
**Hydrometry — Measurement of liquid
flow in open channels — Velocity
area methods using point velocity
measurements**

*Hydrométrie — Mesurage du débit des écoulements à surface libre —
Méthodes d'exploration du champ des vitesses utilisant le mesurage
de la vitesse par point*

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 113, *Hydrometry*, Subcommittee SC 1, *Velocity area methods*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 318, *Hydrometry*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This fifth edition cancels and replaces the fourth edition (ISO 748:2007), which has been technically revised. The main changes compared with the previous edition are as follows:

- the document has been updated to take account of technological developments;
- [Clause 7](#) has been revised to reduce uncertainties in measurements;
- ISO 9196 regarding measurement under ice conditions has been incorporated.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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Hydrometry — Measurement of liquid flow in open channels — Velocity area methods using point velocity measurements

1 Scope

This document specifies methods for determining the velocity and cross-sectional area of water flowing in open channels and for calculating the discharge employing point velocity measurement devices.

It is applicable to methods using rotating-element current meters, acoustic doppler velocimeters (ADV), acoustic doppler current profiler (ADCP) stationary method, surface velocity measurement including floats and other surface velocity systems.

Although some general procedures are discussed, this document does not describe in detail how to use or deploy these systems.

NOTE For detailed procedures, refer to guidelines from instrument manufacturers and the appropriate public agencies.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 772, *Hydrometry — Vocabulary and symbols*

ISO 25377:2020, *Hydrometric uncertainty guidance (HUG)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 772 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

4 Principle of the methods of measurements

The principle depends upon determining velocity and cross-sectional area.

This is characterized as shown by [Formula \(1\)](#):

$$Q = \bar{V}A \quad (1)$$

where

Q is the flow (m³/s);

\bar{V} is the mean velocity (m/s) (averaged over the cross-section);

A is the cross-sectional area (m²).

A measuring site shall be chosen conforming to the specified requirements.

The cross-sectional area shall be measured by a method specified in this document, appropriate to the dimensions.

Velocity observations shall be made by a method specified in this document.

The discharge shall be calculated by a method specified in this document.

5 Site selection

5.1 Selection of site

The site selected should conform to the following requirements.

- a) The channel at the measuring site shall be straight and of uniform cross-section and slope in order to minimize abnormal velocity distribution. The straight length should be at least six times the width of the channel upstream, and at least three times the downstream width.
- b) Flow directions for all points on any vertical across the width shall be parallel to one another and at right angles to the measurement section.
- c) The bed and margins of the channels shall be stable and well defined at all stages of flow in order to facilitate accurate measurement of the cross-section and ensure uniformity of conditions during and between discharge measurements.
- d) The curves of the distribution of velocities shall be regular in the vertical and horizontal planes of measurement.
- e) Conditions at the section and in its vicinity shall also be such as to preclude changes taking place in the velocity distribution during the period of measurement.
- f) Sites displaying vortices, reverse flow or dead water shall be avoided.
- g) The measurement section (including approach and exit) shall be clearly visible across its width and unobstructed by trees, aquatic growth or other obstacles.
- h) When gauging from a bridge with divide piers, each section of the channel shall be measured separately. Particular care shall be taken in determining the velocity distribution when bridge apertures are surcharged or obstructed.
- i) The depth of water at the section shall be sufficient at all stages to ensure whichever device is deployed it conforms to the manufacturer's minimum criteria for use.
- j) If the site is to be established as a permanent station, it shall be easily accessible at all times with all necessary measurement equipment appropriate to the flow conditions.
- k) The section shall be sited away from pumps, sluices and outfalls, if their operation during a measurement is likely to create unsteady flow conditions.
- l) Sites where there is converging or diverging flow shall be avoided.
- m) If a suitable straight section includes a bridge, wading and boat measurements shall be made away from the effects of the bridge.
- n) The measurement of flow under ice cover is dealt with in [Annex E](#). For streams that are subject to formation of ice cover, the main part of this document shall be used when the stream is free flowing.

- o) It may, under certain conditions of river flow or level, prove necessary to carry out measurements on sections upstream or downstream of the original chosen location. This is quite acceptable if there are no substantial unmeasured losses or gains to the river in the intervening reach and so long as all flow measurements can be related to any stage value recorded at the principal reference section.

NOTE Ideal measurement conditions can be found when all requirements are satisfied. If ideal conditions are not available, it is still possible to make a measurement, but uncertainty will be increased.

5.2 Demarcation of site

5.2.1 A permanent station, or one likely to be used frequently for future measurement, shall be provided with means for demarcation of the cross-section and for determination of stage.

5.2.2 The position of each cross-section, normal to the mean direction of flow, shall be defined on the two banks by clearly visible and readily identifiable markers. Where a site is subject to considerable snow cover, the section line-markers may be referenced to other natural objects and, if possible, the position noted using a global navigation satellite system (GNSS).

5.2.3 The stage shall be read from a gauge at the start and end of the measurement period. If the water level changes rapidly, a level measurement is recommended to be taken at least every 30 min.

5.2.4 An auxiliary gauge on the opposite bank shall be installed where there is likelihood of a difference in the level of water surface between the two banks. The mean of the measurements taken from the two gauges shall be used as the mean level of the water surface and as a base for the cross-sectional profile of the stream.

6 Measurement of cross-sectional area

6.1 General

The cross-sectional profile of the open channel at the gauging-site shall be determined at a sufficient number of points to establish the shape of the bed and to minimize the uncertainty in the calculation of the cross-sectional area.

6.2 Measurement of width

Measurement of the width of the channel and the width of the individual segments shall be obtained by measuring the horizontal distance from or to a fixed reference point which shall be in the same vertical plane as the cross-section at the measuring site.

6.3 Measurement of depth

Measurement of depth shall be made at intervals close enough to define the cross-sectional profile accurately. The number of points at which depth is to be measured shall be at each vertical where velocity is measured.

The number of sampling verticals depends on the variability of the water depth in the cross-section. This number is adequate when the number of points does not significantly change the value of the cross-section obtained.

Where it is impracticable to take more than one reading of the depth, the uncertainty in measurement may be increased (see [Clause 9](#)).

When measuring depths with a wire not normal to the surface, see [Annex F](#).

7 Measurement of mean velocity

7.1 Determination of mean velocity using point velocity measurements

7.1.1 General

A range of instruments are available to measure point velocity. These are described in [Annex A](#).

7.1.2 Measurement procedure

Velocity observations are normally made at the same time as measurements of the depth. Where, however, the two measurements are made at different times, such as at a pre-surveyed station, the velocity observations shall be taken at a sufficient number of places, and the horizontal distance between observations shall be measured as described in [6.2](#) and [6.3](#).

For all measurements, the best professional judgement of an experienced hydrographer should be used, and detailed notes regarding the measurement and assumptions made should be included in the record.

In judging the recommended minimum number of verticals in small channels that are to be defined for the purpose of determining flow at a particular location, the following criteria shall be applied.

- Channel width < 0,5 m $n \geq 15$
- Channel width > 0,5 m and < 5m $n \geq 20$
- Channel width > 5 m $n \geq 22$

As far as possible, verticals should be chosen so that the discharge of each segment is less than 5 % of the total and shall not exceed 10 % of the total.

For very small channels, practical considerations do not always allow the recommended minimum number of verticals.

The distance between two verticals shall be greater than the width of the sensor and should not be less than the minimum recommendations of the specific instrument used.

In all instances, measurements of depth made at the water's edge are additional to the above. The first and last verticals shall be as close as practically possible to the water's edge.

The device used for point velocity measurement shall be held in position for a minimum of 30 s to obtain a good representation of mean velocity. It shall be held so movement of the instrument is minimized during the measurement period.

In channels where the flow is unsteady, it is possible to correct for the variations in the total discharge during the period of the measurement not only by observing the change in stage, but also by continuously measuring the velocity at some conveniently chosen point in the main current.

For continuity with previous versions of this document, the following criteria can be used but the level of uncertainty of the overall measurement will be much greater.

- Channel width < 0,5 m $n = 5$ to 6
- Channel width > 0,5 m and < 1 m $n = 6$ to 7
- Channel width > 1 m and < 3 m $n = 7$ to 12
- Channel width > 3 m and < 5 m $n = 13$ to 16
- Channel width > 5 m $n \geq 22$

See [Table D.6](#) for guidance on percentage uncertainty in measurement of mean velocity due to a limited number of verticals.

7.1.3 Oblique flow

If oblique flow is unavoidable, either the velocity component perpendicular to the cross-section should be measured directly or the velocity magnitude measured and corrected based upon the angle from perpendicular. Special instruments have been developed for measuring the angle and velocity at a point simultaneously. Where, however, these are not available and there is insignificant wind, the angle of flow throughout the vertical can be assumed to be the same as that observed on the surface. This angle can be measured with appropriate equipment provided that the operator is located above the measurement vertical. If the channel is very deep, subjected to tides or the local bed profile is changing rapidly, this assumption shall not be accepted without confirmation.

If the measured angle between the flow direction and the perpendicular to the cross-section is θ , the velocity used for the computation of flow discharge shall be as shown by [Formula \(2\)](#):

$$v_c = v_m \times \cos\theta \quad (2)$$

where

v_c is the velocity corrected;

v_m is the velocity measured.

NOTE Some current meters are equipped to measure the normal component of velocity directly when held perpendicular to the measurement cross-section in oblique flow. This correction is not applied in such cases.

7.1.4 Determination of the mean velocity in a vertical

7.1.4.1 Choice and classification

The choice of the method for determining mean velocity depends on certain factors. These are safety, time available, width and depth of the channel, bed conditions in the measuring section and the upstream reach, rate of change of stage, degree of accuracy desired and equipment used.

These methods are classified as follows:

- a) velocity distribution method (see [7.1.4.2](#));
- b) reduced point methods (see [7.1.4.3](#));
- c) integration method (see [7.1.5](#)).

7.1.4.2 Velocity distribution method

Using this method, the values of the velocity are obtained from observations at a number of points in each vertical between the surface of the water and the bed of the channel. The number and spacing of the points shall be so chosen as to define accurately the velocity distribution in each vertical with a difference in readings between two adjacent points of not more than 20 % with respect to the higher value. The location of the top and the bottom readings shall be chosen, taking into account the specification under [7.1.2](#) and [7.1.3](#).

This subclause deals primarily with the determination of mean velocity in the vertical. It can be necessary to apply the same principle to the determination of mean velocity close to the vertical side

or wall of a channel. The velocity curve can be extrapolated from the last measuring point to the bed or vertical side of the channel by calculating v_x from [Formula \(3\)](#):

$$v_x = v_a \left(\frac{x}{a} \right)^{\frac{1}{m}} \quad (3)$$

where

v_x is the open point velocity in the extrapolated zone at a distance x from the bed or vertical side;

v_a is the velocity at the last measuring point at a distance a from the bed or vertical side;

m is an exponent.

The mean velocity, \bar{v} , between the bottom (or a vertical side) of the channel and the nearest point of measurement (where the measured velocity is v_a) can be calculated directly from [Formula \(4\)](#):

$$\bar{v} = \left(\frac{m}{m+1} \right) v_a \quad (4)$$

Generally, m lies between 5 and 7 but it can vary over a wider range depending on the hydraulic resistance. The value $m = 4$ applies to coarse beds or coarse vertical sides while $m = 10$ is characteristic of smooth beds or smooth vertical sides.

m is obtained as shown by [Formula \(5\)](#):

$$m = \frac{C_{\text{ver}}}{\sqrt{g}} \left(\frac{2\sqrt{g}}{\sqrt{g} + C_{\text{ver}}} + 0,3 \right) \quad (5)$$

where

g is the acceleration due to gravity (m/s^2);

C_{ver} is Chezy's coefficient on a vertical ($\text{m}^{0,5}/\text{s}$).

NOTE An alternative method of obtaining the velocity in the region below the last measuring point is based on the assumption that the velocity for some distance up from the bed of the channel is proportional to the logarithm of the distance X from that boundary. If the observed velocities at points approaching the bed are plotted against $\log X$, then the best-fitting straight line through these points can be extended to the boundary. The velocities close to the boundary can then be read from the graph.

7.1.4.2.1 ADCP stationary method

In the ADCP stationary method, the ADCP is held in a specific location for a specified time and then averaging the data at that vertical to obtain a mean velocity profile or a depth-integrated mean velocity at that location.

It should be noted that ADCP instrumentation cannot measure velocity near the ADCP transducers, above the transducers or near the bed. Current manufacturer software allows extrapolation in these areas based upon the measured velocities to compute a mean velocity for the vertical.

7.1.4.3 Reduced point methods

7.1.4.3.1 General

These methods, less strict than methods exploring the entire field of velocity, are used frequently because they require less time than the velocity-distribution method (see [7.1.4.2](#)).

It is recommended that for a new gauging section the accuracy of the selected method be assessed by the velocity distribution method.

7.1.4.3.2 One-point method

Velocity observations shall be made on each vertical by exposing the current meter at 0,6 of the depth below the surface. The value observed shall be taken as the mean velocity in the vertical.

7.1.4.3.3 Two-point method

Velocity observations shall be made on each vertical by exposing the current meter at 0,2 and 0,8 of the depth below the surface. The average of the two values shall be taken as the mean velocity in the vertical. See [Formula \(6\)](#):

$$\bar{v} = 0,5(v_{0,2} + v_{0,8}) \quad (6)$$

An alternative method of determining the mean velocity of a vertical is the Kreps method which uses velocity observations at the surface and at 0,62 of the depth below the surface.

When using the Kreps method, velocity observations shall be made as near as possible to the surface and 0,62 of the depth below the surface. See [Formula \(7\)](#):

$$\bar{v} = 0,31 \times v_0 + 0,634 \times v_{0,62} \quad (7)$$

NOTE The Kreps method, which was developed by the Austrian hydrologist Harald Kreps, is also a two-point method^[21].

7.1.4.3.4 Three-point method

Velocity observations shall be made on each vertical by exposing the current meter at 0,2, 0,6 and 0,8 of the depth below the surface. The 0,6 measurement may be weighted and the mean velocity \bar{v} obtained from [Formula \(8\)](#):

$$\bar{v} = 0,25(v_{0,2} + 2v_{0,6} + v_{0,8}) \quad (8)$$

7.1.4.3.5 Five-point method

Velocity measurements are made by exposing the current meter on each vertical at 0,2, 0,6 and 0,8 of the depth below the surface and as near as possible to the surface and the bed. The mean velocity \bar{v} is obtained from [Formula \(9\)](#):

$$\bar{v} = 0,1(v_0 + 3v_{0,2} + 3v_{0,6} + 2v_{0,8} + v_{\text{bed}}) \quad (9)$$

7.1.4.3.6 Six-point method

Velocity observations are made by exposing the current meter on each vertical at 0,2, 0,4, 0,6 and 0,8 of the depth below the surface and as near as possible to the surface and the bed. The mean velocity \bar{v} can be found from [Formula \(10\)](#):

$$\bar{v} = 0,1(v_0 + 2v_{0,2} + 2v_{0,4} + 2v_{0,6} + 2v_{0,8} + v_{\text{bed}}) \quad (10)$$

7.1.4.3.7 Alternate sampling methods

Alternative sampling methods for determining the mean velocity in the vertical may be utilized under exceptional circumstances, e.g. high velocity, rapidly changing stage or floating debris, provided the

method applied can be demonstrated by experiment to give results of a similar accuracy to those listed above.

7.1.5 Integration method

In the integration method, the velocity throughout each vertical is measured by raising and lowering a current meter through the entire depth on each vertical at a uniform rate. The speed at which the meter is lowered or raised should not be more than 5 % of the mean water velocity and should not in any event exceed 0,04 m/s. Two complete cycles should be made on each vertical and, if the results differ by more than 10 %, the operation (two complete cycles) should be repeated until results within this limit are obtained.

The integration method gives good results if the time of measurement allowed is sufficiently long (60 s to 100 s). The technique can be, but is not normally, used in depths of less than 1 m.

The average number of revolutions is the total number of revolutions divided by the total time taken for the measurement in that vertical. The average velocity can then be read from the instrument calibration corresponding to the average number of revolutions. Uncertainties introduced by using meters with more than one calibration equation should be avoided.

7.1.6 Errors and limitations

Estimates of the possible errors that can occur when using the various methods detailed in 7.2 are given in [Clause 9](#). It should be noted that these estimates are of possible random errors which can occur even when all the precautions noted earlier and below are observed. If the measurement is not made under these best conditions, additional uncertainty shall be included when estimating the overall uncertainty of the measurement.

Errors can arise:

- a) if the flow is unsteady;
- b) if material in suspension interferes with the performance of the current meter;
- c) if oblique flow occurs, and the appropriate correction factors are not known accurately;
- d) if the instrument used for measurement of velocity is outside the range established by the calibration;
- e) if the set-up for measurement (such as rods or cables suspending the current meter, the boat, etc.) is different from that used during the calibration of the instrument, in which case it is possible that a systematic error is introduced;
- f) if there is significant disturbance of the water surface by wind;
- g) if the device is not held steadily in the correct place during the measurement or when an oscillating movement occurs; in the latter case, the resultant of the flow velocity and the transverse velocities gives rise to serious positive errors.

7.2 Determination of mean velocity from surface velocity

7.2.1 General

Traditionally, determination of mean velocity from surface velocity was not encouraged as uncertainties are high. As technologies have developed, there are a greater range of techniques and instruments that are able to calculate mean velocity more accurately using measurements from the water surface.

Instruments that are designed to measure discharge by measuring surface velocity only shall conform to the relevant parts of this document.

7.2.2 Non-contact systems

A range of instruments are available to measure surface velocity. Some are described in [Annex C](#).

Particular attention shall be paid to [Clause 5](#).

Measurement of the cross-sectional area shall be in accordance with [Clause 6](#).

The velocity coefficient at a site shall be derived using a proven technique. If the site is to be used regularly, an index rating shall be calculated. This shall be applied to the surface velocity measured to ensure the mean velocity is used in the calculation of the discharge.

Calculation of uncertainties shall be with reference to [9.3](#) and ISO 25377:2020.

7.2.3 Surface one-point method by current meter

The depth of submergence of the current meter shall be uniform over all the verticals; care shall be taken to ensure that the current meter observations are not affected by random surface-waves and wind. This "surface" velocity may be converted to the mean velocity in the vertical by multiplying it by a predetermined coefficient specific to the section and to the discharge.

The coefficient shall be computed for all stages by correlating the velocity at the surface with the velocity at 0,6 of the depth or, where greater accuracy is desired, with the mean velocity obtained by one of the other methods described previously.

7.2.4 Measurement of velocity using floats

A full description of this method is described in [Annex B](#).

This method shall only be used when it is impossible to employ other point measurement devices, however, it is a useful technique in cases of reconnaissance or because of access difficulties, excessive velocities and depths or the presence of material in suspension.

7.2.5 Exceptions

Where it is not possible to check the coefficient directly, it may be assumed for guidance that, in general, the coefficient of the surface velocity varies between 0,84 and 0,90 depending on the shape and velocity profile of the channel.

7.2.6 Main sources of error

Errors that can occur during the measurement of surface velocity are listed below. They shall be taken into consideration when estimating the overall error as given in [Clause 9](#).

Errors can arise:

- a) if the coefficient from which the mean velocity is obtained from the surface velocity is not known accurately;
- b) if the cross-section has been measured incorrectly;
- c) if the cross-section is unstable, i.e. has a moving bed;
- d) if the measured velocity does not reflect the true velocity due to unstable flow or oblique currents;
- e) if floats are used and their motion is biased relative to the water surface motion due to wind.

8 Computation of discharge

8.1 Arithmetic methods

8.1.1 General

The methods shown below can be enhanced by adding additional bathymetric verticals with no velocity. This is especially useful for surface velocity gaugings and for varying discharge conditions, but also to improve the efficiency of routine measurements.

Where the bed is uneven, and if time and cost allow, determining the depth at points midway between the annotated verticals as shown in [Figure 2](#) can provide a more accurate determination of the area of each panel.

8.1.2 Mean-section method

The cross-section is regarded as being made up of a number of segments, n , each bounded by two adjacent verticals (see [Figure 1](#)).

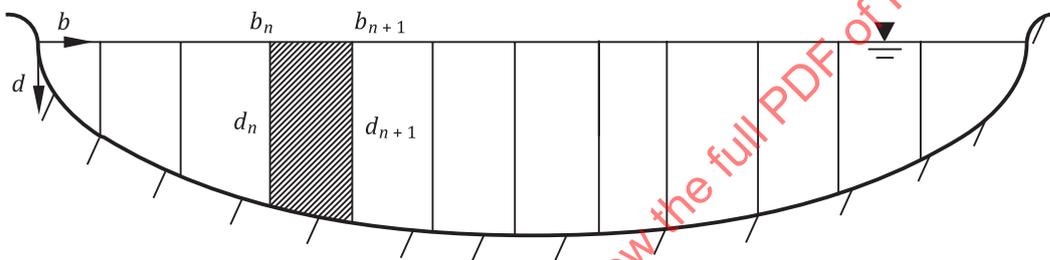


Figure 1 — Diagram illustrating the mean section method

The flow in the shaded panel is calculated as shown by [Formula \(11\)](#):

$$q = (b_{n+1} - b_n) \left(\frac{d_{n+1} + d_n}{2} \right) \left(\frac{\bar{v}_{n+1} + \bar{v}_n}{2} \right) \quad (11)$$

where \bar{v} is the average velocity in each vertical.

The additional discharge in the segments between the bank and the first vertical, and between the last vertical and the other bank, can be estimated from [Formula \(11\)](#), on the assumption that the velocity at the banks is zero. If, however, this discharge is a significant proportion of the total flow, then [Formula \(4\)](#) may be used to obtain the mean velocity in the region of the bank.

The total flow is equal to the sum of the discharge in each panel, thus, as shown by [Formula \(12\)](#):

$$Q = \sum_{n=1}^m (b_{n+1} - b_n) \left(\frac{d_{n+1} + d_n}{2} \right) \left(\frac{\bar{v}_{n+1} + \bar{v}_n}{2} \right) \quad (12)$$

8.1.3 Mid-section method

The cross-section is regarded as being made up of a number of segments, each containing a vertical (see [Figure 2](#)).

The discharge in each segment shall be computed by multiplying $\bar{v} \cdot n$ by the corresponding depth and width as measured along the water-surface line. This width shall be taken to be the sum of half the width from the adjacent vertical to the vertical for which $\bar{v} \cdot n$ has been calculated plus half the width from this vertical to the corresponding adjacent vertical on the other side. The value for $\bar{v} \cdot n$ in the two half-widths next to the banks may be taken as zero.

For this reason, the first and last verticals of a measurement should be as close to the banks as possible if the mid-section method of calculation is used.

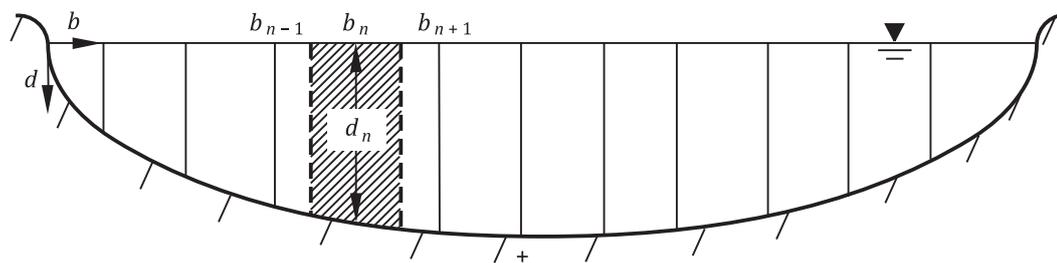


Figure 2 — Diagram illustrating the mid-section method

For this method, the flow in each panel is calculated as shown by [Formula \(13\)](#):

$$q = \bar{v}_n d_n \left(\frac{b_{n+1} - b_{n-1}}{2} \right) \quad (13)$$

where \bar{v} is the average velocity in the vertical.

The computation is carried out at each vertical and the total discharge through the section is obtained by summing these partial discharges, as shown by [Formula \(14\)](#):

$$Q = \sum_{n=1}^m \bar{v}_n d_n \left(\frac{b_{n+1} - b_{n-1}}{2} \right) \quad (14)$$

8.1.4 Bathymetric verticals

Adding additional verticals to define the channel bathymetry but with no velocity measurements is a very useful procedure, especially for surface velocity gaugings and for varying discharge conditions, but also to improve the efficiency of routine measurements.

Bathymetric verticals can be inserted anywhere between the normal verticals (one or several, and not necessarily “midway”). There are two computation options, both acceptable:

- correct the wetted area of each panel using the bathymetric verticals, and no change to estimated panel velocities;
- estimate the missing velocities at bathymetric verticals: instead of a simple linear interpolation, interpolate linearly the $\frac{V}{\sqrt{H}}$ ratios (proportional to the local Froude or Chezy numbers).

The advantage of b) is to account for the measured depth in the estimation of the mean velocities over the panels. This option is not recommended when there is no velocity vertical between the edge and a bathymetric vertical.

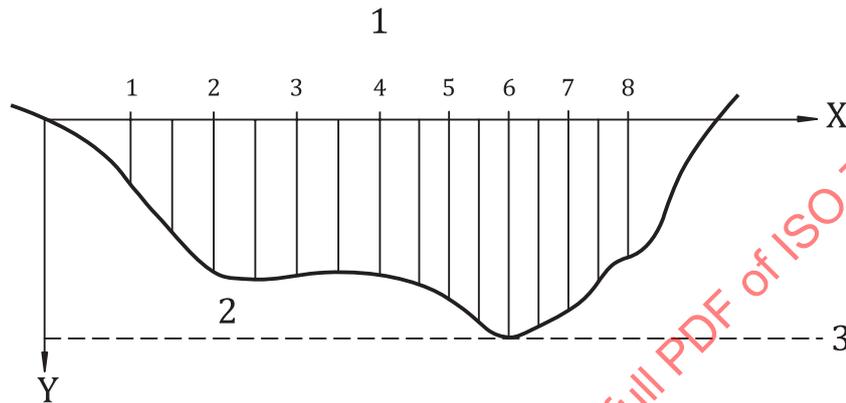
8.2 Independent vertical method

This method is useful for measuring streams with rapidly changing discharge. Several verticals are chosen and their distances measured from a fixed reference point (see [Figure 3](#)). For each gauging, measurements of velocity and depth are made using one of the methods described above. The water level is measured at the beginning and end of the series of measurements on each vertical. For each segment, a separate stage discharge relation is prepared. Subsequently, the discharge of the river at a given stage can be determined by combining the discharges for each segment when corrected for the change in water level between the moment of measurement and the moment of calculation of the total discharge.

Over time and across a large range of flow, it is possible to derive a relationship between stage and unit-width discharge for each vertical. A family of curves can then be constructed. Each curve represents an independent stage discharge relationship for the corresponding segment of channel width (see [Figure 4](#)). This assumes that the channel geometry remains constant and that no change occurs in the position of a vertical relative to the reference point.

For a given value of stage, total flow in the cross-section is obtained by using a mathematical method by summation of all segment discharges (see [Figure 5](#)), or with a graphical method (see [Figure 6](#)) by plotting the unit-width discharge for all verticals and determining the area under this curve.

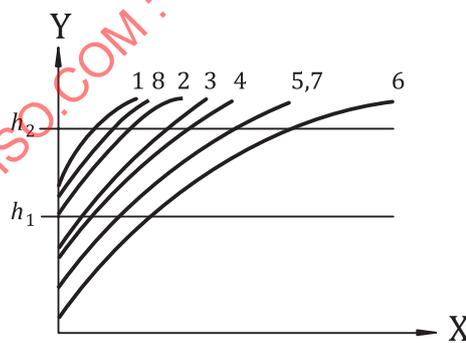
Total flow in the cross-section for any given value of stage can be obtained by either of these methods.



Key

- | | | | |
|---|-------------------|---|-------------|
| X | channel width (m) | 1 | verticals |
| Y | stage (m) | 2 | channel bed |
| | | 3 | stage datum |

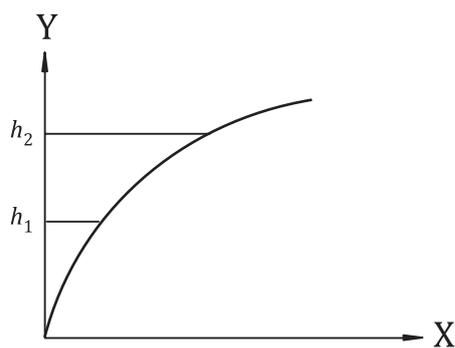
Figure 3 — Verticals in cross-section



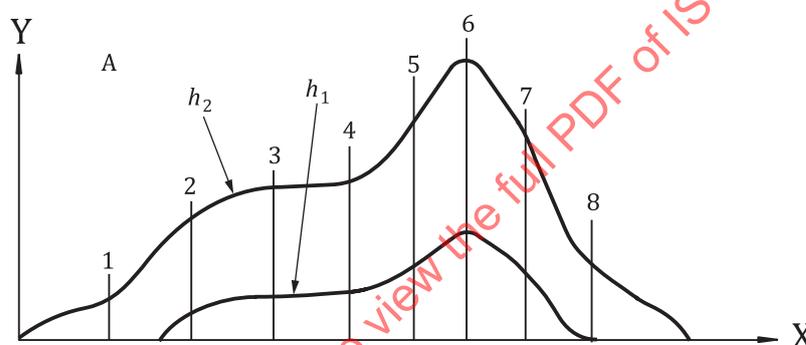
Key

- | | |
|---|--------------------------------|
| X | discharge per unit (m^3/s) |
| Y | stage (m) |

Figure 4 — Stage/discharge curves for individual verticals

**Key**X total discharge (m³/s)

Y stage (m)

Figure 5 — Total discharge (mathematical method)**Key**

X distance (m)

Y discharge per unit width (m³/s)A distribution of q for h_1 or h_2 **Figure 6 — Computation of discharge from current meter measurement — Independent vertical method****8.3 Mean-section method — Horizontal planes**

Instead of determining the mean velocity in each vertical, the mean velocities for a number of horizontal planes can be determined by a corresponding procedure to that given in 7.1.4.2. A similar method to that given in 8.1.2 can then be used to determine the discharge. The use of horizontal and vertical-plane computation is particularly suited to measurements in regular-shaped channels, as it enables a check to be made on the accuracy of the computation.

9 Uncertainties in flow measurement**9.1 General**

The uncertainty of discharge is discussed in ISO 25377. A reference should be made to ISO 25377. Annex D examines the individual components of the uncertainty and provides examples. It should not be assumed, however, that these are generally applicable, and it should be stressed that the observations on which they are based do not include all kinds and sizes of rivers, see ISO 1088.

9.2 Method of calculating the uncertainty in discharge by measurement of velocity by current meter

9.2.1 General

The measurement method, briefly, consists of dividing the channel cross-section under consideration into segments by m verticals and measuring the width, depth and mean velocity (denoted by b_i , d_i and \bar{v}_i , respectively) associated with each vertical i . The mean velocity \bar{v}_i at each vertical is computed from point velocity measurements made at each of several depths on the vertical. The flow is computed as shown by [Formula \(15\)](#):

$$Q = F \sum b_i d_i v_i \quad (15)$$

where

Q is the flow (in cubic metres per second);

F is a factor, assumed to be unity, that relates the discrete sum over the finite number of verticals to the integral of the continuous function over the cross-section.

9.2.2 Contributory uncertainties

The relative (percentage) combined standard uncertainty in the measurement is shown by [Formula \(16\)](#):

$$u(Q)^2 = u_m^2 + u_s^2 + \frac{\sum_{i=1}^m (b_i d_i \bar{v}_i)^2 (u_{b,i}^2 + u_{d,i}^2 + u_{\bar{v},i}^2)}{\left(\sum_{i=1}^m (b_i d_i \bar{v}_i)\right)^2} \quad (16)$$

where

$u(Q)$ is the relative (percentage) combined standard uncertainty in discharge;

$u_{b,i}, u_{d,i}, u_{\bar{v},i}$ are the relative (percentage) standard uncertainties in the width, depth and mean velocity measured at vertical i ;

u_s is the uncertainty due to variable responsiveness of the current meter (u_{cm}), width measurement instrument (u_{bm}) and depth sounding instrument (u_{ds}):

$$u_s = \sqrt{u_{cm}^2 + u_{bm}^2 + u_{ds}^2} \quad (17)$$

An estimated practical value of 1 % may be taken for this expression.

u_m is the uncertainty due to the limited number of verticals;

m is the number of verticals.

The mean velocity \bar{v}_i at vertical i is an estimate of the average of point measurements of velocity made at one or more depths in the vertical (see, for example, [7.1.5](#)). The uncertainty in \bar{v}_i is computed as shown by [Formula \(18\)](#):

$$u(\bar{v}_i)^2 = u_{p,i}^2 + \left(\frac{1}{n_i}\right) (u_{c,i}^2 + u_{e,i}^2) \quad (18)$$

where

- $u_{p,i}^2$ is the uncertainty in mean velocity \bar{v}_i due to the limited number of depths at which velocity measurements are made at vertical i ;
- n_i is the number of depths in the vertical i at which velocity measurements are made;
- $u_{c,i}$ is the uncertainty in the velocity at a particular measuring point in vertical i due to lack of repeatability of the current meter;
- $u_{e,i}$ is the uncertainty in point velocity at a particular depth in vertical i due to velocity fluctuations (pulsations) in the stream during the exposure time of the current meter.

Combining [Formulae \(16\)](#) and [\(18\)](#) results in [Formula \(19\)](#):

$$u(Q)^2 = u_m^2 + u_s^2 + \frac{\sum_{i=1}^m (b_i d_i \bar{v}_i)^2 \left(u_{b,i}^2 + u_{d,i}^2 + u_{p,i}^2 + \left(\frac{1}{n_i} \right) (u_{c,i}^2 + u_{e,i}^2) \right)}{\left(\sum_{i=1}^m (b_i d_i \bar{v}_i) \right)^2} \quad (19)$$

If the measurement verticals are placed so that the segment discharges $(b_i d_i \bar{v}_i)$ are approximately equal and if the component uncertainties are equal from vertical to vertical, then [Formula \(19\)](#) simplifies to [Formula \(20\)](#):

$$u(Q) = \left[u_m^2 + u_s^2 + \left(\frac{1}{m} \right) \left(u_b^2 + u_d^2 + u_p^2 + \left(\frac{1}{n} \right) (u_c^2 + u_e^2) \right) \right]^{\frac{1}{2}} \quad (20)$$

EXAMPLE It is required to estimate the uncertainty in a current meter gauging from the following particulars:

Number of verticals used in the gauging:	20
Number of points taken in the vertical (0,2 and 0,8):	2
Average velocity in measuring section:	above 0,3 m/s
Exposure time of current meter:	3 min
Rating of current meter:	individual rating

Component uncertainties (percentages) can be obtained from information given in [Annex D](#), which presents the results of investigations carried out since the publication of the first edition of this document in 1968.

$u_m = 2,5$	(see Table D.6)
$u_s = 1,0$	(see above)
$u_b = 0,5$	(see D.2 , line 1)
$u_d = 0,5$	(see D.3 , line 2)
$u_p = 3,5$	(see Table D.4)
$u_c = 1,0$	(see Table D.5)
$u_e = 3,0$ (at 0,2 depth)	(see Table D.3)
$= 3,0$ (at 0,8 depth)	(see Table D.3)

Therefore:

$$u_e = \sqrt{3^2 + 3^2} = 4,2$$

Using [Formula \(20\)](#):

$$u(Q) = \left[u_m^2 + u_s^2 + \left(\frac{1}{m} \right) \left(u_b^2 + u_d^2 + u_p^2 + \left(\frac{1}{n} \right) \left(u_c^2 + u_e^2 \right) \right) \right]^{\frac{1}{2}}$$

$$u(Q) = \left[2,5^2 + 1,0^2 + \left(\frac{1}{20} \right) \left(0,5^2 + 0,5^2 + 3,5^2 + \left(\frac{1}{2} \right) \left(1,0^2 + 4,2^2 \right) \right) \right]^{\frac{1}{2}}$$

results in:

$$u(Q) = 2,89 \%$$

The expanded uncertainty at the 95 % confidence level, U_{95} , is obtained by applying a coverage factor of $k = 2$.

Thus:

$$U_{95}(Q) = k \times u(Q)$$

$$= 2 \times 2,89$$

$$= 5,78 \%$$

Therefore:

$$U_{95}(Q) = 6 \%$$

If the measured flow is $Q \text{ m}^3/\text{s}$, the result of the measurement is expressed as:

$$Q \text{ m}^3/\text{s} \pm 6 \%$$

where the expanded uncertainty, coverage factor is $k = 2$, and the approximate level of confidence = 95 %.

9.3 Method of calculating the uncertainty in discharge by measurement of velocity using floats

9.3.1 General

While there have been considerable investigations carried out into the uncertainties in current meter gauging, little work has been performed into the uncertainties in float gauging. As a result, there is little guidance in the literature and little research reported to allow reliable recommendations to be made. The analysis in this subclause is therefore given as guidance until more information is available.

9.3.2 Contributory uncertainties

Calculate the discharge as shown by [Formula \(21\)](#) (see [Clause B.5](#)):

$$Q = F \sum_{i=1}^n K_f \bar{v}_i \left(\frac{A'_i + A_i}{2} \right) \tag{21}$$

where

Q is the discharge (cubic metres per second);

- F is a factor, assumed to be unity, that relates the discrete sum over the finite number of verticals to the integral of the continuous function over the cross-section;
- n is the number of segments;
- K_f is the coefficient of velocity for the float;
- \bar{v}_i is the mean float velocity in the i th segment;
- A_i and A'_i are the i th segment areas of upstream and downstream cross-sections, respectively.

The overall uncertainty in discharge is composed of:

- a) uncertainties in width: $u_{b,i}$ in estimating cross-section areas;
- b) uncertainties in depth: $u_{d,i}$ in estimating cross-section areas (allowing for scour and fill, if any);
- c) uncertainties in determination of surface float velocities: $u\bar{v}_i$, composed of:
 - the uncertainty in the coefficient of velocity for the float, $u_{k,f}$;
 - the uncertainty of the length of travel path, $u_{L,i}$;
 - the uncertainty of the time taken for the passage of the float, $u_{t,i}$, see [Formula \(22\)](#):
$$u_{v,i}^2 = u_{k,f}^2 + u_{L,i}^2 + u_{t,i}^2 \quad (22)$$
- d) uncertainty due to the limited number of segments used, u_m .

9.3.3 Combined uncertainty in discharge

The method of calculation is similar to that given in [9.3.2](#), see [Formula \(23\)](#):

$$u_Q = \sqrt{u_m^2 + \frac{1}{m}(u_b^2 + u_d^2 + u_v^2)} \quad (23)$$

EXAMPLE Float gauging with five paths using surface floats:

$u_m = 7,5 \%$ (see [Table D.6](#)). This may be reduced provided the areas are determined from a detailed cross-section and the velocities are determined from a smoothed velocity distribution.

$u_{k,f} = 15 \%$ (see [Table D.4](#))

$u_L = 5 \%$ (estimated)

$u_t = 5 \%$ (estimated)

$$u_v = \sqrt{u_{k,f}^2 + u_L^2 + u_t^2}$$

$$= \sqrt{15^2 + 5^2 + 5^2}$$

= 16,5 % (or taken from [Table D.4](#) alone = 15 %)

$u_b = 1 \%$ (estimated)

$u_d = 1 \%$ (estimated)

Therefore:

$$u(Q) = \sqrt{7,5^2 + \frac{1}{5}(1+1+16,5^2)}$$

$$u(Q) = 10,5 \%$$

The expanded uncertainty at a level of confidence of approximately 95 %, U_{95} , is obtained by applying a coverage factor of $k = 2$.

Then:

$$\begin{aligned} U_{95}(Q) &= k \cdot u(Q) \\ &= 2 \times 10,5 \\ &= 21 \% \end{aligned}$$

Therefore:

$$U_{95}(Q) = 21 \%$$

If the measured flow is $Q \text{ m}^3/\text{s}$, the result of the measurement is expressed as:

$$Q \text{ m}^3/\text{s} \pm 21 \% \text{ (expanded uncertainty, coverage } k = 2, \text{ approximate level of confidence} = 95 \%)$$

9.4 Limitations

For ideal conditions and procedure, the computed uncertainty usually lies between 5 % and 7 %. However, for many measurements done in non-ideal conditions, the uncertainty values obtained have some limitations.

The following limitations have been identified.

- a) The informative values given in [Annex D](#) for uncertainty components are derived from empirical studies, they are specific to an instrument type and to some measurement conditions.
- b) Top, bottom and edge velocity extrapolations are not taken into account in the uncertainty analysis, though their contribution is not necessarily negligible.
- c) When vertical integration of velocity is performed directly (velocity distribution method), a negligible default value (0,5 %) is attributed to the u_p component. For non-ideal measurements with not enough velocity points and often significant top/bottom extrapolations, the value of u_p should be taken higher than 0,5 %.
- d) Most of the computed uncertainty usually stems from the term u_m , which is an empirical function of the number of verticals m , with no consideration of the spatial distribution of verticals, compared to the transversal variation in bed geometry and flow distribution.
- e) Time-integration error in the case of varying discharge during the measurement is not estimated.

NOTE This effect is different from hysteresis, i.e. the discharge deviation to the steady conditions due to transient flow effects.

- f) Some uncertainty components are missing from the equation. In particular, a term accounting for systematic errors due to the vertical velocity integration method should be added (this is obvious for surface velocity gaugings, but also for other techniques). Other missing error sources include: position, inclination and orientation of the instruments (current meters, rod, sounding, etc.) resulting in velocity projection errors and position and depth errors; and bed changes when bathymetry is not measured simultaneously with velocities.

9.5 Interpolated variance estimator (IVE)

The IVE^[15] quantifies uncertainty in mid-section velocity-area measurements, whatever the instrumentation. The method is as given in 9.2 but rather than using laboratory or empirical results to estimate uncertainty in the depth and velocity, it instead relies on information contained in the many verticals collected during the measurement. For width uncertainty and for systematic uncertainties caused by meter fabrication errors, the values suggested by this document are employed. IVE does not address consistent field user biases such as persistent meter tilt or flow angularity. Testing has shown that the IVE method provides more sensitivity to measurement conditions than the standard ISO method. Recent comparisons of IVE with other methods for computing measurement uncertainty^[19] indicate that IVE provides a more realistic estimate relative to other methods tested. IVE should only be applied when 10 or more verticals are used.

9.6 Q+

Similar to the IVE and Flaure methods, the Q+ method^[18] is a variant of this document's method for computing the uncertainty of velocity-area discharge measurements, which aims at improving the estimation of the uncertainties due to the spatial integration of velocities and depths throughout the cross-section. An alternative computation of the vertical velocity integration uncertainty (u_p) is proposed when the velocity distribution method is applied. The lateral flow integration uncertainty (u_m) is also estimated directly from the velocity and depth measurements instead of the look-up table values of this document. The lateral depth integration uncertainty and the lateral velocity integration uncertainty are estimated separately in the form of two distinct uncertainty components, $u_m(D)$ and $u_m(V)$, which may be combined to compute u_m . Thus, the improved sampling of the cross-sectional geometry using bathymetric verticals can be assessed. Both $u_m(D)$ and $u_m(V)$ uncertainty components are computed based on an angle (or slope) reflecting the maximum possible errors in the bed profile, i.e. in the wetted areas of the panels. This angle can be user-defined or estimated from the data^[19].

9.7 Flaure

The Flaure method (for “FLow Analogue Uncertainty Estimation”)^[19] estimates the uncertainty component relating to the limited number of verticals. High-resolution reference gaugings (with 31 and more verticals) are used to assess the uncertainty component through a statistical analysis. Instead of subsampling purely randomly the verticals of these reference stream-gaugings, a subsampling method is developed in a way that mimics the behaviour of a hydrometric technician. A sampling quality index (SQI) is suggested and appears to be a more explanatory variable than the number of verticals. This index takes into account the spacing between verticals and the variation of unit flow between two verticals.

This new method was applied to 3185 stream-gaugings with various flow conditions and compared with the other methods (this document, IVE, Q+ with a simple automated parametrization). Results show that Flaure is overall consistent with the Q+ method but not with this document and IVE methods, which produce clearly overestimated uncertainties for discharge measurements with less than 15 verticals.

Annex A (informative)

Use of point velocity current meters

A.1 General

As far as possible, the type of measuring equipment should be selected to minimize the depth of the unmeasured zones.

A.2 Rotating-element current meters

A.2.1 General

Rotating-element current meters shall be manufactured, calibrated and maintained in accordance with ISO 2537 and ISO 3455. They should be used only within their calibrated range and fitted on suspension equipment similar to that used during calibration.

In the vicinity of the minimum speed of response, the uncertainty in determining the velocity is high. Care should be exercised when measuring velocities near the minimum speed of response.

For high velocities, the propeller, in the case of propeller-type current meters, or the reduction ratio where available, shall be chosen in order that the maximum speed of rotation can be correctly measured by the revolution counter.

No rotating-element current meter shall be selected for use where the depth at the point of measurement is less than four times the diameter of the impeller that is to be used, or of the body of the meter itself, whichever is the greater. No part of the meter shall break the surface of the water. An exception to this is cases where the cross-section is very shallow at one side but is the best available.

A spin test, where appropriate, should be performed before and after each discharge measurement to ensure the mechanism of the current meter operates freely, see ISO 2537.

A.2.2 Integration method using current meter

The speed at which the current meter is lowered or raised shall not be more than 5 % of the mean water velocity and shall not in any event exceed 0,04 m/s. Two complete cycles shall be made on each vertical. If the results differ by more than 10 %, the operation (two complete cycles) shall be repeated until results within this limit are obtained.

When a sounding rod or weight is used, it will not be possible to measure the velocity throughout the entire vertical; a zone may, for example, remain unmeasured near the channel bed. An estimate of the unit width discharge of this zone can be obtained using [Formula \(A.1\)](#):

$$q_u = \frac{2v_m h_f}{3} \quad (\text{A.1})$$

where

q_u is the unit width discharge below the measured zone;

v_m is the mean velocity for the measured part of the vertical;

h_f is the depth of the unmeasured zone.

Similarly, the unit width discharge for any unmeasured zone near the surface is obtained using [Formula \(A.2\)](#):

$$q_s = \frac{v_m h_s}{0,9} \quad (\text{A.2})$$

where

q_s is the unit width discharge above the measured zone;

v_m is the mean velocity for the measured part of the vertical;

h_s is the depth of the unmeasured zone.

A.3 Acoustic doppler velocimeters (ADV)

Hand-held ADVs are acoustic point-velocity current meters. They use two or three transducers to transmit sound pulses into the water and a receiving transducer to sample the reflected signal and compute the velocity in the sample volume. They provide velocity measurements at a single point and typically come with software and/or hardware interfaces for computing discharge with various methods previously discussed. ADVs determine water velocity by measuring the change in acoustic frequency (or Doppler shift) in reflections from moving particles or scatters (such as suspended sediment) in the flow, which are assumed to be moving at the same velocity as the water.

The sampling methodology, site selection criteria, and discharge calculation methods applied to undertaking a traditional current meter gauging also apply to the ADVs. ADV current meters are capable of operation in low velocities and shallow depths of water.

A.4 Acoustic echo correlation velocimeters (AECV)

Hand-held AECVs are point-velocity current meters that measure the full velocity profile. Velocities are measured from the bottom to the surface simultaneously and seamlessly. Positioning at different sampling depths is not required.

Acoustic reflectors such as sediment particles and air bubbles that are present in the water are scanned with ultrasonic pulses and the reflected received signals are stored as echo patterns. Further ultrasonic scans are performed every few milliseconds and consecutive echo patterns are compared to determine the particulate movements, and thus water velocity, within the measurement window. A full water depth velocity profile is determined by analysing these measurements in up to 16 vertical slices or layers.

The sampling methodology, site selection criteria and discharge calculation methods applied to undertaking a traditional current meter gauging also apply to the AECVs. AECV current meters are capable of operation in low velocities and shallow depths of water.

A.5 Acoustic doppler current profiler (ADCP) stationary method

The stationary method utilizes the ADCP to measure discharge on a vertical by vertical basis, similar to a standard current meter.

The ADCP sensors can be used suspended from a bridge, cableway or by wading, as traditionally with other current meter types. It is also capable of holding position by means of manned and remote-control boats. It is important that the instrument is held stationary as it is sensitive to flow angles.

NOTE Location of the verticals for the measurement can, with good conditions, be eased by the use of GNSS systems coupled to the ADCPs.

The ADCP sensors send multiple acoustic pulses into the water to measure the full velocity profile within the vertical (with extrapolation for near bed and near surface boundaries). From this, the calculation of the mean velocity of the water and the depth of the channel for each measured vertical is made. Calculation of discharge by mid-section or mean-section methods are then made conforming to [Clause 7](#). They also conform to the IVE^[15].

A.6 Electromagnetic current meters

Electromagnetic current meters are acceptable for making measurements of point velocity. They shall be calibrated throughout the range of velocity for which they are to be used. They shall meet accuracy requirements similar to rotating-element current meters. They should not be used outside the range of calibration. It is possible that electromagnetic current meters are capable of operation in shallower depths than rotating-element current meters and of detecting and measuring flow reversal.

No electromagnetic current meter should be selected for use where the depth at the point of measurement is less than three times the vertical dimension of the probe, see ISO/TS 15768. An exception to this is the case where the cross-section is very shallow at one side but is the best available.

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Annex B (informative)

Surface velocity measurement using floats

B.1 Measurement of velocity using floats

B.1.1 General

This method shall only be used when it is impossible to employ a current meter because of access difficulties, excessive velocities and depths, the presence of material in suspension or in cases of reconnaissance.

B.1.2 Selection of site

Three cross-sections shall be selected along the reach of the channel as described in [Clause 5](#), at the beginning, midway and at the end of the reach. The cross-sections shall be far enough apart for the time which the floats take to pass from one cross-section to the next to be measured accurately. The midway cross-section shall be used only for the purpose of checking the velocity measurement between the cross-sections at the beginning and at the end of the reach. A minimum duration of float movement of 20 s is recommended.

B.1.3 Measuring procedure

The float shall be released far enough above the upper cross-section to attain a constant velocity before reaching the first cross-section. The time at which the float passes each of the three cross-sections is then noted. This procedure shall be repeated with the floats at various distances from the bank of the river.

Increasing the number of floats used to determine the velocity in each segment will improve the accuracy of the measurement.

The width of the channel shall be divided into a certain number of segments of equal width. If, however, the channel is very irregular, each segment shall have approximately the same discharge. The number of segments shall not be less than three, but where possible a minimum of five shall be used, the actual number of segments depending on the time available for these observations at the particular stage of the river.

B.2 Types of float

B.2.1 Surface floats

These may be used during floods when velocity measurements are to be made quickly. They shall not be used when their movement is likely to be affected by winds.

B.2.2 Double floats

These may be used for measurements of velocities in deep rivers. The sub-surface body may be positioned at 0,6 of the depth below the surface, or at other depths to obtain direct velocity measurements at these depths.

B.2.3 Other types of floats

B.2.3.1 General

Other methods of obtaining the mean velocity in each segment may be used if the bed profile is regular over the measuring reach.

B.2.3.2 Sub-surface floats

These may be used for measurement of velocities in very deep rivers. The length of the sub-surface float, sometimes called the “multiple float”, which consists of separate elements suitably attached together to permit flexibility and supported by a surface float, shall be approximately equal to the water depth, but the float shall in no case touch the bottom.

B.3 Determination of velocity

B.3.1 Method

The float velocity shall be determined by dividing the distance between the cross-sections by the time taken by the float to travel this distance. Several measurements of the float velocities shall be taken. The mean of these measurements shall be multiplied by the appropriate coefficient to obtain the mean velocity in the segment. The coefficient derived from current meter measurements at the site at a stage as near as possible to that during the float measurement may be used for converting the float velocity to mean velocity.

B.3.2 Surface floats

Where it is not possible to check the coefficient directly, it may be assumed for guidance that, in general, the coefficient of the surface float varies between 0,84 and 0,90 depending upon the shape of the velocity profile. The higher values are usually obtained when the bed is smooth, but values outside this range can occur under certain circumstances.

B.3.3 Double floats

Where it is not possible to check the coefficient directly, it may be accepted for guidance that when the sub-surface body is situated at 0,5 of the depth, the coefficient is approximately equal to 1,0, and at 0,5 of the depth, the coefficient is approximately equal to 0,96.

B.3.4 Other types of floats

Where a direct check on the coefficient is not possible, it may be assumed that the coefficient of the sub-surface floats and velocity rods is in the range of 0,8 to 1,0.

B.4 Main sources of error

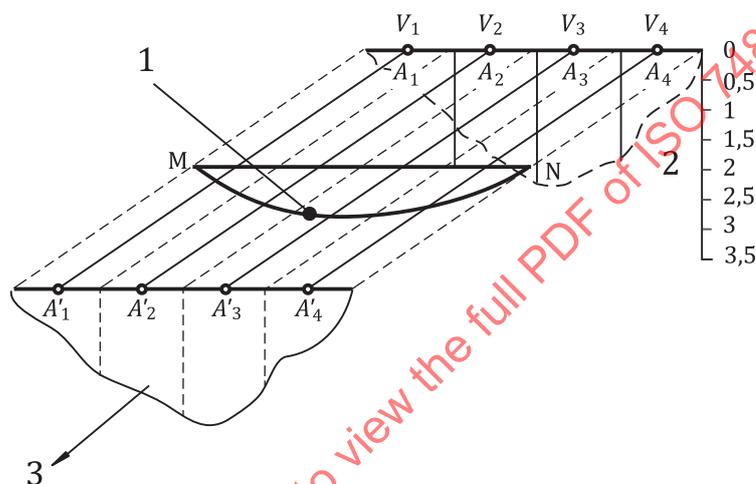
Errors can arise:

- if the coefficient from which the mean velocity is obtained from the float velocity is not known accurately;
- if too few segments are used for the velocity distribution;
- if a sub-surface float or velocity-rod is used and the depth of the channel is not uniform throughout the measuring reach;
- if the float does not travel in the centre of the panel due to oblique currents;

- if there is wind; but it should be noted that this error is generally negligible in comparison with the others listed above, unless a surface float is used.

B.5 Determination of discharge from surface float velocity measurements

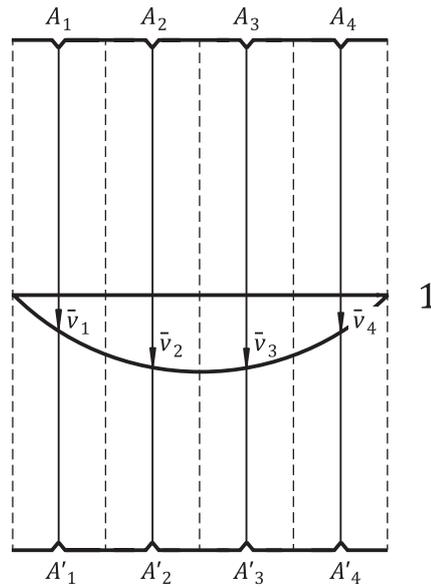
If the upstream and downstream cross-sections are plotted as shown in [Figure B.1](#) and then divided into a suitable number of segments of equal width, the cross-sectional area of each of these segments can be determined. Halfway between the two cross-section lines, another line MN shall be drawn parallel to the cross-sectional lines. The starting and ending points of each float may then be plotted and joined by firm lines, while the surface-points separating the various panels of the two cross-sections may be joined by dotted lines. Where the firm lines cross the line MN, the corresponding mean velocity (float velocity multiplied by the appropriate coefficient, see NOTE below) shall be plotted normal to MN and the end points of these velocity vectors joined to form a velocity-distribution curve (see [Figure B.2](#)).



Key

- 1 surface velocity distribution
- 2 depth (m)
- 3 direction of flow

Figure B.1 — Measurement sections and float paths



Key

1 velocity (m/s)

Figure B.2 — Mean velocity-distribution curve from float measurements

The mean area of corresponding segments of the upper and lower cross-sections, when multiplied by the mean velocity for this panel as shown by the velocity-distribution curve, represents the discharge through that segment. The summation of the discharges for all the segments is equal to the total discharge. The mean velocity in a panel may be determined by measuring, by means of a planimeter, the area under the velocity-distribution curve for the corresponding segment or, alternatively, an approximate value may be adopted equal to the reading of the velocity halfway across the panel. See [Formula \(B.1\)](#):

$$Q = \sum_{i=1}^m \bar{v}_i \frac{A_i + A'_i}{2} \tag{B.1}$$

where

\bar{v}_i is the mean velocity in the segment;

A_i is the area of upstream segment;

A'_i is the area of downstream segment.

NOTE When it is impossible to obtain satisfactory movement of the floats across the whole width of the river, for instance if the floats move towards the centreline of the flow, an unadjusted discharge can be determined by measuring the mean of the surface velocities. This discharge is then multiplied by a coefficient determined from the results of current meter measurements carried out simultaneously with float measurements at the level which approximates to that of the float measurements.

Annex C (informative)

Example surface velocity systems

C.1 Surface velocity radars

C.1.1 General

Velocity radars are used to measure surface velocities and do not penetrate the water surface.

The radar's ability to return a surface-water velocity is influenced by:

- a) the quality of disturbances or waveforms on the water surface;
- b) the air gap or the distance between the radar unit and the water surface;
- c) the potential noise imposed by wind drift, eddies, secondary flows and macro turbulence.

Accordingly, the following procedures should be followed.

Typically, the vertical containing the maximum-surface velocity will contain the maximum velocity. Velocities should be measured relative to a known position or geo-reference. At least 20 to 25 surface-water velocities are needed to adequately identify the maximum-surface water velocity and y-axis. The velocity radar can be pointed upstream (preferred) or downstream from a bridge or walkway. It should be oriented parallel to flow lines and tilted (from horizontal) at a nominal 45-degree incidence angle. It should be noted that different radar units operate at different incidence angles. It's important to note when collecting velocity data to avoid wind-dominated reaches, eddies, secondary flows and macro turbulence.

C.1.2 Guidelines for surface radar installation — Sample quick start guide

Data should be collected at the cross-section of interest and in the vicinity of the velocity radar footprint:

- choose straight channels with parallel streamlines;
- choose a stream bed free of large rocks, weeds and obstructions that would create turbulence/slack water;
- use sections that are parabolic, trapezoidal or rectangular;
- use velocities greater than 0,1 m/s to 0,4 m/s and depths greater than 0,3 m;
- avoid variable flow conditions downstream of piers or channel obstructions (highly turbulent conditions should be avoided);
- avoid sections influenced by tributaries or contributing drainage channels.

Collect the following stream flow and channel data at the cross-section of interest:

- similar to any other point velocity discharge measurement;
- at the y-axis, record the surface-water velocity and point velocities, throughout the water column using the six-point method as a minimum (see [7.1.4.3.6](#));
- confirm the location of the y-axis by repeating this procedure to the left and right of the y-axis;

- water depth at the y-axis;
- wind speed and direction.

To estimate the position of the y-axis, rely on the location of the maximum-surface water velocity; it generally coincides at the same vertical as the maximum velocity.

Develop an index velocity to ascertain mean velocity for the section.

Velocity radars can be deployed by hand or fixed on bridges, light cableways or cable stays.

C.2 Particle image velocimetry (PIV)

PIV is a technique using images continuously filmed with video or still cameras. Three methods are currently practised:

- the large-scale particle image velocimeter (LSPIV) determines the velocity vector by matching water surface patterns between two images obtained at different time points;
- the particle track velocimeter (PTV) tracks a tracer;
- the space and time image velocimeter (STIV) monitors the movement of water surface patterns to determine the velocity vector.

Aside from experimental studies, image conversion is sometimes necessary when these techniques are applied to actual flows. For example, in the case of the video images obtained from the river line with few angles of repose and from the aircraft with large angle of repose, images should be converted with the explicit orthorectification method. Additionally, installation and location-survey of ground control points are necessary for accurate orthorectification of the water surface plane. Ideally, the ground control points should be installed at more than six locations distributed in the x, y, and z planes of the channel. Infrared cameras are available for 24 h operation.

C.3 Laser

Laser doppler instruments focus a beam of light from a laser which is mounted above the flow at a specific point. The frequency difference of the transmitted and reflected light gives the velocity at the point of measurement. The laser can be focused at a precise point in the flow field; it can also penetrate the liquid surface. In this way, a single laser can be used to scan both across the flow field horizontally and, to a degree which depends on the clarity of the water, through the depth. This enables the mean fluid velocity to be estimated over a range of flow conditions.

Annex D (informative)

Uncertainties in the velocity-area measurement

D.1 General

It should be noted that the values given in this annex are the result of investigations carried out since the publication of the first edition of this document in 1973. Reference should be made to ISO 25377:2020 and ISO 1088. Nevertheless, it is recommended that each user should determine independently the values of the uncertainties which apply to a specific measurement condition. The values in the tables are relative standard uncertainties (“one standard deviation” values, level of confidence approximately 68 %), expressed as percentages of the measured value.

The information given in the tables can also be used to determine the optimum measurement procedure for a desired accuracy.

Error varies by method and by instrument and should be determined case by case.

See also [Clause 9](#).

D.2 Uncertainties in width (u_b)

The uncertainty in the measurement of width should be no greater than 0,5 %.

As an example, the error introduced for a particular range finder having a base distance of 800 mm varies approximately as given in [Table D.1](#).

Table D.1 — Example of uncertainties for a range finder (standard uncertainties, level of confidence approximately 68 %)

Range of width m	Absolute error m	Relative uncertainty %
0 to 100	0 to 0,15	0,15
101 to 150	0,15 to 0,25	0,2
151 to 250	0,3 to 0,6	0,25

D.3 Uncertainties in depth (u_d)

For depths up to 0,300 m, the uncertainty should not exceed 1,5 %. For depths over 0,300 m, the uncertainty should not exceed 0,5 %.

As an example, the uncertainty in depth in an alluvial river whose depth varied from 2 m to 7 m and where the velocity varied up to 1,5 m/s was, for these conditions, of the order of 0,05 m measured using a suspension cable.

As another example, measurements of depth were taken with a sounding-rod up to a depth of 6 m, and beyond that value by a log line with standard air-line and wet-line corrections. These observations were made within the range of 0,087 m/s to 1,3 m/s, the results are given in [Table D.2](#).

Table D.2 — Examples of uncertainties in depth measurements (standard uncertainties, level of confidence approximately 68 %)

Range of depth m	Absolute uncertainty m	Relative uncertainty %	Remarks
0,4 to 6	0,02	0,65	With sounding rod.
6 to 14	0,025	0,25	With log-line and air- and wet-line corrections.

NOTE Column 3 relative uncertainties were computed from column 2 absolute uncertainties using mid-range depths 3,2 m and 10 m.

D.4 Uncertainties in determination of the mean velocity

D.4.1 Times of exposure (u_e)

The percentage uncertainty in point velocity measurement taken at different exposure times and points in the vertical, shown in [Table D.3](#), are given as guidance and should be verified by the user.

Table D.3 — Percentage uncertainties in point velocity measurement due to limited exposure time (standard uncertainties, level of confidence approximately 68 %)

Velocity m/s	Point in vertical							
	0,2D, 0,4D or 0,6D				0,8D or 0,9D			
	Exposure time min							
	0,5	1	2	3	0,5	1	2	3
0,050	25	20	15	10	40	30	25	20
0,100	14	11	8	7	17	14	10	8
0,200	8	6	5	4	9	7	5	4
0,300	5	4	3	3	5	4	3	3
0,400	4	3	3	3	4	3	3	3
0,500	4	3	3	2	4	3	3	2
1,000	4	3	3	2	4	3	3	2
over 1,000	4	3	3	2	4	3	3	2

D.4.2 Number of points in the vertical (u_p)

The uncertainty values shown in [Table D.4](#) were derived from many samples of irregular vertical velocity curves. They are given as guidance and should be verified by the user.

Table D.4 — Percentage uncertainties in the measurement of mean velocity at a vertical, due to limited number of points in the vertical (standard uncertainties, level of confidence approximately 68 %)

Method of measurement	Uncertainties %
Velocity distribution	0,5
Five points (see 7.1.4.3.5)	2,5
Two points (0,2D and 0,8D) (see 7.1.4.3.3)	3,5
One point (0,6D) (see 7.1.4.3.2)	7,5
Surface (see 7.3.3)	15

D.4.3 Rotating-element current meter rating (u_c)

The uncertainty values shown in [Table D.5](#) are given as guidance and are based on experiments performed in several of the world's rating tanks.

Table D.5 — Percentage uncertainties in point velocity measurement due to current meter rating error (standard uncertainties, level of confidence approximately 68 %)

Velocity measured m/s	Uncertainties	
	Individual rating	Group or standard rating
0,03	10	10
0,10	2,5	5
0,12	1,25	2,5
0,25	1,0	2
0,50	0,5	1,5
Over 0,50	0,5	1,0

D.4.4 Number of verticals (u_m)

The uncertainty values in [Table D.6](#) are given as guidance and should be verified by the user.

Table D.6 — Percentage uncertainties in the measurement of mean velocity due to the limited number of verticals (standard uncertainties, level of confidence approximately 68 %)

Number of verticals	Uncertainties
	%
5	7,5
10	4,5
15	3,0
20	2,5
25	2,0
30	1,5
35	1,0
40	1,0
45	1,0

See Reference [\[20\]](#).

Annex E (informative)

Velocity measurement under ice conditions

E.1 Safety practice for measurements from ice cover

Before taking measurements on ice it should be ensured that the personnel performing the measurements have appropriate education and knowledge about working on ice. The safety guidelines given in this annex shall not be seen as a complete set but as an introduction.

As a general rule, the ice shall consist of solid clear ice and not be thinner than 0,1 m. Preferably, the air temperature is no more than a couple of degrees above zero centigrade. Particular precautions shall be taken during spring when the sun can convert solid morning ice to rotten ice within a couple of hours. If the ice is not clear but consists of frozen snow/slush or a combination, the thickness should be at least 0,2 m.

The whole cross-section shall be checked. This is especially important if the ice is snow covered. Snowdrifts at the banks reduce ice formation and very thin ice or even open water under the snow can be found. If high velocities are part of the cross-section, this section can freeze later than the rest or even stay open. Variation in ice thickness can be huge and if snow covered this cannot be seen. The safe and checked cross-section may be marked if necessary.

The strength of the ice cover shall continuously be tested using an ice chisel or ice prod when the river is crossed. The speed of a vehicle crossing the ice cover shall be low (especially near the river banks) to prevent wave formation which could increase the pressure on the ice. Stricter precautions shall be taken where water flows above the ice, or when new ice layers are formed, since the ice cover is likely to be thin.

Operators taking measurements of discharge from the ice cover shall be equipped with appropriate safety equipment such as a life jacket or rescue suit, safety ice nails, a winter lifeline and a hot beverage. An extra set of dry clothes shall be easily available.

E.2 Velocity-area method

E.2.1 General

The principle of this method is described in the main part of this document. For channels in which a surface layer of ice exists, the cross-sectional area of water flowing is taken as the area bounded by the bed line (or wetted perimeter) and the lower edge of the ice cover or slush. When flow is between layers of ice, the cross-sectional area also includes the area bounded by the lower ice layer and the lower surface of the ice cover or slush. At times, the ice sheets on the riverbanks are thick enough to reach the riverbeds. Therefore, it is important to use poles for indicating the locations of riverbanks.

The instrument used can be mechanical such as current meters or hydroacoustic such as ADCPs or ADVs. When an ADCP is used, the stationary method should be chosen.

E.2.2 Selection of site

Discharge measurements under ice conditions are best conducted at sites where the geometry of the cross-sections is well known. The site can be unsuitable for observations if:

- a) more than 25 % of the cross-section is filled with slush, which is distributed unevenly over the cross-section;

- b) dead zones occupy more than 10 % of the cross-section;
- c) there are large areas with very low stream velocities below the recommended low limit for the instrument;
- d) it is located in the backwater zone downstream of an ice gorge or ice jam:
- e) it is liable to ice up owing to the freezing of water flowing through cracks on the surface of the ice cover indicating a possible breakup of the ice.

However, in the aforementioned conditions, division of the cross-sectional area and observation of every divided section will increase the accuracy of the discharge measurements.

During the open water period, i.e. the period in which there is no ice cover, sites additional to those normally used for water discharge measurements should be selected and marked on the banks. After the ice cover at the river reach selected for measurements has stabilized, a preliminary survey shall be made to select a longitudinal profile with a length equal to several widths. An appropriate number of holes shall be drilled along the profile to determine the occurrence of slush and its distribution. In channels in which slush is found to be present, and when it is impossible to select another measurement reach, the measurement site shall be located at the centre of a uniform river reach.

Following the preliminary choice of the site, four or five holes shall be drilled across the river at equal distances to determine whether a regular velocity distribution exists and to establish the slush and ice thickness over the cross-section. Sites in which slush divides the river into separate streams shall be avoided. Braided channels which, in the open water period, are unsuitable for the measurement of discharge owing to the multiplicity of channels, may be suitable under winter conditions since the shallower channels can become blocked by slush or ice, leaving the main channel unblocked and flowing.

E.2.3 Frequency of water discharge measurements

The frequency of water discharge measurements during the winter period shall be such as to ensure a reliable estimation of the discharge. If conditions of stable ice cover exist, methods of hydraulic interpolation of winter flow may be used. However, under difficult conditions (such as those of unstable ice cover and incomplete freezing) measurements shall be taken as frequently as possible since, in this case, the discharge is computed by the interpolation of the observed discharges. The time at which the daily discharge measurement shall be made shall be carefully chosen so as to correctly represent the time span for the observation. For example, if daily mean values are observed, the discharge measurement shall be made when the discharge is as close as possible to the daily mean.

E.2.4 Measurements of ice cover thickness

The ice cover thickness shall be measured using ice-measuring sticks which are lowered into the drilled holes. A zero reading may also be obtained. Using an L-shaped measurement pole enables the measurement of the thicknesses from the top of river ice to the bottom of the ice sheet and from the top of the river ice to the bottom of the slush ice. In this case, averaging the measurements conducted at four points, including the front, back, right and left of a hole, will result in an average ice thickness around the hole.

E.2.5 Measurements of slush depth

For small depths of slush, measurements may be made using an ice-measuring stick. The slush depth is indicated by a change in the resistance to clockwise and anticlockwise rotation of the stick during its rise, i.e. the resistance to rotation increases when the slush layer is reached. For thicker depths of slush, measurements may be made in a similar manner using a special rod with a stop plate or a perforated disc attached to its end. In addition, current meters can be used for slush depth measurements. The current meter is lowered below the slush layers and is then gradually lifted until a zero reading is obtained. It should be borne in mind, however, that the actual slush depth can be somewhat smaller than that obtained by measurement, because a zero reading will also be obtained when the flow velocity decreases to 0,03 m/s to 0,04 m/s. Hydroacoustic instruments are not suited for slush depth measurements.

E.2.6 Determination of the effective depth

In an ice-covered channel, the effective depth is computed by subtracting the distance between the water surface and the bottom of the ice layer or slush from the total depth. If using a current meter, the total water depth in the channel is measured using a rod or a cable suspended sounding weight which is lowered using a winch; the latter method is similar to the depth measurements made from a boat under open channel conditions. If a hydroacoustic instrument is used, the depth is measured by the instrument itself positioned by the operator at a known distance below the ice or slush.

E.2.7 Velocity measurements

E.2.7.1 Use of current meters and hydroacoustic instruments under winter conditions

Velocity measurements using current meters are carried out by lowering them into holes drilled in the ice cover. The current meters can be lowered using a suspension rod, a hand-operated cable (for small depths) or cable suspension equipment (for depths exceeding 3 m to 4 m). During velocity measurements, the device by which the current meter is held shall be located near the upstream side of the hole and shall be held rigidly at the upper edge of the hole to avoid the influence of vertical stage pulsation.

To prevent the current meter from freezing up when it is carried between one measurement vertical and another, it may be placed in a bucket containing heated water or in a hot-air chamber. In measurement verticals with shallow water depth, when the current meter is lowered on a rod without a tailpiece, care shall be taken to ensure the correct position of the current meter with regard to direction of flow in the vertical. In measurement verticals where slush is present, vane current meters may be used in preference to cup-type meters which are liable to become blocked by slush ice.

Before the current meter is lowered, it is advisable to clean a passage in the slush by means of a steel or wooden pole with discs or by using an elliptical (round-shaped) weight suspended on a cable.

Velocity measurements using hydroacoustic instruments are carried out by also positioning them into holes drilled in the ice cover and just below ice cover or slush. When moving the instrument from one vertical to next this should be done quickly. A thin layer of ice on the transducers will thaw fast when put in the water again but thick layers can be more troublesome. The temperature of the batteries can be more crucial and precautions to not let them to get too cold should be made.

E.2.7.2 Selection of verticals for velocity measurements

The principles governing the location of velocity verticals under ice conditions are similar to those governing the location of velocity verticals under open channel conditions. These principles are as follows.

- a) The minimum number of velocity verticals shall be as specified in [7.1.2](#), to ensure sufficient accuracy in velocity interpolation with respect to the channel width. Sections between successive verticals shall contain substantially equal proportions of the total water discharge.
- b) The location of the vertical shall be such as to reflect the flow structure and the cross-section of the river bottom in the best possible way.
- c) When current meters are used, the distance between each vertical shall exceed the propeller diameter of the current meter; therefore, in very small rivers (brooks) there may be a small number of verticals.

The profile of the bottom at the gauging station shall be determined and the location of the verticals shall be selected prior to the formation of ice cover. When this is not feasible, approximately 20 holes shall be drilled along the cross-section at equal distances. (From hydrometric practice it has been found that 20 is the minimum number of holes required to reproduce the channel profile with sufficient accuracy.) Furthermore, the intervals of the measurement holes can be determined depending on the width of the river.