

Measurement of liquid flow in open channels —

Part 3C: Methods for determination of the stage-discharge relation

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National foreword

This Part of this British Standard, which has been prepared under the direction of the Industrial-process Measurement and Control Standards Committee, is identical with ISO 1100-2:1982 “*Liquid flow measurement in open channels — Part 2: Determination of the stage-discharge relation*”, published by the International Organization for Standardization (ISO).

Terminology and conventions. The text of the International Standard has been approved as suitable for publication as a British Standard without deviation. Some terminology and certain conventions are not identical with those used in British Standards; attention is drawn especially to the following.

The comma has been used as a decimal marker. In British Standards it is current practice to use a full point on the baseline as the decimal marker.

Wherever the words “International Standard” appear, referring to this standard, they should be read as “British Standard”.

Cross references

International Standard	Corresponding British Standard
ISO 31	BS 5775 <i>Specification for quantities, units and symbols</i> (Identical) BS 3680 <i>Measurement of liquid flow in open channels</i>
ISO 748:1979	Part 3A:1980 <i>Velocity area methods</i> (Identical)
ISO 772:1978	Part 1:1979 <i>Vocabulary and symbols</i> (Technically equivalent)
ISO 1000:1981	BS 5555:1981 <i>Specification for SI units and recommendations for the use of their multiples and of certain other units</i> (Identical) BS 3680 <i>Measurement of liquid flow in open channels</i>
ISO 1100-1:1981	Part 3B:1983 <i>Guide for establishment and operation of a gauging station</i> (Identical)
ISO 1438-1:1980	Part 4A:1981 <i>Thin-plate weirs</i> (Technically equivalent)
ISO 3455:1976	Part 8C:1980 <i>Calibration of rotating-element current-meters in straight open tanks</i> (Identical)
ISO 3846:1977	Part 4E:1980 <i>Free overfall weirs of finite crest width (rectangular broad-crested weirs)</i> (Identical)
ISO 4363:1977	Part 10B:1980 <i>Measurement of suspended sediment</i> (Identical)
ISO 4364:1977	Part 10C:1980 <i>Bed material sampling</i> (Identical)
ISO 4369:1979	Part 3D:1980 <i>Moving-boat method</i> (Identical)
ISO 4375:1979	Part 8D:1980 <i>Cableway system for stream gauging</i> (Identical)
ISO 5168:1978	BS 5844:1980 <i>Methods of measurement of fluid flow: estimation of uncertainty of a flow-rate measurement</i> (Identical)

At present there are no corresponding British Standards for the following International Standards quoted for information purposes only:

ISO 555-1, ISO 555-2, ISO 1070, ISO 1088, ISO 2537, ISO 3454, ISO 3847, ISO 4359¹⁾, ISO 4360, ISO 4366, ISO 4373, ISO 4377¹⁾, ISO/TR 7178¹⁾, ISO 7066-1¹⁾.

The World Meteorological Organisation (WMO) documents No. 49 and No. 168 constitute informative matter only.

Textual errors. When adopting the text of the International Standard, the textual errors listed below were discovered. They have been marked in the text and have been reported to ISO in a proposal to amend the text of the International Standard. In Table 3, column 11 delete the formula $\left[\frac{Q_i - Q_c}{Q_c} \times 100\right]^2$ and

substitute $d^2 = \left[\frac{Q_i - Q_c}{Q_c} \times 100\right]^2$.

In the list of symbols on page 26 delete “ Q_n ” and substitute “ Q_n ”.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 36, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

¹⁾ At present at the stage of draft.

1 Scope and field of application

This International Standard 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 permit the stage-discharge relation to be determined to the accuracy required by this International Standard.

Stable and unstable channels are considered, including those subject to ice conditions, but considerable care must be taken if this International Standard is applied to flow conditions which suddenly or rapidly vary.

An analysis is included of the uncertainties involved in the preparation and the use of the stage-discharge relation.

2 References

ISO 31, *Quantities, units and symbols*.

ISO 555-1, *Liquid flow measurement in open channels — Dilution methods for measurement of steady flow — Part 1: Constant rate injection method*.

ISO 555-2, *Liquid flow measurement in open channels — Dilution methods for measurement of steady flow — Part 2: Integration (sudden injection) method*.

ISO 748, *Liquid flow measurement in open channels — Velocity-area methods*.

ISO 772, *Liquid flow measurement in open channels — Vocabulary and symbols*.

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

ISO 1070, *Liquid flow measurement in open channels — Slope-area method*.

ISO 1088, *Liquid flow measurement in open channels — Velocity-area methods — Collection of data for determination of errors in measurement*.

ISO 1100-1, *Liquid flow measurement in open channels — Part 1: Establishment and operation of a gauging station*.

ISO 1438-1, *Liquid flow measurement in open channels using weirs and venturi flumes — Part 1: Thin-plate weirs*.

ISO 2537, *Liquid flow measurement in open channels — Cup-type and propeller-type current meters*.

ISO 3454, *Liquid flow measurement in open channels — Sounding and suspension equipment*.

ISO 3455, *Liquid flow measurement in open channels — Calibration of rotating-element current-meters in straight open tanks*.

ISO 3846, *Liquid flow measurement in open channels by weirs and flumes — Free overfall weirs of finite crest width (rectangular broad-crested weirs)*.

ISO 3847, *Liquid flow measurement in open channels by weirs and flumes — End-depth method for estimation of flow in rectangular channels with a free overfall*.

ISO 4359, *Liquid flow measurement in open channels using flumes²⁾*.

ISO 4360, *Liquid flow measurement in open channels by weirs and flumes — Triangular profile weirs*.

ISO 4363, *Liquid flow measurement in open channels — Methods for measurement of suspended sediment*.

ISO 4364, *Liquid flow measurement in open channels — Bed material sampling*.

ISO 4366, *Echo sounders for water depth measurement*.

ISO 4369, *Measurement of liquid flow in open channels — Moving boat method*.

ISO 4373, *Measurement of liquid flow in open channels — Water level measuring devices*.

ISO 4375, *Measurement of liquid flow in open channels — Cableway system for stream gauging*.

ISO 4377, *Liquid flow measurement in open channels — Flat-V weirs²⁾*.

ISO 5168, *Measurement of fluid flow — Estimation of uncertainty of a flow-rate measurement*.

ISO 7066, *Assessment of uncertainty in calibration and use of flow measuring devices — Part 1: Linear calibration graphs²⁾*.

ISO/TR 7178, *Investigation of the total error in measurement of flow by velocity area methods²⁾*.

WMO No. 49, *World Meteorological Organization — Technical Regulations*.

WMO No. 168, *World Meteorological Organization — Guide to Hydrological Practices*.

3 Definitions and symbols

For the purpose of this International Standard, the definitions and symbols given in ISO 772 apply. Those which are not covered by ISO 772 are given in the text of this International Standard. A list of symbols used is included at the end of this International Standard.

²⁾ At present at the stage of draft.

4 Units of measurement

The International System of Units (SI Units) is used in this International Standard 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. The principles of the establishment and operation of a gauging station are described in ISO 1100-1.

6 Calibration of a gauging station

6.1 General preparation of stage-discharge relation

6.1.1 The primary object of a gauging station is to provide a record of the discharge of the open channel or river at which it is sited. This is achieved by measuring stage and converting this to discharge by means of a stage-discharge relation which correlates discharges to either the water level at a section of the channel or the measurements of water level at each end of a reach. In the former case a single gauge station is employed. In the latter case, a twin gauge station is necessary and a different procedure for establishing the stage-discharge relation is used. For a gauging station calibrated by a velocity area method, the stage-discharge relation is determined from field measurements of stages and corresponding discharges; the calibration so established holds good only so long as no significant alteration takes place in the characteristics of the reach. Since a river is continuously in course of development, its characteristics are subject to changes which may affect the calibration. These changes may take place gradually as a result of slow processes of erosion or accretion or they may occur suddenly as a consequence of alterations in the channel. In addition, temporary changes may be caused by the growth and decay of aquatic weeds, by the formation and breakup of ice cover or by the deposition of debris. It is essential therefore to keep an established stage-discharge relation continuously under review in order to be assured that its validity is maintained, and to redetermine the relation when it is shown to have been significantly altered by any changes which have occurred.

6.1.2 Depending on the stability of the channel, the stage-discharge relation may be classed as stable or unstable. By accepted definition, a stable channel is one wherein the physical form and frictional properties of the bed and sides remain constant with respect to time. Conversely therefore, an unstable channel is one wherein the physical form and frictional properties vary with respect to time; that is, the channel itself is mobile. However in any reach, whether stable or unstable, any transient natural or artificial phenomenon may affect the actual relationship between stage and discharge at that time. Thus a stable channel may exist as an unstable reach. In all cases instability in a stage-discharge relation arises from variable conditions of back-water for a given discharge at the gauging site concerned and this is true, also, for changes in mean velocity of approach at a given stage due to unstable conditions occurring upstream from the gauging site, although the effect so experienced is a secondary rather than primary manifestation.

In all circumstances of variable backwater at a given discharge, a stable channel will provide a stable stage-discharge relation when the energy slope of the water in the reach concerned can be included as a parameter in the discharge relation.

6.2 Stable stage-discharge relation

6.2.1 The relation between stage and discharge is determined by correlating measurements of discharge with corresponding observations of stage. This correlation may be done manually by combinations of graphical and mathematical means or by using computer techniques (see Annex A).

6.2.2 The simplest expression of the stage-discharge relation is a plot on arithmetically divided graph paper with discharges plotted as abscissae against corresponding stages as ordinates. Since discharge often ranges over several orders of magnitude, it is sometimes more convenient to plot the relation on single or double logarithmically divided, paper. The stage used in plotting should be the weighted mean stage during the period of discharge measurement computed from the equations

$$\bar{z} = \frac{\sum q_i \bar{z}_i}{Q}$$

$$q_i = b_i d_i \bar{v}_i$$

where

- $\bar{z}$ is the mean water level above the gauge datum;
- q_i is the discharge in the i th segment of the cross-section;
- $\bar{z}_i$ is the mean water level in the i th segment of the cross-section corresponding to discharge q_i ;
- Q is the total discharge and equal to the sum of the segment discharge $\sum q_i$;
- b_i is the width of the i th segment of the cross-section;
- d_i is the depth of the i th segment of the cross-section;
- $\bar{v}_i$ is the mean velocity in the i th segment of the cross-section.

The method is shown schematically in Figure 1.

6.2.3 A smooth curve should be drawn by eye through the array of data points to detect points which may be in error. In the case of a single control, the relation may generally be expressed by a power curve of the form $Q = C(h + a)^\beta$ (see Annex A). In the case of a multiple control, the relation may have to be expressed by several power curves with inflexions and reversals in curvature indicating changes from the influence of one control to another. If the stage measurements have been adjusted to relate to a zero which coincides with the level at which discharge becomes zero, then on double logarithmic paper the relation between $(h + a)$ and Q will plot as a straight line or a series of straight lines, otherwise the relation between h and Q will plot as a curve.

6.2.4 The curve should be defined by a sufficient number of measurements suitably distributed throughout the whole range of water levels. This number will depend on the range to be covered, the shape of the curve and the desired accuracy but measurements at closer intervals of stage are desirable at the lower and upper ends of the range. The accuracy being obtained is given by the value of the “standard error of the mean relationship” (see clause 8) and if this value is considered to be unacceptable, more discharge measurements should be taken.

6.2.5 The curve should be examined for hysteresis (see Annex B). Where possible the measurements should have been made at steady stage, but if not, those taken at rising or falling stages should be indicated by distinguishing symbols. At most gauging stations it will be found that there is a tendency for a gauging taken on a rising stage to indicate a higher discharge than one taken at the same water level on a falling stage. Because of this, rising stage measurements generally plot below a curve and falling measurements above a curve established under steady stage conditions. In the case of stable channels, a mean curve can generally be adopted.

6.2.6 The equation for the curve should be obtained, or the curve may be treated as a purely graphic record. The equation may be computed mathematically using the least squares procedure (see Annex A). Alternatively stage-discharge equations may be prepared by computer direct from the gauging data but it is still advisable to plot the gaugings for preliminary examination to determine if they should be split into ranges for separate treatment. Computer techniques should be used only when discharge measurements can be said to have known weight.

6.3 Unstable stage-discharge relation

6.3.1 *Unstable channels*

In unstable channels the 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 at any given point in the channel. Such variations in control are evident particularly during and after flood periods, under ice conditions and during periods of weed growth and decay in channels susceptible to weed growth. In many such cases acceptable estimates of discharge during periods when no actual measurements are available may be achieved as follows: all discharges measured are plotted against their corresponding stages and each point labelled by date order. The lie of the points is then examined for shifts in control with reference to their chronological order and, provided that there are sufficient measured values, smooth curves may be drawn for those periods when little or no shift is apparent, and from which discharges in correct chronological context within that water year may then be estimated. Where weed growth is a cause of instability, the general effect is seasonal. During the growing season the weeds progressively increase the friction and decrease the discharge capacity of the channel with the resultant backwater effect demanding progressively higher stages to pass any given discharge. As the weeds decay, the reverse effect is observed. After a flood event and as new growth becomes established, the magnitude of the negative shifting control corrections to the base rating (backwater effect) will again increase.

6.3.2 *Unstable reaches*

Although the geometry and friction properties of the channel in a measuring reach may, in themselves, be stable, a simple invariable relationship between stage and discharge will not exist if those channel properties are not in overall control of the depth of flow for any given discharge. Such loss of overall control due to abnormal conditions of backwater can be caused by weed growth, by tributary inflow downstream, by artificial regulation downstream, by tidal influence, by ice, or by some combination of these. It may prove possible to deal effectively with weed growth in the manner described in 6.3.1 but the problem of tributary inflow causing variable backwater requires measurement of water surface slopes concurrently with stage measurement at the gauging site.

In reaches where artificial regulation controls the depth of flow for purposes of navigation, the water surface slopes can be extremely small, especially below median discharge, and conventional methods of discharge evaluation using water surface slope as a parameter are impracticable. A possible solution then is the generally complex one of calibrating the regulating structure which controls the reach, but the presence of river traffic and the effects of frequent locking operations introduce additional problems and, in any case, calibration of the lower range of discharges would necessarily be a theoretical assumption when reach velocities are likely to be well below the lower limit of calibration of current meters and unmeasurable leakage past the weir gate seals is then large relative to the total discharge.

When such a weir comprises a large number of gates of different kinds and dimensions the number of permutations and combinations of gate openings which will maintain the same headwater level at a given discharge can be considerable. At the same time, the supposition that the discharge of any number of gates located randomly among a group of the same kind will be the theoretical discharge of one type-gate multiplied by the number of identical gates open may well prove to be in obvious error, especially so when partial opening of gates is permitted, for it takes no account of the relative changes in hydraulic interference between gates. In the case of weir systems which include elements oblique to or in line with the approach channel axis the problem can become aggravated by significant headwater and tailwater slopes along the line of the weir such that water surface levels in respect of individual gates can be only very approximately estimated unless water surface levels are measured simultaneously at a sufficient number of locations along the weir.

For the field calibration of regulating weirs, when the practical limitations of the situation and of available methods of independent measurement of discharge restrict calibration to a relatively small number of selected discharges within the operating range of the weir, certain assumptions regarding hydraulic correspondence as between the various types of weir gates involved are unavoidable, and it is therefore a very important part of the calibration procedure to identify standard sequences of opening and closing the weir gates and to ensure that these are adhered to not only during calibration but also thereafter as routine operational procedures. Usually such standard procedures will depend primarily upon the structural and hydraulic designs of the weir and upon the operational and environmental requirements, but in some circumstances the hydrometric interest may be important enough to justify both hydraulic designs and operational procedures which are particularly favourable to consistent evaluations of discharge.

In otherwise stable reaches which are subject to tidal influence during the flood tide period only, a stable relationship between stage and discharge may often be constructed by making discharge measurements only at times of low tide, but the use of such a relationship is limited to providing discharge estimates at times of low tide. Generally, for regulated reaches, and for reaches affected by tides, a solution may be the use of the ultrasonic (acoustic) or other methods of continuous measurement of mean velocity at the gauging cross-section.

When an unstable reach contains an unstable channel the effects of shifts in control in the stage-slope-discharge relationship will be evident in the same way as for the stage-discharge relation in an unstable channel when not subject to abnormal backwater, and validation of the curves of relation as a function of time would be in accordance with the procedure outlined in 6.3.1.

6.3.2.1 *Shifting controls*

The term *shifting control* as ordinarily used in connection with measurement of flow in open channels refers to that condition where the stage-discharge relations do not remain permanent but vary from time to time, either gradually or abruptly, because of changes in the physical features that form the control for the station.

A stage-discharge curve will retain its original shape only so long as the elements that form the control retain their original physical characteristics or as long as the changes in characteristics are compensating with respect to their effects on the stage of water at the gauge. The effect of a shift in the control will generally result in a change in stage for a given discharge or, conversely, in a change in discharge shown by the rating for a given stage. Therefore, if conditions such as vegetal or aquatic growths, accumulations of ice, or the confluence (backwater) of tributary streams which disturb the permanency of the stage-discharge relation cause a change in stage, these changes in the stage-discharge relations due to shifting controls may be treated as though they were a direct result of scour or fill, or other normal changes in the physical characteristics of the bed or banks of the stream. If discharge measurements indicate that the stage-discharge relation has changed from a previous definition, it is possible to use shifting-control corrections (addition or subtraction from the gauge height) or adjustments to the gauge height record such that the effective gauge height is in agreement with the measured discharge and rating. When adjusting the gauge-height record, it is important that the integrity of the stage record be maintained. Shifting-control corrections may be applied with time and/or stage.

The frequency of changes in the stage-discharge relations due to the modification of control conditions and the magnitude of these changes are generally dependent on climate, physiographic, geologic, vegetal and soil conditions within the valley or area through which the stream flows. The primary cause of change, however, is usually channel scour or fill associated with high water velocities and/or discharges. Shifting control conditions are often so complex that it is difficult to foresee the changes that may occur or positively analyse the changes that have occurred.

There is no satisfactory substitute for discharge measurements in defining shift adjustments during periods of shifting control, especially during peak stage. Hence, every effort to obtain discharge measurements at extremes of stage should be made. Likewise, there can be no substitute for experience and familiarity with the control sensitivity in analysing the stage-discharge record using shifting-control corrections for discharge determination.

6.3.2.2 Shifting controls due to ice conditions

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 computation largely dependent on discharge measurement timing and frequency. Discharge measurements shall be made before and after the formation of the ice cover to determine the initial decrease in discharge, at appropriate intervals to define the flow recession under the ice cover, and before and after the ice breakup to determine when the open water stage discharge relation becomes applicable. Ice thickness shall be measured every time a discharge measurement is made.

Methods used to compute daily discharge are :

6.3.2.2.1 Effective gauge heights (effective stage)

Effective gauge heights are computed for each discharge measurement using the open water stage discharge relation. These effective gauge heights are then plotted on a hydrograph of daily mean gauge heights, and a hydrograph of effective gauge heights is interpolated between discharge measurements using the stage hydrograph as a guide. Daily mean discharges shall be computed using the effective gauge heights and the open water stage-discharge relation.

6.3.2.2.2 Backwater

The difference in stage between the effective gauge height and the recorded height (backwater) is computed for each discharge measurement. Backwater values between discharge measurements are interpolated using air temperature, ice thickness, or other hydrologic information as a guide. Effective gauge heights are then determined by subtracting the backwater from daily mean gauge heights. Daily mean discharges shall be computed using the effective gauge heights and the open water stage-discharge relation.

6.3.2.2.3 Modified backwater

Discharge measurements are used to compute K in the relation :

$$B = K \log Q_e / Q_i$$

where

- B is the backwater in appropriate stage units;
- K is the constant;
- Q_e is the equivalent ice free discharge from stage-discharge relation;
- Q_i is the discharge at freeze-up.

The value of K is interpolated between discharge measurements and the value of B computed for each day using the equation. Daily mean discharges shall be computed as in 6.3.2.2.2.

6.3.2.2.4 Gauge height versus backwater relation

The discharge measurements are used to determine the relationship between gauge height and backwater, with the backwater being computed as in 6.3.2.2.2. If the relationship is reasonably well defined, daily backwater values can be computed using the daily mean gauge height. Daily mean discharges shall be computed as in 6.3.2.2.2.

6.3.2.2.5 Adjusted discharge

Equivalent open water discharges are computed using gauge heights and the open water stage-discharge relation, and a discharge hydrograph prepared. The discharge measurement results are plotted on this hydrograph and a hydrograph of daily discharges interpolated between discharge measurements using the hydrograph of equivalent open water discharges as a guide. Daily mean discharges shall be determined directly from the hydrograph.

6.3.2.2.6 Interpolated discharge

Daily mean discharges shall be determined by direct interpolation, usually linear or log linear, between the values of discharge obtained by measurement. Interpolation may be modified by the use of air temperature records and the stage record as judgement tools.

6.3.2.2.7 Recession curve

Larger streams, particularly those streams which have significant lake storage, may exhibit a semi-logarithmic form of recession from the time of formation of an ice cover until breakup of the ice cover. The general mathematical form of the equation is:

$$Q_2 = Q_1 K^{-\Delta t}$$

where

- Q_2 is the discharge at time t_2 ;
- Q_1 is the discharge at time t_1 ;
- K is the recession constant;
- Δt is the elapsed time interval ($t_2 - t_1$).

If the slope of the recession line (K) is invariant from year to year, a single discharge measurement can be used to define the recession. Daily mean discharges shall be computed utilizing the recession equation or a graphical semi-logarithmic plot.

6.3.2.2.8 *Winter rating curve*

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 relation has been verified by discharge measurement, daily mean discharges shall be computed from the winter stage discharge relation and gauge heights.

One or more of the above methods of computation may prove to be satisfactory for computation of daily mean discharge under ice cover at a particular gauging station. Several methods should be tested and the method which produces the best results selected as the standard method for the gauging station.

6.3.3 *Evaluation involving surface slope (fall)*

In the case of unstable reaches, the evaluation of the stage-discharge relation requires additionally the use of the value of fall between two reference gauges located within the reach concerned, one of which is the gauging station reference gauge.

The plotting of the stage-discharge observations with the value of fall against each observation will reveal whether the relationship is affected by variable slope at all stages or is affected only when the fall reduces below a particular value. In the absence of any channel control, the discharge would be affected by the fall at all times, and the correction is applied as indicated in the constant fall method (see Annex C). When the discharge is affected only when the fall reduces below a particular value, the normal-fall method is applied (see Annex C).

6.4 **Extrapolation of the stage-discharge relation**

A stage-discharge curve should not be applied outside the range of observations upon which it is based. If estimates of flow, however, are required, they should be so identified having regard to the range, number and quality of the observations which have been made, to the natural features of the gauging station and to the conditions of flow with respect to time. Little reliance shall be placed on extrapolation below the lowest observed value (see Annex D).

6.5 **Rating table**

A rating table can be prepared directly from the stage-discharge curve(s) 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 curves**

7.1 The curves shall invariably express the stage-discharge relation objectively and shall therefore be tested for absence from bias and goodness of fit in the periods between shifts of control, and for the shifts in control. Methods for locating shifts in control in the stage-discharge curves due either to physical changes in the channel features or to changes occurring in course of time are also indicated in Annex A.

7.1.1 *Bias test for check gaugings* (test 1)

As long as check gaugings plot within the S_e uncertainty band without significant bias, the established stage-discharge relation may be considered valid. A test such as the Student's " t " test is recommended to decide whether check gaugings can be accepted as being part of the homogeneous sample of observations making up the stage-discharge curve. Such a test will indicate whether or not the stage-discharge relation requires re-calculation or the section requires re-calibration.

7.1.2 When carrying out any test for bias, the check gaugings should relate to a homogeneous period of time such as a water year or a winter or summer season.

7.1.3 An example of Student's " t " test (test 1) is given in Annex A (see Table 5).

7.1.4 *Tests for bias for unstable channels* (tests 2 and 3)

For stable channels where the control is uniform and remains unchanged, it will be possible to fit a mathematical curve as explained in clause 6. More frequently, even in a stable channel, where the curve has to be drawn by visual estimation, for example when the section is not uniform, the tests described for unstable channels become equally necessary.

7.1.5 In the case of natural unstable channels, different controls come into operation at different stages in different years, so that not only are the curves for the rising and falling stages different from each other and from year to year, but there are also inflexions and discontinuities due to shifts in control within a stage. The inordinate labour involved in fitting the high-degree composite curves rules them out in practice. The best-fitting rising and falling curves have, therefore, to be drawn by visual estimation and shall therefore be tested, for absence from bias and for goodness of fit, separately for the individual portions between shifts in control.

7.1.6 For absence from bias, there are two tests. In one, the curve is tested to satisfy the basic requirements that a significantly equal number of points are expected to lie above and below an unbiased curve so that the deviations are not more than those due to chance fluctuations (test 2). In the other, the condition that the algebraic sum of the percentage deviations of the observed discharges from an unbiased curve should not be significantly different from zero is tested by comparing the mean of the percentage deviations with the standard error (test 3).

7.1.7 Test for goodness of fit (test 4)

For goodness of fit, a test is applied to check that a sign-change in deviations (i.e. observed value minus expected value from the curve) is as likely as a non-change of sign. This test also helps in detecting shifts in control at different stages (test 4).

7.1.8 It is as important for the analyst to try to understand why the measurements plot as they do on a stage-discharge relation as it is to apply certain statistical tests. The analyst should consider what has been happening to the controlling stream characteristics to help in understanding why various measurements plot as they do.

7.2 The tests recommended in **7.1.1**, **7.1.4** and **7.1.7** are described in Annex A with examples illustrating their application.

8 Uncertainty in the stage-discharge relation and in a continuous measurement of discharge

8.1 Methods for estimating the uncertainties in the stage-discharge relation and daily mean, monthly mean, and annual discharge are given in Annex A (see **A.3**). Examples of the procedure are given in this section.³⁾

³⁾ In Annex A, clause **A.3**, the statistical analysis considers each segment of the rating curve between inflexion points. These segments are treated separately and Figure 2 shows one such segment. Statistical analysis is appropriate when a logarithmic transformation is possible.

8.1.1 Example of calculation for S_e and S_{mr}

Using the stage-discharge curve tabulation in Table 1 for the curve in Figure 2, the required tabulation for S_e and S_{mr} is given in Table 3 where the logarithms are to the base 10.

S_e from equation **A.3.2.3 a)** gives

$$\begin{aligned} S_e &= t \left[\frac{31}{30} \left(\frac{12,336\ 4}{31} - \frac{1,530\ 1^2 \times 5,266\ 5}{31} \right) \right]^{1/2} \\ &= t (0,000\ 2)^{1/2} \\ &= 2 \times 0,014\ 14 \times 2,3 \times 100 \\ &= \pm 6,2\ \% \end{aligned}$$

S_e from equation **A.3.2.3 b)** gives

$$\begin{aligned} S_e &= t \left(\frac{0,005\ 48}{30} \right)^{1/2} \\ &= 2 \times 0,0135 \times 2,3 \times 100 \\ &= \pm 6,2\ \% \end{aligned}$$

S_e from the equation in **A.3**, note 6, gives

$$\begin{aligned} S_e &= t \left(\frac{291,18}{30} \right)^{1/2} \\ &= 2 \times 3,115 \\ &= \pm 6,2\ \% \end{aligned}$$

The calculation for S_{mr} for each of 32 observations proceeds from the equation in **A.3.2.4** as follows:

$$\begin{aligned} \text{For observation No. 1, } S_{mr} &= t S_e \left(\frac{1}{32} + \frac{0,351\ 2}{5,266\ 5} \right)^{1/2} \\ &= 6,2 \times 0,313 \\ &= \pm 1,94\ \% \end{aligned}$$

$$\begin{aligned} \text{For observation No. 18, } S_{mr} &= t S_e \left(\frac{1}{32} + 0 \right)^{1/2} \\ &= 6,2 \times 0,177 \\ &= \pm 1,1\ \% \end{aligned}$$

$$\begin{aligned} \text{For observation No. 32, } S_{mr} &= t S_e \left(\frac{1}{32} + \frac{0,518\ 3}{5,266\ 5} \right)^{1/2} \\ &= 6,2 \times 0,360 \\ &= \pm 2,23\ \% \end{aligned}$$

NOTE 1 The S_{mr} values in Table 3 have been calculated by a computer program and therefore differ slightly from the above values.