INTERNATIONAL STANDARD

ISO 1100-2

Second edition
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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

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 m²	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

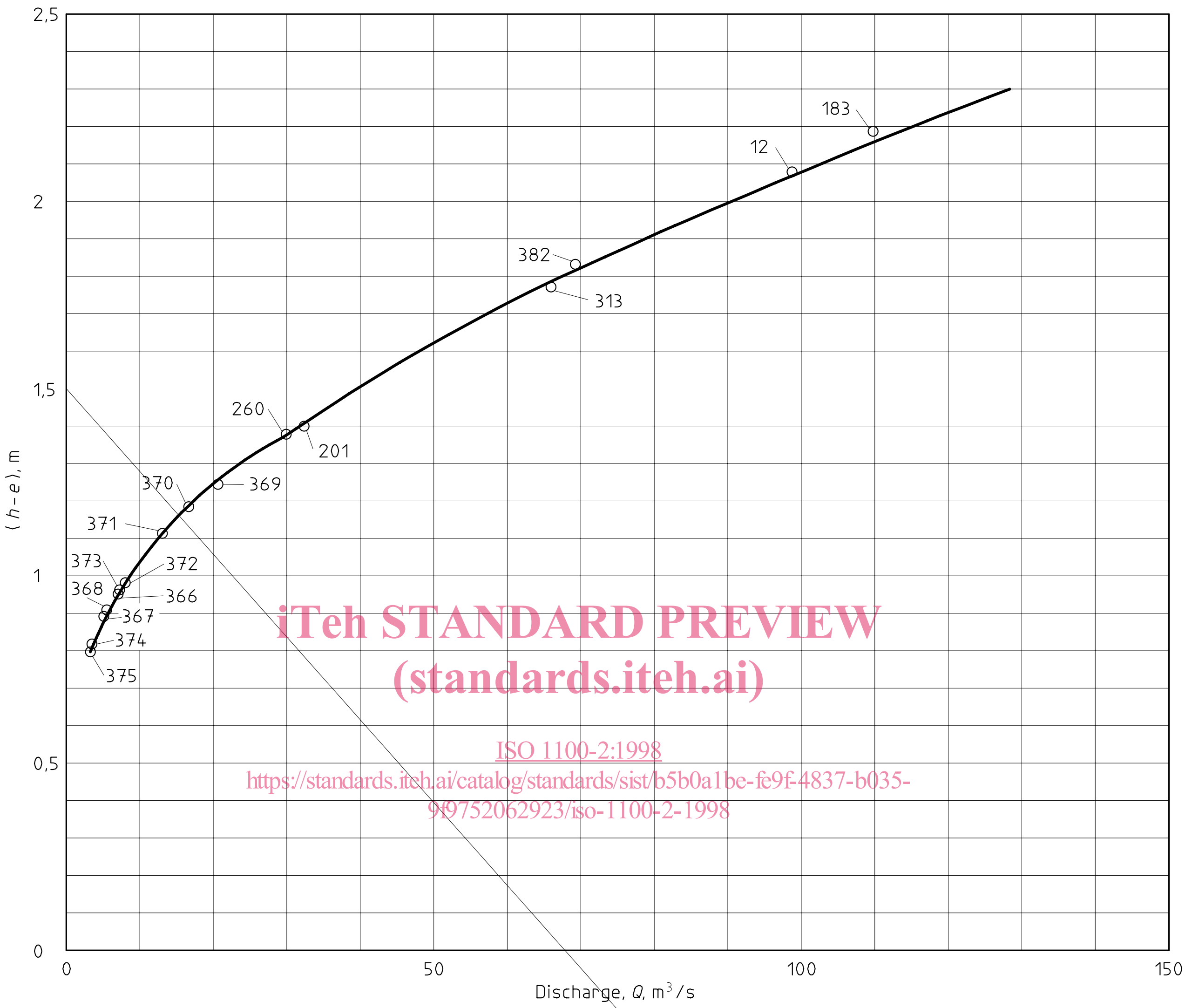
6.2.3 Arithmetic plotting scales

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.

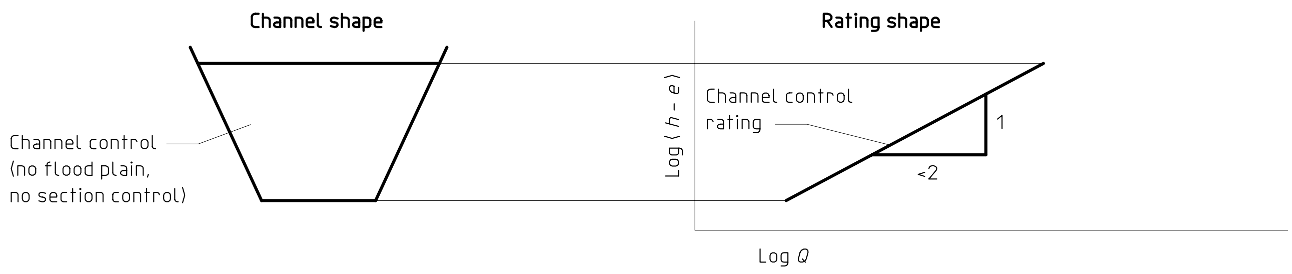
The above discussion applies to control sections of regular shape (triangular, trapezoidal, parabolic, etc.). When a significant change in shape occurs, such as a trapezoidal section control with a small V-notch for extreme low water, there will be a change in the rating curve slope at the point where 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



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