ACCURACY OF STREAM-FLOW DATA.

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DEGREE OF ACCURACY REQUIRED.

The laws relating to many natural phenomena have been reduced to an exact science; those for many more are largely empirical and are based on experiments and assumptions that only approximate the truth. In the empirical class are included the laws of the science of hydrology and especially of that branch of hydrology which relates to the flow of water in open channels. It is possible, nevertheless, by carefully considering the various factors, to reduce the incidental errors so that resulting records will be sufficiently accurate for the purposes for which stream-flow data are required.

In most problems two degrees of accuracy must be considered—first, that which is practicable or possible to obtain, and, second, that which is desirable or necessary. The obtainable accuracy of stream-flow data depends largely on the amount of money available for their collection. The desirable accuracy depends on the proposed use of the data.

Stream-flow records have three principal uses—first, in predicting flow, generally in connection with the design of hydraulic works; second, in the immediate operation of hydraulic works; and, third, in studying conditions of past flow, usually in connection with the adjustment of water rights. For the second and third uses data as accurate as can be collected may be needed. In considering the first use, however, it should be remembered that both the total flow of a stream and its regimen change from year to year, and that the conditions existing at any particular time may never recur. For this use, therefore, reasonably accurate records that extend over a considerable period are much more valuable than extremely accurate data covering a short period.

Studies of the accuracy of stream-flow data serve to determine the methods to be followed in their collection so that the records may meet the requirements of the proposed uses. Notes on accuracy that accompany stream-flow records should give, first, information by which the technical man may study the records and judge their accuracy, and, second, information by which both the general and the technical user may judge the reliability of the records without making a study. These two uses should be kept in mind in preparing the data as well as the notes. Consideration of the accuracy of records to be collected at any station should begin with the reconnaisance for the site and continue through the selection, establishment, maintenance, and operation of the station, the computation and interpretation of the data, and the preparation of the records for publication. In other words, records should be collected with the desired degree of accuracy in view instead of leaving it to be determined after the field data are collected and estimates have been made.

In this discussion of accuracy it has been assumed that personal or instrumental errors, both in field and office, are reduced to a negligible amount. In order that this assumption may be true, however, all operations connected with the work must be carefully conducted and instruments must be kept in proper working order.

The conditions affecting accuracy may introduce errors that may be consistently compensating, consistently cumulative, or alternately compensating and cumulative. Therefore care must be taken to determine the way in which the incidental errors affect the results.

CONDITIONS AFFECTING ACCURACY OF RECORDS OF DAILY DISCHARGE.

The obtainable accuracy of records of daily discharge of a stream depends on the following factors, information in regard to which will determine the methods of operation and give a basis for evaluating the records after they are collected:

1. Permanence of the stage-discharge relation.
2. Precision with which the discharge rating curve is defined.
3. Refinement of gage readings.
4. Frequency of gage readings.
5. Methods of applying the daily gage heights to the rating table to obtain the daily discharge.

Permanence of the stage-discharge relation.—The permanence of the relation of discharge to stage as determined by the control is a fundamental factor in the collection of records of daily discharge of a stream. It may be disturbed either by a change in the control itself or by conditions that counteract the effect of the control, such as backwater from log or ice jams or floods in tributary streams below the station. The general character of the control and the conditions that may affect it are determined by inspection. The effectiveness of the control, however, can be finally determined only by plotting the results of discharge measurements. If such plotting does not define a smooth curve the inconsistency is due to poor current-meter measurements of discharge, to instability of the control, or to disturbing influences. If the control is unstable the accuracy of the record will depend on the number of the discharge measurements and their distribution as to time and stage.

Errors due to lack of permanence of the stage-discharge relation may be either compensating or cumulative, according to the physical conditions affecting the nature and stability of the control.

Precision of the discharge rating curve.—The precision with which the discharge rating curve is defined depends on the accuracy of the discharge measurements, their distribution in range, and the permanence of the control. If the relation of the discharge to stage were permanent and truly defined by the rating curve and the discharge measurements were absolutely accurate a series of measurements for a station would plot on a smooth curve. Unfortunately, such ideal conditions do not exist; therefore, a series of measurements for a station will plot somewhat discordantly, and the rating curve should be drawn among them in such a way as to represent average conditions. For permanent conditions of control combined with a good measuring section the variations of individual measurements from the mean curve should be comparatively small and as likely to be plus as minus. The probable error of a rating curve may be computed by the method of least squares and will be a factor in determining the probable error of the estimates of daily discharge.

Errors in determinations of daily discharge resulting from errors in the position of the rating curve will be cumulative for any stage but may be partly compensating if the curve used lies first on one side and then on the other side of the true curve.

Refinement of gage readings.—Refinement of gage readings affects the accuracy of stream-flow data to a degree dependent on the sensitiveness of the station, which in turn is determined by the size and shape of the channel at the control in relation to the quantity of discharge. The sensitiveness is indicated by the magnitude of the change in stage accompanying a given change in discharge. The limiting requirement as to sensitiveness should be a change in stage that is readable on the gage used for a change of 1 per cent in discharge. In general the more sensitive the station the more accurate the records that can be collected by ordinary methods and the less refinement necessary in the gage readings.

Errors due to lack of refinement in reading will generally be compensating, but they may be cumulative when the stage shows only small fluctuations during a considerable period or when they are due to systematic personal errors of the observer.

The degree of refinement in record of stage necessary to give a sufficiently accurate determination of discharge will vary inversely with the stage and is determined by the sensitiveness of the station as disclosed by a study of the discharge rating curve.

Gages are usually read to hundredths, quarter-tenths, half-tenths, or tenths. The resulting absolute errors of observations in individual readings are shown by the following table:

Absolute errors for individual gage readings.

	Maximum error.	Average error.	
	Foot.	*Foot.*	*Fractional part of a tenth of a foot.*
Readings to hundredths	0.005	0.0025	$\frac{1}{40}$
Readings to quarter-tenths	.012	.006	$\frac{1}{16}$
Readings to half-tenths	.025	.012	$\frac{1}{8}$
Readings to tenths	.05	.025	$\frac{1}{4}$

For staff and chain gages 2 per cent has been selected, more or less arbitrarily, as the limit of allowable average error in a determination of daily discharge due to errors in the determination of mean daily gage height. The table indicates that the maximum error for any one day is twice the average error, so that the maximum error for any one day may be 4 per cent. According to the law of probabilities the average error in the determination of monthly mean discharge for fluctuating stages resulting from a 2 per cent average error in the determination of mean daily discharge is about one-third of 1 per cent.

The refinement to which the records of mean daily gage height must be used—whether to hundredths, half-tenths, or tenths—in order to obtain this limit of accuracy in determinations of discharge at any given stage will depend on the percentage of difference in discharge for such least differences in gage readings at that stage, as shown by the rating table.

In determining this refinement the engineer should proceed as follows and enter the results in a table of the form given below, in which the Potomac at Point of Rocks, which is read once daily to hundredths, is used as an example.

Limits of accuracy in the use of gage readings.

Station.	Present readings.		Minimum gage height.	Minimum discharge.	Error in discharge due to error of 0.1 foot in the gage at minimum discharge.	Use gage heights to—		
	Number per day.	To—				Hundredths below—	Half tenths between—	Tenths above—
		Foot.	*Feet.*	*Sec.-ft.*	*Per cent.*	*Feet.*	*Feet.*	*Feet.*
Potomac River at Point of Rocks, Md.	1	0.01	0.40	580	36	1.0	1.0-2.0	2.0

The discharge rating table shows that the minimum discharge is 580 second-feet and occurs at gage height 0.4 foot. The difference per tenth between gage heights 0.4 and 0.5 foot is 210 second-feet, or 36.2 per cent of the minimum discharge.

The limits of stage between which it is necessary to use mean daily gage heights to hundredths, half-tenths, and tenths, respectively, in order not to introduce an average error of over 2 per cent in the determination of daily discharge are shown in the last three columns and are determined by trial by testing values from the discharge rating table at selected half-foot intervals, as follows:

In testing at the 2-foot gage height for gage records to tenths the difference between the discharge at 2.0 feet and that at 2.1 feet is found to be 360 second-feet. The average error of a mean daily record to tenths is one-fourth tenth. Therefore at gage height 2.0 feet the average error for such record, expressed in second-feet, is $\frac{360}{4}=90$ second-feet, which is 1.8 per cent of 5,020 second-feet, the discharge at the 2-foot stage. Therefore it is not necessary to use gage-height records closer than 0.1 foot above the 2-foot stage, as above this stage the average error is less than 2 per cent, which is the allowable error.

A continuation of this analysis shows that in order to keep the error in the determination of discharge resulting from lack of refinement in gage readings below 2 per cent, the gage at Point of Rocks should be used to hundredths below the 1-foot stage, to half-tenths between 1.0 foot and 2.0 feet, and to tenths above 2.0 feet.

For a record obtained with a water-stage recorder the same procedure is followed except that the allowable error should be 1 per cent.

For stations with shifting control the methods of analysis above described can be used only in a general way.

In practice the limits of use of gage heights can be readily determined by the following rules:

Find the stage at which the difference in discharge per tenth is 8 per cent of the discharge at that stage. Gage heights above this stage should be used to tenths.

Find the stage at which the difference in discharge per tenth is 16 per cent of the discharge at that stage. Gage heights below this stage should be used to hundredths.

Gage heights between the two stages thus found should be used to half-tenths.

Frequency of gage readings.—The frequency of gage readings is an important factor in the accuracy of records of streams that are subject to considerable daily fluctuation in stage. To obtain a gage record so accurate that its use with the rating table will give the true mean discharge for the day the number of readings should vary, according to the nature of the fluctuations, from one or two daily to a continuous record obtained by some form of water-stage recorder.

To ascertain the frequency required it is necessary to compare the daily discharge obtained from one gage reading daily or the mean of two readings daily with that obtained from the mean of hourly gage heights or by a discharge integrator.

Errors due to insufficient gage readings may be cumulative or compensating, or alternately one and the other, according to the nature of the fluctuations in stage.

Methods of applying the daily gage heights to the rating table.—The method of applying daily gage heights to the rating table to ascertain mean daily discharge is determined by the curvature of the rating curve.

Theoretically, the mean daily discharge of a stream is the mean of the discharge for every second during the day. In ordinary computation of daily flow, it is assumed that the rate of discharge throughout the day varies so little or with such regularity that the daily discharge may be determined by entering a rating table with a mean daily gage height obtained either from a few observations or from a continuous record made by a water-stage recorder. As discharge is in general an increasing curvilinear function of gage height, the use of a mean daily gage height with a rating table gives a result that is always too small. The magnitude of this error, which will vary with the curvature of the rating curve and with the daily range in stage, will determine whether the daily discharge can be ascertained directly by finding a mean daily gage height or indirectly by averaging the discharge corresponding to gage heights for shorter intervals. Hourly discharge is frequently used. As an ultimate limit the absolute mean discharge for the day may be ascertained by a discharge integrator, which operates much as a planimeter operates and contains as an essential element the rating curve of the station. Such an integrator has been devised by E. S. Fuller, formerly assistant engineer, United States Geological Survey.

It is necessary, therefore, to study each gaging station, in order to determine the length of the period that should be used in applying the gage heights to the rating table. In such an investigation a maximum allowable error of 1 per cent is assumed. The amount of daily range in stage allowable for a given mean daily stage, in order that errors due to curvature of the rating curve shall not exceed 1 per cent, can be found graphically by constructing a chord to the rating curve such that the horizontal distance, measured by the discharge scale, from its middle point to the curve equals 1 per cent of the discharge at the gage height of the middle point. The difference in gage height at the ends of the chord will be the allowable daily range.

A table of such limits covering the range of stage, used with tables of mean daily stage and range in stage, will indicate the days for which the mean daily discharge can be found directly from the mean daily gage height and those for which more frequent intervals are necessary.

The errors resulting from the application of the gage height to the rating table will in general be cumulative, and their magnitude will vary with the method used in making the computations.

ACCURACY OF MONTHLY OR YEARLY MEANS.

The foregoing discussion of accuracy relates only to determinations of daily discharge. For many uses the mean flow for longer periods may be sufficient. The monthly mean is in general use for hydraulic studies. If errors resulting from all causes in the estimates of daily discharge are compensating, the probable error in the determination of mean monthly discharge will be much less than the probable error of the individual determinations of daily discharge. A careful analysis of the estimates of daily discharge and monthly means computed from them shows that large errors in the daily estimates may be so compensated that the errors in the monthly means are small.