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Hydrometry — Measurement of liquid flow in open channels —

Part 2:
Determination of the stage-discharge relationship

Hydrométrie — Mesurage du débit des liquides dans les canaux découverts —

Partie 2: Détermination de la relation hauteur-débit

Reference number
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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.

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 1100-2 was prepared by Technical Committee ISO/TC 113, *Hydrometry*, Subcommittee SC 1, *Velocity area methods*.

This third edition cancels and replaces the second edition (ISO 1100-2:1998). Most of the clauses have been updated and technically revised. Major revisions have been made to Clause 5, including a new figure of a stage-discharge relationship and shift curves. Clause 7 has been revised to be consistent with new standards on uncertainty.

It also incorporates the Technical Corrigendum ISO 1100-2:1998/Cor.1:2000.

ISO 1100 consists of the following parts, under the general title *Hydrometry — Measurement of liquid flow in open channels*:

— *Part 1: Establishment and operation of a gauging station*

— *Part 2: Determination of the stage-discharge relationship*

Hydrometry — Measurement of liquid flow in open channels —

Part 2: Determination of the stage-discharge relationship

1 Scope

This part of ISO 1100 specifies methods of determining the stage-discharge relationship for a gauging station. A sufficient number of discharge measurements, complete with corresponding stage measurements, are required to define a stage-discharge relationship to the accuracy required by this part of ISO 1100.

Stable and unstable channels are considered, including brief descriptions of the effects on the stage-discharge relationship of shifting controls, variable backwater and hysteresis. Methods of determining discharge for twin-gauge stations, ultrasonic velocity-measurement stations, electromagnetic velocity-measurement stations and other complex rating curves are not described in detail. These types of rating curve are described separately in other International Standards, Technical Specifications and Technical Reports, which are listed in Clause 2 and the Bibliography.

2 Normative references

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

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

ISO 772, *Hydrometry — Vocabulary and symbols*

ISO 5168, *Measurement of fluid flow — Procedures for the evaluation of uncertainties*

ISO 9123, *Measurement of liquid flow in open channels — Stage-fall-discharge relationships*

ISO 15769, *Hydrometry — Guidelines for the application of acoustic velocity meters using the Doppler and echo correlation methods*

ISO/TS 24154, *Hydrometry — Measuring river velocity and discharge with acoustic Doppler profilers*

3 Symbols

For the purposes of this document, the symbols given in ISO 772 and the following apply:

A cross-sectional area

B cross-sectional width

β power-law exponent (slope on logarithmic plot) of the rating curve

C_D coefficient of discharge

C Chezy's channel roughness coefficient

e effective gauge height of zero flow

h gauge height of the water surface

$(h - e)$ effective depth

H total head (hydraulic head)

n Manning's channel roughness coefficient

N number of stage-discharge measurements (gaugings) used to define the rating curve

p number of rating-curve parameters (Q_1, β, e) estimated from the N gaugings

P_w wetted perimeter

Q total discharge

Q_o steady-state discharge

Q_1 power-law scale factor of rating curve, equal to discharge when effective depth of flow $(h - e)$ is equal to 1

r_h hydraulic radius, equal to the effective cross-sectional area divided by the wetted perimeter, A/P_w

S standard error of estimate

S_f friction slope

S_o water surface slope corresponding to steady discharge

t time

u standard uncertainty

U expanded uncertainty

V_w velocity of a flood wave

4 Principle of the stage-discharge relationship

4.1 General

The stage-discharge relationship is the relationship at a gauging station between stage and discharge and is sometimes referred to as a rating curve or rating. The principles of the establishment and operation of a gauging station are described in ISO 1100-1.

4.2 Controls

4.2.1 General

The stage-discharge relationship for open-channel flow at a gauging station is governed by channel conditions at and downstream from the gauge, referred to as a control. Two types of control can exist, depending on channel and flow conditions. Low flows are usually controlled by a section control, whereas high flows are usually controlled by a channel control. Medium flows can be controlled by either type of control. At some stages, a combination of section and channel control might occur. These are general rules, and exceptions can and do occur. Knowledge of the channel features that control the stage-discharge relationship is important. The development of stage-discharge curves where more than one control is effective, where control features change and where the number of measurements is limited requires judgement in interpolating between measurements and in extrapolating beyond the highest or lowest measurements. This is particularly true where the controls are not permanent and tend to shift from time to time, resulting in changes in the positioning of segments of the stage-discharge relationship.

4.2.2 Section control

A section control is a specific cross-section of a stream channel, located downstream from a water-level gauge that controls the relationship between gauge height and discharge at the gauge. A section control can be a natural feature, such as a rock ledge, a gravel bar, a severe constriction in the channel or an accumulation of debris. A section control can also be a man-made feature, such as a small dam, a weir, a flume or an overflow spillway. Section controls can often be visually identified in the field by observing a riffle, or pronounced drop in the water surface, as the flow passes over the control. Frequently, as gauge height increases because of higher flows, the section control will become submerged to the extent that it no longer controls the relationship between gauge height and discharge. At this point, the riffle is no longer observable, and flow is then regulated either by another section control further downstream or by the hydraulic geometry and roughness of the channel downstream (i.e. channel control).

4.2.3 Channel control

A channel control consists of a combination of features throughout a reach at and downstream from a gauge. These features include channel size, shape, curvature, slope and roughness. The length of channel reach that controls a stage-discharge relationship varies. The stage-discharge relationship for a relatively steep channel could be controlled by a short channel reach, whereas the relationship for a flat channel could be controlled by a much longer channel reach. Additionally, the length of a channel control will vary depending on the magnitude of flow. Precise definition of the length of a channel-control reach is usually neither possible nor necessary.

4.2.4 Combination controls

At some stages, the stage-discharge relationship can be governed by a combination of section and channel controls. This usually occurs for a short range in stage between section-controlled and channel-controlled segments of the rating curve. This part of the rating curve is commonly referred to as a transition zone of the rating curve and represents the change from section control to channel control. In other instances, a combination control can consist of two section controls, where each has a partial controlling effect. More than two controls acting simultaneously are rare. In any case, combination controls and/or transition zones occur for very limited parts of a stage-discharge relationship and can usually be defined by plotting procedures. Transition zones, in particular, represent changes in the slope or shape of a stage-discharge relationship.

4.3 Governing hydraulic equations

Stage-discharge relationships are hydraulic relationships that can be defined according to the type of control that exists. Section controls, either natural or man-made, are governed by some form of the weir or flume equations. In a very general and basic form, these equations are expressed as:

$$Q = C_{\mathrm{D}} B H^{\beta} \quad (1)$$

where

Q is the discharge, in cubic metres per second;

C_D is a coefficient of discharge and includes several factors;

B is the cross-sectional width, in metres;

H is the hydraulic head, in metres;

β is a power-law exponent, dependent on the cross-sectional shape of the control section.

Stage-discharge relationships for channel controls with uniform flow are governed by the Manning or Chezy equation as it applies to the reach of the controlling channel downstream from a gauge. The Manning equation is:

$$Q = \frac{A r_h^{0,67} S_f^{0,5}}{n} \quad (2)$$

where

A is the cross-sectional area, in square metres;

r_h is the hydraulic radius, in metres;

S_f is the friction slope;

n is the channel roughness.

The Chezy equation is:

$$Q = C A r_h^{0,5} S_f^{0,5} \quad (3)$$

where C is the Chezy form of roughness.

The above equations are generally applicable for steady or quasi-steady flow. For highly unsteady flow, such as tidal or dam-break flow, equations such as the Saint-Venant unsteady-flow equations would be necessary. However, these are seldom used in the development of stage-discharge relationships and are not described in this part of ISO 1100.

4.4 Complexities of stage-discharge relationships

Stage-discharge relationships for stable controls (such as rock outcrops and man-made structures such as weirs, flumes and small dams) present few problems in their calibration provided a suitable maintenance regime can be achieved. However, complexities can arise when controls are not stable and/or when variable backwater occurs. For unstable controls, segments of a stage-discharge relationship can change position occasionally, or even frequently. This is usually a temporary condition which can be accounted for through the use of the shifting-control method.

Variable backwater can affect a stage-discharge relationship both for stable and unstable channels. Sources of backwater can be downstream reservoirs, tributaries, tides, vegetation, ice, dams and other obstructions that influence the flow at the gauging-station control.

A complexity that exists for some streams is hysteresis, which results when the water surface slope changes due to either rapidly rising or rapidly falling water levels in a channel-control reach. Hysteresis is also referred to as loop rating curves and is most pronounced in relatively flat-sloped streams. On rising stages, the water surface slope is significantly steeper than for steady-flow conditions, resulting in greater discharge than indicated by the steady-flow rating curve. The reverse is true for falling stages. See 5.8.3 for details of hysteresis rating curves.

Another complexity exists when rivers are in flood because it is often difficult to define flood-plain storage and to represent such flows in the flood-plain rating-curve section. Complex flow interactions between the main channel and flood plain often result in flow patterns that are difficult to define at the measuring section.

5 Stage-discharge calibration of a gauging station

5.1 General

The primary object of a stage-discharge gauging station is to provide a record of the discharge of the open channel or river at which the water level gauge is sited. This is achieved by measuring the stage and converting this stage to discharge by means of a stage-discharge relationship which correlates discharge and water level. In some instances, other parameters, such as index velocity, water surface fall between two gauges or rate-of-change in stage, can also be used in rating-curve calibrations (see ISO 9123 and ISO 15769). Stage-discharge relationships are usually calibrated by measuring discharge and the corresponding gauge height. Theoretical computations can also be used to aid in the shaping and positioning of the rating curve. Stage-discharge relationships from previous time periods should also be considered as an aid in the shaping of the rating curve.

5.2 Preparation of a stage-discharge relationship

5.2.1 General

The relationship between stage and discharge is defined by plotting measurements of discharge with corresponding observations of stage, taking into account whether the discharge is steady, increasing or decreasing, and also noting the rate of change in stage. This can be done either manually by plotting on paper or automatically using computerized plotting techniques. The plotting scale used could be an arithmetic scale or a logarithmic scale. Each has certain advantages and disadvantages, as explained in 5.2.3 and 5.2.4. It is customary to plot the stage as ordinate and the discharge as abscissa. However, when using the stage-discharge relationship to derive discharge from a measured value of stage, the stage is treated as the independent variable.

5.2.2 List of discharge measurements

The first step prior to plotting stage versus discharge is the preparation of a list of discharge measurements that will be used for the plot. The measurements should be checked to ensure that the recorded stages are related to a common datum and that the discharge calculations are accurate. As a minimum, this list should include 15 or more measurements, all taken during the period of analysis. More measurements would be required if the rating curve is complex because of multiple section and channel controls or if the site experiences an extreme range in stage. These measurements should be well distributed over the range of gauge heights experienced. The list should also include low and high measurements from other times that might be useful in defining the correct shape of the rating curve and/or in extrapolating the rating curve. Extreme low and high measurements should be included wherever possible.

For each discharge measurement in the list, the following items should be included:

a) a unique identification number;

b) the date of measurement;

c) the gauge height for the measurement;

d) the total discharge;

e) the accuracy of measurement, as determined by the hydrographer;

f) the rate of change in stage during the measurement, a plus sign indicating a rising stage and a minus sign indicating a falling stage.

The list of measurements could include other information; however, this is not mandatory. Table 1 shows a typical list of discharge measurements, including a number of items in addition to the mandatory items.

Table 1 — Typical list of discharge measurements made by a hydrographer using current meters and depth soundings

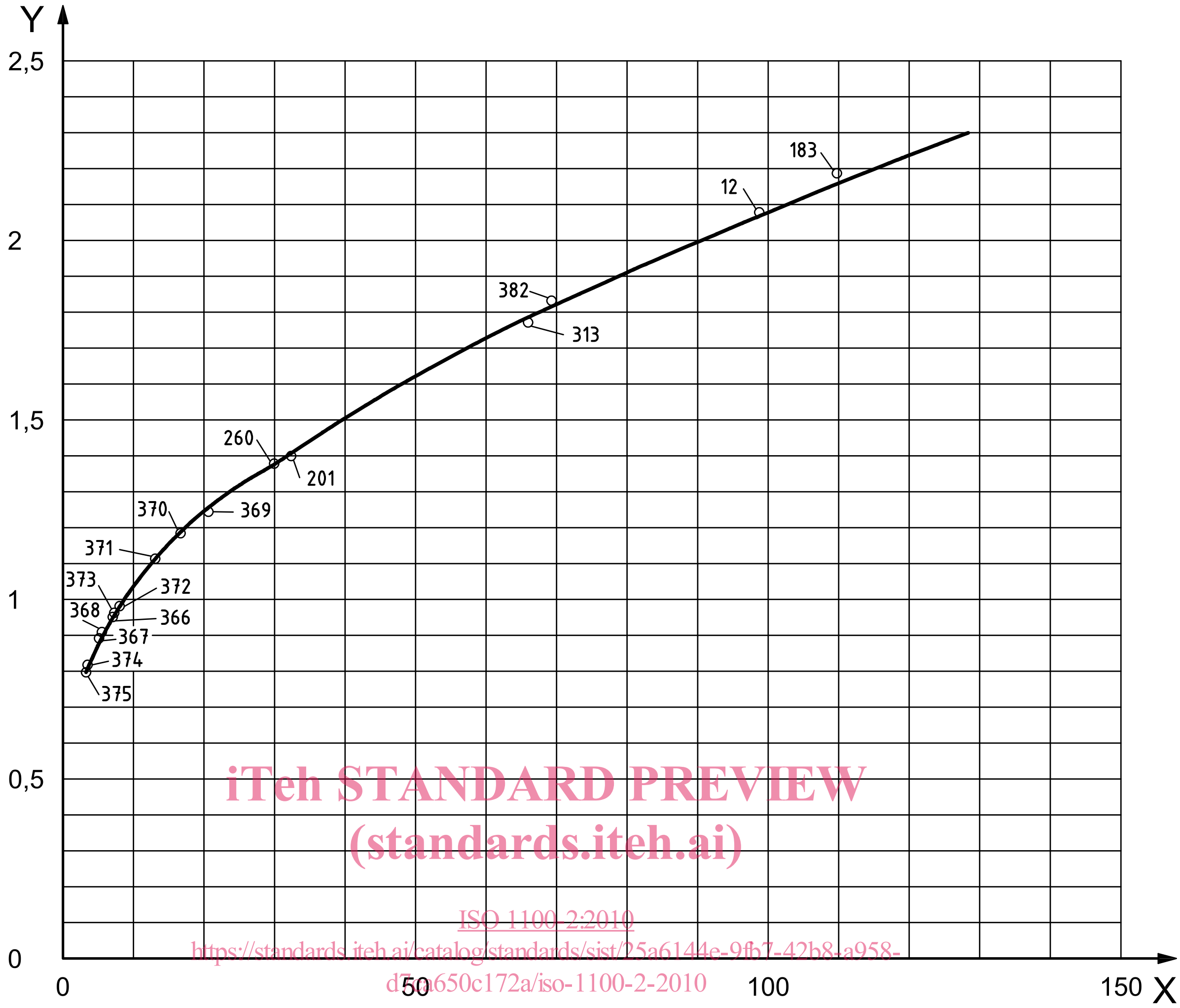
ID number	Date (yy/mm/dd)	Made by	Width m	Area m²	Mean velocity m/s	Gauge height m	Effective depth m	Discharge m³/s	Method	Number of verticals	Gauge height change m/h	Rated
12	38/04/08	MEF	36,27	77,94	1,272	2,682	2,080	99,12	0,2/0,8	22	−0,082	GOOD
183	55/02/06	GTC	33,53	78,41	1,405	2,786	2,186	110,2	0,6/0,2/0,8	22	−0,047	GOOD
201	57/02/04	AJB	28,96	21,92	1,511	2,002	1,402	33,13	0,6/0,2/0,8	21	−0,013	POOR
260	63/03/13	GMP	26,52	21,46	1,400	1,981	1,381	30,02	0,6	22	−0,020	GOOD
313	66/08/24	HFR	30,18	42,08	1,602	2,374	1,774	67,40	0,6/0,2/0,8	22	+0,006	GOOD
366	73/08/21	MAF	28,96	14,86	0,476	1,557	0,957	7,080	0,6	21	0	GOOD
367	73/10/10	MAF	28,96	13,66	0,361	1,490	0,890	4,928	0,6	21	0	GOOD
368	73/11/26	MAF	29,26	14,21	0,373	1,509	0,909	5,296	0,6	18	0	GOOD
369	74/02/19	MAF	29,87	16,26	1,291	1,838	1,238	20,99	0,6	21	0	GOOD
370	74/04/09	MAF	29,26	21,27	0,805	1,780	1,180	17,13	0,6/0,2/0,8	21	0	GOOD
371	74/05/29	MAF	29,57	19,69	0,688	1,710	1,110	13,54	0,6	21	0	GOOD
372	74/07/10	MAF	28,96	16,81	0,458	1,573	0,973	7,703	0,6	21	0	GOOD
373	74/08/22	MAF	29,26	15,79	0,481	1,570	0,970	7,590	0,6	21	0	GOOD
374	74/10/01	MAF	29,26	13,19	0,264	1,414	0,814	3,483	0,6	21	0	GOOD
375	74/11/11	MAJ	28,96	11,71	0,283	1,396	0,796	3,313	0,6	21	0	GOOD
382	75/10/01	MAF	30,48	43,76	1,598	2,432	1,832	69,95	0,2/0,8	21	+0,017	GOOD

NOTE Discharge measurements made with acoustic Doppler current profilers require additional parameters, including the number of transects and the range of discharges measured during the transects (see ISO/TS 24154).

5.2.3 Arithmetic plotting scales

The simplest type of plot uses an arithmetically divided plotting scale, as shown in Figure 1. Scale subdivisions should be chosen to cover the complete range of gauge height and discharge expected to occur at the gauging site. Scales should be subdivided in uniform increments that are easy to read and interpolate. The choice of scale should also produce a rating curve that is not unduly steep or flat. If the range in gauge height or discharge is large, it may be necessary to plot the rating curve in two or more segments to provide scales that are easily read with the necessary precision. This procedure can result in separate curves for low water, medium water and high water.

Graph paper with arithmetic scales is convenient to use and easy to read. Such scales are ideal for displaying a rating curve and have an advantage over logarithmic scales in that zero values of gauge height and/or discharge can be plotted. However, for analytical purposes, arithmetic scales have practically no advantage. A stage-discharge relationship on arithmetic scales is usually a curved line, concave downward, which is difficult to shape correctly if only a few discharge measurements are available. Logarithmic scales, on the other hand, have a number of analytical advantages as described in 5.2.4. Generally, a stage-discharge relationship is first drawn on logarithmic plotting paper for shaping and analytical purposes and then later transferred to arithmetic plotting paper if a display plot is needed.



Key

X discharge, Q, in cubic metres per second

Y effective depth, $(h - e)$, in metres

NOTE The numbers indicated against the plotted observations are the ID numbers given in Table 1.

Figure 1 — Arithmetic plot of stage-discharge relationship

5.2.4 Logarithmic plotting scales

Most stage-discharge relationships, or segments thereof, are best analysed graphically through the use of logarithmic plotting. To utilize this procedure fully, gauge height should be transformed to effective depth of flow on the control by subtracting from it the effective gauge height of zero discharge. A rating-curve segment for a given control will then tend to plot as a straight line with an equation form as described in 5.2.5.3. The slope of the straight line will conform to the type of control (section or channel), thereby providing valuable information for correctly shaping the rating-curve segment. Additionally, this feature allows the analyst to calibrate the stage-discharge relationship with fewer discharge measurements. The slope of a rating curve is the ratio of the horizontal distance to the vertical distance. This method of measuring the slope is used since the dependent variable (discharge) is always plotted as the abscissa.

Rating curves for section controls such as weirs or flumes conform to Equation (1) in 4.3 and, when plotted logarithmically, will have a slope of 1,5 or greater, depending on control shape, velocity of approach and minor variations of the coefficient of discharge. Logarithmic rating curves for most weir shapes will plot with a slope of 2 or greater. An exception is the sharp-crested rectangular weir, which plots with a slope slightly greater than 1,5. Logarithmic rating curves for section controls in natural channels will almost always have a slope of 2 or greater.

Rating curves for channel controls are governed by Equation (2) or (3) and, when plotted as effective depth versus discharge, the slope is usually between 1,5 and 2. Variations in the slope of the rating curve when channel control exists are the result of changes in roughness and friction slope as depth changes.

5.2.5 Rating-curve shape

5.2.5.1 General

The details provided in 5.2.2 to 5.2.4 apply to control sections of regular shape (triangular, trapezoidal, parabolic, etc.). When a significant change in shape occurs, such as a trapezoidal section control with a small V-notch for extremely low water, there will be a change in the rating-curve slope at the point where the control shape changes. Likewise, when the control changes from section control to channel control, the logarithmic plot will show a change in slope. These changes are usually defined by short curved segments of the rating curve, referred to as transitions. This information about the plotting characteristics of a rating curve is extremely useful in the calibration and maintenance of the rating curve and in later analysis of shifting control conditions. By knowing the kind of control (section or channel), and the shape of the control, the analyst can define the correct hydraulic shape of the rating curve with greater precision. Additionally, this information allows the analyst to extrapolate accurately a rating curve or, conversely, to know when extrapolation is likely to lead to a large uncertainty.

Figure 2 provides examples of a hypothetical rating curve showing the logarithmic plotting characteristics for channel and section controls and for cross-section shape changes. Figure 2 a) shows a trapezoidal channel with no flood plain and with channel-control conditions. The corresponding logarithmic plot of the rating curve, when plotted with an effective gauge height of zero flow, e, that results in a straight-line rating curve, has a slope less than 2. In Figure 2 b), flood plain has been added, which is also a channel control. There is a change in the shape of the control cross-section which results in a change in the shape of the rating curve above the bankfull stage. If the upper segment (above the transition curve) is re-plotted to the correct value of effective gauge height of zero flow, it would also have a slope less than 2. In Figure 2 c), a section control for low flow has been added. This results in a change in rating-curve shape because of the change in control. For the low-water part of the rating curve, the slope will usually be greater than 2.

Figure 3 is a logarithmic plot of an actual rating curve, using the measurements shown in Table 1. This rating curve is for a stream where section control exists throughout the range of flow, including the high-flow measurements. The effective gauge height of zero flow, e, for this stream is 0,6 m, which is subtracted from the gauge height of the measurements to define the effective depth of flow at the control. The slope of the rating curve below 1,4 m is about 4,3, which is greater than 2 and conforms to a section control. Above 1,5 m, the slope is 2,8, which also conforms to a section control. The change in slope of the rating curve above about 1,5 m is caused by a change in the shape of the control cross-section. Below about 1,4 m, the control section is essentially triangular in shape. In the range 1,4 m to 1,5 m, the control shape changes to trapezoidal, resulting in the transition curve in the rating curve. And above about 1,5 m, the control cross-section is basically trapezoidal.

The examples shown in Figures 2 and 3 are intended to illustrate some of the principles of logarithmic plotting. The analyst should use these principles to the greatest extent possible, but should always be aware that there are probably exceptions and differences that occur at some sites.

