INTERNATIONAL STANDARD

ISO 1100-2

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Measurement of liquid flow in open channels —

Part 2:
Determination of the stage-discharge relation

Mesurage de débit des liquides dans les canaux découverts —
Partie 2: Détermination de la relation hauteur-débit

Reference number
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Contents

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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.

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.

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

This second edition cancels and replaces the first edition (ISO 1100-2:1982), which has been technically revised.

Annexes A and B of this part of ISO 1100 are for information only.

Measurement of liquid flow in open channels —

Part 2:
Determination of the stage-discharge relation

1 Scope

This part of ISO 1100 specifies methods of determining the stage-discharge relation for a gauging station. A sufficient number of discharge measurements, complete with corresponding stage measurements, is required to define a stage-discharge relation 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 relation of ice and hysteresis. Methods for determining discharge for twin-gauge stations, ultrasonic velocity stations, electromagnetic velocity stations, and other complex ratings are not described in detail. These types of rating are described in other International Standards and Technical Reports, namely ISO/TR 9123, ISO 6416 and ISO 9213, as shown in clause 2.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 1100. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO 1100 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 31:1992 (all parts), *Quantities, units and symbols*.

ISO 772:1996, *Hydrometric determinations — Vocabulary and symbols*.

ISO 1000:1992, *SI units and recommendations for the use of their multiples and of certain other units*.

ISO/TR 5168: –[1)], *Measurement of fluid flow — Evaluation of uncertainties*.

ISO 6416:1992, *Liquid flow measurement in open channels — Measurement of discharge by the ultrasonic (acoustic) method.*

ISO/TR 9123:1986, *Liquid flow measurement in open channels — Stage-fall-discharge relations*.

ISO 9196:1992, *Liquid flow measurement in open channels — Flow measurements under ice conditions*.

ISO 9213:1992, *Measurement of total discharge in open channels — Electromagnetic method using a full-channel-width coil.*

[1)] To be published. (Revision of ISO 5168:1978)

3 Definitions and symbols

For the purpose of this part of ISO 1100, the definitions and symbols given in ISO 772 apply. Those that are not covered by ISO 772 are given in the text of this part of ISO 1100. The symbols used in this part of ISO 1100 are given below:

A cross-sectional area,

C_D a coefficient of discharge,

C Chezy's channel rugosity coefficient,

h gauge height of the water surface,

β slope of the rating curve,

Q total discharge,

Q_o steady-state discharge,

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

S_f friction slope,

S_o water surface slope corresponding to steady discharge,

v_w velocity of a flood wave,

B cross-section width,

e effective gauge height of zero flow,

H total head (hydraulic head),

n is Manning's channel rugosity coefficient,

p is a constant that is numerically equal to the discharge when the effective depth of flow ($h - e$) is equal to 1,

t is time.

4 Units of measurement

The International System of Units (SI Units) is used in this part of ISO 1100 in accordance with ISO 31 and ISO 1000.

5 Principle of the stage-discharge relation

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

5.1 Controls

5.1.1 General

The stage-discharge relation for open-channel flow at a gauging station is governed by channel conditions 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 may be controlled by either type of control. At some stages, a combination of section and channel control may occur. These are general rules and exceptions can and do occur. Knowledge of the channel features that control the stage-discharge relation 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, usually 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 relation.
Controls and their governing equations are described in the following clauses.

5.1.2 Section control

A section control is a specific cross-section of a stream channel, located downstream from a water-level gauge, that controls the relation between gauge height and discharge at the gauge. A section control can be a natural feature such as a rock ledge, a sand bar, a severe constriction in the channel, or an accumulation of debris. Likewise, a section control can be a manmade feature such as a small dam, a weir, a flume, or an overflow spillway. Section controls can frequently 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 relation 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).

5.1.3 Channel control

A channel control consists of a combination of features throughout a reach downstream from a gauge. These features include channel size, shape, curvature, slope, and rugosity. The length of channel reach that controls a stage-discharge relation varies. The stage-discharge relation for relatively steep channels may be controlled by a relatively short channel reach, whereas, the relation for a relatively flat channel may be controlled by a much longer channel reach. In addition, 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.

5.1.4 Combination controls

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

5.2 Governing hydraulic equations

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

$$Q = C_D B H^{1,5} \quad (1)$$

where

Q is discharge, in cubic metres per second (m^3/s),

C_D is a coefficient of discharge and may include several factors,

B is cross-section width, in metres (m), and

H is hydraulic head, in metres.

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

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

where

A is cross-section area, in square metres,

r_h is hydraulic radius, in metres,

S_f is friction slope, and

n is channel rugosity.

The Chezy equation is:

$$Q = C\, A\, r_h^{0,50}\, S_f^{\,0,50} \qquad (3)$$

where C is the Chezy form of rugosity.

The above equations are generally applicable for gradually varied, uniform flow. For highly varied, nonuniform flow, equations such as the Saint-Venant unsteady flow equations would be appropriate. However, these are seldom used in the development of stage-discharge relations, and are not described in this part of ISO 1100.

5.3 Complexities of stage-discharge relations

Stage-discharge relations for stable controls such as a rock outcrop, and manmade structures such as weirs, flumes, and small dams usually present few problems in their calibration and maintenance. However, complexities can arise when controls are not stable and/or when variable backwater occurs. For unstable controls, segments of a stage-discharge relation may 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 relation, both for stable and unstable channels. Sources of backwater can be downstream reservoirs, tributaries, tides, ice, dams and other obstructions that influence the flow at the gauging station control.

Another 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 sometimes referred to as loop ratings, 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. The reverse is true for falling stages. See 6.8.4 for details on hysteresis ratings.

The succeeding clauses of this part of ISO 1100 will describe in more detail some of the techniques available for analyzing the various complexities that may arise.

6 Stage-discharge calibration of a gauging station

6.1 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 lever gauge is sited. This is achieved by measuring the stage and converting this stage to discharge by means of a stage-discharge relation, 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 may also be used in rating calibrations. Stage-discharge relations are usually calibrated by measuring discharge and the corresponding gauge height. Theoretical computations may also be used to aid in the shaping and positioning of the rating curve. Stage-discharge relations from previous time periods should also be considered as an aid in the shaping of the rating.

6.2 General preparation of a stage-discharge relation

6.2.1 General

The relation 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 may be done manually by plotting on paper, or by using computerized plotting techniques. A choice of two types of plotting scale is available, either an arithmetic scale or a logarithmic scale. Each has certain advantages and disadvantages, as explained in subsequent clauses. It is customary to plot the stage as ordinate and the discharge as abscissa, although when using the stage-discharge relation to derive discharge from a measured value of stage, the stage is treated as the independent variable.

6.2.2 List of discharge measurements

The first step before making a plot of stage versus discharge is to prepare a list of discharge measurements that will be used for the plot. At a minimum this list should include at least 12 to 15 measurements, all made during the period of analysis. These measurements should be well distributed over the range in gauge heights experienced. It should also include low and high measurements from other times that might be useful in defining the correct shape of the rating and/or for extrapolating the rating. Extreme low and high measurements should be included wherever possible.

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

a) Unique identification number

b) Date of measurement

c) Gauge height of measurement

d) Total discharge

e) Accuracy of measurement

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

Other information might be included in the list of measurements, but is not mandatory. Table 1 shows a typical list of discharge measurements, including a number of items in addition to the mandatory items. The discharge measurement list may be handwritten for use when hand-plotting is done, or the data may be a computer list where a computerized plot is developed.

Table 1 — Typical list of discharge measurements

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

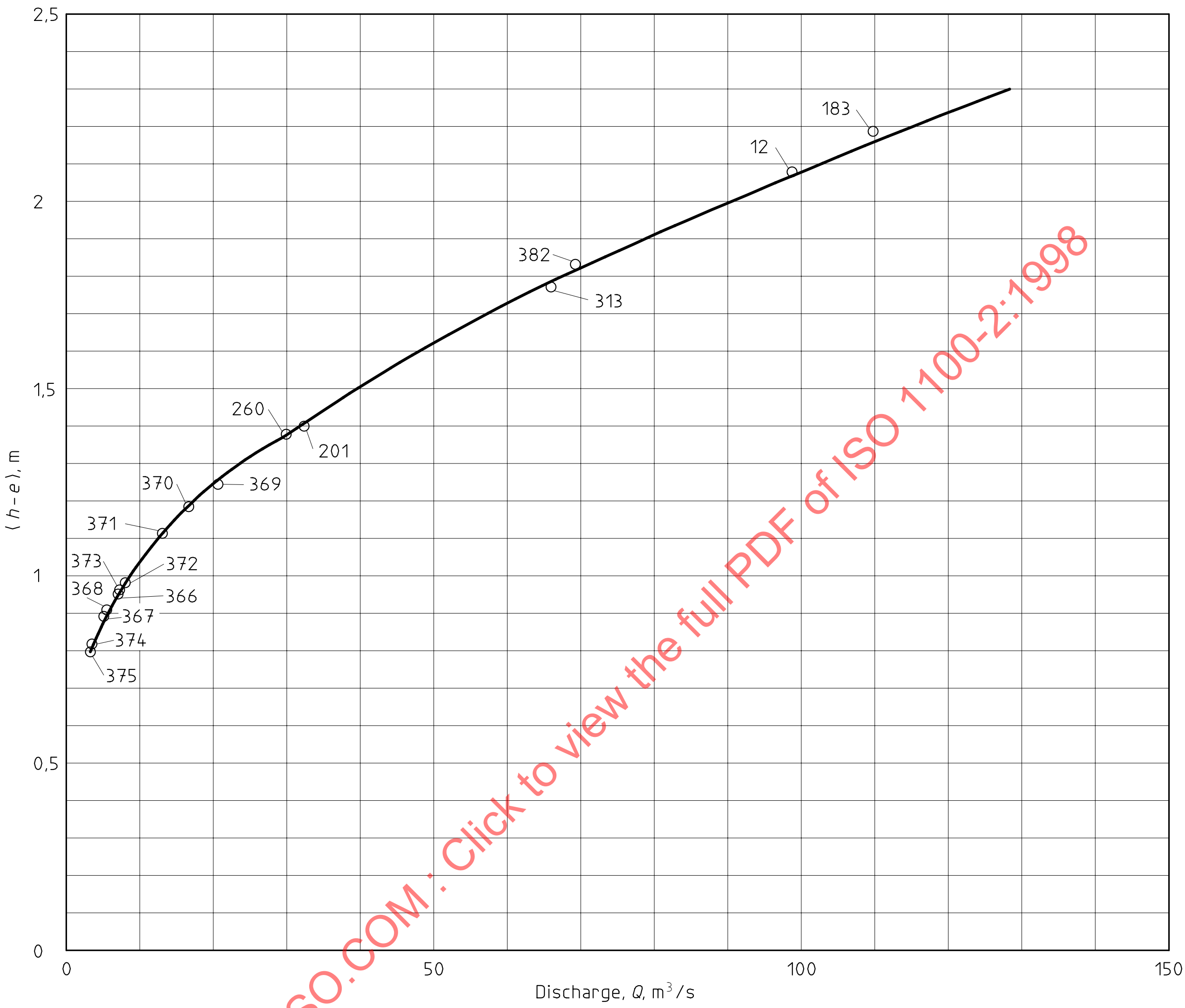
6.2.3 Arithmetic plotting scales

The simplest type out measurements 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, even increments that are easy to read and interpolate. They should also be chosen to produce a rating curve that is not unduly steep or flat. Usually the curve should follow a slope of between 30° and 50°. 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 may result in separate curves for low water, medium water, and high water. Care should be taken to see that, when joined, the separate curves form a smooth, continuous combined curve.

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 relation on arithmetic scales is almost always a curved line, concave downward, which can be 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 the next clause. Generally, a stage-discharge relation 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.

6.2.4 Logarithmic plotting scales

Most stage-discharge relations, or segments thereof, are best analyzed graphically through the use of logarithmic plotting paper. To utilize fully this procedure, 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 6.2.4.2. The slope of the straight line will conform to the type of control (section or channel), thereby providing valuable information to shape correctly the rating curve segment. In addition, this feature allows the analyst to calibrate the stage-discharge relation with fewer discharge measurements. The slope of a rating curve is the ratio of the horizontal distance to the vertical distance. This non-standard way of measuring slope is necessary because the dependent variable (discharge) is always plotted as the abscissa.



NOTE — Numbers indicated against plotted observations refer to ID numbers given in table 1.

Figure 1 — Arithmetic plot of stage-discharge relation

Rating curves for section controls such as a weir or flume conform to equation (1), and when plotted logarithmically the slope will be 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 ratings for section controls in natural channels will almost always have a slope of 2 or greater. This characteristic slope of 2 or greater for most section controls allows the analyst to identify easily the existence of section control conditions simply by plotting discharge versus effective depth, (h-e), on logarithmic plotting paper.

Rating curves for channel controls, on the other hand, are governed by equation (2) or (3), and when plotted as effective depth versus discharge the slope will usually be between 1,5 and 2. Variations in the slope of the rating when channel control exists are the result of changes in rugosity and friction slope as depth changes.

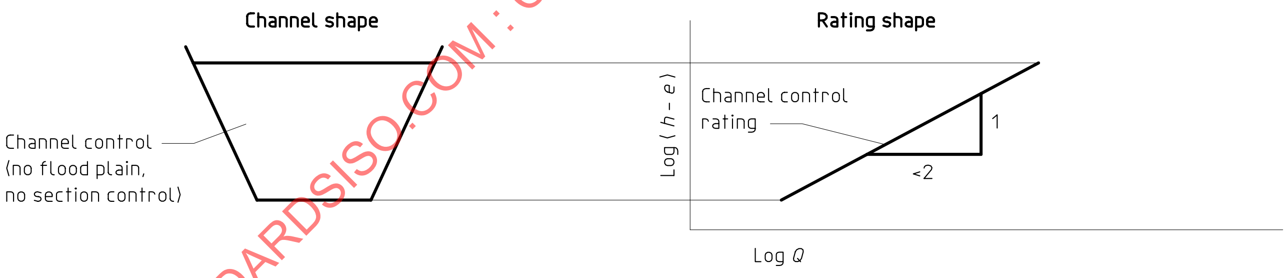
The above discussion applies to control sections of regular shape (triangular, trapezoidal, parabolic, etc.). When a significant change in shape occurs, such as a trapezoidal section control with a small V-notch for extreme low water, there will be a change in the rating curve slope at the point where 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, referred to as transitions. This kind of knowledge about the plotting characteristics of a rating curve is extremely valuable in the calibration and maintenance of the rating, 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 more precisely define the correct hydraulic shape of the rating curve. In addition, these kinds of information allow the analyst to extrapolate accurately a rating curve, or conversely, know when extrapolation is likely to lead to significant errors

Figure 2 gives examples of a hypothetical rating curve showing the logarithmic plotting characteristics for channel and section controls, and for cross-section shape changes. Insert A in figure 2 shows a trapezoidal channel with no flood plain and with channel control conditions. The corresponding logarithmic plot of the rating curve, when plot ted with an effective gauge height of zero flow (*e*) that results in a straight fine rating, has a slope less than 2. In insert B a flood plain has been added which is also channel control. This is a change to the shape of the control cross-section, and results in a change in the shape of the rating curve above bankful stage. If the upper segment (above the transition curve) were replotted to the correct value of effective gauge height of zero flow, it too would have à slope less than 2. In the third plot, insert 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, the slope will usually be greater than 2.

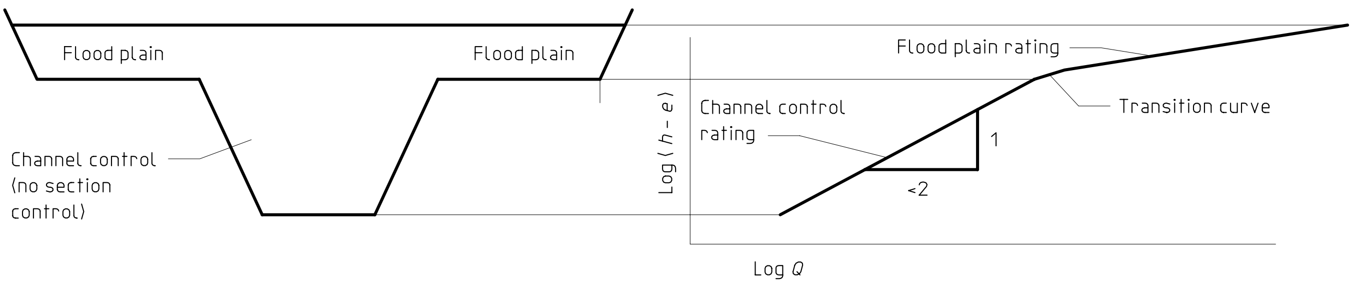
Figure 3 is a logarithmic plot of an actual rating curve, using the measurements shown in table 1. This rating is for a real stream where section control exists throughout the range of flow, including the high flow measurements. The effective gauge height of zero flow (*e*) for this stream is 0,6 metres, 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 below 1,4 m is about 4,3, which is greater than 2 and conforms to a section control. Above1,5 m, the slope is 2,8, which also conforms to a section control. The change in slope of the rating 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 a triangular shape. In the range of 1,4 to 1,5 m the control shape is changing to trapezoidal, resulting in the transition curve of the rating. And above about 1,5 m the control cross-section is basically trapezoidal.

The examples of figures 2 and 3 are intended to illustrate some of the principals of logarithmic plotting. The analyst should try to use these principals to the best extent possible, but should always be aware that there are probably exceptions and differences that occur at some sites.

A



B



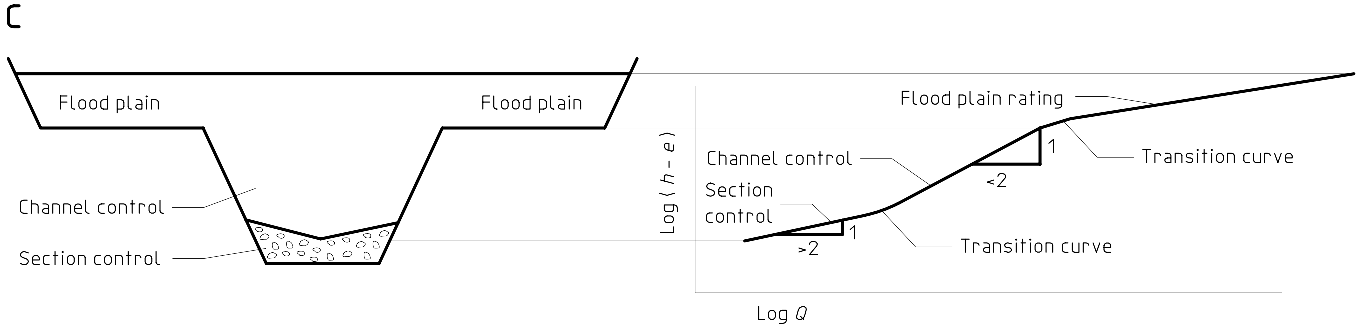
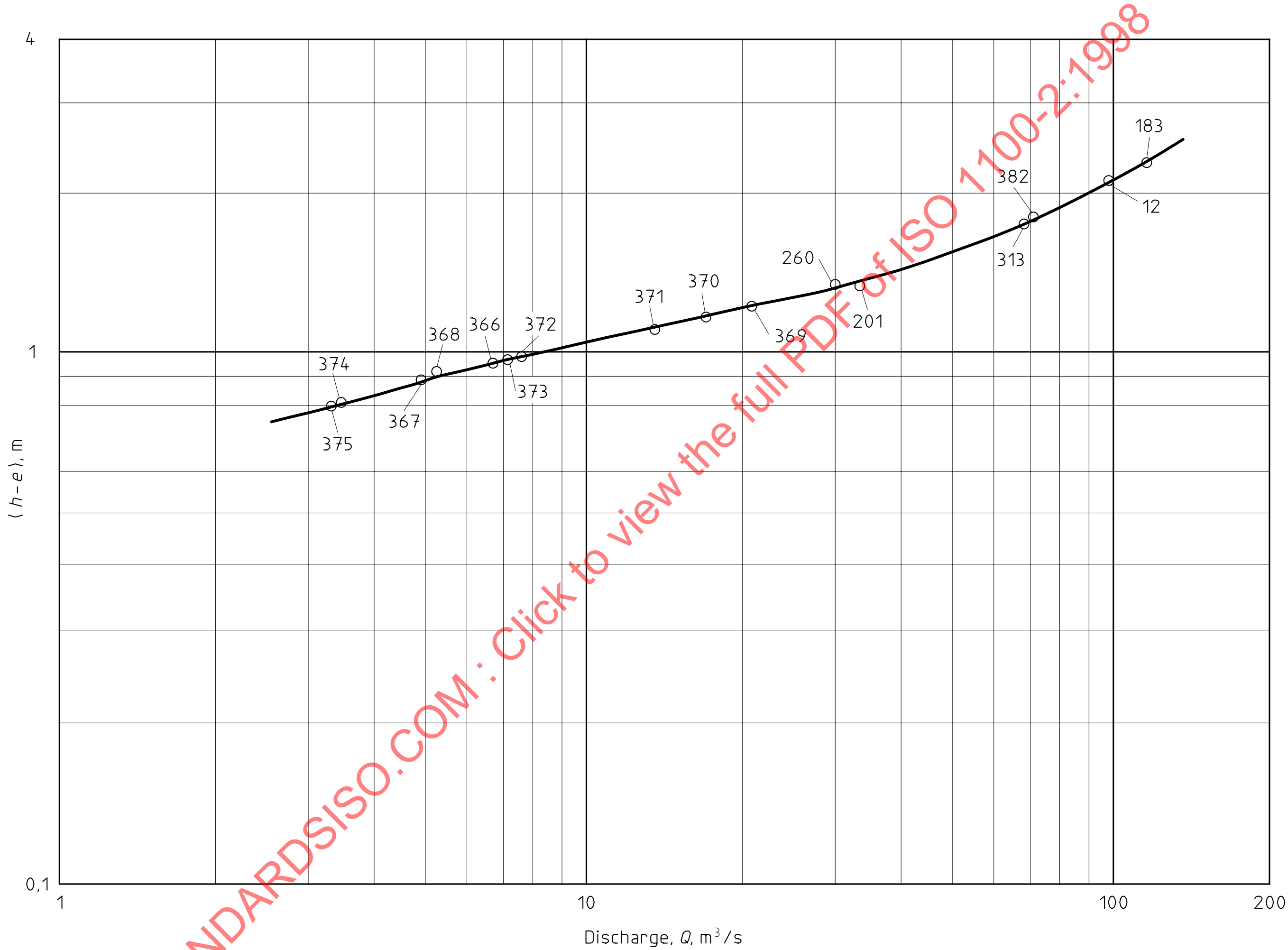


Figure 2 — Relation of channel and control properties to rating curve shape



NOTE — Numbers indicated against plotted observations refer to ID numbers given in table 1.

Figure 3 — Logarithmic plot of stage-discharge relation

6.2.4.1 Gauge height of zero flow

The actual gauge height of zero flow is the gauge height of the lowest point in the control cross-section for a section control [sometimes referred to as the cease-to-flow (CTF) value]. For natural channels, this value can sometimes be measured in the field by measuring the depth of flow at the deepest place in the control section, and subtracting this depth and the velocity head from the gauge height at the time of measurement.

The effective gauge height of zero flow is a value that, when subtracted from the mean gauge heights of the discharge measurements, will cause the logarithmic rating curve to plot as a straight fine. For regular shaped section controls, the effective gauge height of zero flow will be nearly the same as the actual gauge height of zero flow. For irregular shaped controls, the effective gauge height of zero flow is greater than the actual gauge height of zero flow. At points where the control shape changes significantly, or where the control changes from section control to channel control, the effective gauge height of zero flow will usually change. This results in a need to analyze rating curves in segments (separate logarithmic plots for each control condition) to properly define the correct hydraulic shape for each control condition. The gauge height minus the effective gauge height of zero flow is the effective depth of flow on the control.

The effective gauge height of zero flow should be determined for each rating curve segment. For regular shaped controls, this value will be close to the actual gauge height of zero flow. For most controls, however, a more exact determination can be made by a trial-and-error method of plotting. A value is assumed, and measurements are potted based on this assumed value. If the resulting curve shape is concave upward, then a somewhat larger value for the effective gauge height of zero flow should be used. A somewhat smaller value should be used if the curve plots concave downward. Usually only a few trials are needed to find a value that results in a straight fine for the rating curve segment. The effective gauge height of zero flow is sometimes referred to as the logarithmic scale offset.

6.2.4.2 Logarithmic equation

The equation for a straight line rating curve on logarithmic plotting paper is:

$$Q = p(h - e)^\beta \quad (4)$$

where

$(h - e)$ is the effective depth of water on the control,

h is the gauge height of the water surface,

e is the effective gauge height of zero flow,

β is the slope of the rating curve, and

p is a constant that is numerically equal to the discharge when the effective depth of flow $(h - e)$ is equal to 1.

6.3 Curve fitting

6.3.1 General

The curve fitting process for stage-discharge relations includes the actual drawing, positioning, and shaping of the rating. Hydraulic analysis and mathematical fitting can be used to aid in the curve fitting process, but in the final analysis, the stage-discharge relation must conform to the calibration measurements. On the other hand, the analyst must realize that the rating should be hydraulically correct, and that every calibration measurement does not necessarily fit on the same rating curve because of shifting control conditions that sometimes occur. The curve fitting process should result in curve shapes that conform to control changes, as described in previous clauses.

6.3.2 Graphical curves

Graphical curves are those that are drawn with the aid of drawing instruments such as straight edges and pre-shaped plastic curves. The analyst first plots the calibration measurements, determines which of these should be on the rating curve, and then fits a curve or straightedge to the measurements by eye to produce a smooth curve with as little variation from the measurements as possible. The analyst should always consider all available information about the control and the actual gauge height of zero flow in order to give proper consideration to transition curves and other changes in the shape and slope of the rating curve. Graphical fitting of rating curves is aided considerably if plotting is performed on logarithmic plotting paper and careful choice of effective gauge height of zero flow is made. In so doing, it is usually possible to define segments of rating curves by a straight fine rather than a curved line.

6.3.3 Hydraulic equation curves

The shape of stage-discharge relations can sometimes be defined through the use of hydraulic equations, namely equations (1), (2) and (3). Where section control exists, the weir equation (1) can be used to compute rating curve points. Coefficients of discharge, C , are defined in other International Standards for certain types of weirs and flumes, so that a reasonably accurate rating curve can be computed that will conform to correct hydraulics. For natural section controls, such as a rock outcrop or sand bar, the coefficient of discharge can be estimated on the basis of calibration measurements. Widths and depths can be determined from a surveyed cross-section of the control section.

For segments of the rating curve that are influenced by channel control, the shape of the rating can be defined through the use of equation (2) or (3). An average or typical cross-section in the control reach is surveyed to define the channel characteristics of cross-section area and hydraulic radius. The Manning rugosity, n, or the Chezy C is estimated from field observations. The friction slope is estimated from channel surveys, maps, or calibration measurements. Equation (2) or (3) can then be used to compute discharge for a few selected gauge heights to define the shape of the rating curve. This is a simplified procedure which assumes steady, uniform flow. More complex situations involving non-uniform flow can be analyzed with various techniques of backwater curve computation. Computer programs are available for such analyses.

For either case, section or channel control, the rating computed by the hydraulic equations is used only for defining the hydraulic shape of the rating. The correct position of the rating is defined by the calibration measurements. This procedure can also be used to aid in determining when measurements define a new rating position, such as may be the result of a shifting control.

6.3.4 Mathematical rating curves

For gauging stations where the control is stable with little or no shifting, the stage-discharge relation can be defined by mathematical computations, such as regression analysis. Care should be taken, however, because if the calibration measurements used for regression are not all part of the same rating curve, then the regression results may define a rating that is not hydraulically correct. Such a rating can lead to erroneous results when applying the rating for the purpose of computing daily discharges.

Ratings defined by regression analysis should not be used through transition segments or through segments of the rating that are affected by changes in control shape. Second- or third-order polynomials might be useful to define these changes in rating shapes. The analyst should use care, however, to be sure the rating shape is hydraulically reasonable.

6.4 Combination control stage-discharge relations

Combination control rating curves are sometimes referred to as compound control rating curves. A compound control may consist of two section controls, each of which controls a segment of the rating curve. For instance, a rock riffle section may control extreme low flows, but at higher flows a different cross-section located downstream from the rock riffle may cause submergence of the rock riffle and become the controlling section for medium flows. The plot of such a rating will usually exhibit a change in slope that reflects the change in effective gauge height of zero flow for the two section controls. Also, there will usually be a transition curve between the two rating segments which represents partial controlling effect from each of the controls. Graphical analysis of compound, or combination, controls of this type requires separate logarithmic plots for each segment of the rating in order to define the segments as straight lines, and properly compute the rating curve slope. When analyzed in this manner, the rating curve slope for each segment will be greater than 2.

A compound rating may also be a combination of section control for low flows and channel control for medium or high flows. This has been discussed to some extent in previous clauses. Graphical analysis usually requires that separate plots be made for the section control segment and the channel control segment. A transition curve between the two segments will represent the range of flow where there is partial control from both the section and channel controls. The slope of the section control segment should be greater than 2, and the channel control segment less than 2, when analyzed in this manner.

6.5 Stable stage-discharge relations

A stable stage-discharge relation is one that does not vary, or change positions, over a period of time. Such a relation results from stable channel and control conditions, which for natural channels is a relative term. Virtually all natural channels are subject to at least occasional change as a result of scour, deposition, or growth of vegetation.

For stable channels and controls, the stage-discharge relation can usually be defined easily by fitting a curve to the calibration measurements as described in previous clauses. The example shown in figure 3 represents a stable stage-discharge relation because the control is a natural section of rock outcropping that is not subject to change. Shifts of this rating can occur, however, because of debris that might accumulate on the control.

6.6 Unstable stage-discharge relations

Unstable stage-discharge relations are defined as those that shift and change positions frequently. Channel geometry and friction properties, and hence the control characteristics, vary continuously as a function of time, and so also does the stage-discharge relation. These conditions are most evident during floods and during periods when ice or vegetative growth occur. Channel scour and deposition may be a frequent occurrence in some channels due to the nature of the bed and bank materials, thus causing shifts of the rating. Likewise, weeds, trees and other vegetation may affect the relation between stage and discharge during certain times of the year.

It is usually not possible to define all changes of the rating with discharge measurements for unstable channels and controls. Shifting control techniques should then be used to estimate the position of the rating during periods of time between measurements. These techniques are described in a subsequent clause.

For some gauging stations where unstable channel conditions exist, it is sometimes advisable to install a weir or flume, if practicable, to stabilize the rating. In other cases, if the rating is unstable because of variable backwater, a twin-gauge system might be used. This method is described briefly in a subsequent clause, and in detail in ISO/TR 9123. Another possible way of defining the rating where variable backwater exists is to use an index velocity gauge in conjunction with the stage gauge. Two types of index velocity gauge can be used, the electromagnetic type and the ultrasonic type. These are described in detail in ISO 9213 and 6416.

6.7 Shifting controls

Shifting controls occur when channel conditions are unstable, as described in previous clauses. When this condition exists, discharge measurements made at different times represent different positions of the rating curve. Frequent discharge measurements should be made during a period of shifting control to define the stage-discharge relation, or magnitude of shifts, during that period. However, even with infrequent discharge measurements the stage-discharge relation can be estimated with reasonably good accuracy if the few available discharge measurements are supplemented with a knowledge of shifting-control behaviour.

Minor deviations of discharge measurements may result from minor random fluctuations resulting from the dynamic force of moving water. Also, it is recognized that discharge measurements are not error-free. Consequently, an average rating curve drawn in such a way that the discharge measurements are evenly balanced about the curve may result in a more accurate determination of discharge than any single measurement. If a group of consecutive discharge measurements subsequently plot to the right or left of the rating curve, it is usually clear that a shift in the rating has occurred. On the other hand, if a single discharge measurement departs significantly from the rating, it may not be clear whether this represents a shift or some unexplained error in the discharge measurement. The analyst must ultimately be the judge as to whether or not a measurement or group of measurements define a control shift. Such rating changes may be highlighted by plotting the deviation of each gauging from an average rating curve versus time. The deviations may be expressed as either percentages, stage differences or standardized residuals.

When discharge measurements indicate a shift of the rating curve, the analyst may determine if the shift is a temporary condition, or if it may be permanent. If the shift is expected to last for several months or longer it may be best to draw a new rating curve. If the shift is a temporary condition that may change again soon, then it is best to handle the shifting control condition by drawing a temporary shift curve to define discharge during the time of shift and until new information indicates another shift of the rating. Experience and knowledge of each control is the best way of knowing whether rating shifts are temporary or permanent.

Shift curves are usually shaped similar to the original rating curve. That is why it is important to have the original, or base, rating curve shaped correctly as defined by the hydraulics of the stream channel. Scour or deposition of a natural section control results in a change in the actual and effective gauge height of zero flow. This frequently results in a shift curve that is parallel to the original rating curve when plotted on arithmetic plotting paper. That is, the difference in gauge height between the original rating and the shift curve is equal through a range in stage controlled by the section control. This same shift curve, if plotted on logarithmic plotting paper, will be concave upward and above the original rating for a deposition condition, and concave downward and below the original rating for a scour condition. If a determination of the actual gauge height of zero flow was made at the time of the discharge measurement, then this is equivalent to having a second discharge measurement which can greatly help in defining the shift curve position and shape.

Shift curves for section controls tend to be asymptotic to the original rating at the higher stages of section control. This is usually a good place to merge a shift curve with the base rating, because shifts that apply to a section control probably do not apply to the channel control, or they may become so small relative to channel control discharges that percentage-wise they are insignificant. The transition curve between section control and channel control ratings is a good place to merge shift curves and base ratings if it is determined that a shift of one does not apply to the other.

Channel scour, deposition and vegetative growth are usually the causes of shifts when channel control exists. Scour usually occurs during stream rises, and deposition occurs during stream recessions. This is an over-simplification, however, because the process of sediment transport is complex and in reality cannot be analyzed easily. In fact, for some stream reaches, scour and deposition may be occurring simultaneously at different places in the channel control reach. Discharge measurements are very important for defining shift curves during flood conditions if shifting control is likely to occur.

When several discharge measurements made over a period of time appear to lie on the same shift curve, it is usually best to draw an average shift curve to use during the period of the measurements. This average shift curve is probably more accurate than any one of the individual measurements. The analyst should carefully determine, however, that the average shift curve is logical and hydraulically accurate. A shift curve that departs significantly from correct hydraulic conditions will lead to erroneous determinations of discharge during periods when discharge measurements are not available.

For streams that shift continuously, it is usually necessary to define shift curves on the basis of discharge measurements, determinations of the gauge height of zero flow, and hydraulic characteristics of the rating curve, and then continuously adjust the shift curve between itself and another shift curve (or the base rating) on the basis of time. The shift curve adjustment may be uniform, or proportional, based on time, or if specific changes can be defined, a shift curve can be abruptly changed to correspond to the control change. For instance, a deposition of debris on a section control may quickly wash out during a small rise, thus causing a shift curve to change back to the original rating or to another position of the shift curve. This can sometimes be detected by examination of the gauge height record, where abrupt changes may signify abrupt changes to the control. Where no obvious reason can be determined for a shift curve change, it is usually assumed that the change is gradual over time, and the shift curve is thus adjusted by time.

Shifting control procedures are complex and frequently difficult to interpret. Quite often there is more than one logical explanation or interpretation. Experience with a given stream is important in defining the shift characteristics and in making a logical analysis.

6.8 Variable backwater effects

6.8.1 General

Several conditions can occur in the downstream reaches of a stream to cause apparent changes to the stage-discharge relation. Previously clauses have discussed shifts of the control. This clause discusses conditions of variable backwater which may cause submergence, or partial submergence, of a control and result in stage-discharge relations that require more complex analysis.

Variable backwater may result from downstream influences such as reservoirs or tributary streams, from ice effect or from dynamic conditions known as hysteresis. Each of these is discussed in subsequent clauses.

6.8.2 Downstream backwater influences

Downstream conditions may occasionally exist such that water levels downstream from a channel control reach or a section control may rise sufficiently to submerge partially the control. When this happens the control will no longer be fully effective in defining the stage-discharge relation. A downstream reservoir can cause this to happen if it fills enough to submerge the control. Likewise, a tributary stream that enters below or within the control reach might cause variable backwater effects when that tributary is flowing sufficiently to submerge the control. Beaver dams or other obstructions in the channel downstream from the control may cause some degree of submergence and thereby invalidate the stage-discharge relation.

For some conditions of downstream backwater, particularly if it is of short duration and occurs very infrequently, it may be easiest and best to analyze the discharge record using shifting control methods. Sometimes the extent and magnitude of the backwater can be determined by examining a graphical plot of the stage record and estimating the non-backwater stage during the period of backwater.

For variable backwater conditions that are significant and persist for long periods of time, other measures are required to analyze the discharge record. One approach is to establish two gauges, a base gauge at the primary site at which the discharge record is needed, and an auxiliary gauge usually located some distance downstream from the base gauge. For some streams, the auxiliary gauge may be located upstream, but this is not usually recommended if a suitable downstream site is available. Through the use of calibration measurements for the range of backwater conditions, a rating curve that relates discharge to gauge height at the base gauge, and water surface fall between the base gauge and the auxiliary gauge, can be defined. This type of rating is referred to as a stage-fall-discharge relation, and can be used to compute accurately discharge from the simultaneous records of stage at the two gauges. Details for defining stage-fall-discharge relations are given in ISO/TR 9123.

Another approach for defining discharge in reaches where variable backwater exists is through the use of mathematical models of one-dimensional unsteady flow conditions. This is an emerging technology that utilizes high speed computers. As in stage-fall-discharge relations, two gauges in a reach are required. In addition, surveys of several cross-sections along with estimates of channel rugosity are needed. Several discharge measurements are needed to calibrate the model.

A third method to define discharge in streams affected by variable backwater is through the use of one stage gauge and an auxiliary gauge of index velocity. Index velocity may be determined by a vane assembly suspended in the stream to record vane deflection caused by stream velocity, by an electromagnetic meter that measures velocity by electric current induction caused by a conductor (water) moving through a magnetic field, or by ultrasonic methods that measure velocity on the basis of differences in sound propagation in the upstream/downstream directions through a defined stream reach. With the advent of electronic methods, such as the electromagnetic and ultrasonic methods, the vane gauge method is not commonly used today. The details of the electromagnetic and ultrasonic methods of equipment installation, maintenance, and rating calibration are given in ISO 6416 and ISO 9213, and are not discussed further in this document.

6.8.3 Ice effects

The formation of ice in stream channels or on section controls affects the stage-discharge relation by causing backwater that varies with the quantity and nature of the ice, as well as with the discharge. Because of the variability of the backwater effect, discharge measurements should be made as frequently as possible when the stream is under ice cover, particularly during periods of freeze-up and thaw when flow is highly variable. In midwinter the frequency of measurements will depend on climate, accessibility, size of stream, and winter runoff characteristics.

Where temperatures are severe, streams will form an ice cover at the beginning of winter and undergo a general recession in flow until the start of the spring freshet. The ice effect on the stage-discharge relation is primarily a function of the ice regime and ice thickness with the accuracy of discharge computation largely dependent on discharge measurement timing and frequency.

One or more of the following methods of computation may prove to be satisfactory for computation of daily discharge under ice cover at a particular gauging site. Several of the methods should be tested and the one which produces a result in best agreement with information available from other sources be selected as the standard method for the gauging station. For more details on the measurement of discharge during periods of ice, see ISO 9196.

6.8.3.1 Equivalent gauge height method

Equivalent gauge heights are computed for each discharge measurement using the open-water rating curve. These equivalent gauge heights are then plotted on a hydrograph of daily mean gauge heights, and a hydrograph of equivalent gauge heights is interpolated between discharge measurements using the stage hydrograph as a guide. Daily discharges are then computed using the equivalent gauge heights and the open-water rating curve.

6.8.3.2 Backwater method

The difference between the effective gauge height and the recorded gauge height is defined as backwater, and is computed for each discharge measurement. Backwater values are interpolated between discharge measurements using air temperature, ice thickness, or other hydrologic information as a guide. Effective gauge heights can then be computed by subtracting the backwater values from the recorded gauge heights. Daily discharge is computed by using the effective gauge heights and the open-water rating curve.

Various modifications of the effective gauge height method and the backwater method can be used to compute daily discharge.

6.8.3.3 Adjusted discharge method

Open-water discharge values are computed using the recorded gauge heights and the open-water rating curve, and a discharge hydrograph is prepared. The discharge measurement results are plotted on this hydrograph and a hydrograph of daily discharges is interpolated between discharge measurements using the open-water discharge hydrograph as a guide. Daily mean discharges can then be determined directly from the hydrograph.

6.8.3.4 Direct-discharge interpolation method

Daily mean discharges can be determined by direct interpolation between discharge measurements, usually linear or log-linear, during periods when it is believed that discharge changes are fairly uniform. The interpolation procedure can be modified at times when the air temperature and stage records indicate significant changes. See ISO 9196 for additional detail.

6.8.3.5 Recession curve method

Large streams, particularly those that have significant storage characteristics, may exhibit typical recession characteristics between the time of ice formation and the break-up of ice cover. By defining semilogarithmic recession charcteristics from a number of discharge measurements, it is sometimes possible to use the recession curve during other ice-affected periods when only one or two discharge measurements are available. Typical recession curves of this kind can be used from year to year without the necessity of frequent discharge measurements. Daily discharges can be determined directly from the recession curve for periods when no discharge measurements are available.

6.8.3.6 Winter rating curves

Some streams, particularly large ones, may have winter ice regimes that are so consistent from winter to winter that it is possible to develop a winter stage-discharge relation. Once the existence of such a curve has been verified by discharge measurements, daily discharges can be computed from the winter rating curve using recorded gauge heights.

6.8.4 Hysteresis effect, or loop ratings

The stage-discharge relation for a gauging station gives the value of the normal discharge, that is the steady-flow discharge, for a given stage. The discharge for a particular stage may, for some streams, be greater than the normal discharge during rising stages, and less than normal during falling stages. This effect is known as hysteresis, or loop rating. It is most pronounced for mild sloped streams where dynamic flow conditions are imposed, such as stream reaches downstream from a dam during periods of hydropower generation, or stream reaches in urban areas where runoff is accelerated because of impervious surfaces and other drainage improvements.

For gauging sites where the hysteresis effect is severe, instantaneous values of discharge determined from the steady-state rating curve can be significantly different from the true discharge. For these sites it may be necessary to use auxiliary equipment to supplement the gauge height record in order to determine discharges accurately. A twin-gauge approach utilizing the stage-fall-discharge relation can be used as described in 6.8.2 (see also ISO/TR 9123). Or a twin-gauge approach using an unsteady flow model, as described in 6.8.2, might be used. In other situations it might be feasible to use a velocity index relation, as described in 6.8.2, to compute discharge. All of these methods require additional equipment and therefore are more expensive to install and operate than the single-gauge approach.

If the hysteresis effect is not severe, but of sufficient magnitude as to need correction, it may be possible to use a single-gauge record of stage in conjunction with the rate-of-change in stage to compute discharge. For certain conditions, it is possible to compute the true discharge, Q, of an unsteady flow from the steady-state discharge, Q_o, by using the following equation:

$$Q = Q_o\left[1 + \frac{1}{S_o v_w} \cdot \frac{dh}{dt}\right]^{0,50} \qquad (5)$$

where

S_o is the water surface slope corresponding to steady, non-uniform flow,

v_w is the velocity of flood wave,

$\frac{dh}{dt}$ is the time rate of change of stage.

The slope, S_o, may be determined from observation of gauges during conditions of steady flow. Alternatively, it may be approximately computed from Manning's or Chezy's equation.

The rate of change of stage, dh/dt, may be obtained from the recorded observations of stage at the gauge.

The wave velocity, v_w, is given by the equation,

$$v_w = \frac{dQ}{dA} = \frac{1}{B} \cdot \frac{dQ}{dh} \qquad (6)$$

where

A is the cross-sectional area,

B is the surface width at the cross-section, and

$\frac{dQ}{dh}$ can be approximated from the stage-discharge relation.

The above conditions are valid when the rise and fall of the stream is gradual, that is, where the rate of change in velocity or the acceleration head can be neglected. Likewise, velocity should not be great, so that velocity head can safely be neglected. When a sufficient number of discharge measurements are available, it may be possible to calibrate a gauging site with a family of curves by evaluating the term $1/S_o v_w$ as a single parameter.

6.8.5 Tidal discharge measurements — Loop ratings

Discharge measurements undertaken in coastal rivers affected by ocean tides will exhibit a diurnal loop rating condition. Measurements undertaken in these zones shall be completed quickly. More recently, ultrasonic measurement methods have proven satisfactory.

6.9 Extrapolation of the stage-discharge relation

A stage-discharge relation should not be applied outside the range of discharge measurements upon which it is based. If estimates of flow, however, are required outside the range, it may be necessary to make an extrapolation of the rating curve. Such extrapolations, either above the highest measurement or below the lowest measurement, should be made with care and through the use of methods that help to define the shape and position of the extrapolated part of the curve. Before making any kind of rating extrapolation, the channel and control should be carefully examined for some distance downstream and upstream of the gauge. Flow obstructions, contractions, expansions, debris, channel shape changes, and other conditions should be noted. If abnormal channel conditions exist that cannot be accounted for in the rating analysis, then a rating extrapolation should not be made.

The simplest method for extrapolating a rating curve is by logarithmic plotting. To use this method correctly, the analyst should have a good understanding of the control conditions and logarithmic plotting methods. Otherwise, this method could lead to large errors. The part of the rating curve requiring extrapolation should be plotted with the effective gauge height scale chosen so that the rating plots as a straight line. In addition, the analyst must have knowledge of the type of control (section or channel), and the shape of the control through the range of extrapolation. If the control shape does not change significantly and the channel rugosity remains fairly constant, then a straight-line extrapolation on the logarithmic plot is reasonable. A logarithmic extrapolation of this type is particularly suited to channel control conditions for medium and high flows, but should probably never be used to extrapolate more than about 1,5 times the highest measured discharge. Special care is needed when extrapolating below the lowest discharge measurement. For very low flows, when section control exists, it is very important to know the shape of the control and the gauge height of zero flow. Sometimes it is best to plot the rating curve on arithmetic plotting paper so that the gauge height of zero flow can be plotted, especially if the rating must be extrapolated to zero discharge.

The shape of the stage-discharge relation can sometimes be defined through the use of the weir equation [equation (1)], the Manning equation [equation (2)], or the Chezy equation [equation (3)]. These equations can be applied above the highest or below the lowest discharge measurements by using cross-section surveys, high-water mark surveys, and estimates of rugosity, discharge coefficients, or friction slope.

The weir equation will apply to low-water extrapolations where section control exists. Values of the discharge coefficient, C, can be calculated from discharge measurements and cross-section data of the control, and then extrapolated to the range of interest below the lowest discharge measurement. This is a good technique for defining the shape of the rating curve in the range where discharge measurements are not available.

The Manning and Chezy equations can be used to extrapolate the high end of a rating curve when channel control exists, and when it is reasonably certain that bed form does not change with the increase in discharge. Estimates can be made of the channel rugosity for the range of extrapolation. Friction slope can be estimated from discharge measurements in the lower range and extrapolated to the higher range. In some cases, highwater marks may be available to aid in the estimate of friction slope. Cross sectional area, A, and hydraulic radius, r, can be computed from cross-section surveys of a typical section in the control reach. Care should be taken if the shape of the cross-section changes appreciably, because friction slope may also change significantly. Where overbank flow occurs, the friction slope for flows above bankful may differ greatly from that when the flow is within banks.

Estimates of high discharges can sometimes be made that will aid in the extrapolation of the high end of a stage-discharge relation. The slope-area method is one such technique. See ISO 1070 for a description of this method. Another method may be used when another gauging site exists on the same stream, either upstream or downstream. By careful accounting of additions, withdrawals and channel storage, the peak discharge may be estimated for the site where an extrapolation is required.

The velocity-area method is also sometimes used to extrapolate a rating curve. This method requires the definition of a stage-area relation from a survey of the cross-section at the gauge, and the definition of a stage-velocity relation which must be estimated in the range of stage where the extrapolation is needed. The stage-velocity relation can be defined accurately in the range where discharge measurements are available, but is usually difficult to estimate accurately in the range above the highest measurements. For this reason, the velocity-area method is not considered as good as the method described above using the Manning or Chezy equation.

It is recommended that, whenever possible, extrapolations should be made using two or more of the above described methods. Results can then be compared and the extrapolated part of the rating curve can be defined with added confidence.

6.10 Rating tables

A rating table can be prepared directly from the stage-discharge relation or from the equation(s) of the curve(s), showing the discharges corresponding to stages in ascending order, and at intervals suited to the desired degree of interpolation. This can be conveniently performed by a computer program using the stage-discharge relation. However, it may be useful to program the data for computer evaluation using the stage-discharge equations without resorting to a rating table.

7 Methods of testing stage-discharge relations

A stage-discharge relation should be checked periodically by making check discharge measurements. The period of time between check measurements will vary depending on several factors, including relative stability of the rating curve, hydrologic events such as floods that might affect the rating curve, and other indications that the rating curve may have changed. During certain periods, such as floods or extreme drought, it is desirable to obtain additional check measurements to reduce the need for rating curve extrapolations and to define effects of backwater or hysteresis if they are present. Also, when a discharge measurement deviates significantly from the rating curve or from previous discharge measurements, then another check measurement should be made immediately to either confirm or refuse the accuracy of the first discharge measurement.

Generally, when a check discharge measurement plots within a small percentage of the rating curve, it is assumed that the rating curve still applies and no correction is made either in the form of a shift or a new rating. The percentage that a measurement may deviate from the rating without applying a correction is usually based on the accuracy of the discharge measurement. See ISO 748 for a description of computing discharge measurement error. If, for instance, most discharge measurements are made to ± 5 % accuracy, then shifting control techniques will not be employed unless a check measurement plots further than 5 % from the rating curve.

In some countries, a statistical analysis is made of the rating curve to define the standard deviation of the measurements from the mean rating curve. When one or more measurements indicate a deviation of 2 standard deviations from the rating curve, then a shift curve is defined or a new rating is defined. Standard deviations are usually defined separately for each segment of a rating curve.

A bias check is also performed in some cases to define periods when the rating may be shifted even though check measurements are within the specified accuracy of discharge measurement error, or within the standard deviation for the rating curve. For instance, two or more measurements may plot within 5 % of the rating curve, but are all on the same side of the rating curve. Various statistical tests may be used to test for bias.

When testing and checking stage-discharge relations, it is very important that the analyst understands why the measurements plot as they do. Without this understanding, the analyst might incorrectly apply and interpret certain statistical tests. The analyst should always consider what has been happening to the controlling stream characteristics and make decisions on this basis rather than arbitrarily using statistical results. Stage-discharge relations are hydraulic functions, not statistical, and should be analyzed accordingly.

8 Uncertainty in the stage-discharge relation

8.1 General

The theory and statistical equations for estimating the uncertainties in the stage-discharge relation and daily mean, monthly mean, and annual mean discharges are given in Annex A. Numerical examples of estimating the uncertainty of the stage-discharge relation and the daily mean discharge, using the procedures in Annex A, are given in this clause.

The statistical analysis, as described in Annex A, considers each segment of the rating curve separately between inflection points, or between transition curves. One segment of a rating curve, as shown in table 2, is used herein for demonstrating these computations.

8.2 Example of uncertainty calculations for individual gaugings

The standard error of estimate, s_e, of individual gaugings can be computed from the equation given in A.2.3 in Annex A. Substituting into this equation from table 2, the standard error of estimate, s_e, is calculated as:

$$s_e = [(0{,}02999/(32 - 2)]^{0{,}5} = 0{,}03162$$

When the number of observations is large, then the Student's t value used in the calculation of the 95 % confidence limit may be taken as 2. Thus, the uncertainty of the distribution of the points about the fitted line, $0{,}95s_e$ in percent, is defined as:

$$0{,}95s_e = 2s_e \times 100 \quad (7)$$

Therefore, using the value of s_e calculated above, the uncertainty of the rating curve segment, in percent, is

$$0{,}95 s_e = 2 \times 0{,}03162 \times 100 = 6{,}3\ \%$$

This equation defines two parallel straight lines on either side of the rating curve segment, and at a distance $2s_e$ from it. In other words, 95 % of the observations, on average, will be contained within these limits (6,3 %).

For those instances where the dispersion about the fitted line is not considered small, the random percent uncertainty, $2s_{mr}$, for individual values of ln Q_c at any stage, ln$(h - e)$, can be calculated from the equation given in A.2.4 in Annex A.

Substituting the values for observation number 1 in table 2 gives the following:

$$2s_{mr} = \pm 2(0{,}03162)\left[\frac{1}{32} + \frac{1{,}86225}{27{,}92422}\right]^{0{,}5} \times 100$$
$$= \pm 1{,}98\ \%\ \text{(rounded to 2,0 \% in table 2).}$$

Similar computations were made for each observation in table 2, and the percent uncertainty is shown in the last column. These uncertainties can be plotted on either side of the stage-discharge curve for each observed value of $(h - e)$. Such a plot will show the symmetrical limits of the 95 % uncertainty. The minimum width of these limits will occur at the mean value of ln$(h - e)$.

Table 2 — Tabulated values required to calculate s_e and s_{mr}

Obs No.	$h - e$ (e = 0,115)	Q Measured	Q_c Rating	ln ($h - e$) = x	$(x - \bar{x})^2$	ln $Q = y$	ln $Q_c = y_c$	$(y - y_c)^2$	$2s_{mr}$ %
1	0,157	2,463	2,323	– 1,851 51	1,862 25	0,901 38	0,842 86	0,003 42	2,0
2	0,158	2,325	2,345	– 1,845 16	1,844 96	0,843 72	0,852 29	0,000 07	2,0
3	0,188	2,923	3,060	– 1,671 31	1,402 92	1,072 61	1,118 41	0,002 10	1,8
4	0,192	3,242	3,160	– 1,650 26	1,353 49	1,176 19	1,150 57	0,000 66	1,8
5	0,219	3,841	3,865	– 1,518 68	1,064 65	1,345 73	1,351 96	0,000 04	1,7
6	0,259	4,995	4,996	– 1,350 93	0,746 60	1,608 44	1,608 64	0,000 00	1,5
7	0,278	5,410	5,568	– 1,280 13	0,629 28	1,688 25	1,717 04	0,000 83	1,5
8	0,279	5,422	5,598	– 1,276 54	0,623 59	1,690 46	1,722 41	0,001 02	1,5
9	0,287	5,883	5,846	– 1,248 27	0,579 74	1,772 07	1,765 76	0,000 04	1,4
10	0,295	6,154	6,097	– 1,220 78	0,538 63	1,817 10	1,807 80	0,000 09	1,4
11	0,348	7,376	7,851	– 1,055 55	0,323 41	1,998 23	2,060 64	0,003 89	1,3
12	0,405	9,832	9,902	– 0,903 87	0,173 89	2,285 64	2,292 74	0,000 05	1,2
13	0,433	11,321	10,968	– 0,837 02	0,122 61	2,426 66	2,394 98	0,001 00	1,2
14	0,461	12,372	12,072	– 0,774 36	0,082 65	2,515 44	2,490 89	0,000 60	1,2
15	0,465	11,825	12,233	– 0,765 72	0,077 76	2,470 22	2,504 14	0,001 15	1,2
16	0,501	13,826	13,711	– 0,691 15	0,041 73	2,626 55	2,618 20	0,000 07	1,1
17	0,511	14,102	14,132	– 0,671 39	0,034 05	2,646 32	2,648 44	0,000 00	1,1
18	0,606	19,020	18,345	– 0,500 88	0,000 20	2,945 49	2,909 36	0,001 31	1,1
19	0,624	19,970	19,185	– 0,471 60	0,000 23	2,994 23	2,954 13	0,001 61	1,1
20	0,632	20,280	19,563	– 0,458 87	0,000 78	3,009 64	2,973 64	0,001 30	1,1
21	0,681	21,204	21,931	– 0,384 19	0,010 54	3,054 19	3,087 90	0,001 14	1,1
22	0,731	23,996	24,442	– 0,313 34	0,030 11	3,177 89	3,196 30	0,000 34	1,1
23	0,926	36,242	35,098	– 0,076 88	0,168 09	3,590 22	3,558 14	0,001 03	1,2
24	1,225	54,591	53,855	0,202 94	0,475 83	3,999 87	3,986 30	0,000 18	1,4
25	1,411	67,327	66,859	0,344 30	0,690 83	4,209 56	4,202 59	0,000 05	1,5
26	1,646	79,050	84,631	0,498 35	0,970 65	4,370 08	4,438 30	0,004 65	1,6
27	1,895	110,783	104,989	0,639 22	1,268 07	4,707 57	4,653 86	0,002 89	1,8
28	2,517	162,814	162,095	0,923 07	1,987 91	5,092 61	5,088 18	0,000 02	2,0
29	3,150	227,600	228,478	1,147 40	2,670 83	5,427 59	5,431 44	0,000 01	2,3
30	3,165	228,800	230,145	1,152 15	2,686 38	5,432 85	5,438 71	0,000 03	2,3
31	3,191	228,500	233,044	1,160 33	2,713 27	5,431 54	5,451 23	0,000 39	2,3
32	3,225	236,600	236,854	1,170 93	2,748 30	5,466 37	5,467 44	0,000 00	2,3
Sum				– 15,579 70	27,924 22			0,029 99	
Mean ($\bar{x}$)				– 0,486 87					
s_e								0,031 62	