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Measurement of liquid flow in open channels — Stage-fall-discharge relationships

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

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 9123 was prepared by Technical Committee ISO/TC 113, *Hydrometric determinations*, Subcommittee SC 1, *Velocity area methods*.

This first edition of ISO 9123 cancels and replaces Technical Report ISO/TR 9123:1986, which has been technically revised.

Measurement of liquid flow in open channels — Stage-fall-discharge relationships

1 Scope

This International Standard specifies methods for determining stage-fall-discharge relationships 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 gauge height measurements. A number of discharge measurements are required in order to calibrate the rating to the accuracy required by this International Standard.

The preparation of rating curves is not described in detail in this International Standard.

NOTE For a more detailed description of preparing rating curves, see the methods described in ISO 1100-2

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

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

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

ISO 1100-2, *Measurement of liquid flow in open channels — Part 2: Determination of the stage-discharge relation*.

3 Terms and definitions

For the purposes of this International Standard, the terms and definitions and symbols given in ISO 772 apply. Note, however that the application of the definition of backwater given in ISO 772 to the determination of discharge under intermittent or continuous backwater conditions should take into account that a higher gauge height would prevail for a given discharge than would be the case if the variable backwater was not present.

4 Units of measurement

The International System of Units (SI System) is used in this International Standard in accordance with ISO 1000.

5 General considerations

5.1 Importance of backwater

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

5.2 Backwater conditions

Constant backwater, as caused by section controls for instance, will not adversely affect the stage-discharge relationship. The presence of variable backwater, on the other hand, does not allow the use of simple stage-discharge relationships 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.

5.3 Gauging requirements

Many of these sites can be operated as stage-fall-discharge stations by using a reference gauge at which gauge height 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 gauge height continuously. When the two gauges are set to the same datum, the difference between the two gauge height records is the water-surface fall and provides a measure of water-surface slope. The shorter the slope reach, the closer the relationship 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 gauge height 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.

5.4 Types of stage-fall-discharge relationships

5.4.1 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 relationship. Stage-fall-discharge methods fall into the following two broad categories:

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

b) variable-fall method.

The applicable method for a stream reach depends to a large degree on whether the backwater is intermittent or always present.

5.4.2 The constant-fall method works best when backwater is always present at all gauge heights, but can sometimes be adapted to intermittent backwater conditions.

5.4.3 The unit-fall method is the simplest and requires the least amount of data for calibration. The unit-fall method should be used as a starting point before attempting more complex methods.

5.4.4 Variable-fall methods are the most complex and require the most data for calibration. The variable-fall method works best for the intermittent backwater condition.

NOTE The unit-fall method, the constant-fall method and the variable-fall method, are also referred to in this International Standard as unit-fall rating, constant-fall rating and variable-fall rating.

6 Unit-fall method

6.1 General

The unit-fall method is a special case of the constant-fall method, where the constant fall is unity (1 m). The unit-fall method is used with the assumption that the relationship between the discharge ratio (Q/Q_c) and the fall ratio (h/h_c) is exactly a square root relationship, as given by the following formulae:

$$Q/Q_\text{c} = (h/h_\text{c})^{0,5} = (h/1)^{0,5} = h^{0,5}$$

$$Q = Q_\text{c}(h^{0,5}) \text{ or } Q_\text{c} = Q/(h^{0,5})$$

where

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

h is the measured fall, expressed in metres;

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

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

6.2 Method of analysis

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.

6.3 Computation of discharge

The rating shall be used to compute discharge by determining the value of Q_c 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.

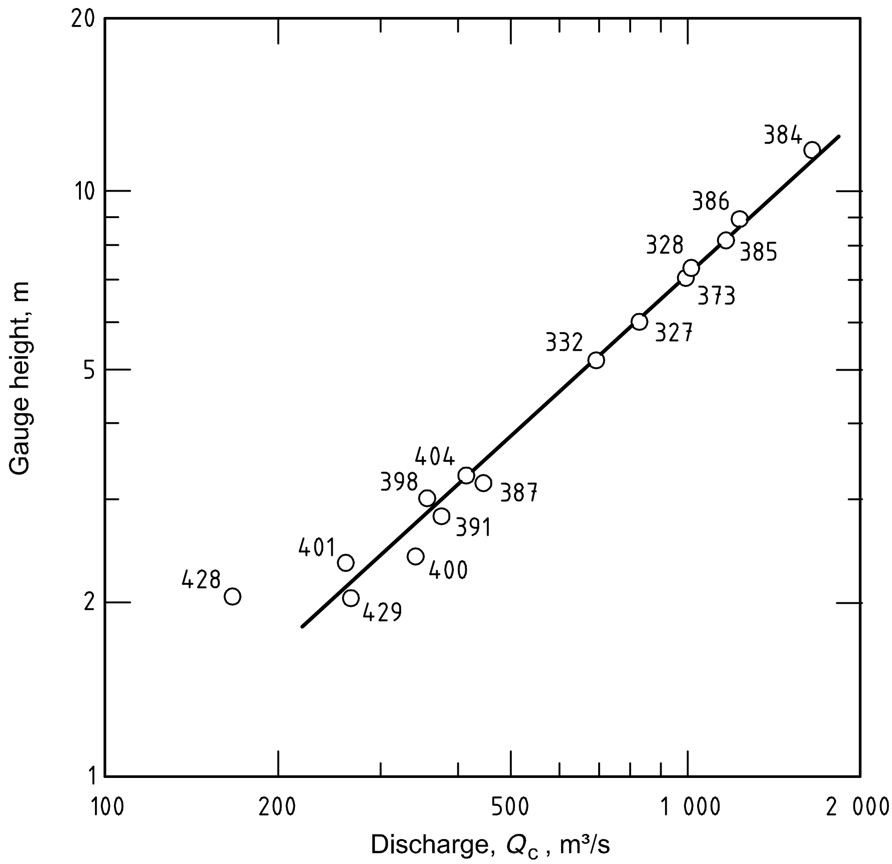
If backwater is intermittent, it is also necessary to develop a free-fall rating or rating where backwater is not present. The free-fall rating shall be used at all times except during periods when backwater is suspected, during which times discharge should be computed from both the free-fall and unit-fall ratings. The lower of the two discharges shall be considered to be the true value.

6.4 Example of unit-fall method

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 gauge heights and at all times.

Table 1 — Unit-fall calibration measurements

Measurement No.	Gauge height m	h m	Q m^3/s	$Q\sqrt{h}$	Q_c m^3/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



Fall, $h_c = 1$ m

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

Figure 1 — Unit-fall rating

7 Constant-fall method

7.1 General

The constant-fall method is more complex than the unit-fall method in that it uses two relationship curves. In addition, it does not require that the constant fall be equal to unity, but can be any selected value. The constant fall is usually selected to be equal to the average fall in the gauging reach. The constant-fall method requires the use of the following two curves:

a) the relationship between gauge height and discharge for a constant fall of some specified value;

b) the relationship between measured fall, h, and the discharge ratio, Q/Q_c.

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

7.2 Method of analysis

One method of developing a constant-fall rating is to compute first a unit-fall rating, as described in 6.2. This relationship between gauge height to discharge can then be used to compute discharge ratios, Q/Q_c, for each discharge measurement. These ratios shall be plotted against the measured fall, or gauge differences, to define the relationship between the fall and the discharge ratio. This curve shall then be used to refine the stage-discharge relationship. 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 relationship is similar to a unit-fall rating but without the assumption that the ratio curve varies as a square root function.

A second method of developing a constant-fall rating is to develop a stage-discharge relationship 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, h_c.

To define the rating, first each measured discharge is divided by the square root of h/h_c, then this value is plotted against the corresponding gauge height at the reference gauge. The square root shall only be used initially and shall be later adjusted. A curve shall be fitted to the plotted points and the curve value of discharge Q_c, shall be determined for each discharge measurement. The ratio of Q/Q_c shall be plotted against the measured fall, h, for each discharge measurement and a curve shall be fitted to these points.

The two curves, gauge height versus discharge, Q_c and measured fall, h, versus discharge ratio, Q/Q_c, shall be refined by alternately adjusting one while holding the other fixed. Two or three trials will usually be adequate. For clarity, variables denoted with a star (*) are those determined directly from a relationship curve.

7.3 Computation of discharge

Discharge is computed from constant-fall ratings by the following procedure:

a) Enter the constant-fall rating with the gauge height and determine the rating discharge, Q_c^*.

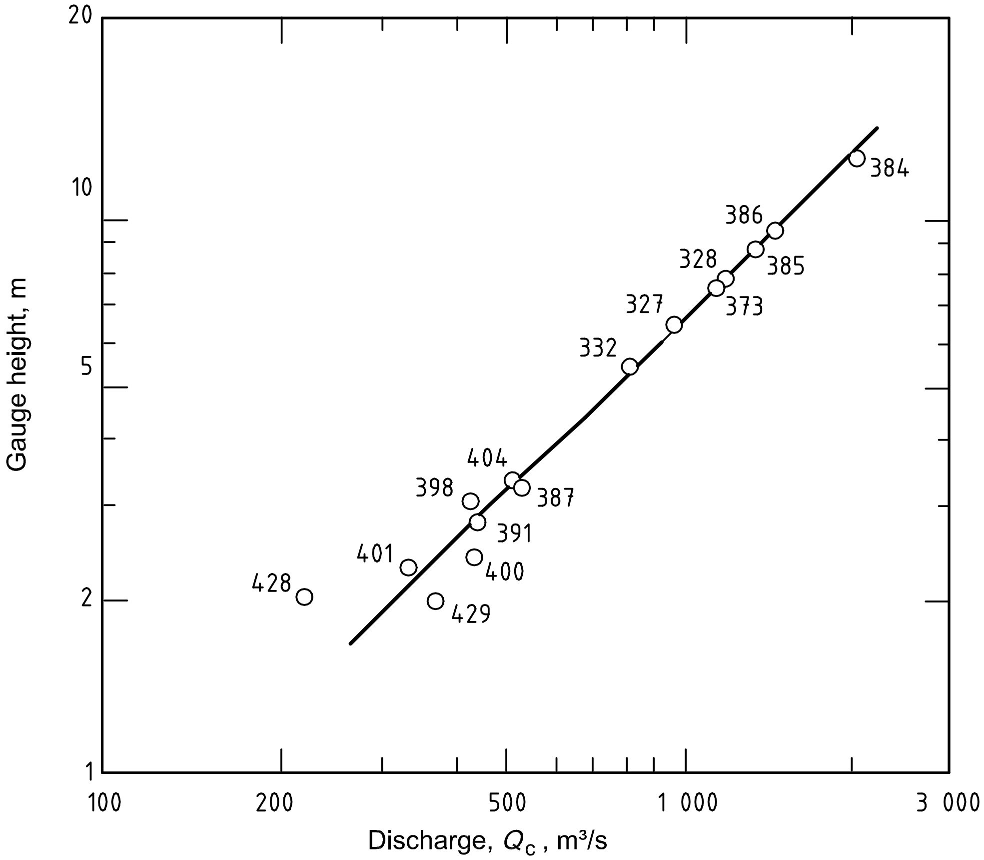
b) Enter the constant-fall ratio curve with the measured fall, h, and determine the ratio $(Q/Q_\mathrm{c})^*$.

c) Multiply the rating discharge, Q_c by the ratio $(Q/Q_\mathrm{c})^*$ to obtain the true discharge, Q.

7.4 Example of constant-fall method

Figures 2 and 3, and Table 2 illustrate the constant-fall method developed from the same data used in Table 1, and corresponding to a constant fall of 1,3 m. This rating was developed using the second procedure described in 7.2. The curves in Figures 2 and 3 are the final results of several trials and refinements.

The unit-fall example described in 6.4, and the constant-fall ratings described in this clause give essentially the same results and indicate the unit-fall method is as good as the constant-fall method in this instance. Both ratings indicate large percentage errors in the low-discharge range, as would be expected, because of more difficult measuring conditions.



Fall, $h_c = 1{,}3$ m
The numbers on the plot refer to the measurement number (see Table 2).

Figure 2 — Constant-fall stage-discharge-rating curve

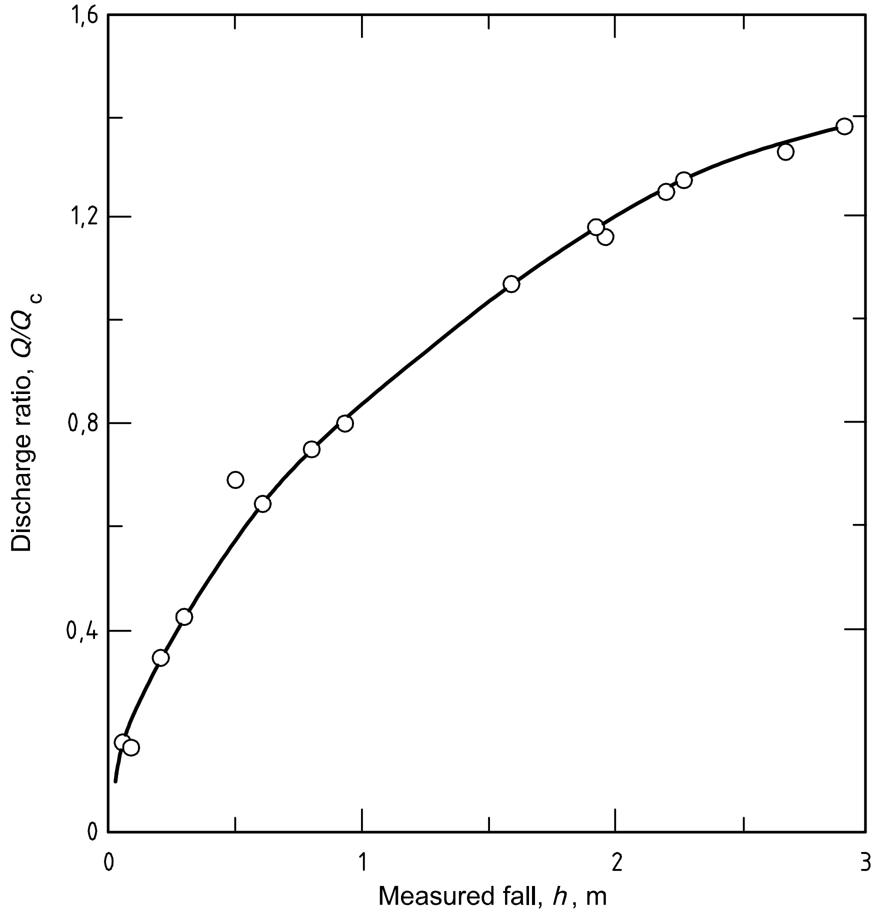


Figure 3 — Constant-fall ratio curve

Table 2 — Constant-fall calibration measurements (h_c = 1,3 m)

Measurement No.	Gauge height m	h m	Q m³/s	h/h_c	Q_c^* [a] m³/s	Q/Q_c^*	$(Q/Q_c)^*$ [b]	Q_c [c] m³/s	Q [d] m³/s	Difference in measured value of Q %
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 star (*) are those determined directly from a relationship curve.

[a] Value taken from the curve in Figure 2.

[b] Value taken from the curve in Figure 3.

[c] $Q_c = \frac{Q}{(Q/Q_c)^*}$

[d] $Q = Q_c^* \times (Q/Q_c)^*$

8 Variable-fall method

8.1 General

Variable-fall methods are the most complex of all stage-fall-discharge relationships, and 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 relationship between gauge height 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 relationship between gauge height and fall is developed which represents the minimum fall affected by backwater.

8.2 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 relationship will correspond to average-fall conditions and can be used only when backwater is present. A separate rating where backwater is not present 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 lesser of the two values shall be considered to be correct.

8.3 Limiting-fall method

8.3.1 General

The limiting-fall method is best for gauging stations where there are times when backwater is not present. In this method, the rating curve of gauge height versus discharge defines a condition where backwater is not present. This same rating curve can be used to compute discharge at other times when backwater is present. This feature makes the limiting-fall method the most versatile of all stage-fall-discharge methods for streams where backwater is intermittent.

8.3.2 Method of analysis

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, h. A stage-discharge curve shall be drawn so as to pass through those measurements which are not affected by backwater.

Second, the measured fall, h, 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. Points to the right represent falls exceeding the limiting, or minimum, fall which is affected by backwater. Thus the name limiting-fall rating.

Thirdly, values of Q_r^* and h_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 h/h_r^* shall be computed. These ratios shall be plotted against each other and an average ratio curve shall be drawn.

Finally, each of the three curves, i.e., the stage-fall, stage-discharge and limiting-fall 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.

8.3.3 Computation of discharge

The three curves can be used to compute discharge by the following procedure:

a) Determine the gauge height and corresponding measured fall, h, for which discharge is to be computed.

b) Enter the measured discharge rating, Q, with the gauge height, and determine the rating discharge, Q_r^*, from the limiting-fall stage-discharge rating curve.

c) Enter the fall rating h with the gauge height, and determine the rating fall, h_r^* from the limiting-fall stage-fall relationship curve.

d) Compute the fall ratio by dividing the measured fall, h, by the rating fall, h_r^*.

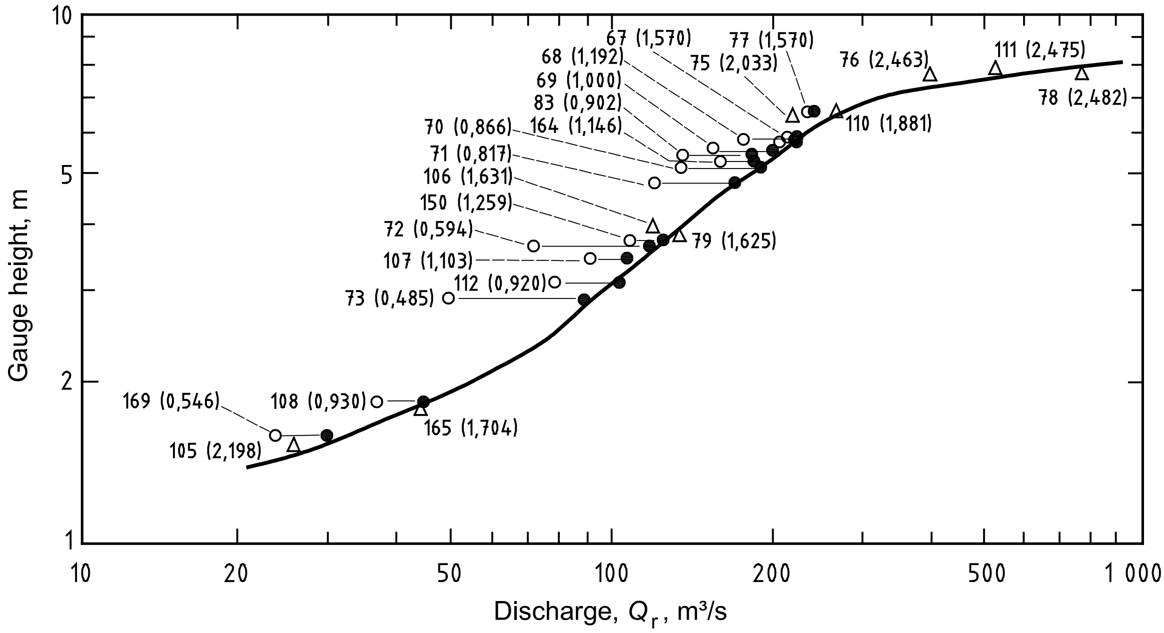
e) Enter the discharge ratio rating with the fall ratio, h/h_r^*, and determine the discharge ratio, (Q/Q_r^*) from the limiting-fall ratio curve.

f) Compute the true discharge, Q^*, by multiplying the rating discharge, Q_r^*, times the discharge ratio, $(Q/Q_r)^*$.

8.3.4 Example of limiting-fall method

Figures 4, 5 and 6, and Table 3, illustrate a limiting-fall rating for a site with intermittent backwater. These curves represent the final results after making several trials and refinements. In Figure 5 the plotted points show the fall after adjustment by the fall ratio. The measured fall has been omitted from this plot, except for those measurements where backwater is not present.

In the limiting-fall method the stage-discharge rating is essentially a non-backwater rating and can be used to compute discharge either when backwater 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 method. The limiting-fall method is the most complex of all the various fall ratings, but provides for the best use of available data.



Key

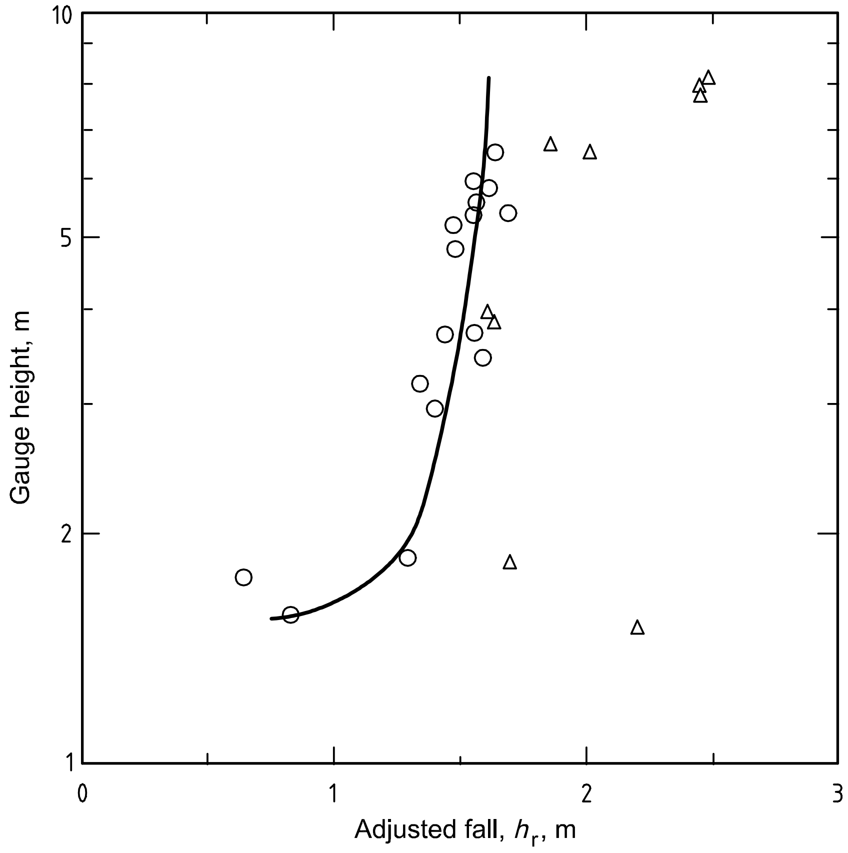
△ Measurements where no backwater is present

○ Measurements affected by backwater

● Measurements adjusted for a condition when no backwater is present

NOTE The numbers on the plot refer to the measurement number with the measured fall, h, given in parentheses (see Table 3).

Figure 4 — Limiting-fall stage-discharge-rating curve



Key

△ Measurements where no backwater is present

○ Measurements affected by backwater

Figure 5 — Limiting-fall stage-fall relationship curve

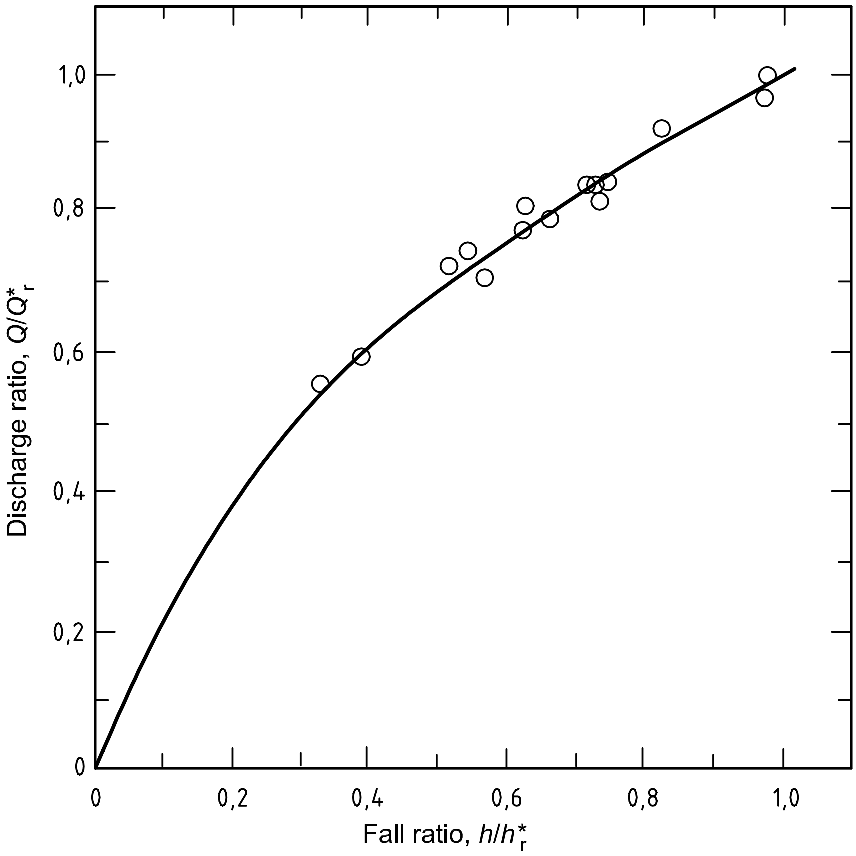


Figure 6 — Limiting-fall ratio curve

Table 3 — Limiting-fall calibration measurements

Measurement No.	Gauge height	h	Q	Q_r^* [a]	Q/Q_r^*	h_r^* [b]	h/h_r^*	$(Q/Q_r)^*$ [c]	Q_r [d]	Difference in value of Q_r	$(h/h_r)^*$ [c]	h_r [e]
	m	m	m^3/s	m^3/s		m			m^3/s	%		m^3/s
67	5,956	1,570	214	213	1,005	1,609	0,975	0,99	216	1,4	1,00	1,570
68	5,907	1,192	178	211	0,844	1,609	0,741	0,85	209	−0,9	0,73	1,630
69	5,614	1,000	154	198	0,778	1,600	0,625	0,77	200	1,0	0,63	1,587
70	5,246	0,866	134	181	0,741	1,588	0,545	0,72	186	2,9	0,58	1,492
71	4,865	0,817	119	165	0,721	1,573	0,519	0,70	170	3,0	0,55	1,485
72	3,725	0,594	70,5	119	0,591	1,527	0,389	0,60	118	−1,4	0,38	1,564
73	2,916	0,485	48,7	87,2	0,558	1,454	0,333	0,55	88,6	1,5	0,34	1,425
75 [f]	6,559	2,033	217	242	—	1,628	—	—	217	−10,3	—	—
76 [f]	7,705	2,463	391	379	—	1,646	—	—	391	3,2	—	—
77	6,514	1,570	233	240	0,973	1,625	0,966	0,98	238	−0,7	0,95	1,652
78 [f]	8,077	2,482	767	736	—	1,646	—	—	767	4,2	—	—
79 [f]	3,868	1,625	134	125	—	1,536	—	—	134	7,2	—	—
83	5,416	0,902	133	189	0,706	1,591	0,567	0,73	183	−3,3	0,53	1,702
105 [f]	1,512	2,198	25,7	26,6	—	0,698	—	—	25,7	−3,4	—	—
106 [f]	3,895	1,631	120	126	—	1,536	—	—	120	−4,8	—	—
107	3,487	1,103	89,8	110	0,817	1,509	0,731	0,84	107	−2,7	0,69	1,599
108	1,859	0,930	36,8	43,9	0,839	1,280	0,726	0,84	43,8	−0,2	0,72	1,291
110 [f]	6,690	1,881	259	248	—	1,631	—	—	259	4,4	—	—
111 [f]	8,001	2,475	524	549	—	1,646	—	—	524	−4,6	—	—
112	3,158	0,920	78,2	96,9	0,807	1,478	0,623	0,77	102	4,8	0,68	1,354
150	3,697	1,259	110	118	0,928	1,527	0,824	0,90	122	3,1	0,87	1,447
164	5,334	1,146	156	185	0,841	1,591	0,720	0,84	185	0,1	0,73	1,570
165 [f]	1,817	1,704	43,0	41,9	—	1,237	—	—	43,0	2,6	—	—
169	1,585	0,546	23,8	30,0	0,792	0,832	0,656	0,80	29,7	−1,1	0,65	0,839

NOTE For clarity, variables denoted with a star "*" are those determined directly from a relationship curve.

[a] Values taken from the curve in Figure 4.

[b] Values taken from the curve in Figure 5.

[c] Values taken from the curve in Figure 6.

[d] $Q_r = \frac{Q}{(Q/Q_r)^*}$

[e] $h_r = \frac{h}{(h/h_r)^*}$

[f] Measurement where no backwater is present.

9 Rating curves and tables

All rating curves for stage-fall-discharge methods shall be prepared in accordance with methods described in ISO 1100-2. Each of the rating curves can be adapted to rating tables for easy application. Rating tables should show the discharges and falls corresponding to gauge heights in ascending order. The discharge ratios corresponding to either the measured fall (constant-fall method) or the fall ratio (limiting-fall method) should also be arranged in ascending order.

10 Method of computation

Computation of occasional discharge values can easily be performed by hand calculations directly from the curves and tables. However, if extended periods of hourly or daily discharges are needed, such as for a water year, it is best to perform these repetitive calculations by programming the method for computer calculations.

11 Periodic checking of stage-fall-discharge ratings

Stage-fall-discharge ratings should be checked periodically to ascertain that there have been no significant changes in the ratings. This can be done by making discharge measurements at regular intervals such as once every two or three months and plotting the fall-adjusted discharge on the stage-discharge rating. Deviations in excess of ± 10 % should alert the user to a possible shift, provided the possible error is not in excess of about ± 10 %. Several measurements over a period of time that all plot to one side of the rating, regardless of size of error, would indicate a shift of the rating.

12 Extrapolations

The stage-fall-discharge ratings should not be extrapolated beyond the limits of definition. Little reliance should be given to flow estimates based on an extrapolated rating and such flow estimates should be identified as being estimates.

13 Uncertainties

The complexities involved in the stage-fall-discharge methods make it difficult to assess the overall uncertainty of the computed discharges. The uncertainty of gauge height and fall measurements are usually small, but the derivation of the rating curves may have large uncertainties. For the more complex stage-fall-discharge ratings the final results may only be considered as approximate. However, for large rivers having highly variable backwater conditions, these methods may be the only ones available, and the results should be accepted.

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