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A METHOD OF DETERMINING THE DAILY DISCHARGE OF RIVERS OF VARIABLE SLOPE

BY

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A METHOD OF DETERMINING THE DAILY DISCHARGE OF RIVERS OF VARIABLE SLOPE.

By M. R. HALL, WARREN E. HALL, and C. H. PIERCE.[1]

FORMULAS.

The usual method of estimating the daily discharge of a stream by means of a discharge rating curve assumes that the velocity and therefore the slope of the river surface remain constant for the same gage height. In reality this assumption is not true of any stream for rapidly rising or falling stages, and in many streams the variation in slope for the same gage height becomes so large as to seriously affect the accuracy of the method. (See fig. 1.)

Rivers with very flat slopes show in a marked degree the effect of the variation in slope due to changing stage, especially the rapid changes caused by the passing of flood crests. Still greater variations occur when flatness of slope is conjoined with discharge into a body of water subject to large fluctuations of surface elevation. Such conditions occur in the lower part of the Mississippi River basin, where large rivers join the Mississippi and where the elevation of the surface of the main river varies about 50 feet between extreme high and low water stages. For streams of this nature it is proposed to base the estimate of daily discharge on both the gage height and the slope—the slope, or relative difference in elevations of water surface, to be determined by gage-height records obtained at two stations the proper distance apart on the stream with gages set to the same datum—and then, the slope for each day and at the time of each discharge measurement having been determined, to adjust the discharge values on the assumption that for the same gage height and conditions of channel the velocity will vary with the square root of the slope.

$$V = c\sqrt{Rs} \quad \text{(Chezy formula.)}$$

$$V_1 = c\sqrt{R_1 s_1}$$

$$V_2 = c\sqrt{R_2 s_2}$$

$R_1 = R_2$, as for the same gage height the cross-section area and consequently the hydraulic radius remain constant; the coefficient c

[1] Method devised by M. R. Hall in 1908; elaborated and described by W. E. Hall and C. H. Pierce.

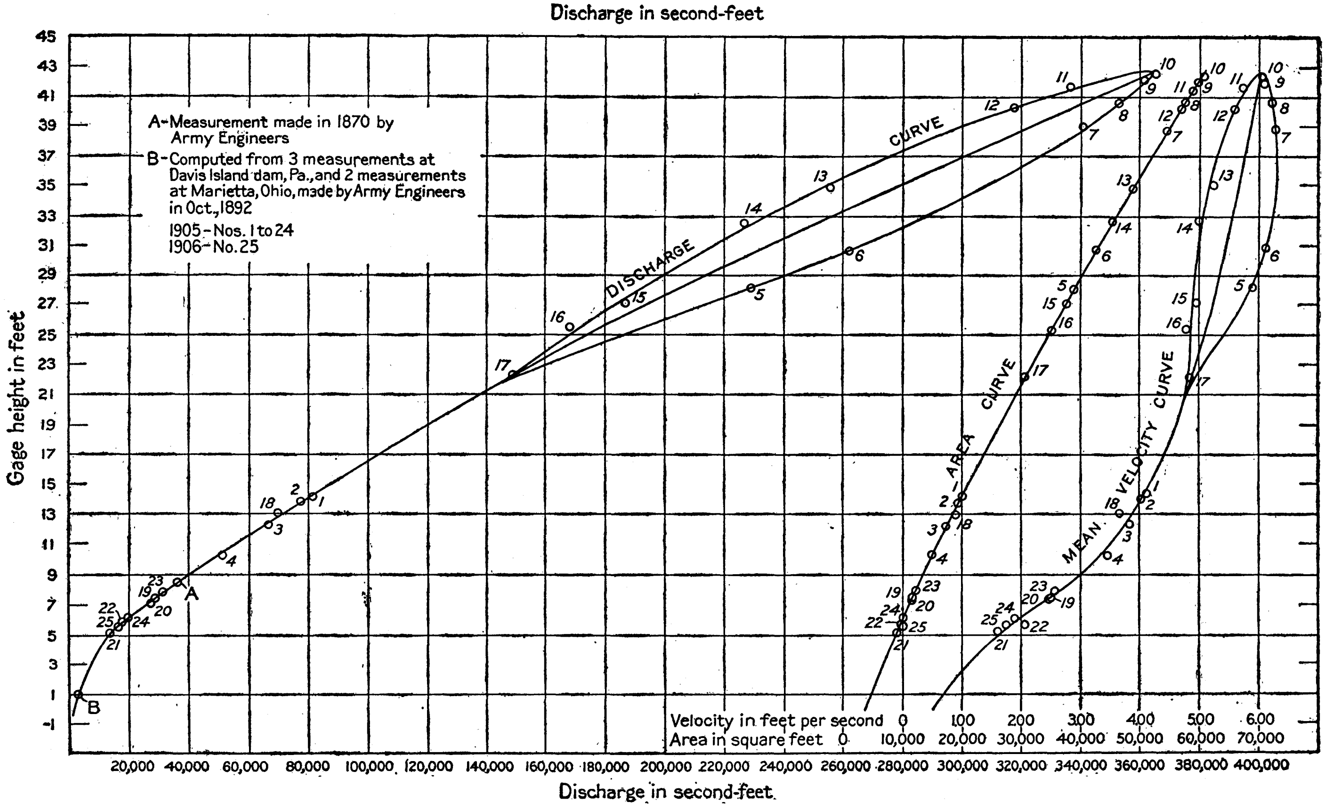

FIGURE 1.—Discharge, area, and mean velocity curves for Ohio River at Wheeling, W. Va.

remains the same if the conditions of the stream bed do not change, hence

$$\frac{V_1}{V_2}=\frac{\sqrt{s_1}}{\sqrt{s_2}}$$

If Q_1, a, and V_1 represent corresponding values of the discharge, area, and velocity: $Q_1=aV_1$, and similarly, $Q_2= aV_2$ for the same gage height but different slope, therefore

$$\frac{Q_1}{Q_2}=\frac{\sqrt{s_1}}{\sqrt{s_2}}$$

The slope (s) in the Chezy formula is the total fall or difference in elevation of water surface divided by distance (d) between the two points:

$$s=\frac{H}{d}$$

Hence

$$\sqrt{s_1}=\sqrt{\frac{H_1}{d}}$$

and

$$\sqrt{s_2}=\sqrt{\frac{H_2}{d}}$$

where H_1, s_1, H_2, and s_2 represent corresponding values of the fall and slope between the points. By dividing,

$$\frac{\sqrt{s_1}}{\sqrt{s_2}}=\frac{\sqrt{\frac{H_1}{d}}}{\sqrt{\frac{H_2}{d}}}=\frac{\sqrt{H_1}}{\sqrt{H_2}}$$

or

$$\frac{Q_1}{Q_2}=\sqrt{\frac{H_1}{H_2}}$$

Let Q_n be the "normal" discharge corresponding to H_n, the "normal" or average difference in elevation of water surface between the two points. Then

$$\frac{Q_1}{Q_n}=\sqrt{\frac{H_1}{H_n}}$$

In the above expression Q_1 represents the actual discharge of the stream as determined by the current meter and H_1 the corresponding difference in elevation of water surface between the two gages, or gage-height difference if the two gages are set to the same datum; Q_n represents a "normal" or theoretical value of the discharge for the "normal" or average gage-height difference. The value of H_n may be arbitrarily assumed, but to make the ratio of $\frac{H_1}{H_n}$ as near unity as possible H_n is taken as the average difference in elevation of water surface between the points.

By means of discharge measurements the values of Q_1 may be determined for different gage heights; $\frac{H_1}{H_n}$ will be likely to vary with the different measurements and will be greater or less than unity according as the slope of the stream at the time of the measurement is greater or less than the average slope. The values of Q_n as determined from the expression

$$Q_n = \frac{Q_1}{\sqrt{\frac{H_1}{H_n}}}$$

will, however, give a well-defined curve when plotted in the same way as the ordinary discharge rating curve. (See fig. 2.) The "normal" discharge curve for D_n having been determined, a "normal" rating table is prepared from it in the ordinary way. (See Table 3, pp. 62–63.)

To find the actual discharge of the stream at any stage and for any slope the "normal" discharge is taken from the "normal" rating table and multiplied by the proper value of $\sqrt{\frac{H_1}{H_n}}$, since

$$Q_1 = Q_n\sqrt{\frac{H_1}{H_n}}$$

APPLICATION OF THE METHOD.

In using this method the distance between the two gages should be such that the readings will readily show any appreciable change of slope; at the same time it must not be great enough to admit of breaks in the profile of the stream surface or of changed conditions due to inflow or outflow between the two gages. The theory on which the method is based assumes the same hydraulic radius throughout the distance. This condition is practically fulfilled by the streams in the low "delta" country of the Mississippi basin and in other places in which conditions are such as to require the use of the method.

Yazoo River at Greenwood, Miss., affords a good illustration of the effect of backwater and the application of the above method. The Yazoo and its tributaries lie in the region known as the Delta, a very flat country formed in comparatively recent times by deposits of silt from Mississippi River. Before the extensive levee system was built the whole Delta was covered at times by flood water from the Mississippi. The Yazoo flows in a southerly direction, paralleling the Mississippi in a general way, for almost 200 miles, finally joining it near Vicksburg. The elevation of extreme low-water surface at Vicksburg is 40 feet above mean sea level, with maximum flood-stage elevation of 94 feet (1884), giving a variation in stage of 54 feet. The elevation of water surface of Yazoo River at Greenwood, Miss., ranges from 93 feet to about 130 feet above mean sea level. This gives a variation in stage of about 37 feet. It may, then, be easily seen that Yazoo River at Greenwood is directly affected by variation in stage of Mississippi River at Vicksburg, and from gage-height readings of a single gage at Greenwood it would be impossible to determine if a high stage of the Yazoo was caused by a large discharge or by backwater from the Mississippi.

By means of a second gage at Philipp, a considerable distance above Greenwood, the difference in elevation of the water surface between the two points can be determined. A large tributary, the Yalobusha, joins the Tallahatchie between the two gages to form Yazoo River proper. It appears, however, that the conditions of flow of the Yalobusha and the Tallahatchie are so nearly the same that the inflow of the Yalobusha does not seriously affect the slope relations as determined by the gages at Philipp and Greenwood. Fifteen discharge measurements made during 1908, 1909, 1911, and 1912 (see Table 1) give a well-defined "normal" discharge rating curve (fig. 2). From this rating curve a "normal" rating table was prepared in the ordinary way. (See Table 3.) For determining the "normal" or average fall between the two gages the mean gage-height difference from September 6, 1908 (the date of establishment of the Philipp station), to December 31, 1912, was computed and found to be very nearly 17 feet; therefore 17 was adopted as the value of H_n.

For simplicity of notation the letter z has been taken as representing the value of $\frac{H_1}{H_n}$, or the difference in gage-height reading (at Philipp and Greenwood) divided by 17. A table was then prepared giving the values of z and $\sqrt{z}$ for gage-height differences varying from 6 to 28 feet. (See Table 2.)

The true discharge of Yazoo River at Greenwood on any date is, then, the "normal" discharge taken from the rating table multiplied by the $\sqrt{z}$ factor taken from Table 2. For example:

		Gage height in feet.
June 10, 1912.	Philipp	120.4
	Greenwood	110.9
	Difference	9.5
		Sec.-ft.
Q_n at Greenwood (from rating table)		12,900
$\sqrt{z}$ (from table)		0.748
True discharge $= Q_n \sqrt{z}$		9,650

For convenience of computation the work may be tabulated and all the numerical work preserved for reference or checking. The computation of daily discharge of Yazoo River at Greenwood, Miss., for the month of April, 1912, has been so arranged in Table 5.

Another way of applying the slope method is by means of parallel rating tables. Table 4 is such a rating table prepared for values of z ranging from 0.4 to 1.5. It will be seen that for $z = 1.0$ the table is that of the "normal" discharge. The use of this table obviates the necessity of multiplying by $\sqrt{z}$, for the multiplication is performed

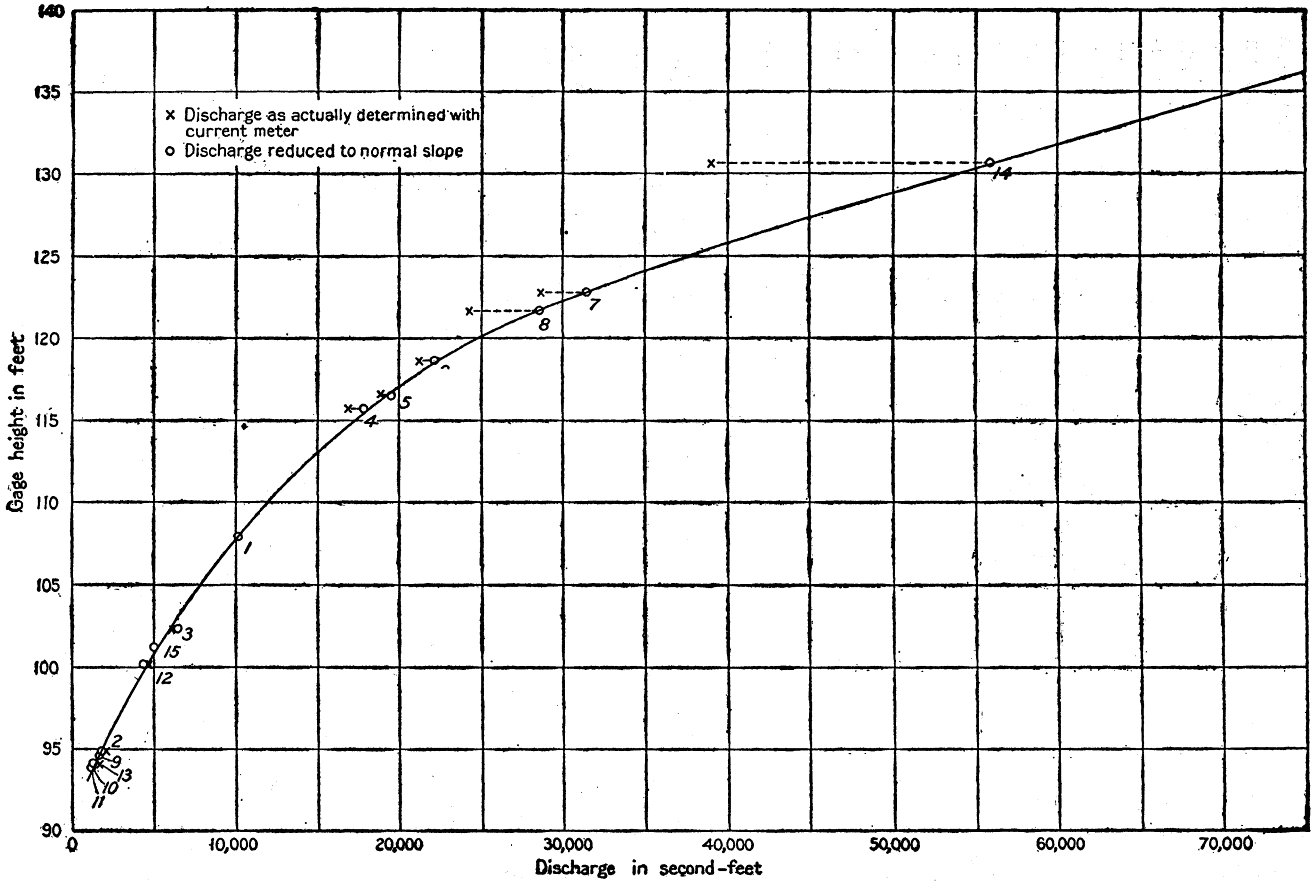

FIGURE 2.—Rating curve for Yazoo River at Greenwood, Miss.

in preparing the table. As the table shown is made out to give the true discharge corresponding to values of z which vary by tenths, considerable interpolation is involved in its application. The results obtained should be the same as those by the previous methods. An example is given below.

		Gage height in feet.
June 10, 1912.	Philipp	120.4
	Greenwood	110.9
	Difference	9.5

z=0.559 (by Table 2).

For z 0.5, Q_1 (by Table 4)	9,130
For z 0.6, Q_1 (by Table 4)	10,020
Difference for 1 tenth	890

0.59×890=520. 9,130+520=9,650 second-feet.

The use of the 20-inch slide rule is allowable in both of these methods and gives results exact to three significant figures. By using the slide rule and Table 2 the work is made largely mechanical and consists of tabulation in the form of Table 5.

It is believed that by making some modifications this method of basing the discharge on both the gage height and the slope can be successfully applied to tidal streams having a diurnal variation in stage and slope due to the action of the tide.

SUMMARY.

The following is a brief summary of methods of handling a "slope station," with a few precautions which experience has shown to be necessary.

FIELD WORK.

1. Locate the two gages at such distance apart as will give as much fall as possible between them without any break in slope or changed condition of stream bed.

2. Between the two gages there should be no riffle, no important tributary, no lake or material narrowing of channel. The water surface between the two should be as nearly a plane surface at all stages as possible.

3. It is absolutely necessary that the gages be set to the same datum.

4. Automatic gages should be used if possible. If ordinary gages are used great care should be taken to read the gages simultaneously. This applies to time of taking discharge measurements as well as daily gage heights.

5. Publish the gage heights from gage nearest to measuring section. The other gage will then be merely a "slope gage" unless the gages are far enough apart to warrant a rating at both sites. It would be convenient to call the gage used for gage heights gage "No. 1"; the slope gage would then be "No. 2."

6. It is not at all necessary to measure the distance between the two gages. This distance has the value of unity in the computation and may thus be disregarded. (See p. 55.)

OFFICE WORK.

1. When ready to begin office computations, obtain the normal fall between the two gages in the manner shown on page 57 of this paper. A good normal slope may usually be obtained from a few months' records. For convenience, use for the normal slope the even foot nearest to the mean value. When once assumed, the same normal slope should be used from year to year, regardless of the fact that a mean of the slopes for several years may differ from the normal slope assumed. Much work can be saved by following this method.

2. Make the normal rating curve in the following manner:

(*a*) For each measurement find the slope (or fall) between the two gages at the time of measurement.

(*b*) Divide that slope by the normal slope, and the result will be the value z.

(*c*) Divide the discharge, obtained by actual meter measurement, by the square root of the z value ($\sqrt{z}$), and the result obtained will be the "normal discharge." That is, the result will give what the discharge would have been had the slope been normal.

(*d*) Plot the "normal discharges," using the gage heights from nearest gage (gage No. 1) as ordinates. (No further use will be made of gage heights from No. 2 after slope is obtained.) Draw "normal curve" through the plotted points.

3. Make a normal "rating table" similar to Table 3.

4. To compute daily discharge the first method described in this paper has proved to be the best. Proceed as follows:

(*a*) Make a table for all values of $\sqrt{z}$ that are likely to be needed, similar to Table 2.

(*b*) Rule sheets similar to Table 5, then put readings from gage No. 1 in first column and those from gage No. 2 in second column. The procedure is then simply a matter of using the slide rule. For each day the difference between readings on gage No. 1 and gage No. 2 is the slope. Divide that slope by the normal slope and take the square root of result either by slide rule or from table of $\sqrt{z}$. (See Table 2.)

(*c*) Get normal discharge from the normal rating, using gage heights from gage No. 1.

(*d*) Multiply the normal discharge by $\sqrt{z}$, and the true discharge is obtained.

Finally, it should be reiterated:

1. Set both gages exactly to same datum.

2. Read gages simultaneously. If the normal fall amounts to more than 1 foot, read to nearest 0.01 foot; if less than 1 foot, read to 0.005, or nearer if possible.

TABLES.

TABLE 1.—*Discharge measurements of Yazoo River at Greenwood, Miss., in 1908–1912.*

Date.	Hydrographer.	Width.	Area of section.	Mean velocity.	Gage height.	Actual discharge.	Philipp gage height.	Fall.	z	$\sqrt{z}$	Normal discharge.	Measurement No.
		Feet.	*Sq. ft.*	*Ft. per sec.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Feet.*			*Sec.-ft.*	
1908.												
June 17	M. R. Hall	307	5,220	1.95	107.84	10,200	125.0	17.2	1.012	1.006	10,100	1
Dec. 5	W. A. Lamb	252	1,340	1.43	94.90	1,920	115.3	20.4	1.200	1.095	1,750	2
9	do	300	3,380	1.85	102.35	6,260	118.5	16.2	0.953	0.976	6,410	3
1909.												
Feb. 27	do	411	7,860	2.19	115.60	17,100	131.1	15.5	.912	.955	17,900	4
Mar. 4	do	416	8,270	2.30	116.55	19,000	132.8	16.2	.953	.976	19,500	5
12	Tallahatchie Drainage Commission engineers	660	9,690	2.26	118.51	21,900	135.0	16.5	.971	.985	22,200	6
27	do	662	13,300	2.15	122.72	28,600	136.8	14.1	.829	.910	31,400	7
Apr. 3	do	659	11,500	2.11	121.65	24,300	133.9	12.3	.724	.851	28,600	8
Aug. 24	E. H. Swett	260	1,540	1.10	94.67	1,690	113.0	18.4	1.082	1.040	1,620	9
26	do	259	1,430	1.01	94.28	1,450	112.7	18.4	1.082	1.040	1,390	10
27	do	258	1,400	1.00	94.16	1,410	112.5	18.3	1.076	1.037	1,360	11
1911.												
Aug. 21	R. E. Robertson	305	2,940	1.57	100.12	4,620	119.5	19.4	1.141	1.068	4,330	12
Nov. 18	do	269	1,290	1.19	94.30	1,540	112.9	18.6	1.094	1.046	1,470	13
1912.												
Apr. 5	W. E. Hall	663	17,300	2.26	130.64	39,100	138.9	8.3	.488	.699	55,900	14
Sept. 25	do	285	3,030	1.67	101.16	5,070	118.9	17.7	1.041	1.020	4,970	15

TABLE 2.—*Correction factors z and $\sqrt{z}$ for reducing "normal" discharge to true discharge computed on assumption of 17.0 feet as the normal gage-height difference—Philipp to Greenwood, Miss.—Yazoo River.*

Gage-height difference.	0		1		2		3		4		5	
	z	$\sqrt{z}$	z	$\sqrt{z}$	z	$\sqrt{z}$	z	$\sqrt{z}$	z	$\sqrt{z}$	z	$\sqrt{z}$
Feet.												
6	0.353	0.594	0.359	0.599	0.365	0.604	0.371	0.609	0.376	0.613	0.382	0.618
7	.412	.642	.418	.646	.424	.651	.429	.655	.435	.660	.441	.664
8	.471	.686	.476	.690	.482	.694	.488	.699	.494	.703	.500	.707
9	.529	.727	.535	.731	.541	.735	.547	.740	.553	.744	.559	.748
10	.588	.767	.594	.771	.600	.775	.606	.779	.612	.782	.618	.786
11	.647	.804	.653	.808	.659	.812	.665	.816	.671	.819	.676	.822
12	.706	.840	.712	.844	.718	.847	.724	.851	.729	.854	.735	.857
13	.765	.875	.771	.878	.776	.881	.782	.884	.788	.888	794	.891
14	.824	.908	.829	.911	.835	.914	.841	.917	.847	.920	.853	.924
15	.882	.939	.888	.942	.894	.946	.900	.949	.906	.952	.912	.955
16	.941	.970	.947	.973	.953	.976	.959	.979	.965	.982	.971	.985
17	1.000	1.000	1.006	1.003	1.012	1.006	1.018	1.009	1.024	1.012	1.029	1.014
18	1.059	1.029	1.065	1.032	1.071	1.035	1.076	1.037	1.082	1.040	1.088	1.043
19	1.118	1.057	1.124	1.060	1.129	1.063	1.135	1.065	1.141	1.068	1.147	1.071
20	1.176	1.085	1.182	1.087	1.188	1.090	1.194	1.093	1.200	1.096	1.206	1.098
21	1.235	1.111	1.241	1.114	1.247	1.117	1.253	1.119	1.259	1.122	1.265	1.125
22	1.294	1.137	1.300	1.140	1.306	1.143	1.312	1.145	1.318	1.148	1.324	1.150
23	1.353	1.163	1.359	1.166	1.365	1.168	1.371	1.171	1.376	1.173	1.382	1.176
24	1.412	1.188	1.418	1.190	1.424	1.193	1.429	1.195	1.435	1.198	1.441	1.200
25	1.470	1.212	1.476	1.215	1.482	1.217	1.488	1.220	1.494	1.222	1.500	1.225
26	1.529	1.237	1.535	1.239	1.541	1.242	1.547	1.244	1.553	1.247	1.559	1.249
27	1.588	1.260	1.594	1.263	1.600	1.265	1.606	1.267	1.612	1.270	1.618	1.272
28	......	......	......	......	......	......	......	......	......	......	......	......
29	......	......	......	......	......	......	......	......	......	......	......	......
30	......	......	......	......	......	......	......	......	......	......	......	......

TABLE 2.—*Correction factors z and $\sqrt{z}$ for reducing "normal" discharge to true discharge computed on assumption of 17.0 feet as the normal gage-height difference—Philipp to Greenwood, Miss.—Yazoo River*—Continued.

Gage-height difference.	6		7		8		9	
	z	$\sqrt{z}$	z	$\sqrt{z}$	z	$\sqrt{z}$	z	$\sqrt{z}$
Feet.								
6	0.388	0.623	0.394	0.628	0.400	0.632	0.406	0.637
7	.447	.669	.453	.673	.459	.678	.465	.682
8	.506	.711	.512	.716	.518	.720	.524	.724
9	.565	.752	.571	.756	.576	.759	.582	.763
10	.624	.790	.629	.793	.635	.797	.641	.801
11	.682	.826	.688	.829	.694	.833	.700	.837
12	.741	.861	.747	.864	.753	.868	.759	.871
13	.800	.894	.806	.898	.812	.901	.818	.904
14	.859	.927	.865	.930	.871	.933	.876	.936
15	.918	.958	.924	.961	.929	.964	.935	.967
16	.976	.988	.982	.991	.988	.994	.994	.997
17	1.035	1.017	1.041	1.020	1.047	1.023	1.053	1.026
18	1.094	1.046	1.100	1.049	1.106	1.052	1.112	1.055
19	1.153	1.074	1.159	1.077	1.165	1.079	1.171	1.082
20	1.212	1.101	1.218	1.103	1.224	1.106	1.229	1.108
21	1.271	1.127	1.276	1.129	1.282	1.132	1.288	1.134
22	1.329	1.152	1.335	1.155	1.341	1.158	1.347	1.160
23	1.388	1.178	1.394	1.181	1.400	1.183	1.406	1.186
24	1.447	1.203	1.453	1.205	1.459	1.208	1.465	1.210
25	1.506	1.227	1.512	1.230	1.518	1.232	1.524	1.235
26	1.565	1.251	1.571	1.254	1.576	1.256	1.582	1.258
27	1.624	1.274	1.629	1.277	1.635	1.279	1.641	1.281
28	....	....	....	....	....	....	....	....
29	....	....	....	....	....	....	....	....
30	....	....	....	....	....	....	....	....

NOTE.—The values of $\sqrt{z}$ are not exact in the third decimal place.

TABLE 3.—*Rating table for Yazoo River at Greenwood, Miss., for normal slope (fall of 17.0 feet), from Sept. 6, 1908, to Dec. 31, 1912.*

[z=1.0.]

Gage height.	Discharge.	Difference.	Gage height.	Discharge.	Difference.	Gage height.	Discharge.	Difference.	Gage height.	Discharge.	Difference.
Feet.	*Sec.-ft.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Sec.-ft.*
93.00	900	40	95.80	2,200	50	98.60	3,660	60	101.40	5,340	60
93.10	940	40	95.90	2,250	50	98.70	3,720	60	101.50	5,400	60
93.20	980	40	96.00	2,300	50	98.80	3,780	60	101.60	5,460	60
93.30	1,020	40	96.10	2,350	50	98.90	3,840	60	101.70	5,520	60
93.40	1,060	40	96.20	2,400	50	99.00	3,900	60	101.80	5,580	60
93.50	1,100	40	96.30	2,450	50	99.10	3,960	60	101.90	5,640	60
93.60	1,140	40	96.40	2,500	50	99.20	4,020	60	102.00	5,700	70
93.70	1,180	40	96.50	2,550	50	99.30	4,080	60	102.10	5,770	70
93.80	1,220	40	96.60	2,600	50	99.40	4,140	60	102.20	5,840	70
93.90	1,260	40	96.70	2,650	50	99.50	4,200	60	102.30	5,910	70
94.00	1,300	50	96.80	2,700	50	99.60	4,260	60	102.40	5,980	70
94.10	1,350	50	96.90	2,750	50	99.70	4,320	60	102.50	6,050	70
94.20	1,400	50	97.00	2,800	50	99.80	4,380	60	102.60	6,120	70
94.30	1,450	50	97.10	2,850	50	99.90	4,440	60	102.70	6,190	70
94.40	1,500	50	97.20	2,900	50	100.00	4,500	60	102.80	6,260	70
94.50	1,550	50	97.30	2,950	50	100.10	4,560	60	102.90	6,330	70
94.60	1,600	50	97.40	3,000	50	100.20	4,620	60	103.00	6,400	70
94.70	1,650	50	97.50	3,050	50	100.30	4,680	60	103.10	6,470	70
94.80	1,700	50	97.60	3,100	50	100.40	4,740	60	103.20	6,540	70
94.90	1,750	50	97.70	3,150	50	100.50	4,800	60	103.30	6,610	70
95.00	1,800	50	97.80	3,200	50	100.60	4,860	60	103.40	6,680	70
95.10	1,850	50	97.90	3,250	50	100.70	4,920	60	103.50	6,750	70
95.20	1,900	50	98.00	3,300	60	100.80	4,980	60	103.60	6,820	70
95.30	1,950	50	98.10	3,360	60	100.90	5,040	60	103.70	6,890	70
95.40	2,000	50	98.20	3,420	60	101.00	5,100	60	103.80	6,960	70
95.50	2,050	50	98.30	3,480	60	101.10	5,160	60	103.90	7,030	70
95.60	2,100	50	98.40	3,540	60	101.20	5,220	60	104.00	7,100	70
95.70	2,150	50	98.50	3,600	60	100.30	5,280	60	104.10	7,170	70

TABLE 3.—*Rating table for Yazoo River at Greenwood, Miss., for normal slope of 1.0 (fall of 17.0 feet), from Sept. 6, 1908, to Dec. 31, 1912*—Continued.

Gage height.	Discharge.	Difference.	Gage height.	Discharge.	Difference.	Gage height.	Discharge.	Difference.	Gage height.	Discharge.	Difference.
Feet.	*Sec.-ft.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Sec.-ft.*
104.20	7,240	70	111.50	13,500	100	118.80	22,660	170	126.10	41,310	310
104.30	7,310	70	111.60	13,600	100	118.90	22,830	170	126.20	41,620	310
104.40	7,380	70	111.70	13,700	100	119.00	23,000	170	126.30	41,930	310
104.50	7,450	70	111.80	13,800	100	119.10	23,170	170	126.40	42,240	310
104.60	7,520	70	111.90	13,900	100	119.20	23,340	170	126.50	42,550	310
104.70	7,590	70	112.00	14,000	110	119.30	23,510	180	126.60	42,860	310
104.80	7,660	70	112.10	14,110	110	119.40	23,690	180	126.70	43,170	310
104.90	7,730	70	112.20	14,220	110	119.50	23,870	180	126.80	43,480	310
105.00	7,800	80	112.30	14,330	110	119.60	24,050	180	126.90	43,790	310
105.10	7,880	80	112.40	14,440	110	119.70	24,230	190	127.00	44,100	320
105.20	7,960	80	112.50	14,550	110	119.80	24,420	190	127.10	44,420	320
105.30	8,040	80	112.60	14,660	110	119.90	24,610	190	127.20	44,740	320
105.40	8,120	80	112.70	14,777	110	120.00	24,800	200	127.30	45,060	320
105.50	8,200	80	112.80	14,880	110	120.10	25,000	200	127.40	45,380	320
105.60	8,280	80	112.90	14,990	110	120.20	25,200	200	127.50	45,700	320
105.70	8,360	80	113.00	15,100	110	120.30	25,400	210	127.60	46,020	320
105.80	8,440	80	113.10	15,210	110	120.40	25,610	210	127.70	46,340	320
105.90	8,520	80	113.20	15,320	110	120.50	25,820	210	127.80	46,660	320
106.00	8,600	80	113.30	15,430	110	120.60	26,030	210	127.90	46,980	320
106.10	8,680	80	113.40	15,540	110	120.70	26,240	220	128.00	47,300	330
106.20	8,760	80	113.50	15,650	110	120.80	26,460	220	128.10	47,630	330
106.30	8,840	80	113.60	15,760	110	120.90	26,680	220	128.20	47,960	330
106.40	8,920	80	113.70	15,870	110	121.00	26,900	230	128.30	48,290	330
106.50	9,000	80	113.80	15,980	110	121.10	27,130	230	128.40	48,620	330
106.60	9,080	80	113.90	16,090	110	121.20	27,360	230	128.50	48,950	330
106.70	9,160	80	114.00	16,200	120	121.30	27,590	240	128.60	49,280	330
106.80	9,240	80	114.10	16,320	120	121.40	27,830	240	128.70	49,610	330
106.90	9,320	80	114.20	16,440	120	121.50	28,070	240	128.80	49,940	330
107.00	9,400	80	114.30	16,560	120	121.60	28,310	240	128.90	50,270	330
107.10	9,480	80	114.40	16,680	120	121.70	28,550	250	129.00	50,600	340
107.20	9,560	80	114.50	16,800	120	121.80	28,800	250	129.10	50,940	340
107.30	9,640	80	114.60	16,920	120	121.90	29,050	250	129.20	51,280	340
107.40	9,720	80	114.70	17,040	120	122.00	29,300	260	129.30	51,620	340
107.50	9,800	80	114.80	17,160	120	122.10	29,560	260	129.40	51,960	340
107.60	9,880	80	114.90	17,280	120	122.20	29,820	260	129.50	52,300	340
107.70	9,960	80	115.00	17,400	130	122.30	30,080	270	129.60	52,640	340
107.80	10,040	80	115.10	17,530	130	122.40	30,350	270	129.70	52,980	340
107.90	10,120	80	115.20	17,660	130	122.50	30,620	270	129.80	53,320	340
108.00	10,200	90	115.30	17,790	130	122.60	30,890	270	129.90	53,660	340
108.10	10,290	90	115.40	17,920	130	122.70	31,160	280	130.00	54,000	350
108.20	10,380	90	115.50	18,050	130	122.80	31,440	280	130.10	54,350	350
108.30	10,470	90	115.60	18,180	130	122.90	31,720	280	130.20	54,700	350
108.40	10,560	90	115.70	18,310	130	123.00	32,000	280	130.30	55,050	350
108.50	10,650	90	115.80	18,440	130	123.10	32,280	280	130.40	55,400	350
108.60	10,740	90	115.90	18,570	130	123.20	32,560	290	130.50	55,750	350
108.70	10,830	90	116.00	18,700	130	123.30	32,850	290	130.60	56,100	350
108.80	10,920	90	116.10	18,830	130	123.40	33,140	290	130.70	56,450	350
108.90	11,010	90	116.20	18,960	130	123.50	33,430	290	130.80	56,800	350
109.00	11,100	90	116.30	19,090	130	123.60	33,720	290	130.90	57,150	350
109.10	11,190	90	116.40	19,220	130	123.70	34,010	290	131.00	57,500	350
109.20	11,280	90	116.50	19,350	130	123.80	34,300	300	131.10	57,850	350
109.30	11,370	90	116.60	19,480	130	123.90	34,600	300	131.20	58,200	350
109.40	11,460	90	116.70	19,610	130	124.00	34,900	300	131.30	58,550	350
109.50	11,550	99	116.80	19,740	130	124.10	35,200	300	131.40	58,900	350
109.60	11,640	90	116.90	19,870	130	124.20	35,500	300	131.50	59,250	350
109.70	11,730	90	117.00	20,000	140	124.30	35,800	300	131.60	59,600	350
109.80	11,820	90	117.10	20,140	140	124.40	36,100	300	131.70	59,950	350
109.90	11,910	90	117.20	20,280	140	124.50	36,400	300	131.80	60,300	350
110.00	12,000	100	117.30	20,420	140	124.60	36,700	300	131.90	60,650	350
110.10	12,100	100	117.40	20,560	140	124.70	37,000	300	132.00	61,000	350
110.20	12,200	100	117.50	20,700	140	124.80	37,300	300	132.10	61,350	350
110.30	12,300	100	117.60	20,840	140	124.90	37,600	300	132.20	61,700	350
110.40	12,400	100	117.70	20,980	140	125.00	37,900	310	132.30	62,050	350
110.50	12,500	100	117.80	21,120	140	125.10	38,210	310	132.40	62,400	350
110.60	12,600	100	117.90	21,260	140	125.20	38,520	310	132.50	62,750	350
110.70	12,700	100	118.00	21,400	150	125.30	38,830	310	132.60	63,100	350
110.80	12,800	100	118.10	21,550	150	125.40	39,140	310	132.70	63,450	350
110.90	12,900	100	118.20	21,700	150	125.50	39,450	310	132.80	63,800	350
111.00	13,000	100	118.30	21,850	160	125.60	39,760	310	132.90	64,150	350
111.10	13,100	100	118.40	22,010	160	125.70	40,070	310	133.00	64,500	350
111.20	13,200	100	118.50	22,170	160	125.80	40,380	310			
111.30	13,300	100	118.60	22,330	160	125.90	40,690	310			
111.40	13,400	100	118.70	22,490	170	126.00	41,000	310			

NOTE.—The above table is applicable for backwater conditions. It is based on 15 discharge measurements made during 1908, 1909, 1911, and 1912 and is well defined below 60,000 second-feet. Above gage height 130.00 feet the rating curve is a tangent, the difference being 350 per tenth.

TABLE 4.—*Rating table for Yazoo River at Greenwood, Miss., Sept. 6, 1908, to Dec. 31, 1912.*

[Computed on basis of 17.0 feet (z=1.0) as the normal gage-height difference between Philipp and Greenwood, Miss.]

z=0.4		z=0.5		z=0.6		z=0.7		z=0.8		z=0.9	
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec. ft.*
110.0	7,600	110.0	8,500	110.0	9,300	110.0	10,000	110.0	10,700	110.0	11,400
.1	7,660	.1	8,570	.1	9,380	.1	10,080	.1	10,790	.1	11,490
.2	7,720	.2	8,640	.2	9,460	.2	10,160	.2	10,880	.2	11,580
.3	7,780	.3	8,710	.3	9,540	.3	10,240	.3	10,970	.3	11,670
.4	7,840	.4	8,780	.4	9,620	.4	10,320	.4	11,060	.4	11,760
.5	7,900	.5	8,850	.5	9,700	.5	10,400	.5	11,150	.5	11,850
.6	7,960	.6	8,920	.6	9,780	.6	10,480	.6	11,240	.6	11,940
.7	8,020	.7	8,990	.7	9,860	.7	10,560	.7	11,330	.7	12,030
.8	8,080	.8	9,060	.8	9,940	.8	10,640	.8	11,420	.8	12,120
.9	8,140	.9	9,130	.9	10,020	.9	10,720	.9	11,510	.9	12,210
111.0	8,200	111.0	9,200	111.0	10,100	111.0	10,800	111.0	11,600	111.0	12,300
.1	8,260	.1	9,270	.1	10,180	.1	10,890	.1	11,690	.1	12,400
.2	8,320	.2	9,340	.2	10,260	.2	10,980	.2	11,780	.2	12,500
.3	8,380	.3	9,410	.3	10,340	.3	11,070	.3	11,870	.3	12,600
.4	8,440	.4	9,480	.4	10,420	.4	11,160	.4	11,960	.4	12,700
.5	8,500	.5	9,550	.5	10,500	.5	11,250	.5	12,050	.5	12,800
.6	8,560	.6	9,620	.6	10,580	.6	11,340	.6	12,140	.6	12,900
.7	8,620	.7	9,690	.7	10,660	.7	11,430	.7	12,230	.7	13,000
.8	8,680	.8	9,760	.8	10,740	.8	11,520	.8	12,320	.8	13,100
.9	8,740	.9	9,830	.9	10,820	.9	11,610	.9	12,410	.9	13,200

z=1.0		z=1.1		z=1.2		z=1.3		z=1.4		z=1.5	
Gage height.	Discharge.	Gage height	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*
110.0	12,000	110.0	12,600	110.0	13,200	110.0	13,700	110.0	14,200	110.0	14,700
.1	12,100	.1	12,700	.1	13,300	.1	13,810	.1	14,320	.1	14,820
.2	12,200	.2	12,800	.2	13,400	.2	13,920	.2	14,440	.2	14,940
.3	12,300	.3	12,900	.3	13,500	.3	14,030	.3	14,560	.3	15,060
.4	12,400	.4	13,000	.4	13,600	.4	14,140	.4	14,680	.4	15,180
.5	12,500	.5	13,100	.5	13,700	.5	14,250	.5	14,800	.5	15,300
.6	12,600	.6	13,200	.6	13,800	.6	14,360	.6	14,920	.6	15,420
.7	12,700	.7	13,300	.7	13,900	.7	14,470	.7	15,040	.7	15,540
.8	12,800	.8	13,400	.8	14,000	.8	14,580	.8	15,160	.8	15,660
.9	12,900	.9	13,500	.9	14,100	.9	14,690	.9	15,280	.9	15,780
111.0	13,000	111.0	13,600	111.0	14,200	111.0	14,800	111.0	15,400	111.0	15,900
.1	13,100	.1	13,710	.1	14,310	.1	14,920	.1	15,520	.1	16,030
.2	13,200	.2	13,820	.2	14,420	.2	15,040	.2	15,640	.2	16,160
.3	13,300	.3	13,930	.3	14,530	.3	15,160	.3	15,760	.3	16,290
.4	13,400	.4	14,040	.4	14,640	.4	15,280	.4	15,880	.4	16,420
.5	13,500	.5	14,150	.5	14,750	.5	15,400	.5	16,000	.5	16,550
.6	13,600	.6	14,260	.6	14,860	.6	15,520	.6	16,120	.6	16,680
.7	13,700	.7	14,370	.7	14,970	.7	15,640	.7	16,240	.7	16,810
.8	13,800	.8	14,480	.8	15,080	.8	15,760	.8	16,360	.8	16,940
.9	13,900	.9	14,590	.9	15,190	.9	15,880	.9	16,480	.9	17,070

NOTE.—The above table is applicable for backwater conditions. Table is complete only for gage heights 110.0 to 111.9 feet.

TABLE 5.—*Slope method of computing discharge of Yazoo River at Greenwood, Miss., for month of April, 1912.*

Day	Gage height.			$\sqrt{z}$.	"Normal" discharge, Q_n.	True discharge $Q_n\sqrt{z}$.
	Philipp.	Greenwood.	Difference or fall.			
	Feet.	*Feet.*	*Feet.*		*Second-feet.*	*Second-feet.*
1	138.6	129.9	8.7	0.716	53,700	38,400
2	138.7	130.2	8.5	.707	54,700	38,700
3	138.8	130.3	8.5	.707	55,000	38,900
4	138.9	130.5	8.4	.703	55,800	39,200
5	139.0	130.6	8.4	.703	56,100	39,400
6	139.0	130.7	8.3	.699	56,400	39,400
7	139.0	130.7	8.3	.699	56,400	39,400
8	139.0	130.6	8.4	.703	56,100	39,400
9	138.8	130.5	8.3	.699	55,800	39,000
10	138.8	130.3	8.5	707	55,000	38,900
11	138.7	130.2	8.5	.707	54,700	38,700
12	138.6	130.0	8.6	.711	54,000	38,400
13	138.6	129.8	8.8	.720	53,300	38,400
14	138.4	129.6	8.8	.720	52,600	37,900
15	138.4	129.5	8.9	.724	52,300	37,900
16	138.3	129.7	8.6	.711	53,000	37,700
17	138.4	130.4	8.0	.686	55,400	38,000
18	138.4	130.0	8.4	.703	54,000	38,000
19	138.4	129.9	8.5	.707	53,700	38,000
20	138.3	129.9	8.4	.703	53,700	37,800
21	138.3	129.9	8.4	.703	53,700	37,800
22	138.2	129.8	8.4	.703	53,300	37,500
23	138.0	129.6	8.4	.703	52,600	37,000
24	137.9	129.4	8.5	.707	52,000	36,800
25	137.8	129.1	8.7	.716	50,900	36,500
26	137.8	128.8	9.0	.727	49,900	36,300
27	137.6	128.6	9.0	.727	49,300	35,800
28	137.5	128.4	9.1	.731	48,600	35,500
29	137.5	128.4	9.1	.731	48,600	35,500
30	137.4	128.4	9.0	.727	48,600	35,300
Total			257.4			1,135,500
Mean			8.6			37,800
Maximum	139.0	130.7	9.1			39,400
Minimum	137.4	128.4	8.0			35,300

NOTE.—This month is a typical period showing backwater effect of Mississippi River on Yazoo River. It will be noticed that fall between Philipp and Greenwood is considerably below normal (17.0 feet). The "normal" discharges are taken from Table 3, three significant figures being used.

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