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Hydrometric determinations — Flow measurement in open channels using structures — Flat-V weirs

Déterminations hydrométriques — Mesure de débit dans les canaux découverts au moyen de structures — Déversoirs en V ouvert

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 4377 was prepared by Technical Committee ISO/TC 113, *Hydrometry*, Subcommittee SC 2, *Flow measurement structures*.

This fourth edition cancels and replaces the third edition (ISO 4377:2002), which has been technically revised to update the treatment of uncertainty to be consistent with the other standards relating to flow measurement structures.

Hydrometric determinations — Flow measurement in open channels using structures — Flat-V weirs

1 Scope

This International Standard describes the methods of measurement of flow in rivers and artificial channels under steady or slowly varying conditions using flat-V weirs (see Figure 1).

Annex A gives guidance on acceptable velocity distribution.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies

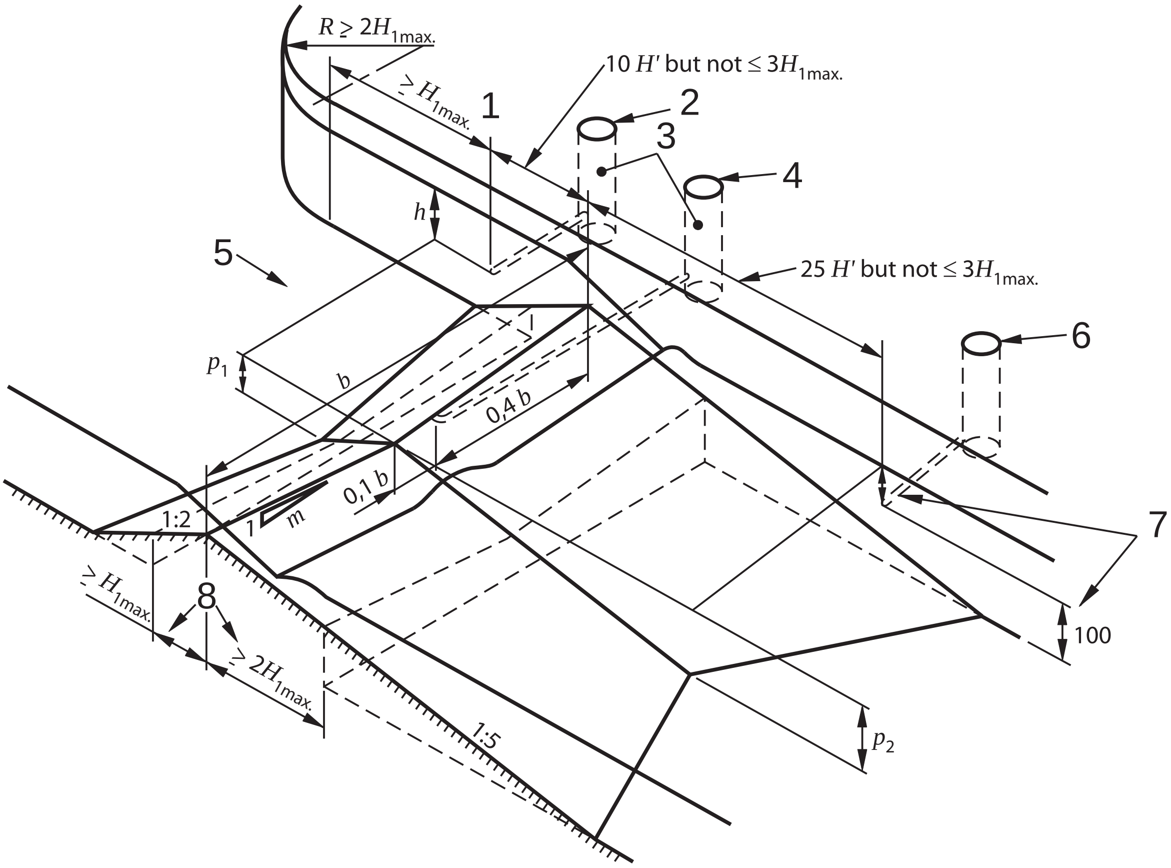
ISO 772, *Hydrometry — Vocabulary and symbols*

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

3 Terms and definitions

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

Dimensions in millimetres



Key

1	head gauging section	b	crest width
2	upstream tapping	H'	difference between the invert (apex) of the V and the top of the V
3	stilling wells	H_{1max}	maximum upstream total head above crest elevation
4	crest tapping	h	gauged head above lowest crest elevation
5	flow	p	difference between mean bed level and lowest crest elevation
6	downstream head measuring point		
7	minimum 100 mm above stilling basin level		
8	limits of permissible upstream and downstream truncations		

Figure 1 — Triangular profile flat-V weir

4 Symbols

The following is a list of symbols used, with the corresponding units of measurement.

Symbol[a]	Meaning	Units
A	Area of cross-section of flow	m^2
B	Width of approach channel	m
b	Crest width	m
C_D	Coefficient of discharge	Non-dimensional
C_De	Effective coefficient of discharge	Non-dimensional
C_dr	Drowned flow reduction factor	Non-dimensional
C_v	Coefficient of approach velocity	Non-dimensional
g	Gravitational acceleration (standard value)	ms^{-2}
H	Total head above lowest crest elevation	m
H_1e	Total effective upstream head	m
H_2e	Total effective downstream head	m
H_1max	Maximum upstream total head above crest elevation	m
h	Gauged head above lowest crest elevation	m
h_1	Upstream gauged head	m
h_1e	Effective upstream gauged head	m
h_2	Downstream gauged head	m
h_2e	Effective downstream gauged head	m
h_p	Separation pocket head	m
h_pe	Effective separation pocket head relative to lowest crest elevation	m
h', H'	Difference between lowest and highest crest elevations	m
K_1,K_2	Constants	Non-dimensional
k_h	Head correction factor	m
L_1	Distance of upstream head measurement position from crest line	m
m	Crest cross-slope (1 vertical: m horizontal)	Non-dimensional
n	Number of measurements in a set	Non-dimensional
p	Difference between mean bed level and lowest crest elevation	m
Q	Discharge	$\mathrm{m}^3\mathrm{s}^{-1}$
Q_dfv	Total daily flow volume	$\mathrm{m}^3\mathrm{d}^{-1}$
t	Measurement observation frequency time	minutes
$\bar{v}$	Mean velocity at cross-section	m/s
$\bar{v}_\mathrm{a}$	Mean velocity in approach channel	m/s
u_h	Absolute uncertainty in head measurement	m
$u(E)$	Absolute uncertainty in gauge zero	m
$u^*{}_{(\mathrm{CD})}$	Percentage uncertainty in discharge coefficient	Non-dimensional
$u^*(C_\mathrm{v})$	Percentage uncertainty in coefficient of velocity	Non-dimensional
$u^*(C_\mathrm{dr})$	Percentage uncertainty in drowned flow reduction factor	Non-dimensional
$u^*(h)$	Percentage uncertainty in head measurement	Non-dimensional
$u^*(H_\mathrm{e})$	Percentage uncertainty in total effective head	Non-dimensional
$U^*(Q)$	Percentage uncertainty in discharge determination	Non-dimensional
$U^*(Q_\mathrm{dmf})$	Percentage uncertainty in the daily mean flow	Non-dimensional
$U^*(Q_\mathrm{dfv})$	Percentage uncertainty in the total daily flow volume	Non-dimensional
Z_h, Z_H	Shape factors	Non-dimensional
α	Coriolis energy coefficient	Non-dimensional

Subscript

1	denotes upstream value
2	denotes downstream value
e	denotes "effective" and implies that corrections for fluid effects have been made to the quantity
a	denotes approach channel

5 Characteristics of flat-V weirs

The standard flat-V weir is a control structure, the crest of which takes the form of a shallow V when viewed in the direction of flow.

The standard weir has a triangular profile with an upstream slope of 1 (vertical): 2 (horizontal) and a downstream slope of 1:5. The cross-slope of the crest line shall not be steeper than 1:10. The cross-slope shall lie in the range of 0 to 1:10 and, at the limit when the cross-slope is zero, the weir becomes a two-dimensional triangular profile weir.

The weir can be used in both the modular and drowned ranges of flow. In the modular flow range, discharges depend solely on upstream water levels and a single measurement of upstream head is sufficient. In the drowned flow range, discharges depend on both upstream and downstream water levels, and two independent head measurements are required. For the standard flat-V weir, these are

— the upstream head, and

— the head developed within the separation pocket which forms just downstream of the crest or, as a less accurate alternative, the head measured just downstream of the structure.

The flat-V weir will measure a wide range of flows and has the advantage of high sensitivity at low flows.

Operation in the drowned flow range minimizes afflux at very high flows. Flat-V weirs shall not be used in steep rivers (see 6.2.2.6), particularly where there is a high sediment load.

There is no specified upper limit for the size of this structure. Table 1 gives the ranges of discharges for three typical weirs.

Table 1 — Ranges of discharge

Elevation of crest above bed m	**Crest/cross-slope ratio**	**Width** m	**Range of discharge** m^3s^{-1}
0,2	1:10	4	0,015 to 5
0,5	1:20	20	0,030 to 180 (within maximum head of 3 m)
1,0	1:40	80	0,055 to 630 (within maximum head of 3 m)

6 Installation

6.1 Selection of site

6.1.1 The weir shall be located in a straight section of the channel, avoiding local obstructions, roughness or unevenness of the bed.

6.1.2 A preliminary study of the physical and hydraulic features of the proposed site shall be made, to check that it conforms (or can be constructed or modified to conform) to the requirements necessary for measurement of discharge by the weir. Particular attention shall be paid to the following:

a) the adequacy of the length of channel of regular cross-section available (see 6.2.2.2);

b) the uniformity of the existing velocity distribution (see Annex A);

c) the avoidance of a steep channel (see 6.2.2.6);

d) the effects of increased upstream water levels due to the measuring structure;

e) the conditions downstream (including such influences as tides, confluences with other streams, sluice gates, mill dams and other controlling features, such as seasonal weed growth, which might cause drowning);

f) the impermeability of the ground on which the structure is to be founded and the necessity for piling, grouting or other means of controlling seepage;

g) the necessity for flood banks, to confine the maximum discharge to the channel;

h) the stability of the banks, and the necessity for trimming and/or revetment;

i) the uniformity of the approach channel section;

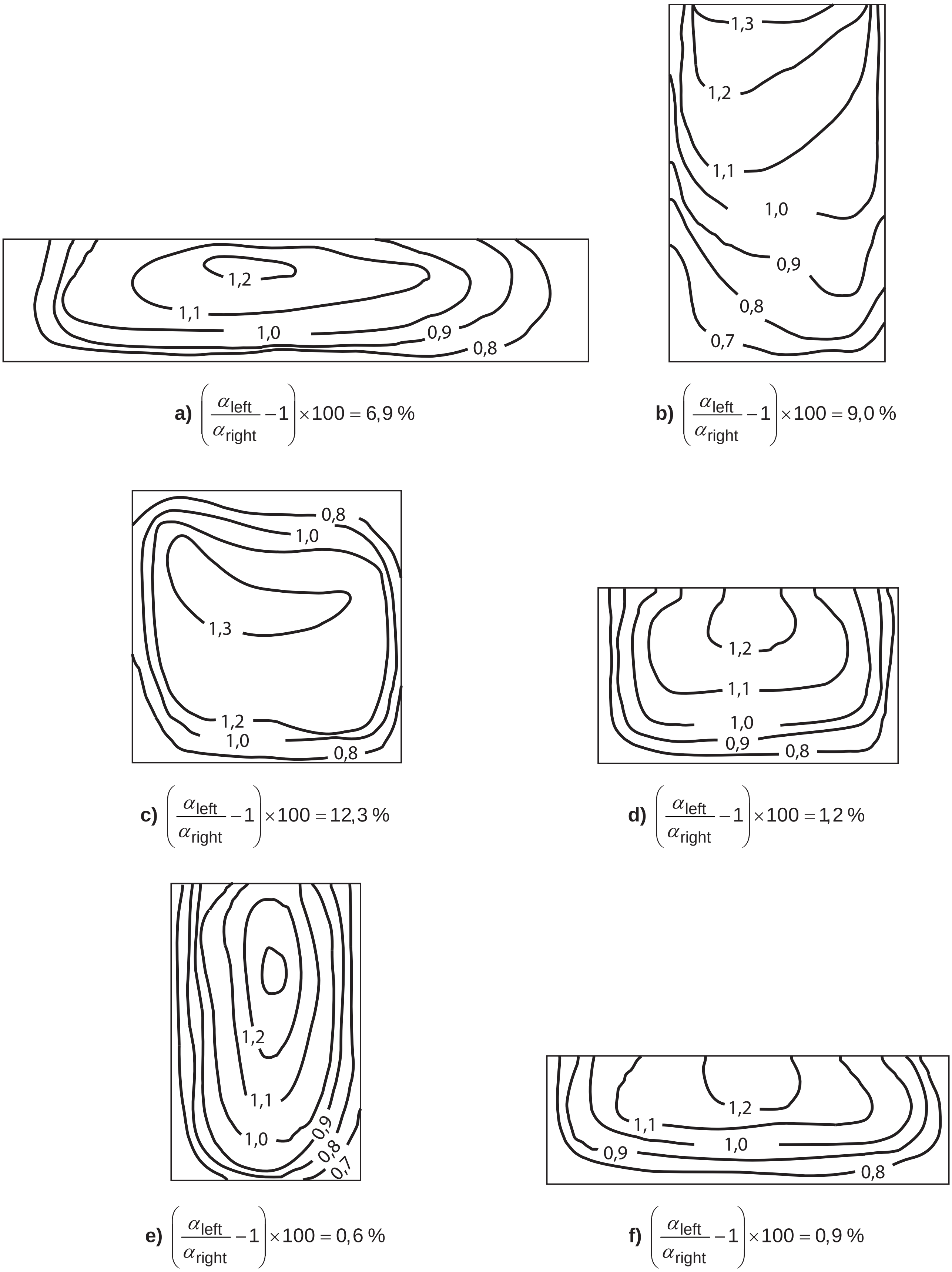
j) the effect of wind on the flow over the weir, especially when it is wide and the head is small and when the prevailing wind is in a transverse direction.

k) If silt removal could be an operation and maintenance requirement, consideration should be given to the accessibility of the site for heavy plant following construction and reinstatement of the site.

l) A suitable location is required for the instrument building/housing to allow the effective operation and maintenance of the intake pipe and stilling well.

6.1.3 If the site does not possess the characteristics necessary for satisfactory measurements, or if an inspection of the stream shows that the velocity distribution in the approach channel deviates appreciably from the examples shown in Figure 2, the site shall not be used unless suitable improvements are practicable.

6.1.4 Weirs act as obstacles to the movement of most fish and other aquatic species. Care should therefore be taken to ensure that the installation of gauging structures such as flat-V weirs does not have a detrimental effect on the aquatic ecology where this might be an issue. In addition, care should be taken to ensure that any gauging structure complies with the relevant national and international legislation and regulations, for example the European Parliament EU Water Framework Directive (Directive 2000/60/EC). Where the movement of aquatic life could be compromised by the installation of a flow measurement structure, this may have to be reflected in the design, e.g. limit the crest height and provide an adequate depth of stilling basin. Alternatively, a fishpass could be installed (ISO 26906).



a) $\left(\frac{\alpha_{\text{left}}}{\alpha_{\text{right}}}-1\right)\times 100 = 6{,}9\ \%$

b) $\left(\frac{\alpha_{\text{left}}}{\alpha_{\text{right}}}-1\right)\times 100 = 9{,}0\ \%$

c) $\left(\frac{\alpha_{\text{left}}}{\alpha_{\text{right}}}-1\right)\times 100 = 12{,}3\ \%$

d) $\left(\frac{\alpha_{\text{left}}}{\alpha_{\text{right}}}-1\right)\times 100 = 1{,}2\ \%$

e) $\left(\frac{\alpha_{\text{left}}}{\alpha_{\text{right}}}-1\right)\times 100 = 0{,}6\ \%$

f) $\left(\frac{\alpha_{\text{left}}}{\alpha_{\text{right}}}-1\right)\times 100 = 0{,}9\ \%$

Figure 2 — Examples of velocity profiles in the approach channel

6.2 Installation conditions

6.2.1 General requirements

The complete measuring installation consists of an approach channel, a weir structure and a downstream channel.

NOTE 1 The condition of each of these three components affects the overall accuracy of the measurements. Installation requirements include such features as the surface finish of the weir, the cross-sectional shape of the channel, channel roughness and the influence of control devices upstream or downstream of the gauging structure.

NOTE 2 The distribution and direction of velocity can have an important influence on the performance of a weir (see 6.2.2 and Annex A).

NOTE 3 Once a weir has been installed, any physical changes in the installation will change the discharge characteristics; recalibration will then be necessary.

6.2.2 Approach channel

6.2.2.1 If the flow in the approach channel is disturbed by irregularities in the boundary (e.g. large boulders or rock outcrops, or by a bend, sluice gate or other feature which causes asymmetry of discharge across the channel), the accuracy of gauging may be significantly affected. The flow in the approach channel shall have a symmetrical velocity distribution (see Annex A). This can be achieved by providing a long, straight approach channel of uniform cross-section.

6.2.2.2 A minimum required length of straight approach channel shall be five times the width of the water surface at maximum flow, provided flow does not enter the approach channel with high velocity via a sharp bend or angled sluice gate.

NOTE 1 The length of straight approach channel required refers to the distance upstream from the upstream head measuring location (see Figure 1).

NOTE 2 A greater length of uniform approach channel is desirable if it can be readily provided.

6.2.2.3 In a natural channel where it is uneconomic to line the bed and banks with concrete for this distance, and iwhere the width between the vertical walls of the lined approach to the weir is less than the approach width of the natural channel, the banks shall be profiled to give a smooth transition from the approach channel width to the width between the vertical side walls. The unlined channel upstream of the contraction shall nevertheless conform to 6.2.2.1 and 6.2.2.2.

6.2.2.4 Vertical side walls constructed to effect a narrowing of the natural channel shall be symmetrically aligned with the centre line of the channel and curved to a radius not less than 2 $H_{1\text{max}}$ as shown in Figure 1. The tangent point of this radius nearest to the weir crest shall be at least $H_{1\text{max}}$ upstream of the head measurement section. The height of the side walls shall be chosen to contain the design maximum discharge.

6.2.2.5 In a channel where the flow is free from floating and suspended debris, good approach conditions can also be provided by suitably placed baffles formed of vertical laths. No baffle shall be nearer to the point at which the head is measured than 10 times the maximum upstream head.

6.2.2.6 Under certain conditions, a hydraulic jump may occur upstream of the measuring structure, for example if the approach channel is steep. Provided the wave created by the hydraulic jump is at a distance upstream of no less than 20 times the maximum upstream depth, flow measurement is feasible, subject to confirmation that an even velocity distribution exists at the gauging station.

6.2.2.7 Conditions in the approach channel can be verified by inspection or measurement for which several methods are available such as acoustic Doppler current profilers (ADCPs), current meters, floats or concentrations of dye, the last being useful in checking conditions at the bottom of the channel. A complete and quantitative assessment of velocity distribution can be made by means of an ADCP or a current meter. The velocity distribution shall comply with the requirements of A.5.

6.3 Weir structure

6.3.1 The structure shall be rigid and watertight and capable of withstanding flood flow conditions without damage from outflanking or from downstream erosion. The weir crest shall be straight when viewed from above and at right angles to the direction of flow in the upstream channel. The geometry shall conform to the dimensions given in Clause 5 and Figure 1.

The weir shall be contained within vertical side walls, and the crest width shall not exceed the width of the approach channel (see Figure 1). Weir blocks may be truncated but their horizontal dimensions shall not be reduced in the direction of flow to less than $H_{1\text{max}}$ and 2 $H_{1\text{max}}$, upstream and downstream of the crest line respectively, where $H_{1\text{max}}$ is the maximum upstream total head, expressed in metres, relative to the lowest crest elevation.

6.3.2 The weir and the approach channel as far as the upstream tapping point shall be constructed with a smooth non-corrodible material. A good surface finish is important near the crest but can be relaxed a distance along the profile of 0,5 $H_{1\text{max}}$ upstream and downstream of the crest line.

The crest shall be formed by using smooth material resistant to erosion and corrosion, for example, an embedded stainless steel insert with bevelled edges to conform with the surface of the weir block.

6.3.3 In order to minimize uncertainty in the discharge, the following tolerances are acceptable:

a) crest width (0,2 % with a maximum of 0,01 m);

b) upstream slope 1,0 %;

c) downstream slope 1,0 %;

d) crest cross-slope 1,0 %;

e) point deviations from the mean crest line ± 0,2 % of the crest width.

NOTE Laboratory installations will normally require higher accuracy.

6.3.4 The structure shall be measured upon completion and mean dimensional values and their standard deviations (SD) at the 68 % confidence limits computed. The former are used for computation of discharge and the latter are used to obtain the overall uncertainty of a single determination of discharge (see 11.2).

6.4 Downstream conditions

Conditions downstream of the structure are an important factor controlling the tailwater level. This level is one of the factors which determines whether modular or drowned flow conditions will occur at the weir. It is essential, therefore, to calculate or observe tailwater levels over the full discharge range and make decisions regarding the type of weir and its required geometry in light of this evidence.

7 Maintenance

Maintenance of the measuring structure and the approach channel is important to enable accurate measurements to be made. The approach channel shall be kept clean and free from silt and vegetation for at least the distance specified in 6.2.2.2. The float wells, tappings and connecting pipework shall also be kept clean and free from deposits.

The weir structure shall be kept clean and free from clinging debris and care taken in the process of cleaning to avoid damage to the weir crest.

The weir crest shall be inspected for erosion damage regularly. If the mean effective radius of the crest exceeds 5 mm, then refurbishment shall be considered. Algae growth on weir crests can be a particular problem which if not controlled can result in large inaccuracies in the computed discharges. In particular, the inaccuracies can be very large when the weir is operating close to the minimum recommended head (see 9.7.1).

Erosion lowers the zero datum and affects the coefficient of discharge at low flows (see 8.3 and Clause 9). In such cases, the crest shall be repaired *in-situ* or removed and replaced.

If conditions are modular when maintenance is carried out, a useful check on the satisfactory operation of a crest tapping is to ensure that the readings accord with the specification given in 9.5, i.e. when the weir is modular, the value of $h_{\mathrm{pe}}/H_{1\mathrm{e}}$ always lies within the range (40 ± 5) %.

8 Measurement of head(s)

8.1 General

Where spot measurements are required, the heads can be measured by vertical staff gauges, hooks, points, wires or tape gauges. Where continuous records are required, recording devices such as chart recorders or stand-alone telemetry data loggers shall be used.

The measurement of head is covered in more detail in ISO 4373.

NOTE As the size of the weir and head decreases, small discrepancies in construction and in the zero setting and reading of the head measuring device become of greater relative importance.

8.2 Stilling (gauge) wells

8.2.1 It is common practice to measure the upstream head in a stilling well to reduce the effects of water surface irregularities. At some locations, it may be more appropriate to install the water level sensor in a tube.

Periodic checks on the measurement of the head in the approach channel shall be made. This shall be made using a staff gauge, or dipping device (see 8.1) located adjacent to the intake pipe or water level sensor tube. It is essential that the manual head measurement point is truly representative of the water level at the intake pipe or recorder tube. Check measurements shall also be made periodically within the stilling well or tube to ensure that the water level in the stilling well agrees with external reference measurement. If there is a significant difference, there may be a need to undertake maintenance, e.g. flush stilling well or undertake further investigation to explain differences.

Where the weir is designed to operate in the drowned flow range, a separate stilling well shall be used to record the piezometric head where a crest-tapping is installed. This develops within the separation pocket which forms immediately downstream of the crest or in the channel downstream of the structure. If downstream heads are to be used to determine discharges within the drowned flow range, an appropriately sited downstream stilling well or water level sensor tube shall be installed.

8.2.2 Stilling wells or water level sensor tubes shall be vertical and of sufficient height and depth to cover the full range of water levels. In field installations, they shall have a minimum height of 0,3 m above the maximum water levels expected. Stilling wells shall be connected to the appropriate head measurement positions by means of pipes.

8.2.3 Both the stilling well and the connecting (intake) pipe(s) shall be watertight. Where the well is provided for the accommodation of the float and counterweight recorder, it shall be of adequate size and depth.

8.2.4 The invert of the pipe shall be positioned at a distance of not less than 0,06 m below the lowest water level to be measured.

8.2.5 Pipe connections to the upstream and downstream head measurement positions shall terminate either flush with, or at right angles to the boundary of the approach and downstream channels. The channel boundary shall be plain and smooth (equivalent to carefully finished concrete) within a distance 10 times the diameter of the pipes from the centreline of the connection. The pipes may be oblique to the wall only if it is fitted with a removable cap or plate, set flush with the wall, through which a number of holes are drilled. The edges of these holes shall not be rounded or burred. Perforated cover plates are not recommended where weed or silt are likely to be present.

8.2.6 The static head at the separation pocket immediately downstream of the crest of the weir shall be transmitted to its gauge well by one of the following:

a) an array of tapping holes set into a plate covering a cavity in the crest of the weir block;

b) the underside of the plate supporting a manifold into which the static head is communicated via an array of feed tubes;

c) a horizontal conduit leading from the cavity through the weir block beneath the crest and terminating at the gauge well;

d) a flexible transmission tube to communicate static head within the manifold to the gauge well;

e) a watertight seal around the transmission tube to prevent static head within the cavity from influencing the static head transmitted from within the manifold.

The static head within the manifold may be at a different pressure because of leakage around the periphery of the cover plate.

These arrangements minimize the occurrence of silting within the communication path between the separation pocket and the gauge well and provide for the effective purging of the pipework by the occasional back-flushing of the system. For this purpose, a volume of water shall periodically be introduced into the gauge well. The modular value of $h_{\mathrm{pe}}/H_{1\mathrm{e}}$ always lies within the range (40 ± 5) % and a check on this value during the modular flow conditions provides a sound method for determining whether the crest tapping is performing satisfactorily. If the value of this ratio is not within this range, the installation should be checked for leakage around the tapping plate and/or general blockage of the system (see 9.5).

Figure 3 shows the general arrangement for the crest-tapping installation. The size and disposition of the crest tapping holes is given in Table 2.

8.2.7 When using crest-tapping or downstream water level recorder data to estimate flows when flat-V weirs are operating in the drowned flow range it is essential that these are synchronized accurately with the upstream head recorder. This can be achieved by linking each water level sensor to a multi-channel logger with a single clock (see 9.6).

8.2.8 Adequate additional depth shall be provided in wells to avoid the danger of floats, if used, grounding either on the bottom or on any accumulation of silt or debris. A minimum distance of 0,5 m between the invert of the intake pipe and the bottom of the well is usually recommended.

The gauge well arrangement may include an intermediate chamber of similar size and proportions as the approach channel, to enable silt and other debris to settle out where it may be readily seen and removed.

8.2.9 The diameter of the connecting pipe or width of slot to the upstream well shall be sufficient to permit the water level in the well to follow the rise and fall of head without appreciable delay. Care should be taken however not to oversize the pipe, in order to ensure ease of maintenance and to damp out oscillations due to short period waves.

NOTE No firm rule can be laid down for determining the size of the connecting pipe to the upstream well, because this is dependent on a particular installation, e.g. whether the site is exposed and thus subject to waves, and whether a larger diameter well is required to house the floats of recorders. However, some practitioners and suppliers recommend that the area of the intake pipe or slot should be 0,1 % of the area of the stilling well. It is sometimes advantageous for maintenance purposes to use a larger diameter intake pipe. A removable plate with holes can be fixed to the watercourse end of the pipe to provide the required stilling (reduced area of intake) and to prevent the ingress of fauna.

Table 2 — Arrangements for crest tappings

Crest tapping holes	Crest width b m			
	0,30 to 0,99	1,00 to 1,99	2,00 to 3,99	> 4,00
Hole diameter (mm)	5	5	10	10
Hole pitch (mm)	25	25	40	50
Number of tapping holes	3	5	7	9
Offset of centre hole from centre line of weir	0,1b	0,1b	0,1b	0,1b
Distance of the array of holes downstream of the crest (mm)	10	15	20	20
Bore diameter of manifold feeder tubes (mm)	5	5	10	10
Bore diameter of transmission tube (mm)	15	20	25	30

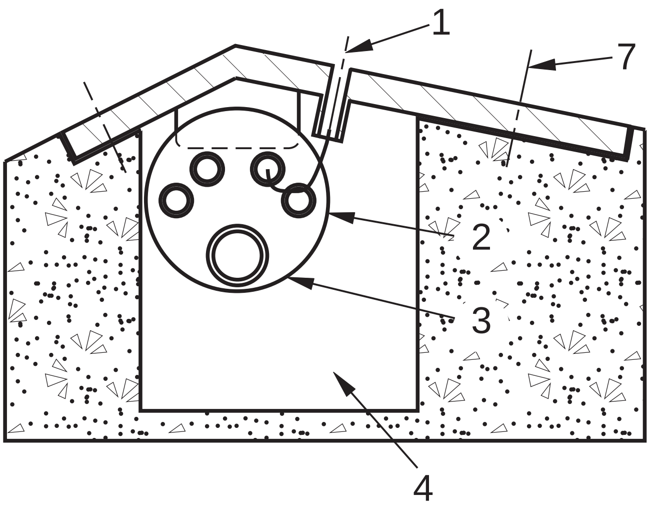
8.3 Zero setting

8.3.1 Accurate initial setting of the zeros of the head measuring devices with reference to the lowest level of the crest (apex of the v) and subsequent regular checks of these settings is essential.

8.3.2 An accurate means of checking the instrument zero at frequent intervals shall be provided. Bench marks, in the form of horizontal metal plates, can be set up on the top of the vertical side walls at the head monitoring points and in the gauge wells. These shall be accurately levelled to ensure their elevation relative to crest level is known. An alternative, or addition, to the external plate is a staff gauge zeroed to the weir crest.

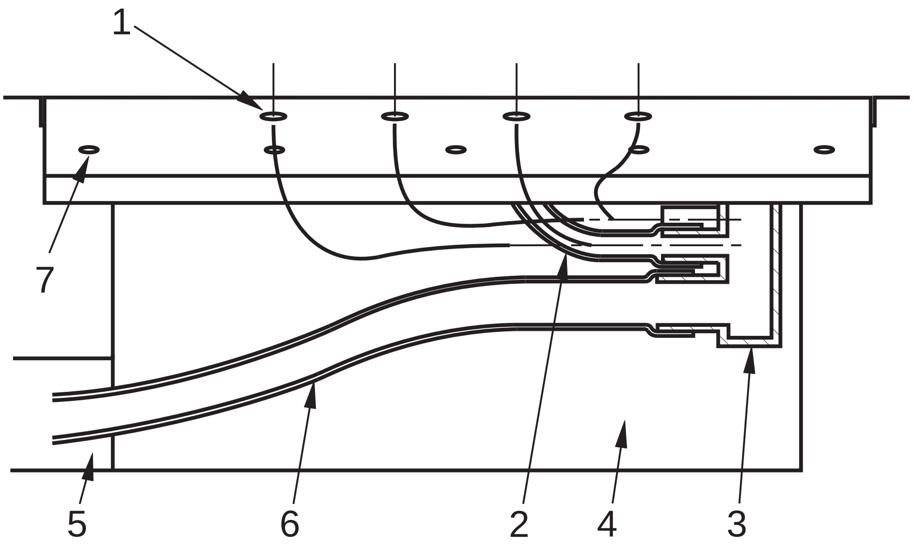
Instrument set-up zeros can be checked with respect to these bench marks without the necessity of re-surveying the crest each time. These can also be used to check that the level inside the stilling well is the same as the level in the watercourse. This will provide a check on whether the intake pipe or stilling well have become silted up. Any settlement of the structure may, however, affect the relationships between crest and bench mark levels and it is advisable to make occasional checks on these relationships.

8.3.3 A zero check based on the water level (either when the flow ceases or just begins) is susceptible to serious errors due to surface tension effects and shall not be used.

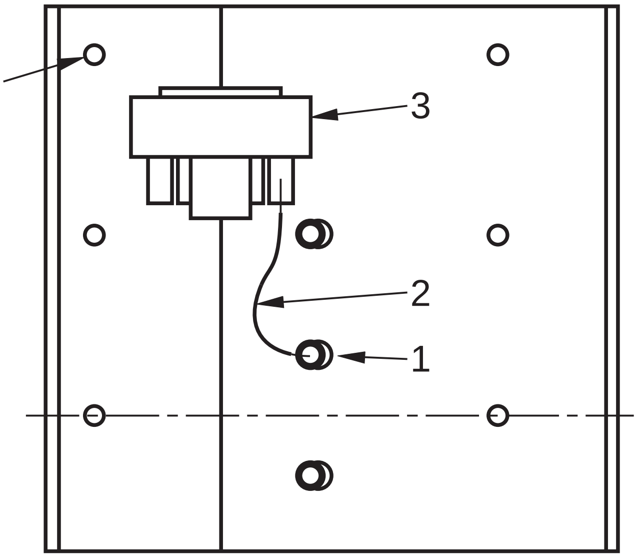


a) Cross-section through one crest tapping and showing part of the weir block

Figure 3 (*continued*)



b) Downstream view with section through the manifold (item 3)



c) View of the underside of the crest plate

Key

1 crest tappings
2 feed tubes communicating crest head to the manifold (some shown as single lines only)
3 manifold [section in view b)]
4 cavity in the crest of the weir block
5 conduit leading to a gauge well
6 transmission tube (other end sealed within the conduit but communicating head in the manifold to the gauge well)
7 holes for screw-mounting the crest plate onto the weir block

Figure 3 — Arrangements for crest tappings

8.3.4 Values for the crest cross-slope, m, and the gauge zero can be obtained by measuring the crest elevation at regular intervals along the crest line. A best fit straight line is positioned through the measured points for each side of the weir, and the intersection of these lines is the gauge zero level. The mean of the crest cross-slopes (m) for the two sides is used in the discharge formulae. For field installations, the use of standard levelling techniques is recommended, but precise micrometer or Vernier gauges shall be used for laboratory installation.

8.4 Location of head measurement sections

8.4.1 The approach flow to a flat-V weir is three-dimensional. Drawdown in the approach to the lowest crest elevation is more pronounced than in other positions across the width of the approach channel. This results in a depression in the water surface immediately upstream of the lowest crest position. Further upstream this depression is less pronounced and at a distance of 10 times the V-height, $10H'$, the water surface elevation across the width of the channel is constant. To achieve an accurate assessment of the upstream head, the tapping shall be set $10H'$ upstream of the crest line. $H' = b/2m$ is the difference between lowest and highest crest elevation, in metres. However, if this distance is less than $3\,H_{\text{max}}$ the tapping shall be set $3\,H_{\text{max}}$ upstream of the crest to avoid drawdown effects.

8.4.2 If other considerations necessitate siting the tapping closer to the weir, then corrections to the discharge coefficients are necessary if $H_1/p_1 > 1$. In all cases, a reduction in the coefficient is applicable and the percentage reductions depend on the tapping point location. The value of $H_1/p_1 > 1$ is given in Table 3.

8.4.3 Flat-V weirs can be used for gauging purposes in the drowned flow range if a tapping is incorporated at the crest. The centre position of the 10 crest tapping holes (see Table 2) shall be offset laterally from the position of the lowest crest elevation a distance of 0,1 times the total crest width (see Figure 3 and Table 2).

8.4.4 Alternatively, flat-V weirs can be used for gauging purposes in the drowned flow range if a downstream tapping is incorporated.

NOTE This method is not as accurate as the method described in 8.4.3.

The downstream tapping shall be $25H'$ or $3H_{1\text{max}}$, whichever is greater, downstream of the crest line and set at a level 100 mm above the downstream bed level.

Table 3 — Corrections to discharge coefficients

L_1	H_1/p_1		
	1	2	3
	Correction %		
$10H'$	0,0	0,0	0,0
$8H'$	0,0	0,3	0,6
$6H'$	0,0	0,6	0,9
$4H'$	0,0	0,8	1,2

H_1 is the upstream total head relative to lowest crest elevation, expressed in metres;

p_1 is the height of lowest crest elevation relative to upstream bed level, expressed in metres;

L_1 is the distance of upstream head measurement position from crest line, expressed in metres.

9 Discharge relationships

9.1 Equations of discharge

9.1.1 In terms of total head, the basic discharge equation for a flat-V weir operating under modular flow conditions is:

$$Q = 0{,}8 C_{\mathrm{De}} \sqrt{g}\, m Z_{\mathrm{H}} H_{1\mathrm{e}}{}^{5/2} \tag{1}$$

where

Q is the total discharge expressed in cubic metres per second (m^3/s);

C_{De} is the effective coefficient of discharge in the modular range;

g is the gravitational acceleration (standard value) expressed in metres per second squared (m/s^2);

m is the mean crest cross-slope (1 vertical: m horizontal);

Z_{H} is the shape factor;

$H_{1\mathrm{e}}$ is the effective upstream total head relative to lowest crest elevation expressed in metres (m).

Alternatively, the discharge equation may be expressed in terms of gauged head by introducing a coefficient of velocity dependant upon the weir and flow geometries:

$$Q = 0{,}8 C_{\mathrm{De}} C_v \sqrt{g}\, m Z_{\mathrm{h}} h_{1\mathrm{e}}{}^{5/2} \tag{2}$$

where

C_{v} is the coefficient of velocity;

Z_{h} is the shape factor;

$h_{1\mathrm{e}}$ is the effective upstream gauged head relative to lowest crest elevation expressed in metres (m).

9.1.2 In terms of total head, the basic discharge equation for a flat-V weir operating under drowned flow conditions is:

$$Q = 0{,}8 C_{\mathrm{De}} C_{\mathrm{dr}} \sqrt{g}\, m Z_{\mathrm{H}} H_{1\mathrm{e}}{}^{5/2} \tag{3}$$

where C_{dr} is the drowned flow reduction factor.

The corresponding gauged head equation is:

$$\mathrm{Q} = 0{,}8 C_{\mathrm{De}} C_{\upsilon} C_{\mathrm{dr}} \sqrt{g}\, m Z_{\mathrm{h}} h_{1\mathrm{e}}{}^{5/2} \tag{4}$$

Values for the modular coefficient of discharge, C_{De}, are given in Table 4.

Table 4 — Summary of recommended coefficients, limitations and tolerances

Flat-V weirs	Crest cross-slope		
	1:40 or less	1:20	1:10
a) $H_1/H' \leq 1,0$			
Modular coefficient C_{De}	0,625[a]	0,620[a]	0,615[a]
Head correction factor, k_{h}	0,000 4 m	0,000 5 m	0,000 8 m
Standard uncertainty in discharge coefficient, $u^*(C_{\mathrm{De}})_{68}$	1,5 %	1,6 %	1,45 %
Modular limit[b]	65 % to 75 %	65 % to 75 %	65 % to 75 %
Other limitations	$H'/p_1 \leq 2,5$	$H'/p_1 \leq 2,5$	$H'/p_1 \leq 2,5$
	$H_1/p_2 \leq 2,5$	$H_1/p_2 \leq 2,5$	$H_1/p_2 \leq 2,5$
Upstream tapping	$10H'$	$10H'$	$10H'$
b) $H_1/H' > 1,0$			
Modular coefficient C_{De}	0,630[a]	0,625[a]	0,620[a]
Head correction factor, k_{h}	0,000 4 m	0,000 5 m	0,000 8 m
Standard uncertainty in discharge coefficient, $u^*(C_{\mathrm{De}})_{68}$	1.25 %	1.4 %	1.15 %
Modular limit[b]	65 % to 75 %	65 % to 75 %	65 % to 75 %
Other limitations	$H'/p_1 \leq 2,5$	$H'/p_1 \leq 2,5$	$H'/p_1 \leq 2,5$
	$H_1/p_2 \leq 8,2$	$H_1/p_2 \leq 8,2$	$H_1/p_2 \leq 4,2$
Upstream tapping	$10H'$	$10H'$	$10H'$

[a] Computations under non-modular conditions are based on $C_{\mathrm{De}} = 0,631$, $C_{\mathrm{De}} = 0,629$ and $C_{\mathrm{De}} = 0,620$ respectively.

[b] See 9.5.

9.2 Effective heads

Effective heads are obtained by reducing observed values by a small constant amount which corrects for fluid property effects. Thus:

$$h_{1\mathrm{e}} = h_1 - k_{\mathrm{h}} \tag{5}$$

and

$$H_{1\mathrm{e}} = H_1 - k_{\mathrm{h}} = h_1 + \frac{\alpha \bar{v}_a^{\,2}}{2g} - k_{\mathrm{h}} \tag{6}$$

Values for the head correction factor, k_{h}, are given in Table 4. The value of the Coriolis energy coefficient, α, shall be checked on site by measuring the velocity distribution at the section where the head is measured. At the design stage, the value of α shall be taken as 1,2.

9.3 Shape factors

Shape factors are introduced into discharge equations for flat-V weirs because the geometry of flow changes when the discharge exceeds the V-full condition. Thus:

when $h_1 \leq h'$,

$$Z_h = Z_H = 1{,}0 \tag{7}$$

when $h_1 > h'$,

$$Z_h = [1{,}0 - (1{,}0 - h'/h_{1e})^{5/2}] \tag{8}$$

and

$$Z_H = [1{,}0 - (1{,}0 - H'/H_{1e})^{5/2}] \tag{9}$$

where

h' $(= H' = b/2m)$	is the difference between the lowest and highest crest elevations, expressed in metres;
b	is the crest width, expressed in metres.

Values of Z_h, Z_H in terms of h_{1e}/h' and H_{1e}/H' are given in Table 5.

9.4 Coefficient of velocity

9.4.1 The coefficient of velocity, C_v, is related to the modular coefficient of discharge, C_{De}, the ratio h'/p_1 and the ratio h_{1e}/h'.

9.4.2 The coefficient of velocity, C_v, occurs in Equations (2) and (4), together with the shape factor, Z_h. As indicated in 9.3, this shape factor is a function of h_{1e}/h', one of the factors affecting C_v. It is convenient to present data for the product $C_v Z_h$ in terms of h'/p_1 and h_{1e}/h' since C_v and Z_h are not required separately. Numerical values of this product are given in Table 6.

NOTE The determination of discharge using the gauged head and the coefficient of velocity is more appropriate for hand calculation. For computer applications, the preferred method of calculation of discharge is by means of Equations (1) and (3); the total head (H_{1e}) being calculated by the successive approximation method (see 10.2.1).

Table 5 — Evaluation of Z_h and Z_H in terms of h_{1e}/h' and H_{1e}/H'

h_{1e}/h' or H_{1e}/H'	**0,00**	**0,01**	**0,02**	**0,03**	**0,04**	**0,05**	**0,06**	**0,07**	**0,08**	**0,09**
0,0 to 0,9	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
1,0	1,000	1,000	1,000	1,000	1,000	1,000	0,999	0,999	0,999	0,998
1,1	0,998	0,997	0,996	0,996	0,995	0,994	0,993	0,992	0,991	0,990
1,2	0,989	0,987	0,986	0,985	0,984	0,982	0,981	0,979	0,978	0,976
1,3	0,974	0,973	0,971	0,969	0,968	0,966	0,964	0,962	0,960	0,958
1,4	0,956	0,954	0,952	0,950	0,948	0,946	0,944	0,942	0,940	0,938
1,5	0,936	0,934	0,932	0,929	0,927	0,925	0,923	0,921	0,918	0,916
1,6	0,914	0,912	0,909	0,907	0,905	0,903	0,900	0,896	0,898	0,895
1,7	0,891	0,889	0,887	0,884	0,882	0,880	0,877	0,875	0,873	0,871
1,8	0,868	0,866	0,864	0,861	0,859	0,857	0,855	0,852	0,850	0,848
1,9	0,846	0,843	0,841	0,839	0,837	0,834	0,832	0,830	0,828	0,825
2,0	0,823	0,821	0,819	0,817	0,814	0,812	0,810	0,808	0,806	0,804
2,1	0,801	0,799	0,797	0,795	0,793	0,791	0,789	0,787	0,784	0,782
2,2	0,780	0,778	0,776	0,774	0,772	0,770	0,768	0,766	0,764	0,762
2,3	0,760	0,758	0,756	0,754	0,752	0,750	0,748	0,746	0,744	0,742
2,4	0,740	0,738	0,736	0,734	0,732	0,731	0,729	0,727	0,725	0,723
2,5	0,721	0,719	0,717	0,716	0,714	0,712	0,710	0,708	0,707	0,705
2,6	0,703	0,701	0,699	0,698	0,696	0,694	0,692	0,691	0,689	0,687
2,7	0,685	0,684	0,682	0,680	0,679	0,677	0,675	0,674	0,672	0,670
2,8	0,669	0,667	0,665	0,664	0,662	0,661	0,659	0,657	0,656	0,654
2,9	0,653	0,651	0,649	0,648	0,646	0,645	0,643	0,642	0,640	0,639
3,0	0,637	—	—	—	—	—	—	—	—	—

NOTE To evaluate Z_h or Z_H from this table, the appropriate value of h_{1e}/h' or H_{1e}/H' is inserted as a combination of the values in the first column and in the first row (above the horizontal rule).

EXAMPLE The value of Z_h corresponding to $h_{1e}/h' = 2,23$ is given at the intersection formed by the horizontal line from 2,2 with the vertical line from 0,03, and Z_h is therefore = 0,774.

9.5 Conditions for modular/drowned flow

The modular limit for flat-V weirs is not single valued as in the case of a two-dimensional weir, i.e. a weir with a horizontal crest line. In the case of the flat-V weir, the modular limit in terms of $H_{2\mathrm{e}}/H_{1\mathrm{e}}$ is (70 ± 5) % depending on the ratio $H_{1\mathrm{e}}/H'$. The total effective downstream head $H_{2\mathrm{e}}$, is calculated in the same way as $H_{1\mathrm{e}}$.

Under modular flow conditions, the value of $H_{2\mathrm{e}}/H_{1\mathrm{e}}$ is less than or equal to (70 ± 5) % and will depend on the nature of the downstream channel. The value of $h_{\mathrm{pe}}/H_{1\mathrm{e}}$ is, however, constant in the modular flow range and is independent of conditions in the downstream channel. The modular value of $h_{\mathrm{pe}}/H_{1\mathrm{e}}$ always lies within the range (40 ± 5) % and a check on this value during the modular flow conditions provides a sound method for determining whether the crest tapping is performing satisfactorily. If the value of this ratio is not within this range, the installation should be checked for leakage around the tapping plate and/or general blockage of the system.

Table 6 — $C_v Z_h$ in terms of h'/p_1 and h_{1e}/h'

h_{1e}/h'	h'/p_1												
	0,2	**0,4**	**0,6**	**0,8**	**1,0**	**1,2**	**1,4**	**1,6**	**1,8**	**2,0**	**2,2**	**2,4**	**2,6**
0,05	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
0,10	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
0,15	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
0,20	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
0,25	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,001	1,001	1,001	1,001
0,30	1,000	1,000	1,000	1,000	1,000	1,000	1,001	1,001	1,001	1,001	1,001	1,001	1,001
0,35	1,000	1,000	1,000	1,000	1,001	1,001	1,001	1,001	1,001	1,002	1,002	1,002	1,002
0,40	1,000	1,000	1,000	1,001	1,001	1,001	1,002	1,002	1,002	1,002	1,003	1,003	1,003
0,45	1,000	1,000	1,001	1,001	1,002	1,002	1,003	1,003	1,003	1,004	1,004	1,004	1,005
0,50	1,000	1,001	1,001	1,002	1,002	1,003	1,004	1,004	1,004	1,005	1,005	1,006	1,006
0,55	1,000	1,001	1,001	1,002	1,003	1,004	1,005	1,005	1,006	1,007	1,007	1,008	1,008
0,60	1,000	1,001	1,002	1,003	1,004	1,005	1,006	1,007	1,008	1,009	1,009	1,010	1,011
0,65	1,000	1,001	1,003	1,004	1,005	1,006	1,008	1,009	1,010	1,011	1,012	1,013	1,013
0,70	1,001	1,002	1,003	1,005	1,007	1,008	1,010	1,011	1,012	1,013	1,015	1,016	1,017
0,75	1,001	1,002	1,004	1,006	1,008	1,010	1,012	1,013	1,015	1,016	1,018	1,019	1,020
0,80	1,001	1,003	1,005	1,008	1,010	1,012	1,014	1,016	1,018	1,020	1,021	1,023	1,024
0,85	1,001	1,004	1,007	1,009	1,012	1,015	1,017	1,020	1,022	1,024	1,025	1,027	1,029
0,90	1,001	1,004	1,008	1,011	1,015	1,018	1,021	1,023	1,026	1,028	1,030	1,032	1,034
0,95	1,002	1,005	1,009	1,014	1,017	1,021	1,024	1,027	1,030	1,033	1,035	1,037	1,039
1,00	1,002	1,006	1,011	1,016	1,020	1,025	1,028	1,032	1,035	1,038	1,040	1,043	1,045
1,05	1,002	1,007	1,013	1,018	1,023	1,028	1,032	1,036	1,039	1,042	1,045	1,048	1,050
1,10	1,001	1,006	1,012	1,019	1,024	1,029	1,034	1,038	1,042	1,046	1,049	1,052	1,054
1,15	0,997	1,004	1,011	1,017	1,024	1,029	1,034	1,039	1,043	1,047	1,050	1,053	1,056
1,20	0,993	1,000	1,007	1,015	1,021	1,028	1,033	1,038	1,042	1,047	1,050	1,054	1,057
1,25	0,986	0,994	1,003	1,011	1,018	1,024	1,030	1,036	1,040	1,045	1,049	1,052	1,056
1,30	0,979	0,988	0,997	1,005	1,013	1,020	1,026	1,032	1,037	1,042	1,046	1,050	1,053
1,35	0,971	0,980	0,990	0,999	1,008	1,015	1,022	1,027	1,033	1,038	1,042	1,046	1,050
1,40	0,962	0,972	0,983	0,992	1,001	1,009	1,016	1,022	1,028	1,033	1,037	1,041	1,045
1,45	0,953	0,963	0,974	0,985	0,994	1,002	1,009	1,016	1,022	1,027	1,031	1,036	1,040
1,50	0,943	0,954	0,966	0,976	0,986	0,995	1,002	1,009	1,015	1,020	1,025	1,030	1,034
1,55	0,932	0,944	0,957	0,968	0,978	0,987	0,995	1,001	1,008	1,013	1,018	1,023	1,027
1,60	0,922	0,934	0,947	0,959	0,969	0,978	0,987	0,994	1,000	1,006	1,011	1,016	1,020
1,65	0,911	0,924	0,938	0,950	0,961	0,970	0,978	0,986	0,992	0,998	1,004	1,008	1,013
1,70	0,900	0,914	0,928	0,940	0,952	0,961	0,970	0,977	0,984	0,990	0,996	1,001	1,005
1,75	0,889	0,904	0,918	0,931	0,942	0,952	0,961	0,969	0,976	0,982	0,988	0,993	0,997
1,80	0,878	0,893	0,908	0,922	0,933	0,943	0,953	0,960	0,968	0,974	0,980	0,985	0,989
1,85	0,867	0,883	0,898	0,912	0,924	0,935	0,944	0,952	0,959	0,966	0,971	0,977	0,981
1,90	0,856	0,873	0,889	0,903	0,915	0,926	0,935	0,943	0,951	0,957	0,963	0,968	0,973
1,95	0,845	0,863	0,879	0,893	0,906	0,917	0,926	0,935	0,942	0,949	0,955	0,960	0,965
2,00	0,835	0,852	0,869	0,884	0,896	0,908	0,917	0,926	0,933	0,940	0,946	0,952	0,957

Table 6 (*continued*)

h_{1e}/h'	h'/p_1												
	0,2	**0,4**	**0,6**	**0,8**	**1,0**	**1,2**	**1,4**	**1,6**	**1,8**	**2,0**	**2,2**	**2,4**	**2,6**
2,05	0,824	0,842	0,859	0,874	0,887	0,899	0,909	0,917	0,925	0,932	0,938	0,944	0,949
2,10	0,814	0,833	0,850	0,865	0,878	0,890	0,900	0,909	0,916	0,923	0,930	0,935	0,940
2,15	0,804	0,823	0,841	0,856	0,869	0,881	0,891	0,900	0,908	0,915	0,921	0,927	0,932
2,20	0,794	0,813	0,831	0,847	0,861	0,872	0,883	0,892	0,900	0,907	0,913	0,919	0,924
2,25	0,784	0,804	0,822	0,838	0,852	0,864	0,874	0,883	0,891	0,899	0,905	0,911	0,916
2,30	0,774	0,795	0,813	0,830	0,843	0,855	0,866	0,875	0,883	0,891	0,897	0,903	0,908
2,35	0,764	0,785	0,804	0,821	0,835	0,847	0,856	0,867	0,875	0,883	0,889	0,895	0,900
2,40	0,755	0,776	0,796	0,812	0,827	0,839	0,850	0,859	0,867	0,875	0,881	0,887	0,893
2,45	0,746	0,768	0,787	0,804	0,819	0,831	0,842	0,851	0,860	0,867	0,874	0,880	0,885
2,50	0,737	0,759	0,779	0,796	0,811	0,823	0,834	0,843	0,852	0,859	0,866	0,872	0,878
2,55	0,728	0,751	0,771	0,788	0,803	0,815	0,826	0,836	0,844	0,852	0,859	0,863	0,870
2,60	0,720	0,742	0,763	0,780	0,795	0,808	0,819	0,828	0,837	0,844	0,851	0,857	0,863
2,65	0,711	0,734	0,755	0,772	0,787	0,800	0,811	0,821	0,829	0,837	0,844	0,850	0,856
2,70	0,703	0,726	0,747	0,765	0,780	0,793	0,804	0,814	0,822	0,830	0,837	0,843	0,849
2,75	0,695	0,719	0,740	0,757	0,772	0,785	0,797	0,806	0,815	0,823	0,830	0,836	0,842
2,80	0,687	0,711	0,732	0,750	0,765	0,778	0,790	0,799	0,805	0,816	0,823	0,829	0,835
2,85	0,679	0,703	0,725	0,743	0,758	0,771	0,783	0,792	0,801	0,809	0,816	0,822	0,828
2,90	0,671	0,696	0,718	0,736	0,751	0,764	0,776	0,786	0,795	0,802	0,809	0,816	0,822
2,95	0,664	0,689	0,711	0,729	0,744	0,758	0,769	0,779	0,788	0,796	0,803	0,809	0,815
3,00	0,657	0,682	0,704	0,722	0,738	0,751	0,762	0,773	0,781	0,789	0,796	0,803	0,809
3,05	0,649	0,675	0,697	0,716	0,731	0,744	0,756	0,766	0,775	0,783	0,790	0,797	0,802
3,10	0,642	0,668	0,690	0,709	0,725	0,738	0,750	0,760	0,769	0,777	0,784	0,790	0,796
3,15	0,636	0,662	0,684	0,703	0,718	0,732	0,743	0,754	0,763	0,771	0,778	0,784	0,790
3,20	0,629	0,655	0,678	0,696	0,712	0,726	0,737	0,748	0,757	0,765	0,772	0,778	0,784
3,25	0,622	0,649	0,671	0,690	0,706	0,720	0,731	0,742	0,751	0,759	0,766	0,773	0,779
3,30	0,616	0,643	0,665	0,684	0,700	0,714	0,725	0,736	0,745	0,753	0,760	0,767	0,773
3,35	0,610	0,637	0,659	0,678	0,694	0,708	0,720	0,730	0,739	0,747	0,755	0,761	0,767
3,40	0,603	0,631	0,653	0,672	0,688	0,702	0,714	0,724	0,733	0,742	0,749	0,756	0,762
3,45	0,597	0,625	0,648	0,667	0,683	0,696	0,708	0,719	0,728	0,736	0,744	0,750	0,756
3,50	0,591	0,619	0,642	0,661	0,677	0,691	0,703	0,713	0,723	0,731	0,738	0,745	0,751
3,55	0,586	0,613	0,637	0,656	0,672	0,686	0,697	0,708	0,717	0,726	0,733	0,740	0,746
3,60	0,580	0,608	0,631	0,650	0,666	0,680	0,692	0,703	0,712	0,720	0,728	0,735	0,741
3,65	0,574	0,602	0,626	0,645	0,661	0,675	0,687	0,698	0,707	0,715	0,723	0,730	0,736
3,70	0,569	0,597	0,620	0,640	0,656	0,670	0,682	0,692	0,702	0,710	0,718	0,725	0,731
3,75	0,563	0,592	0,615	0,635	0,651	0,665	0,677	0,687	0,697	0,705	0,713	0,720	0,726
3,80	0,558	0,587	0,610	0,630	0,646	0,660	0,672	0,683	0,692	0,701	0,708	0,715	0,722
3,85	0,553	0,582	0,605	0,625	0,641	0,655	0,667	0,678	0,687	0,696	0,704	0,711	0,717
3,90	0,548	0,577	0,600	0,620	0,636	0,650	0,662	0,673	0,683	0,691	0,699	0,706	0,712
3,95	0,543	0,572	0,596	0,615	0,632	0,646	0,658	0,668	0,678	0,687	0,694	0,701	0,708
4,00	0,538	0,567	0,591	0,611	0,627	0,641	0,653	0,664	0,674	0,682	0,690	0,697	0,704

EXAMPLE The value of $C_v Z_h$ corresponding to h_{1e}/h' = 3,00 and h'/p_1 = 1,4 is given as 0,762

9.6 Drowned flow reduction factor

9.6.1 The drowned flow reduction factor, C_{dr}, is related to the head ratio h_{pe}/H_{1e}. The functional relationship is given by:

$$C_{dr} = 1{,}078\left[0{,}909 - \left(h_{pe} / H_{1e}\right)^{3/2}\right]^{0{,}183} \qquad (10)$$

where $h_{pe} = (h_p - k_h)$ is the effective separation pocket head relative to lowest crest elevation expressed in metres.

Equation (10) has been derived from Table 7. Calculated numerical values are within 1 % of the tabulated figure.

Table 7 — C_{dr} in terms of h_{pe}/H_{1e}

h_{pe}/H_{1e}	**0,00**	**0,01**	**0,02**	**0,03**	**0,04**	**0,05**	**0,06**	**0,07**	**0,08**	**0,09**
0,3	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
0,4	1,000	0,996	0,993	0,990	0,987	0,983	0,980	0,977	0,973	0,970
0,5	0,966	0,962	0,958	0,955	0,951	0,947	0,943	0,939	0,935	0,931
0,6	0,927	0,922	0,918	0,913	0,908	0,904	0,898	0,893	0,888	0,883
0,7	0,877	0,872	0,865	0,858	0,852	0,845	0,837	0,828	0,820	0,810
0,8	0,801	0,790	0,779	0,768	0,754	0,738	0,723	0,706	0,685	0,663
0,9	0,638	0,611	0,582	0,550	0,513	0,475	—	—	—	—

NOTE To evaluate C_{dr} from this table, the appropriate value of h_{pe}/H_{1e} is inserted as a combination of the values in the first column and in the first row (above the horizontal rule).

EXAMPLE The value of C_{dr} corresponding to $h_{pe}/H_{1e} = 0{,}63$ is given at the intersection formed by the horizontal line from 0,6 with the vertical line from 0,03, and C_{dr} is therefore = 0,913.

9.6.2 In Equation (10), the drowned flow reduction factor is related to the ratio h_{pe}/H_{1e}, i.e. an expression involving total head. If Equation (4) is to be used to compute discharge, C_{dr} shall be related to gauged heads. A convenient way of doing this is given in Tables 8 to 12 where the product $C_v C_{dr}$ is given in terms of h_{1e}/h' and h_{pe}/h_{1e}. Each table corresponds to a different range of the ratio h'/p_1 as follows:

- Table 8 if $0{,}0 \leq h'/p_1 \leq 0{,}5$;
- Table 9 if $0{,}5 < h'/p_1 \leq 1{,}0$;
- Table 10 if $1{,}0 < h'/p_1 \leq 1{,}5$;
- Table 11 if $1{,}5 < h'/p_1 \leq 2{,}0$;
- Table 12 if $2{,}0 < h'/p_1 \leq 2{,}5$.

9.6.3 In the absence of crest tappings, downstream tappings may be used to derive the drowned flow reduction factor. This method is less accurate by a factor of approximately three. The drowned flow reduction factor, C_{dr}, is related to the head ratio $H_{2\mathrm{e}}/H_{1\mathrm{e}}$. The functional relationships are

$$C_{\mathrm{dr}} = 1{,}09\ [0{,}82 - (H_{2\mathrm{e}}/H_{1\mathrm{e}})^4]^{0{,}15} \qquad (11)$$

in the range $0{,}73 < (H_{2\mathrm{e}}/H_{1\mathrm{e}}) < 0{,}93$ and

$$C_{\mathrm{dr}} = 6{,}315 - 6{,}0\ (H_{2\mathrm{e}}/H_{1\mathrm{e}}) \qquad (12)$$

in the range $0{,}93 < (H_{2\mathrm{e}}/H_{1\mathrm{e}}) < 0{,}98$.

Numerical values obtained from the above expressions are given in Table 13. Equations (11) and (12) can be used in the successive approximation method for the computation of discharge but are not suited for use in the coefficient of velocity method, see Clause 10.

Table 8 — $C_{\nu}C_{dr}$ in terms of h_{pe}/h_{1e} and h_{1e}/h' , $0,0 \le h'/p_1 \le 0,5$

h_{pe}/h_{1e}	h_{1e}/h'				
	0,5	**1,0**	**1,5**	**2,0**	**2,5**
0,45	1,000	1,000	1,000	1,000	—
0,46	1,000	0,997	1,000	1,000	—
0,47	1,000	0,994	1,000	1,000	—
0,48	1,000	0,991	0,996	1,000	—
0,49	1,000	0,988	0,992	1,000	—
0,50	0,996	0,985	0,988	1,000	—
0,51	0,993	0,981	0,984	0,999	—
0,52	0,989	0,978	0,980	0,995	—
0,53	0,986	0,975	0,976	0,992	—
0,54	0,982	0,971	0,972	0,988	—
0,55	0,979	0,967	0,968	0,984	—
0,56	0,975	0,963	0,964	0,980	—
0,57	0,971	0,959	0,960	0,976	—
0,58	0,967	0,955	0,956	0,971	—
0,59	0,963	0,951	0,952	0,967	—
0,60	0,959	0,947	0,948	0,962	—
0,61	0,955	0,943	0,943	0,957	—
0,62	0,950	0,939	0,939	0,952	—
0,63	0,945	0,935	0,934	0,947	—
0,64	0,940	0,930	0,930	0,942	—
0,65	0,935	0,925	0,925	0,936	—
0,66	0,930	0,920	0,920	0,930	—
0,67	0,925	0,915	0,915	0,924	—
0,68	0,920	0,910	0,909	0,917	—
0,69	0,914	0,905	0,904	0,910	—
0,70	0,909	0,900	0,898	0,904	—
0,71	0,902	0,894	0,893	0,897	—
0,72	0,895	0,888	0,887	0,890	—
0,73	0,888	0,882	0,881	0,882	—
0,74	0,880	0,876	0,875	0,874	—
0,75	0,870	0,869	0,867	0,866	—
0,76	0,860	0,861	0,860	0,858	0,859
0,77	0,850	0,853	0,853	0,850	0,850
0,78	0,840	0,844	0,845	0,841	0,840
0,79	0,830	0,935	0,836	0,832	0,830
0,80	0,820	0.825	0,827	0,823	0,819
0,81	0,810	0,814	0,817	0,813	0,806
0,82	0,798	0,803	0,807	0,802	0,793
0,83	0,786	0,792	0,796	0,790	0,779
0,84	0,774	0,780	0,785	0,776	0,762
0,85	0,760	0,765	0,771	0,764	0,745
0,86	0,744	0,750	0,757	0,748	0,725
0,87	0,725	0,735	0,742	0,730	0,705
0,88	0,706	0,718	0,724	0,710	0,685
0,89	0,686	0,698	0,705	0,690	0,659
0,90	0,663	0,676	0,682	0,665	0,633
0,91	0,639	0,652	0,658	0,640	0,604
0,92	0,610	0,625	0,628	0,610	0,570
0,93	0,580	0,595	0,598	0,577	0,536
0,94	0,548	0,560	0,560	0,538	0,500

Table 9 — C_vC_{dr} in terms of h_{pe}/h_{1e} and h_{1e}/h' , $0,5 < h'/p_1 \leq 1,0$

h_{pe}/h_{1e}	h_{1e}/h'				
	0,5	**1,0**	**1,5**	**2,0**	**2,5**
0,45	1,000	1,000	1,000	1,000	—
0,46	1,000	1,000	1,000	1,000	—
0,47	1,000	1,000	1,000	1,000	—
0,48	1,000	1,000	1,000	1,000	—
0,49	1,000	0,997	1,000	1,000	—
0,50	1,000	0,994	1,000	1,000	—
0,51	1,000	0,990	1,000	1,000	—
0,52	0,997	0,987	1,000	1,000	—
0,53	0,994	0,984	1,000	1,000	—
0,54	0,990	0,981	0,996	1,000	—
0,55	0,986	0,977	0,992	1,000	—
0,56	0,982	0,974	0,988	1,000	—
0,57	0,978	0,970	0,984	1,000	—
0,58	0,974	0,966	0,980	1,000	—
0,59	0,970	0,962	0,975	1,000	—
0,60	0,965	0,958	0,971	0,995	—
0,61	0,960	0,954	0,967	0,992	—
0,62	0,956	0,950	0,962	0,987	—
0,63	0,951	0,945	0,957	0,982	—
0,64	0,946	0,940	0,952	0,977	—
0,65	0,941	0,936	0,947	0,971	—
0,66	0,935	0,931	0,942	0,966	—
0,67	0,930	0,926	0,937	0,960	—
0,68	0,924	0,921	0,931	0,955	—
0,69	0,918	0,916	0,926	0,949	—
0,70	0,911	0,911	0,920	0,941	—
0,71	0,904	0,905	0,914	0,935	—
0,72	0,896	0,899	0,908	0,927	—
0,73	0,888	0,893	0,902	0,920	—
0,74	0,880	0,886	0,896	0,911	—
0,75	0,870	0,879	0,889	0,904	—
0,76	0,860	0,871	0,881	0,895	0,900
0,77	0,850	0,863	0,874	0,885	0,890
0,78	0,840	0,854	0,866	0,875	0,880
0,79	0,830	0,845	0,857	0,865	0,870
0,80	0,820	0,835	0,847	0,854	0,860
0,81	0,810	0,825	0,836	0,843	0,849
0,82	0,798	0,815	0,826	0,832	0,835
0,83	0,786	0,804	0,815	0,820	0,823
0,84	0,774	0,791	0,802	0,807	0,810
0,85	0,760	0,777	0,790	0,794	0,790
0,86	0,744	0,762	0,775	0,778	0,770
0,87	0,725	0,745	0,760	0,761	0,748
0,88	0,706	0,725	0,740	0,741	0,724
0,89	0,685	0,706	0,720	0,720	0,697
0,90	0,663	0,685	0,699	0,695	0,670
0,91	0,639	0,660	0,675	0,670	0,640
0,92	0,610	0,632	0,645	0,640	0,605
0,93	0,580	0,600	0,615	0,605	0,569
0,94	0,548	0,565	0,578	0,565	0,530

Table 10 — C_vC_{dr} in terms of h_{pe}/h_{1e} and h_{1e}/h' , 1,0 < $h'/p_1 \leq 1{,}5$

h_{pe}/h_{1e}	h_{1e}/h'				
	0,5	**1,0**	**1,5**	**2,0**	**2,5**
0,45	1,000	1,000	—	—	—
0,46	1,000	1,000	—	—	—
0,47	1,000	1,000	—	—	—
0,48	1,000	1,000	—	—	—
0,49	1,000	1,000	—	—	—
0,50	1,000	1,000	1,000	—	—
0,51	1,000	0,997	1,000	—	—
0,52	1,000	0,994	1,000	—	—
0,53	0,999	0,991	1,000	—	—
0,54	0,995	0,987	1,000	—	—
0,55	0,992	0,984	1,000	—	—
0,56	0,989	0,980	1,000	—	—
0,57	0,985	0,977	1,000	—	—
0,58	0,980	0,973	0,995	—	—
0,59	0,975	0,969	0,991	—	—
0,60	0,971	0,965	0,987	1,000	—
0,61	0,966	0,961	0,982	1,000	—
0,62	0,961	0,956	0,977	1,000	—
0,63	0,955	0,952	0,972	1,000	—
0,64	0,950	0,948	0,967	1,000	—
0,65	0,944	0,944	0,962	0,997	—
0,66	0,938	0,939	0,957	0,992	—
0,67	0,931	0,934	0,952	0,987	—
0,68	0,925	0,929	0,947	0,981	—
0,69	0,919	0,924	0,941	0,975	—
0,70	0,912	0,919	0,936	0,970	—
0,71	0,904	0,913	0,930	0,963	—
0,72	0,896	0,906	0,923	0,956	—
0,73	0,888	0,900	0,916	0,949	—
0,74	0,880	0,894	0,910	0,941	—
0,75	0,870	0,886	0,903	0,933	—
0,76	0,860	0,878	0,896	0,924	—
0,77	0,850	0,870	0,889	0,915	—
0,78	0,840	0,861	0,881	0,905	—
0,79	0,830	0,853	0,872	0,894	0,903
0,80	0,820	0,842	0,862	0,883	0,893
0,81	0,810	0,831	0,851	0,871	0,880
0,82	0,799	0,820	0,841	0,859	0,867
0,83	0,786	0,809	0,830	0,845	0,854
0,84	0,773	0,797	0,817	0,830	0,838
0,85	0,760	0,783	0,804	0,814	0,820
0,86	0,744	0,767	0,789	0,795	0,800
0,87	0,725	0,751	0,771	0,775	0,779
0,88	0,706	0,731	0,752	0,755	0,753
0,89	0,686	0,712	0,732	0,733	0,728
0,90	0,663	0,690	0,710	0,707	0,700
0,91	0,639	0,666	0,685	0,682	0,670
0,92	0,610	0,640	0,655	0,653	0,633
0,93	0,580	0,606	0,626	0,620	0,595
0,94	0,548	0,570	0,585	0,580	0,553

Table 11 — $C_v C_{dr}$ in terms of h_{pe}/h_{1e} and h_{1e}/h' , $1{,}5 < h'/p_1 \leq 2{,}0$

h_{pe}/h_{1e}	h_{1e}/h'				
	0,5	**1,0**	**1,5**	**2,0**	**2,5**
0,45	1,000	1,000	—	—	—
0,46	1,000	1,000	—	—	—
0,47	1,000	1,000	—	—	—
0,48	1,000	1,000	—	—	—
0,49	1,000	1,000	—	—	—
0,50	1,000	1,000	1,000	—	—
0,51	1,000	1,000	1,000	—	—
0,52	1,000	0,998	1,000	—	—
0,53	1,000	0,995	1,000	—	—
0,54	1,000	0,992	1,000	—	—
0,55	0,996	0,989	1,000	—	—
0,56	0,992	0,985	1,000	—	—
0,57	0,988	0,982	1,000	—	—
0,58	0,984	0,979	1,000	—	—
0,59	0,979	0,975	1,000	—	—
0,60	0,974	0,971	0,998	1,000	—
0,61	0,969	0,967	0,994	1,000	—
0,62	0,964	0,963	0,989	1,000	—
0,63	0,958	0,959	0,985	1,000	—
0,64	0,952	0,955	0,980	1,000	—
0,65	0,946	0,950	0,975	1,000	—
0,66	0,940	0,945	0,969	1,000	—
0,67	0,933	0,940	0,964	1,000	—
0,68	0,926	0,935	0,959	1,000	—
0,69	0,920	0,930	0,953	0,998	—
0,70	0,913	0,925	0,948	0,992	—
0,71	0,905	0,918	0,942	0,986	—
0,72	0,898	0,912	0,936	0,980	—
0,73	0,889	0,905	0,930	0,973	—
0,74	0,880	0,898	0,923	0,965	—
0,75	0,870	0,890	0,916	0,957	—
0,76	0,860	0,882	0,909	0,949	—
0,77	0,850	0,875	0,901	0,940	—
0,78	0,840	0,866	0,894	0,930	—
0,79	0,830	0,857	0,885	0,920	—
0,80	0,820	0,847	0,875	0,909	—
0,81	0,810	0,837	0,865	0,896	0,908
0,82	0,799	0,826	0,854	0,883	0,896
0,83	0,787	0,815	0,842	0,870	0,884
0,84	0,774	0,800	0,830	0,854	0,870
0,85	0,760	0,786	0,815	0,836	0,854
0,86	0,744	0,771	0,800	0,817	0,834
0,87	0,725	0,755	0,781	0,798	0,813
0,88	0,706	0,736	0,761	0,776	0,791
0,89	0,686	0,716	0,740	0,754	0,766
0,90	0,663	0,695	0,718	0,728	0,740
0,91	0,639	0,672	0,691	0,699	0,706
0,92	0,610	0,645	0,664	0,668	0,670
0,93	0,580	0,611	0,630	0,634	0,630
0,94	0,548	0,575	0,595	0,597	0,588

Table 12 — $C_{\mathrm{v}}C_{\mathrm{dr}}$ in terms of $h_{\mathrm{pe}}/h_{\mathrm{1e}}$ and h_{1e}/h' , 2,0 < $h'/p_1 \leq$ 2,5

$h_{\mathrm{pe}}/h_{\mathrm{1e}}$	h_{1e}/h'				
	0,5	**1,0**	**1,5**	**2,0**	**2,5**
0,45	1,000	1,000	—	—	—
0,46	1,000	1,000	—	—	—
0,47	1,000	1,000	—	—	—
0,48	1,000	1,000	—	—	—
0,49	1,000	1,000	—	—	—
0,50	1,000	1,000	—	—	—
0,51	1,000	1,000	—	—	—
0,52	1,000	1,000	—	—	—
0,53	1,000	0,998	—	—	—
0,54	1,000	0,995	—	—	—
0,55	1,000	0,992	1,000	—	—
0,56	0,996	0,989	1,000	—	—
0,57	0,991	0,986	1,000	—	—
0,58	0,987	0,982	1,000	—	—
0,59	0,982	0,979	1,000	—	—
0,60	0,977	0,975	1,000	1,000	—
0,61	0,972	0,972	1,000	1,000	—
0,62	0,966	0,968	1,000	1,000	—
0,63	0,961	0,964	0,995	1,000	—
0,64	0,955	0,960	0,990	1,000	—
0,65	0,949	0,956	0,985	1,000	—
0,66	0,942	0,951	0,980	1,000	—
0,67	0,935	0,947	0,974	1,000	—
0,68	0,928	0,942	0,969	1,000	—
0,69	0,921	0,937	0,963	1,000	—
0,70	0,914	0,932	0,957	1,000	1,000
0,71	0,906	0,925	0,951	1,000	1,000
0,72	0,898	0,918	0,945	1,000	1,000
0,73	0,889	0,912	0,939	0,994	1,000
0,74	0,880	0,905	0,932	0,985	1,000
0,75	0,870	0,897	0,925	0,976	1,000
0,76	0,860	0,889	0,917	0,968	1,000
0,77	0,850	0,880	0,909	0,959	1,000
0,78	0,840	0,871	0,901	0,949	0,988
0,79	0,830	0,862	0,892	0,939	0,975
0,80	0,820	0,853	0,883	0,927	0,962
0,81	0,810	0,843	0,874	0,914	0,949
0,82	0,799	0,832	0,863	0,900	0,935
0,83	0,787	0,820	0,852	0,886	0,920
0,84	0,774	0,806	0,840	0,871	0,902
0,85	0,760	0,792	0,825	0,855	0,884
0,86	0,744	0,777	0,810	0,837	0,862
0,87	0,725	0,761	0,794	0,817	0,840
0,88	0,706	0,743	0,775	0,795	0,815
0,89	0,686	0,723	0,754	0,770	0,789
0,90	0,663	0,700	0,732	0,744	0,760
0,91	0,639	0,677	0,705	0,716	0,728
0,92	0,610	0,650	0,677	0,684	0,690
0,93	0,580	0,617	0,645	0,646	0,651
0,94	0,548	0,580	0,606	0,605	0,608

Table 13 — C_{dr} in terms of H_{2e}/H_{1e}

H_{2e}/H_{1e}	**0,000**	**0,005**
0,73	0,995	0,992
0,74	0,988	0,986
0,75	0,983	0,981
0,76	0,978	0,976
0,77	0,973	0,970
0,78	0,967	0,964
0,79	0,961	0,958
0,80	0,954	0,949
0,81	0,946	0,942
0,82	0,938	0,934
0,83	0,929	0,925
0,84	0,920	0,915
0,85	0,909	0,903
0,86	0,897	0,891
0,87	0,884	0,877
0,88	0,869	0,861
0,89	0,851	0,842
0,90	0,831	0,820
0,91	0,807	0,792
0,92	0,776	0,756
0,93	0,735	0,705
0,94	0,675	0,645
0,95	0,615	0,585
0,96	0,555	0,525
0,97	0,495	0,465
0,98	0,435	—

NOTE To evaluate C_{dr} from this table, the appropriate value of H_{2e}/H_{1e} is inserted as a combination of the values in the first column and in the first row (above the horizontal rule).

EXAMPLE The value of C_{dr} corresponding to $H_{2e}/H_{1e} = 0{,}895$ is given at the intersection formed by the horizontal line from 0,89 with the vertical line from 0,005, and C_{dr} is therefore = 0,842.

9.7 Limits of application

9.7.1 The practical lower limit of upstream head is related to the magnitude of the influence of fluid properties and boundary roughness. For a well-maintained weir with a smooth crest section (e.g. stainless steel), the minimum head recommended is 0,03 m. If the crest is of smooth concrete or a material of similar texture, a lower limit of 0,06 m is recommended.

9.7.2 There is also a limiting value for the ratio H'/p_1 of 2,5 and there are limitations of H_1/p_2 as detailed in Table 4. These are governed by the scope of the experimental verification and vary with cross-slope.

p_2 is the elevation of the lowest crest elevation relative to the downstream bed level, expressed in metres.

9.7.3 There is a limiting Froude number for the flow conditions in the approach to the weir in order to avoid standing waves which would interfere with the upstream head measurements. The Froude number, $\bar{\upsilon} / \sqrt{\left[g\left(h_1 + p_1\right)\right]}$, shall not exceed 0,5. This should be checked at the design stage and periodically during the operation of structures in alluvial rivers where bed levels may vary with time.

10 Computation of discharge

10.1 General

There are two common methods of computing discharges from gauged head readings. The first obtains results by successive approximation techniques and utilizes the basic "total head" equations. A computer can effectively make the calculations involved in this method. The second method utilizes the relationships which can be derived between the gauged and total heads for particular weir and flow geometries. These enable the coefficient of velocity, C_v, in the discharge equation to be assessed from tables or graphs.

It is important that discharges are calculated using the actual built dimensions of the structure. A survey of the structure should be carried out immediately after the construction and repeated at fixed time intervals and additionally if movement is suspected. The time interval chosen will depend on the risk of changes. Particular attention should be paid to measurement of crest levels, crest cross-slope and gauge zeros.

10.2 Successive approximation method

10.2.1 Computation using individual head measurements

The method of successive approximations is applicable to any weir geometry and can be used for converting gauged heads to total heads in both modular and drowned flow conditions.

The method is as follows.

a) Use Equation (1) if the flow is modular and Equation (3) if the weir is drowned.

b) Determine the coefficient of discharge, C_De, and the head correction factor, k_h, using Table 4.

   Compute the effective gauged head, $h_\text{1e} = h_1 - k_\text{h}$.

c) Determine the cross-sectional area of flow, $A = B\ (h_1 + p_1)$, where B is the width at the upstream gauging station, expressed in metres.

d) Determine the value of K_1 where $K_1 = 0{,}8 C_\text{De} \sqrt{g}\, m$ for modular flow.

e) Assume, as a first approximation, that $H_\text{1e} = h_\text{1e}$ and compute the discharge.

   $Q = K_1 Z_\text{H} H_\text{1e}^{5/2}$ for modular flow

   and $Q = K_1 \text{C}_\text{dr} \text{Z}_\text{h} \text{H}_\text{1e}^{5/2}$ for drowned flow

   where the value of Z_H is obtained from Table 5 or Equations (7) and (9). For drowned flow, the value of C_Dr is obtained from Table 7 or Equation (10) when the separation pocket head is measured and Table 13 or Equations (11) and (12) when the tailwater level is measured.

f) Use this approximate discharge to determine the velocity head.

$$\frac{\alpha \bar{v}^2}{2g} = \frac{\alpha Q^2}{2gA^2} = \text{velocity head} \tag{13}$$

The Coriolis coefficient should normally be taken as 1,2. However, as a refinement, figures may be derived using Figure 2.

g) Calculate a new estimate of the total head, $H_{1e} = h_{1e}$ + velocity head (calculated in the previous step).

h) Repeat steps e) and f) until the difference between successive discharge values is an order of magnitude less than the required uncertainty.

The above method enables discharges to be calculated from individual gauged head readings.

10.2.2 Computation of modular stage-discharge function

The method described in 10.2.1 does not provide the quickest way of computing a modular stage-discharge graph for a particular weir installation where such a plot is required and requires the use of software designed for the purpose. The following methodology provides a technique for estimating the stage-discharge relationship in terms of the measured upstream head (stage).

A concise method of obtaining the theoretical calibration curve is to calculate the relationship between the total head and discharge and then to convert total head to gauged head. This conversion will normally require fewer loops of the successive approximation cycle than in the method described in 10.2.1.

The principle of the method is as follows.

a) Using the total head Equation (1), calculate a series of values of Q for a series of assumed values of H_{1e}; Z_H is obtained from Equation (9) which has already been referred to in 9.3:

$$Z_H = 1 - (1 - H'/H_{1e})^{5/2}$$

where

H' is the difference between the highest and lowest crest elevation;

C_{De} and k_h are obtained from Table 4;

Z_H can be read from Table 5.

b) Convert the series of upstream total effective head values H_{1e} to the corresponding gauged head values.

c) Assume that the upstream water level is at the elevation given by the total head, deduce the cross-sectional area of the approach channel, and calculate the velocity of approach. An approximate value of the gauged head is deduced from:

$$h_1 = H_{1e} - \left(\alpha \bar{v}_a^{\,2} / 2g\right) + k_h \tag{14}$$

d) This provides an improved estimate of water level. Use this to revise the original value for the approach velocity and to obtain a further value of the gauged head h_1. This procedure is repeated until the difference between the successive estimates of the gauged head is an order of magnitude less than the required tolerance.

Repeat steps c) and d) for each pair of values of H_{1e} and Q, to provide a complete modular stage-discharge curve for the structure.

10.3 Coefficient of velocity method

10.3.1 Modular flow conditions

Equation (2) is used in this method of computing discharge from the known quantities, p_1, m, h' and h_1. The method is as follows:

a) Calculate $h_{1e} = h_1 - k_h$ using the appropriate value of k_h from Table 4.

b) Note the appropriate value of C_{De} from Table 4.

c) Calculate the ratios h'/p_1 and h_{1e}/h'. Look up the appropriate value of $C_v Z_h$ from Table 6.

d) Calculate $h_{1e}^{5/2}$.

e) Substitute known values in Equation (2) to determine the discharge.

10.3.2 Drowned flow conditions

Equation (4) is used in this method of computing discharge from known values of p, m, H', h, and h_p. The calculation proceeds as follows:

a) Calculate $h_{1e} = h_1 - k_h$ and $h_{pe} = h_p - k_h$ using Table 4 for the value of k_h.

Note the appropriate values of C_{De} from Table 4.

b) Evaluate h_{pe}/h_{1e}, h_{1e}/h' and h'/p_1. Read off the appropriate value of $C_v C_{dr}$ from Tables 8 to 12, i.e.:

- Table 8 if 0,0 $\leq h'/p$, $\leq$ 0,5;
- Table 9 if 0,5 < h'/p, $\leq$ 1,0 ;
- Table 10 if 1,0 < h'/p, $\leq$ 1,5;
- Table 11 if 1,5 < h'/p, $\leq$ 2,0;
- Table 12 if 2,0 < h'/p, $\leq$ 2,5 .

c) Determine the value of Z_h using Table 5.

d) Substitute known values in Equation (4) to determine the discharge.

e) Calculate $h_{1e}^{5/2}$.

Examples of these computational methods are given in Clause 12.

10.4 Accuracy

10.4.1 The overall accuracy of measurement will depend on the following:

a) the accuracy of construction and finish of the weir;

b) the accuracy of the head measurements;

c) the accuracy of other measured dimensions;

d) the accuracy of the coefficient values;

e) the accuracy of the form of the discharge equations.

The method by which estimates of these constituent uncertainties can be combined to give the overall uncertainty in computed discharge is given in Clause 11. The accuracy of construction and finish of the weir [see point a)] above is not specifically accounted for in the uncertainty analysis referred to in Clause 11 by means of a separate term. Nevertheless, allowance can be made for poor construction and/or finish in the uncertainties on the measured dimensions and the coefficient values.

10.4.2 The standard uncertainties (68 % confidence limits) for the modular discharge coefficients are given in Table 4. These reflect the random and systematic errors which occur in calibration experiments and also the marginal changes in coefficient values which occur with changing distance.

11 Uncertainties in flow determination

11.1 General

11.1.1 This clause provides information for the user of this International Standard to state the uncertainty of a discharge determination obtained for a flat-V weir.

NOTE In accordance with former practice in hydrometry, the expression for uncertainty is continued to be expressed at the 95 % confidence limit for the discharge coefficient and the determined flow rate.

The ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement* (*GUM:1995*) (referred to hereafter as the GUM) and ISO/TS 25377 (referred to hereafter as the HUG) operate using standard uncertainties (i.e. at the 68 % confidence limit). In accordance with the HUG, the uncertainty of a flow determinations using a flat-V weir are estimated as a combined uncertainty, calculated from the various component uncertainties. The HUG requires final resultant uncertainty of measurement to be expressed at the 95 % confidence limit since this is normal hydrometric practice. Nevertheless, in the first instance the standard uncertainty is estimated. Some components of uncertainty are expressed at the 95 % confidence limit while others are standard uncertainties, i.e. those derived from Type-A and Type-B methods (see B.5 and B.6). Those at the 95 % confidence limit shall be converted to the 68 % confidence limit by dividing them by the coverage factor, $k = 2$ at the 95 % confidence level. Having so combined these components to determine the standard uncertainty, this result is now multiplied by the coverage factor ($k = 2$) to express the uncertainty at the 95 % confidence limit.

11.1.2 Annex B provides an introduction to measurement uncertainty based on the GUM and the HUG. Flow determinations in hydrometry are dependent on measurements using various techniques. Annex C which is taken from the HUG provides guidance on the sample values for a variety of hydrometric measurement techniques. These are presented in tabular form with uncertainty estimates ascribed to each technique for the purpose of illustration only. These sample values shall not be interpreted as norms of performance. The uncertainties expressed in Table C.1 are at the 68 % confidence level.

11.1.3 A measurement result comprises:

i) an estimate of the measured value, with

ii) a statement of the uncertainty of the measurement.

11.1.4 A statement of the uncertainty of a flow measurement can be considered to have four separate components of uncertainty:

i) uncertainty of the measurement of head in the channel (u^*h_{1e});

ii) uncertainty of the measurement of the dimensions of the structure (u^*m);

iii) uncertainty of the discharge coefficient stated in Table 4 from laboratory calibration of the flow structure being considered (u^*C_{De});

iv) uncertainty of channel velocity distribution related to the velocity coefficient, C_v, if this is used in the determination of discharge;

v) uncertainty in the drowned flow reduction factor (u^*C_{dr}). This can be ignored if the flow is modular.

This clause does not accommodate iv). It is assumed that the channel hydraulics are substantially equivalent to those existing in the calibration facility at the time of derivation of component iii) and as defined in 6.2.2. Also, with the use of computers, it is recommended that the successive approximation method is used in the calculation (see 10.2).

11.1.5 The estimation of measurement uncertainty associated with items i) and ii) of 11.1.4 is provided in Annex C.

Values taken from Annex C are used in the example in Clause 12. These values are for illustrative purposes only, and they should not be interpreted as norms of performance for the types of equipment listed. In practice, uncertainty estimates shall be taken from test certificates for the equipment, preferably obtained from a laboratory with accreditation to ISO/IEC 17025[6] or sound hydrometric experience including independent, *in-situ* check measurements.

11.2 Combining uncertainties

Refer to B.7.

The extent to which each flow equation parameter contributes to the flow measurement uncertainty, $U(Q)$ is derived by analytical solution using partial differentials of the discharge equation.

$$Q = JC_{De}C_{dr}\sqrt{g}mZ_H H_{1e}^{2,5} \tag{15}$$

where

J is a numerical constant not subject to error;

C_{dr} is equal to 1 for modular flow conditions.

Uncertainties in g, the acceleration due to gravity, may be ignored.

The effect on the value Q due to small dispersions of ΔC_{De}, Δm and Δh_1 is:

$$\Delta Q = J\sqrt{g}\left(\frac{\partial Q}{\partial C_{\mathrm{De}}}\Delta C_{\mathrm{De}} + \frac{\partial Q}{\partial C_{\mathrm{dr}}}\Delta C_{\mathrm{dr}} + \frac{\partial Q}{\partial m}\Delta m + \frac{\partial Q}{\partial h}\Delta h_{1\mathrm{e}}\right) \tag{16}$$

where the partial differentials are the sensitivity coefficients referred to in Clause B.7 and the HUG that relate to the discharge equation. ΔQ is the resultant dispersion of Q due to small dispersions of ΔC_{de}, ΔC_{dr}, Δm and Δh_1. Evaluating the partial differentials and using Equation (16) the relationship can be written:

$$\frac{\Delta Q}{Q} = \frac{\Delta C_{\mathrm{De}}}{C_{\mathrm{De}}} + \frac{\Delta C_{\mathrm{dr}}}{C_{\mathrm{dr}}} + \frac{\Delta m}{m} + 2{,}5\frac{\Delta h_{1\mathrm{e}}}{h_{1\mathrm{e}}} \tag{17}$$

In uncertainty analysis, the values $\frac{\Delta Q}{Q}$, $\frac{\Delta C_{\mathrm{De}}}{C_{\mathrm{De}}}$, $\frac{\Delta C_{\mathrm{dr}}}{C_{\mathrm{dr}}}$, $\frac{\Delta m}{m}$ and $\frac{\Delta h_{1\mathrm{e}}}{h_{1\mathrm{e}}}$ are referred to as dimensionless standard uncertainties and are given the notation $u^*(Q)$, $u^*(C_{\mathrm{De}})$, $u^*(C_{\mathrm{dr}})$, $u^*(m)$ and $u^*(h_{1\mathrm{e}})$. Since the uncertainties of C_{De}, $C_{\mathrm{dr,}}$ m and $h_{1\mathrm{e}}$ are independent of each other, probability requires summation in quadrature rather than a simple summation. The standard uncertainty of the discharge measurement can be estimated thus:

$$U^*(Q) = \sqrt{u^*(C_{\mathrm{De}})^2 + u^*(C_{\mathrm{dr}})^2 + u^*(m)^2 + \left[2{,}5u^*(h_{1\mathrm{e}})\right]^2} \tag{18}$$

NOTE For modular flow, $u^*(C_{\mathrm{dr}})^2 = 0$.

11.3 Uncertainty in the discharge coefficient $u^*(C_{\mathrm{De}})_{68}$ for the flat-V weir

The uncertainty in the discharge coefficient C_{De} has been determined from a series of hydraulic tests using a high calibration facility. For well constructed triangular profile weirs which are installed in a channel in which the approach conditions comply with 6.2.2, the relative standard uncertainty of the coefficient of discharge varies in accordance with the ratio of the total upstream head to the height of the vee and the horizontal parameter of the weir cross-slope (m). The values to be used are contained in Table 4 but are summarized in Table 14.

Table 14 — Uncertainties in the discharge coefficient at the 68 % confidence level

$\mathrm{H}_1/H' \le 1{,}0$		$H_1/H' > 1{,}0$	
m	$u^*(C_{\mathrm{De}})_{68}$ %	m	$u^*(C_{\mathrm{De}})_{68}$ %
40	1,5	40	1,25
20	1,6	20	1,4
10	1,45	10	1,15

11.4 Uncertainty in the drowned flow reduction factor $u^*(C_{\mathrm{dr}})$

There are five factors which influence the uncertainty in C_{dr}:

1) the uncertainties in the laboratory determination of the C_{dr} versus $h_{\mathrm{pe}}/H_{1\mathrm{e}}$ relationship;

2) the uncertainties in the laboratory determination of the C_{dr} versus $H_{2\mathrm{e}}/H_{1\mathrm{e}}$ relationship;

3) the uncertainties in the measurement of the upstream effective head, h_{1e};

4) the uncertainties in the measurement of the separation pocket head, h_{pe};

5) the uncertainties in the measurement of the downstream effective head, h_{2e}.

A suitable expression for the combined uncertainty in the drowned flow reduction factor when using crest tappings is:

$$u^*(C_{dr}) = 5\left(1 - C_{dr}\right)\sqrt{1 + u^*(h_{1e})^2 + u^*{}_{h,pe}{}^2} \tag{19}$$

A suitable expression for the combined uncertainty in the drowned flow reduction factor when using downstream (tailwater) water levels is:

$$u^*(C_{dr}) = 5\left(1 - C_{dr}\right)\sqrt{1 + u^*{}_{h,e1}{}^2 + u^*{}_{h,2e}{}^2} \tag{20}$$

11.5 Uncertainty in the effective head

The uncertainty in effective total head can be considered to consist of four components:

1) the uncertainty in the actual head measurement i.e. instrument uncertainty;

2) the uncertainty in the gauge zero;

3) the uncertainty in the head correction factor k_h. The absolute standard uncertainty is usually taken as 0.1 mm which can be assumed to be negligible relative to the first two uncertainties and for most practical applications can be ignored.

4) the uncertainty in the estimation of total head using the iterative process. If sufficient iterations are used in the computation the uncertainty in the estimation of total head is negligible and can be ignored.

Therefore, if uncertainties in the head correction factor and the iterative process are ignored, the uncertainty in the total head can be estimated as follows:

$$u^*_{He} = 100\frac{\sqrt{u(h_1)^2 + u(E)^2}}{h} \tag{21}$$

where $u(h_1)$and $u(E)$ are the absolute, standard uncertainties in the instrument and the stage zero respectively in the same units as the stage (h_1).

Therefore, the uncertainty in the effective head can be assumed to be a combination of the instrument and gauge zero uncertainties. Examples of the computation of the uncertainty in the effective total head are contained in Clause 12. In addition, reference should also be made to Annexes B and C.

11.6 Uncertainty budget

In reports, an uncertainty budget table may be presented (or referenced) to provide the following information for each source of uncertainty:

a) the method of evaluation (from Annex B);

b) the determined value of relative standard uncertainty $u^*(C_{De})$, $u^*(m)$, $u^*(C_{dr})$ and $u^*(h_{1e})$, including the datum uncertainty of $u^*(h_{1e})$;

c) the relative sensitivity coefficients. The sensitivity coefficient is a measure of the impact of the individual component uncertainty on the overall uncertainty. For v-shaped structures such as a flat-V weir, the head measurement has an exponent value $\beta = 2{,}5$. Therefore, the sensitivity is 2,5 since any error in the head measurement, results in a larger uncertainty in the discharge due to the impact of the exponent on the discharge computation.

The values for each source are then applied according to Equation (18) to give the combined standard uncertainty, $U^*(Q)$. A coverage factor $k = 2$ is then applied to define the uncertainty at the 95 % level of confidence.

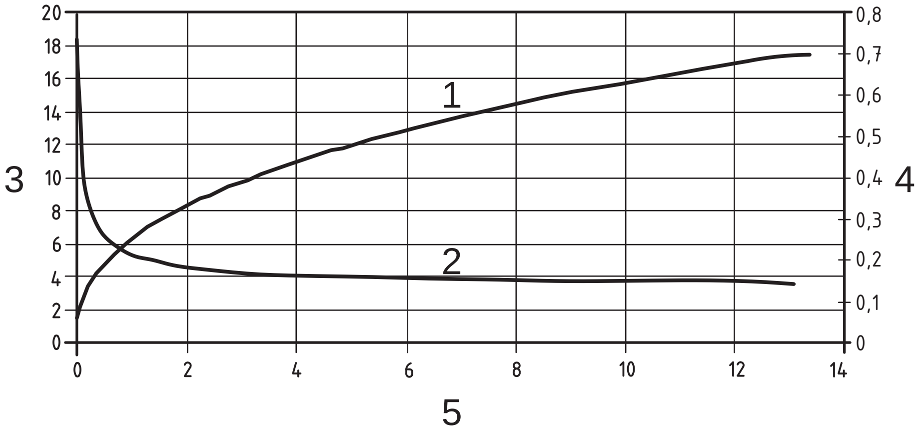
It is customary to present these steps in tabular form with one row for each source and a column for each of the items a) to c) above (see Tables 16 and 18 in Clause 12).

The table may include where appropriate the critical thinking behind the subjective allocation of uncertainty to the quantities m and h_1. This section of the table may be replicated for a range of values of h_1 to determine a relationship between $U^*(Q)$ and h_1.

11.7 Variation of uncertainty with flow and uncertainty in mean daily flow and the daily flow volume

11.7.1 Uncertainty curve

For gauging stations, it is often required to establish the variation of uncertainty with discharge. The uncertainty analysis referred to in 11.2 to 11.6 above can be applied to a range of stages. It is then possible to produce tables and graphs of the relationship between stage and/or flow and uncertainty. An example of an uncertainty curve at the 95 % confidence level for the flat-V weir referred to in Clause 12 (see 12.1 and 12.2) and the corresponding stage discharge relationship is shown in Figure 4.



Key

1 discharge in m^3s^{-1}

2 percentage uncertainty (95 % confidence level)

3 stage (m)

4 derived stage-discharge relationship

5 uncertainty vs. discharge relationship

Figure 4 — Example of an uncertainty vs. discharge curve

11.7.2 Uncertainty in the daily mean flow

The percentage uncertainty in the daily mean flow can be estimated using Equation (22).

$$U^*(Q_{\mathrm{dmf}}) = \frac{\sum U^*(Q_n) \times Q_n}{\sum Q_n} \tag{22}$$

where

n is the number of stage measurements per day, e.g. 96 for a 15 min recording frequency;

Q_n is the flow rate in $\mathrm{m^3 s^{-1}}$ for the nth value in the day;

$U^*(Q_n)$ is the uncertainty in the flow estimate for the nth value in the day;

$U^*(Q_{\mathrm{dmf}})$ is the uncertainty in the daily mean flow at the same coverage factor as the individual flow uncertainties.

11.7.3 Uncertainty in the daily flow volume

The percentage uncertainty in the daily flow volume can be estimated using Equation (23).

$$U^*(Q_{\mathrm{dfv}}) = \sum \left(\frac{U^*(Q_n) \times (Q_n \times t \times 60)}{Q_{\mathrm{dfv}}} \right) \tag{23}$$

where

Q_{dfv} is the total daily flow volume in $\mathrm{m^3 d^{-1}}$;

t is the time interval between readings in minutes, e.g. 15 min;

$U^*(Q_{\mathrm{dfv}})$ is the uncertainty in the daily flow volume at the same coverage factor as the individual flow uncertainties.

12 Examples

12.1 Example 1 — Computation of modular flow at low discharge

12.1.1 Data

A flat-V weir has a crest cross-slope of 1:20,30. The crest width and approach channel width are both 36,0 m and the mean upstream bed level is 0,82 m below the lowest crest elevation. Calculate the discharge when the observed upstream head is 0,621 m. The estimated uncertainty in the gauge zero is 1,0 mm. The head measurements are made using a float and counterweight sensor linked to a logging system by means of a shaft encoder. The basic measurements with their estimated uncertainties are given below:

— $m = 20{,}30$ [$u^*_m = 0{,}2$ % at 1 SD(68 %)]

— $B = b = 36{,}00$ m ($u_B = u_b = 0{,}005$ m)

— $p_1 = 0{,}82$ m ($u_{p1} = 0{,}001$ m)

- $h_1 = 0{,}621$ m
- $H' = h' = 0{,}887$ m ($u_{h'} = 0{,}001$ m)

The appropriate coefficient and head correction values are obtained from Table 4:

- $C_{\text{De}} = 0{,}620$
- $k_{\text{h}} = 0{,}000\,5$ m ($u_{kh} = 0{,}000\,2$ m)

12.1.2 Solution by successive approximation method (see 10.2)

The appropriate discharge Equation (1) is as stated in 9.1:

$$Q = 0{,}8 C_{\text{De}} \sqrt{g}\, m Z_{\text{H}}\, H_{1\text{e}}{}^{5/2}$$

where

$h_{1\text{e}} = h_1 - k_{\text{h}} = 0{,}621 - 0{,}000\,5 = 0{,}620\,5$ m

$h_{1\text{e}} < h'$, hence, flow is confined within the V and Z_{H} = 1,000 from Table 5.

$$0{,}8 C_{\text{De}} \sqrt{g}\, m = 31{,}54\ \text{m}^{1/2}/\text{s}$$

Hence,

$$Q = 31{,}54 H_{1\text{e}}{}^{5/2}\ \text{m}^3\text{s}^{-1} \tag{24}$$

The area of cross-section, A, which is equal to $B\,(h_1 + p_1)$, is 51,88 m^2. Hence, from Equation (13), assuming $\alpha = 1{,}2$, the velocity head is given by:

$$\frac{\alpha \bar{v}_a{}^2}{2g} = \frac{\alpha Q^2}{2gB^2 \left(h_1 + p_1\right)^2} = \frac{Q^2}{44\,000} \tag{25}$$

From these basic values, the calculation of discharge is given in Table 15. Hence, the discharge is 9,65 m^3/s^{-1}.

Table 15 — Example of modular flow discharge calculation

	$\frac{\alpha \bar{v}_a{}^2}{2g}$ From Equation (25) m	$H_{1\text{e}}$ $\left(H_{1\text{e}} = h_{1\text{e}} + \frac{\alpha \bar{v}_a{}^2}{2g}\right)$ m	Q From Equation (24) m^3/s
1st approximation	0,000 0	0,620 5	9,57
2nd approximation	0,0002 1	0,622 7	9,65
3rd approximation	0,002 1	0,622 7	9,65

12.1.3 Solution by coefficient of velocity method (see 10.3)

Even though the successive approximation method is preferred, the modular flow example (see 12.1.2) is also calculated using the coefficient of velocity method for completeness.

The appropriate discharge Equation (2) is as stated in 9.1:

$$Q = 0{,}8 C_{\mathrm{De}} C_v \sqrt{g}\, m Z_{\mathrm{h}} h_{1\mathrm{e}}{}^{5/2}$$

where

$h_{1\mathrm{e}} = h_1 - k_{\mathrm{h}} = 0{,}621 - 0{,}000\,5 = 0{,}620\,5$ m

$C_{\mathrm{De}} = 0{,}620$

As $h'/p_1 = 1{,}08$ and $h_{1\mathrm{e}}/h' = 0{,}70$, from Table 6, $C_{\mathrm{v}} Z_{\mathrm{h}} = 1{,}008$.

$h_{1\mathrm{e}}{}^{5/2} = 0{,}303\,3\ \mathrm{m}^{5/2}$

Substitution in the discharge equation then gives a flow of 9,64 $\mathrm{m}^3\mathrm{s}^{-1}$.

12.2 Example 1 — Uncertainty in computed discharge

12.2.1 Uncertainty in the discharge coefficient

The uncertainty in the discharge coefficient is obtained from Table 14.

$H' = 0{,}887$ m	Cross slope = 1:20
$H_{1\mathrm{e}} = 0{,}623$ m (see Table 15)	
$H_{1\mathrm{e}}/H' = 0{,}702 \leq 1$	
From Table 14	$u^*(C_{\mathrm{De}})_{68} = 1{,}6$ %

12.2.2 Uncertainty in drowned flow reduction factor

The flow is modular.

Therefore, the reduction factor $C_{\mathrm{dr}} = 1$, and as such $u^*(C_{\mathrm{dr}})_{68} = 0$.

12.2.3 Uncertainty in the horizontal; component of the weir crest gradient

From the data provided: $u^*(m) = 0{,}20$ % at the 68 % confidence limit.

12.2.4 Uncertainty in the effective total head

As noted in 11.5, the uncertainty in the head measurement consists of four components, but two these can be ignored. The two main components are

1) the uncertainty in the instrument reading, and

2) the uncertainty in the gauge (stage) zero.

The instrument indicates a head of 0,621 m.

From the table of uncertainties in Annex C, the estimated absolute uncertainty for a float system with a shaft encoder is 0,001 5 m at the 68 % confidence and a bimodal distribution is assumed. Therefore, the absolute uncertainty for the instrument is given by Equation (B.7) from Annex B.

$$u(a_{\text{mean}}) = \frac{(a_{\max} - a_{\min})}{2} = \frac{(622{,}5 - 619{,}5)}{2} = 1{,}5 \text{ mm} = u(h_1)$$

From the table of uncertainties in Annex C, the estimated absolute uncertainty in the stage zero is 0,001 m. A triangular distribution can be assumed. Therefore, the absolute uncertainty for the gauge zero is given by Equation (B.4) from Annex B at the 68 % confidence level.

$$u(a_{\text{mean}}) = \frac{1}{\sqrt{6}}\frac{(a_{\max} - a_{\min})}{2} = \frac{1}{\sqrt{6}}\frac{(622 - 620)}{2} = 0{,}41 \text{ mm} = u(E)$$

The overall uncertainty (68 % confidence level) in the head is estimated using Equation (21), thus:

$$u^*_{h1e} = 100\frac{\sqrt{u(h_1)^2 + u(E)^2}}{h} = 100\frac{\sqrt{1{,}5^2 + 0{,}41^2}}{621} = 0{,}25\ \% \text{ at the 68 \% confidence level}$$

u^*_{h1e} = 0,25 % at the 68 % confidence level

12.2.5 Overall uncertainty

The combined uncertainty estimate is determined from Equation (18)

$$U^*(Q) = \sqrt{u^*(C_{\text{De}})^2 + u^*(C_{\text{dr}})^2 + u^*(m)^2 + \left[2{,}5u^*(h_{1\text{e}})\right]^2}$$

$$U^*(Q) = \sqrt{1{,}6^2 + 0^2 + 0{,}2^2 + 2{,}5^2 \times 0{,}25^2} = 1{,}73\%$$

Therefore, at the 95 % confidence level

$U^*(Q)$ = 1,73 x 2 = 3,46 %

The statement of discharge is therefore:

— The flow rate is 9,65 m^3s^{-1} with an uncertainty of 3,46 % at the 95 % confidence level.

An uncertainty budget for the example is given in Table 16

Table 16 — Uncertainty budget for the modular flow example

	Type/Evaluation	u, u^* value	Sensitivity coefficients	Comment
$u^*(C_{\text{De}})$	B/Normal	1,6 %	1,0	From laboratory tests
$u^*(m)$	B/Triangular	0,2 %	1,0	Installation tolerance
$u\,(E)$	B/Triangular	0,001 m		From Table C.1
$u\,(h)$	B/bimodal	0,001 5 m		From Table C.1
$u^*(h_{1\text{e}})$	Combined	0,25 %	2,5	From 11.5
$U^*(Q)$	Combined	1,73 %		Using Equation (18)

12.3 Example 2 — Computation of drowned flow at high discharge

12.3.1 Data

A flat-V weir has a crest cross-slope of 1:10,1. The crest width and approach channel width are both 25,000 m and the mean upstream bed level is 0,56 m below the lowest crest elevation. Calculate the discharge when the upstream head and crest tapping's record heads of 2,614 m and 2,211 m respectively.

The head and crest tapping measurements are made using float and counterweight water level sensors. The basic measurements with their estimated uncertainties are given below:

— $m = 10{,}1$ [$u^*_m = 0{,}20$ % at 1 SD(68 %)]

— $b = 25{,}000$ m ($u_b = 0{,}004$ m)

— $p_1 = 0{,}56$ m ($u_{p1} =$ 0,002 m)

— $h_1 = 2{,}614$ m

— $h_\mathrm{p} = 2{,}211$ m

— $H' = h'$ = 1,238 m ($u_{H'} =$ 0,001 m)

The appropriate coefficient and head correction values are obtained from Table 4:

— $C_\mathrm{De} = 0{,}620$ m

— $k_\mathrm{h} = 0{,}000\,8$ m ($u_{kh} = 0{,}000\,2$ m)

12.3.2 Solution using successive approximation method (see 10.2)

The appropriate discharge Equation (3) is as stated in 9.1:

$$Q = 0{,}8 C_\mathrm{De} C_\mathrm{dr} \sqrt{g}\, m Z_\mathrm{H} H_\mathrm{1e}{}^{5/2}$$

where

$h_\mathrm{1e} = h_1 - k_\mathrm{h} = 2{,}164 - 0{,}000\,8 = 2{,}613\,2$ m, i.e. 2,613 m

$h_\mathrm{pe} = h_\mathrm{p} - k_\mathrm{h} = 2{,}211 - 0{,}000\,8 = 2{,}210\,2$ m, i.e. 2,210 m

$h_\mathrm{1e} > h'$, hence, flow is above the V-full condition and values of Z_H can be read from Table 5.

$$0{,}8 C_\mathrm{De} \sqrt{g}\, m = 15{,}69 \ \mathrm{m}^{0{,}5}\mathrm{s}$$

Hence,

$$Q = 15{,}69 C_\mathrm{dr} Z_\mathrm{H} H_\mathrm{1e}{}^{5/2} \ \mathrm{m}^3\mathrm{s}^{-1} \tag{26}$$

The area of cross-section, A, which is equal to $B(h_1 + p_1)$, is 79,35 m^2. Hence, from Equation (13), assuming $\alpha = 1{,}2$, the velocity head is given by:

$$\frac{\alpha \bar{v}_a{}^2}{2g} = \frac{\alpha Q^2}{2gB^2\left(h_1 + p_1\right)^2} = \frac{Q^2}{102\ 920} \tag{27}$$

The calculation of discharge then proceeds as shown in Table 17. Hence, the discharge is 122,9 m^{3}s^{-1}.

Table 17 — Example of drowned flow discharge calculation

	$\frac{\alpha \bar{v}_a{}^2}{2g}$	H_{1e}	h_{pe}/H_{1e}	C_{dr}	H_{1e}/H'	Z_H	Q
	From Equation (27)	$H_{1e} = h_{1e} + \frac{\alpha \bar{v}_a{}^2}{2g}$		From Table 7 or Equation (10)		From Table 5 or Equations (7) and (9)	From Equation (26)
	M	m					m^3/s
1st approximation	0,000	2,613	0,845	0,746	2,110	0,799	103,2
2nd approximation	0,103	2,716	0,814	0,786	2,194	0,781	117,1
3rd approximation	0,133	2,746	0,805	0,796	2,218	0,776	121,1
4th approximation	0,142	2,755	0,802	0,799	2,225	0,775	122,4
5th approximation	0,146	2,759	0,801	0,800	2,229	0,774	122,8
6th approximation	0,147	2,760	0,801	0,800	2,229	0,774	122,9

12.3.3 Solution using the coefficient of velocity method (see 10.3)

As already noted the successive approximation method is preferred. However, the non-modular flow example determined by the successive approximation method (see 12.3.2) is also calculated using the coefficient of velocity method for completeness.

The appropriate discharge Equation (4) is as stated in 9.1:

$$Q = 0{,}8 C_{De} C_v C_{dr} \sqrt{g}\, m Z_h h_{1e}{}^{5/2}$$

where

$h_{1e} = h_1 - k_h = 2{,}614 - 0{,}000\ 8 = 2{,}613$ m

$h_{pe} = h_p - k_h = 2{,}211 - 0{,}000\ 8 = 2{,}210$ m

$C_{De} = 0{,}620$

$h_{pe}/h_{1e} = 0{,}845$

$h_{1e}/h' = 2{,}111$

$h'/p_1 = 2{,}211$ (hence, use Table 12)

From Table 12, $C_{\mathrm{v}}C_{\mathrm{dr}} = 0{,}870$ (interpolated)

$Z_{\mathrm{h}} = 0{,}799$ (Table 5)

$h_{1\mathrm{e}}^{5/2} = 11{,}037$

Substitution in the discharge equation gives a flow of 120,4 $\mathrm{m}^3\mathrm{s}^{-1}$.

12.4 Example 2 — Uncertainty in computed discharge

12.4.1 Uncertainty in the discharge coefficient

The uncertainty in the discharge coefficient is obtained from Table 14.

$H' = 1{,}238$ m Cross slope = 1:10,1

$H_{1\mathrm{e}} = 2{,}760$ m (see Table 17)

$H_{1\mathrm{e}}/H' = 2{,}229 > 1$

From Table 14 $u^*(C_{\mathrm{De}})_{68} = 1{,}15\ \%$

12.4.2 Uncertainty in the horizontal; component of the weir crest gradient

From the data provided: $u^*m = 0{,}20\ \%$ at the 68 % confidence limit

12.4.3 Uncertainty in the effective total head

As noted in 11.5, the uncertainty in the head measurement consists of four components, but two these can be ignored. The two main components are

1) the uncertainty in the instrument reading, and

2) the uncertainty in the gauge zero.

The instrument indicates a head of 2.760 m.

From the table of uncertainties in Annex C, the estimated absolute uncertainty for a float system with a shaft encoder at a stage greater than 2.000 m is 0.003 m at the 68 % confidence limit and a bimodal distribution is assumed. Therefore, the absolute uncertainty for the instrument is given by Equation (B.7) from Annex B.

$$u(a_{\mathrm{mean}}) = \frac{(a_{\mathrm{max}} - a_{\mathrm{min}})}{2} = \frac{(2\,763 - 2\,757)}{2} = 3{,}0\ \mathrm{mm} = u(h_1)$$

From the table of uncertainties in Annex C, the estimated absolute uncertainty in the stage zero is 0,001 5 m at the 68 % confidence limit. A triangular distribution can be assumed. Therefore, the absolute uncertainty for the gauge zero is given by Equation (B.4) from Annex B.

$$u(a_{\mathrm{mean}}) = \frac{1}{\sqrt{6}}\frac{(a_{\mathrm{max}} - a_{\mathrm{min}})}{2} = \frac{1}{\sqrt{6}}\frac{(2\,761{,}5 - 2\,758{,}5)}{2} = 0{,}61\ \mathrm{mm} = u(E)$$

The overall uncertainty in the head at the 68 % confidence limit is estimated using Equation (21), thus:

$$u^*_{h1e} = 100\frac{\sqrt{u(h_1)^2 + u(E)^2}}{h} = 100\frac{\sqrt{3{,}0^2 + 0{,}61^2}}{2\,760} = 0{,}11\ \%$$

$u^*_{h1e} = 0{,}11$ % at the 68 % confidence limit

12.4.4 Uncertainty in the separation pocket (crest tapping) head

The uncertainty in the crest tapping head is estimated similarly to the uncertainty in the total upstream head

The instrument indicates a head of 2,211 m.

From the table of uncertainties in Annex C, the estimated absolute uncertainty for a float system with a shaft encoder at a stage greater than 2,000 m is 0,006 m at the 95 % confidence and a bimodal distribution is assumed. Therefore, the absolute uncertainty for the instrument is given by Equation (B.7) from Annex B.

$$u(a_{\text{mean}}) = \frac{(a_{\max} - a_{\min})}{2} = \frac{(2\,766 - 2\,754)}{2} = 6{,}0\ \text{mm} = u(h_\text{p})$$

From the table of uncertainties in Annex C, the estimated absolute uncertainty in the stage zero is 0,003 m at the 95 % confidence limit. A triangular distribution can be assumed. Therefore, the absolute uncertainty for the gauge zero is given by Equation (B.4) from Annex B.

$$u(a_{\text{mean}}) = \frac{1}{\sqrt{6}}\frac{(a_{\max} - a_{\min})}{2} = \frac{1}{\sqrt{6}}\frac{(2\,763 - 2\,757)}{2} = 1{,}22\ \text{mm} = u(E)$$

The overall uncertainty in the crest tapping head at the 95 % confidence limit is estimated using Equation (21), thus:

$$u^*_{hp} = 100\frac{\sqrt{u(h_\text{pe})^2 + u(E)^2}}{h} = 100\frac{\sqrt{6{,}0^2 + 1{,}22^2}}{2\,211} = 0{,}28\ \%\ \text{at the 95 \% confidence limit}$$

$u^*_{hp} = 0{,}14$ % at the 68 % confidence level

12.4.5 Uncertainty in drowned flow reduction factor

The flow is non-modular.

From Table 17, the drowned flow reduction factor is 0,80,

When using a crest tapping, the drowned flow reduction factor can be estimated using Equation (19), thus:

$$u^*_{C,\text{dr}} = 5\left(1 - C_\text{dr}\right)\sqrt{1 + {u^*_{h,\text{e1}}}^2 + {u^*_{h,pe}}^2} = 5 \times (1 - 0{,}8)\sqrt{1 + 0{,}11^2 + 0{,}14^2} = 1{,}02\ \%$$

12.4.6 Overall uncertainty for non-modular flow example

The combined uncertainty estimate is determined from Equation (18).

$$U^*(Q) = \sqrt{u^*(C_\text{De})^2 + u^*(C_\text{dr})^2 + u^*(m)^2 + \left[2{,}5u^*(h_\text{1e})\right]^2}$$

$$U^*(Q) = \sqrt{1{,}15^2 + 1{,}02^2 + 0{,}2^2 + 2{,}5^2 \times 0{,}11^2} = 1{,}57\%$$

Therefore, at the 95 % confidence level

$U^*(Q)$ = 1,57 x 2 = 3,14 %

The statement of discharge is therefore:

— The flow rate is 122,9 m^3s^{-1} with an uncertainty of 3,14 % at the 95 % confidence level.

An uncertainty budget for the example is given in Table 18.

Table 18 — Uncertainty budget for the modular flow example

	Type/Evaluation	**u, u^* value**	**Sensitivity coefficients**	**Comment**
$u^*(C_{\mathrm{De}})$	B/Normal	1,15 %	1,0	From laboratory tests
$u^*(m)$	B/Triangular	0,2 %	1,0	Installation tolerance
$u(E)$	B/Triangular	0,0015 m		From Table C.1
$u(h)$	B/bimodal	0,003 m		From Table C.1
$u^*(h_{1\mathrm{e}})$	Combined	0,11 %	2,5	From 11.5
$u^*(C_{\mathrm{dr}})$	B/Normal	1,02 %	1,0	
$U^*(Q)$	Combined	1,57 %		Using Equation (18)

Annex A
(normative)

Velocity distribution

A.1 An even distribution of velocity over the cross-section of the approach channel in the region of the gauging station is necessary for an accurate measurement of discharge by means of weirs, notches and flumes. This is because the recommended coefficients are empirical values obtained by various investigators in laboratory conditions. These involved either the use of screens to ensure an approximately uniform velocity over the cross-section, or a long straight approach channel conducive to the establishment of a normal distribution of velocities.

A.2 Normal velocity distribution is defined as “the distribution of velocities attained in a channel over a long uniform straight reach”. A characteristic feature of flow in such a channel is that the velocity is at maximum approximately 0,85 of the depth above invert level, with the average velocity occurring at about 0,4 of the depth above invert level.

A.3 Any deviation from the ideal conditions of either uniform or a normal velocity distribution may lead to errors in flow measurement. Quantitative information on the influence of velocity distribution is inadequate to define the acceptable limits of departure from the ideal distributions. The tolerances on discharge coefficients are given in Table 4. Figure 2 provides guidance on the acceptable practical levels of velocity distribution and evenness.

A.4 In Figure 2, different patterns of isovels are shown. The isovels are contours of equal velocity in the direction of flow.

A.5 The percentage difference in the value of α_{left} and α_{right} is shown in Figure 2. Figure 2 c) shows the extreme value for the departure from ideal approach conditions for the tolerances given in Table 4 and this percentage difference shall be regarded as the maximum permissible. This distribution gives the Coriolis energy coefficient of 1,44.

Annex B
(informative)

Introduction to measurement uncertainty

B.1 General

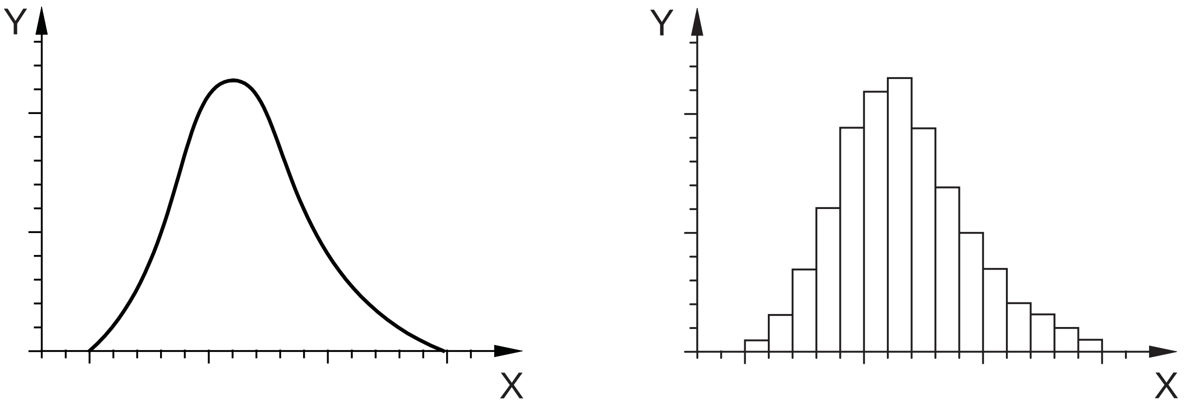
Results of measurements or analysis cannot be exact. The discrepancy between the true value, which is unknowable, and the measured value is the measurement error. The concept of uncertainty is a way of expressing this lack of knowledge. For example, if water is controlled to flow at a constant rate, then a flow meter 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 is defined as:

> *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.



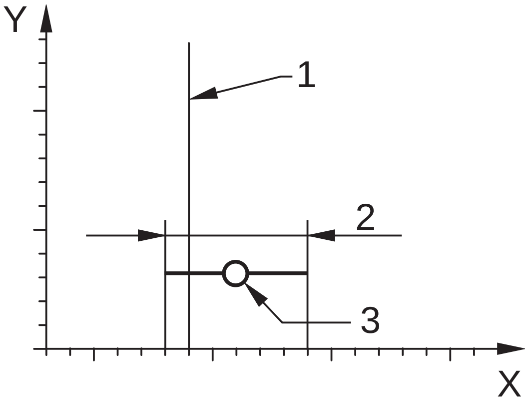
Key
X flow value
Y probability

a)

Key
X flow value
Y number of samples

b)

Table B.1 (*continued*)



Key

1 limit

2 standard deviation

3 mean value

X flow value

Y number of samples

c)

Figure B.1 a) shows that if repeated measurements of a steady flow are made, these follow a probability density function whose shape resembles the plot shown in the figure.

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

Figure B.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).

Figure B.1 — Pictorial representation of some uncertainty parameters

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

So a probability distribution shall 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.

B.3 Random and systematic error

The terms “random” and “systematic” have been applied in hydrometric standards to distinguish between i) random error that represent an inherent dispersion of values under steady conditions, and ii) 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 shall 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, the GUM 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 (say) totalized volume is established over a long time base, the systematic errors, even when reduced, can remain dominant in the estimation of uncertainty.

B.4 Measurement standards

The GUM and the HUG 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:

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

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

   iii) calibration data (from manufacturer).

B.5 Evaluation of Type-A uncertainty

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

$$u(x) = t_\mathrm{e}\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \overline{x}\right)^2} \quad \text{(B.1)}$$

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

$$\overline{x} = \frac{1}{n}\left(x_1 + x_2 + ...x_n\right) \quad \text{(B.2)}$$

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 B.1.

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

$$u\left(\bar{x}\right)=\frac{t_\mathrm{e}}{\sqrt{n}}\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(x_i-\bar{x}\right)^2} \tag{B.3}$$

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 $u\left(\bar{x}\right)$ 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 $u\left(\bar{x}\right)$ and $u(x)$ to show the extent to which averaging is applied.

Table B.1 — t_e factors 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, the number of terms in a sum minus the number of constraints on the terms of the sum (GUM).

B.6 Evaluation of Type-B uncertainty

B.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, the Type-B method of estimation is used:

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

ii) to define upper and lower bounds of the measurement; and then

iii) to 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 the GUM and in B.6.2 to B.6.5.

B.6.2 Triangular distribution

The triangular distribution is represented in Figure B.2.

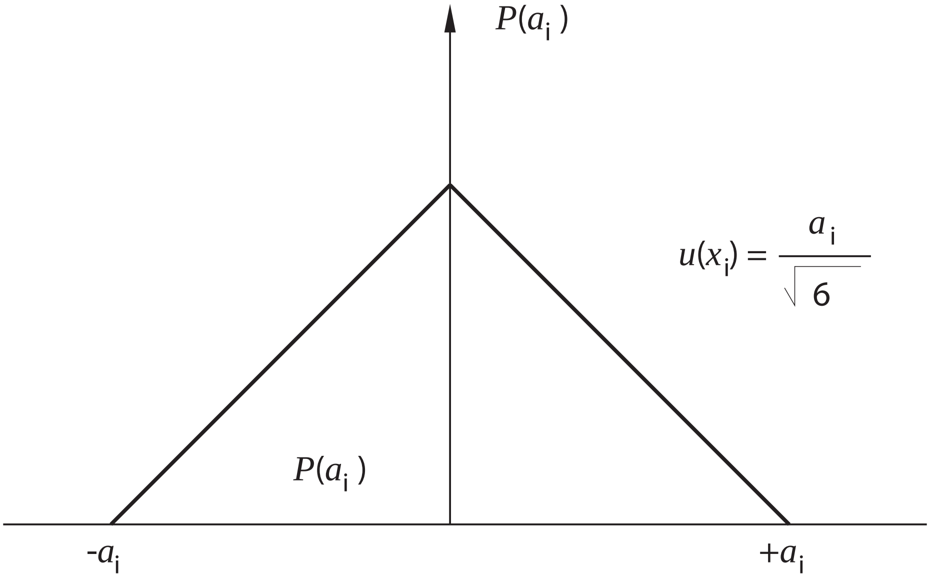


Figure B.2 — Triangular distribution

$$u(a_{mean}) = \frac{1}{\sqrt{6}} \frac{(a_{max} - a_{min})}{2} \qquad \text{(B.4)}$$

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.

B.6.3 Rectangular distribution

The rectangular distribution is represented in Figure B.3.

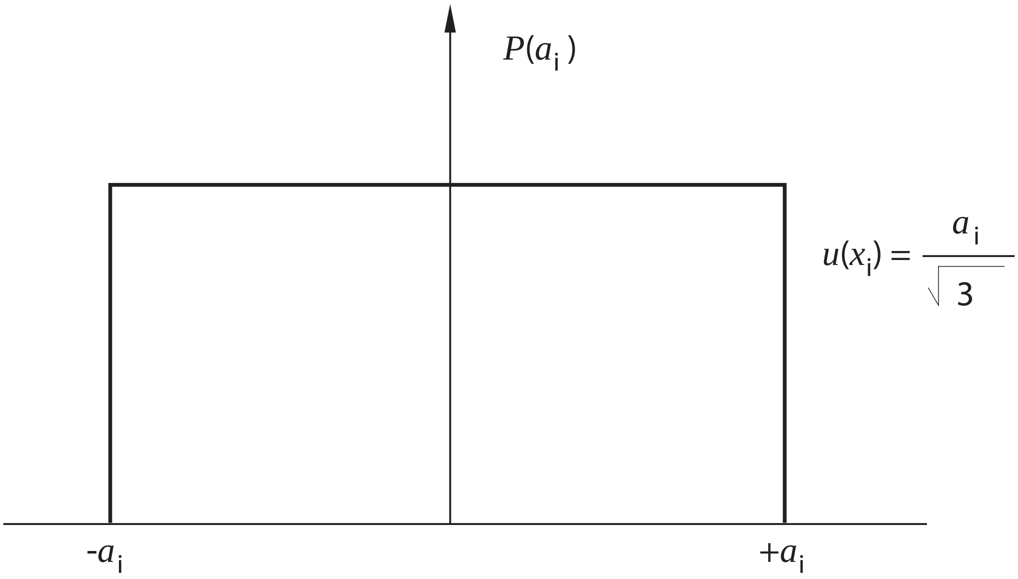


Figure B.3 — Rectangular distribution

$$u(a_{mean}) = \frac{1}{\sqrt{3}} \frac{(a_{max} - a_{min})}{2} \tag{B.5}$$

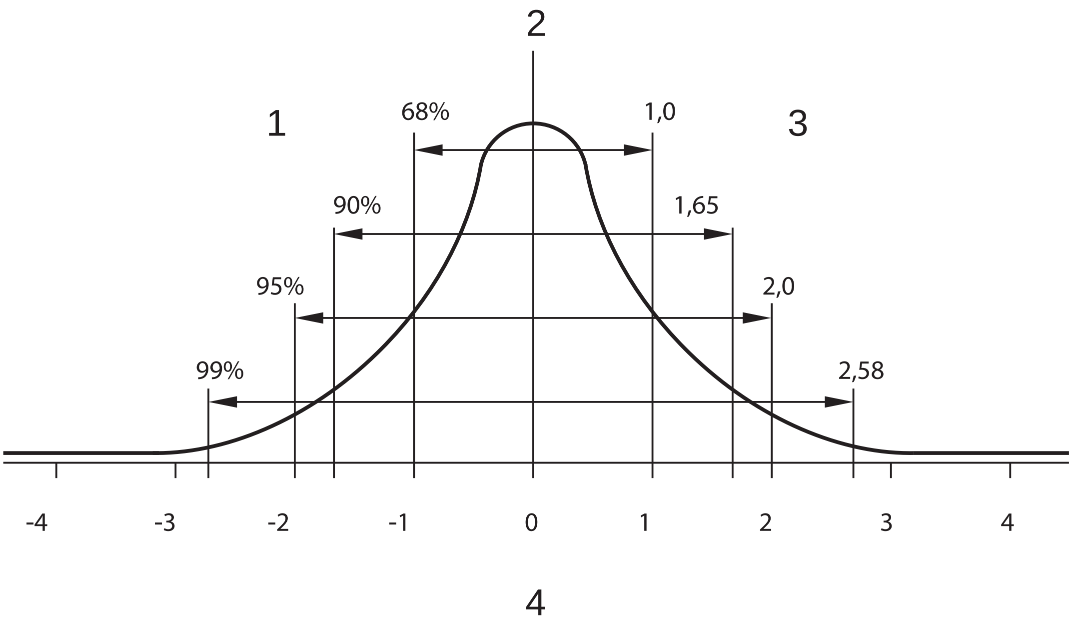
This probability distribution is usually applied to the resolution limit of the measurement instrumentation (i.e. the displayed resolution or the resolution of internal analogue/digital converters).

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.

B.6.4 Normal probability distribution

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



Key

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

Figure B.4 — Normal probability distribution

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

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 $k = 1$.

B.6.5 Bimodal probability distribution

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

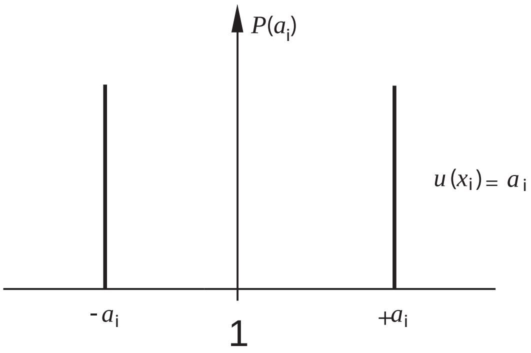


Figure B.5 — Bimodal probability distribution

$$u(a_{\text{mean}}) = \frac{(a_{\text{max}} - a_{\text{min}})}{2} \tag{B.7}$$

Measurement equipment with hysteresis 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.

B.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:

$$Q = b \times h \times \overline{V} \tag{B.8}$$

where

b is the channel width;

h is the depth of water in the channel;

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

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

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

$$\Delta Q = \frac{\partial Q}{\partial b}\Delta b + \frac{\partial Q}{\partial h}\Delta h + \frac{\partial Q}{\partial \overline{V}}\Delta \overline{V} \tag{B.9}$$

where the partial differentials, $\frac{\partial Q}{\partial b}$, $\frac{\partial Q}{\partial h}$ and $\frac{\partial Q}{\partial \overline{V}}$ are sensitivity coefficients. For the equation $Q = b \times h \times \overline{V}$, this is equal to:

$$\frac{\Delta Q}{Q} = \frac{\Delta b}{b} + \frac{\Delta h}{h} + \frac{\Delta \overline{V}}{\overline{V}} \tag{B.10}$$

In uncertainty analysis, the values $\frac{\Delta Q}{Q}$, $\frac{\Delta b}{b}$,$\frac{\Delta h}{h}$ and $\frac{\Delta \overline{V}}{\overline{V}}$ correspond to dimensionless standard uncertainties. They are given the notation $u_\mathrm{c}^*(Q)$, $u^*(b)$, $u^*(h)$ and $u^*(\overline{V})$.

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

$$u_\mathrm{c}^*(Q) \cong \sqrt{u^*\left(\overline{V}\right)^2 + u^*\left(b\right)^2 + u^*\left(h\right)^2} \tag{B.11}$$

Annex C

(informative)

Performance guide for hydrometric equipment for use in technical standards

For guidance on the origins and use of this table, reference should be made to ISO/TS 25377.

Table C.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 (68 % confidence level)				
Velocity (continuous)				A[d]	B	Minimum	25 %	50 %	75 %	Maximum	Minimum	25 %	50 %	75 %	Max.
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	0,000 5 m/s	0,010 m/s	0,022 m/s	0,030 m/s	0,040 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	0,0005 m/s	0,010 m/s	0,018 m/s	0,025 m/s	0,025 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	0,003 m/s	0,005 m/s	0,007 m/s	0,007 m/s	0,010 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	0,003 m/s	0,005 m/s	0,007 m/s	0,007 m/s	0,010 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	0,003 m/s	0,005 m/s	0,007 m/s	0,007 m/s	0,010 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	0,003 m/s	0,005 m/s	0,007 m/s	0,007 m/s	0,010 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	0,001 m	0,001 m	0,001 5 m	0,001 5 m	0,001 5 m
In-contact methods	Encoder/float system[b]	Requires regular maintenance	$u(R)$		Bimodal	applicable	extension 1,250 m	extension 2,500 m	extension 3,750 m	extension 5,000 m	0,001 5 m	0,002 0 m	0,002 0 m	0,002 5 m	0,002 5 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	0,002 m	0,002 m	0,002 5 m	0,002 5 m	0,003 0 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	0,001 m	0,001 m	0,001 5 m	0,001 5 m	0,001 5 m
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	0,002 m	0,004 m	0,010 m	0,025 m	0,060 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	0,002 m	0,004 m	0,010 m	0,025 m	0,060 m

Table C.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 (68 % confidence level)				
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	0,002 m	0,020 m	0,060 m	0,100 m	0,200 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	0,001 m	0,001 m	0,001 5 m	0,001 5 m	0,001 5 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.

Bibliography

[1] ISO 4373, *Hydrometry — Water level measuring devices*

[2] ISO 1100-2, *Measurement of flow in open channels — Part 2: Determination of the stage-discharge relation*

[3] ISO 18365[1], *Hydrometry — Guidelines for selection, establishment and operation of a gauging station*

[4] ISO 26906, *Hydrometry — Fishpasses at flow measurement structures*

[5] ISO/IEC Guide 98-3, *Uncertainty measurement — Part 3: Guide to the expression of uncertainty in measurement* (*GUM:1995*)

[6] ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

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[1] To be published. (Revision of ISO 1100-1:1996 and ISO/TR 8363:1997)

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