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Liquid flow measurements in open channels — Stage-fall-discharge relations

Mesure de débit des liquides dans les canaux découverts — Relations hauteur-chute-débit

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ISO/TR 9123 was prepared by Technical Committee ISO/TC 113, *Measurement of liquid flow in open channels*.

The reasons which led to the decision to publish this document in the form of a technical report type 2 are explained in the Introduction.

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0 Introduction

During the study of this document, ISO/TC 113 was unable to come to agreement as to whether the document belonged to a specific measuring technique. At its meeting held in 1983 in The Hague (Netherlands), ISO/TC 113 decided that the document should be published first as a Technical Report and thereafter it could be considered for publication as an International Standard in its own right or as an annex to an existing International Standard.

1 Scope and field of application

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

2 Reference

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

3 Definitions and symbols

For the purposes of this Technical Report, the definitions and symbols given in ISO 772 and the following definitions apply.

3.1 rating : The relation between discharge and other variables.

3.2 unit-fall rating : The relation between stage and discharge when the fall is equal to 1 m.

4 General considerations

Most programmes for collecting records of discharge of streams are based on the fact that a relatively simple relation exists between stage and discharge so that by simply recording stage and developing the stage-discharge relation, a continuous record of discharge can be computed. Several factors, however, can cause scatter of discharge measurements about the stage-discharge relation at some stations; backwater is one of these factors and is defined as a condition whereby the flow is retarded so that a higher stage is necessary to maintain a given discharge than would be necessary if the backwater were not present.

Constant backwater, as caused by section controls for instance, will not adversely affect the stage-discharge relation. The presence of variable backwater, on the other hand, does not allow the use of simple stage-discharge relations for accurate determination of discharge. Regulated streams may have variable backwater virtually all of the time, while other streams will have only occasional backwater from downstream tributaries, vegetal growth, or from the return of overbank flow. Many of these sites can be operated as slope stations by using a reference gauge at which stage is measured continuously and current-meter measurements of discharge are made occasionally. An auxiliary gauge some distance downstream from the reference gauge is operated to measure stage continuously. When the two gauges are set to the same datum, the difference between the two stage records is the water-surface fall and provides a measure of water-surface slope. The shorter the slope reach, the closer the relation between measured fall and water-surface slope. On the other hand, the longer the slope reach, the smaller the percentage of error in the recorded fall. Precise time synchronization between reference and auxiliary gauges is very important when stage changes rapidly, or when fall is small. Reliable discharge records can usually be computed when fall exceeds about 0,1 m. Timing and gauge-height errors that are trivial at high discharges become significant at very low flow.

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

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

b) variable-fall ratings.

Unit-fall ratings are the simplest and require the least amount of data for calibration. The unit-fall rating should be used as a starting point before attempting more complex ratings. Variable-fall ratings are the most complex and require the most data for calibration. The applicable type of rating for a stream reach depends to a large degree on whether the backwater is intermittent or always present.

Constant-fall ratings work best when backwater is always present at all stages, but can sometimes be adapted to intermittent backwater conditions.

Variable-fall ratings work best for the intermittent backwater condition.

5 Unit-fall method

The unit-fall method is used with the assumption that the relation between the discharge ratio (Q/Q_n) and the fall ratio (F/F_n) is exactly a square root relation, as given by the following formulae :

$$\frac{Q}{Q_n} = \sqrt{\frac{F}{F_n}} = \sqrt{\frac{F}{1}} = \sqrt{F}$$

$$Q = Q_n \sqrt{F} \text{ or } Q_n = \frac{Q}{\sqrt{F}}$$

where

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

F is the measured fall, in metres;

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

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

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

The rating shall be used to compute discharge by determining the value of Q_n from the rating for a given reference gauge height, and multiplying this discharge by the square root of the measured fall. This type of rating will usually be satisfactory when backwater is always present, fall is greater than about 0,1 m, and the datums of the two gauges are within about 0,01 m.

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

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

6 Constant-fall method

A constant-fall method requires the use of the following two curves :

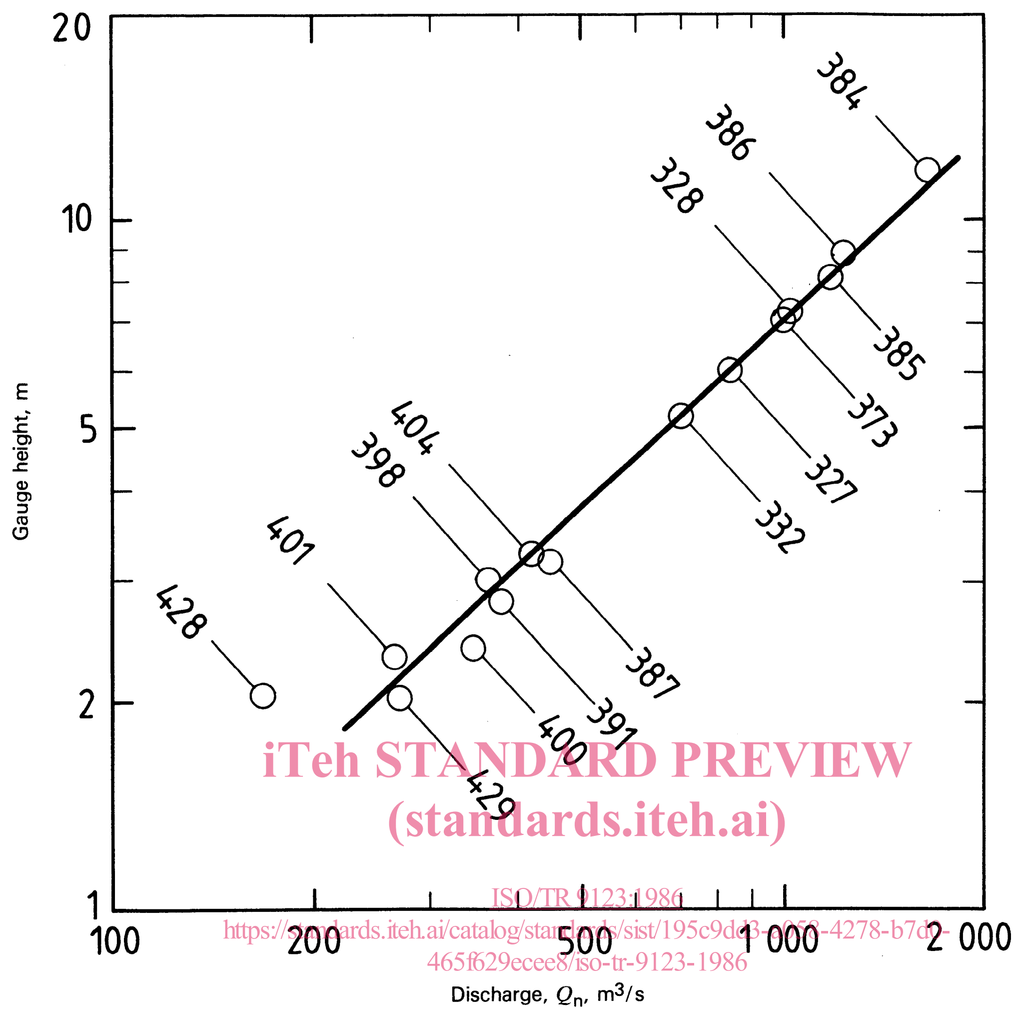
a) the relation between stage and discharge for a constant fall of some specified value;

b) the relation between measured fall, F, and the discharge ratio, Q/Q_n.

A unique feature of the constant-fall method is that the reference gauge and auxiliary gauge need not be at the same datum.

One method of developing a constant-fall rating is to compute first a unit-fall rating. This relation of stage to discharge can then be used to compute discharge ratios, Q/Q_n, for each discharge measurement. These ratios shall be plotted against the measured fall, or gauge differences, to define the relation between fall and the discharge ratio. This curve shall then be used to refine the stage-discharge relation. Alternate refinements of the two curves shall be continued until little or no improvement occurs. This usually takes only two or three trials. The resultant stage-fall-discharge relation is similar to a unit-fall rating but without the assumption that the ratio curve varies as a square root function.

Another method of developing a constant-fall rating is to develop a stage-discharge relation corresponding to the average fall in the slope reach. This will result in a stage-discharge rating corresponding more closely to average conditions. The average fall is computed by arithmetically averaging the measured falls occurring under various conditions of backwater. This number may be rounded to a convenient value and is designated as the constant fall, F_n. To define the rating, first each measured discharge divided by the square root of F/F_n shall be plotted against the corresponding stage at the reference gauge. The square root shall only be used to start with, but it shall be later adjusted. A curve shall be fitted to the plotted points and the curve value of discharge, Q_n, shall be determined for each discharge measurement. The ratio of Q/Q_n shall be plotted against the measured fall, F, for each discharge measurement and a curve shall be fitted to these points.



NOTE — The numbers on the plot refer to the measurement number (see table 1).

Figure 1 — Unit-fall rating

Table 1 — Unit-fall rating

Measurement No.	Gauge height m	F m	Q m³/s	$Q/\sqrt{F_n}$	Q_n m³/s	Difference %
327	5,907	1,917	1 160	838	840	– 0,2
328	7,105	2,182	1 520	1 030	1 030	0
332	5,026	1,597	889	703	700	0,4
373	7,013	2,225	1 490	1 000	1 000	0
384	11,558	2,880	2 830	1 670	1 700	– 1,8
385	8,108	1,920	1 640	1 180	1 190	– 0,8
386	8,638	2,652	1 990	1 220	1 260	– 3,3
387	3,139	0,808	399	444	410	7,7
391	2,755	0,701	317	379	360	5,0
398	2,963	0,616	289	368	388	– 5,4
400	2,359	0,204	156	345	300	13,0
401	2,286	0,290	145	269	290	– 7,8
404	3,206	0,927	411	427	426	0,2
428	2,036	0,058	39,9	166	255	– 53,6
429	2,012	0,061	66,0	267	250	6,4

The two curves shall be refined by alternately adjusting one while holding the other constant. Two or three trials will usually be adequate. For clarity, variables denoted with a prime ′ are those determined directly from a relationship curve.

Figures 2 and 3, and table 2 illustrate a constant-fall rating developed from the same data used in figure 1 and table 1, and corresponds to a constant fall of 1,3 m. The unit-fall and constant-fall ratings essentially give the same results and indicate the unit-fall would be as good as the constant-fall rating. Both ratings indicate larger percentage errors in the low-discharge range, as would be expected, because of more difficult measuring conditions.

7 Variable-fall method

7.1 General

Variable-fall methods can be grouped into the following two types which differ according to how the stage-fall rating is defined :

a) the normal-fall method, in which the relation between stage and fall is defined by drawing a curve through the average fall experienced at each gauge height;

b) the limiting-fall, or free-fall, method in which a relation between stage and fall is developed which represents the minimum fall affected by backwater.

7.2 Normal-fall method

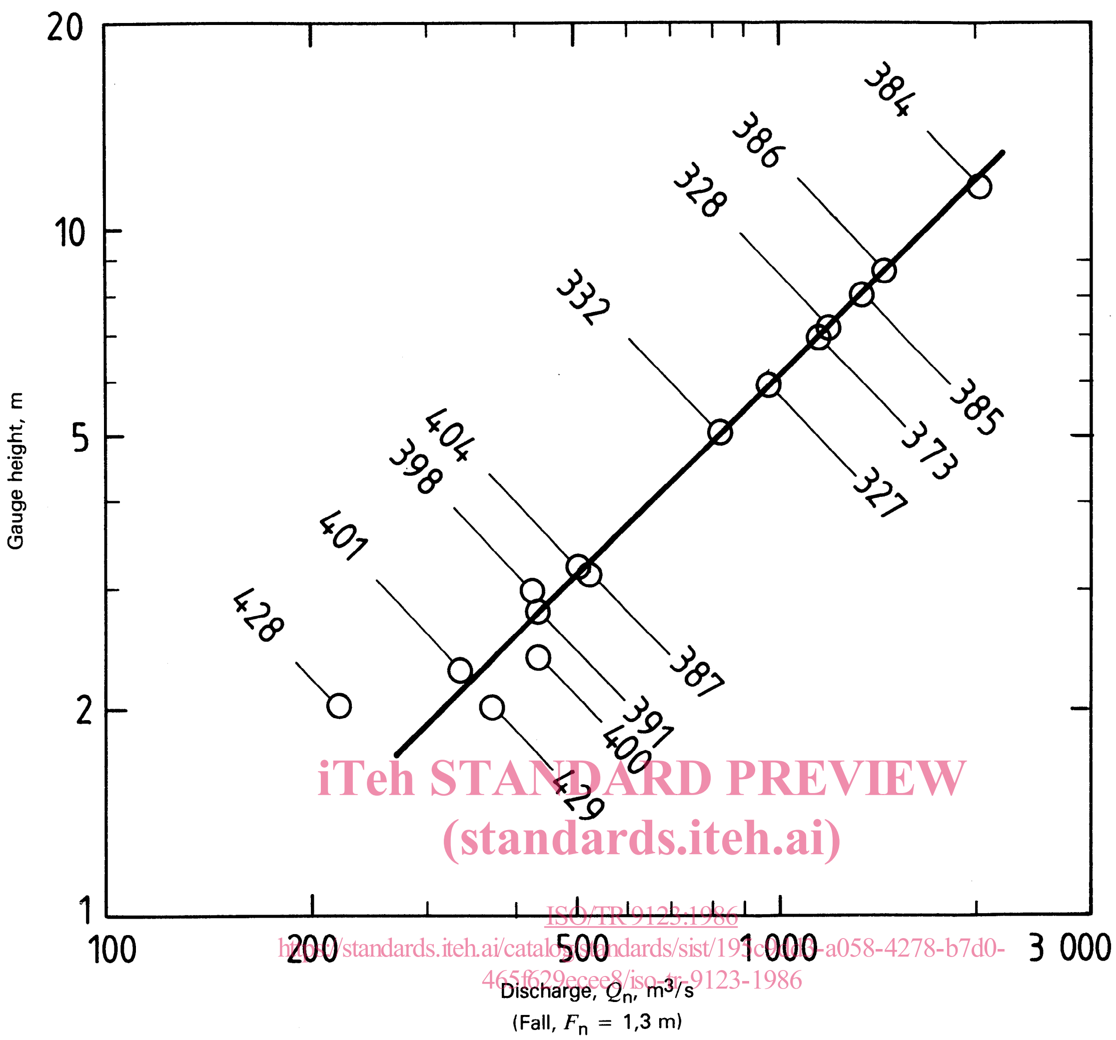
The method for developing a normal-fall rating is similar to that for developing the limiting-fall rating and will not be described here in detail. In the normal-fall method, the stage-discharge relation will correspond to average-fall conditions and can be used only when backwater is present. A separate non-backwater rating is needed to compute discharge if there are times when backwater is not present. For this situation discharge shall be computed by both ratings, and the lower of the two values is considered to be correct.

7.3 Limiting-fall method

The limiting-fall method is best for situations where there are times when backwater is not present. The first step in the limiting-fall method is to plot all measured discharges against the reference gauge height and label each point with the measured fall, F. A stage-discharge curve shall be drawn so as to pass through those measurements which are not affected by backwater. The measured fall, F, shall be plotted on a separate plot against the reference gauge height. A curve shall be drawn through those points representing the minimum fall, but which are free of backwater. For most sites there will be points both to the right and left of this curve. Those points to the right represent falls exceeding the limiting, or minimum, fall which is affected by backwater. Thus the name limiting-fall rating.

Values of Q_r' and F_r' shall be determined from the discharge rating and from the fall rating, respectively, for each discharge measurement and the ratios Q/Q_r' and F/F_r' shall be computed. These ratios shall be plotted against each other and an average ratio curve shall be drawn. Each of the three curves, i.e. the stage-fall, stage-discharge and ratio curves, shall be each in turn refined by holding two of them constant while recomputing and replotting the third one. Two or three trials will usually be adequate.

Figures 4, 5 and 6, and table 3 illustrate the final results of a limiting-fall rating for a site with intermittent backwater. In figure 5 the plotted points show the fall after adjustment by the fall ratio. In the limiting-fall method the stage-discharge rating is essentially a non-backwater rating and can be used to compute discharge either when it is present or when it is not present. This is an advantage of the limiting-fall method, because a separate non-backwater rating is not required as in the normal-fall rating. The limiting-fall rating is the most complex of all the various fall ratings, but provides for the best use of the available data.



NOTE — The numbers on the plot refer to the measurement number (see table 2).

Figure 2 — Constant-fall rating

Table 2 — Constant-fall rating
(F_n = 1,3 m)

Measurement No.	Gauge height	F	Q	F/F_n	Q'_n (from figure 2)	Q/Q'_n	$(Q/Q_n)'$ (from figure 3)	$Q_n = \frac{Q}{(Q/Q_n)'}$	$Q = Q'_n \times (Q/Q_n)'$	Difference in measured value of Q
	m	m	m^3/s		m^3/s			m^3/s	m^3/s	%
327	5,907	1,917	1 160	1,475	980	1,184	1,185	979	1 160	0
328	7,105	2,182	1 520	1,678	1 200	1,267	1,260	1 210	1 510	0,7
332	5,026	1,597	889	1,228	825	1,078	1,075	827	887	0,2
373	7,013	2,225	1 490	1,712	1 190	1,252	1,270	1 190	1 510	– 1,3
384	11,558	2,880	2 830	2,215	2 030	1,394	1,396	2 030	2 830	0
385	8,108	1,920	1 640	1,477	1 380	1,188	1,185	1 380	1 640	0
386	8,638	2,652	1 990	2,040	1 480	1,345	1,350	1 470	2 000	– 0,5
387	3,139	0,808	399	0,622	500	0,798	0,755	530	378	5,3
391	2,755	0,701	317	0,539	440	0,720	0,700	440	308	2,8
398	2,963	0,616	289	0,474	465	0,622	0,660	438	307	– 6,2
400	2,359	0,204	156	0,157	375	0,416	0,350	446	131	16,0
401	2,286	0,290	145	0,223	355	0,408	0,430	337	153	– 5,5
404	3,206	0,927	411	0,713	510	0,806	0,805	511	411	0
428	2,036	0,058	39,9	0,045	305	0,131	0,180	222	54,9	– 37,6
429	2,012	0,061	66,0	0,047	303	0,218	0,175	377	53	19,7

NOTE — For clarity, variables denoted with a prime ′ are those determined directly from a relationship curve.

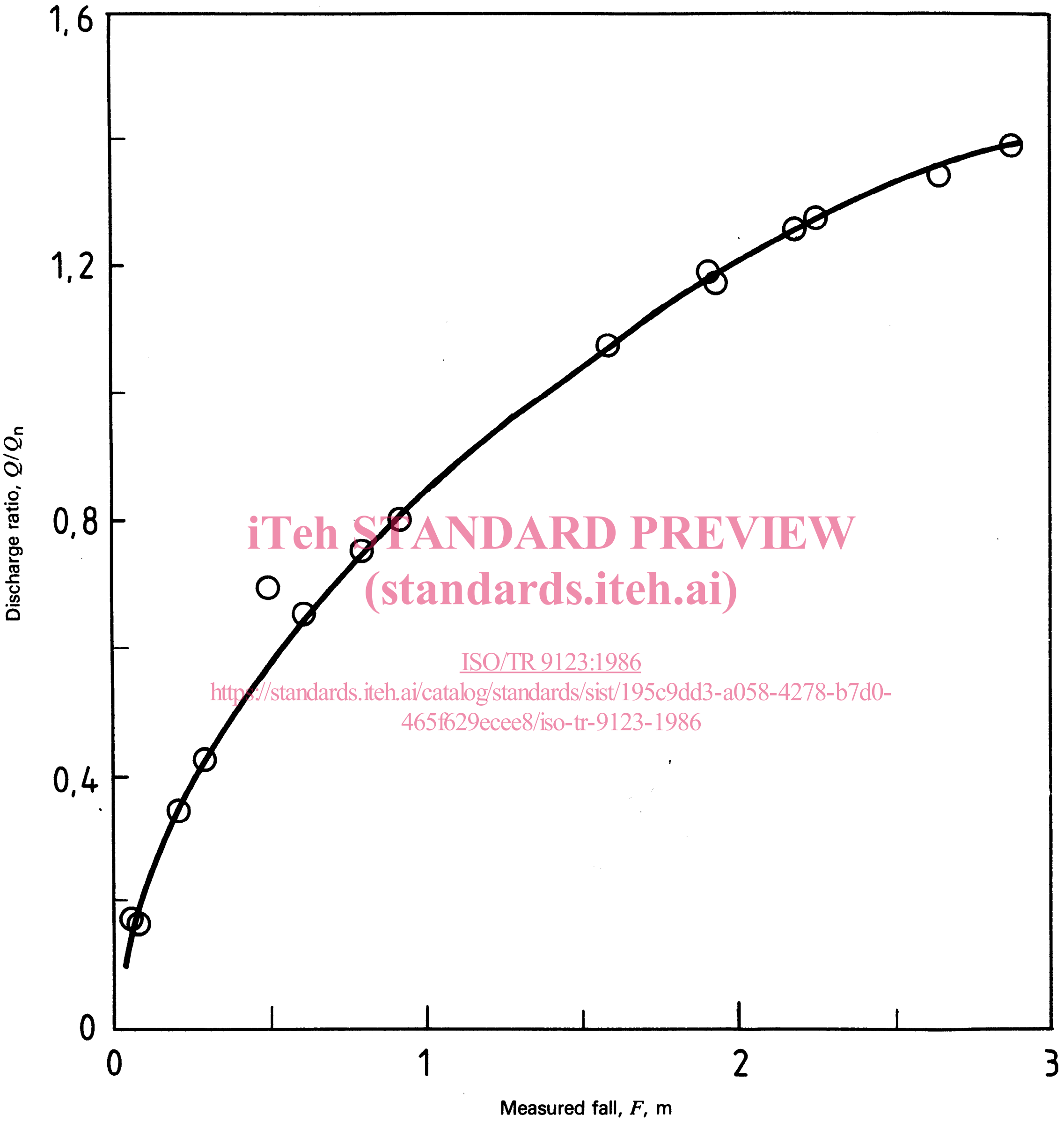
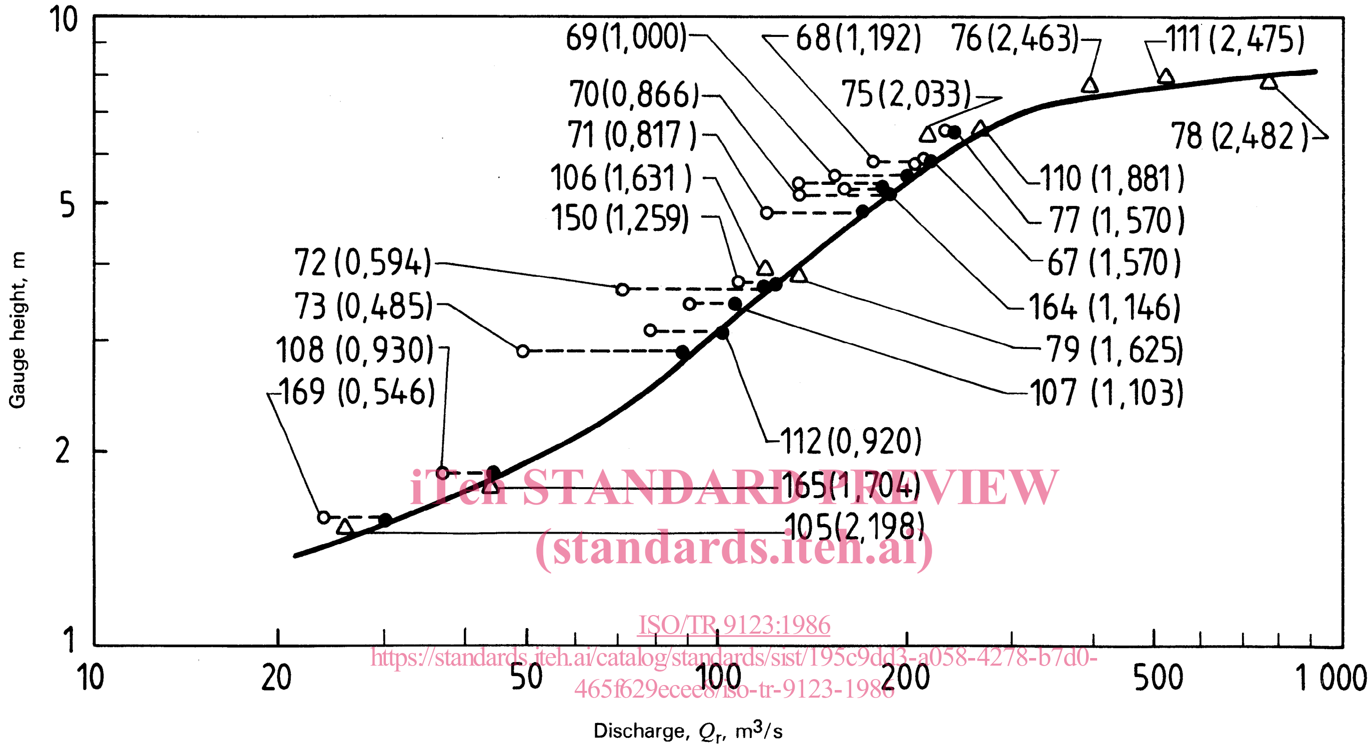
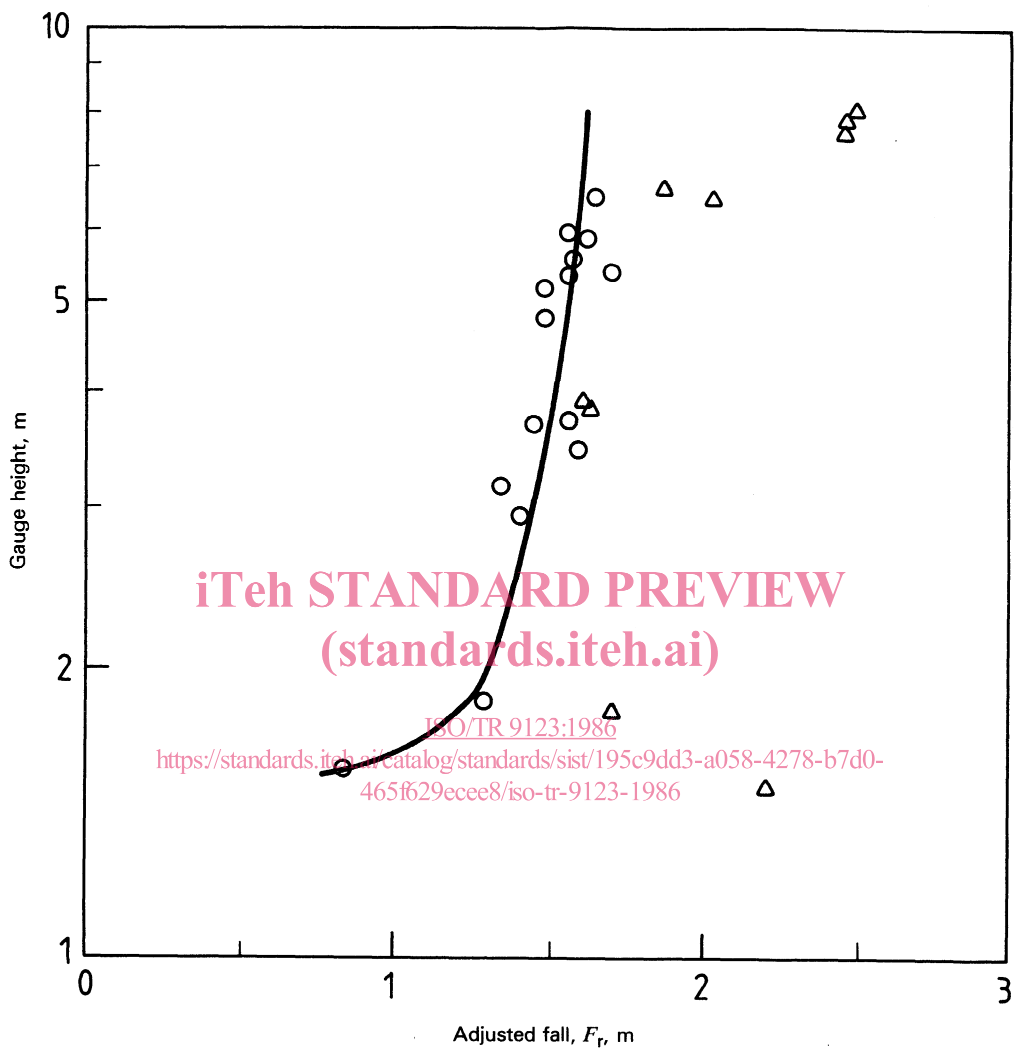


Figure 3 — Constant-fall ratio curve



NOTE — The numbers on the plot refer to the measurement number with the measured fall, *F*, given in parentheses (see table 3). The symbol Δ is used to indicate non-backwater measurements.

Figure 4 — Limiting-fall rating



NOTE — The symbol Δ is used to indicate non-backwater measurements.

Figure 5 — Stage-fall relation