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Hydrometry — Guidelines for the application of acoustic velocity meters using the Doppler and echo correlation methods

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British Standards

National foreword

This British Standard is the UK implementation of ISO 15769:2010. It supersedes BS ISO/TS 15769:2000 which is withdrawn.

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Hydrométrie — Lignes directrices pour l'application des compteurs de vitesse ultrasoniques fixes utilisant l'effet Doppler et la corrélation d'échos

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Foreword

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ISO 15769 was prepared by Technical Committee ISO/TC 113, *Hydrometry*, Subcommittee SC 1, *Velocity area methods*.

This first edition of ISO 15769 cancels and replaces ISO/TS 15769:2000, which has been technically revised.

Hydrometry — Guidelines for the application of acoustic velocity meters using the Doppler and echo correlation methods

1 Scope

This International Standard provides guidelines on the principles of operation and the selection and use of Doppler-based and echo correlation velocity meters for continuous-flow gauging.

This International Standard is applicable to channel flow determination in open channels and partially filled pipes using one or more meters located at fixed points in the cross-section.

NOTE A limitation of the techniques is that measurement is made of the velocity of particles, other reflectors or disturbances.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document applies.

ISO/TS 25377:2007, *Hydrometric uncertainty guidance (HUG)*

ISO 772, *Hydrometry — Vocabulary and symbols*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

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

3.1.1
beam angle
mounting angle of the acoustic transducer relative to the normalized profiling direction

NOTE Different beam angles will be suitable for different applications.

3.1.2
beam width
width of the acoustic signal transmitted, in degrees (°), from the centre of the transducer

NOTE This, coupled with the side lobe of the acoustic signal, will affect the suitability of a particular instrument for its application, based on the mounting location and the distance of the water volume measured from the sensor.

3.1.3
bed-mounted device
upward-looking Doppler or echo correlation device that measures velocities within a beam looking upwards at an angle through the water column

3.1.4
bin
depth cell
portion of the water sampled by the instrument at a known distance and orientation from the transducers

NOTE The instrument determines the velocity in each cell.

3.1.5
blanking distance
portion of water close to the instrument that is not sampled by Doppler technology

NOTE 1 This is left blank to allow the transducer to stop “ringing” before it receives reflected signals.

NOTE 2 It is also used to avoid the instrument sampling velocity in the zone of flow interference created close to, and by, the instrument.

3.1.6
broad-band Doppler
instrument that records velocity at set distances from the sensor (see range-gated Doppler, 3.1.11) using coded acoustic pulses to make multiple velocity measurements from a single pulse pair (ping)

3.1.7
continuous Doppler
simple type of Doppler instrument that measures the Doppler shift of all the particles within the range of the beam, taking the frequency with the largest peak as the average

3.1.8
downward-looking device
instrument that can be deployed floating on the water surface looking down into the water column

3.1.9
echo (cross) correlation
acoustic technique for recognizing echo images that can be used to determine the velocity of particles moving in the flowing water

3.1.10
profiling Doppler
Doppler instrument that discriminates between signals from reflectors at different distances from the sensor and uses this information to moderate the estimate of average velocity

3.1.11
range-gated Doppler
sophisticated Doppler instrument that records particle velocities at pre-set distances from the sensor

NOTE Some instruments can produce velocity profiles along the length of the beam, while others just log measurements from one or more pre-defined cells.

3.1.12
side lobe
most transducers that are developed using current technology have parasitic side lobes that are emitted off the main acoustic beam

NOTE The side-lobe effect needs to be allowed for in the design and operation of the instrument.

3.1.13
side-looker
Doppler usually mounted on the side of the channel

3.1.14
stage
water level measured relative to a fixed datum

EXAMPLE The level of the lowest point in the channel.

3.1.15
upward-looking device
bed-mounted instrument that looks up through the water column

3.2 Abbreviated terms

Abbreviation	Meaning	Notes
ADCP	acoustic Doppler current profiler	
ADP	acoustic Doppler profiler	This is a registered trademark of Sontek/YSI.[1]
ADVM instrument	acoustic Doppler velocity meter	Term used to describe a profiling acoustic Doppler velocity.
ADVP	acoustic Doppler velocity profiler	Alternative acronym and name for ADCP.
H-ADCP	horizontal ADCP	Side/bank-mounted acoustic Doppler velocity profiler.
H-ADVM	horizontal ADVM	Side/bank-mounted acoustic Doppler velocity meter.

4 Principles of operation of the techniques

4.1 Ultrasonic Doppler

The method of velocity measurement used is based upon a phenomenon first identified by Christian Doppler in 1843. The principle of “Doppler shift” describes the difference, or shift, which occurs in the frequency of emitted sound waves as they are reflected back from a moving body.

The sensors of Doppler systems normally contain a transmitting and a receiving device (see Figure 1). A sound wave of high frequency (F_s) is transmitted into the flow of water and intercepted and reflected back at a different frequency by tiny particles or air bubbles (reflectors). A typical reflector n produces a frequency shift $F_{\mathrm{d}n}$. The “shift” between transmitted and reflected frequencies is proportional to the movement of particles relative to the position of the sound source (i.e. the sensor).

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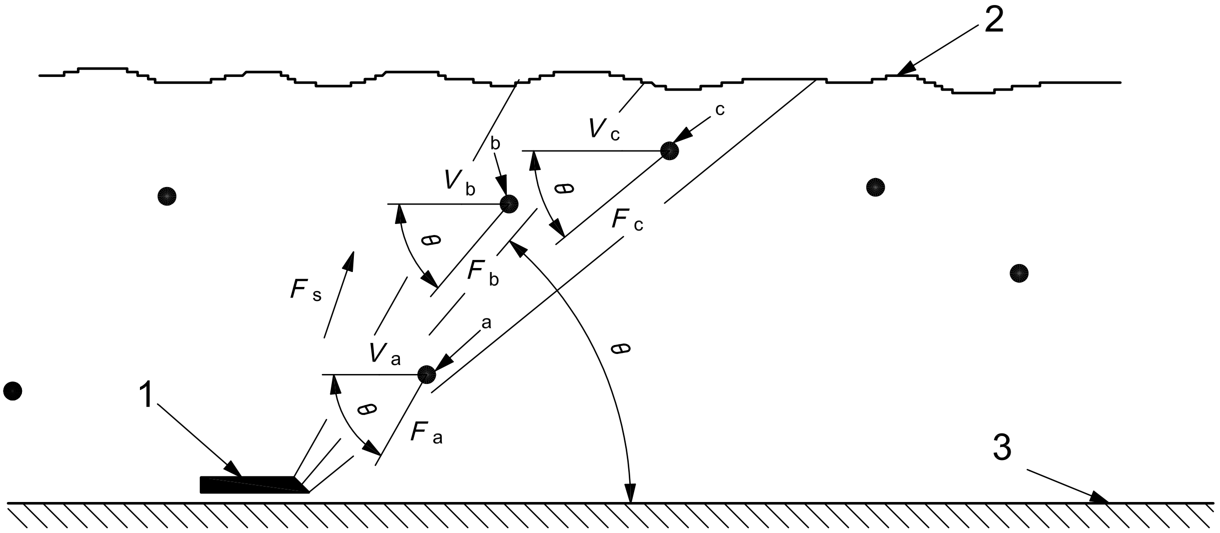
[1] Sontek/YSI is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of this product.



Key

1	Doppler sensor
2	water surface
3	channel bed
a, b and c	particulates
F_s	frequency of transmitted sound pulse
F_a, F_b and F_c	frequency of sound pulses reflected from particulates a, b and c
V_a, V_b and V_c	velocity of particulates a, b and c
.	angle between the horizontal and the angle of the sound beam

Figure 1 — Principle of Doppler ultrasonic flow measurement

Doppler shift only occurs if there is relative movement between the transmitted sound source and the reflected sound source along the acoustic beam (but not if it is perpendicular to it). The velocity of the moving reflector n can be calculated from

a) the magnitude of the Doppler shift,

b) the angle between the transmitted beam and the direction of movement, and

c) the velocity of sound in water.

It can be shown that

$$v_n = F_{\mathrm{d}n} \bullet \mathrm{c}/2F_{\mathrm{s}} \cos ._{n}$$

where

$F_{\mathrm{d}n}$ is the Doppler frequency shift produced by reflector n;

F_{s} is the frequency of sound with no movement;

v_n is the relative velocity between the transmitted sound source and reflector n;

c is the velocity of sound in water;

$._{n}$ is the angle between the reflector's line of motion (the assumed flow path) and the direction of the acoustic beam.

A Doppler velocity meter measures the resultant frequency shift produced by a large number of reflectors, of which reflector n is typical, and from that computes a mean velocity. It is the velocity of moving particles, and not water velocity, which is measured. By including the velocity of many particles, it aims to make an estimate of the mean water velocity of the volume sampled by the acoustic beam. Although the particles, if small, will travel at almost the same speed as the water, sampling errors may occur depending on the spatial and velocity distribution of the particles.

The cross-sectional area is also required to apply the velocity-area calculation of discharge. Most systems incorporate a water-level sensor, and combining the water depth with knowledge of the cross-sectional profile allows the flow to be calculated.

4.2 Operating techniques

4.2.1 Introduction

All Dopplers fit into one of four general categories, based upon the method by which the measurements are made:

a) continuous wave Dopplers;

b) pulsed incoherent profiling Dopplers (including narrow band);

c) pulse-to-pulse coherent;

d) spread spectrum or broad band.

The last three of these four categories are all range gated. Range gating breaks the signal into successive segments and processes each segment independently of the others. This allows the instrument to measure the profile of the velocity at different distances from the instrument, with precise knowledge of the location of each velocity measurement. Reference should be made to the manufacturer's instrument manual to determine the type of instrument in use.

4.2.2 Continuous wave Dopplers

Pulse incoherent or continuous Dopplers are the simplest type of Doppler system. A continuous Doppler transmits a continuous signal with one transducer, while receiving the reflected signal with a separate transducer. The instrument measures the Doppler shift, which is used to calculate the velocity of the particles along the path of the acoustic beam. The instrument takes an average of the measured velocities calculated from the frequency and the strength of the loudest reflected signals. The instrument cannot determine the precise location within the water column. In some situations, this simplicity does not cause any problems but, in channels where the sediment distribution is uneven, the loudest signal may not represent the average velocity in the channel. In addition, in channels with a heavy sediment load, most of the signal would be reflected back before fully penetrating the water column. Thus, the loudest signal would be from close to the instrument and would not be representative of the average velocity in the channel.

4.2.3 Pulse incoherent

Incoherent Doppler or profiling systems are more sophisticated than continuous wave Dopplers, in that they take into account the distance travelled by the reflected signals when calculating the average velocity. An incoherent Doppler transmits a single pulse of sound and measures the Doppler shift, which is used to determine the velocity of the particles along the path of the acoustic beam. Based upon the elapsed time since the pulse was transmitted, and the speed of sound in water, the exact location of the velocity measurement is known. By range gating the return signal at different times, the profile of velocity with the distance away from the instrument can be determined.

4.2.4 Pulse-to-pulse coherent

Coherent Doppler systems follow many of the same measurement principles as incoherent Doppler systems, but use a different method for determining the Doppler shift. Coherent systems transmit one relatively short pulse, record the return signal and then transmit a second short pulse, when the return from the first pulse is no longer detectable. The instrument measures the phase differences between the two returns and uses this to calculate the Doppler shift. Signals too close to the instrument are rejected.

4.2.5 Spread spectrum (broad band)

Like coherent systems, broad-band Dopplers transmit two pulses and look at the phase change of the return from successive pulses. However, with broad-band systems, both acoustic pulses are within the profiling range at the same time. The broad-band acoustic pulse is complex, it has a code superimposed on the wave form. The code is imposed on the wave form by reversing the phase and creating a pseudo-random code within the wave form. This pseudo-random code allows many independent samples to be collected from a single sound pulse. Because of the complexity of the pulse, the processing is slower than in a narrow-band system. However, multiple independent samples are obtained from each ping.

4.2.6 Range gating

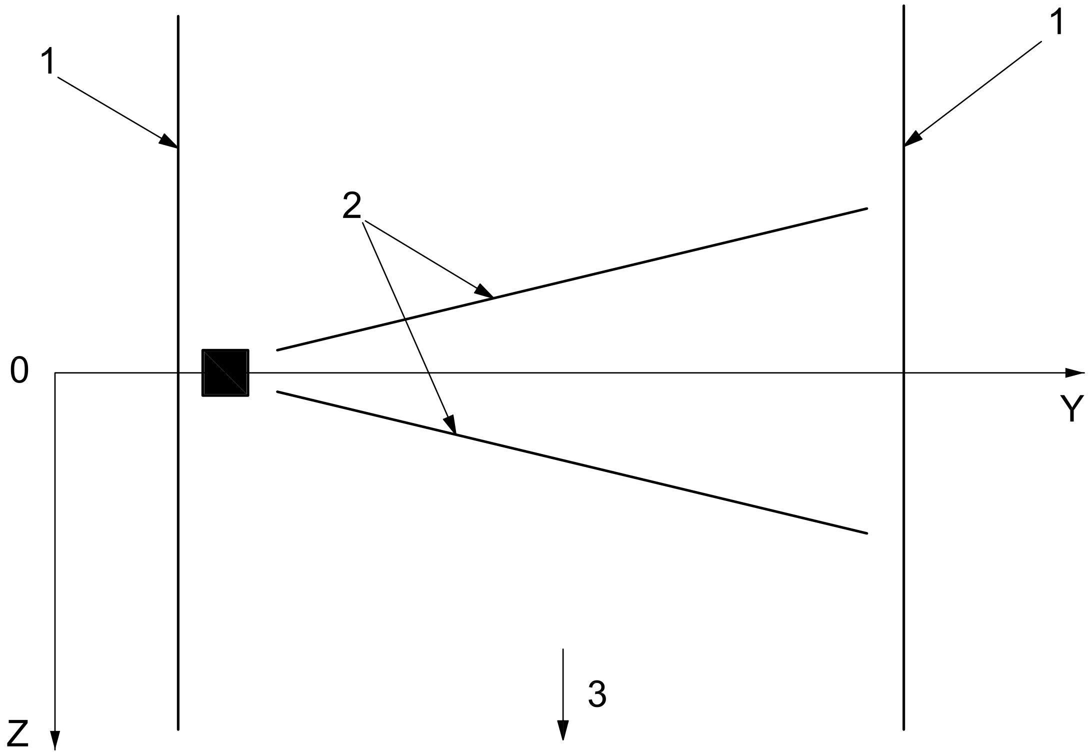
The range gating method breaks the signal into successive segments and processes each segment independently of the others. Side-looking/horizontal ADCPs use this approach, as do several of the more sophisticated bed-mounted devices.

4.3 Bed-mounted Doppler systems

Bed-mounted Doppler systems include all four types of Doppler instrument. They are normally used in smaller channels, for example up to 5 m wide and 5 m deep, where they are often practical and easy to install. However, this does not mean they cannot be used in larger channels, even though it may be difficult to install bed-mounted instruments in particularly deep channels. If siltation is a problem, it may be possible to mount such devices on a raised platform or on the channel sides.

4.4 Side-looking/horizontal ADCPs

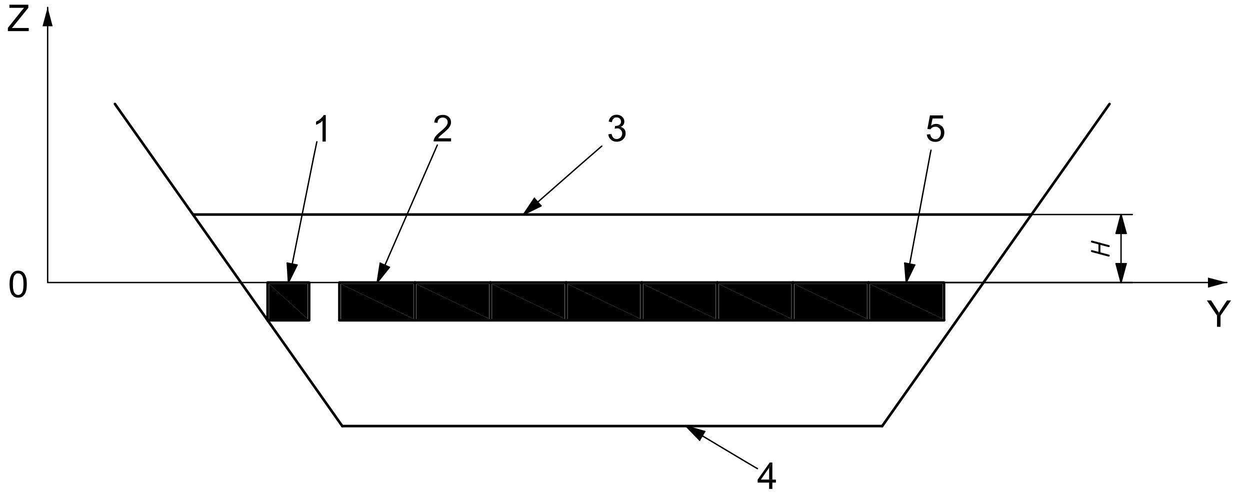
These instruments are usually fixed to the side of the channel and look across the channel to determine velocities in one horizontal layer across the full width, or a portion of the width, of the cross-section (excluding the blanking distance). Most systems consist of two transducers, one sending a beam diagonally across the channel in an upstream direction and the other diagonally across the channel in a downstream direction [see Figures 2 a) and 2 b)]. A fixed, side-looking ADCP does not estimate velocity throughout the full channel cross-section. With a known orientation of the transducers, each beam can be divided into an equal number of cells or bins and the component average velocity in the x-, y- and resultant directions can be determined for each cell. An integrated cell will give an average velocity, or individual cell velocities can then be averaged to determine the index velocity/measured velocity for the sampled length for the full distance sampled, or by selecting cells for a portion of the length. The mean velocity in the x-direction, i.e. at right angles to the measuring cross-section or parallel with the assumed direction of flow, is usually used to derive the velocity-index rating. Effectively, the instrument looks at a single horizontal layer across the channel (see-Figure 3). This layer is divided into one or more sample cells or bins and the average velocity is computed for each. The operator can usually select the size and position of these measurement cells.



Key

1 bank of channel
2 beams
3 direction of flow

a) **Plan view**

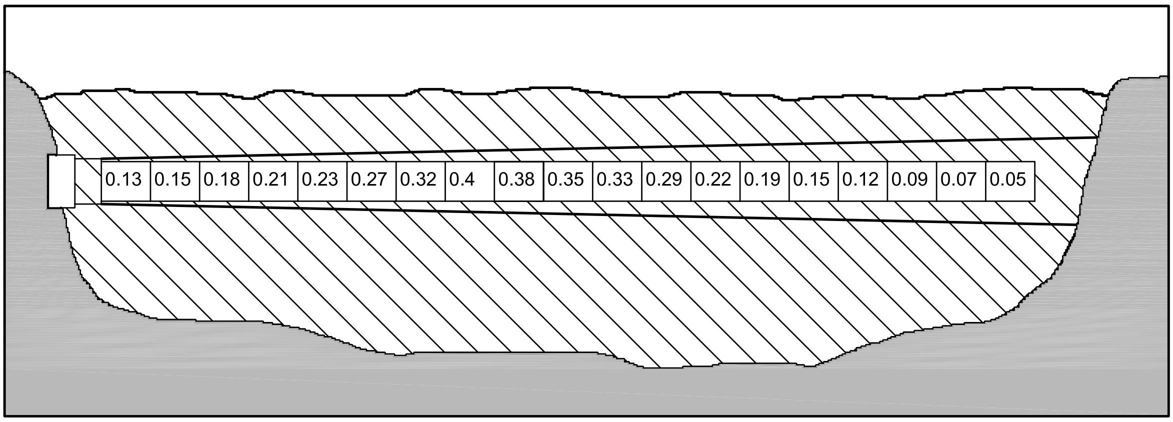


b) **Side view**

Key

1	instrument	4	channel bed
2	first cell	5	last cell
3	water surface	H	height of water above cell

Figure 2 — Diagram illustrating a typical H-ADCP/side-looker beam and cell arrangement



In this example, the beam is sampling the majority of the width of the channel. The average velocity in each cell is that averaged over the full beam width in the cell.

Figure 3 — Sketch illustrating the channel cross-section sampled by a side-looking ADCP, illustrating the spread of the beam, and the measurement cells sampled

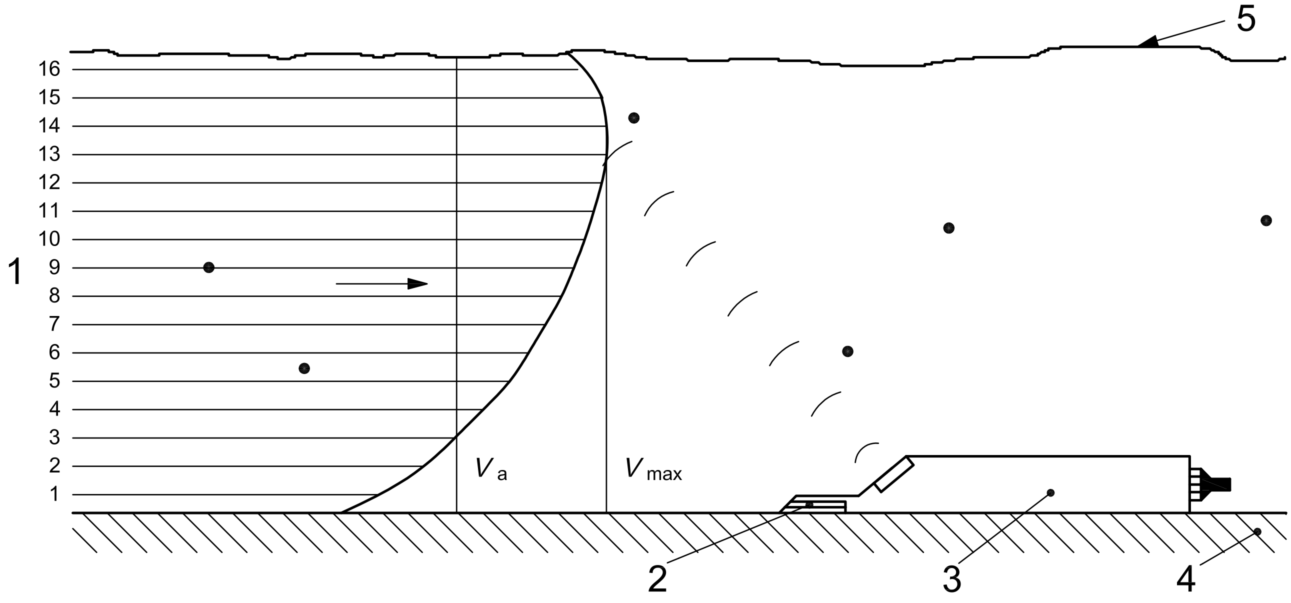
Velocities close to the instrument typically remain unmeasured. This is for the following two reasons.

a) The area near the transducer (blank after transmit) is left blank to allow the transducer to stop "ringing" before it receives reflected signals. The minimum blanking distance can be obtained from the manufacturer's literature.

b) To avoid measuring in the zone of turbulence created by the instrument itself.

4.5 Acoustic (echo) correlation method

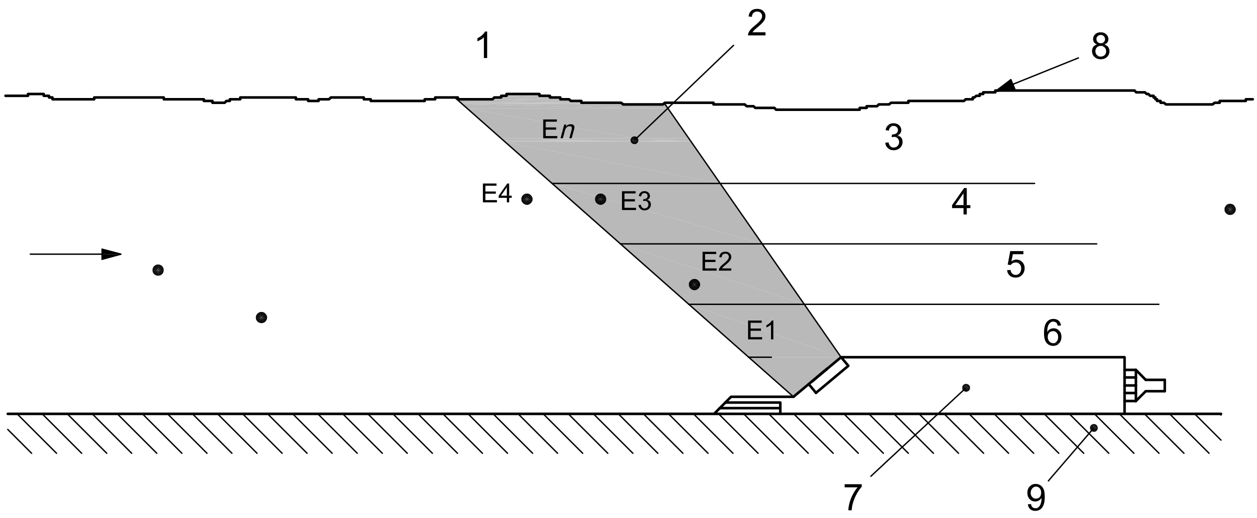
The echo (cross) correlation velocity meter is very similar to a bed-mounted ultrasonic Doppler in size and application. However, even though it is dependent on transmitted sound pulses being reflected back from moving particles, it works on somewhat different principles. An ultrasonic transducer transmits a short ultrasonic pulse (or pulse code) into the water. These pulses are reflected by particles or air bubbles. The reflected ultrasonic echo from the first pulse is received as a characteristic pattern. This is digitized and stored as the first scan of the dated echo pattern. About 0,4 ms to 4 ms later, another ultrasonic pulse is transmitted and the incoming echo patterns are digitized and stored. This is the second scan pattern. Using the travel time difference between the transmission and reception time, the position of the particles in the flow cross-section can be determined. By means of cross-correlation, the echo patterns are checked within different time windows for agreement. The cross-correlation also delivers the temporal movement of the characteristic pattern in the second scan. This temporal movement of the pattern under consideration can be directly converted to the velocity of flow for this particular beam. The process is repeated a large number of times per second and single velocities at different distances are computed in real time. The instrument effectively divides the water column in front of it into a number of cells, so it is possible to accurately determine the velocity profile in the vertical (see Figures 4, 5 and 6).



Key

1	scan windows (cells)
2	water level sensor
3	velocity sensor
4	channel bed
5	water surface
V_a	velocity at cell a
V_{max}	maximum velocity

Figure 4 — Sketch illustrating an echo correlation velocity meter

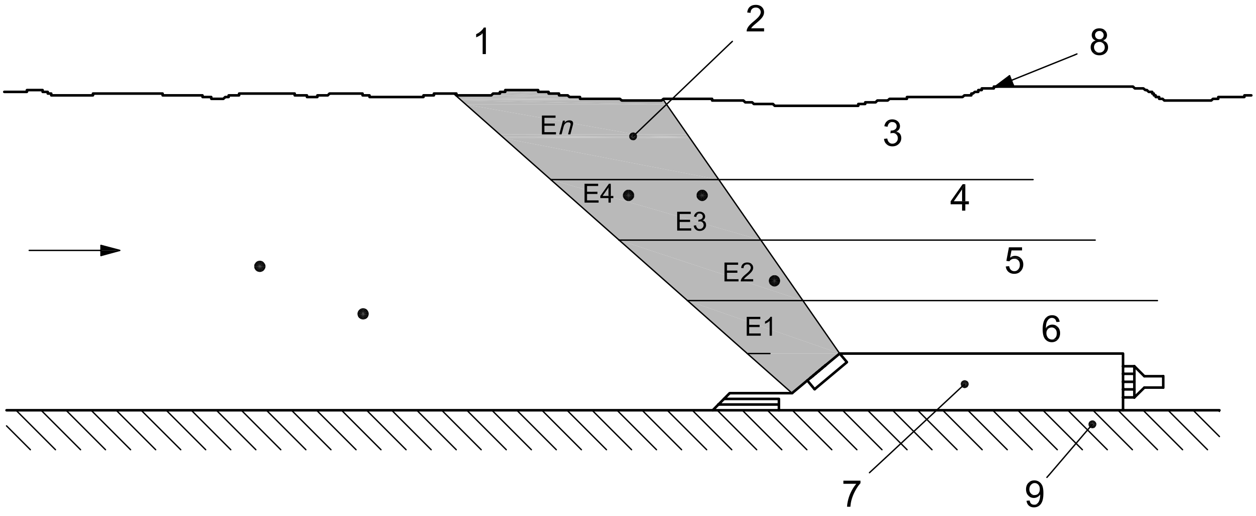


a)

Key

1	E1 to E4 = reflection particle
2	scan 1
3	measuring windows 4 to 16
4	measuring window 3
5	measuring window 2
6	measuring window 1
7	sensor
8	water surface
9	bed level

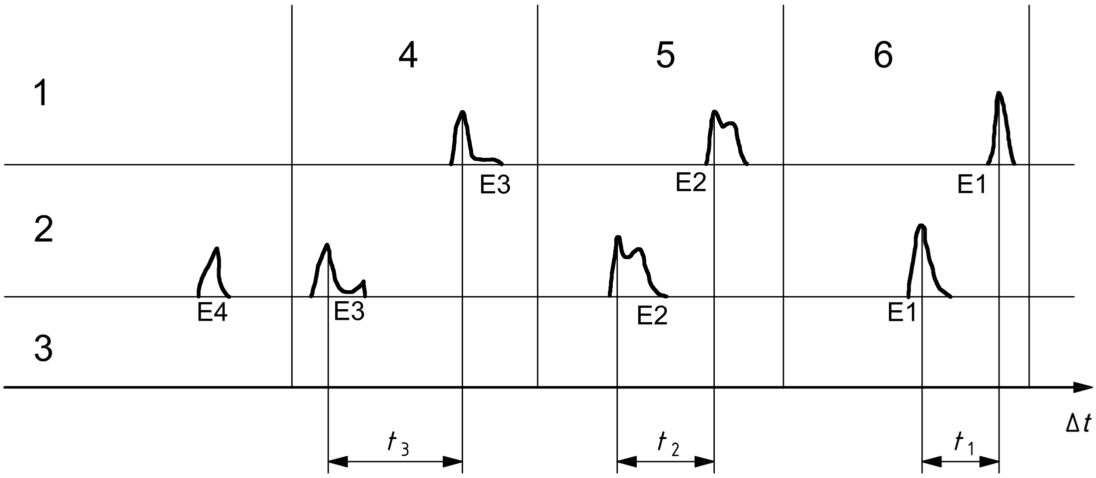
Figure 5 — Sketches illustrating the principles of the echo correlation velocity meter (*continued*)



b)

1 E1 to E4 = reflection particle
2 scan 2
3 measuring windows 4 to 16
4 measuring window 3
5 measuring window 2
6 measuring window 1
7 sensor
8 water surface
9 bed level

Figure 5 — Sketches illustrating the principles of the echo correlation velocity meter



Key

1 signal reception, 1st scan
2 signal reception, 2nd scan
3 signal evaluation
4 measuring window 3
5 measuring window 2
6 measuring window 1

For nth window: E_n is the echo in window n, t_n is the time between echoes in window n and n is the window number.

Figure 6 — Sketch illustrating the principles of the echo (cross) correlation technique

4.6 Velocity-index ratings

With the exception of multi-path transit-time ultrasonic systems with a significant number of operational paths (see ISO 6416), acoustic continuous-flow measuring devices require calibration. Unless the cross-section is relatively small, ultrasonic Doppler and echo correlation systems only measure velocity in part of the cross-section. By measuring the vertical profile, these devices obtain enough information that can be coupled with velocity distribution models to make a reasonable flow determination. As such, the measured velocity needs to be related to the mean velocity in the measuring section for any given stage and flow. A relationship between stage and cross-sectional area is also required. The relationship between mean cross-sectional velocity and the measured velocity (index velocity) is referred to as the velocity-index rating. Bottom-mounted, range-gated devices (that thus measure the vertical profile of velocity) can provide reasonable flow data without calibration in relatively small channels (<2 m to 3 m in width and depth) that are concrete lined with a regular (i.e. trapezoidal) cross-section. Nevertheless, even if the instrument can effectively sample velocity throughout the cross-section, verification gaugings are required to confirm that the discharge is being determined accurately.

In order to establish an index velocity relationship, independent measurements of discharge are made using an independent gauging method and the instrument velocities and stage readings are noted. The discharge obtained by gauging is divided by the cross-sectional area at the velocity-sensing device (obtained from the stage-area relationship), to obtain the mean velocity for that section. A relationship can then be derived to obtain the mean velocity from the measured velocity. The measured velocity is often referred to as the index velocity. There are two types of relationship that are commonly used:

a) mean velocity = function (index velocity);

b) mean velocity = function (index velocity, stage).

The former is used at sites where the relationship between mean velocity and measured velocity is relatively stable, whereas the latter is generally used at sites where the flow conditions vary with not only velocity, but also with stage. A reasonably intensive calibration effort is required to apply the indexing method.

5 Factors affecting operation and accuracy

5.1 General

The factors affecting the performance of Doppler and echo correlation velocity meters may be broadly divided into characteristics of the instrument and those of the channel or the liquid flowing in it. However, the effects interact and must be considered together.

In addition to the issues raised in 5.2 and 5.3, further practical considerations are highlighted in Annex B.

5.2 Characteristics of the instrument

5.2.1 Introduction

The characteristics of the instrument and, in particular, the sensor, will have a bearing on its performance in any given situation. There is no optimum set of characteristics. Some environmental factors will make a particular instrument perform better under some conditions but worse under others.

5.2.2 Ultrasonic beam angle (continuous wave Dopplers)

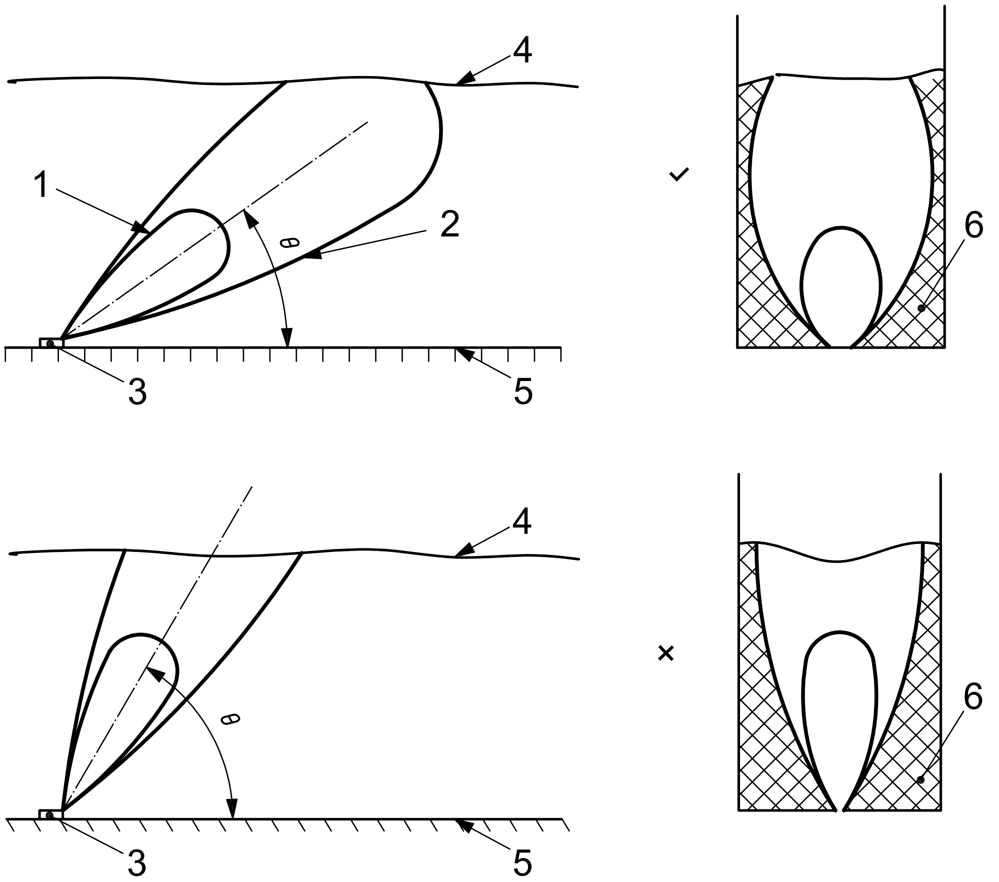
For the simpler, continuous wave bed-mounted Doppler systems, the ultrasonic “beam” is usually transmitted in the approximate shape of a cone. The term “beam angle”, or “projection angle”, in this context, refers to the angle between the cone axis and the flow direction. This subclause describes the effects of beam angle, though in fact the beam “width” must be considered at the same time (see 5.2.3). Range-gated/profiling Dopplers inherently use narrow band widths (typically 1,4° to 2,8°). Therefore, this subclause is mainly concerned with continuous wave Dopplers.

The sensor has to be installed so that it is below the liquid surface under all conditions of interest and in such a way that the beam cone reaches the lateral extremities of the channel as far as possible. The installed position is often a compromise and the installer is frequently obliged to install the sensor on the channel bed, somewhere near the centre of the cross-section. An off-centre position is sometimes used.

Assuming that an ultrasonic Doppler sensor is installed on the bed of the channel, a high angle between the flow direction and ultrasonic beam (for example between 30° and 50°) will enable signals to be obtained throughout the depth up to the limit of the penetration of the beam. However, no signals will be obtained close to the bed on either side of the sensor. Serious sampling errors will occur, particularly when the ratio between the depth of water and width of the channel is low [see Figures 7 a) and 7 b)].

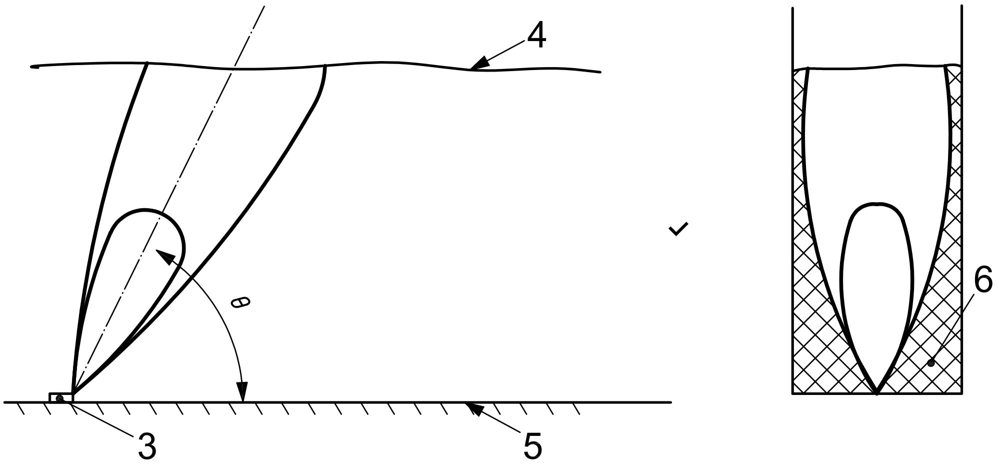
Conversely, a shallow beam angle will allow flow to be measured close to the bed and be best for shallow depths. However, a beam at a shallow angle may not reach the lateral extremities if the channel is too wide or not sufficiently long. In a long channel, the beam might theoretically reach the extremities but the penetration (range) of the beam may not be sufficient to do so [see Figures 7 a) and 7 b)].

Beam “width” also has a bearing on the velocity sampling (see 5.2.3).



a) At low/medium depth a small θ is preferable

Figure 7 — Bed-mounted continuous wave Doppler beam angle effects (*continued*)



b) At high depth large . produces better sampling

Key

1 portion sampled by main beam
2 side lobes
3 sensor
4 water surface
5 channel bed
6 unsampled area (hatched)
✓ preferred situation
× less favourable situation

Figure 7 — Bed-mounted continuous wave Doppler beam angle effects

5.2.3 Beam “width”

Beam width is a loose term indicating the spread of the beam. It is a function of sound frequency and diameter of the transmitter. The designer of the instrument may be constrained by other factors in his scope to vary the beam width.

A wide beam, i.e. one with a cone having a large spread, will give best coverage in that signals will be obtained over a greater area of the channel. However, there will be an uncertainty in velocity measurement, since the wide beam means that the actual angle made by a particular reflector may be different from the mean beam angle assumed by the instrument. Furthermore, a bias could occur depending on the distribution of velocity and reflector concentration.

A narrow beam width would have less angular uncertainty but a poorer coverage (sampling). A narrow beam allows for a longer profiling distance (greater range). Side-lookers and other range-gated and profiling instruments tend to have narrow band widths. This allows the instrument to profile, across the channel, a greater distance before the beam spread strikes a boundary. This makes them far more suitable for use in larger rivers than continuous wave Doppler systems.

If the distribution of reflectors and velocity are both fairly uniform, sampling is unimportant and a narrow beam width would give best results because the uncertainty relating to beam angle is minimized. In contrast, if the velocity distribution is non-uniform, a wide beam width will give a better sample of velocity than a narrow one. If, at the same time, the reflector distribution is uniform, the error relating to beam angle may be acceptable and so a wide beam width will be preferable.

If neither the velocity profile nor the reflector density is uniform, a significant uncertainty of measurement can be expected whatever the beam width.

Care must be taken to ensure that the range (distance from the sensor) and beam width are taken into account to ensure that the acoustic beam is not hitting a surface, i.e. channel bed or water surface (see 5.2.7.3).

5.2.4 Ultrasonic frequency

A lower frequency will generally penetrate further (greater range) but will require a larger transducer for a given beam width. A larger width/depth of channel will therefore benefit from a lower frequency transducer where the larger sensor size will not present a serious obstruction.

5.2.5 Method of determining velocity of sound

The velocity of sound in water varies with density, which is a function of temperature, salinity and pressure. Since the velocity of sound appears in the velocity determination formulae for Doppler-based instruments, errors will occur if no adjustment is made. Some instruments have no dynamic adjustment, though it is possible to put in a fixed calibration factor. This is acceptable provided the conditions do not change. Other instruments have a temperature sensor and a dynamic correction for temperature effects. This is acceptable for conditions where the water content is unchanging but the temperature does change.

When the temperature and salinity are variable, the only satisfactory solutions are for the instrument to measure the velocity of sound or to separately measure or estimate the temperature and salinity and to make a retrospective correction to the recorded data.

The effect of not making full or partial allowance for this variation is described in 5.2.6.

5.2.6 Signal processing

5.2.6.1 Continuous wave Doppler-based technologies

The basic theory shows the calculation of frequency shift resulting from a single moving reflector. In practice, of course, many reflectors are involved, moving at different speeds in different parts of the beam. The processor has to employ averaging methods of measuring frequency shifts.

Processing methods vary. Simple analogue methods are likely to give a higher weight to stronger signals from nearby reflectors. This may be serious if the velocity profile is not uniform. This will provide an additional non-uniform effect relating to beam angle and width.

Instruments employing more sophisticated processing methods attempt to remove the signal strength effect, for example by using Fourier transform techniques. Though this is an improvement, such instruments remain sensitive to non-uniform effects in the water itself.

5.2.6.2 Time/range gating technologies

Some instruments employing “time gating” or “range gating” methods attempt to separate the signals from different parts of the space in the beam, so as to produce information about the distribution of velocity. It is possible, by transmitting in timed bursts and examining received reflections at different delays, to estimate the velocity variation with distance from the sensor. However, it is not possible to say from what angle within the beam width the signals have come. Consequently, whilst this information is useful for profiling type instruments in determining velocity profiles in deep water where the beam is generally aimed across the flow (usually downwards), it is of little value in velocity meters where the beam angle is generally along the channel. This is because the information will come from different distances along the channel, not across it. However, such methods will prevent the processor being swamped by very close strong signals since they can be identified by the short time delay.

An exception to these observations would be the case of an instrument incorporating multiple narrow beams or a single narrow beam whose direction is capable of automatic variation. In such cases, velocities from small defined volumes within the channel could be measured.

It is important to remember that, whilst instruments employing techniques like time gating or Fourier transform analysis are likely to perform better in terms of short range bias, their range will still be limited by beam penetration. As the channel size increases, this will produce another type of range-related sampling error.

5.2.7 Instrument position and portion of the cross-section sampled

5.2.7.1 General

Most bed-mounted ultrasonic Doppler or echo correlation devices or installations will not sample the full cross-section unless the channel is relatively small. The portion of the cross-section sampled will depend on the channel dimensions, the position of the instrument and the design characteristics of the sensor. Echo correlation devices' and bed Dopplers' narrow beams effectively only sample velocity in a vertical direction. Side-lookers effectively sample the velocity in what can be assumed to be a horizontal slice, which may, or may not, extend across the full width of the channel. At some sites, it may be possible to carefully locate the instrument in the channel, to compensate. However, it is more usual to develop a relationship between the measured velocity and the mean velocity (see Clauses 9 and 10). The mean velocity at the location of the instrument can be obtained from the current meter, including moving-boat ADCP gauging data. This is obtained by dividing the measured discharge by the cross-sectional area at the instrument location (see 10.2.2).

5.2.7.2 Bed-mounted Doppler devices

Basic bed-mounted continuous wave Doppler instruments sample the portion of channel contained in the ultrasonic beam before it reaches the water surface. For a typical instrument in a 0,5 m deep channel, this may be a section 0,15 m wide. The deeper the channel, the larger the width sampled, because it penetrates further before receiving interference from the surface. An instrument with a smaller beam angle and larger beam width will sample a greater width, an instrument with a larger beam angle and smaller beam width will sample less. At face value, an instrument with greater beam width may seem to be a better choice, but these instruments have a greater standard deviation in their velocity measurements, which may be a problem at some sites. A balance based on the channel characteristics shall be made when selecting an instrument.

In certain channels, more than one instrument could be used in order to sample a greater proportion of the channel. This may be of some benefit when the velocity distribution is asymmetrical about the centre-line of the channel.

Current meter (including moving-boat ADCP) gaugings carried out prior to installation should aid with Doppler positioning. Most systems allow a multiplier, or equation, to be included to adjust the measured velocity to match the average velocity in the channel. This should be determined by calibration gauging. However, at some sites, a simple linear velocity-index rating may not be suitable, necessitating the computation of discharge using a more complex relationship, possibly using stage as well as index velocity as a parameter.

An instrument sited too close to the bank will receive interference from the bank before it has sampled enough of the channel cross-section.

5.2.7.3 Side-lookers

Side-mounted instruments sample the portion of channel contained in the ultrasonic beam before it reaches the other bank, its range or hits an obstruction e.g. rock on the channel bed. For a typical meter in a 5 m wide channel, this may be a cone 0,15 m in diameter with a length equal to the channel width. The wider the channel, the larger the cone diameter.

Unless the channel has a limited stage range and it is possible for the meter to sample the majority of the width of the cross-section, it will not usually be possible to mount the instrument where it will record close to average velocities for the full range of flows. As the depth of water increases or decreases, the level where average velocities occur moves up and down. Multi-point current meter or moving-boat ADCP gauging of the site at different stages may allow the position of the meter to be optimized, particularly if the site has a narrow stage range. If the site has a wide stage range, an indexing algorithm will be required to convert measured velocity to average velocity and flow, i.e. velocity-index rating. This should be determined by calibration gauging (see 9.1).

5.2.7.4 Echo correlation

Echo correlation devices sample a very narrow vertical slice of water directly upstream of the meter. The instrument divides the vertical slice into a number of cells for which the average velocity is determined. There are sufficient cells sampled to accurately define the velocity profile immediately upstream of the instrument. This is effectively the same as defining the mean velocity in one vertical similar to a current meter gauging (see ISO 748) vertical. It is therefore necessary to define a relationship between the measured velocity and the corresponding mean velocity in the whole of the flowing cross-section at the instrument.

5.3 Channel and water characteristics

5.3.1 Channel geometry

5.3.1.1 General

In order to operate effectively, an ultrasonic transducer should be clear of silt and algae. The beam path should be clear of obstructions such as weed or rocks. Due consideration should be given to the location of the instrument to avoid these pitfalls. See Clause 7.

Most ultrasonic Dopplers measure the water level of the channel and convert this to area using a pre-programmed depth/area relationship. The accuracy of this relationship will affect the accuracy of the eventual flow determination. The channel cross-section should be carefully measured during installation and an appropriate water level versus area relationship derived. The relationship should cover the full stage range expected at the site. With some instruments, it is possible to enter the cross-sectional profiles into the instrument's logging system as a series of coordinates or similar. During calibration and validation gaugings, the cross-section should be checked for any significant changes. Some instruments have facilities to include a silt level in the programme and will use this to adjust the depth/area relationship.

5.3.1.2 Bed-mounted sensors (Doppler and echo correlation)

As the channel becomes wider, the limited range of the instrument will cause the sampled velocity to be from a limited part of the whole channel.

For a small channel, particularly when the depth is also low, the size of the sensor could present a serious obstruction, causing the channel to back up and possibly to silt up (see 5.3.6). The size of the sensor could also disrupt the velocity distribution around it.

A long straight reach of uniform cross-section is preferred. This will encourage the development of a regular flow pattern. The flow pattern should be regular over the length from which the instrument is sampling particle velocities. The straight reach will usually be a longer distance than that required by other methods (e.g. ultrasonic time of flight or electromagnetic), particularly if the beam is at a small acute angle to the flow, as it usually is. The general guide is five times the width to which the sampling length should be added. It may be possible to employ flow straighteners when instruments are deployed in small channels, though they tend to block when used in sewers, raw effluent channels and streams that carry debris.

The length may not be a major problem if the water is particularly shallow, since lack of depth is likely to be a greater limitation.

Most instruments will allow the cross-sectional shape to be programmed. This is used to convert the depth measurement into area, which is multiplied by the velocity measured by the instrument to determine flow. Some systems can only process symmetrical cross-sections. Others require complex geometrical calculations to specify the channel shape. In most cases, the measured velocity is assumed to be the mean velocity. Some systems take the highest velocity and calculate the mean velocity with a calibrated conversion factor. In other systems, it is possible to input more complex velocity-index ratings to determine the discharge *in-situ*. If the discharge is determined *in-situ* it is important to store the raw data, i.e. measured velocity and water level, for reprocessing purposes if the velocity-index rating is improved upon and changed.

Some Doppler systems use velocity distribution as measured for a limited part of a channel combined with a theoretical model of velocity distribution to compute the mean velocity of the channel. Some systems support multiple methods of mean velocity calculation, i.e. theoretical and index velocity equations.

5.3.1.3 Side-lookers

If possible, the channel geometry should be as regular as possible and sites with sudden changes in cross-section or complex geometry shall be avoided, since this will result in more complicated velocity-index ratings. Side-lookers are generally capable, depending on the frequency of the transducers and the amount of depth available (see 5.3.2) of sampling distances from about 0,5 m to in excess of 100 m. However, it should be emphasized that it is not necessary with the side-looking technology and the velocity-index rating method to sample the full width of the channel.

5.3.2 Depth

5.3.2.1 Bed-mounted devices (Doppler and echo correlation)

A minimum depth of 100 mm is required for most bed-mounted Doppler and echo correlation devices. Some of the more sophisticated, range-gated bed-mounted Doppler devices may require a greater depth of flow. Even though some instruments will operate in depths of less than 100 mm, this shall be avoided. In small channels, for example less than 5 m wide, it may be possible to install a simple head-raising device downstream of the sensor to maintain a minimum depth.

The maximum depth is instrument dependent but can vary from 2 m for continuous wave Dopplers and echo correlation devices to up to 10 m for more sophisticated Doppler devices. Some of the more sophisticated range-gated Dopplers will operate in even greater depths.

5.3.2.2 Side-lookers

The minimum depth will be instrument dependent and is partially a function of the distance being sampled and the frequency of the transducers. As a rough rule of thumb, the following guidelines could be used:

a) a minimum depth at the instrument of 0,5 m, assuming the instrument is equidistant between the water surface and the bed; and

b) in most circumstances, the relatively conservative 1:10 rule (aspect ratio) can be applied, i.e. for every 10 m distance, 1 m of depth will be required. In reality, if conditions are favourable, the instrument may be capable of an aspect ratio of 1:20, or even better.

The instrument manufacturers provide tools within the instrument's software to allow the operator to detect when sound pulses are being reflected off the bed, water surface or obstructions in the channel. For many installations it will not be possible to sample the full width of the river but this is not necessary using the velocity-index method.

5.3.3 Reflector density and efficiency

These instruments require sound reflectors to operate. In practice, most watercourses contain sufficient reflectors to allow operation, the exception being extremely clean water. A site survey may be necessary to ascertain whether sufficient decibels can be generated.

Suspended solids or air bubbles will act as reflectors. The density required will depend to some extent on the instrument but, due to the variability of water conditions, most instrument manufacturers offer little guidance.

Air bubbles may act as good reflectors but it is almost impossible to estimate their concentration, size or spatial distribution. It is likely that they will tend towards the surface, which is unlikely to be moving at the average velocity. Too much air will restrict the range of the beam.

Though samples can be taken to assess suspended solids content, the size and nature of the particles will affect their efficiency as reflectors. A high concentration will give good local signals but will limit the range.

The particle distribution throughout the water will affect the velocity sampling. The distribution will be affected by the settling rate which itself is a function of the density and size of the particles.

Best results will be obtained if there is good mixing and an adequate concentration of particles is present.

5.3.4 Homogeneity

It has already been indicated that inhomogeneous distributions of either velocity or reflector concentration will affect the accuracy of flow determination using basic continuous wave Dopplers to some extent. If both occur at the same time, errors are inevitable, because the velocity sampled will not be the average velocity of the water. It is possible to obtain velocity distribution data in relatively large channels using a current meter and to take samples at different parts of the cross-section for measurement of suspended solids content. These measurements may provide an indication of the extent of inhomogeneity at the measurement site. This should not be a problem for pulsed profiling Dopplers.

5.3.5 Velocity of sound

The temperature and dissolved chemical content (e.g. salinity) will affect the velocity of sound in water. If the actual velocity of sound is not measured or if no allowance is made for its variation, uncertainties of up to ±5 % over a temperature range 0 °C to 25 °C may result as follows:

a) the variation of velocity of sound in water with temperature is from 1 400 m/s at 0 °C to 1 500 m/s at 25 °C, i.e. 7 %;

b) the variation of velocity of sound in water with salinity is from 1 480 m/s for fresh water to 1 520 m/s for sea water at 20 °C, i.e. 2,7 %.

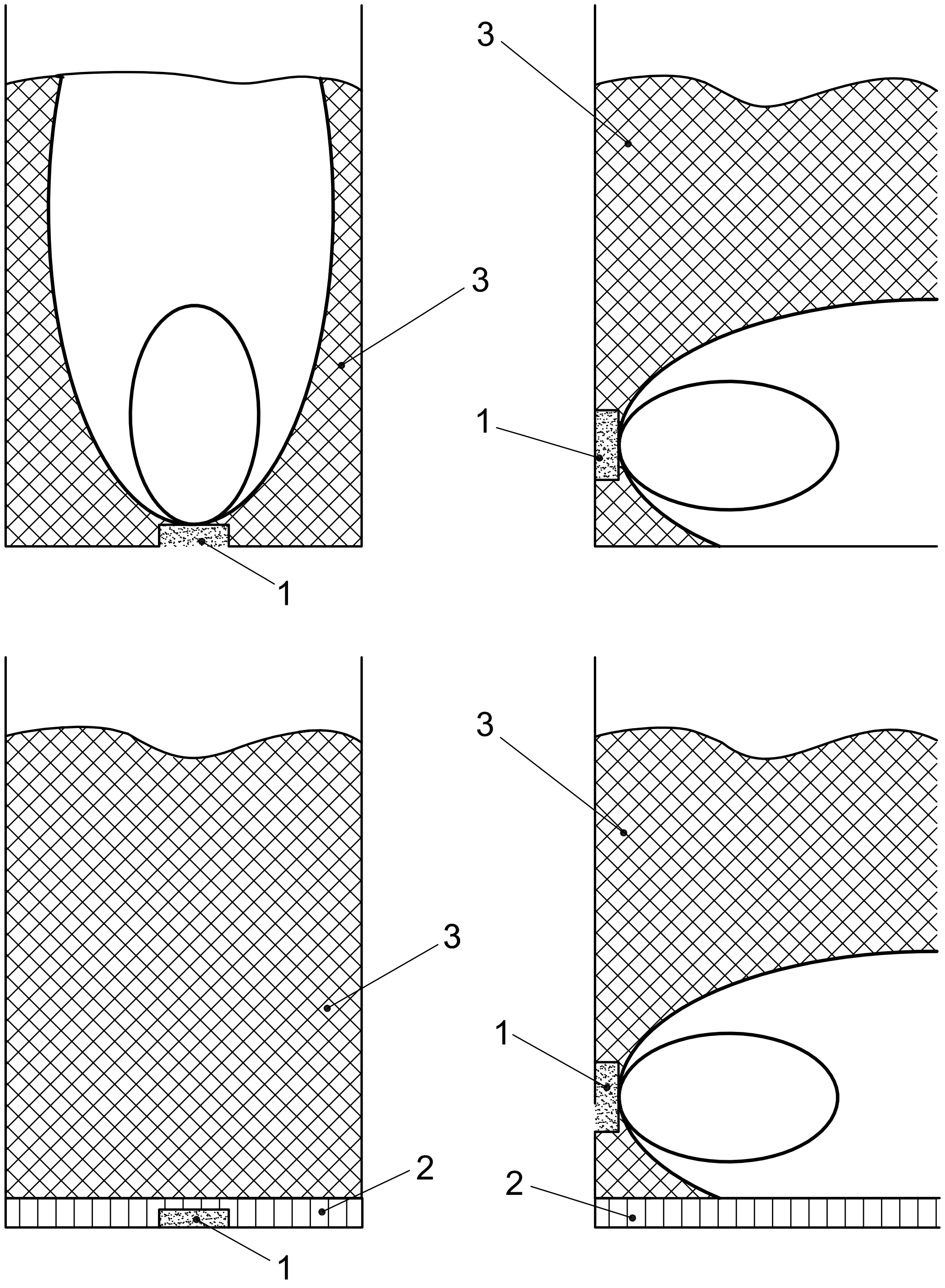
5.3.6 Bed-mounted devices: siltation, sensor position

The obvious location of the sensor is on the bottom, since this guarantees it will be in the water. However, it is also the most likely place to be covered with silt or other water-borne debris. The presence of the sensor itself could aggravate the situation by catching the debris or slowing the flow.

The sensor could be raised by spacing off the bottom or displacing off-centre in a circular bottomed channel, or side mounting (see Figure 8). However, spacing off the bottom increases the obstruction and the tendency to snag debris and alter the velocity profile. Mounting off-centre only works in suitably shaped channels. Side mounting will not work for situations where the depth can be shallow and the beam is less likely to penetrate the channel width in wider channels than if the sensor were central.

There is also the general problem of the reduction in cross-sectional area caused by the silt, which applies for all mounting positions. This would also affect other velocity area methods to some extent, although the electromagnetic method is fairly tolerant of silt build-up (see ISO 9213:2004).

Practical considerations relating to the sensor position are described in Annex B.



Key

1 sensor

2 silt

3 unsampled area (cross-hatched area)

NOTE It is usually preferred to mount a bed-mounted Doppler on the bed, unless the channel is prone to silt deposition.

Figure 8 — Hypothetical cross-sections in a river channel showing possible positions of sensor

5.3.7 Significance of water level uncertainty

The water level is required by the processor to calculate the cross-sectional area with reference to the channel shape programmed into the instrument. The product of area and velocity equals the flow, hence uncertainty in area is as equally important as uncertainty in velocity. The relationship between area and depth and hence the sensitivity to depth measurement uncertainty depends on the shape.

For example, there is a linear relationship in a rectangular channel but, at low depths in a circular channel, a small change of depth produces a larger proportional change of area.

For channels which are narrow at the bottom, depth measurement at low depths is often the dominant factor in the uncertainty of flow measurement.

5.4 Effect of weed

As with silt, all other obstructions should be avoided since they will interfere with the beam. In particular, weed contains gas [air or carbon dioxide (CO_2)] in which sound, of the frequency used by the instrument, will not travel. This will effectively block the beam and reduce the range. It can also potentially affect the accuracy of velocity measurements, since the weeds will reflect sound (and the instrument measures the velocity of whatever reflects sound).

Weed growth upstream of the measuring section can create flow disturbances or variations in velocity distributions. These factors could result in unstable velocity-index ratings.

6 Site selection

6.1 General

The choice of instrument and site selection will depend on a number of factors including the physical characteristics of the channel, the monitoring objectives, ease of installation and the cost-benefits of the resulting data. The following is provided for general guidance purposes but these are not fixed rules.

a) Bed-mounted continuous wave Dopplers and echo correlation devices will generally only be used in smaller artificial and natural watercourses, for example up to 5 m wide and 2 m to 4 m deep.

b) It should be possible to use most pulsed incoherent profiling (including narrow band), pulse-to-pulse coherent or spread spectrum or broad-band devices in channels from about 0,3 m to 10 m deep, and for some instruments up to 20 m deep. In larger, deeper channels, there are obviously logistical and cost considerations that have to be taken into account in relation to construction, installation, and operation and maintenance.

c) Side-lookers can be fixed at one side of the watercourse and can generally be used in channels greater than 0,5 m deep. However, the depth required increases with the distance sampled (see 6.4). As they do not need to sample the full width of the channel, they can be used for a wide variety of applications.

6.2 General site requirements for Dopplers and echo correlation devices

The site selected for all types of Doppler and echo correlation devices should conform as far as possible with the following general requirements.

a) The channel at the measuring site should be straight and of uniform cross-section and slope in order to minimize abnormal velocity distribution. When the length of the channel is restricted, it is recommended that the straight length upstream be at least twice that downstream.

b) Flow directions for all points on any vertical across the width should be parallel to one another and at right angles to the measurement section.

c) The bed and margins of the channels should be stable and well defined at all stages of flow in order to facilitate accurate measurement of the cross-section. The cross-section should be constant with time.

d) The curves of the distribution of velocities should be regular in the vertical and horizontal planes of measurement.

e) Sites displaying vortices, reverse flow or dead water are best avoided.

f) The flow in the measuring reach should be tranquil, i.e. highly turbulent sections, where there is visible white water and significant waves, should be avoided.

g) The measurement section should be unobstructed by trees, aquatic growth or other obstacles.

h) There should be minimal air entrainment in the water column.

i) Where thermal differentiation in the water column occurs, due consideration should be given to the type and positioning of the transducers. In such circumstances, the velocity-index rating could be adversely affected as well.

j) The depth of water at the section should be sufficient at all stages to provide for the effective immersion of the instrument.

k) The velocity range shall be within the measuring range of the instrument. Many systems have an effective operating range of between 0,02 m/s and 5 m/s. Some of the more sophisticated systems will operate successfully at lower velocities, but the uncertainties in the velocity determination will increase more rapidly as the velocity approaches zero.

l) There should be a temporally consistent relationship between the velocity determined by the sensor and the mean cross-sectional channel velocity. At more difficult or complex sites, this relationship may also be a function of stage.

m) There should be a suitable cross-section for gauging at, or within an acceptable distance from, the instrument location.

n) Algal and weed growth should be limited.

o) Acoustic reflectors are required in the water, though it should be noted that, due to the mineral content of water, visually clear water may contain numerous reflectors.

A flow chart to assist with site selection for ultrasonic Doppler and echo correlation instrument installations is given in Annex A.

6.3 Bed-mounted ultrasonic Doppler and echo correlation devices

The following characteristics are generally required.

a) A depth generally less than 2 m for continuous wave Dopplers and echo correlation devices. Pulsed profiling Dopplers can be used in far greater depths, for example up to 20 m. For some devices, the limitation on their use is often caused by the problems of installation and maintenance at higher depths, rather than the limitations of the instrument.

b) The minimum depth will be dependent on the type of sensor. Some instruments will operate with a minimum depth of 100 mm above the sensor. However, a minimum depth of water of 200 mm above the sensor is normally recommended. Pulsed profiling often requires a minimum depth of 0,4 m above the bed (depending on the size and position of the sensor). However, some systems only require a minimum depth of 0,2 m or even less.

c) A uniform suspended solid distribution is required for continuous wave Dopplers but is less important for the pulsed profiling Dopplers.

d) A straight-approach channel length greater than five times the channel width, and a straight channel, downstream of the instrument of twice the channel widths, provided other site selection criteria are satisfied and, in particular, there is a smooth water surface.

If the channel is too shallow and not too wide (e.g. < 5 m), it may be possible to install a small obstruction downstream, such as sandbags, stop-logs or stones, to maintain the required depth. The obstruction should be such that there is no adverse impact on the velocity distribution at the point of measurement, i.e. it should not cause instabilities in the velocity-index rating.

6.4 Side-lookers

Side-mounted range-gated Dopplers have the potential to sample effectively the full width of the channel if required. The maximum width varies between instruments. A minimum depth of 0,5 m is required which, as a rough, first rule of thumb, can be considered to increase in 1 m steps for every 20 m across the section. However, the minimum depth and the distance that can be profiled across the channel are highly dependent on the type of instrument, the beam width and size of the side lobes and their subsequent interference.

A single side-mounted Doppler can only be used in a channel with a wide stage range if the index method for discharge calculation is carried out. When an instrument is considered for permanent installation at such a site, the need for post-processing must be allowed for.

A shallow channel with an asymmetrical bed is not usually a suitable site for a side-mounted look-across instrument.

7 Measurements

7.1 Velocity

7.1.1 Ultrasonic Dopplers (bed mounted)

The Doppler shift or phase shift is used to determine the velocity of particles in the cross-section. The particle velocities are assumed to be the velocity of the flowing water. These instruments measure a portion of the flowing cross-section, which for all but the smallest channels is effectively only a fraction of the flowing cross-section. With the exception of the range-gated instruments which know where and what they are sampling, the portion of the part of the channel which is sampled is not known. A velocity-index rating is required to convert the measured velocity to the mean velocity in the whole of the flowing cross-section.

7.1.2 Ultrasonic Dopplers (H-ADCPs/side-lookers)

Either the Doppler shift or phase shift is used to determine the velocity in a number of cells across the watercourse that can be set beforehand by the user.

NOTE There will be a portion close to the instrument referred to as the blanking zone, which will not be sampled, but this is usually negligible in terms of the flow determination.

The average velocity in the successfully sampled cells or bins can be used to determine the index velocity. At some locations it may be better to only use a selected number of cells to determine the index velocity.

7.1.3 Echo correlation

The acoustic correlation technique is used to track the movement of moving particles or disturbances in the water to estimate their velocity. The velocity of the moving particles or disturbances is assumed to be the water velocity. The water column in front/upstream of the sensor is divided into a number of cells (16 cells are used by one type of instrument) to accurately determine the velocity profile for one vertical. The mean velocity in the vertical (instrument velocity) is the index velocity that needs to be related to the mean velocity in the flowing cross-section.

The mean velocity for the cross-section is obtained by undertaking a number of discharge measurements over a range of flows at the locality using another technique/gauging method (see Clause 10). The discharges obtained from these gaugings are then divided by the corresponding cross-sectional area at the location of the instrument to obtain the mean velocity.

NOTE If the individual discharge measurements are undertaken at a different location from the instrument, the mean velocity obtained at the gauging site will not be the same as the mean velocity at the instrument site (see Clause 10).

7.2 Water level

Water level is usually measured by means of an integral pressure-activated sensor, an upward-looking (water ranging) ultrasonic or a downward-looking (air ranging) ultrasonic water level sensor. The accuracy of these devices is dependent on the range they are designed for (±0,5 % of range is a typical figure). The manufacturer's specification should be consulted. The effect of surface irregularities may degrade the accuracy further. The significance of the depth uncertainty depends on the channel shape.

Care should be taken in the case of a closed conduit, which sometimes runs full and sometimes partly full. When full, the pressure could significantly exceed that produced by a head of water equal to the conduit height. This could cause problems for systems using a pressure level transducer. It is capable of withstanding the maximum pressure and this will probably dictate that a low sensitivity transducer (i.e. with a range much greater than the conduit height) must be used, thus limiting the accuracy. The manufacturer's specification should be consulted. A special transducer or an alternative method of measuring depth may be required.

7.3 Determination of cross-sectional area

When a site is established, a cross-sectional survey should be undertaken at the measuring section, i.e. the cross-section at which the instrument is located. This can be done using any acceptable surveying technique and should be extended upwards to at least the maximum target level, for example the estimated 100-year flood level. The level data should be to a fixed datum, either to national datum or water level (stage) zero. If the former, it is essential to know the level of stage zero relative to national datum. It is also important to know what the height (zero) of the water level sensor on the sensor is, relative to stage zero and/or national datum. The cross-sectional survey data are then used to develop a relationship between water level/stage and cross-sectional area. It should be noted that some systems allow the user to enter the cross-sectional data directly into the instrument. There are software tools available that can be used to convert the survey data into a stage-area relationship. The relationship can take the form of a table or an equation of the form:

$$A = f_n(h) \tag{1}$$

where

A is the cross-sectional area, in square metres (m^2);

f_n is a function of h;

h is the stage, in metres (m).

8 Installation, operation and maintenance

8.1 Installation considerations

8.1.1 General

Establish the best location for the instrument in the cross-section and the need for more than one instrument (see Clause 9).

The installation requirements are in part dependent on the instrument type. Prior to the installation requirements being determined, the instrument type should be selected (see Clause 12).

Each installation is site specific. When the instrument type has been selected, the installation can be designed taking account of the channel bed and bank material. The design of the installation will also depend on the level of siltation in the channel, accessibility and bank side requirements.

In watercourses with very low suspended solids and few other reflectors, the instruments cease to function. During installation, the installation process disturbs the channel sediment, so the instrument may function while the hydrometric staff is on site. During installation in clear streams, it is desirable to allow time for the sediment to settle or return to the site after a few hours to ensure that the Doppler meter is working.

8.1.2 Bed-mounted instruments

8.1.2.1 Installation

This type of system is practical and easy to install in smaller, shallower channels. There may be difficulty installing bed-mounted instruments in particularly deep or large channels. For such sites, it may be preferable to install an H-ADCP/side-looker.

A bed-mounted Doppler or echo correlation device should be fixed to the bed directly or indirectly (on a block or mounting device). Some manufacturers supply suitable mounting devices. Several manufacturers suggest fixing instruments to brackets mounted on the bank and extending into the channel, to avoid entering the water during installation. Most wall brackets collect debris and affect the ability of the sensors to measure velocity accurately. In a wide channel, the bracket should be large enough to reach out into the channel. However, this type of bracket should only be used in extreme circumstances where entry into the channel is not possible.

8.1.2.2 Siltation

A mobile bed, or a section, prone to siltation, may bury the instruments. This does not seem to harm the sensors, but it prevents sensible data from being recorded. The instruments may be installed slightly above the bed, perhaps mounted on a concrete block, to avoid the silt. Side mounting of bed-mounted Dopplers to avoid the silt is not recommended. In such circumstances the installation of an instrument designed for side mounting, i.e. an H-ADCP/side-looker, should be considered. Typical streams considered as applications for Doppler and echo correlation instrumentation are sometimes considerably wider than they are deep. In such situations, look-up instruments mounted on the side of the channel would encounter interference from the water surface and the channel bed before sufficient sampling of the cross-section to estimate average velocity.

If required, it may be possible to stabilize the channel bed in the Doppler cross-section to inhibit siltation. The method used will depend on the severity of the situation. In severe cases, sections of the mobile bed could be replaced with concrete or block work, etc. Simply installing some sort of barrier sunk into the bed may also be sufficient. In some cases the bracket designed to hold the instrument may also serve to stabilize the bed. It should be noted that, if a site is prone to siltation, it will remain an issue whatever measures are taken. It is better to avoid the situation. In some cases, the cost of bed stabilization will be prohibitive.

In sections prone to siltation, the ability of the instruments to determine flow may be affected (see 5.3.6).

8.1.2.3 Location in channel

It is important that the velocities determined by the instrument have a stable relationship with the average velocities in the channel.

8.1.2.4 Surface-mounted devices

Some manufacturers and organizations have installed devices that are traditionally mounted on the bed just below the surface on flotation devices to overcome siltation problems. This can be a viable alternative to bed mounting but the manufacturer's advice should be sought. An alternative independent water level sensor may be required.

8.1.3 H-ADCPs/side-lookers

8.1.3.1 Installation

A side-mounted Doppler should be securely fitted to a specially made bracket mounted on the side of the channel. The design of the bracket will depend on the instrument and the channel. Some manufacturers may be able to give advice as to installation, or supply a mounting bracket, but standard brackets may not be suitable for specific sites and this should be considered before making a purchase. The instrument should be mounted as close to the channel bank as possible to avoid missing too much of the flow and to minimize the area of the obstruction available to trap debris.

Before an installation is made permanent, a check should be made for side-lobe interference. The instrument signal strength can be used to check for boundary interference within the sample volume. If no boundary interference is present, the signal strength of each beam should peak at the transducer and then gradually decrease with distance from the transducer. Boundary interference will cause the signal strength to increase markedly or “spike”. The size of the sample volume would need to be selected so that the spike remains outside the sample volume. Manufacturers recommend that the end of the sample volume be placed no closer than 10 % of the total distance from the instrument to the boundary (for example, if a boundary is discovered at 10 m, the end of the sample volume should be no further than 9 m).

8.1.3.2 Siltation

Siltation problems do not severely affect the installation of side-mounted instruments. The ability of the instruments to estimate flow may be affected as the cross-section changes and could also affect the velocity-index rating.

8.2 General maintenance considerations

Essential maintenance checks should form part of every routine quality assurance visit. Some recommended points to consider are given below. In addition, reference should be made to manufacturer's guidance and operating instructions.

a) Check the sensor for secure fixing, alignment and for build-up of coatings or silt. Ensure that the instrument is correctly aligned, horizontally and vertically. If available, the manufacturer's diagnostic software should be used to check that the instrument is not tilting either forwards, backwards or sideways.

b) A check on the beam clearance should be undertaken at every visit to ensure that the instrument has not moved or that an object has not moved into one or more of the beams.

c) Ensure that the channel is clear of debris, silt deposits and weed.

d) Perform battery checks and replace as necessary.

e) If appropriate, check seals on the instrument according to the manufacturer's instructions.

f) Check that the vent for the pressure sensor (if installed) is not blocked (or filled after flooding).

g) If present, check cables and ducting (for condition and secure fixing).

h) If present, check the instrument housing or kiosk for signs of interference, secure fixing, lock operation, etc.

i) Check for evidence of either scour or deposition at the site; this will affect the validity of the cross-sectional area versus depth relationship used for discharge computations. The measuring section should also be periodically surveyed to amend or reaffirm the validity of this relationship.

j) Note the current hydraulic conditions at the site and check for adverse changes since installation.

k) Check the instantaneous or most recent stage and velocity readings and discharge determinations if computed *in-situ*.

l) Undertake comparisons with another gauging method.

9 Calibration, evaluation and verification

9.1 General

Flow determinations obtained from meters of this type require verification. Performance will be improved by *in-situ* calibration as opposed to verification. Most instruments allow the use of a correction factor, usually fixed, or algorithms, which can change with velocity and/or depth. Use of an algorithm may require additional processing beyond the instrument's own software. Even if it is possible to determine the discharge within the instrument, the basic velocity data should be downloaded and stored for post-processing. A temporary comparison (or check) method of flow measurement is required. In reality, except on very small channels where bed-mounted Dopplers can sample the whole of the flowing cross-section, velocity-index ratings are required (see Clause 10).

There are a number of methods that may be employed for *in-situ* calibration/velocity-index rating purposes.

a) Gauging using point rotating element and electromagnetic current meters, ADVMs and ADCPs.

b) Dilution gauging.

c) On small watercourses, the temporary installation of a weir or flume may be a possibility (provided the velocity distribution is not affected).

d) Volumetric methods.

e) Creating or using limited circumstances whereby the flow also passes through another measuring point up or downstream. Typically, this type of situation may be achievable at waste-water treatment works applications.

For these methods, see ISO/TR 8363. Some practical considerations for application are given in Annex B.

9.2 Calibration and performance checking

9.2.1 General

All types of ultrasonic Doppler and echo correlation devices, even those that have been calibrated in the laboratory, require calibration, or verification. Laboratory calibration only ensures that the instrument is recording the correct average velocity for the sample area, it does not verify that the sampled velocity is correctly converted to actual velocity or flow. This is a site-specific process and cannot be tested in the laboratory.

With most instruments, on-site calibration with conventional current meter gauging is a reasonably easy process. Current meter gaugings are also required to determine the optimum location for the device in the cross-section and any relevant settings to be configured.

Calibration gaugings should be undertaken when the instrument is installed and subsequently over a range of flows. Velocity profiling undertaken prior to installation can also be used to assist calibration, but greater weight should be given to data obtained at the same time as the instrument data.

9.2.2 Indexing method

It is important to undertake reconnaissance velocity profile surveys of the channel in a range of flows prior to installation. The data collected should be used to determine the best height or position for the instrument and, in the case of H-ADCPs/side-lookers, the best settings for the sample cell size and blanking distance.

Once the instrument has been installed, the gauging regime should be continued over a range of flows. This information, and data from gaugings carried out prior to installation, should be used to derive a relationship between the velocity recorded by the instrument and the actual velocity or flow. This relationship may be a simple linear relationship or, depending on the hydraulics and other characteristics of the site, could be a more complex relationship, consisting of more than one equation, some other mathematical function (such as a power law) or a relationship also including stage as a parameter (see Clause 10).

The reconnaissance gaugings should also be used to determine the practicality of applying the indexing method to the site.

9.2.3 Performance checking

When an installation has been successfully calibrated, the calibration should be checked periodically, as for any other gauging station.

10 Determination of discharge

10.1 General

The Doppler and echo correlation techniques described in this International Standard are velocity area methods. Discharge is therefore determined using the continuity equation:

$$Q = \overline{V} \cdot A \tag{2}$$

where

Q is the discharge, in cubic metres per second ($\mathrm{m^3 \cdot s^{-1}}$);

$\overline{V}$ is the mean velocity in the instrument measuring section, in metres per second ($\mathrm{m \cdot s^{-1}}$);

A is the cross-sectional area at the instrument measuring section, in square metres ($\mathrm{m^2}$).

For many installations, the velocity determined by the instrument will not be the same as the mean velocity in the measuring section, since in most channels, the instrument will not sample the whole of the flowing cross-section. The mean velocity is determined using the instrument velocity. This determination is undertaken by using a relationship between the mean velocity and the instrument velocity, usually referred to as the index velocity. Velocity-index relationships can take the following general forms:

$$\overline{V} = f_n(V_\mathrm{i}) \tag{3}$$

$$\overline{V} = f_n(V_\mathrm{i}, h) \tag{4}$$

where

V_i is the instrument/index velocity, in metres per second ($\mathrm{m \cdot s^{-1}}$);

f_n is a function;

h is the stage, in metres (m).

The cross-sectional area is determined using the stage-area relationship (see 7.3).

The following steps are required in the velocity-index rating development process.

a) Develop a stage-area relationship at the instrument measuring section. This can be undertaken at any time, usually when flows are low.

b) Undertake a series of gaugings over as wide a flow and stage range as possible. The number of gaugings required will be dependent on the physical characteristics of the site, similar to the development of conventional stage-discharge relationships (see ISO 1100-2).

c) During each gauging, the instrument stage and velocity or velocities should be recorded at a suitable frequency, e.g. 1 min intervals.

d) For each gauging, the discharge should be computed and divided by the corresponding cross-sectional area at the instrument cross-section to obtain the mean velocity. This can be obtained from the stage-area relationship. It should be noted that the cross-sectional area at the instrument site, and not the gauging site, should be used for this calculation, if they are at different locations (see 7.3).

e) The average instrument stage and velocity should be computed for the period of the gauging. The estimated mean velocity, instrument velocity and, where appropriate, the stage can then be used to derive the velocity-index rating.

10.2 Velocity-index ratings

10.2.1 General

The rating should be the best fit to the field data and should be in sensible consideration with the hydraulics and the other physical characteristics of the site. It should be expressible as one or several mathematical relationships, suitable for use on the data processing and management systems to be used. It should also be valid over the required range of stages and flows.

Care should always be taken when extrapolating relationships. There should be no need to extrapolate the stage-area relationship, since this can be undertaken at low stages and it should be possible to survey the cross-section to an elevation above the maximum predicted water level.

It is important to have a thorough knowledge of the site and a reconnaissance survey is essential. This information should be used to continually develop and refine the rating as the hydraulics of the site, together with measurement data, can assist with the choice of the rating type or form. Finally, it is important to acknowledge that rating development is highly site dependent and hence there is no single methodology or formula that will work at all sites.

10.2.2 Determination of mean velocity from calibration data

For determining the mean velocity, the flow is gauged using another technique, such as conventional current meter or moving-boat ADCP gauging. The mean velocity at the instrument site may be directly available from the gauging data. If not, it can be derived by dividing the gauged flow by the cross-sectional area at the instrument site.

$$\overline{V} = \frac{Q_\mathrm{g}}{A_\mathrm{i}} \tag{5}$$

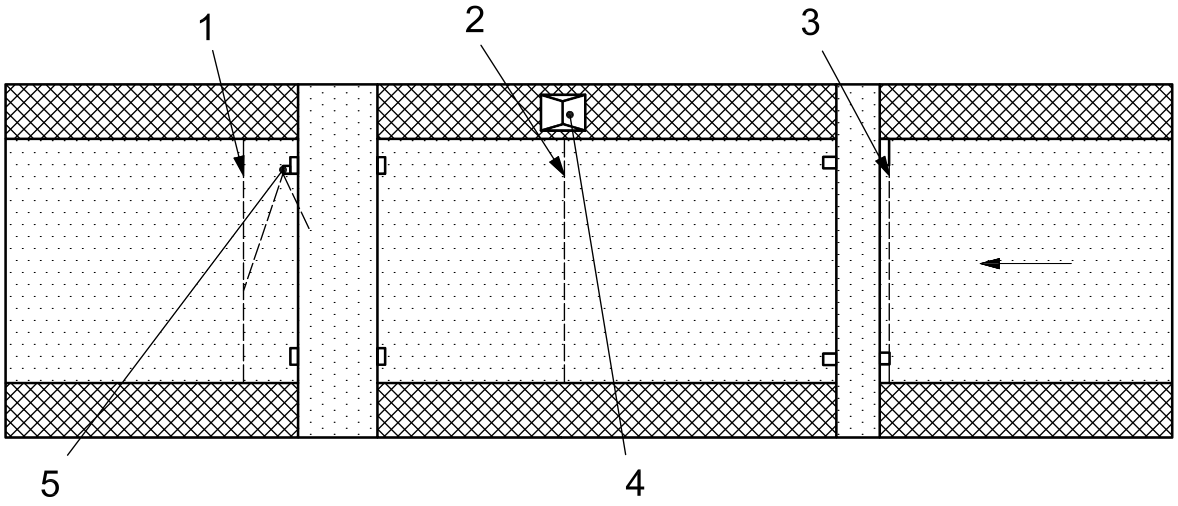
where

$\overline{V}$ is the mean velocity at the instrument site, in metres per second ($\mathrm{m \cdot s^{-1}}$);

Q_g is the gauged discharge, in cubic metres per second ($\mathrm{m^3 \cdot s^{-1}}$);

A_i is the cross-sectional area at the instrument, in square metres ($\mathrm{m^2}$).

It is not necessary to undertake the gauging exactly at the instrument location. Providing there are no inflows or outflows, a convenient site upstream or downstream can be used. It is, however, important to measure the channel cross-sectional area at the instrument site. The mean velocity shall always be calculated by dividing the gauged flow by the cross-sectional area at the instrument site. This is shown in Figure 9, which is a sketch of a hypothetical H-ADCP/side-looker installation.



Key

ADVM	acoustic Doppler velocity meter/H-ADCP	4	gauge
$Q1 = Q2 = Q3$	(Q is the gauged flow)	3	bridge measurement section
1	standard cross-section	5	H-ADCP
2	wading measurement section		

NOTE Area is always computed at location 1.

Figure 9 — Sketch illustrating where the area for computation of mean velocity should be determined (source: *US Geological Survey*)

10.2.3 Distribution of velocity in open channels

Understanding of the distribution of velocity in open channels can assist with the development of velocity-index ratings.

10.2.4 Forms of velocity-index ratings

10.2.4.1 Simple linear relationships

It can be shown that, if the classical form of the velocity distribution applies and there is good hydraulic mixing (strong turbulence), the velocity-index rating could take a straight-line relationship of the form:

$$\overline{V} = aV_{\text{i}} + b \tag{6}$$

where

$\overline{V}$ is the mean velocity in the measuring section, in metres per second ($\text{m}\cdot\text{s}^{-1}$);

V_{i} is the index (measured) velocity, in metres per second ($\text{m}\cdot\text{s}^{-1}$);

a and b are constants.

This type of relationship can be determined by linear regression.

10.2.4.2 Using stage as a parameter

At some sites, the distribution of velocity may not be stable, due to variable backwater effects such as seasonal weed growth. This could indicate that the fit is poor and the relationship is not a good one. In order to resolve this and improve the ability to determine mean velocity from index velocity, stage can be introduced as a parameter.

If stage is introduced as a parameter, the rating can take the following forms:

$$\overline{V} = aV_\mathrm{i} + bh + c \tag{7}$$

or

$$\overline{V} = V_\mathrm{i}(a + bh) + c \tag{8}$$

where

$\overline{V}$ is the mean velocity in the measuring section, in metres per second (m•s^{-1});

V_i is the index (measured) velocity, in metres per second (m•s^{-1});

h is the stage, in metres (m);

a, b and c are constants.

10.2.4.3 Other forms of velocity-index ratings

There may be reasons why the velocity-index rating does not form a straight line. Other forms of velocity-index rating can be applied in the determination of mean velocity; some examples are as follows:

Polynomial: $\overline{V} = aV_\mathrm{i}^2 + bV_\mathrm{i} + c$ (9)

Logarithmic: $\overline{V} = a\ln V_\mathrm{i} + b$ (10)

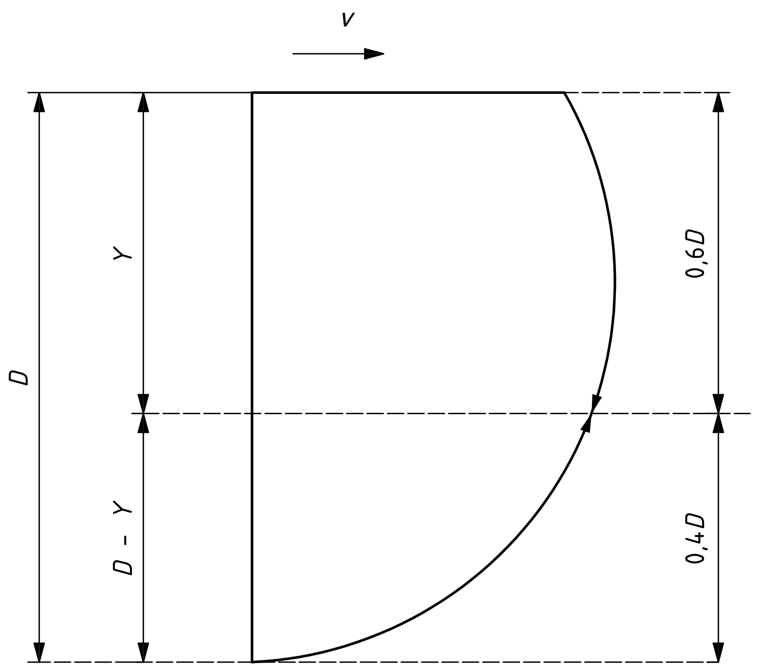
Power law: $\overline{V} = aV_\mathrm{i}^b$ (11)

Exponential: $\overline{V} = a\mathrm{e}^{bV_\mathrm{i}}$ (12)

Even though the above relationships can often give very good fits to the data points, care should be taken when extrapolating beyond the lower or upper limits of available calibration data. If extrapolation is required, it should be ascertained whether the extrapolated equation truly reflects the physical characteristics of the site.

10.2.4.4 Classical form of the velocity distribution and H-ADCPs/side-lookers

If the classical form of the velocity distribution is valid, then it can be shown that the mean velocity occurs at approximately 0,6 of the depth, as shown in Figure 10.



Key

v	velocity
D	depth
Y	depth from the surface

Figure 10 — Sketch illustrating classical form of the velocity distribution and position of mean velocity

If the classical form of the velocity distribution applies, the following equation is sometimes used to determine the mean velocity from a velocity at a fixed level.

$$\overline{V} = \left(\frac{c}{c+1}\right) V_{\mathrm{i}} \left(\frac{D}{D-y}\right)^{\frac{1}{c}} \tag{13}$$

where

D is the total depth;

Y is the depth from the surface (see Figure 10);

c is a constant, often assumed to be 6.

The above equation is sometimes referred to as the 1/6th power law.

This type of relationship is sometimes used to derive a velocity-index rating, particularly as an interim solution until such time as sufficient gauging (calibration) data are available.

10.2.4.5 Compound relationships

Significant changes in the velocity distribution at some threshold stage may be associated with a sudden change in channel geometry. Under such circumstances, it may be appropriate to have separate ratings for different stage ranges.

Two-stage relationships could take the following format:

$$\overline{V} = m_1 V_\mathrm{i} + c_1, \qquad h < h_\mathrm{threshold} \tag{14}$$

$$\overline{V} = m_2 V_\mathrm{i} + c_2, \qquad h \geqslant h_\mathrm{threshold} \tag{15}$$

or, possibly, if a two-parameter (bi-linear multiple regression) relationship is appropriate, then:

$$\overline{V} = V_\mathrm{i}(m_1 + m_2 h) + c_1, \qquad h < h_\mathrm{threshold} \tag{16}$$

$$\overline{V} = V_1(m_3 + m_4 h) + c_2, \qquad h \geqslant h_\mathrm{threshold} \tag{17}$$

where $h_\mathrm{threshold}$ is the stage at the change point.

The decision to use a compound relationship should be based on ground reality; this form should not be used simply because it produces a good fit to the data.

11 Uncertainties in discharge determinations

11.1 General

Hydrometric uncertainty estimations shall be undertaken in accordance with ISO/TS 25377. Additional information is given in ISO/IEC Guide 98-3.

11.2 Definition of uncertainty

All measurements of a physical quantity are subject to uncertainties. These may be due to systematic errors (biases) in the equipment used for calibration and measurement, or to random scatter caused by, for example, a lack of sensitivity of the equipment used for the measurement. The result of a measurement thus is only an estimate of the true value of the measured quantity and therefore is complete only when accompanied by a statement of its uncertainty.

The discrepancy between the true and measured values is the measurement error. The measurement error, which cannot be known, causes an uncertainty about the correctness of the measurement result. The uncertainty is expressed quantitatively as a “parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand” (see ISO/IEC Guide 98-3). ISO/IEC Guide 98-3 further states that the parameter may be, for example, a standard deviation or the half-length of an interval having a stated level of confidence, and that all sources of uncertainty, including those arising from systematic effects, contribute to the dispersion.

The measurement error is a combination of component errors that arise during the performance of various elementary operations during the measurement process. For measurements of composite quantities that depend on several component quantities, the total error of the measurement is a combination of the errors in all component quantities. The determination of measurement uncertainty involves identification and characterization of all components of error, quantification of the corresponding uncertainties, and combination of the component uncertainties. The uncertainties are combined using the statistical rules for combining standard deviations, giving proper consideration to correlations among all of the various sources of measurement error, in order to account for both systematic and random errors. The resulting uncertainty values are termed standard uncertainties; they correspond to one standard deviation of the probability distribution of measurement errors.

ISO/IEC Guide 98-3 states that uncertainties of any measurement shall be determined to one standard deviation. The uncertainty at one standard deviation is referred to as the standard uncertainty.

One standard deviation equates to a confidence level of about 68 %. The uncertainty at two standard deviations is twice the standard uncertainty. Therefore, if the standard uncertainty is estimated, it can then be multiplied by two to obtain the uncertainty at two standard deviations or the 95 % confidence level. This multiplying factor is referred to as the coverage factor. If the uncertainty is expressed at three standard deviations (approximately 99 % confidence level), the coverage factor would be three.

When stating uncertainties, the confidence level or the coverage factor, i.e. the number of standard deviations, should be stated. For example, if the uncertainty was calculated to be 8 % for an estimated discharge of 55,1 $m^3 \cdot s^{-1}$ at the 95 % confidence level, the statement of uncertainty should be stated as follows.

Discharge = 55,1 $m^3 \cdot s^{-1}$ with an uncertainty of 8 % at the 95 % confidence level based on a coverage factor of $k = 2$.

An introduction to uncertainty is contained in Annex C. This includes a description of Types A and B uncertainties and probability distributions that are relevant to hydrometric uncertainty analysis.

11.3 General expectations of performance

In view of the factors (see Clause 6) which can have an adverse effect on the performance, it is important to have a realistic expectation of the sort of accuracy that might be achieved by this method. Ideal conditions (long straight uniform sections with even distribution of velocity and particles and with adequate depth) are rarely encountered, particularly when using simpler, bed-mounted systems that only sample a small portion of the cross-section. The uncertainty of the resultant flow figure is consequently often no better than 10 % (95 % confidence level) and could be significantly worse. However, in many cases the Doppler or echo correlation flow measurement technique may be the only possible method and a 10 % uncertainty or more may be quite acceptable.

The sensitivity and potential accuracy of a Doppler or echo correlation system varies according to the instrument and set-up. Instrument manufacturers will include values for sensitivity and accuracy in the technical specification for their sensors. It is important to remember that these figures indicate the accuracy of the estimated velocity of the reflectors in the sampled section water column, not that of the flow measurement. The following points should be noted.

a) A correctly sited instrument can determine flow to within 5 % to 10 % but a poorly sited instrument can give inaccurate results.

b) A bed-mounted instrument with a narrow beam width will make a more accurate measurement of the velocities it samples. For an H-ADCP/side-looker, a narrow beam will sample further across the cross-section, which could improve the accuracy.

c) Water level is an important factor in the calculation of flow, thus the accuracy of the water level sensor is also important.

NOTE It is intended that, in accordance with the spirit of ISO/TS 25377, manufacturers should provide clearer statements of their instrument's uncertainties and how these are influenced by environmental factors, e.g. temperature and measurement range.

11.4 Methodology of estimating the uncertainty in discharge determination

11.4.1 Sources of uncertainty

11.4.1.1 The uncertainties in the discharge determination can be divided into

a) uncertainties in the estimation of the mean velocity,

b) uncertainties in the determination of cross-sectional area, and

c) uncertainties in the water level/stage measurement.

11.4.1.2 Uncertainties in the mean velocity can be caused by the following.

a) Uncertainties in the instrument's determination of velocity, i.e. measured velocity. This shall be provided by the manufacturer or supplier in accordance with the guidelines laid down in ISO/TS 25377.

b) Uncertainties in the instrument's determination of velocity due to the effect of turbulence, i.e. what is the uncertainty of a finite duration measurement since the real velocity in the water is changing with both space and time? Turbulence could be a significant contributor to overall uncertainty.

c) Uncertainties in the water level measurement, if stage is a parameter in the velocity-index rating or where it is used to derive the area for calculation of mean velocity.

d) Uncertainties in surveying the cross-section and thus the derivation of cross-sectional area, since the area is used to determine the mean velocity from the gauged data.

e) Uncertainties in the gauging data used to derive the velocity-index rating.

f) Uncertainties in the velocity-index rating.

11.4.1.3 Uncertainties in the cross-sectional area can be caused by the following:

a) uncertainties in the cross-sectional survey data;

b) uncertainties in the methodology used to derive area from stage;

c) uncertainties in the water level measurement.

11.4.1.4 Uncertainties in the water level/stage measurement can be caused by the following:

a) uncertainties in the instrument's measurement;

b) uncertainties in the stage zero, i.e. the level to which the water level sensor has been zeroed, e.g. the cease to flow level/lowest point in cross-section;

c) uncertainties due to temporal and spatial variations in the stage at the measurement location, combined with the effective temporal and spatial averaging of the water level/stage measurement device.

11.4.2 Determination of the uncertainty in the velocity-index rating

The uncertainty in the velocity in the velocity-index rating can be determined in the same way as for a conventional stage-discharge relationship (see ISO 1100-2:1998):

$$S_\mathrm{e} = \sqrt{\frac{\sum(\overline{V}_\mathrm{g} - \overline{V}_\mathrm{r})^2}{N-2}} \tag{18}$$

where

S_e is the standard error of estimate;

$\overline{V}_\mathrm{g}$ is the gauged mean velocity;

$\overline{V}_\mathrm{r}$ is the mean velocity from rating;

N is the number of gaugings used to derive the relationship.

$$S_{\mathrm{mr}\overline{V}} = \pm t_{\alpha/2} \cdot S_{\mathrm{e}} \sqrt{\frac{1}{N} + \frac{(V_{\mathrm{index}} - \overline{V}_{\mathrm{index}})^2}{\sum (V_{\mathrm{index}} - \overline{V}_{\mathrm{index}})^2}} \qquad (19)$$

where

$S_{\mathrm{mr}\overline{V}}$ is the standard error of the mean relationship;

t is the Student's t statistic;

α is the confidence level, approximately 68 % for the standard uncertainty (some software packages that undertake linear regression analysis quote confidence limits to the 95 % confidence level, so this should be accounted for when undertaking the uncertainty analysis);

V_{index} is the index velocity value;

$\overline{V}_{\mathrm{index}}$ is the mean of index velocity values used to derive the rating.

The uncertainty for any estimate of mean velocity when using a simple velocity-index rating can be estimated using Equation (19).

11.4.3 Uncertainty in the stage

The uncertainty in the stage measurement can be derived using the following equation:

$$u^*(h) = 100 \frac{\sqrt{u(E)^2 + u(h)^2}}{h} \qquad (20)$$

where

$u^*(h)$ is the overall percentage uncertainty in stage determination;

$u(E)$ is the uncertainty in stage zero; assume triangular distribution;

$u(h)$ is the uncertainty in stage measurement (this will be instrument specific; assume rectangular distribution).

The triangular and rectangular uncertainty distributions are referred to in Annex C.

11.4.4 Overall uncertainty

The overall uncertainty can be obtained by combining the component uncertainties in quadrature, thus:

$$U_Q = \sqrt{u_{V\mathrm{r}}^2 + u_{V\mathrm{i}}^2 + u_{A\mathrm{r}}^2 + mu^*(h)^2} \qquad (21)$$

where

U_Q is the overall uncertainty in the discharge determination;

$u_{V\mathrm{r}}$ is the uncertainty in velocity-index rating;

$u_{V\mathrm{i}}$ is the uncertainty in index/instrument/measured velocity;

$u_{A\mathrm{r}}$ is the uncertainty in cross-sectional area/stage-area relationship;

$u^*(h)$ is the overall uncertainty in stage;

m is a constant dependent on the form of the stage-area relationship. For example, if the relationship is represented by a power law, of the form:

$$A = ah^b \tag{22}$$

where

A is the cross-sectional area, in square metres (m^2).

a and b are constants;

then $m = b^2$.

If the cross-sectional area is derived from a look-up table which has sufficient data points to allow accurate interpolation between consecutive stages, then m = 1.

In the absence of a technique to establish the uncertainties in the stage-area relationship, the analyst should make a professional judgement based on experience, knowledge of the site and the quality of the survey data used to derive the relationship.

Some guidance on possible instrument uncertainties is contained in Annex C of ISO/TS 25377:2007, Performance guide for hydrometric equipment for use in technical standards. This is reproduced in this International Standard as Annex D. However, whenever possible, the uncertainties used should be based on the hydrometric manufacturer's performance specifications and the hydrometrist's own operating experience.

11.4.5 Uncertainty — Example of uncertainty estimation

11.4.5.1 Introduction

An H-ADCP/side-looker has been installed on a small stream in a cross-section that is approximately 3,5 m wide and at the bank-full level is about 2,0 m deep. The channel is stable, trapezoidal in section and has near vertical sides with a level, regular bed. A linear velocity-index rating has been developed using standard least-squares linear regression fitting tools. The gauging data used to develop the rating cover the full flow range up to the bank-full level. The velocity-index rating developed for the site is as follows:

$$\overline{V} = 1{,}267 V_\mathrm{i} - 0{,}006 \tag{23}$$

The uncertainty in a specific flow determination shall be estimated using the following data:

a) measured stage using H-ADCP/side-looker upward-looking ultrasonic water level sensor = 1,107 m;

b) position of instrument water level sensor relative to stage zero = – 0,362 m;

c) measured velocity, i.e. instrument velocity/index velocity = 0,440 m•s^{-1}.

A stage-area relationship has been derived for the site in tabular form using software designed for such a purpose. This has been based on a detailed cross-sectional survey where bed and bank levels have been taken at least every 0,5 m across the channel, and at every significant change in level. The stage-area table has been established in increments of stage of 0,001 m (1 mm).

According to the table, the cross-sectional area corresponding to a stage of 1,107 m = 3,034 m^2.

From Equation (23), the estimated mean velocity $\overline{V} = 1{,}267 \cdot 0{,}440 - 0{,}006 = 0{,}55\ \mathrm{m} \bullet \mathrm{s}^{-1}$.

Estimated discharge (Q) = $\overline{V} \cdot A = 0{,}55 \cdot 3{,}034 = 1{,}669\ \mathrm{m}^3 \bullet \mathrm{s}^{-1}$.

11.4.5.2 Uncertainty in the measured velocity $u_{V\mathrm{i}}$

According to the manufacturer's equipment specifications, the H-ADCP should be capable of measuring to an uncertainty of 0,5 %. This equates to an uncertainty of about 0,002 $\mathrm{m \cdot s^{-1}}$. This is similar to the figure quoted in Table D.1 for the velocity range under consideration at the 68 % confidence limit. Therefore, both the uncertainty specified by the manufacturer and the guidance table are in general agreement in this example.

Therefore, $u_{V\mathrm{i}} = (0{,}002 \mid 0{,}55) \cdot 100\ \% = 0{,}36\ \%$

11.4.5.3 Uncertainty in velocity-index rating $u_{V\mathrm{r}}$

The velocity-index rating has been established by least-squares regression analysis using a commercially available analysis package. As well as determining the best-fit relationship, this package allows the user to determine relevant statistics including the standard error of estimate, the 95 % confidence limits and the standard error of the mean relationship for the fitted relationship. From this information, using a relationship in the form of Equation (19), it has been possible to estimate the uncertainty for a measured velocity of 0,55 $\mathrm{m \cdot s^{-1}}$ to be 9,2 % at the 95 % confidence level or 2 standard deviations, i.e. with a coverage factor of 2.

Therefore, the standard uncertainty, $u_{V\mathrm{r}} = 9{,}2 \mid 2 = 4{,}6\ \%$

11.4.5.4 Uncertainty in the stage measurement u_h

It is estimated that the stage zero can be established to within 0,002 m. Assuming a triangular distribution (see Annex C), the uncertainty in the stage zero can be estimated as follows:

$$u(E) = \frac{1}{\sqrt{6}} \left(\frac{0{,}002 - (-0{,}002)}{2} \right) = 0{,}001\,6 \text{ m}$$

The uncertainty in stage measurement according to the manufacturer's specification is 0,25 %. The measuring range is the stage minus the instrument position, i.e. 1,107 – 0,362 = 0,745 m.

Uncertainty in stage based on the manufacturer's specification is therefore:

0,25 % of 0,745 m = 0,001 9 m

According to Table D.1, the uncertainty at the 95 % confidence level for an in-water ultrasonic level sensor at the 95 % confidence level (2 standard deviations) is 0,003 m. Therefore, the standard uncertainty (standard deviation) is 0,5 · 0,003 m = 0,001 5 m.

A standard uncertainty in the stage measurement of 0,002 m has been assumed. Substituting for $u(E)$ and $u(h)$ in Equation (20), the overall estimated standard uncertainty in the stage is as follows:

$$u^*(h) = 100 \frac{\sqrt{u(E)^2 + u(h)^2}}{h} = 100 \frac{\sqrt{0{,}001\,6^2 + 0{,}002^2}}{1{,}107} = 0{,}23\ \%$$

11.4.5.5 Uncertainty in the cross-sectional area $u_{A\mathrm{r}}$

The cross-section is stable and has been well surveyed. A stage-area table has been derived using software designed for this purpose. Therefore, a standard uncertainty of 2 % in the determined cross-sectional area can be assumed for a stage of 1,107 m at this site.

As the stage-area relationship is based on a table and not a power-law relationship or some other mathematical relationship containing stage to a power, $m = 1$.

11.4.5.6 Uncertainty budget

The individual, estimated uncertainties can be summarized as in Table 1.

Table 1 — Uncertainty budget (for example)

Parameter	Symbol	Standard uncertainty %
Measured velocity	$u_{V\mathrm{i}}$	0,36
Velocity-index rating	$u_{V\mathrm{r}}$	4,60
Area	$u_{A\mathrm{r}}$	2,00
Stage	$u^*(h)$	0,23

11.4.5.7 Overall uncertainty U_Q

The overall standard uncertainty can be obtained by inserting the individual standard uncertainties in Equation (21), thus:

$$U_Q = \sqrt{u_{V\mathrm{r}}^2 + u_{V\mathrm{i}}^2 + u_{A\mathrm{r}}^2 + mu^*(h)^2} = \sqrt{4{,}6^2 + 0{,}36^2 + 2^2 + 0{,}23^2} = 5{,}03\ \%$$

Therefore, at the 95 % confidence level, $U_Q = 5{,}03 \cdot 2 = 10{,}06$ %, approximately 10 %.

The conventional statement of discharge is therefore 1,669 $\mathrm{m}^3 \cdot \mathrm{s}^{-1}$, with an uncertainty of 10 % at the 95 % confidence level based on a coverage factor of $k = 2$.

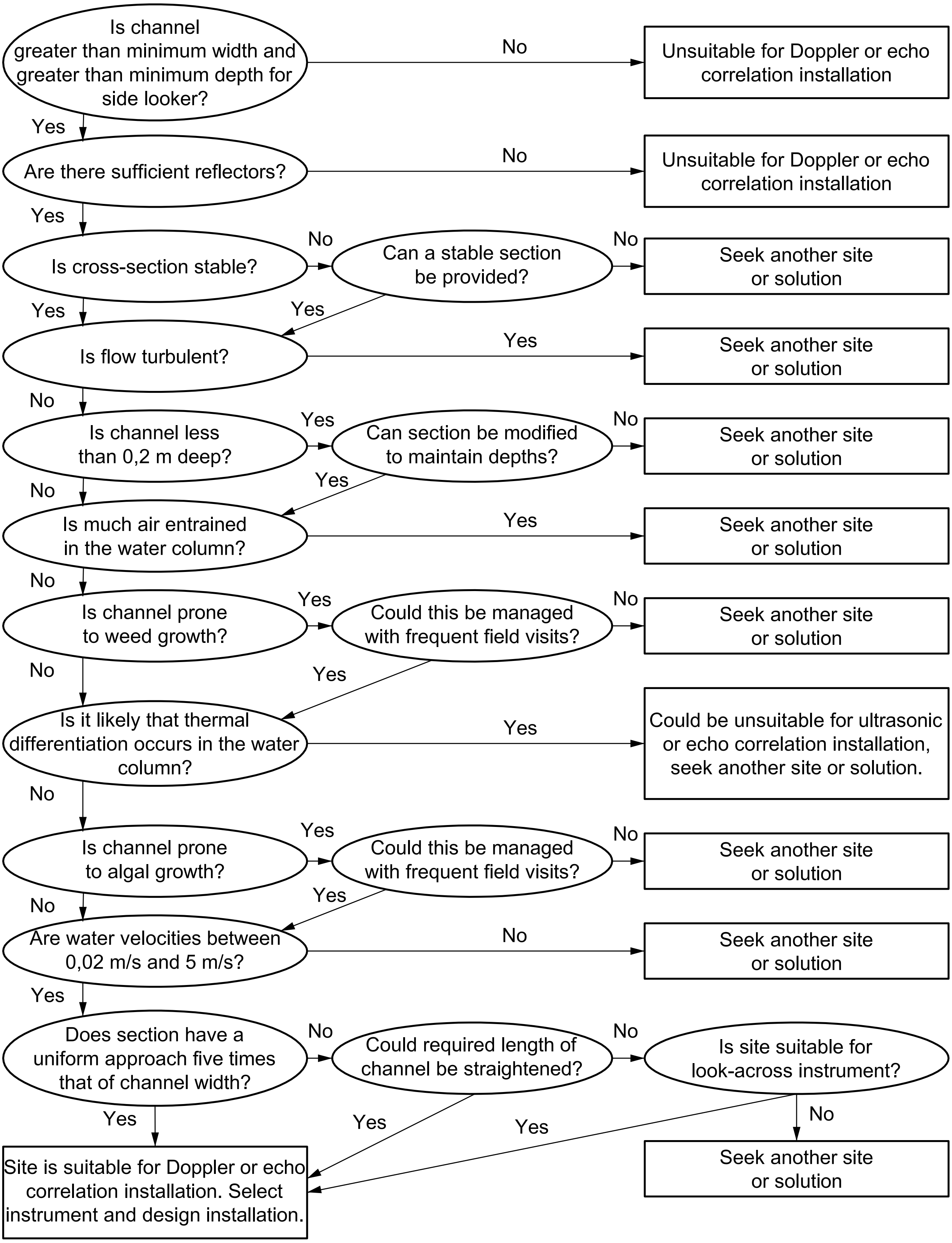
12 Points to consider when selecting equipment

The aim should be to establish what a potential user really requires. This will have dual benefits. The potential users will be encouraged to critically assess and define their requirements and objectives. Equally, manufacturers and suppliers will be presented with a more informed proposal and well-thought-out specification, rather than having to make assumptions due to gaps in knowledge and information from the potential user. The combined result will significantly increase the potential of obtaining a satisfactory outcome, with equipment that is, as far as possible, appropriate to the needs.

A questionnaire will offer an easily understandable, step-by-step, structured approach, with relevant questions helping to focus on the key issues, which will govern the overall suitability and performance of the flow measurement technique. A sample questionnaire is reproduced in Annex E.

Annex A
(informative)

Selection considerations for ultrasonic Doppler and echo correlation devices


Is channel greater than minimum width and greater than minimum depth for side looker?
No
Unsuitable for Doppler or echo correlation installation
Yes
Are there sufficient reflectors?
No
Unsuitable for Doppler or echo correlation installation
Yes
Is cross-section stable?
No
Can a stable section be provided?
No
Seek another site or solution
Yes
Yes
Is flow turbulent?
Yes
Seek another site or solution
No
Is channel less than 0,2 m deep?
Yes
Can section be modified to maintain depths?
No
Seek another site or solution
No
Yes
Is much air entrained in the water column?
Yes
Seek another site or solution
No
Is channel prone to weed growth?
Yes
Could this be managed with frequent field visits?
No
Seek another site or solution
No
Yes
Is it likely that thermal differentiation occurs in the water column?
Yes
Could be unsuitable for ultrasonic or echo correlation installation, seek another site or solution.
No
Is channel prone to algal growth?
Yes
Could this be managed with frequent field visits?
No
Seek another site or solution
No
Yes
Are water velocities between 0,02 m/s and 5 m/s?
No
Seek another site or solution
Yes
Does section have a uniform approach five times that of channel width?
No
Could required length of channel be straightened?
No
Is site suitable for look-across instrument?
Yes
Yes
Yes
No
Site is suitable for Doppler or echo correlation installation. Select instrument and design installation.
Seek another site or solution

Annex B
(informative)

Practical considerations

B.1 General

Physical and hydraulic characteristics of the proposed monitoring site and the needs and objectives of measurement will vary in each case. There are a number of further considerations with regard to the instruments, choice of system and their installation and operation, which will assist the potential user in identifying and, as far as possible, meeting all objectives.

B.2 Capital cost

Instrument specifications vary considerably and accordingly so do their costs. It is important to make a prior judgement of the value of the data before making purchases and, as far as possible, match the instrument to the particular requirement. Consideration should also be given to the full cost of ownership. Therefore, allowance should be made for further costs of installation, operation, maintenance, verification, and the retrieval, processing and validation of data before committing initial expenditure on the instrument.

B.3 Installation

Installation requirements and procedure will depend greatly on characteristics of the equipment, the site, the flow regime and the period over which monitoring is envisaged. A longer-term monitoring programme and sites vulnerable to human or animal interference, or likely to be affected by high flows, will demand a more robust installation.

Sensors should be installed in a stable reach since a stable depth versus area relationship is required to accurately calculate the area component of the discharge equation. A stable bed will also minimize build-up of sediment on top of the sensor, or even its damage or displacement by higher flows laden with debris.

Consideration should also be given to the position and nature of instrument housing, bearing in mind the need for safe and easy access, protection from all anticipated water levels, human or animal interference and the elements. This may be in a secure building or kiosk, underground with manhole access (see B.9) or within the sensor itself, as some instruments do not comprise a separate logger and sensor.

B.4 Calibration and verification

Consideration should be given to the calibration requirements of the chosen systems. Calibration will include both instrument-measured parameters (typically stage and velocity), and the more general site-specific parameters of interest (typically area, mean velocity and flow). Thus, there are instrument calibration issues, and site calibration issues (and some interaction between the two). Key questions will be whether the sensors are factory calibrated or require on-site calibration, what performance or uncertainty levels apply and over what period the calibration can be expected to hold for. It is recommended that, if possible, instruments be obtained with certification and, if this is not possible, that they be tested before installation.

For all systems, including those that claim factory-calibration, it is essential that verification measurements be routinely made with visits to the installed monitoring site. The frequency of verification measurements may normally be reduced with time after installation, unless a reason emerges not to do so. In selecting monitoring sites, some consideration should be given to the feasibility of undertaking subsequent verification measurements. Independent check level measurements should be taken relative to a datum and it is recommended that check velocity measurements be performed regularly to establish an estimate of mean channel velocity or possibly improve the performance by on-site calibration.

Subclause 9.1 offers a number of potential options for making check flow measurements at the site; it is important that an independent technology be used for these measurements. Where possible, some attempt should be made to assess the uncertainty of the check gauging and, if concerns exist over performance of the system, consider the suitability of the monitoring site or the instrument. In all cases a log of records should be maintained and referred back to with each subsequent verification visit to identify possible trends or deterioration in performance.

B.5 Power requirements

Power consumption will vary between different systems but be heavily dependent upon the sampling and logging frequencies employed (see B.6). Availability of an on-site display may be a requirement for certain applications but benefits will need to be balanced against the greater power requirements. Guidance should be sought from manufacturers on power needs for the particular system and mode of operation. Battery or mains-power options may need to be considered, specifically in accordance with the manufacturer's operating instructions. When using rechargeable batteries, these should be put through a full charge cycle to avoid “topping up” and deterioration in capacity.

B.6 Instrument logging mode — Response times, sampling and logging frequencies

B.6.1 Introduction

A wide variety of logging modes exist and reference must be made to manufacturers or suppliers for a detailed specification of a particular instrument. However, the following should be considered before contacting manufacturers or suppliers:

a) sampling frequency;

b) averaging mode and logging frequency;

c) response times;

d) trigger levels;

e) integrated instrumentation.

B.6.2 Sampling frequency

This refers to the frequency at which the sensor takes and records relevant data readings, i.e. depth and velocity.

Very few, if any, flow loggers record data continuously. This is because the power requirement would be considerable and limit the use of battery-powered units to very short logging periods. Instead, most instruments “power up” the sensor for short periods. However, the sample time should be sufficient to reduce the uncertainties caused by turbulence.

Continuous data recording is normally only suitable for mains-powered devices and should only be necessary when data may need to be used in a “real-time” situation.

B.6.3 Averaging mode and logging frequency

The recorded data are usually stored in temporary memory and averaged over a pre-set period, prior to an average depth and velocity value being committed to memory.

On most instruments, the pre-set period over which data can be averaged can be varied to suit the operator's requirements. Typical examples may be the following.

a) Waste-water flows: averaged over 2 min, to give sufficient resolution to enable storm responses to be observed. Alternatively, if only dry weather flows are required, an averaging of 15 min may suffice.

b) Watercourse flow: a coarser recording will often suffice where flow is relatively constant and not subject to sudden variations. Hourly recording may be adequate although 15 min is typical.

c) Industrial process flows: a “real-time” information system may be necessary when it is vital that any variations in flow are known immediately. In such cases, recording may be continuous and the flow is computed and updated, for example, once every 10 s.

B.6.4 Response times

For most applications, depth and velocity data will be recorded, averaged and stored in a solid state memory. The sites will be remote, require battery power and only be visited occasionally. Weekly, fortnightly or monthly visits can be typical to retrieve data, check battery power and instrument condition and to perform verification checks. In such cases, response times are not an important consideration.

However, for some applications, the instrument may need to be used as part of a real-time control system. In such cases, the response time will be important. Typically, it will be necessary for the instrument to warn of a sudden change in the flow. Urban sewage real-time control systems and certain industrial processes will require instruments capable of continuously computing flows from the measured depth and velocity.

B.6.5 Trigger levels

Some instruments have the ability to sample, average and log data at different time intervals depending upon the flow conditions. An example of this would be a depth and velocity monitor that is required to measure both dry weather and storm flows where battery power and memory space may be critical. Reducing the recording and memory logging interval during dry weather to, for example, hourly intervals, will considerably reduce the power consumption and memory space used but still enable adequate data to be collected. During storms, the logger can be pre-set to record and commit to memory at a more frequent rate, thereby enabling adequate storm data to be collected.

Experience has shown that such facilities can be advantageous in being able to reduce the frequency of site visits. However, a considerable amount of knowledge is necessary because it is very easy to set too high a trigger level and not record some of the storm flow, or conversely, set the trigger prematurely. Therefore, triggers should generally only be used if the operator already has a detailed knowledge of the flow range.

B.6.6 Integrated instrumentation

Sometimes it may be necessary for flow (velocity and depth) monitors to be able to talk to other equipment, such as effluent auto-samplers. A typical example may be where sewage samples are required during a storm to measure the “first foul flush” effect. In such cases, a depth trigger, based on the instrument's recorded depth level, could be used to activate an auto-sampler.

B.7 Memory capacity

Signals generated may pass immediately to another system, which would limit the memory capacity requirements of the instrument. However, in many cases, an integrated or connected data logger will form part of the system and its memory capacity shall be sufficient to satisfy the required logging rates and the download frequency. It may also be relevant to establish whether systems operate with either roll-over or finite memory or whether this is user-selectable.

B.8 Portability

The portability of systems may be a consideration in the case of applications, which involve repeated very short-term installations and movement from site to site, particularly where access is less than ideal.

B.9 Access and safety considerations

In confined spaces, and thus potentially explosive atmospheres, it shall be ascertained that instruments are designed, constructed and used in accordance with appropriate standards to ensure the safety of operators, the general public and the sewer or channel system. This responsibility largely rests with the designer or manufacturer or supplier and it has become usual for equipment to be designed and constructed to meet the latest National or equivalent European or International Standards. Users are recommended to seek certification when purchases are made.

Access and safety should be considered from the point of view of both the installer and the operator, since the sensor and the data logger/battery pack may be separate and be associated with different safety requirements.

B.10 Harsh environments

Consideration should be given to the capabilities of instruments, both sensors and logging equipment, to withstand extremes of temperature or direct sunlight. The level of waterproofing of both sensors and logging equipment should also be established, including their ability to withstand flooding.

B.11 On-site display

Consideration should be given to whether there is a need to have an integral display facility within the logger. Where these are used, checks should be made to establish whether the display is constantly live or activated from a key pad, since there may be significant implications for power consumption.

Annex C
(informative)

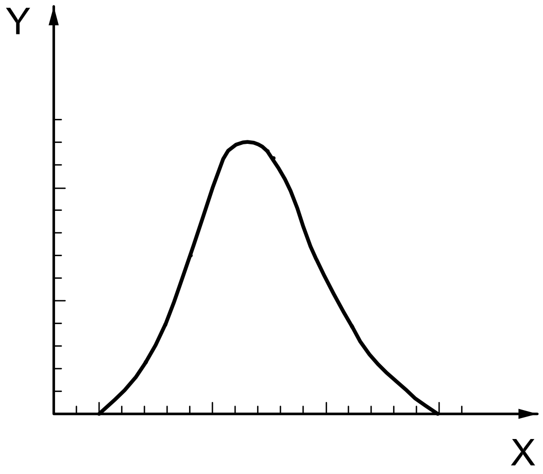
Introduction to measurement uncertainty

C.1 General

Results of measurements or analysis cannot be exact. The discrepancy between the true value, which is unknowable, and the measured value is the measurement error. The concept of uncertainty is a way of expressing this lack of knowledge. For example, if water is controlled to flow at a constant rate, then a flowmeter will exhibit a spread of measurements about a mean value. If attention is not given to the uncertain nature of data, incorrect decisions can be made which have financial or judicial consequences. A realistic statement of uncertainty enhances the quality of information, making it more useful.

The uncertainty of a measurement represents a dispersion of values that could be attributed to it. Statistical methods provide objective values based on the application of theory.

Standard uncertainty equates to a dispersion of measurements expressed as a standard deviation. From this definition, uncertainty can be readily calculated for a set of measurements.



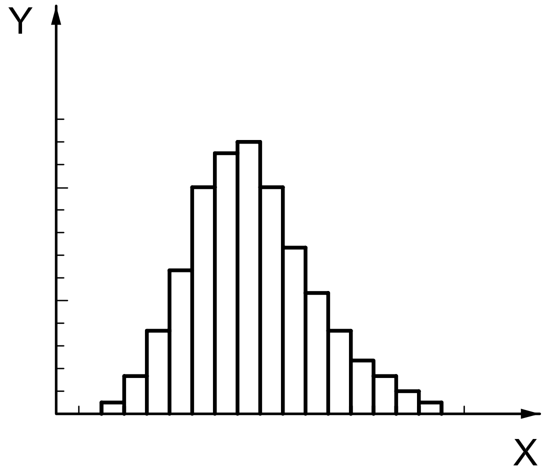
a)

Key

X flow value

Y probability

Figure C.1 — Pictorial representation of some uncertainty parameters (*continued*)

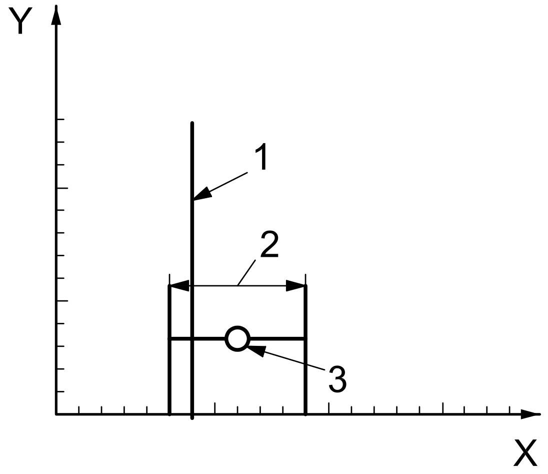


b)

Key

X flow value

Y number of samples



c)

Key

X flow value

Y number of samples

1 limit

2 standard deviation

3 mean value

Figure C.1 — Pictorial representation of some uncertainty parameters

Figure C.1 a) shows the probability that a measurement of flow under steady conditions takes a particular value due to the uncertainties of various components of the measurement process, in the form of a probability density function.

Figure C.1 b) shows sampled flow measurements, in the form of a histogram.

Figure C.1 c) shows standard deviation of the sampled measurements compared with a limiting value. The mean value is shown to exceed the limiting value but is within the band of uncertainty (expressed as the standard deviation about the mean value).

C.2 Confidence limits and coverage factors

For a normal probability distribution, analysis shows that 68 % of a large set of measurements lies within one standard deviation of the mean value. Thus, standard uncertainty is said to have a 68 % level of confidence.

However, for some measurement results, it is customary to express the uncertainty at a level of confidence which will cover a larger portion of the measurements: for example at a 95 % level of confidence (see Figure C.4). This is done by applying a factor, the coverage factor k, to the computed value of standard uncertainty.

For a normal probability distribution, 95,45 % (effectively 95 %) of the measurements are covered for a value of $k = 2$. Thus, uncertainty at the 95 % level of confidence is twice the standard uncertainty value.

In practice, measurement variances rarely closely follow the normal probability distribution. They may be better represented by triangular, rectangular or bimodal probability distributions and only sometimes approximate to the normal distribution.

Therefore, a probability distribution must be selected to model the observed variances. To express the uncertainty of such models at the 95 % confidence limit requires a coverage factor that represents 95 % of the observations. However, the same coverage factor, $k = 2$, is used for all models. This simplifies the procedure while ensuring consistency of application within tolerable limits.

C.3 Random and systematic error

The terms “random” and “systematic” have been applied in hydrometric standards to distinguish between

a) random errors that represent an inherent dispersion of values under steady conditions, and

b) systematic errors that are associated with inherent limitations of the means of determining the measured quantity.

A difficulty with the concept of systematic error is that systematic error cannot be determined without pre-knowledge of true values. If its existence is known or suspected, then steps must be taken to minimize such error, either by recalibration of equipment or by reversing its effect in the calculation procedure, at which point systematic error contributes to uncertainty in the same way as random components of uncertainty.

For this reason, ISO/IEC Guide 98-3 does not distinguish between the treatment of random and systematic uncertainties. Generally, when determining a single discharge, random errors dominate and there is no need to separate random and systematic errors. However, where, for example, totalized volume is established over a long time base, the systematic errors, even when reduced, can remain dominant in the estimation of uncertainty.

C.4 Measurement standards

ISO/IEC Guide 98-3 and ISO/TS 25377 provide rules for the application of the principles of measurement uncertainty: in particular on the identification of components of error, the quantification of their corresponding uncertainties and how these are combined using methods derived from statistical theory into an overall result for the measurement process.

The components of uncertainty are characterized by estimates of standard deviations. There are two methods of estimation:

a) **Type A estimation** (by statistical analysis of repeated measurements from which an equivalent standard deviation is derived).

   This process may be automated in real-time for depth or for velocity measurement.

b) **Type B estimation** (by ascribing a probability distribution to the measurement process).

   This is applicable to

   1) human judgement of a manual measurement (distance or weight),

   2) manual readings taken from instrumentation (manufacturer's statement), or

   3) calibration data (from manufacturer).

C.5 Evaluation of Type A uncertainty

Defined in C.1, the term “standard uncertainty” means a dispersion of measurements expressed as a standard deviation. Thus, any single measurement of a set of n measurements has by definition an uncertainty:

$$u(x) = t_e \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2} \qquad \text{(C.1)}$$

where $\bar{x}$ is the best estimate of the true mean:

$$\bar{x} = \frac{1}{n}(x_1 + x_2 + \ldots\ldots x_n) \qquad \text{(C.2)}$$

and t_e is a factor derived from statistical theory to account for the increased uncertainty when small numbers of measurements are available; refer to Table C.1.

If, instead of a single measurement from the set, the uncertainty is to apply to the mean of all n values, then:

$$u(\bar{x}) = \frac{t_e}{\sqrt{n}} \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2} \qquad \text{(C.3)}$$

For continuous measurement, Type A evaluations may be derived as a continuous variable from the primary measurement, i.e. from water level or water velocity.

By taking average values over large numbers, n, of measurements, the uncertainty of the mean value $u(\bar{x})$ is reduced by a factor of $\frac{1}{\sqrt{n}}$ compared to the uncertainty $u(x)$ of an individual measurement. For this reason, monitoring equipment should specify measurement performance in terms including both $u(\bar{x})$ and $u(x)$ to show the extent to which averaging is applied.

Table C.1 — Factors t_e at 90 %, 95 % and 99 % confidence levels

Degrees of freedom[a]	Confidence level %		
	90	**95**	**99**
1	6,31	12,71	63,66
2	2,92	4,30	9,92
3	2,35	3,18	5,84
4	2,13	2,78	4,60
5	2,02	2,57	4,03
10	1,81	2,23	3,17
15	1,75	2,13	2,95
20	1,72	2,09	2,85
25	1,71	2,06	2,79
30	1,70	2,04	2,75
40	1,68	2,02	2,70
60	1,67	2,00	2,66
100	1,66	1,98	2,63
Infinite	1,64	1,96	2,58

[a] In general, this is the number of terms in a sum minus the number of constraints on the terms of the sum ISO/IEC Guide 98-3.

C.6 Evaluation of Type B uncertainty

C.6.1 General

When there is no access to a continuous stream of measured data or if a large set of measurements is not available, then the Type B method of estimation is used to

a) assign a probability distribution to the measurement process to represent the probability of the true value being represented by any single measured value,

b) define upper and lower bounds of the measurement, and

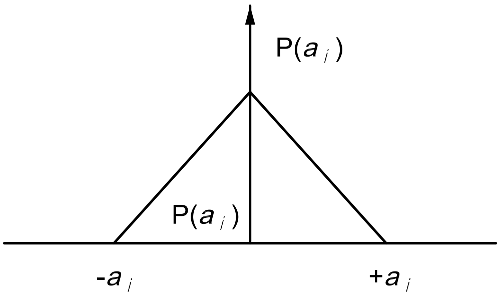
c) determine a standard uncertainty from a standard deviation implied by the assigned probability distribution.

The Type B methods allow estimates of upper and lower bounding values to be used to derive the equivalent standard deviation.

Four probability distributions are described in ISO/IEC Guide 98-3 and in C.6.2 to C.6.5.

C.6.2 Triangular distribution

The triangular distribution is represented in Figure C.2.



$$u(x_i) = a_i / \sqrt{6}$$

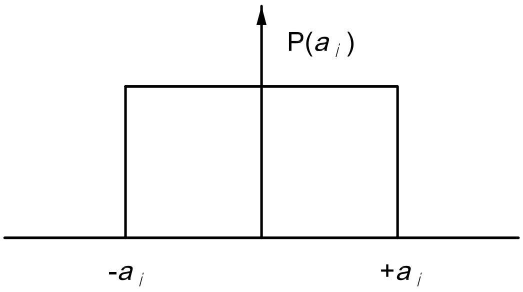
Figure C.2 — Triangular distribution

$$u(x_{\text{mean}}) = \frac{1}{\sqrt{6}} \left(\frac{x_{\text{max}} - x_{\text{min}}}{2} \right) \tag{C.4}$$

This usually applies to manual measurements where the mean value is most likely to be closer to the true value than others between the discernible upper and lower limits of the measurement.

C.6.3 Rectangular distribution

The rectangular distribution is represented in Figure C.3.



$$u(x_\text{i}) = a_\text{i} / \sqrt{3}$$

Figure C.3 — Rectangular distribution

$$u(x_{\text{mean}}) = \frac{1}{\sqrt{3}} \left(\frac{x_{\text{max}} - x_{\text{min}}}{2} \right) \tag{C.5}$$

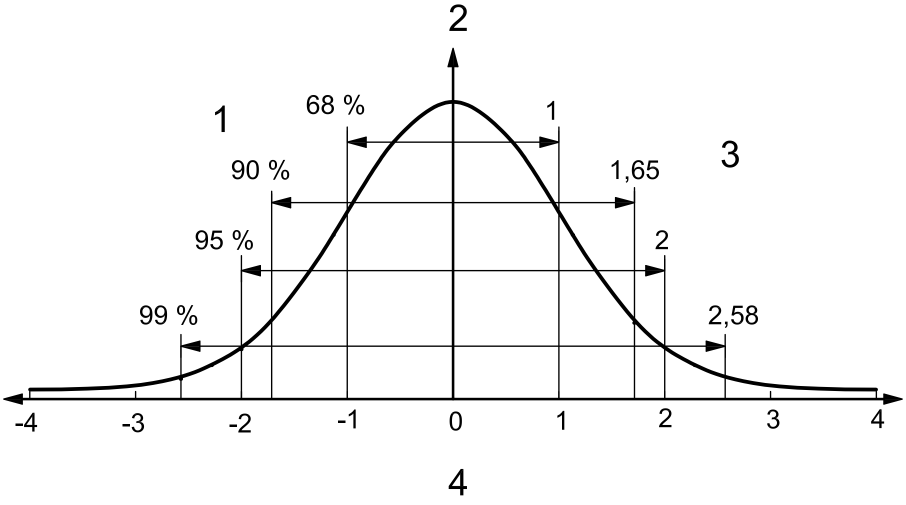
This probability distribution is usually applied to the resolution limit of the measurement instrumentation (i.e. the displayed resolution or the resolution of internal analogue/digital converters).

However, this is not the only source of uncertainty of measurement equipment. There may be uncertainty arising from the measurement algorithm used and/or from the calibration process.

If the equipment measures relative values, then there will also be uncertainty in the determination of its datum.

C.6.4 Normal probability distribution

The normal probability distribution is represented in Figure C.4.



Key

1 percent of readings in bandwidth
2 probability
3 coverage factor
4 standard deviations

Figure C.4 — Normal probability distribution

$$u(x_{\text{mean}}) = \frac{u(\text{specified})}{k} \tag{C.6}$$

where k is the coverage factor applying to the specified uncertainty value.

These are uncertainty statements based on “off-line” statistical analysis, usually as part of a calibration process where they have been derived using a Type A process. When expressed as standard uncertainty, the uncertainty value is to be used directly with an equivalent coverage factor of k = 1.

C.6.5 Bimodal probability distribution

The bimodal probability distribution is represented in Figure C.5.

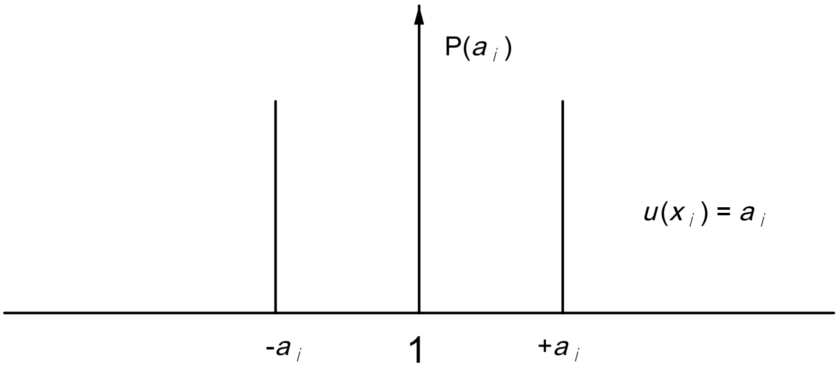


Figure C.5 — Bimodal probability distribution

$$u\left(x_{\text{mean}}\right) = \frac{\left(x_{\text{max}} - x_{\text{min}}\right)}{2} \tag{C.7}$$

Measurement equipment with hystersis can only exhibit values at the upper and lower bounds of the measurement.

An example of this is the float mechanism where friction and surface tension combine to cause the float to move in finite steps.

C.7 Combined uncertainty value u_c

For most measurement systems, a measurement result is derived from several variables. For example, flow measurement, Q, in a rectangular channel can be expressed as a function of independent variables:

$$Q = b \cdot h \cdot \bar{V} \tag{C.8}$$

where

b is the channel width;

h is the depth of water in the channel;

$\bar{V}$ is the mean velocity.

These three components are measured independently and combined to determine a value for Q.

Just as b, h and $\bar{V}$ are combined to determine the value for Q, each component of uncertainty must be combined to determine a value for $u_c(Q)$. This is done by evaluating the sensitivity of Q to a small change δ in b, h or $\bar{V}$. Thus:

$$\delta Q = \frac{\partial Q}{\partial b} \delta b + \frac{\partial Q}{\partial h} \delta h + \frac{\partial Q}{\partial \bar{V}} \delta \bar{V} \tag{C.9}$$

where the partial differentials $\frac{\partial Q}{\partial b}$, $\frac{\partial Q}{\partial h}$ and $\frac{\partial Q}{\partial \bar{V}}$ are sensitivity coefficients. For Equation (C.8) this is equal to:

$$\frac{\delta Q}{Q} = \frac{\delta b}{b} + \frac{\delta h}{h} + \frac{\delta \bar{V}}{\bar{V}} \tag{C.10}$$

In uncertainty analysis, the values $\frac{\delta Q}{Q}$, $\frac{\delta b}{b}$, $\frac{\delta h}{h}$ and $\frac{\delta \bar{V}}{\bar{V}}$ correspond to dimensionless standard uncertainties. They are given the notation $u_c^*(Q)$, $u^*(b)$, $u^*(h)$ and $u^*(\bar{V})$.

Since the uncertainties of b, $\bar{V}$ and h are independent of each other, probability considerations require summation in quadrature.

$$u_c^*(Q) = \sqrt{u^*\left(\bar{V}\right)^2 + u^*\left(b\right)^2 + u^*\left(h\right)^2} \tag{C.11}$$

Annex D
(informative)

Performance guide for hydrometric equipment for use in technical standards

For guidance on the origins and use of Table D.1, reference shall be made to Annex C of ISO/TS 25377:2007.

Table D.1 — Performance guide for hydrometric equipment for use in technical standard examples

Measurement technologies		**Comment**	**Symbol**	**Uncertainty options**		**Norms of measurement performance for use in worked examples** **Installed equipment to have corresponding values certified by manufacturer**									
						Nominal rating of the measurement equipment					**Corresponding measurement uncertainty (95 % confidence level)**				
Velocity (continuous)				A^d	B	Minimum	25 %	50 %	75 %	Maximum	Minimum	25 %	50 %	75 %	Maximum
Point Velocity	Propeller	Calibration certificate	$u(V)$	YES	Rectangular	0,080 m/s	0,750 m/s	1,50 m/s	2,250 m/s	3,000 m/s	0,001 6 m/s	0,014 m/s	0,004 m/s	0,004 m/s	0,006 m/s
	Electro-magnetic	Calibration certificate	$u(V)$	YES	Rectangular	0,080 m/s	0,750 m/s	1,550 m/s	2,250 m/s	3,000 m/s	0,006 m/s	0,020 m/s	0,020 m/s	0,030 m/s	0,040 m/s
Path velocity	Transit time ultrasonics	Sonic velocity Path angle	$u(V)$	YES	Rectangular	0,030 m/s	0,250 m/s	0,250 m/s	0,750 m/s	1,000 m/s	0,006 m/s	0,010 m/s	0,014 m/s	0,014 m/s	0,020 m/s
	Ultrasonic Doppler	Particle-dependent low velocity resolution	$u(V)$	YES	Rectangular	0,030 m/s	0,250 m/s	0,250 m/s	0,750 m/s	1,000 m/s	0,006 m/s	0,010 m/s	0,014 m/s	0,014 m/s	0,020 m/s
	Echo correlation	Particle-dependent	$u(V)$	YES	Rectangular	0,030 m/s	0,250 m/s	0,250 m/s	0,750 m/s	1,000 m/s	0,006 m/s	0,010 m/s	0,014 m/s	0,014 m/s	0,020 m/s
Section velocity	Electro-magnetic	To be calibrated *in situ*	$u(V)$		Rectangular	0,030 m/s	0,250 m/s	0,250 m/s	0,750 m/s	1,000 m/s	0,006 m/s	0,010 m/s	0,014 m/s	0,014 m/s	0,020 m/s
Water level (continuous)^a															
Relative datum (to be applied to all methods)		Manual process	$u(E)$		Triangular or rectangular	Not applicable	0,500 m	1,000 m	1,500 m	2,000 m	0,002 m	0,002 m	0,003 m	0,003 m	0,003 m
In-contact methods	Encoder/ float system^b	Requires regular maintenance	$u(R)$		Bimodal	Appli-cable	extension 1,250 m	extension 2,500 m	extension 3,750 m	extension 5,000 m	0,002 m	0,003 m	0,004 m	0,005 m	0,006 m
	Pressure transducer	Datum value drift	$u(h_1)$		Rectangular	0,010 m	0,500 m	1,000 m	1,500 m	2,000 m	0,004 m	0,004 m	0,005 m	0,005 m	0,006 m
	Ultrasonic	Surface wave effects	$u(h_1)$	YES	Rectangular	0,050 m	0,500 m	1,000 m	1,500 m	2,000 m	0,002 m	0,002 m	0,003 m	0,003 m	0,003 m

Table D.1 *(continued)*

Measurement technologies		Comment	Symbol	Uncertainty options		Norms of measurement performance for use in worked examples Installed equipment to have corresponding values certified by manufacturer									
						Nominal rating of the measurement equipment					Corresponding measurement uncertainty (95 % confidence level)				
Water level (continuous)[a]															
Non-contact methods	Air-ranging ultrasonic[b]	Surface wave effects Air temperature[c]	$u(R)$	YES	Rectangular	Range 0,300 m	Range 1,250 m	Range 2,500 m	Range 3,750 m	Range 5,000 m	0,003 m	0,012 m	0,025 m	0,040 m	0,075 m
	Pulse echo radar	Surface wave effects	$u(R)$		Rectangular	Range 0,300 m	Range 1,250 m	Range 2,500 m	Range 3,750 m	Range 5,000 m	0,004 m	0,012 m	0,025 m	0,035 m	0,050 m
Cross-section profile (distance measurement)															
	Natural channels	Sonar or dip gauging/ GPRS (general packet radio services) or tracking	$u(B)$		Rectangular	0,500 m	5,000 m	10,000 m	15,000 m	20,000 m	0,040 m	0,080 m	0,120 m	0,200 m	0,400 m
	Man-made channels	Manual measurement	$u(B)$		Triangular or rectangular	Not applicable	0,500 m	1,000 m	1,500 m	2,000 m	0,002 m	0,002 m	0,003 m	0,003 m	0,003 m

Many of the values presented in this table are provisional. They are intended to be norms of performance for the technology. Values are to be defined by consensus between users and should be representative of the broad range of equipment available. A formal testing programme may be required to establish the table entries.

[a] Percentage uncertainty for head measurement cannot be specified by the equipment manufacturer. It shall be derived from a relationship of the form $u^*(h) = \sqrt{\frac{u(E)^2 + u(h_1)^2}{h}}$ where $u(E)$ is the uncertainty of the relative datum.

[b] $u^*(h) = \sqrt{\frac{u(E)^2 + u(R)^2}{h}}$ where $u(R)$ is the uncertainty of the range/extension.

[c] The performance figures assume precise compensation for the effects of temperature on sonic velocity. This formula is a practical approximation: $\text{sonic velocity} = 20{,}08\sqrt{\text{absolute temperature of air}}$.

[d] If the unsteady conditions exist, a time-dependent component of uncertainty shall be defined. Instrumentation without this capability shall require a manufacturer's statement of uncertainty relating to unsteady conditions.

Annex E
(informative)

Sample questionnaire — Doppler- and echo-correlation-based flowmeters

E.1 General details

Site name	
Site location	
Purpose of flow measurement	
Proposed duration of flow measurement	
Typical accuracy requirement	
Is a technical specification available?	

E.2 Type of application

Small watercourse	
Sewers: foul sewer	
Surface water sewers	
Combined sewers	
Industrial sewage	
Other effluents (specify)	

E.3 Channel dimensions

		Average	Minimum	Maximum
Circular pipe (diameter)				
Box culvert	Width			
	Height			

Open culvert	Width Height			
Watercourse	Width Height			
Straight channel length available for installation of flowmeter				

E.4 Channel construction

Material of channel walls and bed (e.g. concrete, brick, piled, gravel, silt)	

E.5 Additional channel details

Is weed growth present in channel?	
Is sediment present on channel bed?	
Other relevant information	

E.6 Flow details

Liquid type (e.g. river water, drinking water, raw sewage, screened sewage, final effluent)			
	Typical	Minimum	Maximum
Depth			
Velocity			
Flow			
Suspended solids (mg/l)			
Is the flow aerated? If yes, please give details, including source.			
Chemical content (if applicable)			
Typical water temperature			
Density (if significantly different to water)			

E.7 Channel safety considerations

Is instrument to be installed in a confined space? If yes, please give details.	
Is instrument to be installed in a hazardous area or rated zone? If yes, please give rating details.	
Apart from normal sewage substances, are corrosive or toxic liquids likely to be present? If yes, please give details.	

E.8 Channel access and security

Is vehicular access to the proposed location possible?	
Are there any constraints on channel entry? If yes, please give details (e.g. permits to work, channel closure, entry outside normal working hours, confined space procedures, safety equipment, method statements and risk assessments).	
Are there any concerns over vandalism or theft at this site? If yes, please give details.	
Are you aware of any other issues that need to be considered during the installation of subsequent routine visits? If yes, please give details.	

E.9 Instrument requirements

Portable or fixed instrument	
Preferred power supply requirement (e.g. mains, solar, low voltage, internal battery)	
Is the preferred power supply available at the proposed flowmeter location?	
Required sensor logging interval	
Logging to memory interval	
Required instrument measuring resolution: Depth (mm) Velocity (m/s)	

Required download interval	
Required method of downloading	
Is a display panel required? If yes, please give details of any parameters that the unit is required to display.	
Is real-time access required?	
What is the approximate distance between the flow sensor and control system?	
Will the instrument be mounted outdoors or underground where weather or waterproofing may be required?	
Will the depth sensor be internal or external? If external, please give details of sensor.	
Will the instrument be required to interface with any other instruments? If yes, please give details of the type of instrument and I/O requirements, including alarms.	
Are there any other technical issues that you consider relevant to this application? If yes, please give details.	

E.10 Financial aspects

What is the available budget for the flowmeter instrument?	

E.11 Division of responsibility

Where applicable, please state for each item, whether a customer, distributor, civil contractor, mechanical and electrical contractor, flowmeter supplier or other. Also, what is the contractual relationship? (For example, customer might place a single contract with a civil contractor who buys the flowmeter from a distributor who in turn buys it from the supplier.)

Design of flowmeter	
Design of site layout	
Construction drawings	
Supply of flowmeter	
Supply of mounting hardware	
Supply of peripheral equipment	

Civil work (ducts, supporting piles, buildings, etc.)	
Provision of power supply	
Provision of telephone line	
Installation	
Commissioning	

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