INTERNATIONAL
STANDARD

ISO
9123

Second edition
2017-10

Hydrometry — Stage-fall-discharge relationships

Hydrométrie — Relations hauteur-dénivelé-débit

Reference number
ISO 9123:2017(E)

ISO copyright office
Ch. de Blandonnet 8 • CP 401
CH-1214 Vernier, Geneva, Switzerland
Tel. +41 22 749 01 11
Fax +41 22 749 09 47
copyright@iso.org
www.iso.org

Contents

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 1, *Velocity area methods*.

This second edition cancels and replaces the first edition (ISO 9123:2001), which has been technically revised. The main changes were to improve the text relating to the stage-fall-discharge method and to revise the previous clause on uncertainty in accordance with HUG/GUM and similar related standards on the estimation of uncertainty in flow measurements.

Hydrometry — Stage-fall-discharge relationships

1 Scope

This document specifies methods for determining stage-fall-discharge relationships for a stream reach where variable backwater occurs either intermittently or continuously. Two gauging stations, a base reference gauge and an auxiliary gauge are required for gauge height measurements. A number of discharge measurements are required in order to calibrate the rating to the accuracy required by this document.

The preparation of rating curves is not described in detail in this document.

NOTE For a more detailed description of preparing rating curves, see the methods described in ISO 1100-2.

2 Normative references

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

ISO 772, *Hydrometry — Vocabulary and symbols*

ISO 1100-2, *Hydrometry — Measurement of liquid flow in open channels — Part 2: Determination of the stage-discharge relationship*

3 Terms and definitions

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

Note, however that the application of the definition of backwater given in ISO 772 to the determination of discharge under intermittent or continuous backwater conditions should take into account that a higher gauge height would prevail for a given discharge than would be the case if the variable backwater was not present.

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 and abbreviated terms

4.1 Symbols

Symbol	Meaning	Units
H	measured water level or stage at gauging station	m
$H_{1\mathrm{e}}$	total effective upstream head	m
$H_{2\mathrm{e}}$	total effective downstream head	m
$H_{1\mathrm{max}}$	maximum upstream total head above crest elevation	m
h	measured fall (difference between stage at main gauging station and upstream or downstream secondary gauge)	m
h_c	reference fall or unit fall for constant fall methods	m

Symbol	**Meaning**	**Units**
h^*_r	reference fall or rating fall in limiting fall method	m
h_p	separation pocket head	m
H_o	stage/water level measurement at gauge zero/cease to flow level	m
$H_{u/s}$	upstream stage/water level	m
$H_{d/s}$	downstream stage/water level	m
$H_{u/s}- H_{d/s}$	effective fall	m
N	number of gaugings	non-dimensional
P	number of rating-curve parameters estimated from the N gaugings	non-dimensional
Q	measured discharge	$\mathrm{m^3s^{-1}}$
Q_c	rating-derived discharge for unit and constant fall method	$\mathrm{m^3s^{-1}}$
Q^*_r	rating-derived discharge for limiting fall method	$\mathrm{m^3s^{-1}}$
S^2	estimated variance	
u_H	uncertainty in the stage/water level measurement	m or non-dimensional
$u(h)$	uncertainty in the measured fall	m or non-dimensional
$u(H)$	standard uncertainty in the recorded value of the stage	m
$u(H_0)$	standard uncertainty in the gauge zero	m
$u(H_{u/s})$	uncertainty in the recorded value of the upstream stage	m
$u(H_{d/s})$	uncertainty in the recorded value of the downstream stage	m
$u(H_{u/s}\text{-}H_{d/s})$	uncertainty in the effective fall	m or non-dimensional
$U(Q_e)$	uncertainty in the estimated (computed) discharge	
$u_{HC}(Q)$	uncertainty caused by neglecting all other physical parmeters that affect discharge	
$u_{RC}(Q)$	uncertainty in the stage-fall-discharge relation, mainly related to improper knowledge of hydraulic processes, shape of the assumed function and errors in parameter estimates	
$u(\theta)$	percentage uncertainty due to neglecting all other physical parameters	Non-dimensional
$U\ln(Q_{pr})$	standard uncertainty of prediction	Non-dimensional
α	scale factor that is numerically equal to the discharge when the effective depth of flow/stage $(H - H_0)$ is equal to 1	
β	slope of the rating curve when plotted on logarithm scales	
p	power parameter	
Subscripts		
u/s	denotes the upstream value	
d/s	denotes the downstream value	

4.2 Abbreviations

HUG	Hydrometric uncertainty guidance
GUM	Guide to the expression of uncertainty in measurement
SFD	Stage-fall-discharge

5 General considerations

5.1 Importance of backwater

Most programmes for collecting records of discharge of streams are based on the fact that a relatively simple relationship exists between gauge height and discharge so that, by simply recording gauge height and developing the stage-discharge relationship, a continuous record of discharge can be computed. Several factors, however, can cause scatter of discharge measurements about the stage-discharge relationship at some stations. Backwater is one of these factors and is defined as a condition whereby the flow is retarded so that a higher gauge height is necessary to maintain a given discharge than would be necessary if the backwater were not present. Backwater is caused by constriction such as narrow reaches of a stream channel or downstream structures such as dams/bridges, downstream tributaries or tidal reach of a stream. All these factors can increase or decrease the energy gradient for a given discharge and cause variable backwater conditions. For example, in tidal streams the energy gradient during flood tides is less than the energy gradient during ebb tides.

5.2 Backwater conditions

Constant backwater, as caused by section controls for instance, will not adversely affect the stage-discharge relationship. The presence of variable backwater, on the other hand, does not allow the use of simple stage-discharge relationships for accurate determination of discharge. Regulated streams may have variable backwater virtually all of the time, while other streams will have only occasional backwater from downstream tributaries, vegetal growth, from the return of overbank flow or backwater from the sea.

Actually, the method is valid for steady, gradually varied flows. Large errors occur when the flow is unsteady, and/or it is rapidly varied. Then, the computed fall between the two gauges can be hydraulically meaningless. In such situations, other techniques including water volume balances might be used, not the stage-fall-discharge method. Further, this methodology appears to assume a constant linear relationship in terms of hydraulic gradient between the auxiliary and reference sites. It is possible for this relationship to be compromised by, for example, variable weed growth between the sites. Hence, the flow gaugings at these sites should be taken simultaneously or at least during conditions when the flow is the same at both sites.

5.3 Gauging requirements

Many of the backwater affected sites can be operated as stage-fall-discharge stations by using a base gauge at which gauge height is measured continuously and current-meter measurements of discharge are made occasionally. An auxiliary gauge some distance away from the base gauge, preferably downstream, is operated to measure gauge height continuously.

The auxiliary gauge should be located downstream of the base gauge because

a) it is preferable to set up the main station as far away as possible from the variable backwater cause and

b) when the upstream gauge becomes free from variable backwater (i.e. free-flowing conditions), the measured fall is not representative of the slope of the flow around each gauge and the downstream gauge is still impounded: then the upstream gauge can be rated using a stage-discharge curve, not the downstream one. There is generally no advantage in choosing the downstream gauge as the base gauge.

When the two gauges are set to the same datum, the difference between the two gauge height records is the water-surface fall and provides a measure of water-surface slope. Inflow between these gauges should be minimal. The locations of the base and auxiliary gauge are based on the characteristics of the slope reach. The length of the reach should be such that ordinary errors that occur in the determinations of the gauge heights at gauge stations will cause no more than minor error in computing the fall in the reach. Reliable discharge records can usually be computed when fall exceeds about 0,15 m. Precise time synchronization between the base and auxiliary gauges is very important when gauge height changes rapidly, or when fall is small. Timing and gauge-height errors that are trivial at high discharges become significant at very low flow[16].

It is also essential that the two gauges are levelled accurately to the same datum to minimize the errors not only in the individual stage readings but also the corresponding estimated fall. Therefore, the gauges shall be set to the same zero based on accurate survey techniques.

Channel slope in the reach should be as uniform as possible. The shorter the slope reach, the closer the relationship between measured fall and water-surface slope. On the other hand, the longer the slope reach, the smaller the percentage of error in the recorded fall. The reach should be as far upstream from the source of backwater as is practicable, and inflow between the two gauges should be negligible. If possible, reaches with frequent or appreciable overbank flow should be avoided, as should reaches with sharp bends or unstable channel conditions.

Rarely a slope reach will be found that has all of the above attributes, but these attributes should be considered in making a selection from the reaches that are available for slope measurement.

5.4 Types of stage-fall-discharge relationships

5.4.1 Under conditions of variable backwater, the fall as measured between the base gauge and the auxiliary gauge is used as a third parameter, and the rating becomes a stage-fall-discharge relationship. Stage-fall-discharge methods fall into the following two broad categories:

a) constant-fall method, of which the unit-fall method is a special case;

b) variable-fall method.

The applicable method for a stream reach depends to a large degree on whether the backwater is intermittent or always present.

5.4.2 The constant-fall method works best when backwater is always present at all gauge heights, but can sometimes be adapted to intermittent backwater conditions.

5.4.3 The unit-fall method is the simplest and requires the least amount of data for calibration. The unit-fall method should be used as a starting point before attempting more complex methods.

5.4.4 Variable-fall methods are the most complex and require the most data for calibration. The variable-fall method works best for the intermittent backwater condition.

NOTE The unit-fall method, the constant-fall method and the variable-fall method are also referred to in this document as the unit-fall rating, the constant-fall rating and the variable-fall rating.

6 Unit-fall method

6.1 General

The unit-fall method is a special case of the constant-fall method, where the constant fall is unity (1 m). The unit-fall method is used with the assumption that the relationship between the discharge ratio (Q/Q_c) and the fall ratio (h/h_c) is exactly a square root relationship, as given by the following formulae:

$$Q/Q_c = \left(h/h_c\right)^{0{,}5} = \left(h/1\right)^{0{,}5} = h^{0{,}5} \quad (1)$$

$$Q = Q_c h^{0{,}5} \ \text{ or } \ Q_c = Q/h^{0{,}5} \quad (2)$$

where

Q is the measured discharge, expressed in cubic metres per second;

h is the measured fall, expressed in metres;

Q_c is the discharge, expressed in cubic metres per second, from the rating curve corresponding to the constant fall and the base gauge height;

h_c is the constant fall, expressed in metres (1 m for the unit-fall method).

Note that the value 0,5 of the (h/h_c) exponent is justified by a channel control as modelled by the Chézy equation or the Manning-Strickler equation.

6.2 Method of analysis

The unit-fall rating shall be developed by plotting each measured discharge divided by the square root of the measured fall against the base gauge height for the discharge measurement. The rating curve shall then be fitted to these plotted points.

6.3 Computation of discharge

The rating shall be used to compute discharge by determining the value of Q_c from the rating for a given base gauge height, and multiplying this discharge by the square root of the measured fall. This type of rating will usually be satisfactory when backwater is always present, fall is greater than about 0,15 m, and the datum of the two gauges are within about 0,01 m.

If backwater is intermittent, it is also necessary to develop a free-fall rating or rating where backwater is not present. Gaugings not affected by backwater will normally be those that tend to plot to the right of the stage-discharge plot. If the stage-discharge points are plotted, an outer envelope stage-discharge curve can be derived which should hopefully reflect the gaugings which are backwater-free. Figure 4 may help illustrate this point.

The free-fall rating shall be used at all times except during periods when backwater is suspected, during which times discharge should be computed from both the free-fall and unit-fall ratings. The lower of the two discharges shall be considered to be the true value.

6.4 Example of unit-fall method

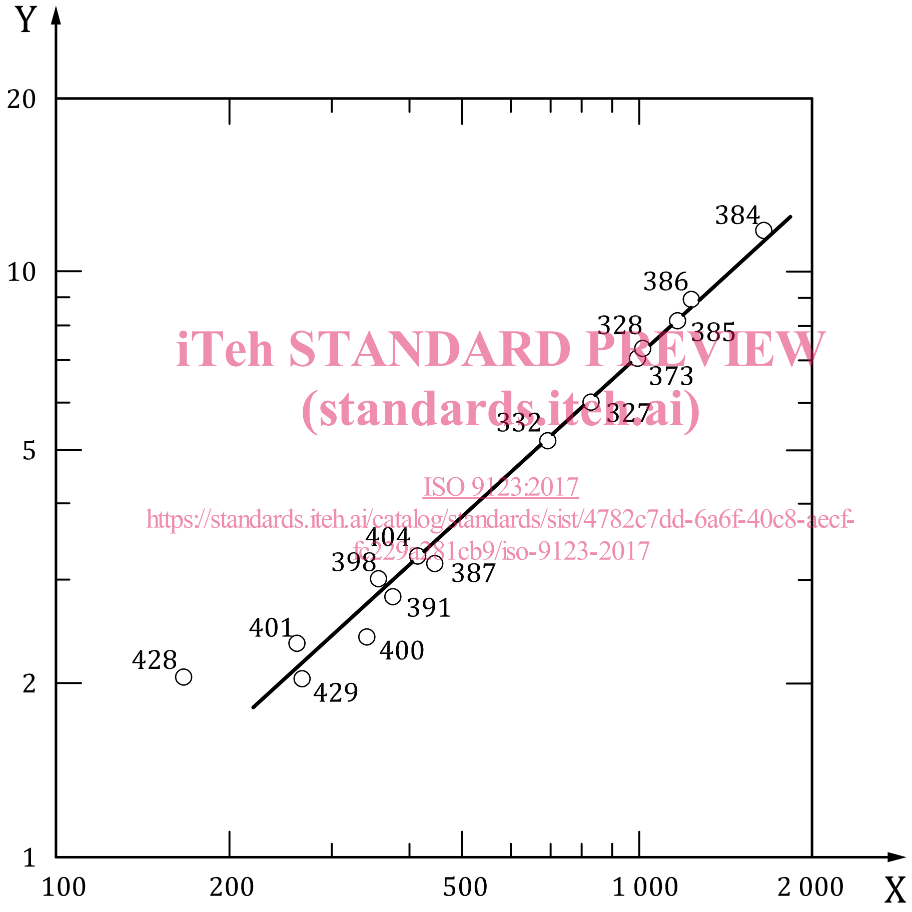
Figure 1 and Table 1 illustrate the unit-fall rating for a site with high backwater from a power dam. The backwater exists at all gauge heights and at all times.

Table 1 — Unit-fall calibration measurements

Measurement no.	Gauge height m	h m	Q m^3/s	$Q\sqrt{h}$	Q_c m^3/s	Difference %
327	5,907	1,917	1 160	838	840	−0,2
328	7,105	2,182	1 520	1 030	1 030	0
332	5,026	1,597	889	703	700	0,4
373	7,013	2,225	1 490	1 000	1 000	0
384	11,558	2,880	2 830	1 670	1 700	−1,8
385	8,108	1,920	1 640	1 180	1 190	−0,8
386	8,638	2,652	1 990	1 220	1 260	−3,3
387	3,139	0,808	399	444	410	7,7

Table 1 *(continued)*

Measurement **no.**	**Gauge height** m	h m	Q m^3/s	$Q\sqrt{h}$	Q_c m^3/s	**Difference** %
391	2,755	0,701	317	379	360	5,0
398	2,963	0,616	289	368	388	−5,4
400	2,359	0,204	156	345	300	13,0
401	2,286	0,290	145	269	290	−7,8
404	3,206	0,927	411	427	426	0,2
428	2,036	0,058	39,9	166	255	−53,6
429	2,012	0,061	66,0	267	250	6,4



Key

X discharge, Q_c, in m^3/s

Y gauge height, in m

NOTE 1 Fall, h_c = 1 m.

NOTE 2 The numbers on the plot refer to the measurement number (see Table 1).

Figure 1 — Unit-fall rating