Designation: D 5541 – 94 (Reapproved 1998)

AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Practice for Developing a Stage-Discharge Relation for Open Channel Flow[1]

This standard is issued under the fixed designation D 5541; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers the development of a curve relating stage (elevation) to discharge. Standard test methods have been documented for measuring discharge and for measuring stage (see Practice D 3858, and Test Methods D 5129, D 5130, D 5243, D 5388, and D 5413). This practice takes the discharge and stage determined by each respective test method and shows a relation between them using a curved line. This curved line is called a stage-discharge relation or rating curve.

1.2 The procedures described in this practice are used commonly by those responsible for investigations of streamflow, for example, the U.S. Geological Survey, Army Corps of Engineers, Bureau of Reclamation, and U.S Agriculture Research Service. For the most part, these procedures are adapted from reports of the U.S. Geological Survey.[2,3]

1.3 The procedures described in this practice apply only to simple freely flowing open-channel flow. Ratings for complex hydraulic conditions of extremely low slope channels using multiple-stage inputs, channels affected by man-induced regulation, or tidal conditions are not described. These types of ratings are described in detail in the documents listed in Footnotes 2 and 3.

1.4 This practice uses the results of current-meter discharge measurements or indirect discharge measurements and the corresponding measured stage to define as much of the stage-discharge relation curve as possible. A theoretical curve is developed for the full range of stage and discharge to shape the curve.

1.5 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 1129 Terminology Relating to Water[4]

D 3858 Practice for Open-Channel Flow Measurement of Water by Velocity-Area Method[4]

D 5129 Test Method for Open Channel Flow Measurement of Water Indirectly by Using Width Contractions[4]

D 5130 Test Method for Open-Channel Flow Measurement of Water Indirectly by Slope-Area Method[4]

D 5243 Test Method for Open-Channel Flow Measurement of Water Indirectly at Culverts[4]

D 5388 Test Method for Measurement of Discharge by Step-Backwater Method[4]

D 5413 Test Methods for Measurement of Water Levels in Open Water Bodies[4]

2.2 *ISO Standard:*

ISO 1100/2 Liquid Flow Measurement in Open Channels—Part 2, Determination of Stage-Discharge Relation[5]

3. Terminology

3.1 *Definitions*—For definitions of terms used in this practice, refer to Terminology D 1129.

3.2 *Symbols:Symbols:*

GH = gage height or stage, ft (m).

Q = discharge, ft^3/s (m^3/s).

4. Summary of Practice

4.1 The stage-discharge relation is developed by plotting stage versus discharge from discharge measurements or other determinations of flow, either manually or through the use of computer programs and fitting a curve to these points. The stage should be determined at a single gage datum for the entire range in stage. Stages determined in stilling wells, at outside gages, and at bridge abutments can be significantly different and should not be interchanged. Discharge measurements may not be available for the entire range in stage of the stage-discharge relation. A theoretical rating curve should be developed for the entire range in stage using Test Method D 5388.

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[1] This practice is under the jurisdiction of ASTM Committee D-19 on Water and is the direct responsibility of Subcommittee D19.07 on Sediments, Geomorphology, and Open-Channel Flow.

Current edition approved April 15, 1994. Published July 1994.

[2] Kennedy, E. J., "Discharge Ratings at Gaging Stations: U.S. Geological Survey," *Techniques of Water-Resource Investigations*, Book 3, Chapt. A10, 1984, p. 59.

[3] Rantz, S. E., et al., *Measurement and Computation of Streamflow: Vol 2, Computation of Discharge*, U.S. Geological Survey, Water-Supply Paper No. 2175, 1982, p. 631.

[4] *Annual Book of ASTM Standards*, Vol 11.01.

[5] Available from American National Standards Institute, 11 West 42nd St., 13th Floor, New York, NY 10036.

This theoretical curve is used as a guide to shape the stage-discharge relation at places where discharge measurements are not available.

5. Significance and Use

5.1 This practice is particularly useful for determining the discharge at a gaging station or a location where discharge information is repeatedly needed.

5.2 This practice is applicable only for open-channel flow conditions where channel hydraulics permit a stable relation between stage and discharge.

6. Channel Hydraulics

6.1 The stage-discharge relation for open-channel flow at a gaging station or other stage reference point is governed by channel conditions downstream from that point, referred to as a control. 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, control features change, and the number of measurements is limited usually requires judgment in interpolating between measurements and in extrapolating beyond the highest or lowest measurements.

6.1.1 *Section Controls*—A section control is a specific cross section of the stream channel that controls the relation between stage and discharge at that point in the channel. A section control can be a natural feature such as a rock ledge, sand bar, or severe constriction in the channel. A section control can likewise be a manmade feature such as a small dam, weir, flume, or overflow spillway. Section controls can frequently be identified visually in the field by observing a riffle, or pronounced drop in the water surface, as the flow passes over the control. As stage increases because of higher flows, the section control will frequently become submerged to the extent that it no longer controls the relation between stage and discharge. At this point, the riffle is no longer observable, and flow is then controlled by either another section control further downstream or by channel control.

6.1.2 *Channel Controls*—A channel control consists of a combination of features throughout a reach downstream from a gage. These features include channel size, shape, curvature, slope, and roughness. 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 not possible or necessary.

6.1.3 *Combination Controls*—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 a section-controlled segment of the rating and a channel-controlled segment 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. Combination controls or transition zones, or both, occur for very limited parts of a stage-discharge relation and can usually be defined by plotting procedures. In particular, transition zones represent changes in the slope or shape of a stage-discharge relation.

6.2 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. A combination of section and channel control may occur at some stages. These are general rules, and exceptions can and do occur.

7. Interferences

7.1 The stage-discharge relation may be affected by the deposition or removal of stream bed or bank material by flowing water, usually at high flow conditions or manmade changes. Large changes may require a redefinition of the rating curve. Small, transitory changes may be facilitated by adjustments to the stage observations. An example of a temporary shift would be a beaver dam on a section control or debris deposited on a dam or bridge piling that would be expected to be removed or eventually wash away.

7.2 Aquatic growth may develop in a stream during the growing season. This growth would result in a temporary backwater situation. Adjustments to stage observations would normally be made during these periods.

7.3 Ice cover changes river hydraulics and alters the stage-discharge relation.

7.4 Hysteresis may affect the high flow stage-discharge relation 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. The water surface slope on rising stages is significantly steeper than that for steady flow conditions, resulting in greater discharge than indicated by the steady flow rating. The reverse is true for falling stages. If discharge measurements are made at both rising and falling stages, a single curve splitting these measurements will generally result in satisfactory accuracy. It may be necessary to use separate curves for rising and falling conditions in extreme cases.

8. Sampling

8.1 Sampling as defined in Terminology D 1129 is not applicable in this practice.

9. Calibration

9.1 Verify the stage-discharge relation periodically with current-meter or indirect discharge measurements to ascertain that the relation has not changed. Large floods are most likely to cause erosion or filling of the channel and cause the relation to shift. The frequency of current meter measurements depends on the stability of a stream and is based in part on past experience. As a rule of thumb, monthly measurements should be made at a new site, at least until the range of stage is covered.

10. Procedure

10.1 If sufficient current-meter discharge measurements are available for the entire range in stage and discharge that is necessary, develop the entire rating curve by plotting stage versus discharge on logarithmic or rectangular coordinate plotting paper. Logarithmic plotting paper is preferred because, in the usual situation of compound controls, changes in the slope of the logarithmically plotted rating identify the range in stage for which the effective controls exist. Select a convenient stage scale on the logarithmic paper so that all of the discharge measurements below bankfull stage plot in a relatively straight line. There are three segments for a rating curve as a general rule, and they are identified by the changes in slope of the curve. A typical rating curve is shown in Fig. 1. At low stages, the curve is straight and relatively flat until the channel width is full (1.8 ft (0.55 m)). From this point until bankfull (2.34 ft (0.71 m)), the curve is much steeper. Above bankfull, the water will spread out and the curve will be flat and straight.

10.1.1 It is often desirable to plot the low-flow component of the rating on rectangular coordinate plotting paper. This presents an opportunity to plot at an expanded scale. For small streams that go dry or nearly so, the point of zero flow can be plotted to help shape the extreme low-flow portion of the curve. A rectangular plot is shown in Fig. 1.

10.2 If sufficient discharge measurements are not available for the entire range in stage and discharge that is necessary, develop a theoretical rating curve using the stepbackwater test method. This theoretical curve is used as a guide to shape the rating curve. Plot the theoretical rating curve on logarithmic plotting paper. All of the current-meter discharge measurements are plotted on the same paper. Adjust the theoretical curve to go through the current-meter measurements. The adjustments to the theoretical curve may not be the same at the upper, middle, and lower sections of the curve.

10.3 Discharge measurements are sometimes made under undesirable conditions. The hydrographer making the measurement may rate the measurement excellent, good, fair, or poor. A measurement that is rated excellent, good, fair, or poor is believed to be within 2, 5, 8, and over 8 % of the correct value, respectively. When adjusting the theoretical rating to go through the measurements, give consideration to how accurate the measurements are believed to be.

11. Precision and Bias

11.1 Determination of the precision and bias for this practice is not possible due to the high degree of instability of open-channel flow. A minimum bias, measured under ideal conditions, is related directly to the bias of the equipment used to obtain stage and discharge values. A maximum precision and bias cannot be estimated due to the variability of the sources of potential errors and the temporal and spatial variability of open-channel flow. Any estimate of these errors could be very misleading to the user.

11.2 Stage-discharge relations represent hydraulic functions that are subject to frequent changes, as described in Section 7. Each discharge measurement represents a variable range of precision as well as defining a unique hydraulic condition. Various statistical tests have been used to test for bias. Users should always consider what is happening to controlling hydraulic characteristics and make decisions on this basis rather than arbitrarily using statistical techniques.

11.3 A comprehensive discussion of tests for bias is presented in ISO 1100/2.

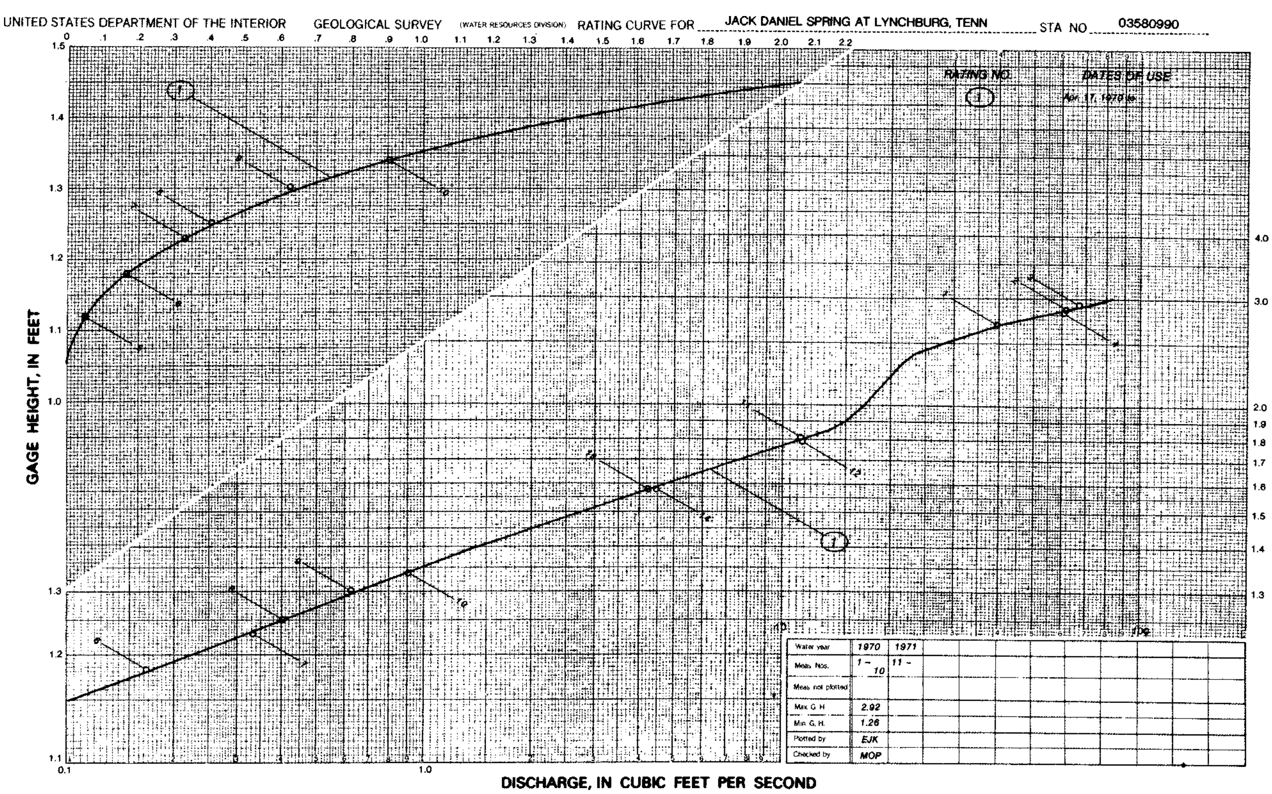

FIG. 1 Typical rating-curve sheet.

12. Keywords

12.1 discharge; rating curve; stage; stage-discharge relation