भारतीय मानक
Indian Standard

IS 14673 : 2022
ISO 4360 : 2020

हाइड्रोमेट्री — त्रिकोणीय प्रोफइल वियर के प्रयोगद्वारा खुले चैनलों के प्रवाह का मापन

(दूसरा पुनरीक्षण)

Hydrometry — Open Channel Flow Measurement Using Triangular Profile Weirs

(Second Revision)

ICS 17.120.20

भारतीय मानक ब्यूरो
BUREAU OF INDIAN STANDARDS
मानक भवन, 9 बहादुर शाह ज़फर मार्ग, नई दिल्ली - 110002
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI - 110002
www.bis.gov.in www.standardsbis.in

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Hydrometry Sectional Committee WRD 01

NATIONAL FOREWORD

This Indian Standard which is identical with ISO 4360 : 2020 'Hydrometry – Open channel flow measurement using triangular profile weirs' issued by the International Organization for Standardization (ISO) is being considered to be adopted by the Bureau of Indian Standards after the recommendation of the Hydrometry Sectional Committee, WRD 01 and approval of the Water Resources Division Council.

This standard was originally published in 1999 which was identical with ISO 4360 : 1984. The second revision of this standard has been undertaken to align it with the latest version of ISO 4360 : 2020

The text of ISO Standard has been approved as suitable for publication as an Indian Standard without deviations. Certain terminologies and conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following:

a) Wherever the words 'International Standard' appear referring to this standard, they should be read as 'Indian Standard'.

b) Comma (,) has been used as a decimal marker, while in Indian Standards, the current practice is to use a point (.) as the decimal marker.

In this adopted standard, reference appears to certain International Standards for which Indian Standards exist. The corresponding Indian Standards, which are to be substituted in their respective places, are listed below along with their degree of equivalence for the editions indicated:

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
ISO 772 Hydrometry — Vocabulary and symbols	IS 1191 : 2016 Hydrometry — Vocabulary and symbols (*third revision*)	Identical

For the purpose of deciding whether a particular requirement of this standard is complied with the final value, observed or calculated expressing the result of a test or analysis shall be rounded off in accordance with IS 2 : 2022 'Rules for rounding off numerical values (*second revision*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

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Foreword

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

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

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

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

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

This document 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 4360:2008), which has been technically revised.

The main changes compared to the previous edition are as follows.

— The calculations and examples have been updated to correct an error in the previous edition.

— A URN has been added containing a spreadsheet that has been developed to support the standard and facilitate calculation of discharge and uncertainty (see Annex C).

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

Indian Standard

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(Second Revision)

1 Scope

This document specifies methods for the measurement of the flow of water in open channels under steady flow conditions using triangular profile weirs. The flow conditions considered are steady flows which are uniquely dependent on the upstream head and non-modular (drowned) flows which depend on downstream as well as upstream levels.

2 Normative references

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

ISO 772, *Hydrometry — Vocabulary and symbols*

3 Terms and definitions

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

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

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

4 Symbols

Symbol	Unit of measurement	Quantity
α	dimensionless	Coriolis coefficient
A	m^2	area of approach channel
B	m	width of approach channel
b	m	breadth of weir crest perpendicular to flow direction
C_d	dimensionless	coefficient of discharge
C_v	dimensionless	coefficient of velocity
$C_v f$	dimensionless	combined coefficient of velocity for non-modular flow
f	dimensionless	non-modular (drowned) flow reduction factor
g	m/s^2	acceleration due to gravity
H	m	total head relative to crest level
h	m	gauged head relative to crest level (upstream head is inferred if no subscript is used)
N	dimensionless	number of measurements in a set
p	m	height of weir (difference between upstream mean bed level and crest level)
Q	m^3/s	volumetric rate of flow
$u(\ )$	as parameter	standard uncertainty in parameter specified in parentheses

Symbol	Unit of measurement	Quantity
$u^*(\ )$	%	percentage uncertainty in parameter specified in parentheses
$\overline{v}$	m/s	mean velocity
U	%	expanded percentage uncertainty

Subscripts:

0 datum

1 upstream

2 downstream

c combined

p measured crest tapping head above crest level

max maximum

min minimum

5 Principle

The discharge over a triangular profile weir is a function of the upstream head on the weir (for modular flow), upstream and downstream head (for non-modular flow), the geometrical properties of the weir and approach channel and the dynamic properties of the water.

6 Installation

6.1 General

The required conditions regarding selection of site, installation conditions, the measuring structure, the approach channel, the downstream channel, maintenance, measurement of head, and gauge wells which are generally necessary for flow measurement are given in the following subclauses.

6.2 Selection of site

A preliminary survey shall be made of the physical and hydraulic features of the proposed site, to check that it conforms (or can be made to conform) to the requirements necessary for accurate measurement by a weir.

Particular attention should be paid to the following features in selecting the site:

a) availability of an adequate length of channel of regular cross-section;

b) the existing velocity distribution;

c) the avoidance of a steep channel, if possible;

d) the effects of any raised upstream water level due to the measuring structure;

e) conditions downstream including such influences as tides, confluences with other streams, sluice gates, mill dams and other controlling features which might cause non-modular flow;

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 in natural channels;

i) the clearance of rocks or boulders from the bed of the approach channel;

j) the effect of wind; wind can have a considerable effect on the flow in a river or over a weir, especially when these are wide and the head is small and when the prevailing wind is in a transverse direction.

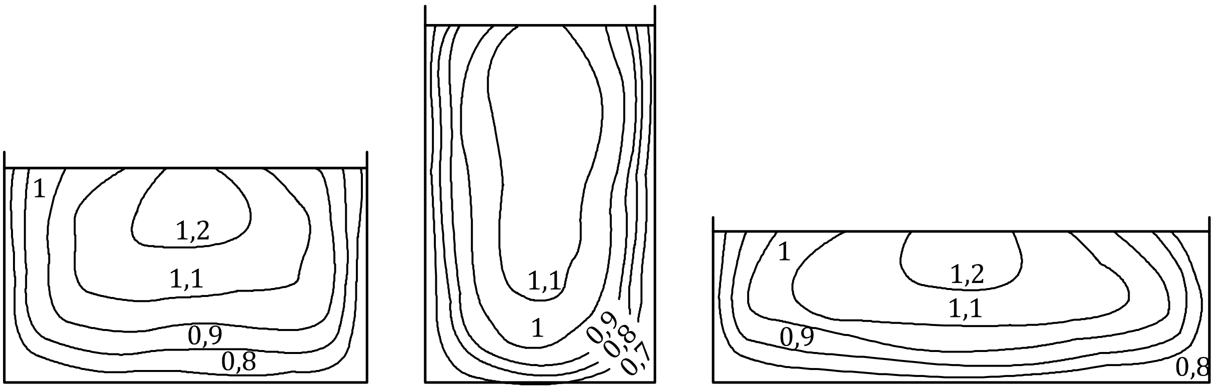
If the site does not possess the characteristics necessary for satisfactory measurement, the site shall be rejected unless suitable improvements are practicable.

If an inspection of the stream shows that the existing velocity distribution is regular, then it may be assumed that the velocity distribution will remain satisfactory after the construction of a weir.

If the existing velocity distribution is irregular and no other site for a gauge is feasible, due consideration shall be given to checking the distribution after the installation of the weir and to improving it if necessary.

A complete and quantitative assessment of velocity distribution may be made by means of a current-meter, other point velocity measurement technique or an acoustic Doppler profiler. Information about the use of current-meters is given in ISO 748[1] and information on Doppler profilers in ISO 24578[2].

Figure 1 gives examples of satisfactory velocity distributions.



NOTE The contours refer to values of local flow velocity relative to the mean cross-sectional velocity.

Figure 1 — Examples of satisfactory velocity distributions

6.3 Installation conditions

6.3.1 General

The complete measuring installation consists of an approach channel, a measuring structure and a downstream channel. The conditions of each of these three components affect the overall accuracy of the measurements.

Installation requirements include features such as the surface finish of the weir, the cross-sectional shape of the channel, the channel roughness and the influence of control devices upstream or downstream of the gauging structure.

The distribution and direction of velocity have an important influence on the performance of the weir, these factors being determined by the features mentioned above.

Once an installation has been installed, the user shall prevent any change which could affect the discharge characteristics.

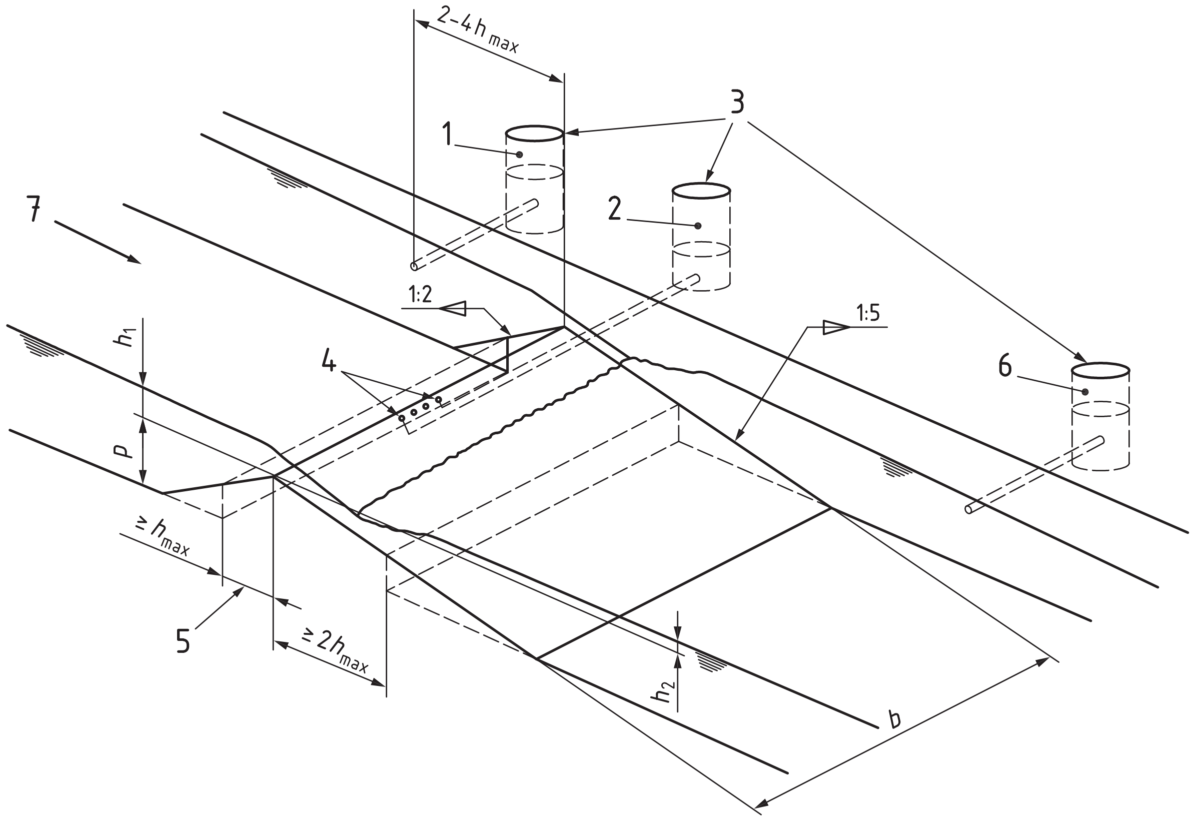
6.3.2 Measuring structure

The structure shall be rigid and watertight and capable of withstanding flood flow conditions without distortion or fracture. It shall be at right angles to the direction of flow and shall conform to the dimensions given in the relevant clauses.

The weir comprises an upstream slope of 1 (vertical) to 2 (horizontal) and a downstream slope of 1 (vertical) to 5 (horizontal). The intersection of these two surfaces forms a straight line crest, horizontal and at right angles to the direction of flow in the approach channel. Particular attention shall be given to the crest itself, which shall possess a well-defined corner of durable construction. The crest may be made of pre-formed sections, carefully aligned and jointed, or may have a non-corrodible metal insert, as an alternative to in situ construction throughout.

The dimensions of the weir and its abutments shall conform to the requirements indicated in Figure 2. Weir blocks may be truncated but not so as to reduce their dimensions in plan to less than h_{max} for the 1:2 slope and 2 h_{max} for the 1:5 slope.

Figure 2 shows the general arrangement of the triangular profile weir.



Key

1 upstream head measurement

2 crest tapping head measurement

3 gauge wells

4 crest tappings

5 limit of truncated sections

6 downstream head measurement

7 direction of flow

Figure 2 — General arrangements of the triangular profile weir

6.3.3 Approach channel

On all installations, the flow in the approach channel shall be smooth, free from disturbance and shall have a velocity distribution as satisfactory as possible over the cross-sectional area. This can usually be verified by inspection or measurement. In the case of natural streams or rivers, this can only be attained by having a long straight approach channel free from projections into the flow. Figure 1 gives examples of satisfactory velocity distributions.

The following general requirements shall be complied with.

a) As the altered flow conditions due to the construction of the weir might cause a build-up of shoals of debris upstream of the structure, which in time might affect the flow conditions, the likely consequential changes in the water level shall be taken into account in the design of gauging stations.

b) In an artificial channel, the cross-section shall be uniform and the approach channel shall be straight for a length equal to at least 5 times its water-surface width.

c) In a natural stream or river, the cross-section shall be reasonably uniform and the approach channel shall be straight for a sufficient length to ensure a satisfactory velocity distribution.

d) If the entry to the approach channel is through a bend, or if the flow is discharged into the channel through a conduit or a channel of smaller cross-section, or at an angle, then a longer length of straight approach channel is likely to be required to achieve a regular velocity distribution.

e) Flow conditioning devices such as baffles and flow straighteners shall not be installed closer to the points of measurement than a distance 10 times the maximum head to be measured.

f) Under certain conditions, a standing wave can occur upstream of the gauging device, for example if the approach channel is steep. Provided that this wave is at a distance of not less than 30 times the maximum head upstream, flow measurement is feasible, subject to confirmation that a regular velocity distribution exists at the gauging station and that the Froude number in this section is no more than 0,6.

If a standing wave occurs within this distance, the approach conditions and/or the gauging device shall be modified.

6.3.4 Downstream channel

The channel downstream from the structure is usually of no importance if the weir has been designed so that the flow is modular (i.e. unaffected by tailwater level) under all operating conditions. A downstream gauge may be provided to measure tailwater levels to determine if and when non-modular flow occurs. The downstream gauge shall be installed sufficiently far downstream to avoid excessively disturbed flow and be truly representative of downstream channel conditions. This shall be determined on a site by site basis.

In the event of the possibility of scouring downstream, which phenomenon can also lead to the instability of the structure, particular measures to prevent this happening should be adopted. The design of such measures is outside the scope of this document.

A crest tapping and separate gauge well shall be fitted if the weir is designed to operate in a non-modular condition or if there is a possibility that the weir could drown in the future.

The latter circumstance could arise if the altered flow conditions due to the construction of the weir have the effect of building up shoals of debris immediately downstream of the structure or if river works are carried out downstream at a later date.

Fish passage baffles can be installed on the downstream face of the weir to improve fish passage as set out in ISO/TR 19234[3].

7 Maintenance

Maintenance of the measuring structure and the approach channel is important to secure accurate continuous measurements.

The approach channel shall be kept free of silt, vegetation and obstructions which might have deleterious effects on flow conditions specified for the standard installation.

Where used, gauge wells and their entry from the channel shall also be kept clean and free from deposits. The downstream channel shall be kept free of obstructions which could result in non-modular flow.

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

Head-measurement piezometers, connecting conduits and gauge wells shall be cleaned and checked for leakage. The device used to measure head shall be checked periodically to ensure accuracy.

If a flow straightener or similar is used in the approach channel, it shall be kept clean.

8 Measurement of head(s)

8.1 General

Where spot measurements are required, the heads can be measured by staff gauges, hooks, points, wires or tape gauges.

Where continuous records are required, recording gauges shall be used.

Devices for the measurement of head are described in ISO 4373[4].

Periodic checks on the measurement of the head in the approach channel shall be made.

The accuracy of the head measuring device shall be considered when considering the uncertainty of the flow measurement (see Clause 10).

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

8.2 Location of head measurement(s)

8.2.1 Modular (free) flow

Flow is modular when it is independent of variations in tailwater level. This requirement is met when the tailwater total head is equal to or less than 75 % of the upstream total head.

The location for the measurement of head on the weir should be at a sufficient distance upstream from the weir to avoid the region of surface drawdown. On the other hand, it should be close enough to the weir to ensure that the energy loss between the section of measurement and the control section on the weir shall be negligible. Taking these considerations into account, the head-measurement section shall be located at a distance between 2 and 4 times the maximum head ($2\ h_{max}$ to $4\ h_{max}$) upstream of the crest.

8.2.2 Non-modular (drowned) flow

A significant error in the calculated discharge will develop if the tailwater total head above crest level exceeds 75 % of the upstream total head, unless a crest tapping or downstream (tailwater) measurement is provided and two independent head measurements are made.

When a crest tapping is used, non-modular flow occurs when the head recorded by the crest tapping exceeds 25 % of the upstream total head. Where the weir is designed to operate under non-modular flow, a second measurement of head is required. For more accurate flow measurement, the head shall be measured within the separation pocket immediately downstream of the crest. Alternatively, the head can be measured in the channel downstream (tailwater) of the structure. However, the uncertainties in the flow measurements made using tailwater data will generally be greater than those obtained from a well-maintained crest tapping. The optimum position for the crest tapping is at the centre of the weir crest. The tapping may be off-centre on weirs wider than 2,0 m provided that the distance from the centreline of the crest tapping to the nearer side wall or pier is greater than 1,0 m.

8.3 Gauge wells

Where there are water surface irregularities, a gauge well (sometimes referred to as a stilling well) may be used to improve the stability of the measurement and thus reduce the effect of short period variations due to surface movements caused by wind or waves.

Gauge wells 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 0,6 m above the highest water levels expected. Gauge wells shall be connected to the appropriate head measurement positions by means of pipes, slots or holes.

Both the well and the connecting pipe shall be watertight. Where the well is provided for the accommodation of the float of a level recorder, it shall be of adequate size and depth. Care shall be taken to ensure that there is sufficient clearance around the float such that it cannot foul on the sides of the well.

The connecting pipe shall have its invert not less than 0,10 m below the lowest level to be gauged.

Pipe connections to the upstream and downstream head measurement positions shall terminate flush with, and 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 centre line of the connection. The pipes may be oblique to the wall only if they are 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.

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.

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

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 any oscillations due to short period waves.

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.

The static head at the separation pocket immediately downstream of the crest of the weir shall be transmitted to its gauge well as follows.

a) An array of tapping holes shall be set into a plate covering a cavity in the crest of the weir block.

b) The underside of the plate shall be supported on a manifold into which the static head is communicated via an array of feed tubes.

c) A horizontal conduit shall lead from the cavity through the weir block beneath the crest and terminating at the gauge well.

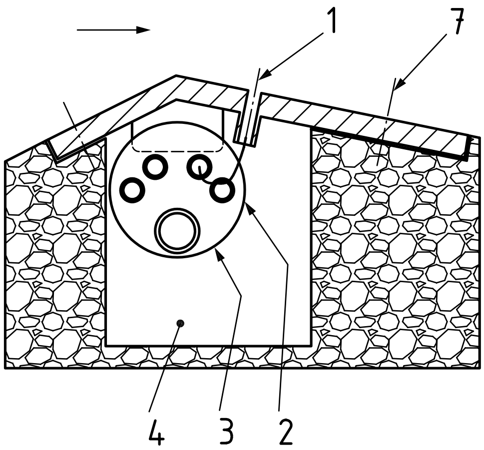
d) A flexible transmission tube shall communicate static head within the manifold to the gauge well.

e) A watertight seal around the transmission tube shall prevent static head within the cavity (which can be different because of leakage around the perimeter of the cover plate) from influencing the static head transmitted from within the manifold.

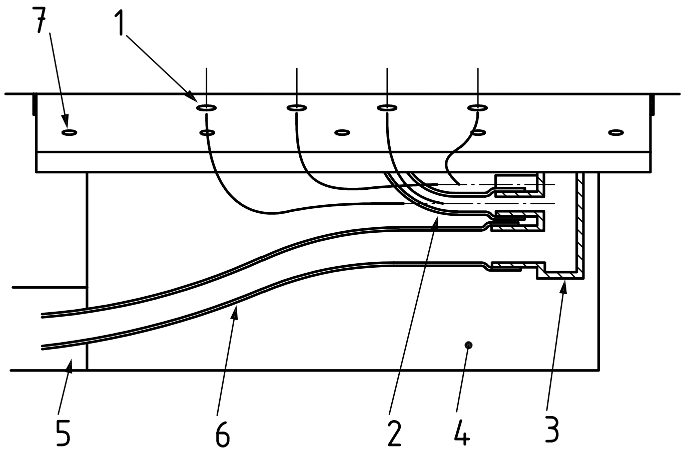
These arrangements minimize the occurrence of silting within the communication path between the separation pocket and the gauge well and allow effective purging of the pipework by the occasional backflushing of the system. For this purpose, a volume of water shall periodically be introduced to the gauge well.

Figure 3 shows the general arrangement for the crest tapping installation.

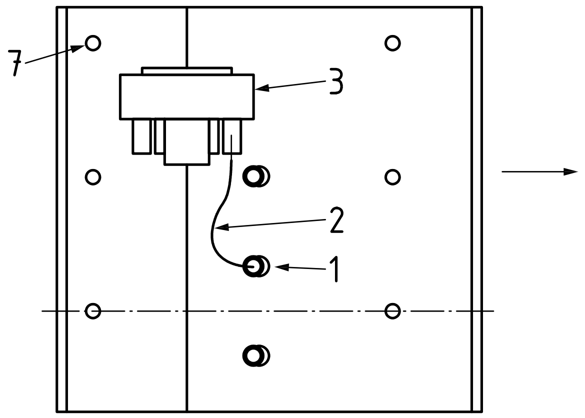
The crest tapping shall consist of five to 10 holes of 10 mm diameter drilled in the weir block with centres 75 mm apart, 20 mm down from the weir crest on the 1:5 slope. The edges of the holes shall not be rounded or burred. The number of holes shall be sufficient to ensure that the water level in the gauge well follows variations in crest separation pocket pressure without significant delay.



a) Side view (in direction of flow)



b) Side view (normal to flow)



c) View of tappings from underneath the weir

Key

1 crest tappings

2 feed tubes communicating crest head to the manifold (some shown as single lines only)

3 manifold [Figure 3 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 — General arrangement for the crest tapping installation

8.4 Zero setting

Accurate initial setting of the zeros of the head measuring devices with reference to the level of the crest, and subsequent regular checking of these settings, is essential.

An accurate means of checking the zero at frequent intervals shall be provided. Benchmarks, in the form of horizontal metal plates, shall be set up on the top of the vertical side walls and in the gauge wells. These shall be accurately levelled to ensure their elevation relative to crest level is known.

NOTE Instrument zeros can be checked relative to these benchmarks without the necessity of resurveying the crest each time. Any settlement of the structure can, however, affect the relationships between crest and benchmark levels and it is advisable to make occasional checks on these relationships.

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.

The crest elevation shall be measured with respect to benchmarks at regular intervals across the breadth of the weir with not less than 10 measurements in total. The mean of these crest elevation measurements shall be used to define the gauge zero.

8.5 Dimensions

To minimize uncertainty in the flow calculation, it is essential that the "as built" and post construction surveyed dimensions of the structure are used to determine discharge.

9 Discharge characteristics

9.1 Formulae of discharge

A spreadsheet (available at: https://standards.iso.org/iso/4360/ed-4/en/) has been developed to accompany this document to facilitate discharge calculations. See Annex C.

9.1.1 Modular (free) flow

In terms of total upstream head, the basic discharge formula for a triangular profile weir operating under modular flow conditions is shown as Formula (1):

$$Q = C_d \sqrt{g} b H_1^{1,5} \tag{1}$$

The total upstream head, H_1, is given by Formula (2):

$$H_1 = h_1 + \frac{\alpha \bar{v}^2}{2g} \tag{2}$$

For straight open channels, the Coriolis coefficient lies in the range 1,03 to 1,10. For practical purposes, a value of 1,05 may be assumed.

The total head formula is solved by iteration. An initial assumption is made that $H_1 = h_1$ and an initial value of Q is computed. The mean velocity of approach, $\bar{v}$, is then computed from values of Q and A, the cross-sectional area of the approach channel. Formula (2) then provides a refined value of H_1. This process is repeated until successive values of H_1 are within the bounds of accuracy required.

Alternatively, the discharge modular flow formula may be expressed in terms of gauged head by introducing a coefficient of velocity dependent upon the weir and flow geometries, as shown in Formula (3):

$$Q = C_d C_v \sqrt{g} h_1^{1,5} \tag{3}$$

where C_v is the coefficient allowing for the effect of approach velocity $(H_1 / h_1)^{1,5}$ (non-dimensional) and is determined as described in 9.2.2.

9.1.2 Non-modular flow

In terms of total head, the basic discharge formula for a triangular profile weir operating under non-modular flow conditions is shown as Formula (4):

$$Q = C_{\mathrm{d}} f \sqrt{g} b H_1^{1,5} \tag{4}$$

where f is the non-modular flow reduction factor (non-dimensional).

Alternatively, the non-modular flow discharge formula may be expressed in terms of gauged head by introducing a coefficient of velocity dependent formula the weir and flow geometries, as shown in Formula (5):

$$Q = C_{\mathrm{d}} C_{\mathrm{v}} f \sqrt{g} b h_1^{1,5} \tag{5}$$

9.2 Coefficients

9.2.1 Coefficient of discharge, C_{d}

C_{d} is almost independent of h_1, except at very low heads (h_1 < 0,1 m) when surface tension effects become important. C_{d} is given Formula (6):

$$C_{\mathrm{d}} = 0,633 \left(1 - \frac{0,000\,3}{h_1} \right)^{1,5} \tag{6}$$

where h is expressed in metres. For practical purposes, C_{d} can be set equal to 0,633 for $h_1 \geq 0,1$ m for manual calculations. The spreadsheet solution provided with this document uses Formula (6) for the full range of h_1 values.

9.2.2 Coefficient of velocity for modular flow, C_{v}

The coefficient of velocity, C_{v}, for the modular flow formula is obtained from Figure 4 where A is the area of the approach channel.

9.2.3 Non-modular flow reduction factor, f, with crest tappings

The non-modular flow reduction factor f when using crest tappings is determined from Formula (7) with a tolerance of ± 1 %.

NOTE Under modular flow conditions, the value of h_{p}/H_1 is constant at 0,20 and the value of f is 1,00.

$$f = 1,04 \left[0,945 - \left(\frac{h_{\mathrm{p}}}{H_1} \right)^{1,5} \right]^{0,256} \tag{7}$$

9.2.4 Non-modular flow reduction factor, f, with tailwater recorder

The non-modular flow reduction factor f when using a tailwater recorder is determined from Formula (8) or Formula (9) depending on the ratio H_2/H_1.

$$f = 1,035 \left[0,817 - \left(\frac{H_2}{H_1} \right)^{4} \right]^{0,0647} \qquad \text{if } 0,75 < H_2/H_1 \leq 0,93 \tag{8}$$

$$f = 8,686 - 8,403 \frac{H_2}{H_1} \qquad \text{if } 0,93 < H_2/H_1 \leq 0,98 \tag{9}$$

9.3 Limitations

The following general limitations are recommended:

— $h_1 \geq 0{,}03$ m (for a crest section of smooth metal or equivalent);

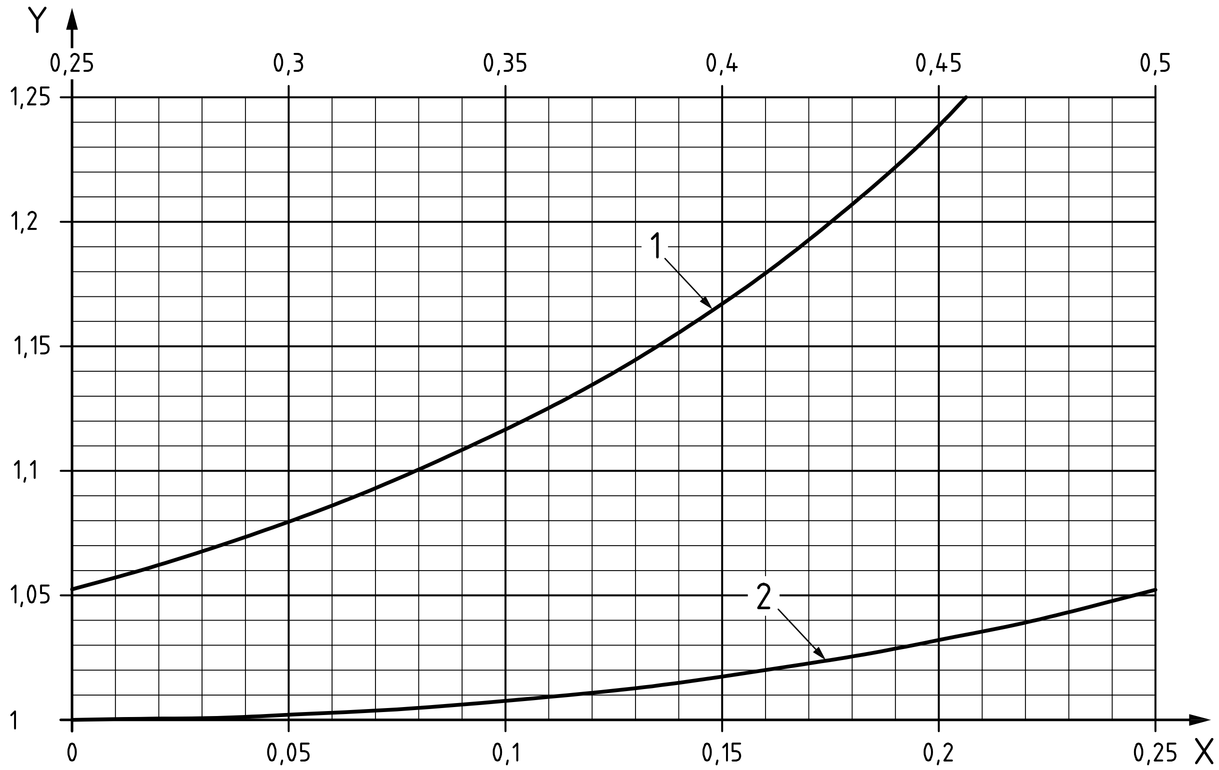
— $h_1 \geq 0{,}06$ m (for a crest section of fine concrete or equivalent);

— $P \geq 0{,}06$ m;

— $b \geq 0{,}1$ m;

— $h_1/P \leq 4{,}5$;

— $b/\ h_1 \geq 2{,}0$.



Key

Y C_v

X $C_d b h_1$

1 $C_d b h_1/A \geq 0{,}25$

2 $C_d b h_1/A \leq 0{,}25$

Figure 4 — Coefficient of velocity, C_v, in terms of $C_d \dfrac{bh_1}{A}$

10 Uncertainties of flow measurement

10.1 General

The spreadsheet (see Annex C) for use with this document incorporates uncertainty calculations.

10.1.1 This clause provides information to state the uncertainty of a measurement of discharge.

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

ISO/IEC Guide 98-3 (referred to hereafter as the GUM)[5] and ISO/TS 25377 (referred to hereafter as the HUG)[6] operate using standard uncertainties (i.e. at the 68 % confidence level). However, the HUG requires final resultant uncertainty of measurement to be expressed at the 95 % confidence level. Some components of uncertainty are expressed at the 95 % level, i.e. $u_{95}(C_d)$ while others are standard uncertainties, i.e. those derived from Type A and Type B methods (see A.5 and A.6). Before these can be combined, those at the 95 % level shall be converted to the 68 % confidence level by dividing them by the coverage factor, k. Having so combined these components to determine the standard uncertainty, this result is now multiplied by the coverage factor ($k = 2$) to express uncertainty at the 95 % confidence level.

10.1.2 Annex A is an introduction to measurement uncertainty. It provides supporting information based on the GUM and the HUG.

10.1.3 A measurement result comprises:

a) an estimate of the measured value, with

b) a statement of the uncertainty of the measurement.

10.1.4 A statement of the uncertainty of a flow measurement made using a flow measurement structure has four separate components of uncertainty:

a) uncertainty of the measurement of head in the channel;

b) uncertainty of the dimensions of the structure;

c) uncertainty of the discharge coefficient stated in this document from laboratory calibration of the flow structure being considered;

d) uncertainty of channel velocity distribution related to the velocity coefficient, C_v.

This subclause does not accommodate component d). It is assumed that the channel hydraulics are substantially equivalent to those existing in the calibration facility at the time of derivation of component c).

10.1.5 The estimation of measurement uncertainty associated with items a) and b) of 10.1.4 is provided in Annex B.

Values taken from Annex B are used in the example in Clause 11. These values are for illustrative purposes only, they should not be interpreted as norms of performance for the types of equipment listed. In practice, uncertainty estimates should be taken from test certificates for the equipment, preferably obtained from a laboratory conforming to ISO/IEC 17025[7].

10.2 Combining measurement uncertainties

See A.7.

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

The general formula of discharge for modular and for non-modular flow is Formula (4) where $f = 1$ for modular flow conditions.

The effect on the value Q due to small dispersions of C_d, C_v (or $C_v f$), b and h_1 is ΔC_d, ΔC_v, (or $\Delta C_v f$), Δb and Δh_1. These are calculated from Formula (10). Note that the quantities ΔC_v, or $\Delta C_v f$ are assumed to be determined without error from Figure 4. Also, because H_1 is calculated from h_1 and geometry, the uncertainty in H_1 is already accounted for.

$$\Delta Q = \frac{\partial Q}{\partial C_\mathrm{d}} \Delta C_\mathrm{d} + \frac{\partial Q}{\partial b} \Delta b + \frac{\partial Q}{\partial h} \Delta h \qquad (10)$$

The partial derivatives are the sensitivity coefficients of A.7 that relate to the discharge formula. ΔQ is the resultant dispersion of Q. Evaluating the partial differentials and using Formula (3), the relationship can be written as shown in Formula (11):

$$\frac{\Delta Q}{Q} = \frac{\Delta C_\mathrm{d}}{C_\mathrm{d}} + \frac{\Delta b}{b} + 1{,}5 \frac{\Delta h}{h} \qquad (11)$$

Thus, the relative sensitivity coefficients are given by Formulae (12) to (14):

$$\frac{\partial Q}{\partial C_d} = 1 \qquad (12)$$

$$\frac{\partial Q}{\partial b} = 1 \qquad (13)$$

$$\frac{\partial Q}{\partial h} = 1{,}5 \qquad (14)$$

The values $\frac{\Delta Q}{Q}, \frac{\Delta b}{b}, \frac{\Delta C_\mathrm{d}}{C_\mathrm{d}}$ and $\frac{\Delta h}{h}$ are referred to as dimensionless standard uncertainties and are given the notation $u^*(Q)$, $u^*(C_\mathrm{d})$, $u^*(b)$ and $u^*(h_1)$. The uncertainties of b, C_d and h_1 are independent of each other and the covariance is zero, so, probability requires summation in quadrature rather than a simple summation, as shown in Formula (15).

$$u^*(Q) \cong \sqrt{u^*(C_\mathrm{d})^2 + u^*(b)^2 + \left[1{,}5 u^*(h_1)\right]^2} \qquad (15)$$

10.3 Uncertainty of discharge coefficient $u(C_\mathrm{d})$ for the triangular profile weir

The discharge coefficient C_d has been determined from a series of hydraulics tests using a high-resolution calibration facility.

For well-constructed triangular profile weirs which are installed in a channel in which the approach conditions comply with those given in 6.3.3, the relative standard uncertainty of the coefficient of discharge C_d is given in Formula (16).

$$u^*(C_\mathrm{d}) = (5C_\mathrm{v} - 4{,}5)\,\% \qquad (16)$$

10.4 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 A);

b) the determined value of relative standard uncertainty $u^*(C_\mathrm{d})$, $u^*(b)$ and $u^*(h_1)$ including datum uncertainly of $u^*(h_1)$;

c) the relative sensitivity coefficients.

The values for each source are then applied according to Formula (15) 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.

The table may include, where appropriate, the critical thinking behind the subjective allocation of uncertainty to the quantities b 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 Example

11.1 General

In presenting examples, the formulae given in Clause 10 define the relationship between the parameters which determine flow rate.

Uncertainty of the discharge coefficient is a fundamental uncertainty and is defined by Formula (16). To determine the overall uncertainty of flow measurement, practical estimations shall be made of the head measurement uncertainty and the uncertainty of the measurement of physical dimensions.

Annex A provides a consistent framework for evaluating these uncertainties for the commonly used measurement techniques.

One such technique is selected in 11.3 for the example that follows.

11.2 Characteristics — Gauging structure

The example relates to modular flow conditions, therefore:

$f = 1$

A structure has the characteristics shown in Table 1.

Table 1 — Example weir dimensions

Item	Symbol	Value	Units
Approach channel width	B	0,599	m
Weir crest width	b	0,599	m
Height of weir crest above bed	p	0,205	m

11.3 Characteristics — Gauged head instrumentation

An air firing ultrasonic sensor is used to measure the upstream head. A measured head relative to the datum of 105 mm (0,105 m) is recorded.

11.4 Discharge coefficient

The value of the discharge coefficient for head values over 0,100 m, refer to 9.2.1, is C_d = 0,633.

11.5 Discharge calculation

The flow rate is calculated from Formula (3), with a value of C_v derived by iteration or with reference to Figure 4 and with:

$$C_d \frac{bh_1}{A} = 0{,}214$$

where

$$A = B(h_1 + p)$$

From which C_v = 1,039.

Applying these values to Formula (3):

$$Q = 0{,}633 \times 1{,}039 \times \sqrt{9{,}81} \times 0{,}599 \times 0{,}105^{1{,}5}$$

$$Q = 0{,}042 \text{ m}^3/\text{s}$$

11.6 Uncertainty statement

11.6.1 From Formula (16), the value for uncertainty of the discharge coefficient is:

$$u^*(C_d) = (5 \times 1{,}039 - 4{,}5) = 0{,}695 \ \%$$

with a coverage factor at $k = 2$

$$u^*_{95}(C_d) = 1{,}390 \ \%$$

11.6.2 From a survey, the width of the weir crest, b, varies from a minimum of 0,597 m to a maximum of 0,601 mm. Using Formula (A.4), the value of uncertainty of the width of the weir may be written:

$$u(b) = \frac{1}{\sqrt{6}} \cdot \left(\frac{\text{maximum} - \text{minimum}}{2} \right)$$

$$u(b) = \frac{1}{\sqrt{6}} \left(\frac{0{,}601 - 0{,}597}{2} \right)$$

$$u(b) = 0{,}000\,82 \text{ m}$$

or

$$u^*(b) = \frac{0{,}000\,82}{0{,}599} \times 100\%$$

$$u^*(b) = 0{,}14 \ \%$$

11.6.3 The uncertainty of h has two components:

Uncertainty of the datum:

From a survey across the weir crest, the maximum and minimum values for p are established as 0,206 m and 0,204 m respectively.

Assuming a triangular probability distribution, Formula (A.4) gives a standard uncertainty of the datum of:

$$\frac{1}{\sqrt{6}}\left(\frac{h_{0\max}-h_{0\min}}{2}\right)=0{,}000\,41\ \text{m}$$

Uncertainty of the measurement:

In the absence of specific calibration data, the measurement uncertainty is based on the sample data given in Annex B and a value of 2 mm (0,002 m) is assumed.

The uncertainty of h_1 is therefore:

$$u(h_1)=\sqrt{0{,}000\,41^2+0{,}002^2}=0{,}002\,1\ \text{m}$$

$$u^*(h_1)=1{,}94\ \%$$

If the crest is liable to accumulate algal or other growth, the uncertainty value of head measurement shall be increased accordingly.

11.6.4 The combined uncertainty value is determined from Formula (15):

$$u^*(Q)=\sqrt{0{,}695^2+0{,}14^2+(1{,}5\times1{,}94)^2}=3{,}00\ \%$$

or using a coverage factor $k = 2$:

$U^*_c(Q)$ = 5,99 % at the 95 % level of confidence.

11.6.5 The statement of discharge is therefore:

— the flow rate is 0,042 m^3/s;

— with an uncertainty of 5,99 % at the 95 % level of confidence with a coverage factor of $k = 2$.

11.6.6 An uncertainty budget for the example is given in Table 2.

Table 2 — Uncertainty budget for the example

	Type/ Evaluation	u^* Value	Sensitivity coefficients	Comment
$u^*(C_d)$	B/ Normal	0,695 %	1,0	From laboratory tests
$u^*(b)$	B/ Triangular	0,14 %	1,0	From Formula (A.4)
$u^*(h_1)$	Combined	1,94 %	1,5	From 11.6.3
$u^*(Q)$	Combined	3,00 %	—	Using Formula (15)

Annex A
(informative)

Introduction to measurement uncertainty

A.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 information, making it more useful.

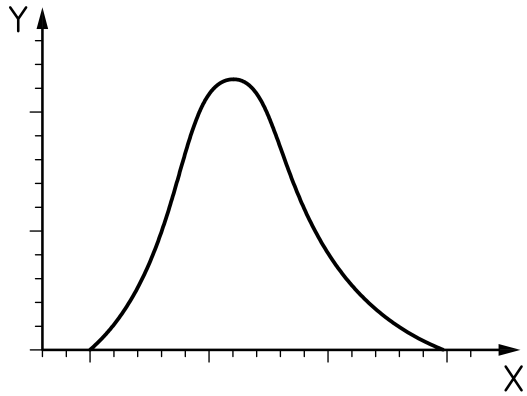
The uncertainty of a measurement represents a dispersion of values that could be attributed to it. Statistical methods provide objective values based on the application of theory.

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 set of measurements.

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



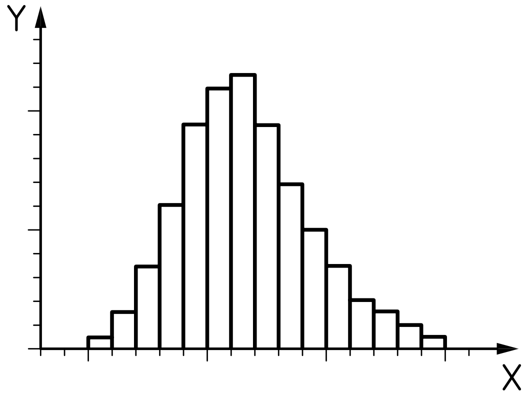
Key

X flow value

Y probability

Figure A.1 — Pictorial representation of some uncertainty parameters

Figure A.2 shows sampled flow measurements, in the form of a histogram.



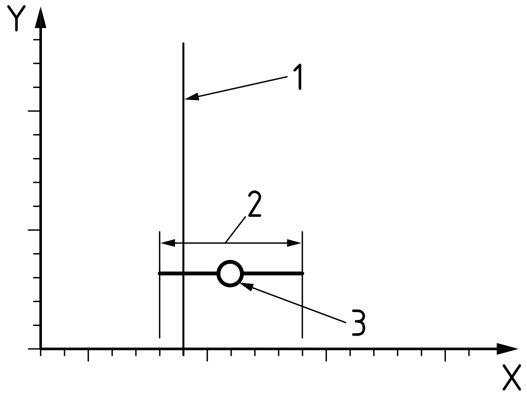
Key

X flow value

Y number of samples

Figure A.2 — Pictorial representation in form of a histogram of discrete values

Figure A.3 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).



Key

1 limit

2 standard deviation

3 mean value

X flow value

Y number of samples

Figure A.3 — Measurements with a limiting value

A.2 Confidence limits and coverage factors

For a normal probability distribution, analysis shows that 68 % of a large set of measurements lie 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 covers a larger portion of the measurements: for example at a 95 % level of confidence. 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 should be selected to model the observed variances. To express the uncertainty of such models at the 95 % confidence level 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.

A.3 Random and systematic error

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

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

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

A difficulty with the concept of systematic error is that systematic error cannot be determined without pre-knowledge of true values. If its existence is known or suspected, then steps should 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.

A.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

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

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

   3) calibration data (from manufacturer).

A.5 Evaluation of Type-A uncertainty

Defined in A.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 given by Formula (A.1):

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

where $\bar{x}$, the "best estimate", is the mean value as determined by Formula (A.2)

$$\bar{x}=\frac{1}{n}(x_1+x_2+.....x_n) \tag{A.2}$$

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 A.1.

If, instead of a single measurement from the set, the uncertainty is to apply to the mean of all n values, then Formula (A.3) should be applied.

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

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

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

Table A.1 — t_e factors at 90 %, 95 % and 99 % confidence levels

Degrees of freedom	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.6 Evaluation of Type-B uncertainty

A.6.1 General

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

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

b) define upper and lowers bounds of the measurement; and then

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

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

Four probability distributions are described in the GUM and in A.6.2 to A.6.5.

A.6.2 Triangular distribution

The triangular distribution is represented in Figure A.4. The standard uncertainty should be calculated according to Formula (A.4).

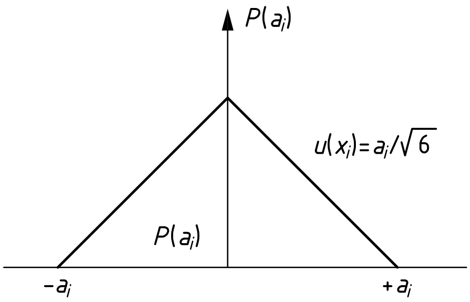


Figure A.4 — Triangular distribution

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

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.

A.6.3 Rectangular distribution

The rectangular distribution is represented in Figure A.5. The standard uncertainty should be calculated according to Formula (A.5).

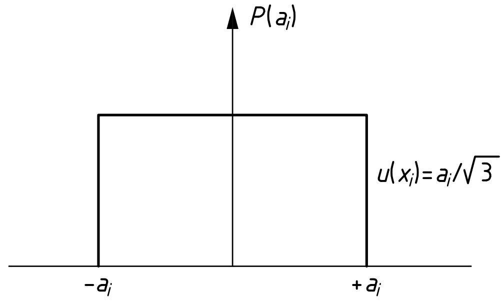


Figure A.5 — Rectangular distribution

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

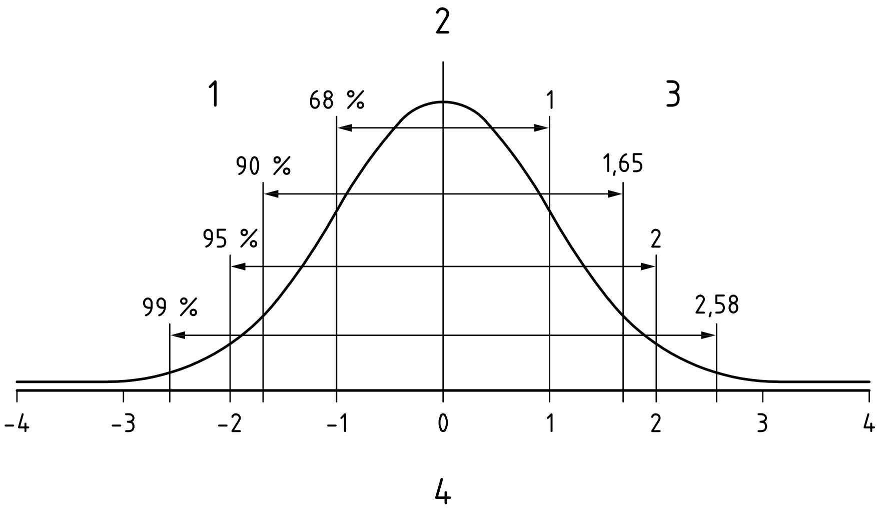
This probability distribution is usually applied to the resolution limit of the measurement instrumentation (i.e. the displayed resolution or the resolution of internal analogue/digital converters).

However, this is not the only source of uncertainty of measurement equipment. There can 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.

A.6.4 Normal probability distribution

The normal probability distribution is represented in Figure A.6. The standard uncertainty should be calculated according to Formula (A.6).



Key

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

Figure A.6 — Normal probability distribution

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

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.

A.6.5 Bimodal probability distribution

The bimodal probability distribution is represented in Figure A.7. The standard uncertainty should be calculated according to Formula (A.7).

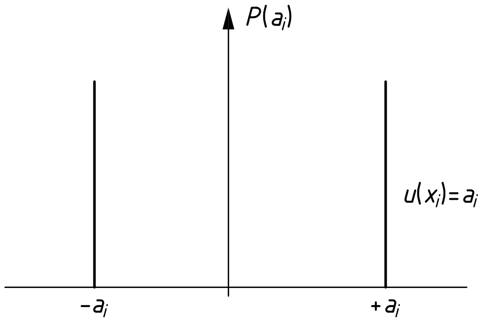


Figure A.7 — Bimodal probability distribution

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

Measurement equipment with hysteresis can only exhibit values at the upper and lowers 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.

A.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 as shown in Formula (A.8).

$$Q=b\times h\times\overline{V} \quad \text{(A.8)}$$

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 $\bar{V}$ are combined to determine the value Q, so each component of uncertainty is 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, as shown in Formula (A.9).

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

where the partial differentials, $\frac{\partial Q}{\partial b}$, $\frac{\partial Q}{\partial h}$ and $\frac{\partial Q}{\partial \bar{V}}$, are sensitivity coefficients. For Formula (A.8), this is equal to Formula (A.10).

$$\frac{\Delta Q}{Q} = \frac{\Delta b}{b} + \frac{\Delta h}{h} + \frac{\Delta \bar{V}}{\bar{V}} \tag{A.10}$$

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

Since the uncertainties of b, V and h are independent of each other, probability considerations require summation in quadrature, as shown in Formula (A.11).

$$u_c^*(Q) \cong \sqrt{u^*(\bar{V})^2 + u^*(b)^2 + u^*(h)^2} \tag{A.11}$$

Annex B
(informative)

Sample measurement performance for use in hydrometric worked examples

Table B.1 — Sample measurement performance for use in hydrometric worked examples

Measurement technologies		Comment	Symbol	Uncertainty options		Installed equipment to have corresponding values certified by the manufacturer									
						Nominal range of measurement					Corresponding standard uncertainty (68 % confidence level)				
Velocity (continuous)				A	B	Minimum	25 %	50 %	75 %	Maximum	Minimum	25 %	50 %	75 %	Maximum
Point velocity	Propeller	Calibration certificate	$u(V)$	YES	Normal	0,005 m/s	1,250 m/s	2,500 m/s	3,750 m/s	5,000 m/s	0,000 5 m/s	0,010 m/s	0,022 m/s	0,030 m/s	0,040 m/s
	Electromagnetic	Calibration certificate	$u(V)$	YES	Normal	0,005 m/s	0,750 m/s	1,500 /s	2,250 m/s	3,000 m/s	0,000 5 m/s	0,010 m/s	0,018 m/s	0,025 m/s	0,025 m/s
Path velocity	Time of flight sonar	Sonic velocity path angle	$u(V)$	YES	Rectangular	0,030 m/s	0,250 m/s	0,500 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
	Gated Doppler sonar	Particle dependent - low velocity resolution	$u(V)$	YES	Rectangular	0,030 m/s	0,250 m/s	0,500 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
	Sonar correlation	Particle dependent	$u(V)$	YES	Rectangular	0,030 m/s	0,250 m/s	0,500 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	EM	To be calibrated in situ	$u(V)$	—	Rectangular	0,030 m/s	0,250 m/s	0,500 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

Table B.1 *(continued)*

Measurement technologies					Installed equipment to have corresponding values certified by the manufacturer										
		Comment	Symbol	Uncertainty options	Nominal range of measurement					Corresponding standard uncertainty (68 % confidence level)					
Water level (continuous)			A	B	Minimum	25 %	50 %	75 %	Maximum	Minimum	25 %	50 %	75 %	Maximum	
Relative datum (to be applied to all methods)		Manual process	$u(E)$	—	Triangular	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	Requires regular maintenance	$u(h_1)$	—	Bimodal	Extension 0,200 m	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
	Sonar	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	Pulse echo ultrasound	Surface wave effects Air temperature compensation	$u(R)$	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 opto/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
Cross-section profile (distance measurement)															
	Natural channels	Sonar or dip gauging / GPRS 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	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

Annex C
(informative)

Spreadsheet for use with this document

C.1 General

A spreadsheet file is provided for use with this document at the following web address: https://standards.iso.org/iso/4360/ed-4/en/.

The spreadsheet replicates the calculation of the discharge and uncertainty as described in Clauses 9 and 10.

The data entry cells do not include error trapping, to prevent inappropriate entries or combinations of entries from being made.

In order to avoid potential instability and other problems that can result in spreadsheets from the use of implicit formulae to handle iterations, all iterations used in the spreadsheets are accomplished by setting out successive iterations in different rows or columns of the worksheets. No macros are used.

C.2 Structure of spreadsheet

The spreadsheet is structured such that data are entered on only one worksheet, whose title tab is “Data entry”. This worksheet also includes the results of calculations of discharge and uncertainty for a single gauged head. The other worksheets contain detailed workings, together with the results of the stage-discharge rating and uncertainty calculations, in both tabular and graphical forms. The worksheets included in the spreadsheet are shown in Table C.1.

Table C.1 — Spreadsheet contents

Worksheet	Contents
Data entry	Input of data for flume geometry Discharge and uncertainty for specific head value under modular and non-modular flows
Modular flow calculation	The stage discharge and uncertainty calculations
Modular flow discharge curve	Graph of the stage discharge curve (40 points)
Modular flow uncertainty curve	Graph of the discharge uncertainty curve
Non-modular with crest tapping	Calculation of discharge and uncertainty for a single discharge point in non-modular flow conditions for input values of h_1 and h_p
Non-modular with tailwater	Calculation of discharge and uncertainty for a single discharge point in non-modular flow conditions for input values of h_1 and h_2

Bibliography

[1] ISO 748, *Hydrometry — Measurement of liquid flow in open channels using current-meters or floats*

[2] ISO 24578, *Hydrometry — Acoustic Doppler profiler — Method and application for measurement of flow in open channels*

[3] ISO/TR 19234, *Hydrometry — Low cost baffle solution to aid fish passage at triangular profile weirs that conform to ISO 4360*

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

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

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

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

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Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110002
Telephones: 2323 0131, 2323 3375, 2323 9402 *Website*: www.bis.gov.in

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