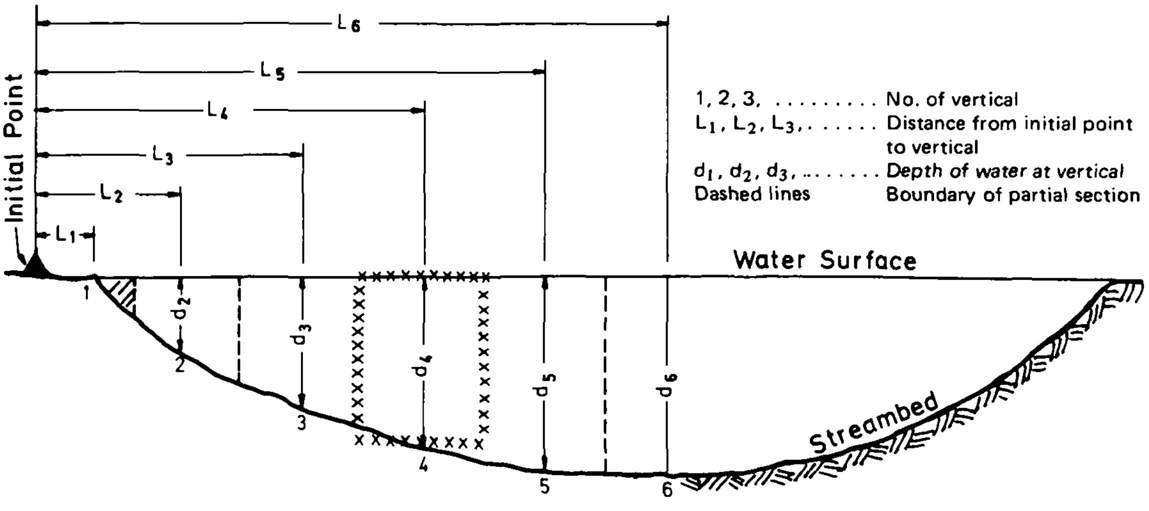


Figure 29. The mid-section method of computing current-meter measurements.

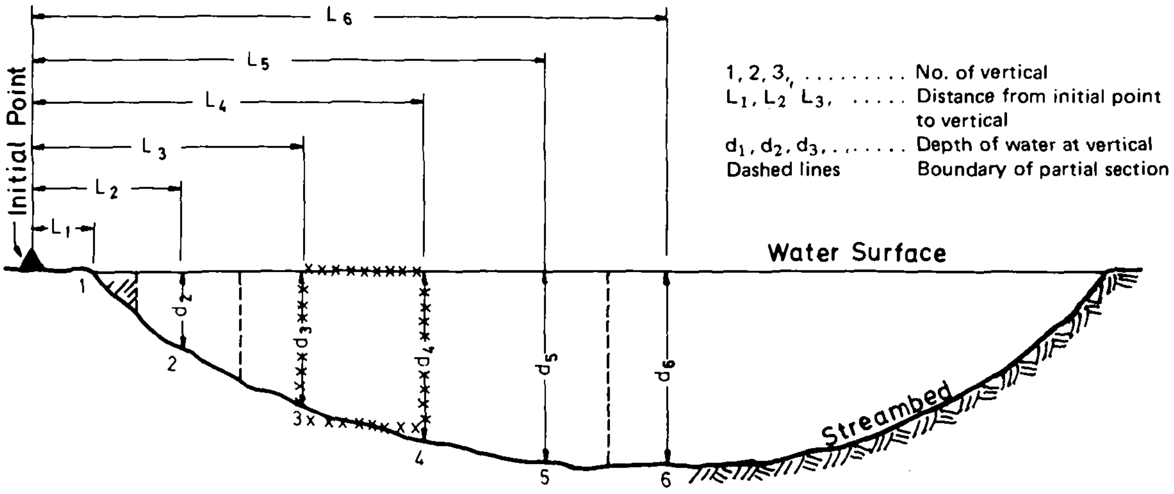


Figure 30. The mean-section method of computing current-meter measurements.

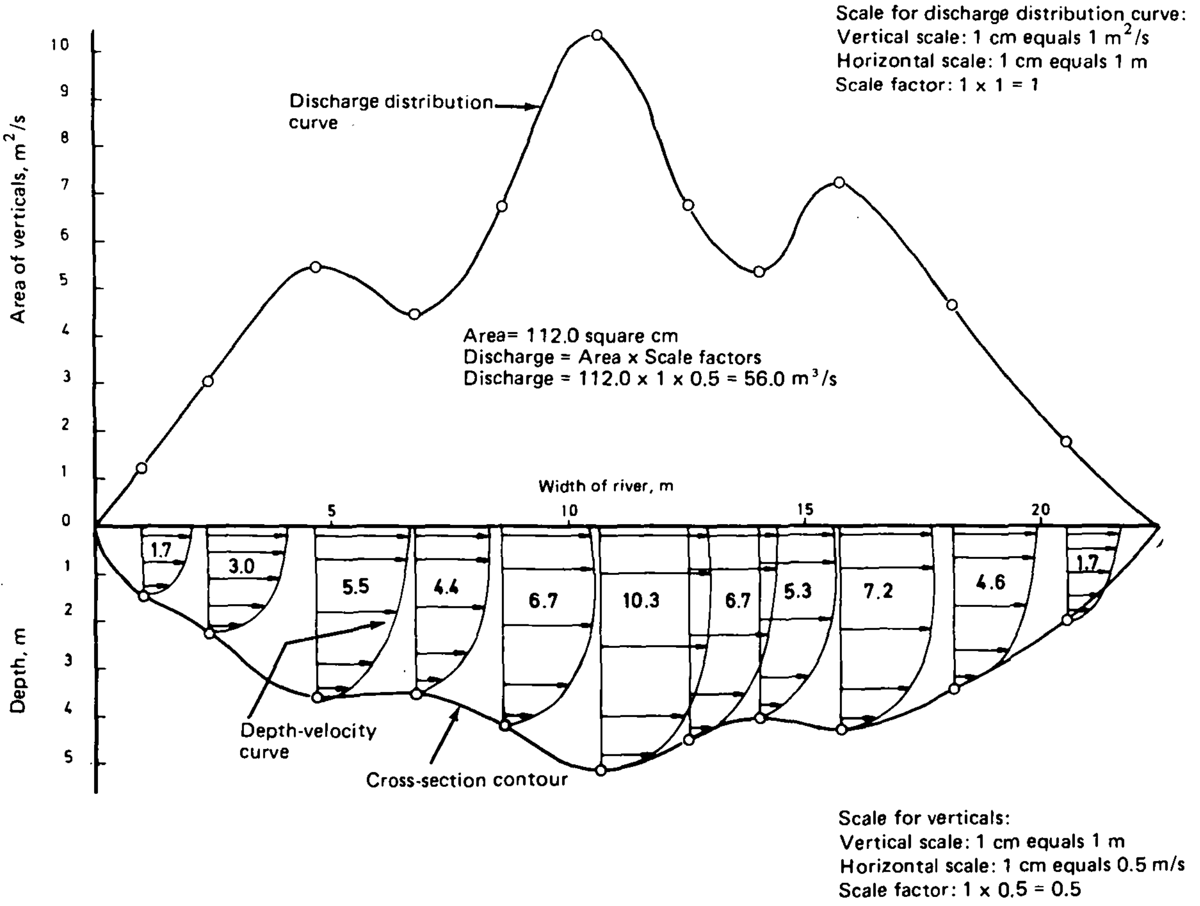
2.4.3 The Graphical Depth-Velocity Integration Method

The procedure for the depth-velocity method is as follows (Figure 31):

Firstly, draw up the depth-velocity curve for each vertical by plotting the velocity observations against their corresponding depths and draw a smooth curve through the points.

Secondly, measure the area contained by each curve and its vertical by means of a planimeter, or more simply, count it up by using a draftman's dividers.

Thirdly, plot the areas obtained in step two over the water-surface line of the measuring cross-section and draw a smooth curve through the points. The area enclosed between this curve and the water-



Scale for discharge distribution curve:
Vertical scale: 1 cm equals 1 m^2/s
Horizontal scale: 1 cm equals 1 m
Scale factor: 1 x 1 = 1

Area= 112.0 square cm
Discharge = Area x Scale factors
Discharge = 112.0 x 1 x 0.5 = 56.0 m^3/s

Scale for verticals:
Vertical scale: 1 cm equals 1 m
Horizontal scale: 1 cm equals 0.5 m/s
Scale factor: 1 x 0.5 = 0.5

Figure 31. The graphical depth-velocity integration method of computing current-meter measurements.

surface line represents the discharge through the cross section.

The above computation procedure is used when the velocity has been observed at multiple points in the vertical due to irregular vertical-velocity distribution.

References Section 2.4: [1], [2], [3], [4], [6], [7], [10].

2.5 Mean Gauge Height for Current Meter Measurements

The mean gauge height corresponding to the measured discharge is one of the two coordinates used in plotting the discharge rating curve for gauging stations. An accurate determination of the gauge height is therefore as important as an accurate measurement of the discharge. The correct gauge height for a measurement will be that which is observed at the same time as the gravity centre of the flow is gauged.

When gauging discharge during constant or nearly constant stream stage, there is no difficulty in deciding the gauge height that corresponds with the measured discharge. If the change in gauge height is less than 5 cm during the measurement, the arithmetical mean of the gauge height at the start and end of the measurement can usually be taken as the mean gauge height.

Discharge measurements at time of high water must usually be made during a rising or falling stage when a considerable change in the gauge height may occur. The correct gauge height is obtained by computing a weighed mean gauge height, which for a non-recording gauge requires additional observations of stage between the start and end of the measurement. These readings are made at regular intervals, say every 20 or 30 minutes. The assistance of a gauge reader is usually necessary for obtaining the readings. The mean gauge heights during the set time intervals and the corresponding measured partial discharges are used to compute the mean gauge height of the measurement. The formula used is

$$H = \frac{q_1h_1 + q_2h_2 + q_3h_3 + \ldots . + q_nh_n}{Q} \qquad (2.7)$$

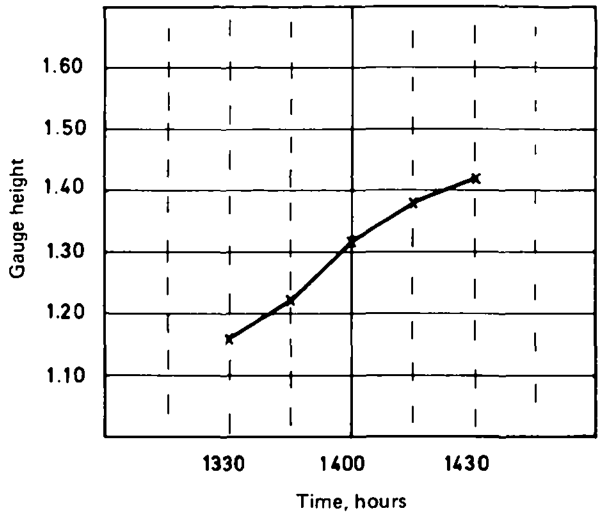
where

H = mean gauge height,
$q_1, q_2, \ldots$ = discharge measured in time interval 1,2,...,
$h_1, h_2, \ldots$ = mean gauge height in time interval 1,2,...,
Q = total discharge measured

Figure 32 shows the computation of a weighed mean gauge height using the given formula. The graph is a reproduction of the gauge height graph during the discharge measurement.

As stated above, an accurate gauge height for the discharge measurement is as important as the accuracy of the discharge measurement itself. In this respect, it is to be emphasized that a fixed and permanent gauge datum must be maintained. The datum of the gauge must be carefully checked by level relative to a permanent bench mark at periodic intervals, at least once a year and especially after the floods.

It is recommended that a check level of the gauge datum should be regarded as an integrated part of the discharge measurement. It should always be run and the water-level gauge reset as required *before* the discharge measurement is carried out.



Time (1)	G.H. (2)	Mean G.H. (3)	Q (4)	Column (3) x (4)
1330	1.16	1.19	20.4	24.3
1345	1.22	1.27	24.2	30.7
1400	1.32	1.35	33.0	44.6
1415	1.38	1.40	42.3	59.2
1430	1.42			
	Sum		119.9	158.9

$$\text{Mean G.H.} = \frac{(3) \times (4)}{(4)} = \frac{158.9}{119.9} = 1.325$$

Figure 32. Computation of a weighted mean gauge height.

References Section 2.5: [4], [6].

2.6 Factors Affecting the Accuracy of Current Meter Measurements

For accurate and reliable measurements of discharge by current meter, especially in natural stream channels, a knowledge of many factors is essential, in addition to the specific procedure followed in making the discharge measurement. The wide variety in the character of a stream with respect to climatic conditions, both seasonal and regional, and in the behaviour of the measuring equipment when used under various circumstances, give rise to many problems which may affect the specific procedure of the work.

2.6.1 *Use and Care of the Equipment*

Accuracy in gauging streams can only be expected when the equipment is properly assembled, adjusted and kept in good condition. The current meter, the revolution counter and the stop watch, in particular, must receive the best care and protection both when in use and when being transported, as they are the most delicate and sensitive items of the gauging equipment.

The current meter receives necessarily a certain amount of hard usage that may result in damage, such as a chipped rotor, damaged bearings or a bent shaft, any one of which may cause the current meter to under-register. Observation of velocities taken at sections with irregular and uncertain profiles and the presence of floating drift probably present the greatest hazard to the current-meter equipment. Floating drift can usually be seen in time to allow for the removal of the equipment from the water. Sometimes, however, a measurement is so valuable that considerable rough usage of the equipment is justified. After such usage, the current meter should be thoroughly checked.

Damage to the gauging equipment during transportation is generally due to careless packing or negligence in protection. Cases are provided for use in transporting the current meters and the weights. The stop watch should always be carried in a protective case or on a string around the neck when in use. Revolution counters should be packed carefully to avoid accidental short circuits which may discharge the battery. The hydrographer who takes pride in the care and protection of his gauging equipment will find himself amply repaid for the extra time and effort that may be required to maintain it in the best possible condition.

2.6.2 *Measuring Cross Section*

Regardless of the method employed, the accuracy of current-meter measurements will depend to a large measure on the characteristics of the gauging station. If those characteristics are ideal or even favourable, an inexperienced operator should obtain satisfactory results without much difficulty. On the other hand, if these conditions are adverse, it may tax the ingenuity of the most skilful and experienced hydrographer to make satisfactory discharge measurements.

2.6.3 *Spacing of Verticals*

Where the profile of the cross section is irregular, velocities are also irregular and additional verticals are required to obtain an accurate measurement. The verticals should be spaced so as to disclose the real shape of the bed profile and the true mean velocity of the flowing water.

2.6.4 *Measurement of Depth*

Because the discharge is computed as the product of area and velocity, any incorrect readings of the depth of water will produce a corresponding error in the measured discharge.

2.6.5 *Turbulent and Pulsating Flow*

Current meters are rated in laminar (streamline) flow by being pulled through still water. Therefore, any turbulent or pulsating flow at the gauging site will cause inaccuracies. However, unless these disturbances of flow are pronounced, the errors will be small and negligible. If there is excessive turbulence, the gauging site should be improved or moved to a better location.

In general, a vertical-shaft cup-type current meter tends to over-register in excessive turbulence and a horizontal-shaft propeller-type current meter tends to under-register under those conditions.

2.6.6 *Angle of Current*

An error in the measurement of velocity is caused if the current is not at 90 degrees to the measuring cross section. For small angles the error is negligible. If a serious error is suspected, another measuring cross-section should be selected.

2.6.7 *Insufficient Weight of Line-Suspended Current Meter*

To prevent large vertical angles while gauging from a cableway or bridge and to keep the current meter steady while measuring the velocities, a sufficiently heavy weight should always be used.

2.6.8 *Wind*

Wind may affect the accuracy of a current-meter measurement by causing vertical movements of the current meter or agitating the water surface and affecting the 0.2 depth velocity in shallow water.

2.6.9 *Vertical and Horizontal Motion of Current Meter*

A current meter suspended on a line is not held rigidly in position and so may occasionally have vertical and horizontal movements. Insufficient weight, wind, wave action or a poor gauging site will generally increase these movements. The hydrographer should try to keep the movements within safe limits.

2.6.10 Drift and Aquatic Growth in Stream Channels

Large drift such as logs or tree branches may necessitate hurry in making observations in order to avoid loss of the current meter. This may cause errors in the observations of both depths and velocities.

Fine drift may collect around the shaft or pivot of the current meter which could cause it to under-register.

The presence of aquatic growth in the measuring cross-section may not only interfere with the operation of the current meter but may also seriously affect the distribution of the velocities, particularly near the bed of the stream.

If the current meter is used in such conditions, it should be inspected frequently and given spin tests to check its performance.

2.6.11 Effects of Piers, Piling and Eddies

As a rule, these conditions should be avoided. They do not appear generally and the hydrographer has to make his own decision on the spot as to which way the gauging should be carried out.

2.7 Accuracy of Current Meter Measurements

From Section 2.6 it can be concluded that a current-meter measurement at a given site is subject to three principal sources of errors: a) personal, b) instrumental, and c) methodic.

2.7.1 Personal Error

Personal errors are those made by the hydrographer when reading the instruments, counting the revolutions and in making biased observations by consistently reading too high or too low. Some of the factors contributing to such errors are weather conditions, the hydrographer's attitude and inadequate training. These errors can not be controlled, but they may be minimized by training and by instilling a pride of accomplishment. Personal errors are difficult to evaluate, but in general, they are considered to be small.

2.7.2 Instrumental Error

The kind of instruments used, the accuracy of their calibration and their condition affect the discharge measurement. Instruments used in making discharge measurements include the current meter, the timer, the depth indicator and the width indicator.

The current-meter error is caused by defects in the current meter and by turbulent flow. Turbulent water affects the revolution-velocity rating of the current meter which is based on towing it through still water. The instrument error due to rating the current meter in still water and operating it in turbulent flow is difficult to evaluate. A comparison of the results of velocity measurements made by the Price cup-type current meter and the Ott propeller-type current meter agreed within one per cent. Because the propeller-type current meter tends to under-register and the cup-type current meter tends to over-register in turbulent flow, these comparisons indicate that the effect of turbulence, usually, is small.

The errors introduced by the other instruments used in the current-meter measurement are believed to be still smaller than those introduced by the current meter. Most investigators agree that the instrumental errors are not greater than one per cent.

2.7.3 Methodic Error

The methodic error is made up of three components:

1. The error due to the restricted observation time at each individual observation point, the velocity-pulsation error.
2. The error due to the restricted number of observation points in each vertical, the velocity-depth error.

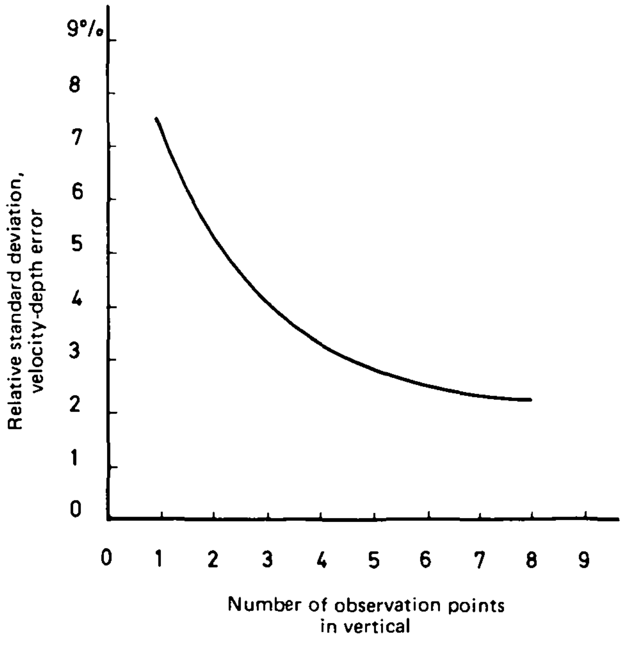


Figure 33. The velocity-depth error as function of the number of observation points in the vertical [8].

3. The error due to the restricted number of verticals in the measuring cross-section, the velocity-width error.

The velocity-pulsation error is due to the character of the flow, that is, turbulence and pulsation. The true mean velocity will be approached closer the longer the time-interval of the velocity observation is made. Investigations under the direction of the International Organization for Standardization (ISO) indicate that a time-interval of 60 seconds is more than sufficient for most natural streams [8].

The velocity-depth error. In order to closely approach the mean velocity in the measuring vertical, observations at many points in the vertical should be made. However, as long as the flow is uniform or nearly so, the number of points in the vertical is of less importance than the number of verticals in the measuring cross-section (Figure 33).

The velocity-width error. The number of verticals in the measuring cross-section has a large influence on the final error of the current-meter measurement (Figure 34). This is quite natural since most streams have a relatively small depth-width ratio which promotes an irregular velocity distribution across the stream.

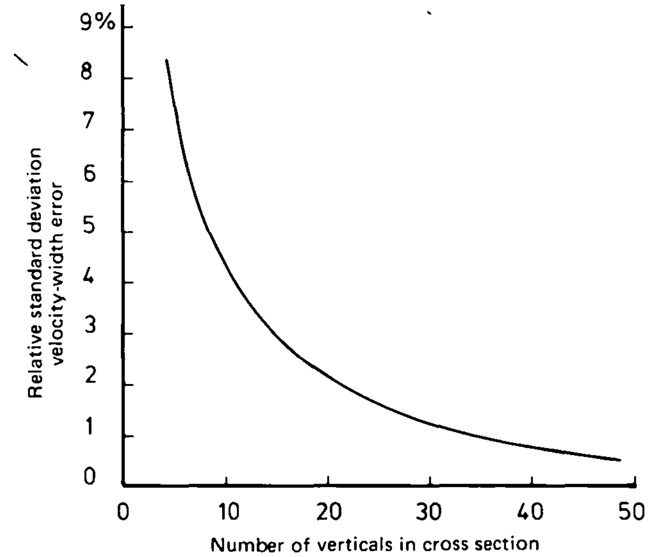


Figure 34. The velocity-width error as function of the number of verticals in the measuring cross section [8].

References Section 2.7: [8], [10].

3 THE RELATIVE SALT DILUTION METHOD

3.1 General

The application of chemical tracers in gauging streamflow has been known for many years. Early techniques consisted of injecting a chemical substance of known concentration into the stream water at a constant rate and then determining the steady state concentration of the tracer at some location sufficiently far downstream where a homogeneous mixture of the tracer and the stream water was assured. The degree of dilution of the tracer permits the stream discharge to be calculated from the equation

$$q\,c = (Q + q)\,C \qquad (3.1)$$

where

q = rate of injection of tracer,
c = concentration of tracer,
Q = stream discharge,
C = steady state concentration of tracer at sampling site.

As Q is much greater than q, Equation (3.1) reduces to

$$Q = M/C \qquad (3.2)$$

where M is amount of tracer injected into the stream per unit of time ($M = q\,c$).

Originally, the concentration of the chemical substance used as a tracer was determined by titration, and this, together with the complicated procedure of maintaining a constant injection, limited the field applicability of the *tracer dilution method.*

The method was developed further by making use of an ionizing substance as a tracer and the corresponding change in the electrolytic conductivity of the stream water to determine the dilution of the tracer. In addition, instead of a constant-rate injection, a sudden bulk injection was introduced. Thus, the improved technique consisted of the sudden bulk injection of a known amount of salt in solution followed by the determination of the time-concentration graph at the downstream sampling site. The stream discharge was then obtained from the amount of salt injected and the area under the time-concentration graph.

R. Søgnen, in his *relative salt dilution method* refined and simplified the method by introducing relative concentrations and developing a practical procedure for field application. [15].

3.2 Theory

S litres of a salt solution are released into a stream carrying an unknown discharge of Q litres per second (l/s). The magnitude of S is assumed negligible compared to Q. At a downstream observation site where the salt solution is homegeneously mixed with the stream water, the flow will consist of a very dilute salt solution. The salt concentration will rise from zero, reach a peak value and then fall back to zero as the solution wave passes the site (Figure 35). Each instant, the stream water at the observation site will contain different quantities of the injected salt solution, that is,

$S = s_1 + s_2 + \ldots + s_i + \ldots + s_n$

where

S = amount of salt solution injected (litre),
s_i = amount of salt solution passing observation site at the i-th instant (litre),
n = time required for the passage of the salt solution wave (second).

Assume that the concentration of the salt solution in the stream water each instant is $c_1, c_2, \ldots, c_n$. Thus

$s_1 = Qc_1, s_2 = Qc_2, \ldots, s_n = Qc_n$

Further

$$S = s_1 + s_2 + \ldots + s_n$$
$$S = Qc_1 + Qc_2 + \ldots + Qc_n$$
$$S = Q(c_1 + c_2 + \ldots + c_n)$$
$$S = Q\sum_0^n c\,dt$$
$$S = Q\,A$$

or

$$Q = S/A \qquad (3.3)$$

where

Q = water discharge of the stream,
S = volume of salt solution injected,
A = area under the time-concentration graph.

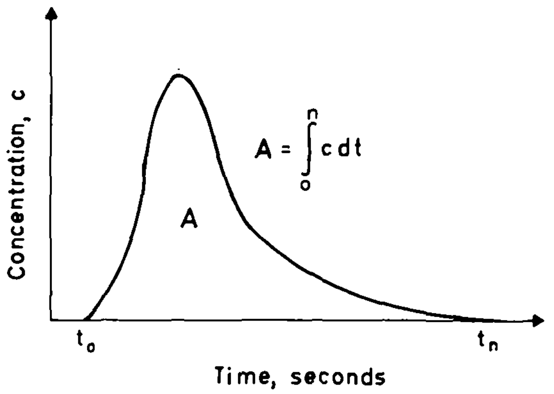


Figure 35. Time-concentration graph resulting from a sudden injection of tracer.

From Equation (3.3) can be seen that the determination of the stream discharge is theoretically independent of

a) the distance between the injection site and the observation site,
b) the duration of the injection,
c) the velocity of the flow,
d) the size and shape of the cross section.

The two critical conditions which must be fulfilled are

a) the injected salt solution must be homogeneously mixed with stream water at the downstream observation site,
b) the whole of the salt solution must pass the observation site.

3.3 The Measuring Procedure

3.3.1 The Measuring Reach

The measuring reach should not have any dead-water zones or large eddies where the salt solution may be trapped and slowly leak back into the flow, thus greatly increasing the measuring time. To reduce the measuring time, the distance between the injection site and the observation site should not be unnecessarily long. However, it is an absolute condition that the mixing of the salt solution and the stream water should be complete over the whole cross section at the observation site. This is easier to obtain in relatively deep and narrow channels. The mixing is further promoted by high turbulence and disturbances such as narrows, rapids and falls. An uneven bottom with rocks and boulders is better than an even sand-bed channel.

In general, rapid mixing occurs where the flow of water is discontinuous. Such discontinuities are found at waterfalls and rapids, at large hydraulic jumps, and at severe contractions followed by rapid expansions of the stream channel. These conditions must apply across the whole of the stream channel so that the overall flow is affected.

Although mixing is promoted by turbulence and disturbances in the stream channel such as rocks and boulders, lateral mixing in streams where no discontinuity occurs requires a very great distance, much longer than one would expect. Under such conditions, the following empirical formula has been proposed [18]:

$$L = b\,Q^{1/3} \qquad (3.4)$$

where

L = distance between injection site and observation site (m),
b = ~~14~~ for mid-stream injection, 50
b = ~~60~~ for injection at one bank, 200
Q = stream discharge (m^3/s).

3.3.2 Preparation of the Salt Solution

Any readily soluble salt may be used to make up the salt solution. However, the cheapest and most convenient to use is common salt (NaCl), preferably fine-grained table salt which dissolves quickly.

The amount of salt (NaCl) required per 1 m³/s of stream discharge depends on the mixing length. A long reach requires more than a short reach for the same discharge. The *background conductivity* (i.e. the natural conductivity measured when no salt solution is present) of natural water also affects the minimum amount of salt that can be used. As a rule of thumb, 0.2 kg of salt per 1 m³/s of discharge is considered sufficient for natural water with low background conductivity. Under good conditions, however, discharges of up to 140 m³/s have been measured by the use of not more than 12 kg of salt (i.e. 86 grammes of salt per 1m³/s of discharge).

~~The minimum concentrations of NaCl which may be measured with an accuracy of the order of ± 1% by the conductivity-metric method are shown in the following table against the conductivity of natural water. When the natural water has a very low conductivity, the minimum concentrations may be reduced to 1/10 of those indicated in the table.~~

~~*Table 3. Minimum concentration of NaCl that can be accurately detected* [12].~~

~~Conductivity of natural water (μS/m x 10⁻³)~~	~~100~~	~~20~~	~~10~~	~~2~~
~~Minimum concentration of NaCl, measurable with ± 1 % accuracy (kg/m³ x 10⁻³)~~	~~10~~	~~2~~	~~1~~	~~1~~

The solubility of NaCl at 15°C is 3.6 kg to 10 litres of water. However, under field conditions not more than 2.5 kg should be used to 10 litres of water.

A sensitive conductivity meter must be used, ~~capable of detecting variations in conductivity of about 1/10 000 that of natural water~~ (Figure 36).

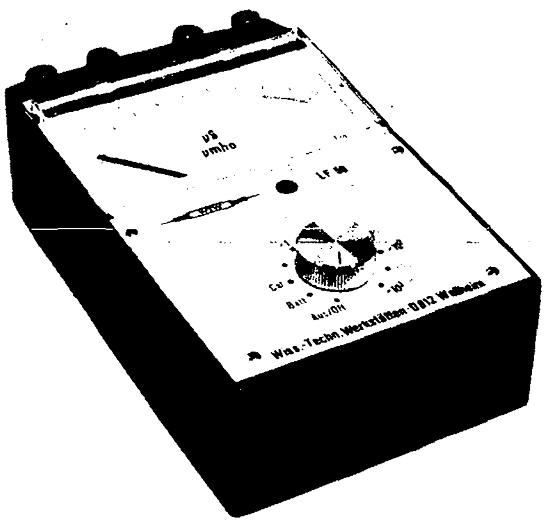


Figure 36. Battery-powered conductivity meter for field use (half-size).

It is not necessary to know exactly the concentration of the salt solution. However, the volume of the salt solution must be exactly known. Since it is important that only salt in solution be added to the stream water, the solution should be prepared in a separate container and then decanted into a calibrated injection tank with a fixed needle gauge. This is the so-called *primary solution*. It is most convenient to standardize the volume of the solution used and to vary the concentration according to the magnitude of the flow. For small streams, a volume of 20–50 litres of primary solution is suitable. For larger streams, a volume of 100 litres may be necessary. A small sample of about 100 millilitres is retained in a clean bottle for the purpose of developing a conductivity-concentration relation, see Section 3.3.4. The procedure in drawing off this sample is as follows: When decanting the primary solution into the calibrated injection tank, the injection tank is filled to about half a litre above the index mark. The small sample is then drawn off, after which the excess solution in the injection tank is removed. Before the small sample is drawn off, the contents of the tank must be stirred thoroughly.

3.3.3 Observation of the Solution Wave

The primary solution is injected into the river, preferably as close as possible to the centre of flow in order to reduce the mixing length. It is not necessary that the injection is instantaneous, an injection time of up to 2–3 minutes is quite tolerable.

The passage of the solution wave at the downstream observation site is recorded by means of an electrode placed in the main flow and connected to a conductivity meter. Readings are taken every 5 seconds during the passage of the main part of the wave. When recording the tail of the wave, longer intervals are used. (Table 4b).

In the *relative salt dilution* method, it is of no consequence whether or not the conductivity meter is correctly calibrated. All that is required is a set of conductivity readings which are to be compared with a conductivity-concentration relationship which is developed by use of the same instrument. The reading of the background conductivity measured in the stream may be adjusted by manipulating the gap between the electrode plates until a setting is obtained that will give a favourable range of conductivity readings when the solution wave passes the observation site. For this purpose, an adjustable electrode is necessary in the relative dilution method (Figure 37).

The temperature of the stream water must be recorded both before and after the measurement.

In relatively steep and cascading streams, an alternative arrangement is to divert some of the stream water into a wooden trough in which the electrode is placed. In this way, disturbances in the recordings due to air bubbles passing between the electrode plates are avoided. The diverted flow should be about 2–5 l/s. (Figure 38).

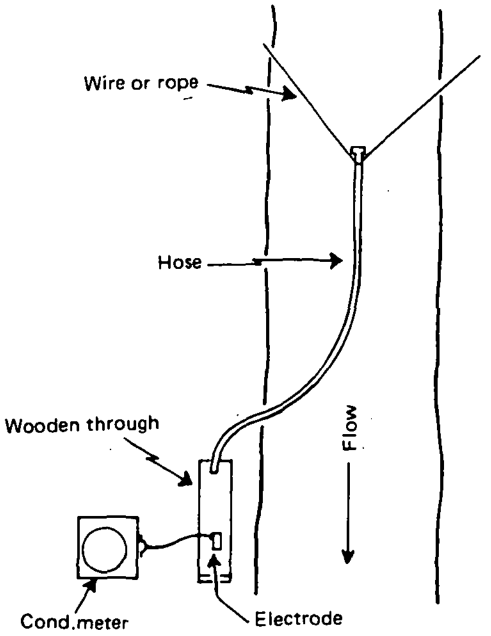


Figure 38. Sketch of measuring site. A continuous sampling of stream water is accomplished by means of a hose placed in the middle of the stream. The electrode may be placed directly in the stream; however, air bubbles will often disturb the readings.

3.3.4 The Calibration Curve

In order to convert the conductivity recordings of the solution wave into concentration values, a concentration-conductivity relation must be developed. This is the so-called *calibration curve*. In actual practice, the calibration curve is developed before the measurement of the solution wave is carried out. The accuracy of the relative dilution method depends largely on a careful performance of the development of the calibration curve. The calibration procedure is as follows, see flow chart in Figure 39:

1. 10 ml of the primary solution that was retained in the small bottle is measured into a 1000 ml flask by a spooled pipette. Fill up the flask to the index mark with stream water and mix well. By arbitrarily selecting the concentration of the primary solution equal to one, the solution in the 1000 ml flask will have a concentration equal to

$$\frac{10}{1000} \times 1 = 0.01 \; (-)$$

   This is the *secondary solution*, that is, the primary solution diluted 100 times.
2. Measure exactly 20 litres of stream water into a wide-necked tank and place it in the stream in order to keep the temperature of the contents constant during the calibration process.
3. Place the electrode in the stream and record the conductivity of the stream water. This is the natural background conductivity of the stream water. The temperature of the stream water is measured and recorded.

   If the background conductivity of the stream water is relatively high, then adjust the adjustable electrode until a low scale-reading is obtained. The final reading of the background conductivity is recorded.
4. Next, place the electrode in the wide-necked tank and stir the water in the tank until the needle of the

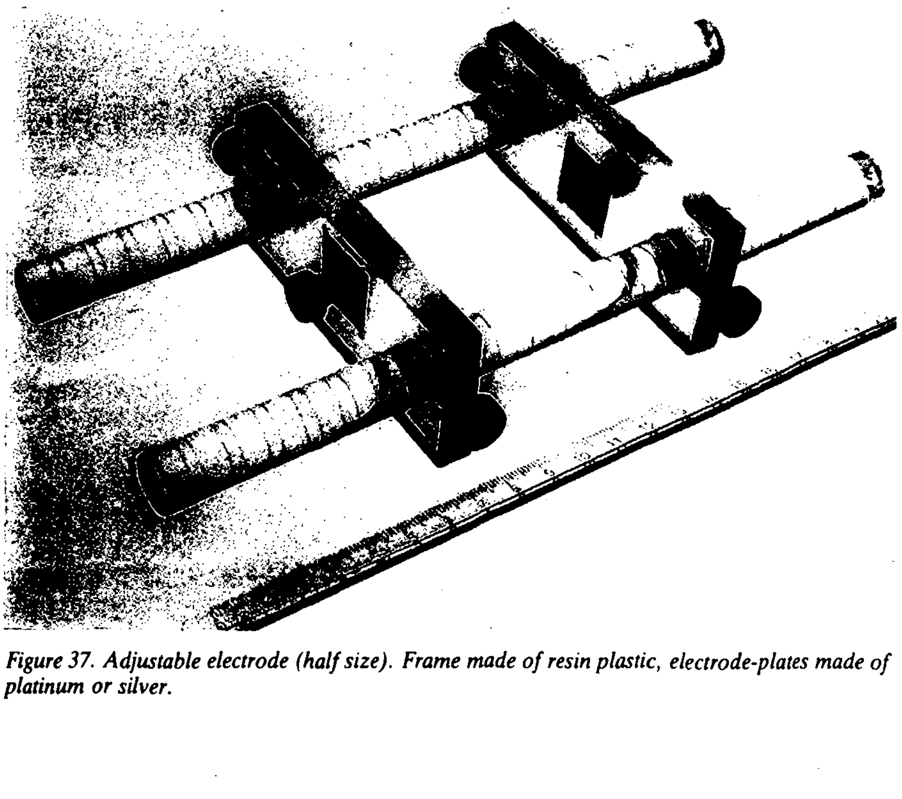


Figure 37. Adjustable electrode (half size). Frame made of resin plastic, electrode-plates made of platinum or silver.

conductivity meter has come to rest. A reading is taken and recorded and the temperature in the tank is read and recorded.

It would be expected that the conductivity reading taken in the tank would give the same value as the reading taken of the water in the stream. However, it is normally found that the reading in the tank is 5–15 per cent higher than readings taken simultaneously in the stream. The difference is due to electrostatic effects of the tank. However, this is of no consequence as corrections are applied.

5. Withdraw exactly 10 ml of the secondary solution by a pipette and empty it into the 20 litres tank, thus obtaining a solution of relative concentration

20,010 $$\frac{10 \times 0.01}{\cancel{20{,}020}} = 5.0 \times 10^{-6}\ (-)$$

   The solution is stirred thoroughly and a conductivity reading taken and recorded when the needle has come to rest.
6. Add consecutively 10 ml, 10 ml, ...,~~25 ml~~ into the tank in the same way as in step 5. Record the results as shown in Table 4a, columns 1, 2 and 3. In order to minimize inaccuracies, it is advisable to use 10 ml ~~and 25 ml~~ pipettes filled to capacity.
7. Construct the calibration curve by plotting the relative concentration values (ordinate axis) against the corresponding conductivity values (abscissa axis) as shown in Figure 40. The calibration curve should be linear, although in practice, a small curvature may be tolerated at the lower end of the curve. However, if the plot is not substantially linear, the procedure must be repeated.

   Before the calibration curve can be finally plotted, two corrections must be made as follows:

   Firstly, since the conductivity readings made with the electrode in the stream will be converted to concentration values by means of the calibration curve, the calibration curve must start from the same base value as the background reading of the stream water. Usually, the background conductivity in the tank will be somewhat higher than that in the stream, because the restricted volume of the tank affects the resistance of open electrodes. The difference in background readings may be eliminated by use of confined electrodes. A confined electrode is an electrode mounted in an insulating casing. The calibration is proportionally adjusted by multiplying all the conductivity readings by the ratio (Table 4a, column 4)

$$\frac{\text{stream background conductivity}}{\text{tank background conductivity}}$$

   Secondly, if there was an appreciable temperature change in the tank during the calibration process, the readings must be adjusted. This problem is usually avoided by keeping the calibration tank submerged up to the neck in the stream water during the calibration.

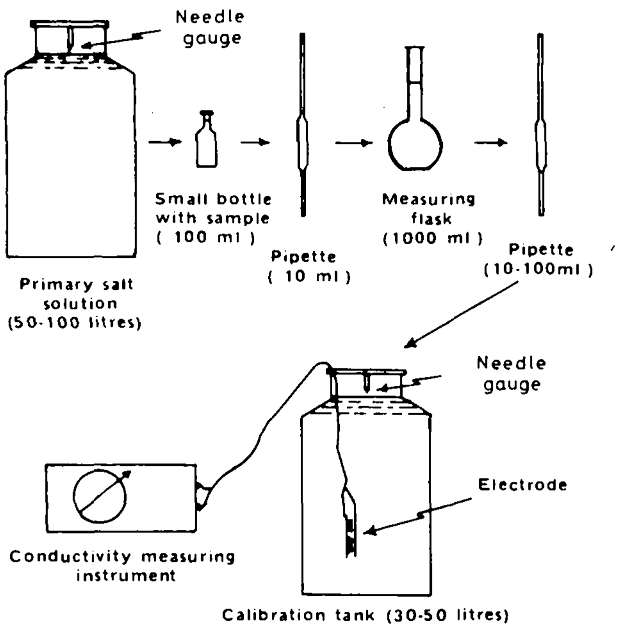


Figure 39. Diagram illustrating the calibration procedure.

3.4 The Calculation

The conductivity readings are converted to relative concentration values by means of the calibration curve and plotted against the corresponding time readings. A graph is drawn through the plotted points and the area under the resulting time-concentration graph is determined by a planimeter or simply counted up by means of a draftsman's dividers. (Figure 40).

The discharge is computed by the equation

$$Q = \frac{S}{a \times b \times A} \qquad (3.5)$$

where

Q = stream discharge (l/s),
S = volume of primary solution (l),
a = scale factor for abscissa axis,
b = scale factor for ordinate axis,
A = area under the time-concentration graph (cm^2).

The calibration curve and the time-concentration graph are constructed on the same graph sheet. The procedure for plotting the time-concentration graph is as follows, see Table 4b reading at 75 seconds, and Figure 40: Draw a vertical line through a conductivity reading on the conductivity axis to the calibration curve. Where this line meets the calibration curve, extend a horizontal line until it intersects a vertical line drawn through the corresponding time reading on the time axis. The point of intersection is a point on the time-concentration graph. Repeat the procedure for all the time and conductivity readings and draw a graph through the resulting points.

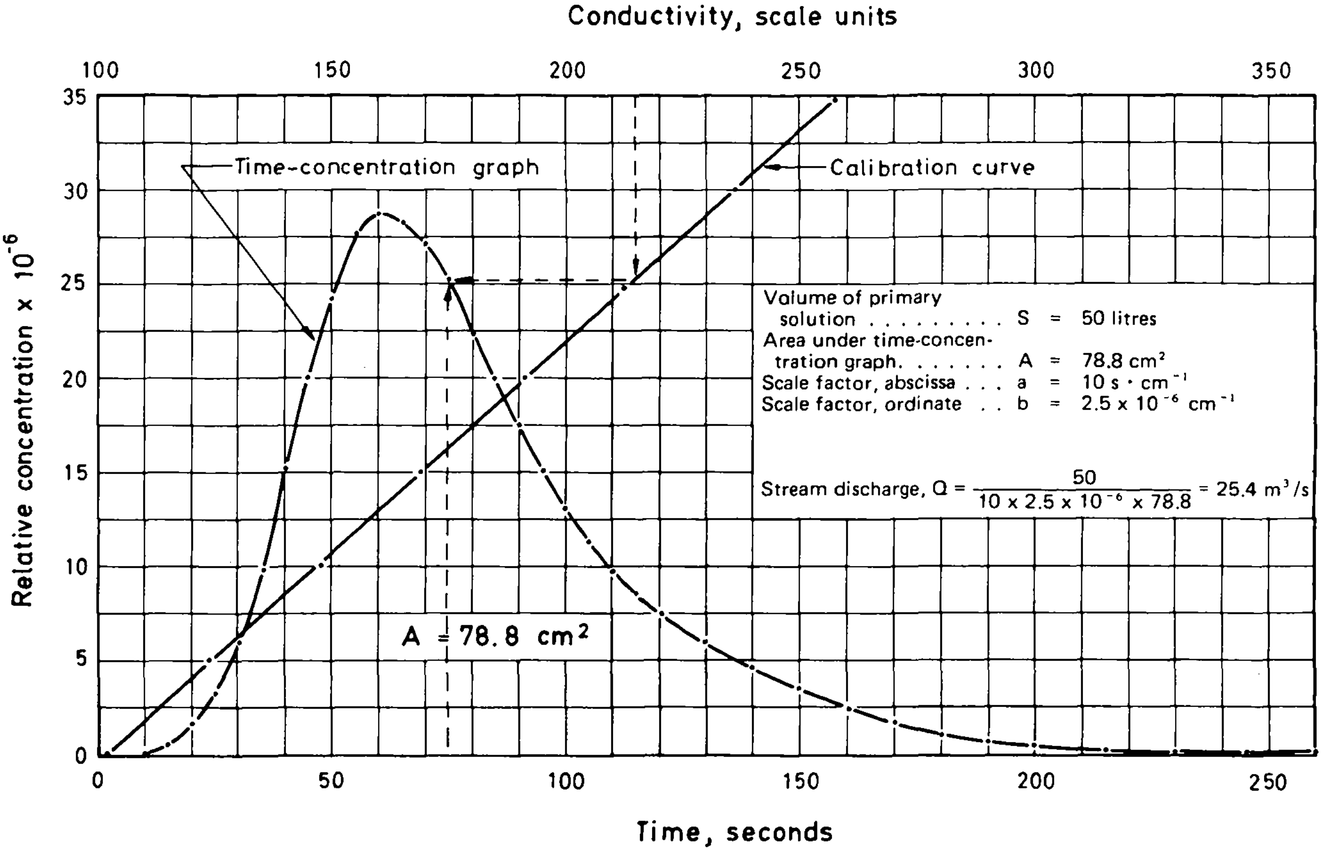


Figure 40. Computation of a relative salt dilution discharge measurement.

3.5 Sources of Error

The importance of complete mixing of the primary solution with the streamflow is stressed.

Changes in the temperature of an electrolyte cause variation in the electrolytic conductivity. Therefore, care must be taken to keep the calibration tank at a constant temperature during the calibration process. It is of no consequence should the temperature in the tank not be exactly equal to the temperature in the stream because the readings are adjusted (Section 3.3.4). The important thing is that the water temperature should be constant – in the tank during the calibration process and in the stream during the observation of the solution wave. If temperature variations should occur, corrections can be made by constructing a temperature correction graph. The error caused by changes in temperature during a measurement is more serious in cold streams than in warm tropical streams because the change in conductivity is greatest at the lower temperatures.

The careful and correct use of the pipettes is of utmost importance.

Polarization at the electrode plates may occur. To avoid this effect, the electrode plates should be made of pure silver or platinum.

Air bubbles in the water may have a disturbing effect if they pass between the electrode plates. This is avoided by placing the electrode in a wooden trough into which a constant flow of water is led by a hose (Figure 38).

The electrode must be kept in the same position in the tank during the calibration procedure and the agitation should always be done in the same manner.

If all the measurement procedures are carried out accurately and carefully, and if the physical characteristics of the measuring reach are fully satisfactory, the relative dilution method can be considered as having the same degree of accuracy as the current meter method under good conditions.

Table 4. Procedure for the Relative Salt Dilution Method, calibration curve and observation of solution wave.
a) Calibration

Secondary solution added to tank, cumulative ml	Relative concentration	Conductivity, scale units Readings	Conductivity, scale units Adjusted readings	
0	0.0	112	102	
10	5.0×10^{-6}	136	124	
20	10.0×10^{-6}	162	148	
30	15.0×10^{-6}	185	169	
40	20.0×10^{-6}	209	191	
50	24.9×10^{-6}	232	212	
60	~~30.0~~ $\times 10^{-6}$	258	236	29.9
70	34.9×10^{-6}	281	257	

The first reading, without salt solution added, gives the background conductivity in the tank, i.e. 112 scale units.

$$\text{Adjustment factor} = \frac{\text{stream background conductivity}}{\text{tank background conductivity}}$$

$$= 102/112$$

$$= 0.915$$

Initial temperature of calibration: 21.2°C.
Final temperature of calibration: 21.3°C.

b) Measurement in Stream

Time seconds	Conductivity scale units	Time seconds	Conductivity scale units
0	102	100	161
10	102	105	153
15	105	110	146
20	110	115	140
25	117	120	136
30	129	130	129
35	146	140	123
40	170	150	118
45	191	160	113
50	210	170	110
55	225	180	107
60	230	190	105
65	228	200	103
70	223	215	103
75	215	230	102.5
80	201	245	102.5
85	191	260	102.5
90	180	275	102.5
95	170	300	102.5

Readings 1 and 2 give the background conductivity of the stream water. The solution wave arrives at the sampling site at about 15 seconds, the reading is 105 scale units on the conductivity meter.

References Chapter 3: [12], [15], [16], [17], [18].

Table 5. List of equipment for the Relative Salt Dilution Method.

1. Conductivity meter. For rivers with high background conductivity, a multiple range instrument is recommended. Linear scale is preferable to logarithmic scale.
2. Adjustable electrode with silver or platinum faces mounted on a suitable plastic frame, Figure 37. Commercial conductivity cells may be adapted to the purpose.
3. Insulated two-conductor low inductance cable of sufficient length.
4. Frame with weight; for anchoring the electrode in the stream.
5. Stopwatch.
6. Calibration tank, 20–50 litre capacity, aluminium, calibrated or equipped with a variable needle gauge, with large opening for easy access of electrode.
7. Two tanks of 50–100 litre capacity, calibrated or equipped with needle gauge; for preparing the primary solution.
8. Glass or plastic bottle of about 100 ml capacity with tight stopper; for storing calibration sample of primary solution.
9. 1000 ml flask with long narrow neck, calibrated with index mark.
10. Pipettes of 10, 25, 50 and 100 ml capacity.
11. Thin paper tissue, absorbent; for drying and cleaning equipment.
12. Thermometer, subdivided to 0.1°C, mounted in housing.
13. Mixing dowels; for use in preparing the primary solution and in the calibration, separate dowel to be used for each purpose.
14. Graph paper.

All glassware should be in duplicate.

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APPENDIX A

CURRENT METER MEASUREMENT NOTES

CURRENT METER MEASUREMENT NOTES

To systematize the recording and the computation of current-meter measurements, standard form No. H7a is used on which data are recorded and computed.

One side of the form (Plate 1) contains a complete list of headings showing necessary data that must be collected and recorded if the measurement is to be of maximum value. The column headings (Plate 2) are self-explanatory and no measurement of discharge should be considered complete until all information indicated by the column headings has been obtained and entered in the spaces provided.

All entries of data should be made directly on this form immediately after their observation and not recorded elsewhere to be transferred at a later date. Those headings that do not apply to the particular measurement should be deleted so as to leave no doubt that the information may have been overlooked. The substitution of initials for names and the abbreviations of names of places should be avoided.

Data are recorded in the following order beginning at the left side of the sheet (Plate 2):

1. *Distance from initial point* – distance from initial point to the vertical as read off from a tag line stretched across the stream.
2. *Sounded Depth* – depth with no corrections applied.
3. *Angle* – vertical angle of a suspension cable as measured by a protractor.
4. *Revised Depth* – values obtained by subtracting air and wet-line corrections from column 2.
5. *Unrevised Depth of Observation* – use this column when unable to compute corrections during the measurement.
6. *Revised Depth of Observation* – position of the current meter below the water surface, that is, 0.2, 0.6, 0.8, etc. of the depth.
7. *Revolutions* – number of revolutions of the rotor of the current meter during an observation interval.
8. *Time* – time interval over which the revolutions of the rotor are observed.
9. *Velocity at Point* – velocity at point of observation in a vertical obtained directly from the rating table of the current meter used.

10. & 11. *Multiplier* – used for multiple-point method only.

12. *Mean Velocity in the Vertical* –
    - a) for 0.6 method, mean velocity is equal to value in column 9.
    - b) for 0.2/0.8 method, the average of the two velocities in column 9 is taken as mean velocity.
    - c) for multiple-point method, mean velocity must be computed by arithmetic integration using column 10. & 11., or by plotting the depth-velocity curve for the vertical.
13. *Mean Velocity in Section* – the average of the mean velocity in two adjacent verticals; the velocity near the water's edge is estimated as a percentage of the mean velocity in the first vertical measured, in some cases it might approach zero, in which case, the mean velocity in the section is half only of the mean velocity in the first vertical (i.e. mean-section method).
14. *Area of Section* – product of mean depth of a section and width of the section.
15. *Discharge in Section* – product of mean velocity of a section and area of the section, i.e. (column 13) x (column 14).
16. *Discharge accumulated* – for successive accumulation of the values in column 15.
17. *Remarks*.

Reference: [7].

INSTRUCTIONS

1. Hydrographers must fill out and complete these measurement notes in full, have them checked, and forwarded to Ubungo through R.H.O. within two weeks of carrying out the gaugings.
2. The current rating curve for the gauging station should be available and where possible the gaugings are to be calculated and checked against this curve in the field.
3. Where the gauging deviates more than 4 per cent from the current rating curve, a check gauging is required as soon as possible.
4. The most Probable sources of error are:—
   (a) poor gauging stretch;
   (b) changed control;
   (c) changed staff gauges.
   If check gaugings still plot more than 4 per cent out, then the above points should be investigated and the action being taken should be noted under remarks.

NOTES:

W. D & P
HYDROLOGY
FORM H 7a

Gauging Stn. No. ....
Gauging No. ....
Date ....

DISCHARGE MEASUREMENT NOTES

.................................River at..

Time	Recorder	Staff Gauge

Observer ... ...
Mean gauge height... ... .
Discharge in m^3/sec. ... .
Area in m^2 ... ...
Mean vel. in m/sec. ... .
Width in metres ... ...

Meter type and No.. Pivot or propellor No......................................
Date meter rated..............................Spin test before.............................after.............................
Weights used and means of measurement..Position.............................
of gauging section.. m above / below gauge....................................
Chart removed from.. to..
Condition of (1) control...(2) intake pipe...
....(3) gauge staves...
Wind and weather conditions...
Per cent deviation from current rating curve.................................No. of sheets...................................
Remarks ....
....
....
....

Plotted	by	Date	Entered	by	Date

PLATE 1

Distance from initial point	Sounded depth	Angle	Revised depth	Unrevised depth of obs.	Revised depth of obs.	Revs.	Time	VELOCITY					Area of section	Discharge in section	Discharge accum.	Remarks
								Vel. at point	Multiplier		Mean vel. in vert.	Mean vel. in section				
Totals																

Computed.. *Date*.. *Checked by*.. *Date*..

PLATE 2

APPENDIX B

THE MID-SECTION METHOD OF COMPUTING CURRENT METER MEASUREMENTS

INSTRUCTIONS

1. Hydrographers must fill out and complete these measurement notes in full, have them cheeked, and forwarded to Ubungo through R.H.O. within two weeks of carrying out the gaugings.
2. The current rating curve for the gauging station should be available and where possible the gaugings are to be calculated and checked against this curve in the field.
3. Where the gauging deviates more than 4 per cent from the current rating curve, a check gauging is required as soon as possible.
4. The most Probable sources of error are:—
   - (a) poor gauging stretch;
   - (b) changed control;
   - (c) changed staff gauges.

   If check gaugings still plot more than 4 per cent out, then the above points should be investigated and the action being taken should be noted under remarks.

NOTES:

Current-meter measurement computed by the mid-section method.

W D & P
HYDROLOGY
FORM H 7a

Gauging Stn. No. 10

DISCHARGE MEASUREMENT NOTES

Gauging No. 23

MALAGARASI River at MBELAGULE

Date 24.7.76

Time	Recorder	Staff Gauge
0810		1.47
1045		1.47

Observer ... ... T. S. ALLIY

Mean gauge height 1.47

Discharge in m³/sec. ... 50.2

Area in m² 460.4

Mean vel. in m/sec. ... 0.109

Width in metres 102.0

Meter type and No. A. OTT 7675 Pivot or propellor No. 1

Date meter rated Spin test before 93 sec. after 85 sec.

Weights used and means of measurement 25 kg, cableway Position .2/.8, .6

of gauging section m above below gauge

Chart removed from to

Condition of (1) control clean (2) intake pipe cleaned

(3) gauge staves intact

Wind and weather conditions calm and sunny

Per cent deviation from current rating curve No. of sheets 3

Remarks

Plotted	by	Date	Entered	by	Date

GAUGING STATION MBELAGULE **No.** 10 **SHEET No.** 1 of 3

DATE 24.7.76 **MEAN GAUGE HEIGHT** 1.47

Distance from initial point	Sounded depth	Angle	Revised depth	Unrevised depth of obs	Revised depth of obs.	Revs.	Time	VELOCITY					Area of section	Discharge in section	Discharge accum.	Remarks
								Vel. at point	Multiplier		Mean vel. in vert.	Mean vel. in section				
0.00	0.00		Water's edge, R B at 08.10 hrs.													
6.00	3.08	0	-	-	0.62	10	81	.037			.038	.038	18.48	0.702	0.702	
					2.46	10	75	.040								
12.00	4.28	0	-	-	0.86	40	70	.151			.137	.137	25.68	3.518	4.220	
					3.42	30	65	.123								
18.00	4.66	0	-	-	0.93	50	75	.176			.150	.150	27.96	4.194	8.414	0840 hrs
					3.73	30	64	.125								
24.00	5.54	0	-	-	1.11	30	61	.131			.123	.123	33.24	4.089	12.503	
					4.43	30	70	.115								
30.00	5.30	0	-	-	1.06	30	60	.133			.130	.130	31.80	4.134	16.637	
					4.24	30	63	.127								
Totals																

Computed.................. *Date*.................. *Checked by*.................. *Date*..................

GAUGING STATION MBELAGULE **No.** 10 **SHEET No.** 2 of 3

DATE 24. 7. 76 **MEAN GAUGE HEIGHT** 1.47

Distance from initial point	Sounded depth	Angle	Revised depth	Unrevised depth of obs.	Revised depth of obs.	Revs.	Time	VELOCITY					Area of section	Discharge in section	Discharge accum.	Remarks
								Vel. at point	Multiplier		Mean vel. in vert.	Mean vel. in section				
36.00	5.26	0	-	-	1.05	30	55	.145			.142	.142	31.56	4.482	21.119	
					4.21	30	57	.140								
42.00	5.25	0	-	-	1.05	30	60	.133			.131	.131	31.50	4.126	25.245	0910 hrs
					4.20	30	62	.129								
48.00	5.38	0	-	-	1.08	30	62	.129			.127	.127	32.28	4.100	29.345	
					4.30	30	64	.125								
54.00	5.38	0	-	-	1.08	30	61	.131			.130	.130	32.28	4.196	33.541	
					4.30	30	62	.129								
60.00	5.52	0	-	-	1.10	20	53	.102			.096	.096	33.12	3.180	36.721	0940 hrs
					4.42	20	60	.090								
66.00	5.18	0	-	-	1.04	20	52	.104			.101	.101	31.08	3.139	39.860	
					4.14	20	55	.098								
Totals																

Computed........................ *Date*........................ *Checked by*........................ *Date*........................

GAUGING STATION MBELAGULE **No.** 10 **SHEET No.** 3 of 3

DATE 24.7.76 **MEAN GAUGE HEIGHT** 1.47

Distance from initial point	Sounded depth	Angle	Revised depth	Unrevised depth of obs.	Revised depth of obs.	Revs.	Time	Velocity					Area of section	Discharge in section	Discharge accum.	Remarks
								Vel. at point	Multiplier		Mean vel. in vert.	Mean vel. in section				
72.00	5.10	0	–	–	1.02	20	52	.104			.095	.095	30.60	2.907	42.767	
					4.08	20	63	.086								
78.00	4.92	0	–	–	0.98	20	53	.086			.090	.090	29.52	2.657	45.424	
					3.94	20	58	.093								
84.00	4.90	0	–	–	0.98	20	56	.097			.093	.093	29.40	2.734	48.158	1010 hrs
					3.92	20	61	.089								
90.00	4.62	0	–	–	0.92	10	55	.052			.053	.053	27.72	1.469	49.627	
					3.70	10	52	.054								
96.00	2.37	0	–	–	0.47	10	68	.043			.041	.041	14.22	0.983	50.210	
					1.90	10	76	.039								
102.00	0.00	Water's edge, L.B.			at 1045 hrs.											
													460.44			
Totals																

Computed........................ *Date*........................ *Checked by*........................ *Date*........................

APPENDIX C

THE MEAN-SECTION METHOD OF COMPUTING CURRENT METER MEASUREMENTS

INSTRUCTIONS

1. Hydrographers must fill out and complete these measurement notes in full, have them checked, and forwarded to Ubungo through R.H.O. within two weeks of carrying out the gaugings.
2. The current rating curve for the gauging station should be available and where possible the gaugings are to be calculated and checked against this curve in the field.
3. Where the gauging deviates more than 4 per cent from the current rating curve, a check gauging is required as soon as possible.
4. The most Probable sources of error are:—
   (a) poor gauging stretch;
   (b) changed control;
   (c) changed staff gauges.
   If check gaugings still plot more than 4 per cent out, then the above points should be investigated and the action being taken should be noted under remarks.

NOTES:

Current-meter measurement computed by the mean-section method.

W. D & P
HYDROLOGY
FORM H 7a

Gauging Stn. No. 10

Gauging No. 23

DISCHARGE MEASUREMENT NOTES

MALAGARASI River at MBELAGULE

Date 24.7.76

Time	Recorder	Staff Gauge
0810		1.47
1045		1.47

Observer ... ... T. S. Alliy

Mean gauge height 1.47

Discharge in m³/sec. ... 49.5

Area in m² 460.3

Mean vel. in m/sec. ... 0.108

Width in metres 102.0

Meter type and No. A.OTT 7675 Pivot or propellor No. 1

Date meter rated Spin test before 93 sec. after 85 sec.

Weights used and means of measurement 25 kgs. cableway Position .2/.8, .6

of gauging section m above/below gauge

Chart removed from to

Condition of (1) control clean (2) intake pipe cleaned

(3) gauge staves intact

Wind and weather conditions calm and sunny

Per cent deviation from current rating curve No. of sheets 3

Remarks

Plotted	by	Date	Entered	by	Date

GAUGING STATION MBELAGULE **No.** 10 **SHEET No.** 1 of 3

DATE 24.7.76 **MEAN GAUGE HEIGHT** 1.47

Distance from initial point	Sounded depth	Angle	Revised depth	Unrevised depth of obs.	Revised depth of obs.	Revs.	Time	Velocity					Area of section	Discharge in section	Discharge accum.	Remarks
								Vel. at point	Multiplier		Mean vel. in vert.	Mean vel. in section				
0.00	0.00		Water's edge, R.B. at 0810 hrs.								.000					
												.019	9.24	0.176	0.176	
6.00	3.08	0	-	-	.62	10	81	.037								
					2.46	10	75	.040			.038					
												.088	22.08	1.943	2.119	
12.00	4.28	0	-	-	.86	40	70	.151								
					3.42	30	65	.123			.137					
												.144	26.82	3.862	5.981	
18.00	4.66	0	-	-	.93	50	75	.176								
					3.73	30	64	.125			.150					
												.136	30.50	4.148	10.129	
24.00	5.54	0	-	-	1.11	30	61	.131								
					4.43	30	70	.115			.123					
												.126	32.52	4.098	14.227	
30.00	5.30	0	-	-	1.06	30	60	.123								
					4.24	30	63	.127			.130					
												.135	31.68	4.227	18.454	
Totals																

Computed.................. *Date*.................. *Checked by*.................. *Date*..................

GAUGING STATION MBELAGULE **No.** 10 **SHEET No.** 2 of 3

DATE 24.7.76 **MEAN GAUGE HEIGHT** 1.47

Distance from initial point	Sounded depth	Angle	Revised depth	Unrevised depth of obs.	Revised depth of obs.	Revs.	Time	Velocity					Area of section	Discharge in section	Discharge accum.	Remarks
								Vel. at point	Multiplier		Mean vel. in vert.	Mean vel. in section				
36.00	5.26	0	-	-	1.05	30	55	.145								
					4.21	30	57	.140			.142					
												.136	31.53	4.288	22.742	
42.00	5.25	0	-	-	1.05	30	60	.133								
					4.20	30	62	.129			.131					
												.129	31.89	4.114	26.856	
48.00	5.38	0	-	-	1.08	30	62	.129								
					4.30	30	64	.125			.127					
												.128	32.28	4.132	30.988	
54.00	5.38	0	-	-	1.08	30	61	.131								
					4.30	30	64	.125			.130					
												.113	32.70	3.695	34.683	
60.00	5.52	0	-	-	1.10	20	53	.102								
					4.42	20	60	.090			.096					
												.098	32.10	3.146	37.829	
66.00	5.18	0	-	-	11.04	20	52	.104								
					4.14	20	55	.098			.101					
Totals												.098	30.84	3.022	40.851	

Computed.................... *Date*.................... *Checked by*.................... *Date*....................

GAUGING STATION....MBELAGULE.................................. **No.**10......................... **SHEET No.**..3 of 3.......

DATE.. 24.7.76.................... **MEAN GAUGE HEIGHT**......1.47..............................

Distance from initial point	Sounded depth	Angle	Revised depth	Unrevised depth of obs.	Revised depth of obs.	Revs.	Time	Velocity Vel. at point	Multiplier		Mean vel. in vert.	Mean vel. in section	Area of section	Discharge in section	Discharge accum.	Remarks
72.00	5.10	0	–	–	1.02	20	52	.104								
					4.08	20	63	.086			.095					
												.092	30.06	2.766	43.617	
78.00	4.92	0	–	–	0.98	20	53	.086								
					3.94	20	58	.093			.090					
												.092	29.46	2.710	46.327	
84.00	4.90	0	–	–	0.98	20	56	.097								
					3.92	20	61	.089			.093					
												.073	28.56	2.085	48.412	
90.00	4.62	0	–	–	0.92	10	55	.052								
					3.70	10	52	.054			.053					
												.047	20.97	0.986	49.398	
96.00	2.37	0	–	–	0.47	10	68	.043								
					1.90	10	76	.039			.041					
												.020	7.11	0.142	49.540	
102.00	0.00	Water's edge, L.B. at 1045 hrs.														
													460.34			
Totals																

Computed.............................. *Date*.............................. *Checked by*.............................. *Date*..............................

APPENDIX D

RATING OF CURRENT METERS

Practical Hints

When rating current meters, the following precautions should be observed:

1. The towing velocity should not coincide with the velocity of propagation in the rating tank.
   The so-called *Epper Effect* is a complex phenomenon influenced by the geometry of the rating tank and the size of the current meter and its means of suspension. Simply stated, the effect is the slowing down of the current-meter rotor and under-registration of the current meter when the rotor rotates within the wave produced as the current meter is towed through the tank. Ratings within the range of the wave show a greater velocity for a given towing velocity than would be indicated by interpolating the normal ratings for higher and lower velocities. The wave produced by towing the current meter moves with a certain velocity, the so-called *velocity of propagation*, independent of the towing velocity. The dependence of this critical velocity v_c on the depth of the water in the tank is given by the equation

   $$v_c = \sqrt{gd} \qquad \text{(D.1)}$$

   where

   g = acceleration due to gravity, 9.81 m/s,
   d = depth of water (m).

   The Epper Effect may cause a significant error in the rating of the current meter within a narrow band in the velocity range from $0.5\ v_c$ to $1.5\ v_c$. The magnitude of the Epper Effect depends on the size of the current meter and suspension equipment relative to the cross-sectional area of the tank. It may be negligible when a very small current meter is rated.
2. Before the current meter is immersed in the water, it shall be checked for cleanliness, lubrication and for its mechanical and electrical functioning.
3. The current meter shall be towed along the centre line of the rating tank.
4. The current meter shall be placed at such a depth below the water surface that the surface influence is negligible. For a propeller-type current meter, a depth twice the diameter of the propeller is generally sufficient. A cup-type current meter should be immersed to a depth of at least one and a half times the height of the rotor, or 0.3 m, whichever is greater.
5. Care shall be taken to ensure that the carriage vibrations (especially noticeable at lower speeds) and the rod vibrations (especially noticeable at higher speeds) are low enough not to influence the speed of revolution of the current meter.
6. The minimum response velocity is determined by gradually increasing the carriage velocity from zero until the rotor revolves at a constant speed.
7. Measurements shall be carried out from the response velocity at a sufficient number of towing velocities to enable the rating of the current meter to be defined accurately. The intervals between the towing velocities should be closer at the lower end of the range. The total number of rating points should be about:
   10–12 for rating up to 2 m/s
   12–16 for rating up to 5 m/s
   16–20 for rating up to 8 m/s
8. The water in the tank should come to rest after each run. The time needed for the water to still depends on the dimensions of the tank, the use of baffles, the previous test velocity, and the size and shape of the current meter and suspension equipment immersed in the water.

The following mean values may be given for guidance:

Velocity	Stilling time
m/s	min
0.5	10
2	15
5	25
8	30

Computation of the Rating Equations

From the time, distance travelled and number of propeller revolutions, the velocity in metres per second (v) and propeller speed in revolutions per second (n) are computed for each run in the rating tank. An expanded method of plotting the data is used in order to magnify the normal scatter of the data points and to facilitate estimation of the rating curve. In the expanded method, an assumed asymptote to the actual rating curve $v = f(n)$ is drawn through origo (Figure D.1). The equation of the assumed asymptote is $v_o = b_o n$, where b_o is equal to the pitch of the propeller.

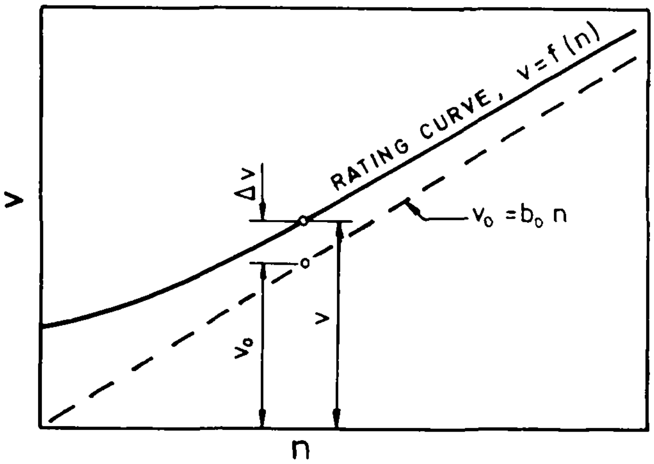

Figure D.1. Schematic graph of current-meter rating curve and assumed asymptote.

The pitch is the distance in metres the current meter must travel in the rating tank in order for the propeller to make one revolution.

The expanded rating curve is drawn to show the difference Δv between the observed velocity v and the velocity determined by the assumed asymptote v_o that is shown in Figure D.1. This difference is written $\Delta v = (v - v_o)$. Substituting $b_o n$ for v_o, gives $\Delta v = (v - b_o n)$ as the ordinate for the expanded rating curve shown in Figure D.2. Typical observed data and calculation of runs in a rating tank for a propeller-type current meter are shown in Table D.1.

After the data are plotted on graph paper, the next step is to draw the expanded rating curve through the plotted points (Figure D.2). In most cases, the rating curve is estimated by two straight line segments. Coordinates are selected from the straight line segments (or extension of these) for computation of the rating equations.

The form of the rating equation is based on the equation for a straight line

$y = kx + b$

Substituting $(v_o - b_o n)$ for y, and n for x, the equation becomes

$v - b_o n = kn + b$

Solving for v, the equation is simplified to form

$$v = (b_o + k)n + b \qquad \text{(D.2)}$$

where

v = velocity (m/s),
b_o = pitch of propeller (m),
k = slope of the plotted line,
n = revolutions per second,
b = intercept on y-axis.

An example of the computations to determine the rating equations is shown in Table D.2.

Table D.1. Observed and calculated data of a current-meter rating.

Run	Distance m	Time s	Rev.	Rev. per second (n)	Metres per second (v)	$v_0 = b_0 n$	$\Delta v = (v - b_0 n)$
1	21.244	56.15	150	2.671	0.378	0.321	0.057
2	27.581	54.63	200	3.661	0.505	0.439	0.066
3	34.196	60.63	250	4.123	0.564	0.495	0.069
4	40.535	59.02	300	5.083	0.687	0.610	0.077
5	46.735	53.63	350	6.526	0.871	0.783	0.088
6	46.439	45.64	350	7.669	1.018	0.920	0.098
7	46.205	38.95	350	8.986	1.186	1.078	0.108
8	46.186	35.89	350	9.752	1.287	1.170	0.117
9	46.141	32.43	350	10.792	1.423	1.295	0.128
10	46.116	30.00	350	11.667	1.537	1.400	0.137
11	46.086	27.46	350	12.746	1.678	1.530	0.148
12	46.086	25.68	350	13.629	1.795	1.635	0.160
13	46.071	24.50	350	14.286	1.880	1.714	0.166
14	46.067	23.06	350	15.178	1.998	1.821	0.177
15	46.061	21.80	350	16.055	2.113	1.927	0.186

Pitch of propeller b_0 = 0.120 m

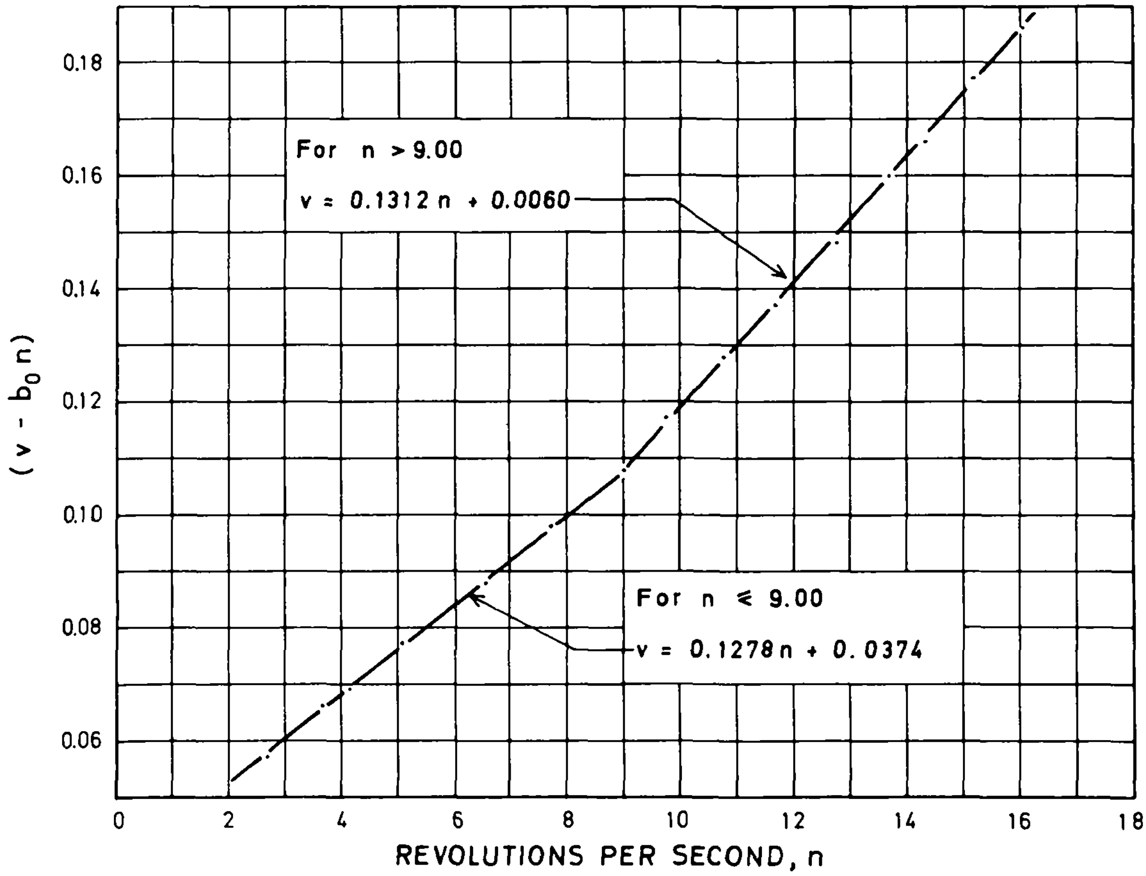

Figure D.2. Plot of expanded current-meter rating curve, from Table D.1.

Table D.2. Computations to determine the current-meter rating equations.

1	2	3	4	5	6	7	8	9	10	11
$(v-0.12n)_2$	$(v-0.12n)_1$	n_2	n_1	Col. 1 – Col. 2	Col. 3 – Col. 4	$k = \frac{\text{col. 5}}{\text{col. 6}}$	kn_1	b = col. 2 – Col. 8	0.12 + k	$v = (0.12 + k)n + b$
0.170	0.060	17.000	2.900	0.110	14.100	0.0078	0.0226	0.0374	0.1278	$v = 0.1278\,n + 0.0374$
0.185	0.090	15.950	7.500	0.095	8.450	0.0112	0.0840	0.0060	0.1312	$v = 0.1312\,n + 0.0060$

Intersection of the two segments at $n = 9.00$

For $n \leq 9.00$

$v = 0.1278\,n + 0.0374$

For $n > 9.00$

$v = 0.1312\,n + 0.0060$

References: [14], [19], [20], [21].

APPENDIX E

THE SLOPE-AREA METHOD

THE SLOPE-AREA METHOD

Principle

A measuring reach is chosen for which the area of a mean cross section of the stream is determined and the surface slope of the flowing water in that reach is measured. The mean velocity is then established by using known empirical formulas which relate the velocity to the hydraulic mean depth, the surface slope corrected for kinetic energy of the flowing water and the characteristics of the bed and bed material. The discharge is computed as the product of the mean velocity and the area of a mean cross section of the stream.

The Measuring Reach

The site shall be easily accessible at all times.

The measuring reach shall be, as far as possible, uniform. If no uniform reach is available, the reach should be preferably converging rather than diverging.

The flow in the channel shall be, as far as possible, contained within its banks at all stages, otherwise the overflow would have to be measured separately.

The accuracy of the slope-area method is increased if the river banks and bed are reasonably stable and the river reach fairly straight, uniform and free from obstructions and disturbances.

The length of the measuring reach depends on the channel slope. The length of the reach shall be such that the surface fall in the reach is at least ten times the expected error in the measurement of the fall.

In the reach selected, a minimum of three cross sections is generally desirable. These shall be clearly marked on the banks by means of easily identifiable markers. If, for any reason, it is not possible to survey more than one cross section, the central one only may be surveyed.

The position of each cross section shall be normal to the general direction of the flow.

The cross sections for each discharge measurement shall be surveyed as near as possible to the time at which the measurement is made. It is often impossible to survey the cross sections during floods and, therefore, an error may be introduced owing to an unobserved and temporary change in the cross sections. If, however, the measuring reach is stable, it will be sufficient to survey the cross sections before and after the flood season.

Reference Gauges

The measuring reach shall be provided with reference gauges for the determination of stage and fall of the surface in the reach.

The reference gauge shall be a vertical gauge or an inclined gauge. The markings shall be clear and sufficiently accurate; the lowest marking and the highest marking on the reference gauge shall be respectively below and above the lowest and highest anticipated water level.

The reference gauge shall be securely fixed to an immovable and rigid support in the stream and shall be related to a fixed bench mark by levelling.

Crest-stage gauges are suitable where only the peak level during each flood has to be determined. Peak discharges can be calculated from two such gauges installed in a reach of the river, provided the time-lag in the reach is negligible.

Gauges shall be installed on both banks of the river, at not fewer than three cross sections, making a total of at least six gauges. The gauges shall have a common datum.

The gauge shall be observed continuously for a minimum period of 2 min. or the period of a complete oscillation, whichever is longer, and the maximum and minimum readings taken and averaged.

All gauges shall be observed at suitable intervals and readings recorded throughout the period of measurement, including initial and terminal readings.

When accurate gauges do not exist or have been destroyed, and when no other method can be employed, a rough estimate of the slope during the peak stage can be made by means of flood marks on the banks. Several dependable highwater flood marks for each bank shall be used in determining the water level.

Determination of the Surface Slope

Slope is computed from the gauge observations at either end of the reach, the intermediate gauge(s) being used to confirm that the slope is uniform throughout the reach.

Determination of the Mean Cross-Sectional Area

If the reach is substantially uniform and there are insignificant differences in the cross-sectional areas, A_1, $A_2 \ldots A_m$, the mean area of the cross sections may be taken as

$$\bar{A} = \frac{A_1 + 2A_2 + \ldots + 2A_{(m-1)} + A_m}{2(m-1)} \qquad (E.1)$$

Determination of the Wetted Perimeter

For each cross section, the corresponding wetted perimeter shall be determined. If the wetted perimeters are P_1, $P_2 \ldots P_m$ respectively, then the mean wetted perimeter may be taken as

$$\bar{P} = \frac{P_1 + 2P_2 + \ldots + 2P_{(m-1)} + P_m}{2(m-1)} \qquad (E.2)$$

Determination of the Mean Velocity

The mean velocity in a reach L (Figure E.1) when the flow is not significantly different from steady flow, using Manning's formula, will be

$$v = \frac{R^{2/3} \quad S^{1/2}}{n} \tag{E.3}$$

where

v = mean velocity (m/s),
R = hydraulic mean depth (m),
n = Manning's coefficient of roughness,
S = slope corrected for the kinetic energy difference at the two ends and for eddy losses in the reach, namely,

$$\frac{Z_1 - Z_2 + \left(\frac{v_1^2}{2g} - \frac{v_2^2}{2g}\right)(1 - k)}{L} \tag{E.4}$$

The reach shall be, as far as possible, uniform. If no uniform reach is available, the reach should be preferably converging rather than diverging to facilitate an appropriate correction for change in kinetic energy. However, if the reach is expanding, then the slope correction must include some allowance for eddy loss as well as the correction for the change in kinetic energy between the end-sections. Thus, k in Equation E.4 is taken to be zero for a uniform or contracting reach and equal to 0.5 for an expanding reach.

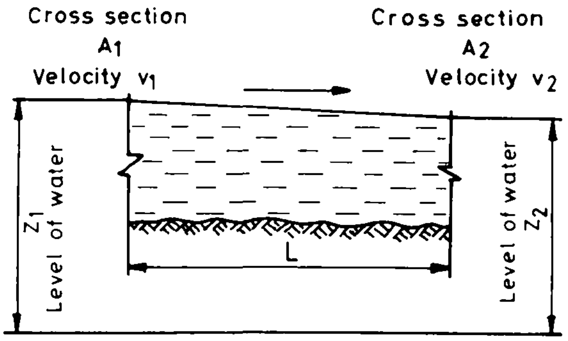

Figure E.1. Definition sketch of a slope-area reach.

Values of Manning's Coefficient

Often a reasonable value of the roughness coefficient can be extrapolated from discharge measurements taken by more accurate methods at lower stages, as for example by the current-meter method, the values so obtained may be used provided there are no changes in the channel characteristics at the higher stages. The accuracy of this extrapolated coefficient decreases as the difference between the stage of interest and the highest of the lower stages increases.

In the absence of measured data, the values given in Table E.1 may be used as a guide for alluvial channels with fine bed material and in the case of channels having vegetation, rocky banks, etc. The values given in Table E.2 may be assumed for channels with relatively coarse bed material and not characterized by bed formations.

The data given for the coefficients in the tables should be used *only as a guide*, as appreciable errors will be introduced when R is small and the size of the bed material is large.

Computation of Discharge

The discharge shall be calculated by multiplying the mean velocity by the mean area of the cross sections in the measuring reach.

In case the cross-sectional area of the stream is not uniform in the reach, the use of average values for the area A, wetted perimeter P, and hydraulic mean depth R will not yield correct results. In such cases, the conveyance factor for each cross section is evaluated and then the geometric mean of the conveyance factors of the cross sections gives the mean conveyance factor for the measuring reach. The conveyance factor K of a cross section is given by the equation

$$K = \frac{A\,R^{2/3}}{n} \tag{E.5}$$

Thus, the Manning discharge equation in terms of the mean conveyance for the channel is

$$Q = \sqrt{K_1 K_2 S} \tag{E.6}$$

where S is as previously defined.

In the case of a composite cross section, the values of the roughness coefficient over different portions of the section are likely to vary. The section shall be split into relatively homogeneous segments and the velocities and discharges for each segment calculated separately and added up.

Accuracy

The accuracy of the measurement depends on the correct determination of the slope and of the coefficient of roughness. The coefficient is likely to change with varying stages of flow. If no experimental determination has been made, considerable experience is necessary in choosing the correct value of the roughness coefficient to be assumed.

An error will also be introduced if the areas of the cross sections of the measuring reach are not approximately equal.

Table E.1. Manning's roughness coefficient for channels other than those with coarse bed material [9].

Type of channel and description	Manning's coefficient *n*
A. Excavated or dredged	
a) Earth, straight and uniform	
1 Clean, recently completed	0.016 to 0.020
2 Clean, after weathering	0.018 to 0.025
3 With short grass, few weeds	0.022 to 0.033
b) Rock cuts	
1 Smooth and uniform	0.025 to 0.040
2 Jagged and irregular	0.035 to 0.050
B. Natural streams	
B. 1 *Minor streams*	
(top width at flood stage less than 30 m (100 ft))	
a) Streams on plains Clean, straight, full stage no rifts or deep pools	0.025 to 0.033
B. 2 *Flood plains*	
a) Pasture, no brush	
1 Short grass	0.025 to 0.035
2 High grass	0.030 to 0.050
b) Cultivated areas	
1 No crop	0.020 to 0.040
2 Mature row crops	0.025 to 0.045
3 Mature field crops	0.030 to 0.050
c) Brush	
1 Scattered brush, heavy weeds	0.035 to 0.070
2 Light brush and trees (without foliage)	0.035 to 0.060
3 Light brush and trees (with foliage)	0.040 to 0.080
4 Medium to dense brush (without foliage)	0.045 to 0.110
5 Medium to dense brush (with foliage)	0.070 to 0.160
d) Trees	
1 Cleared land with tree stumps, no sprouts	0.030 to 0.050
2 Same as above, but with heavy growth of sprouts	0.050 to 0.080
3 Heavy stand of timber, a few felled trees, little undergrowth, flood-stage below branches	0.080 to 0.120
4 Same as above, but with flood-stage reaching branches	0.100 to 0.120
5 Dense willows, in mid-summer	0.110 to 0.200

Table E.2. Manning's roughness coefficient for channels with relatively coarse bed material and not characterized by bed formations [9].

Type of bed material	Size of bed material mm	Manning's coefficient *n*
Gravel	4 to 8	0.019 to 0.020
	8 to 20	0.020 to 0.022
	20 to 60	0.022 to 0.027
Pebbles and shingle	60 to 110	0.027 to 0.030
	110 to 250	0.030 to 0.035

References: [9], [22].