Technical Assistance
HYDROLOGY PROJECT

DHV CONSULTANTS & DELFT HYDRAULICS with HALCROW, TAHAL, CES, ORG & JPS

VOLUME 4
HYDROMETRY

FIELD MANUAL - PART IV

CURRENT METER GAUGING

Table of Contents

GENERAL

The Field Manual on Hydrometry, comprises the procedures to be carried out to ensure proper execution of design of the hydrometric network, and operation and maintenance of water level and streamflow gauging stations. The operational procedures are tuned to the task descriptions prepared for each Hydrological Information System (HIS) function. The task description for each HIS-function is presented in Volume 1 of the Field Manual.

It is essential, that the procedures, described in the Manual, are closely followed to create uniformity in the field operations, which is the first step to arrive at comparable hydrological data of high quality. Further, reference is made to the other volumes of the manual where hydro-meteorology, sediment transport measurements and water quality sampling and analysis is described. It is stressed that hydrometry cannot be seen in isolation; in the HIS integration of networks and of activities is a must.

This Volume of the Field Manual consists of 8 parts:

- Part I deals with the steps to be taken for network design and optimisation. Furthermore, site selection procedures are included, tuned to the suitability of a site for specific measurement procedures.
- Part II comprises operation of water level gauging stations equipped with staff gauges, autographic chart recorders or digital water level recorders.
- Part III comprises the preparatory activities and execution of float measurements, including selection of float type, reach preparation, observation practice and discharge computation
- Part IV comprises the preparatory activities and execution of current meter measurements by wading, and from cableways, bridges and boats. The procedure for discharge computation is included.
- Part V deals with the field application of the Acoustic Doppler Current Profiler (ADCP). It covers operating modes and site conditions, deployment, operating set-up and measurement runs as well as the data handling and recording.
- Part VI presents the required activities for the execution of the Slope-Area Method and the procedure to be applied to arrive at a discharge.
- Part VII comprises Field Inspections and Audits, with required check lists and standard forms.
- Part VIII, finally, deals with routine maintenance of gauging stations and calibration of equipment.

The procedures as listed out in this manual are in concurrence with the ISO standards as far as available for the various techniques and applicable to the conditions in peninsular India.

1 INTRODUCTION

Current meter measuring techniques have been described in detail in Volume 4, Design Manual, Hydrometry, Chapter 6, including instrumentation and techniques for measuring and recording velocity, depth and width, and computing discharge. Whilst a wide range of techniques are available, the options at a particular site are more limited by the geometric and hydraulic characteristics of the channel and by the facilities and instruments available at the site. Nevertheless the observer is required to make a judgement of the method to apply at a particular time and flow, at a particular site. Selection must be made of the method of suspension (wading, bridge cableway, boat), the location of gauging, the current meter, the number of verticals to use in the cross section and the interval and the number of points in the vertical. The circumstances of the gauging are then recorded as header information for the gauging on a standard gauging form before proceeding with the gauging.

This part of the Field Manual includes:

1. Method of suspension
2. Selection of site
3. Selection of current meter/accessories
4. Selection of vertical interval and number
5. Selection of number of points in the vertical
6. Preliminary gauging notes
7. Current meter measurement

- General
- By Wading
- From cableway
- From bridges
- From boats
- Special conditions

8. Computation of discharge

2 METHOD OF SUSPENSION

In high flows a single method of suspension is usually available at a site (cableway, bridge or boat). At low flows the option may be available to use one of these methods or wading gauging. Current meter measurements by wading are preferred if conditions permit. Wading measurements with the current meter supported on a graduated wading rod which rests on the bed of the stream are normally more accurate than those from cableways and bridges as the operator has more control over the general gauging procedure. This is particularly the case in the selection of cross section, which may not be the usual measuring section, and in the selection of verticals and measurement of depth.

However, the hydrometric supervisor should ensure that conditions are safe for wading gauging. Code for safe practice in stream gauging, notes that conditions approach the limit for safe wading measurement when the surface velocity exceeds 1 m/sec and the water exceeds mid-thigh depth. Under such conditions the gauging observer should wear a line attached to a secure anchorage or held by a team member on the bank. Special precautions need to be taken when the water is too turbid for the bed to be clearly visible or when the bed material is soft and unstable.

3 SELECTION OF SITE

Site selection is covered in detail in Volume 4, Design Manual, Hydrometry, Chapter 4. However, even once a site location has been fixed, some deployment methods might allow some local flexibility.

The site is fixed for **cableway** gauging.

For **bridge** gauging, the option may be available of using the upstream or downstream side. The downstream side is more frequently used but this is not invariably the best side. The advantages of using the upstream side are:

- Hydraulic characteristics at the upstream side of the bridge openings are often more favourable
- Approaching floating drift can be seen with less difficulty
- The stream bed at the upstream side of the bridge is not likely to scour as badly as at the downstream side but there may be afflux if the bridge waterway is tight.

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

- Vertical angles are more easily measured because the sounding line will move away from the bridge
- The flow lines of the river may be straightened out by passing through a bridge opening with piers
- The downstream side is less likely to be affected by accumulation of debris against piers

For **wading** gauging there is greater choice for the gauging section. The best wading measurement section should be chosen with respect to flow conditions on the day of discharge measurement. It may differ from one measurement to the next and in particular there is no necessity for wading gauging to be done at the cableway section which may be unsuitable in low flows. The location may be several hundred metres upstream or downstream from the staff gauges as long as there is no inflow or outflow in the intervening reach. The following characteristics are ideal

- A straight reach with the threads of velocity parallel to each other
- Stable river bed free of large rocks and protruding obstructions which would create turbulence
- A flat bed profile to eliminate vertical components of velocity

It is usually not possible to satisfy all these conditions but the best available site can be modified to provide acceptable conditions. Often it is possible to build dikes to cut off dead water and shallow flows in a cross section or to improve the cross section by removing rocks and debris within the section and from the reach of river immediately upstream from it. After modifying a cross section, allow the flow to stabilise before starting the discharge measurement.

The cross section used for **boat** measurement is usually fixed by the cableway when the boat/cableway system is in use, or by the position of bank side markers which are used for positioning the boat in the cross section.

4 SELECTION OF CURRENT METER/ACCESSORIES

A limited number of current meters (often 2) are available for gauging at a particular station, usually a standard larger diameter (100 to 125 mm diameter) and a smaller diameter Pygmy meter. The larger diameter meter will be used for bridge, cableway and boat measurement but for wading gauging the meter chosen will depend on the depth of flow.

The selected current meter should normally be used in water less than four times the diameter of the impeller because the registration of the meter is affected by its proximity to the water surface and the bed. Thus a standard 100 mm diameter meter should not normally be used when the depth of water across the section is less than 0.4 metres. In addition, ISO 748 recommends that the horizontal axis of the current meter is situated at a distance not less than one and a half times the rotor height from the water surface or three times the rotor height from the bed. In particular no part of the meter should break the surface of the water. Where only a small number of verticals (< 4) exist on the river margins with a depth less than 0.4 m, it is usually not profitable to change to a smaller meter.

The miniature (Pygmy) meter is best suited for gauging in depths of less than 0.5 metres when the expected velocity is less than the meter's maximum calibration velocity (usually about 1 m/sec).

In general meters should be selected which will operate within their calibration range, and particular consideration should be given to performance and the minimum speed of response in rivers with very low velocities.

If a river is too deep or too rapid to wade, the current meter is suspended from a boat, bridge or cableway. A sounding weight is suspended below the current meter to keep it stationary in the water. The weight also prevents damage to the meter when the assembly is lowered to the bed provided the instrument is handled carefully and the bed can be detected. The size of the sounding weight used in current meter measurements depends on the depth and velocity in the cross section. As a rule of thumb the size of the weight in kg should be greater than 5 times the product of velocity (m/sec) and depth (metres).

5 SELECTION OF VERTICAL INTERVAL AND NUMBER

For rivers greater than 10 m wide it is recommended, in line with ISO 748 and other practice, that at least 20 verticals be used and that the discharge in any one segment does not exceed 10% of the total. Between 20 and 30 verticals will normally be used. Uncertainties in streamflow measurement are expressed as percentages. The percentage uncertainty of using say 25 verticals is of the same order for all widths of river, irrespective of the width of segments.

For small rivers less than 10 metres in width the following selection criteria are recommended:

Channel width w (m)	Number of verticals
$0 < w < 0.5$	3 to 4
$0.5 \leq w < 1$	4 to 5
$1 \leq w < 3$	5 to 8
$3 \leq w < 5$	8 to 10
$5 \leq w < 5$	10 to 20
$w \geq 10$	20

Notes:

1. Two additional verticals not included in the above are required close to each of the two water's edges (banks).
2. In all instances depths and velocities made at the waters edge are additional to above.
3. The difference in water depth between two adjacent verticals should not exceed 50% of the smaller.
4. The difference in velocity between non-zero samples taken at the same proportion of depth in adjacent verticals shall not exceed 50% of the smaller.

Generally such standards should be considered as minimum requirement, rather than an upper limit.

Special care has to be taken when selecting the number or verticals used when bridge gauging. For some types of bridges under certain flow conditions the current meter will be by necessity deployed between the bridge piers i.e. the position of the bridge piers relative to the current meter can be such that each bridge span or arch acts effectively as a separate channel. Some bridges have a large number of spans and in many cases this could result in only one velocity measurement being taken between each span. To treat each bridge span as a separate channel requiring upwards of 10 verticals would at most sites be too time consuming. Therefore, as a compromise it is recommended that 5 verticals should be taken between each bridge span including one at each edge. If this not possible than an absolute minimum of 3 should be taken i.e. one at each edge and one in the middle. If the location of the current meter is such that it is located upstream or downstream of the bridge piers e.g. where the bridge deck is cantilevered, then the number of verticals can be selected as per the guidance given above.

After a sufficiently long period of time covering the full range of flow conditions it could be demonstrated that it might be possible to reduce the number of verticals used at a gauging site without significantly reducing the accuracy. This should only be done on the basis of an analysis of the available gauging data. This might be particularly useful in situations where the stage is changing rapidly and time availability in which to complete the gauging is short.

6 SELECTION OF NUMBER OF POINTS IN THE VERTICAL

Current meters measure the velocity of water at a point. The measurement of discharge in open channels requires the determination of mean velocity for each sampling vertical across the measuring section. A number of methods are in use to define the mean velocity in a vertical and the choice of method will depend on the time available, the accuracy required, the width, depth and bed conditions of the river and the rate of change of stage. Methods are usually defined by the number of measurements taken in each vertical and are described in detail in Chapter 6 of Volume 4, Design Manual, Hydrometry.

If the velocity distribution in a vertical is close to the regular classical form then it can be assumed that the mean velocity occurs at 0.6 of the depth (D) from the surface i.e. 0.6D. The one (0.6D) and two point (0.2D & 0.8D) methods are adequate for most routine fieldwork. The former is used for depths less than 1.0 m and the latter for depths greater than a 1.0m, but for the latter also the 0.6D method may be used.

In some cases it is only possible to use the surface velocity method in which case the surface velocity is multiplied to a coefficient similar to that for a surface water float, say 0.85. Such coefficients should be confirmed by estimating the mean velocity by another method.

An alternative to 0.6D is to position the current meter at 0.5D and multiply the resulting velocity by 0.95 to obtain the mean in the vertical. This method is particularly good if the observer has difficulty working out 0.6D as it is easier to half something than multiply by 0.6. In addition it avoids the confusion that sometimes occurs with inexperienced operators whether they should measure 0.6D from the surface or from the bed of the river.

Note: It is 0.6D from the surface or 0.4D from the riverbed. It is also interesting to note that recent research has shown that the uncertainties in the mean velocities based on the 0.5D method are slightly less than those obtained using the 0.6D method.

At important and/or difficult sites it is recommended that in the first instance the two point or even one of the other methods involving more points is used. If it can be demonstrated that the velocity distributions follow the classical form then it would be possible to revert to the 0.6D, or possible even the 0.5D method.

NOTE: In terms of reducing the overall uncertainty in the discharge measurement it is better to use more verticals than trying to measure more points in the vertical.

7 PRELIMINARY GAUGING NOTES

After the cross section has been selected and gauging equipment assembled for current meter measurement, notes concerning the circumstances of the gauging are prepared before proceeding with the observation. For each discharge measurement the following information is recorded on a standard discharge measurement form (Figure 1)

1. The name of the river, the station and code number
2. The mode of observation or suspension - by wading, boat, cableway or bridge
3. The location of the discharge measurement site - whether at the standard section or at an alternative section, the distance upstream or downstream from the reference staff gauges in the case of wading gauging, and whether upstream or downstream from the bridge in the case of bridge gauging.
4. The meter Make and model reference and the serial number of the meter body and impeller (if used).
5. The date of the most recent meter calibration, the rating number and the rated spin.
6. The outcome of the spin test on site. Note that the test should be carried out by blowing on the gauge rather than by rotating with the finger as this can damage the bearings
7. Sounding weight used (if any)
8. The names of personnel carrying out the gauging.
9. Weather conditions including wind speed and direction (whether upstream or downstream)
10. Other pertinent information affecting the control conditions or which might be expected to affect the stage-discharge relation including:

- scouring and lowering of the river bed level either at the gauges or at the control site
- construction of bunds downstream to raise water level for abstraction or diversion
- extraction of sand or gravel from the river channel
- blockage or partial blockage of the channel by floating or other debris in flood
- significant weed growth in the channel or on the weir and its subsequent removal.
- damage or possible changes to the level of the reference staff gauge.

11. The date and time of commencement of gauging and concurrent gauge heights, including supplementary gauges where they exist.
12. Identify the stream bank, LB or RB (left bank or right bank respectively) when facing downstream, at which the gauging commences.

The gauging is now ready to begin. General practice is described first; particular matters relating to wading, cableway, bridge and boat gauging follow.

8 CURRENT METER MEASUREMENT

8.1 GENERAL

A simplified form (Figure 2) is used for standard gaugings, including all wading gaugings, where complication of cable drag (wet and dry line corrections), boat drift or flow oblique to the channel do not arise. A more comprehensive form (Figure 3) is used for these conditions.

Set up the gauging section for width measurement and vertical selection. Indicate on the note sheet, the distance of the initial measurement point to the water’s edge and record the depth at the water’s edge

Compute the setting of the meter for the particular method to be used at that depth. Record the meter position (as 0.2, 0.6, 0.8.....). After the meter is placed at the proper depth, permit it to become adjusted to the current before starting the velocity observation. The time required for such adjustment is usually only a few seconds if the velocities are more than 0.3 m/sec, but for lower velocities, particularly if the current meter is suspended by a cable, a longer period of adjustment is needed.

The exposure time to be selected will be dependent on the physical characteristics of the river channel being monitored. However, it is important that the time selected is sufficient to minimise errors due to pulsations Conversely if the discharge is changing rapidly the time selected should not be too long.

Generally for most Indian applications it is recommended that **an exposure time of 60 seconds** be adopted. If the velocities are very low and there are less than 20 counts in fifty seconds the exposure time should be increased to 100 seconds. Alternatively the time it takes to record 20 revolutions should be measured. In situations where the stage is varying rapidly it is possible that the exposure time could be reduced to 30 seconds.

If an electro-mechanical counter is used with headphones, count the number of revolutions for the specified period. Start the stopwatch simultaneously with the first signal or click, counting “zero” not “one”. End the count on 60 seconds or at a convenient round number of clicks depending on the type of rating table available and record the number of revolutions and the time interval precisely.

Where electronic counters with built in timer are available, set the pre-selection switch to 60 secs (or other duration as required) and switch on. The counter will automatically stop at 60 secs and display the number of revolutions. Record time and revolutions.

It is not generally necessary to repeat an observation count at a particular vertical and setting.

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

Details specific to particular modes of suspension are described in the following sections.

..............................STATE SURFACE WATER SECTOR

DISCHARGE MEASUREMENT NOTES

Basin .... River .... Site.............................. Code No .... Date ....
Method of Observation/Suspension ...Wading / Cableway / Bridge / Boat ....
Location of Measurement Site ..Standard / Alternative .... Upstream / Downstream ......metres from Reference Staff Gauge
Meter Make and Number.................................Meter Serial No. ....Impeller Serial No. ....
Rating Equation No.......................... Date of Last Rating .... Rated Spin...............secs
Actual Spin before measurement................................secs Actual spin after measurement ....secs
Sounding weight used .... Weight .... Kg
Observation made by ....
Weather Conditions ....
Condition of Water ....Fairly clear / Ordinarily Silty / Intensely Silty
Wind ...Very slight / Slight / Strong / Very Strong Direction ...Upstream / Downstream / Cross
Changes in Control - Describe (Scouring, deposition, bunding, debris, weed etc.) ....
....
....
....
Character of River bed ....
....

GAUGE READINGS

Time	Ref. Staff gauge		Panel Flow	S. G. x Flow		U/s Gauge	D/s Gauge	Recorder
		Start						
		Finish						

Total .... Distance U/s to Ref Gauge ....

Weighted mean gauge height = ☐ Distance Ref. to d/s Gauge ....

Zero R L (GTS)... m

Gauging Results

Width .... Area .... Mean Velocity .... Mean Gauge height. .... Discharge ....

Number of vertical .... Gauge height change .... Surface water slope ....

Gauging No. ....

Figure 1: Discharge measurement notes - summary form

..............................STATE SURFACE WATER SECTOR

DISCHARGE MEASUREMENT NOTES

Basin .... River .... Site.......................... Code No .... Date ....

No	Distance from initial point	Width	Depth	Proport - ion of depth	Revol- utions	Time in secs	Vel. at point	Vel. in vertical	Area	Dis- charge

Total

Gauging No .... Page ....

Figure 2 Discharge measurement - standard form

..............................STATE SURFACE WATER SECTOR

DISCHARGE MEASUREMENT NOTES

Basin .... River .... Site.......................... Code No .... Date ....

No	Dist. from initial point	Width	Vert. Angle	Air line Cqn.	Wet line Cqn.	Total Cqn.	Correct Depth	Pro-portion of Depth	Time in secs	Revs.	Vel. at point	Vel. in vertical	Ob-lique Angle	Cor-rected Mean Vel. 1	Drift (m)	Drift Vel cqn.	Corrected Mean Vel. 2	Area	Discharge

Total | | |

Gauging No. .... Page ....

Figure 3: Discharge measurement notes - extended form

8.2 CURRENT METER MEASUREMENTS BY WADING

A measuring tape or tag line is stretched across the river at right angles to the direction of flow. The positions of successive verticals used for depth and velocity are located by horizontal measurements from a reference marker (initial point) on the bank usually defined by a pin or a monument.

The position of the operator is important to ensure that the operator’s body does not affect the flow pattern at or approaching the current meter. The best position is to stand facing one or other of the banks, slightly downstream from the meter and at arm’s length from it. The rod is kept vertical throughout the measurement and the meter parallel to the direction of flow. In very narrow channels, avoid standing in the water if feet and legs would occupy a considerable percentage of the cross section; stand on a plank or other support rather than in the water if conditions permit.

Wading rods are usually marked in centimetres and measurements made to the nearest 5 mm.

8.3 CURRENT METER MEASUREMENT FROM CABLEWAYS

Cableways are normally used when the depth of flow is too deep for wading, when wading in a swift current is considered dangerous or when the measuring section is too wide to string a tag line or tape across it.

Cableways and associated equipment assemblies are described in Volume 4, Design Manual, Hydrometry, Chapter 8 and in the Reference Manual.

The operating procedure depends on the type of cableway, whether it is an unmanned instrument carriage controlled from the bank by means of a winch, or a manned personnel carriage or cablecar which travels across the river to make the observations.

In the case of the unmanned cableway, the operator on the bank is able to move the current meter and sounding weight and to place the current meter at the desired point in the river by means of distance and depth counters on the winch. The electrical pulses from the current meter are returned through a coaxial suspension cable and registered on a revolution counter.

The manned cableway is provided with a support for a gauging reel, a guide pulley for the suspension cable and a protractor for reading the vertical angle of the suspension cable. The procedure is as follows:

1. Identify and record the waters edge (RB or LB) in relation to a permanent initial point on the bank by means of a tag line or by the use of painted marks on the track cable, used for spacing the observation verticals.

2. Lower the current meter at the first vertical until the bottom of the weight just touches the water surface and set the depth counter to zero.

3. Lower the current meter assembly until the weight touches the bed; read the counter and record as depth (assuming no correction is required for drag).

4. Raise the meter back to the surface and place the meter axis at the water surface (not the sounding weight) and zero the depth counter again. Calculate 0.6D etc. and lower the meter to the required position. Note that this is conceptually the simplest method of setting the meter; alternatives are described in Chapter 6 of Volume 4, Design Manual, Hydrometry, which do not require the meter to be returned to the surface.

5. When the river is swift and deep and the suspension cable suffers drag, measure the angle that the meter suspension makes with the vertical using a protractor, as a basis for correcting the soundings to obtain the correct vertical depth

6. Measure the velocity at the selected depths in the vertical

7. If there is weed or floating debris in the river, raise the current meter occasionally for inspection and cleaning. This must always be done if the revolution counter registers a sudden drop in velocity.

8. A close watch is required on the upstream channel for floating debris which may snag on or damage the meter. In extreme conditions where the river is carrying large floating and submerged debris in high velocities, it is advisable for one member of the party to stand by with wire cutters to cut the suspension cable in the event that a tree trunk is caught on the meter assembly, and the drag is endangering the cableway and the lives of personnel.

8.4 CURRENT METER GAUGING FROM BRIDGES

When a river cannot be waded, suitable bridges may be used for current meter measurement and intervals on the chosen side (upstream or downstream) marked in advance at a small enough interval to allow sufficient vertical to be taken when the width of flow is at a minimum.

Low footbridges can sometimes be used on a small stream with rod suspension with extension rods. The procedure in low velocities is the same as for a wading measurement but the procedure for obtaining the depth in higher velocities should be modified to eliminate errors caused by the water piling up on the upstream face of the rod as follows:

- For each selected vertical, a point is established on the bridge
- The distance from this point to the water surface is measured by lowering the rod until the base plate just touches the water.
- The rod is then lowered to the bed and the reading again noted at the index point. The difference in these readings is the depth of water in the vertical.

For road bridges care must be taken to ensure that road traffic does not endanger the gauging team or other road users. Particular precaution must be taken on narrow bridges without pedestrian walkways. Warning signs should be set up at appropriate distances on both approaches and the area of working clearly delimited by marker cones. Additional precautions should be taken when the section is subject to the passage of river traffic, with one team member stationed as a lookout to give warning of approaching craft with sufficient time to reel in the suspended equipment.

For higher bridges and for greater depths, the current meter and weight are suspended on a cable controlled by a gauging reel mounted on a bridge derrick. A hand line may sometimes be used with smaller sounding weights (up to 20 kg). The procedure to be followed using a bridge outfit is generally as described for cableway gauging above. The effect of drag angle on the measured depth and the positioning of the current meter must be taken into consideration as must also the effects of oblique flow where the bridge is not normal to the direction of flow.

Girder bridges often have vertical or diagonal members, which require that the current meter assembly carried by a bridge crane must be withdrawn to bypass each interfering member. The handline in contrast can be disconnected from the counter and passed round a bridge member with the sounding weight on the bottom. In such cases and where velocities and depths are sufficiently low, a handline is often more convenient to use although it requires more physical exertion. The handline consists of two separate cables, a rubber-covered coaxial cable and a sounding cable, electrically connected at a small reel. To measure depth using the handline, the meter is first set at the water surface and then the sounding weight is lowered to the bed. The amount of cable let out is measured with a steel tape or graduated rod along the rubber service cord. The depth is the sum of this value and the distance from the meter to the bottom of the sounding weight. When the meter is set for velocity observation the rubber cable may be tied to a hand rail to hold it in place.

8.5 CURRENT METER GAUGING FROM BOATS

Discharge measurements are made from boats where no gauging cableways or suitable bridges are available and the river is too deep to wade. The boat is held in place in the measuring section either by fixing to a cable strung across the river (the boat/cableway method) or by using an adequately powered boat.

If the maximum depth in the section is less than 3 metres and the velocity is low, rods can be used for measuring the depth and supporting the current meter. Otherwise cable suspension with a reel and sounding weight is used as for bridge and cableway measurement.

Position in the cross section may be fixed by using markers on the supporting cableway, by tag line from the shore, or by the use of a variety of surveying methods based on bankside flags (Chapter 6 of Volume 4, Design Manual, Hydrometry). For a particular station, the precise method of observation should be established in advance.

When a boat powered by a motor is used, it is often difficult to maintain it exactly on the transit line throughout the measurement of velocity. A practical solution is to drive the boat forward very slowly and measurements are commenced as it crosses the transit line. It is then allowed to drift slowly astern and again moved forward to cross the transit line. On the second crossing of the transit line, moving in the same direction, the observer stops recording the velocity. Providing the movement of the vessel is not excessive and is slow, the error is negligible. Alternatively, where the position of the boat can be established with precision at the beginning and end of the velocity measurement, a correction to the observed velocity can be made. CWC sometimes apply the following formula

$$V_p = 0.064 + 0.98V_0 + 0.98V_d$$

where: V_p = True velocity in m/sec
V_0 = Observed velocity with the boat drifting, and
V_d = Drift velocity in m/sec (Drift in metres / Meter exposure time)

Provision has been made on the comprehensive current meter observation form (Figure 2) for the assessment of drift and corrected velocity.

Personal safety is an important consideration in boat gauging, and velocity of flow in relation to the power of the boat will limit the conditions under which gauging is possible. All members of the crew should wear serviceable life jackets. The crew should always include one member specifically assigned to the task of propelling, controlling and positioning the boat and that person should have no other function. No gauging should be attempted on any section less than 500 metres upstream from a weir, sluice, waterfall or rapids unless special safety measures have been provided (e.g. rescue vessel)

9 SPECIAL CONDITIONS

There are a number of conditions associated with cableway, bridge and boat gauging which require additional measurement and computation. These include cableway drag and consequent depth corrections, corrections for oblique angle of flow and the effects of rapid changes in stage during the gauging. Provision has been made for each of these in the gauging form (Figure 3) and are described in this section.

Drag (Wet line / Dry line corrections)

When measurements are made by suspending the current meter in deep swift water, it is carried downstream before the weight touches the bottom (Figure 4). The length of cable paid out is more than the true depth. In order to obtain the corrected depth, dry line and wet line corrections, which are functions of the vertical angle θ, are applied to the observed depth, where the angle θ is measured by a fixed protractor.

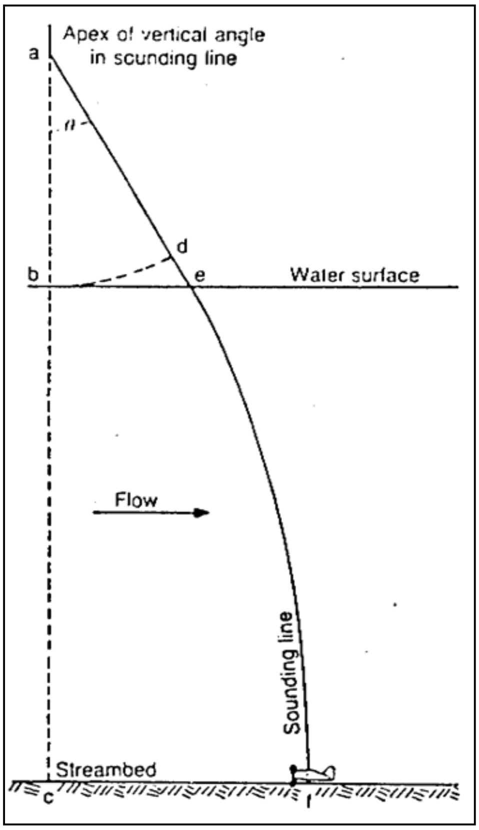

Figure 4:
Definition sketch for dry line and wet line corrections

The recommended routine procedure is as follows:

1. Measure the vertical distance from the guide pulley on the gauging reel to the water surface using the reel counter. This is (ab) the “air line”.
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 weight to the bed. Read the sounded depth (df) and the vertical angle θ of the cable on the protractor.
4. The air line correction (de) for given angle θ (to 36°) and air line is shown in Table 1
5. Calculate the wet line length as (sounded depth - air line correction) (ef = df - de)
6. The wet line correction for given angle θ and wet line length to 35° is shown in Table 2.
7. Add air and wet line corrections and subtract from the sounded depth to give the true depth (bc).

Oblique angle of flow

It is not always possible to select a measurement section which is at right angles to the direction of flow, especially in the case of bridge measurement. In other cases, flow across part of the section may approach it at an oblique angle. It is necessary to obtain the component of velocity normal to the cross section.

Propeller type meters on rod, held firmly at right angles to the cross section will measure the component velocity in such oblique flows and do not need correction. However, cup-type meters and propeller meters on cable suspension align themselves directly into the current and require correction by multiplying the measured velocity by the cosine of the angle between the current direction and the normal direction. With a simple protractor on the Current Meter Measurement Note Sheet, the cosine of the angle can be read directly (Figure 5).

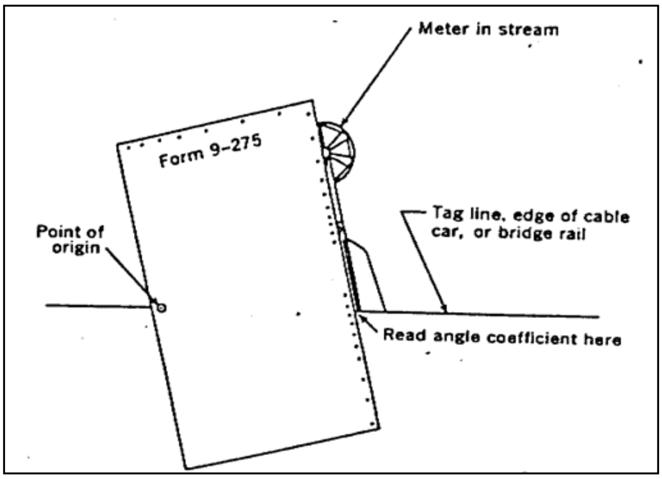

Figure 5:
Using the protractor on the gauging form to determine oblique angle of flow

Multiply the measured velocity by the cosine of the angle to determine the velocity component normal to the measuring section.

Rapidly changing stage - assessment of mean gauge height

The mean gauge height corresponding to the measured discharge is used in plotting the stage-discharge relationship or rating curve for gauging stations. An accurate determination of the gauge height is therefore as important as the accurate measurement of discharge. Where the change in gauge height during a measurement is less than 0.05 m, the arithmetic mean of the gauge heights at the start and end of the measurement can usually be taken as the mean gauge height. However if the gauge height changes rapidly and irregularly, the mean is obtained by weighting the gauge height readings taken during the gauging by the corresponding measured segment discharges that they represent. Provision for the calculation is made on the standard discharge measurement form (Figure 2). The equation used is:

$h = (q_1h_1 + q_2h_2 + q_3h_3 + \ldots\ldots q_nh_n) / Q$

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 interval 1, 2, ...
Q = total discharge measured.

The observer must read the gauge before and after the measurement and at intervals during the gauging. Where a digital stage record is available, stage values from this source can be used. These values are entered to the “Gauge Readings” table on the form with the time of measurement. For each gauge reading, a corresponding panel flow is entered, which is the sum of the flow in segments at and near the time of the gauge reading (from the discharge computation). The sum of these panel discharges should equal the total discharge as previously calculated. In the next column, the product of gauge height and panel discharge is entered. These are summed and divided by the total discharge to give the weighted mean gauge height.

Rapidly changing stage - quick method

Sometimes water level changes so rapidly, especially during rising flood conditions, that it is difficult to assign a mean gauge height to the gauging if the normal number of intervals and exposure time is adopted. In these circumstances it is legitimate to simplify the gauging such that it can be completed in less than 30 minutes, The following simplifications may be made, either singly or in combination.

- Reduce the number of vertical taken to about 15 to 18
- Reduce the velocity observation time to about 30 secs.
- Use measurement only at 0.2 depth and multiply the measured velocities by 0.87 (or an alternative value based on a previous full gauging at the site) to obtain mean velocity in the vertical
- Use a pre-surveyed cross section to assess depth at each vertical from the gauge height observed at each measurement vertical and hence to set the meter at the measurement depth without sounding.

10 COMPUTATION OF DISCHARGE

The first computation of discharge should normally be carried out at the station by the gauging team. The mid-section method is adopted as standard practice and has been incorporated in the Discharge Measurement Form. Having completed the measurements in the cross section, discharge requires only the following computations.

1. **Segment Width** Since the mid-section method assumes that the velocity sampled at each vertical represents a mean velocity in a segment, the segment width (and area) extends from half the distance from the preceding vertical to half the distance to the next. In the case of the two end panels adjacent to the bank (or bridge pier) the segment width is half the distance to the first observation vertical.

2. **Segment Velocity** at a point is read from the appropriate current meter rating table for given revolutions and time. Corrections as required are made for skewed flow and drift. For measurements at 0.6d only, the vertical and segment velocity are the same as the point velocity. For 2-point measurement at 0.2 and 0.8 the segment velocity is the mean of the two velocities. In the case of end panels the segment velocity is taken as zero if the bank is shelving. However, when the cross section boundary is vertical at the edge (e.g. bridge abutments and piers), the segment velocity may not be zero and it is usually necessary to estimate the velocity at the end segments as a percentage of the velocity on the adjacent vertical because it may not be possible to place the current meter close to the boundary.

3. **Segment Area** Segment area is simply the product of segment width and depth.

4. **Segment Discharge** Segment discharge is the product of segment area and velocity. In algebraic terms this is as follows:

$$Q = \Sigma\, q_i = \Sigma\, \bar{v}_i a_i = \Sigma\, \bar{v}_i\, d_i\, (b_{i+1} - b_{i-1}) / 2$$

where q_i = discharge through segment i
v = mean velocity in vertical i
b_{i+1}, b_{i-1} = distances from an initial point on the bank to verticals i +1 and i - 1
d_i = depth of flow at vertical I

Table 1: Air-line correction table

Vertical length in metres	*Vertical angle of sounding line at protractor (degrees)*																											
	5	*8*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*	*25*	*26*	*27*	*28*	*29*	*30*	*31*	*32*	*33*	*34*	*35*
1	0.00	0.01	0.02	0.02	0.02	0.03	0.03	0.04	0.04	0.05	0.05	0.06	0.06	0.07	0.08	0.09	0.09	0.10	0.11	0.12	0.13	0.14	0.16	0.17	0.18	0.19	0.21	0.22
2	0.01	0.02	0.03	0.04	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.13	0.14	0.16	0.17	0.19	0.21	0.22	0.24	0.26	0.29	0.31	0.33	0.36	0.38	0.41	0.44
3	0.01	0.03	0.04	0.05	0.07	0.08	0.09	0.10	0.12	0.14	0.16	0.17	0.19	0.21	0.24	0.26	0.28	0.31	0.34	0.37	0.40	0.43	0.46	0.50	0.54	0.58	0.62	0.66
4	0.02	0.04	0.06	0.07	0.09	0.11	0.12	0.14	0.16	0.18	0.21	0.23	0.26	0.28	0.32	0.34	0.38	0.42	0.45	0.49	0.53	0.57	0.62	0.67	0.72	0.77	0.82	0.88
5	0.02	0.05	0.08	0.09	0.11	0.14	0.16	0.18	0.20	0.23	0.26	0.29	0.32	0.35	0.40	0.43	0.47	0.52	0.56	0.61	0.66	0.72	0.78	0.84	0.90	0.96	1.03	1.10
6	0.00	0.05	0.10	0.10	0.15	0.15	0.20	0.20	0.25	0.30	0.30	0.35	0.40	0.45	0.45	0.50	0.55	0.60	0.65	0.75	0.80	0.85	0.95	1.00	1.05	1.15	1.25	1.35
7	0.05	0.05	0.10	0.15	0.15	0.20	0.20	0.25	0.30	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.75	0.80	0.85	0.90	1.00	1.10	1.15	1.25	1.35	1.45	1.55
8	0.05	0.10	0.10	0.15	0.20	0.20	0.25	0.30	0.35	0.35	0.40	0.45	0.50	0.55	0.65	0.70	0.75	0.85	0.90	1.00	1.05	1.15	1.25	1.35	1.45	1.55	1.65	1.75
9	0.05	0.10	0.15	0.15	0.20	0.25	0.30	0.30	0.35	0.40	0.45	0.50	0.60	0.65	0.70	0.75	0.85	0.95	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.75	1.85	2.00
10	0.05	0.10	0.15	0.20	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.65	0.70	0.80	0.85	0.95	1.05	1.10	1.20	1.30	1.45	1.55	1.65	1.80	1.90	2.05	2.20
11	0.0	0.1	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.9	1.0	1.0	1.1	1.2	1.3	1.4	1.6	1.7	1.8	2.0	2.1	2.3	2.4
12	0.0	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.8	1.0	1.0	1.1	1.2	1.3	1.5	1.6	1.7	1.9	2.0	2.2	2.3	2.5	2.6
13	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.7	0.9	0.9	1.0	1.1	1.2	1.4	1.5	1.6	1.7	1.9	2.0	2.2	2.3	2.5	2.7	2.9
14	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.5	1.6	1.7	1.8	2.0	2.2	2.3	2.5	2.7	2.9	3.1
15	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.6	1.7	1.8	2.0	2.1	2.3	2.5	2.7	2.9	3.1	3.3
16	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.7	0.7	0.8	0.9	1.0	1.1	1.3	1.4	1.5	1.7	1.8	2.0	2.1	2.3	2.5	2.7	2.3	3.1	3.3	3.5
17	0.1	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.5	1.6	1.8	1.9	2.1	2.2	2.4	2.6	2.8	3.0	3.3	3.5	3.8
18	0.1	0.2	0.3	0.3	0.4	0.5	0.6	0.6	0.7	0.8	0.9	1.0	1.2	1.3	1.4	1.5	1.7	1.9	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.5	3.7	4.0
19	0.1	0.2	0.3	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.4	1.5	1.6	1.8	2.0	2.1	2.3	2.5	2.7	2.9	3.2	3.4	3.6	3.9	4.2
20	0.1	0.2	0.3	0.4	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.3	1.4	1.6	1.7	1.9	2.1	2.2	2.4	2.6	2.9	3.1	3.3	3.6	3.8	4.1	4.4

Table 2: Wet-line correction table

Wet-line length, in metres	*Vertical angle of sounding line at protractor (degress)*																									
	10	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*	*25*	*26*	*27*	*28*	*29*	*30*	*31*	*32*	*33*	*34*	*35*
1	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.05	0.05	0.06	0.06	0.07	0.07	0.08	0.08	0.09	0.10	0.10	0.11	0.12	0.12
2	0.02	0.02	0.03	0.03	0.04	0.04	0.05	0.05	0.06	0.06	0.07	0.08	0.08	0.09	0.09	0.10	0.11	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.19
3	0.03	0.04	0.04	0.05	0.05	0.06	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.13	0.14	0.15	0.16	0.18	0.19	0.20	0.21	0.23	0.24	0.26	0.27
4	0.03	0.04	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.13	0.14	0.16	0.17	0.18	0.19	0.21	0.22	0.24	0.25	0.27	0.28	0.30	0.32	0.34
5	0.04	0.05	0.06	0.06	0.07	0.08	0.09	0.10	0.11	0.13	0.14	0.15	0.17	0.18	0.20	0.22	0.24	0.26	0.27	0.29	0.31	0.33	0.35	0.38	0.40	0.42
6	0.05	0.05	0.05	0.05	0.10	0.10	0.10	0.10	0.15	0.15	0.15	0.15	0.20	0.20	0.25	0.25	0.25	0.30	0.30	0.35	0.35	0.40	0.40	0.45	0.45	0.50
7	0.05	0.05	0.05	0.10	0.10	0.10	0.10	0.15	0.15	0.15	0.20	0.20	0.25	0.25	0.25	0.30	0.30	0.35	0.35	0.40	0.40	0.45	0.50	0.50	0.55	0.55
8	0.05	0.05	0.10	0.10	0.10	0.10	0.15	0.15	0.15	0.20	0.20	0.25	0.25	0.30	0.30	0.35	0.35	0.40	0.40	0.45	0.45	0.50	0.55	0.55	0.60	0.65
9	0.05	0.10	0.10	0.10	0.10	0.15	0.15	0.20	0.20	0.20	0.25	0.25	0.30	0.30	0.35	0.35	0.40	0.45	0.45	0.50	0.55	0.55	0.60	0.65	0.70	0.70
10	0.05	0.10	0.10	0.10	0.15	0.15	0.15	0.20	0.20	0.25	0.25	0.30	0.30	0.35	0.35	0.40	0.45	0.45	0.50	0.55	0.60	0.60	0.65	0.70	0.75	0.80
11	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.5	0.5	0.6	0.6	0.6	0.7	0.7	0.8	0.8	0.9
12	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.5	0.5	0.6	0.6	0.6	0.7	0.7	0.8	0.8	0.9	0.9
13	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.9	0.9	1.0	1.0
14	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.9	0.9	1.0	1.0	1.1
15	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.5	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.9	1.0	1.0	1.1	1.2
16	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.9	0.9	1.0	1.1	1.1	1.2	1.2
17	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.9	1.0	1.0	1.1	1.2	1.2	1.3
18	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.9	1.0	1.0	1.1	1.2	1.2	1.3	1.4
19	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.9	0.9	1.0	1.1	1.2	1.2	1.3	1.4	1.5
20	0.1	0.2	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.9	1.0	1.1	1.1	1.2	1.3	1.4	1.5	1.6