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FOREST SERVICE, U.S. DEPT. OF AGRICULTURE, 102 MOTORS AVENUE, UPPER DARBY, PA



ACCURACY IN STREAMFLOW MEASUREMENTS ON THE FERNOW EXPERIMENTAL FOREST

Measurement of streamflow from small watersheds on the Fernow Experimental Forest at Parsons, West Virginia was begun in 1951. Stream-gaging stations are now being operated on 9 watersheds ranging from 29 to 96 acres in size; and 91 watershed-years of record have been collected. To determine how accurately streamflow is being measured at these stations, several of the important factors that influence the accuracy of the records have been studied.

The factors studied were grouped into the following four categories: (1) stream-gaging instrumentation, (2) stage-discharge relation, (3) manual checking of stage, and (4) compilation of data.

Stream-Gaging Instrumentation

The gaging stations on the Fernow Forest are sharp-crested 120° V-notch weirs with either FW-1 or A-35 water-level recorders. Accurate measurement with the 120° V-notch weir requires that: (1) the weir blade be sharp, smooth, and clean; (2) the upstream face of the cutoff wall be vertical and as smooth as possible; (3) the nappe, to be fully aerated, should touch only the upstream edges of the weir blade; and (4) the velocity of approach should be less than 0.5 foot per second (King 1954 and Thomas 1957).

To satisfy these conditions, care in construction and periodic maintenance are required. On the Fernow Forest, the weir blades are frequently checked for irregularities and rust damage, and repairs are made when needed. To ensure proper aeration of the nappe, the cutoff walls have been shaped so that the water falls freely below the notch, leaving an

air space under the waterfall. Weir basins have been constructed with sufficient width, length, and depth to slow velocity of approach. Silt and debris accumulations in the weir basin are removed at least annually. Checks of velocity of approach made in the weir basins with a pygmy current meter have shown that the velocity was usually below the 0.1 foot per second starting velocity of the meter or well below the recommended maximum velocity of approach of 0.5 foot per second.

Stage-Discharge Relation

A rating table showing quantity of flow for stages up to 2.0 feet has been prepared for each of the Fernow weirs. The rating is based on the formula $Q = 4.43H^{2.449}$ (Q is the discharge in cubic feet per second and H is stage in feet) as determined by Hertzler (1938). According to Thomas (1957) there is general agreement among experimenters that stages of less than 0.20 foot will not produce reliable results when the usual discharge formulas are used. This is due in part to the tendency of the nappe to adhere to the weir blade at low stages. Accordingly, the Fernow rating tables were volumetrically checked at low stages and necessary adjustments were made. The maximum stage for rating-table adjustment for any single weir was 0.58 foot, and several weirs required adjustments for stages up to 0.25 foot. For two of the nine weirs in operation, checks indicated that the formula could be used without adjustment.

The procedure for adjusting the rating tables was to compare the averages of series of volumetric check measurements at given stage heights with the standard formula values. If appreciable differences (more than 5 percent) did not occur between the two sets of values, the standard value was used. For weirs in which appreciable differences occurred, the rating tables were adjusted up to the stage where the adjusted rating closely approached the standard rating, by picking discharge values from a curve fitted to the check points (fig. 1).

Adjusting the rating curve naturally improves the accuracy of stream-flow records. However, sources of error still exist: (1) the plotted points are affected by both sampling and measurement error; and (2) the smoothed portion of the curve from which the adjusted rating table values are taken is fitted free-hand between the averages of series of volumetric check points. Thus some of the average check points are above or below the curve, causing a small error in the adjusted values at these points.

As an example of the error introduced by sampling and measurement,

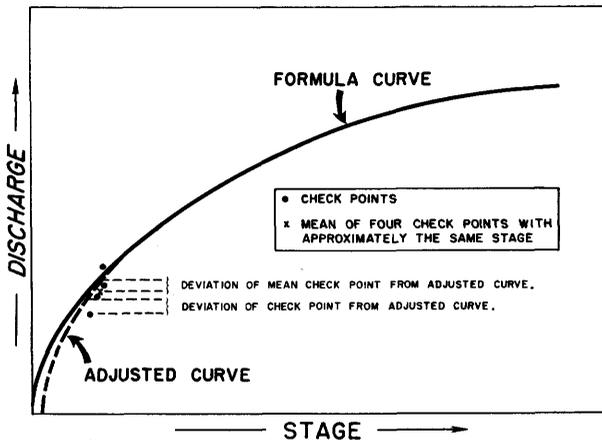


Figure 1. — Schematic drawing of the standard or formula rating curve, the adjusted curve, plotted check points, and mean check points.

the mean of 6 check measurements made at Fernow weir 8 while the stage was 0.207 feet was 0.0854 c.f.s.; the standard deviation was 0.0010 c.f.s. and the standard error of the mean was 0.0004 c.f.s. If the actual or true discharge for this stage is 0.0010 c.f.s. (one standard deviation) higher or lower than the mean of the check measurement, it would make a difference of 1.2 percent or 86 cubic feet of water per day. The necessity of rating a weir is brought out by the fact that discharge for the stage of 0.207 (using Hertzler's formula) is 0.0936 c.f.s., which is 9.6 percent or 906 cubic feet per day higher than the mean of the check measurements.

There is no really good method for determining the error introduced when fitting the adjusted portion of the rating curve to the volumetric check points. About the best that can be done is to compare the deviation of the check points and the adjusted curve values in use, realizing that this is biased because in most instances the curve was based on the check points. A comparison of this type for Fernow weir 8, which required an adjustment in the rating curve up to a stage of 0.58 foot, showed that adjusted-curve values ranged from 99.5 to 105.9 percent of the check points, with most of the values being close to 100 percent. The adjusted values ended up slightly on the standard-curve side of the check points because of the conservative approach used in adjusting; that is, care was used not to overadjust. Since the deviations between check points and adjusted values occur at low stages, they do not represent large differences in streamflow totals. A test of the effect of deviations between volumetric-

check values and adjusted-curve values upon streamflow totals for watershed 8 showed that annual streamflow, using the adjusted-curve values, was 0.13 area-inches higher or 100.3 percent of the total obtained when using check-point values.

Thus it appears that errors in streamflow totals due to deviations in check points and adjusted-rating-table values can safely be estimated at less than 0.5 percent. Deviations between check points and true discharge caused by sampling and measurement error are also estimated to cause less than 0.5 percent error in streamflow totals. Each of the above-mentioned errors is cumulative in nature (although they may partially compensate each other), and it is important that they be kept as small as possible.

Manual Check of Stage

On the Fernow Forest, the continuous-discharge measurements made with the water-level recorders are checked manually, usually weekly, using a hook gage mounted on a metal reference bar over the weir basin. If the hook-gage reading and chart stage differ by more than 0.003 foot, the recorder is adjusted and the previous week's chart is corrected.

Sources of error that must be guarded against to insure accurate hook-gage readings include improper location of the reference bar, changes in reference-bar heights, malfunction of the hook gage, rough water or wave action, and human error in reading the gage.

Location of the reference bar should be far enough upstream to prevent any effect of surface contraction caused by the water falling over the weir blade. This does not present any problem on the Fernow, as all reference bars are located at least 2.5 times the depth of the notch upstream from the cutoff wall, as recommended by King (1954).

There has been some slight change in height of the reference bars at several of the weirs since installation. Periodic checks of the correction factor (differences between bottom of V-notch and zero reading on hook gages) have shown these changes to be gradual and, for any one weir, in one direction. Since the changes are small (usually less than 0.002 feet per year) streamflow records for the period before checking are not corrected, causing the records to be in error by a small amount (in the general magnitude of 0.001 foot). Tests with the Fernow data have shown that a correction factor in error by 0.002 foot causes annual streamflow to be in error by approximately 1 percent.

Human error in reading the hook gage must also be considered. At present the weekly checks on the water-level recorder are based on one hook-gage reading unless the need for a check reading is indicated by

an appreciable difference between the hook-gage reading and the recorder pen trace. For the most part, human errors are compensating as opposed to previously discussed errors, which have been cumulative.

Generally the manual checking of stage would seem to cause less than a 1 percent error in streamflow totals, most of which is due to changing reference-bar heights.

Compilation of Data

Compilation of data is a broad term that includes all operations from marking and tabulation of charts to the computation of discharge totals. These operations are fully described in Proceedings of the Watershed Management Research Conference, (Northeastern Forest Experiment Station 1962).

Factors that affect data compilation include both human errors and errors inherent in the methods being used. Human errors are most likely to occur in those operations that require estimating (for example, picking the mean water level for a segment of the hydrograph). However, the differences between the estimated and actual values are usually small and, being compensating, do not amount to significant values. Actual mistakes in compilation are more difficult to evaluate: a good checking system helps to keep mistakes at a minimum.

Most of the errors in method are confined to the conversion of stage readings to discharge. The point-picking method used on the Fernow involves determining the mean stage for a selected time interval and calculating the discharge from the mean stage. The error involved in this procedure is due to the fact that the mean stage does not correspond exactly to the average discharge of the interval. This is a cumulative error (indicating less discharge than actually occurs); and its magnitude depends upon the stage changes within the time interval concerned. At present the permissible-rise table designed to keep errors in the mean discharge at less than 2 percent is being used. A study of the Fernow data has shown that, on the average, only 39 percent of the permissible rise is used, which would mean that the error due to this source is considerably less than 2 percent, and may safely be estimated to be 1 percent or less.

Many of the procedures used in the compilation of Fernow streamflow data have been added to increase accuracy. These include correcting the pen trace for (1) debris and ice in the V-notch, (2) chart expansion, (3) time, and (4) gage-height errors; and checking each of the various procedures. Also, gage heights are read from the chart to the nearest

Table 1. — Area-inch streamflow values for Fernow watershed 7, water-year 1959-60, eliminating various correction operations or using modifications of present compilation procedures

(In area-inches)

Period	Actual values using present methods	No corrections made for —				Totals with elimination of checking of compilations nearest 0.005 foot			
		Time errors	Gage-height errors	Debris and ice errors	Chart expansion	Anything	Totals if gage height read to		
Growing season (May - Oct.)	4.245	4.245	4.274	4.357	4.241	4.398	4.295	4.254	
Dormant season (Nov. - Apr.)	25.264	25.264	25.356	25.503	25.069	25.495	25.107	25.239	
Annual	29.509	29.509	29.630	29.860	29.310	29.893	29.402	29.493	
ACTUAL VALUE MINUS OTHER VALUES (DIFFERENCES)									
Growing season	....	0	+0.029	+0.112	-0.004	+0.153	+0.050	+0.009
Dormant season	....	0	+0.092	+0.239	-0.195	+0.231	-0.157	-0.025
Annual	....	0	+0.121	+0.351	-0.199	+0.384	-0.107	-0.016

0.001 foot. Table 1 shows the effects of eliminating pen-trace corrections on annual and seasonal streamflow totals for watershed 7. Errors in time that are caused by improper recorder operation or mistakes in setting the pen did not change the streamflow totals when they were corrected. Corrections for gage-height errors and for debris or ice in the V-notch amounted to 0.121 and 0.351 area-inch respectively for the water-year (out of an annual runoff of 29.509 area-inches). Elimination of chart-expansion corrections caused the annual total to be in error by 0.199 area-inch.

On the Fernow, each step in the compilation of data is checked, most often by someone other than the person doing the original work. The elimination of checking procedures on watershed 7, as shown in table 1, would have caused the annual streamflow to be in error by about 1/10 area-inch. Most of the errors were found during the dormant season, when streamflow is most variable. Table 1 also shows the results of reading gage heights to the nearest 0.005 foot instead of the present method of 0.001 foot. As might be expected, changes in streamflow totals were small.

Generally the amounts of streamflow involved in the various correction and checking operations and in reading the gage height to the nearest 0.001 foot are small. However, the corrections can amount to large percentages during periods of very low stage, when a small absolute difference in flow represents a high percentage of total flow. Since many of the Fernow results are dependent on daily flow values, most of these procedures that provide additional accuracy are necessary.

Conclusions

A summary of the estimates of percentage error in annual streamflow values caused by the various factors studied in this report is as follows:

<i>Source of error</i>	<i>Estimate of percentage error in annual streamflow values</i>
1. Deviation of mean check points from true values plus deviation of adjusted curve from mean check points	1.0
2. Error in manual check of stage	1.0
3. Errors in methods used in compilation of data	1.0
Total of estimate from various sources	<hr style="width: 10%; margin: 0 auto;"/> 3.0

It is realized that the total of 3.0 percent is a rough estimate and that it cannot, on the basis of the data given, be stated that annual Fernow streamflow measurements are within 3 percent of being correct. The estimates have been assigned maximum values, and in most cases the total error due to these sources is probably something less. Also the above errors may compensate for each other. On the other hand, additional sources of error, which have not been evaluated, may add to the estimated percentages. To be on the safe side it might be concluded that Fernow streamflow values are in error in the neighborhood of not more than 3 to 5 percent.

The total estimate of error in stream discharge affects the determination of results of watershed treatments. The errors in measurement, together with the lack of perfect natural correlation between watersheds when the control-watershed approach is used, cause errors of estimate in prediction equations. Following treatment, the magnitude of change in discharge that is needed to establish statistical significance increases with the magnitude of the error of estimate.

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— JAMES W. HORNBECK

Research Forester
Northeastern Forest Experiment Station
Forest Service, U. S. Dept. Agriculture
Parsons, West Virginia