An Empirical Method of Determining Momentary Discharge of Tide-Affected Streams

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1586-D

Prepared in cooperation with the California Department of Water Resources

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By S. E. RANTZ

HYDROLOGY OF TIDAL STREAMS

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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1963

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington 25, D.C.

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AN EMPIRICAL METHOD OF DETERMINING MOMENTARY DISCHARGE OF TIDE-AFFECTED STREAMS

By S. E. RANTZ

ABSTRACT

This report demonstrates a new approach to the difficult and perplexing problem of of determining the momentary discharge of tide-affected streams. The instruments used are standard and consist of a stage recorder at each end of a reach of estuary. The 10.8-mile reach of Sacramento River between gages at Sacramento and Freeport was selected for study, and the required rating curves were derived by use of the coaxial method of graphical multiple correlation. The dependent variable in the correlation is discharge at Sacramento; the independent variables are (1) stage at Sacramento, (2) fall in the reach between Sacramento and Freeport, and (3) algebraic average of the rate of change of stage observed at Sacramento and Freeport.

INTRODUCTION

PURPOSE AND SCOPE OF THE STUDY

The computation of the momentary discharge of a tide-affected stream is a rather complex operation. In recent years the task has become greatly simplified as a result of the widespread use of electronic computors, but the need still remains for a simple operational method of determining discharge. As an example of this need, one might consider the operation of a sewage plant discharging its effluent into a tide-affected stream. For safe and efficient operation of the plant the discharge of the stream must be known, but there is no simple stage-discharge relationship for an estuarine stream because the discharge changes continually under the influence of the tide, even though the river inflow to the estuary may remain constant. The operator of the plant needs a rating curve or table to which he can apply the readings from a pair of river-stage gages and thereby make a reasonably accurate on-the-spot determination of streamflow. This report demonstrates a method of deriving rating curves of this type. The instruments used in the study are standard equipment and consist of a stage recorder at each end of a reach of estuary. Current-meter measurements of discharge were used in establishing the required discharge relationship.

The study is empirical in scope and treatment and is based on 302 measurements of discharge of Sacramento River at Sacramento, Calif. The Sacramento River is tributary to San Francisco Bay (fig. 1), an arm of the Pacific Ocean, and during periods of low flow, tidal effects extend upstream beyond the city of Sacramento for at least 25 miles. The discharge measurements were made at intervals of about 1¼ hours during the course of 12 daily tidal cycles in the years 1957–60. The streamflow measuring section is at the site of the stage recorder in the city of Sacramento; the auxiliary stage recorder is 10.8 miles downstream near the town of Freeport. Local inflow into the 10.8-mile reach of channel is negligible. The reach itself is located far enough upstream on the estuary so that no reversal of flow occurs there. However, when upland discharge (streamflow) into the estuary is less than about 30,000 cfs (cubic feet per second), the discharge is affected by tidal action, and unsteady flow exists in the reach. The relative magnitude of the tidal effect in the reach increases with decrease in the upland flow and with increase in the range in elevation between high and low tides at the mouth of San Francisco Bay. For example, measurements indicate that, with a steady upland flow of 19,000 cfs, the momentary discharge at Sacramento may commonly range from 18,000 cfs to 20,000 cfs in a single day; with a steady upland flow of 7,700 cfs, they indicate that momentary discharge may range from 5,000 cfs to 9,500 cfs in a single day.

ACKNOWLEDGMENTS

This study was performed under the terms of a cooperative agreement between the U.S. Geological Survey and the California Department of Water Resources. The report was prepared by the Surface Water Branch of the Geological Survey under the immediate supervision of Walter Hofmann, District Engineer.

DATA AVAILABLE

Twelve series of discharge measurements, made during the years 1957–60, were available for deriving a relationship between discharge and other hydraulic parameters. Each series of measurements extended over a period of about 33 hours in order to include one complete lunar day (approximately 24.8 hours), and in the course of each series, about 25 discharge measurements were made. Therefore, a total of 302 discharge measurements were available for use in this study. The measurements are summarized in table 1. The recorded stages at Sacramento and at Freeport were used to determine the difference in water-surface elevation (fall) between the two gage sites and to determine the rate of change of stage at each of these two sites.

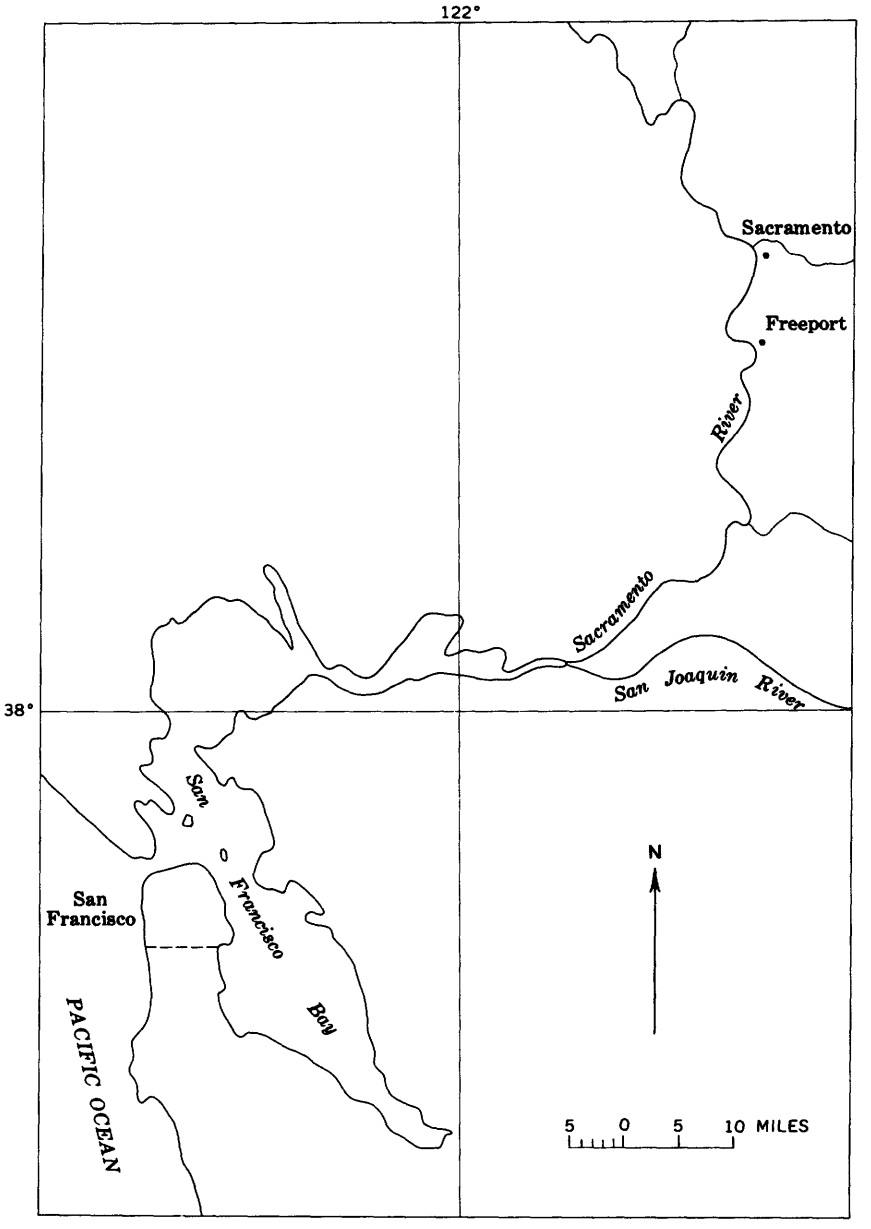

FIGURE 1.—Map of lower Sacramento River.

TABLE 1.—*Summary of Sacramento River discharge measurements*

Series designation	Date of measurements	Number of measurements in series	Average of measured discharges (cfs)	Range of measured discharges (cfs)
	1957			
A	Aug. 27–28	26	9, 780	7, 430–11, 300
B	Oct. 28–29	25	18, 400	17, 600–19, 300
C	Dec. 10–11	27	13, 700	12, 000–14, 800
	1958			
D	July 16–17	26	14, 000	11, 500–15, 500
E	Oct. 21–22	24	12, 900	11, 500–14, 300
F	Dec. 8–9	24	13, 000	10, 600–15, 100
	1959			
G	Apr. 23–24	26	8, 510	4, 060–10, 600
H	Sept. 30–Oct. 1	24	9, 330	6, 800–11, 300
J	Oct. 20–21	24	7, 770	4, 890– 9, 480
	1960			
K	Jan. 14–15	24	10, 900	8, 860–12, 400
L	June 9–10	27	10, 400	6, 860–12, 200
M	Oct. 6–7	25	8, 170	5, 500– 9, 670

The basic data used in the analysis are listed in table 2. The time tabulated in column 3 of these tables is the clock time midway between the start and finish of a discharge measurement. The stage at Sacramento (column 5) and the fall in the reach (column 6) are associated with the time shown in column 3, as are the rates of change of stage at Sacramento and Freeport (columns 7 and 8). Rate of change of stage, as tabulated, is the change in water-surface elevation during a 15-minute period centered on the clock time shown in column 3; the plus sign indicates a rising stage and the minus sign, a falling stage. Column 9 is the algebraic mean of columns 7 and 8. Columns 10 and 11 are discussed later in this report.

Figures 2–13 show discharge hydrographs for Sacramento during the periods when discharge measurements were made and also concurrent stage hydrographs recorded at Sacramento and Freeport.

DERIVATION OF DISCHARGE RELATIONSHIP

THEORETICAL BACKGROUND

Problems involving the unsteady flow of a tide-affected stream are usually analyzed by one of the following methods: (1) analysis of wave harmonics, (2) solution of a set of characteristic equations of unsteady flow (method of characteristics), or (3) integration of the differential equations of unsteady flow based on the mass-energy conservation principle.

The wave approach is impractical where tides are of the mixed type, as at Sacramento, and where the length of reach is short compared to the tidal wavelength the third method is generally the simplest. The tidal wavelength is the product of the wave period (12.4 hours) and the observed wave celerity (about 16.4 miles per hour on the lower Sacramento River). The computed wavelength is therefore about 200 miles, which is considerably longer than the 10.8-mile reach from Sacramento to Freeport. In view of this fact the differential equations of unsteady flow were made the starting point for devising an operational technique for rating Sacramento River at Sacramento.

A detailed discussion of the complex mathematics of the differential equations of unsteady flow is beyond the scope of this report. A sketchy treatment of the general principles underlying these equations is given to provide sufficient background for an understanding of the methodology adopted in this study. The fundamental principles involved in the differential equations are (1) the conservation of mass and (2) the conservation of energy. The differential continuity equation, which evolves from the first principle, states, in effect, that in a short interval of time the net change in discharge between Sacramento and Freeport is equal to the change in storage in the reach. The differential dynamic equation, which evolves from the second principle, states, in effect, that in a short interval of time the change in total head between Sacramento and Freeport is equal to the algebraic sum of the friction-head loss and the acceleration head (energy used to accelerate the flow or gained when the flow is decelerated). The friction-head loss has a constant algebraic sign in this problem because the flow in the reach does not reverse. The acceleration head has the same algebraic sign as the friction-head loss when the velocity is increasing with time and the opposite algebraic sign when the velocity is decreasing with time. The short interval of time just mentioned is relative, and whether an interval of time is short or not depends on the rapidity with which the velocity and cross-sectional area are changing. For the purpose of this study, a time interval of 15 minutes is sufficiently short.

An explicit analytical solution of the differential equations of unsteady flow is not possible, but there are several analytical techniques for a numerical solution by the method of finite differences.

COAXIAL METHOD OF GRAPHICAL CORRELATION

The many complexities involved in the determination of tide-affected discharge virtually dictate that a graphical correlation technique be employed using parameters that are indices of the terms found in the equations for unsteady flow. The dependent variable is

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the measured discharge at Sacramento; the proper selection of independent variables requires some thought. Basically, the equations of unsteady flow differ from those for steady flow by the inclusion of two additional terms: (1) an expression of storage in the reach and (2) an expression of the acceleration head. Past experience of the Geological Survey in rating streams with relatively steady flow, but with variable water-surface slope, has shown that the parameters of stage at one end of the reach and of fall through the reach are the only two independent variables required. Because of the unsteady flow that prevails during periods of low flow at Sacramento, one or more additional independent parameters are needed to serve as indices of storage and of acceleration head. An obvious choice for a third index variable is the rate of change of stage in the reach. The three independent variables to be correlated with measured discharge at Sacramento are therefore: (1) stage at Sacramento, (2) fall in the reach between Sacramento and Freeport, and (3) algebraic average of the change in stage observed at Sacramento and Freeport during a 15-minute interval. As mentioned previously, these variables for the 302 discharge measurements available are listed in table 2.

At this point, this study might appear to be merely a duplication of present Geological Survey practice for rating streams with variable water-surface slope caused by changing discharge. In the Jones, the Boyer, and the Lewis methods of the Geological Survey (Corbett and others, 1943, p. 159–163), water-surface slope and rate of change of stage are also used as parameters. In these three methods, however, rate of change of stage is not used as an index of storage or acceleration head; this parameter is used mathematically to adjust the observed water-surface slope to the slope that would have existed under conditions of constant stage, and the flow is then treated as though it were steady. There is more to consider, however, than just water-surface slope in problems involving rapidly changing discharge. The current Geological Survey rating methods are inadequate when accelerative forces present are too large to be ignored, and for this reason, those rating methods cannot be used to determine the momentary discharge of a tide-affected stream.

Returning to the problem of correlating measured discharge at Sacramento with the three hydraulic variables selected, it is apparent from the differential form of the equations of unsteady flow that no statistical model exists on which to base the relationship. Another complication stems from the fact that joint functions are involved, as the independent variables are interrelated. In other words, no independent variable can be considered individually for the purpose of determining its effect on the discharge; all three independent variables must be considered jointly. In a situation of this kind, the

hydrologist commonly uses a statistical technique known as the coaxial method of graphical multiple correlation. No attempt will be made to discuss this technique in detail, as it is adequately described in standard text books (Linsley and others, 1949, p. 650–656). Suffice it to say that a coaxial relation is actually a series of 3-variable relations arranged with common axes to facilitate plotting and computing. Several trial curves are generally necessary before a satisfactory set of curves is obtained.

The coaxial graphical correlation that is the end product of this study is found on plate 1. The trends of the families of curves are in agreement with the following four hypotheses that were established on the basis of the theoretical considerations discussed earlier:

1. Discharge increases with increasing stage at Sacramento;
2. Discharge increases with increasing fall in the reach;
3. Discharge increases when the stage is rising and decreases when the stage is falling;
4. Because joint functions are involved the individual curves in each family are not parallel but converge.

The method of using the graph is illustrated by the example on plate 1. First, the curves on the upper left are entered with the stage at Sacramento and the fall in the reach; next, the curves on the lower left are entered with the average rate of change of stage; finally the curve on the lower right is entered and the discharge is read. The graph on the upper right is not part of the correlation, but was added to provide a picture of the over-all accuracy of the derived correlation curves. On this comparison graph, measured discharge at Sacramento is plotted against discharge obtained by correlating the basic data listed in table 2.

The single graph on the lower right, for lack of a better name, is referred to as the adjustment graph. It was added to improve the results of the correlation obtained by use of the two families of curves on the left half of plate 1. The need for the adjustment graph might have been eliminated by curving or warping the straight lines that compose the two families of curves, but this course of action was rejected because there was too little increase in accuracy to be gained for the additional work that would be required. The adjustment graph may also serve another purpose. A limited amount of dredging is done in the reach during summer or early fall of each year to maintain the navigation channel. This study indicated that the dredging in the years 1957–60 had no significant effect on the rating curves. If in the future, however, the rating is found to shift because of dredging or other reasons, it will be necessary only to shift the adjustment curve to restore the rating for use, and the tedious task of revising the families of curves will be avoided.

Two additional parameters were considered in an attempt to improve the correlation. Because of the semidiurnal cyclic change in flow, it was felt that the use of an index term relating discharge to position on the tide wave might be helpful. Accordingly, the time in hours after the previous tide crest was tested in the correlation, but no improvement resulted. Another parameter tested was the variation with time of the rate of change of stage. There was theoretical justification for the use of this variable as an index of acceleration head because the second partial derivative of stage with respect to time appears in an expansion of the differential equations of unsteady flow. Use of this parameter made no general improvement in the correlation, however; many derived discharges were improved, but a greater number were impaired.

APPRAISAL OF DERIVED DISCHARGE RELATIONSHIP

Data relating to the adequacy of the derived discharge relationship are found in table 2, figures 2–13, and plate 1.

The discharges derived from the rating curves are tabulated together with the percent differences between these discharges and the measured discharges in columns 10 and 11 of the tables. Figures 2–13 are hydrographs of the derived discharges that may be compared with the hydrographs of measured discharge. The graph in the upper right corner of plate 1, as previously mentioned, also enables one to make a comparison of derived and measured discharges.

Prior to making this study the following criteria had been established for evaluating the adequacy of the rating curves to be derived:

1. For any series of discharge measurements the derived discharges should not be either consistently high or consistently low.
2. For any range of discharge values the derived discharges should not be either consistently higher or lower than the measured discharges.
3. The derived discharges should not differ from the measured discharges by more than ± 10 percent.

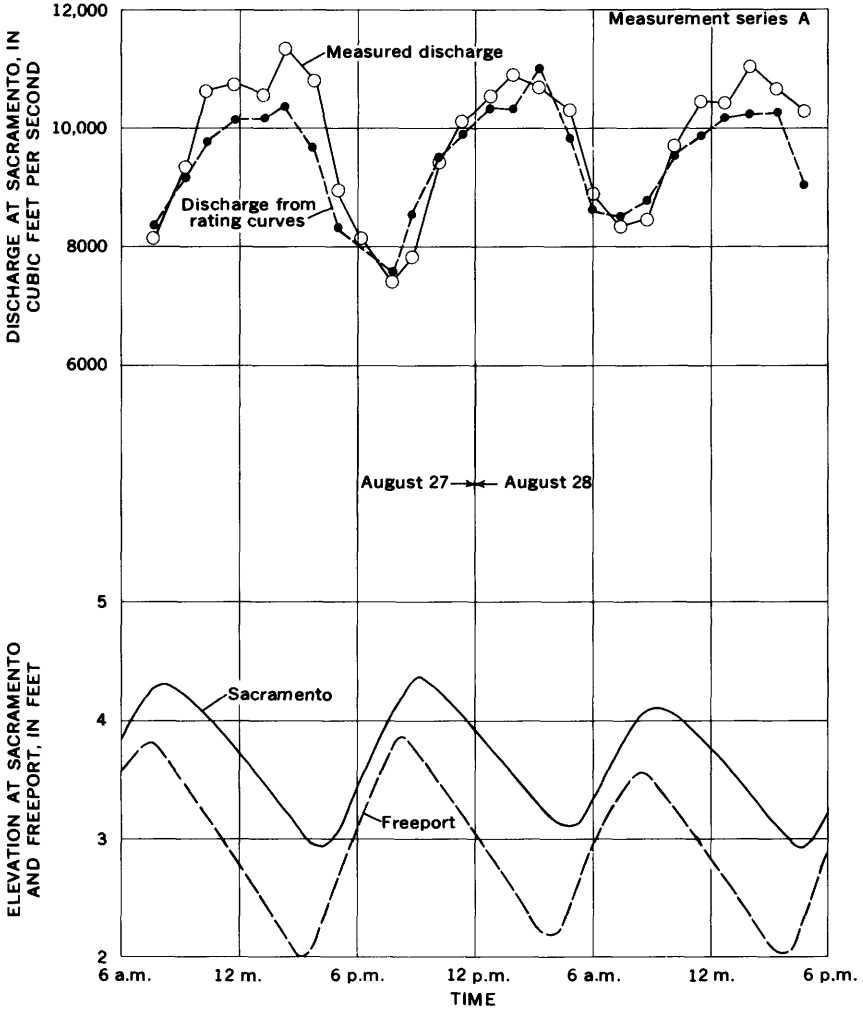

FIGURE 2.—Stage and discharge of Sacramento River, August 27–28, 1957.

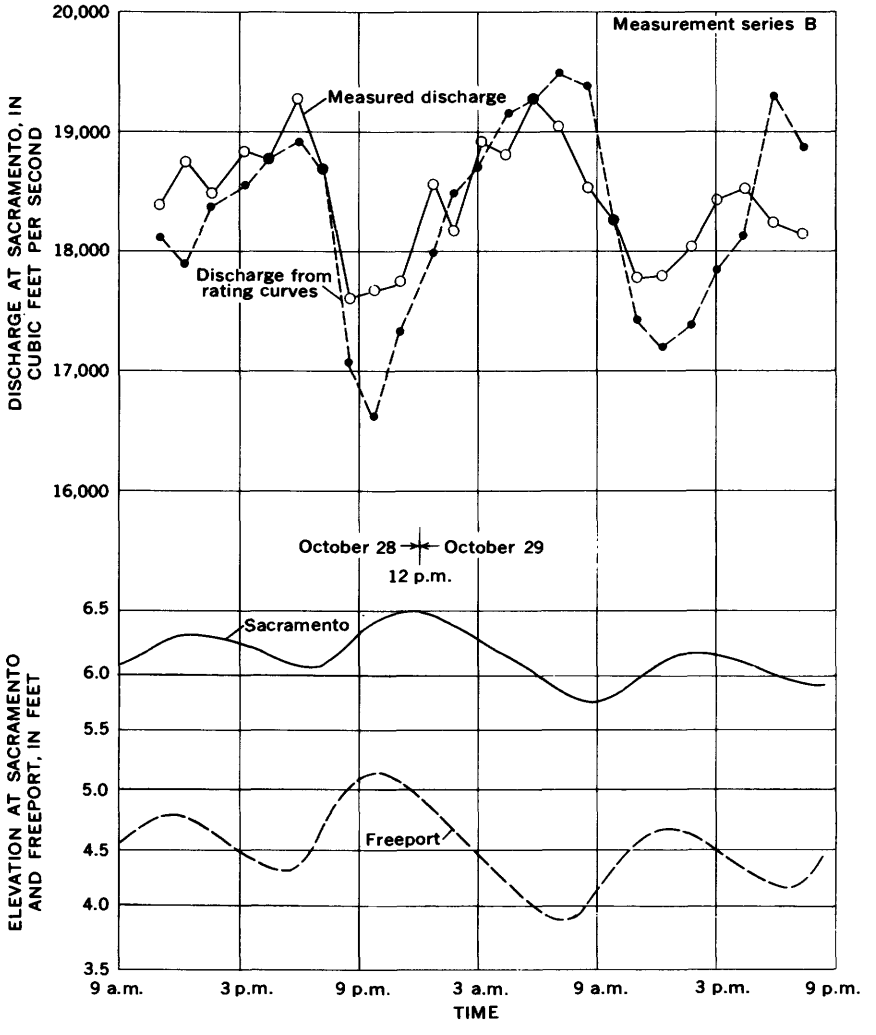

FIGURE 3.—Stage and discharge of Sacramento River, October 28–29, 1957.

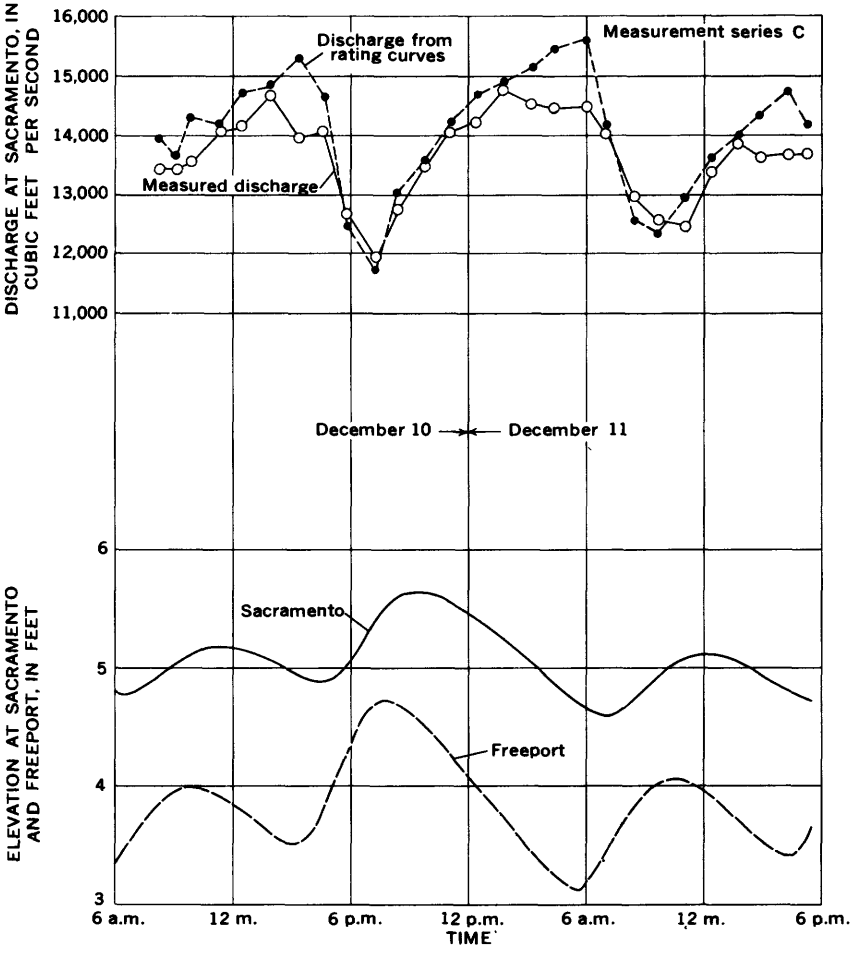

FIGURE 4.—Stage and discharge of Sacramento River, December 10–11, 1957.

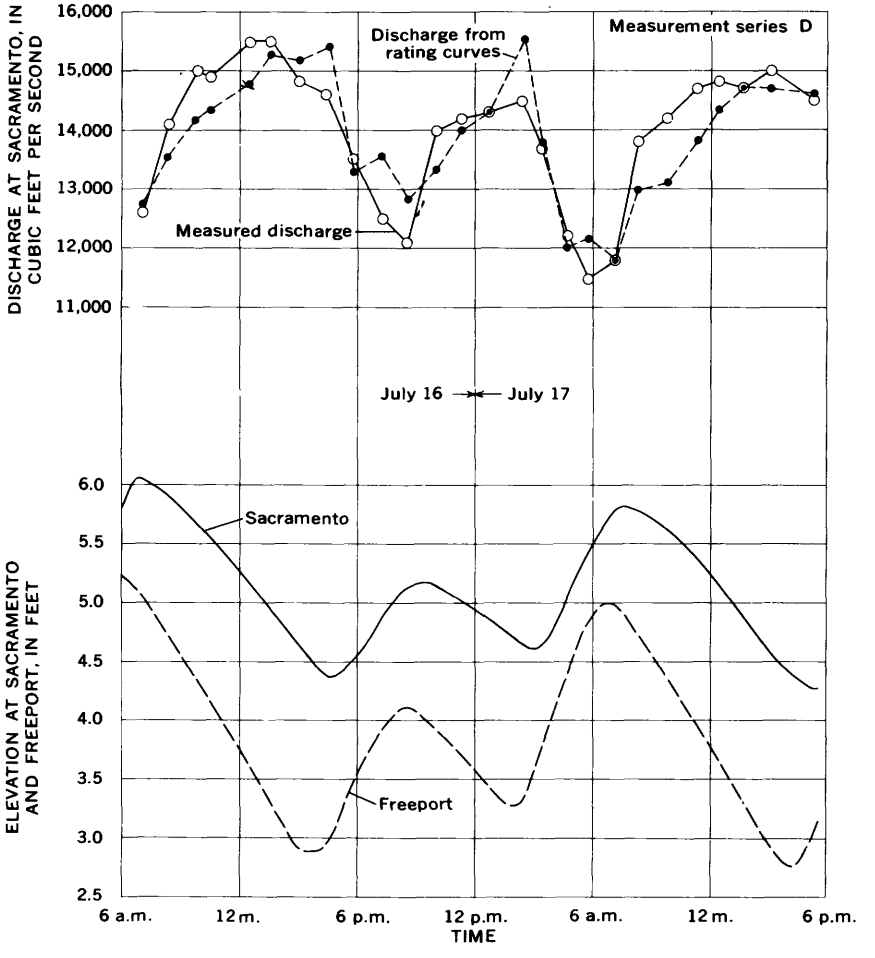

FIGURE 5.—Stage and discharge of Sacramento River, July 16–17, 1958.

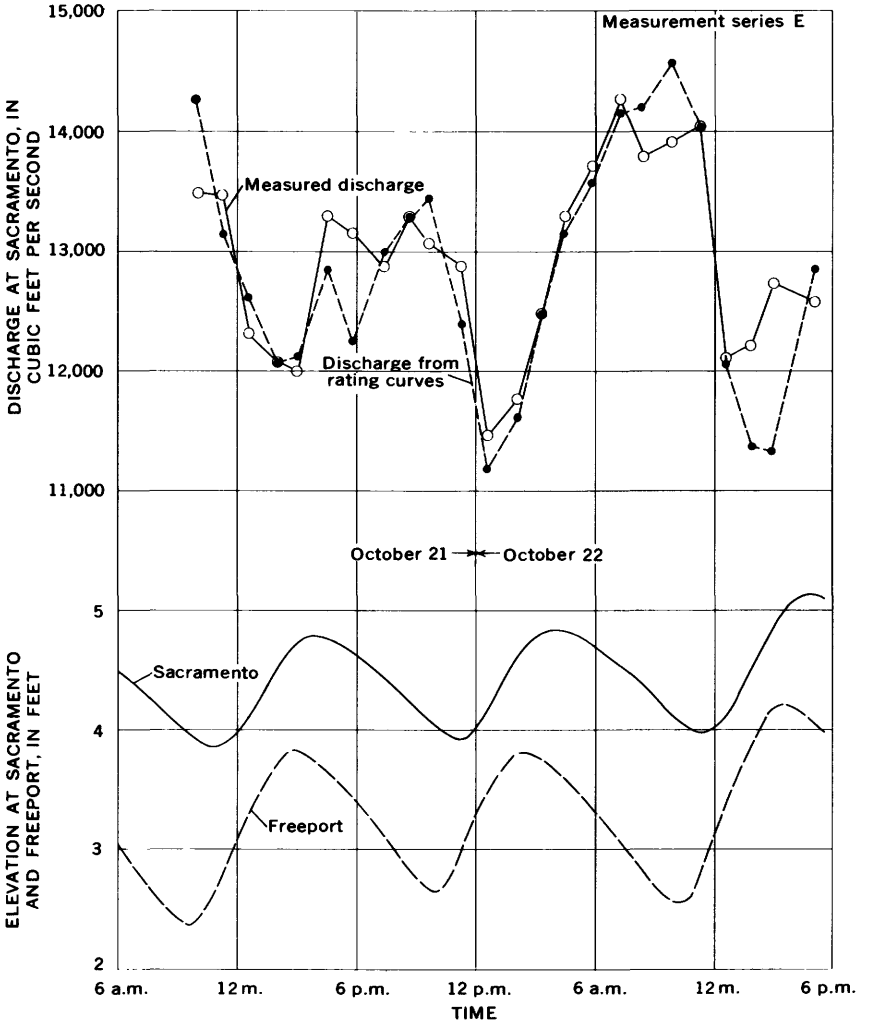

FIGURE 6.—Stage and discharge of Sacramento River, October 21–22, 1958.

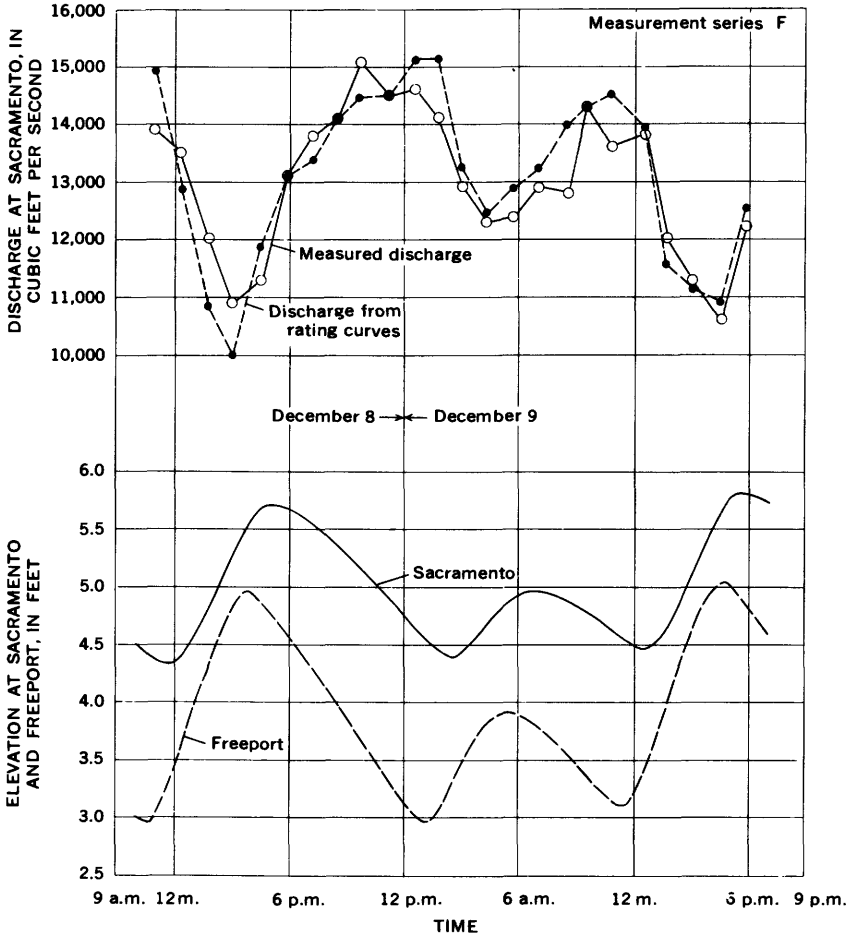

FIGURE 7.—Stage and discharge of Sacramento River, December 8–9, 1958.

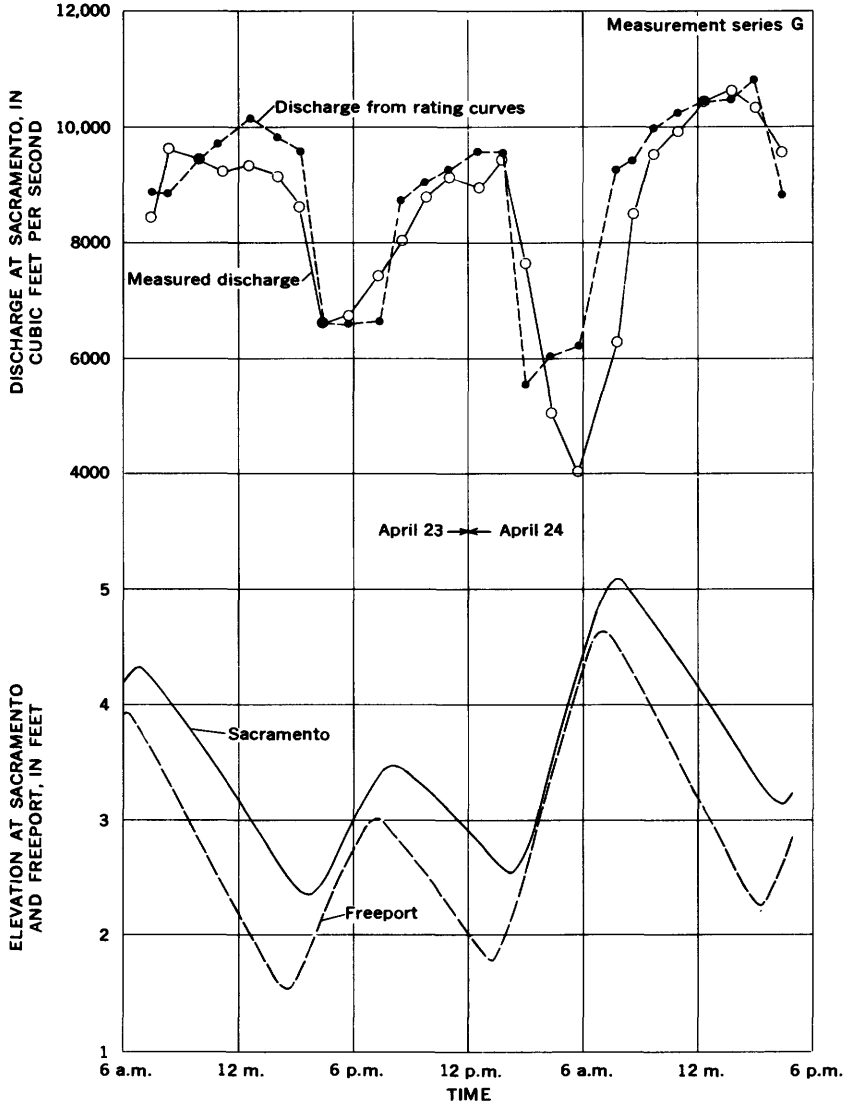

FIGURE 8.—Stage and discharge of Sacramento River, April 23–24, 1959.

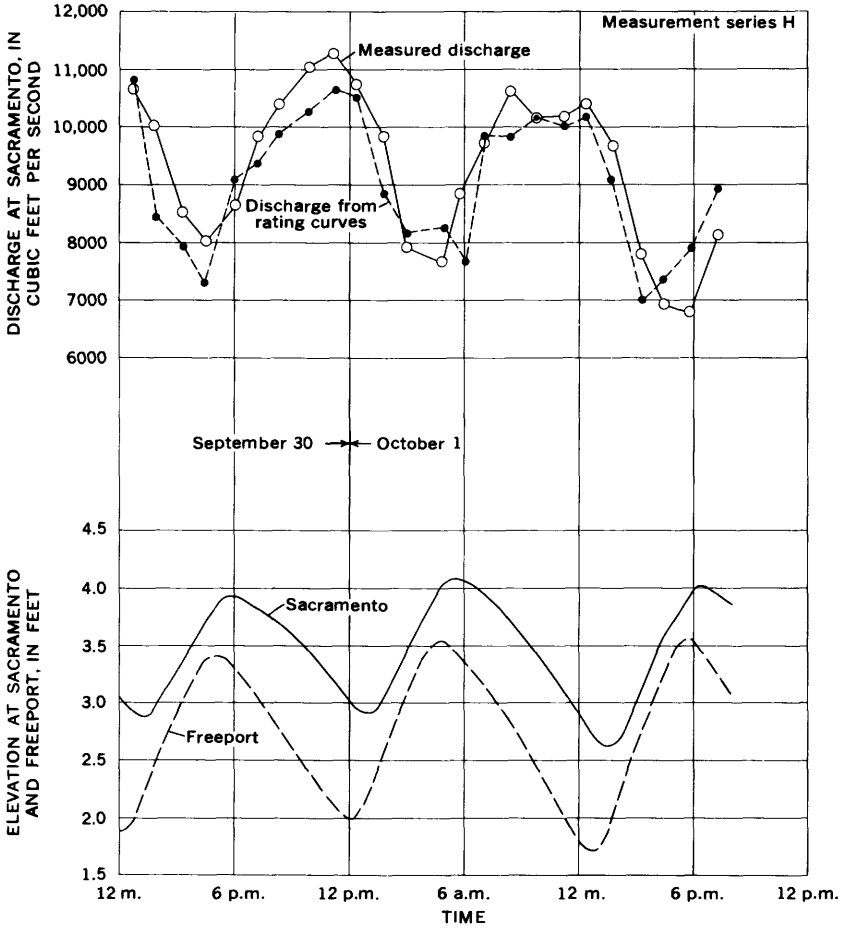

FIGURE 9.—Stage and discharge of Sacramento River, September 30 to October 1, 1959.

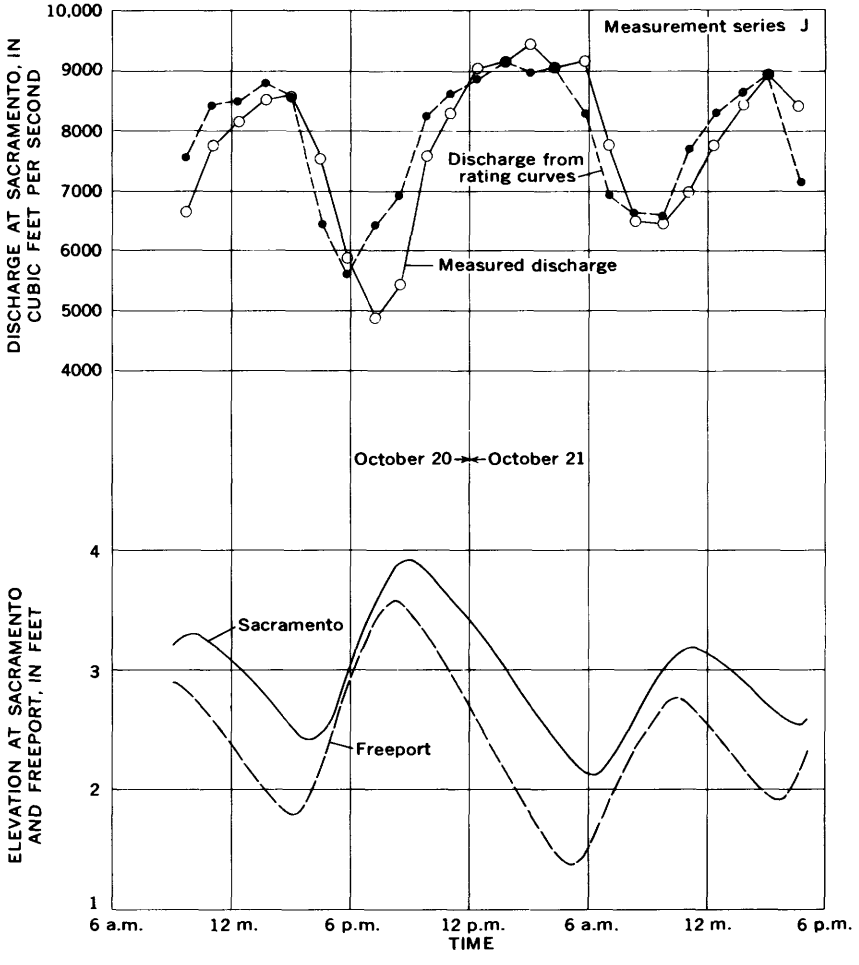

FIGURE 10.—Stage and discharge of Sacramento River, October 20–21, 1959.

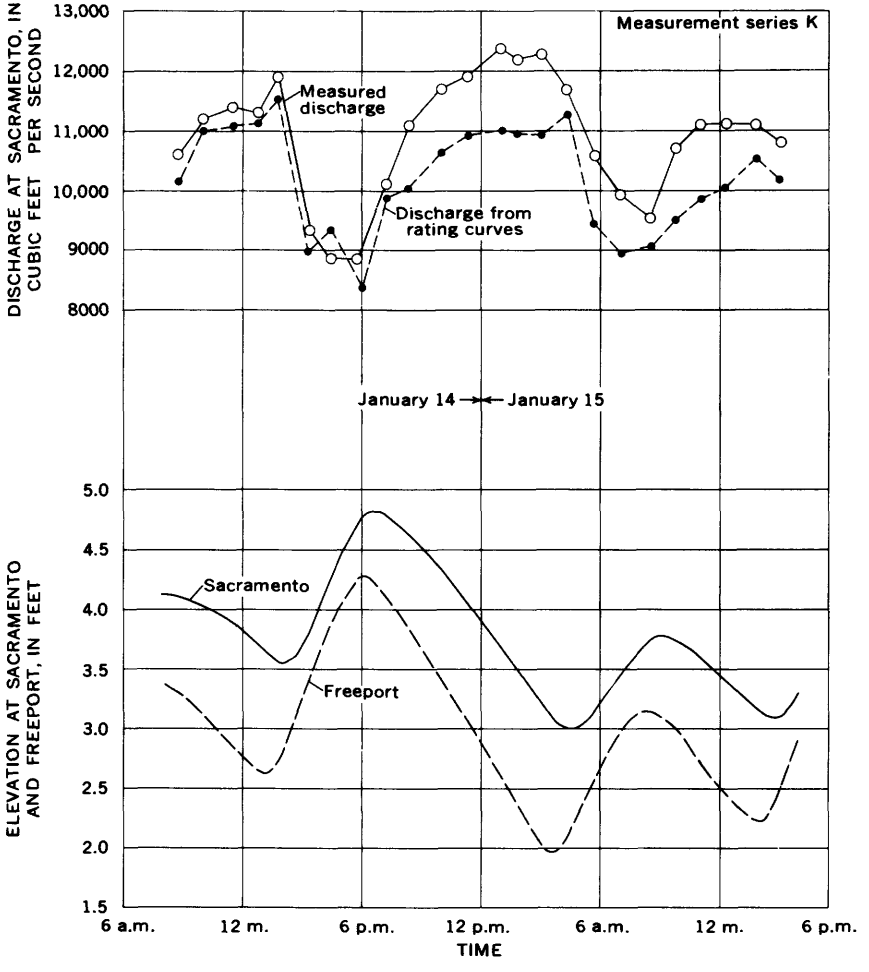

FIGURE 11.—Stage and discharge of Sacramento River, January 14–15, 1960.

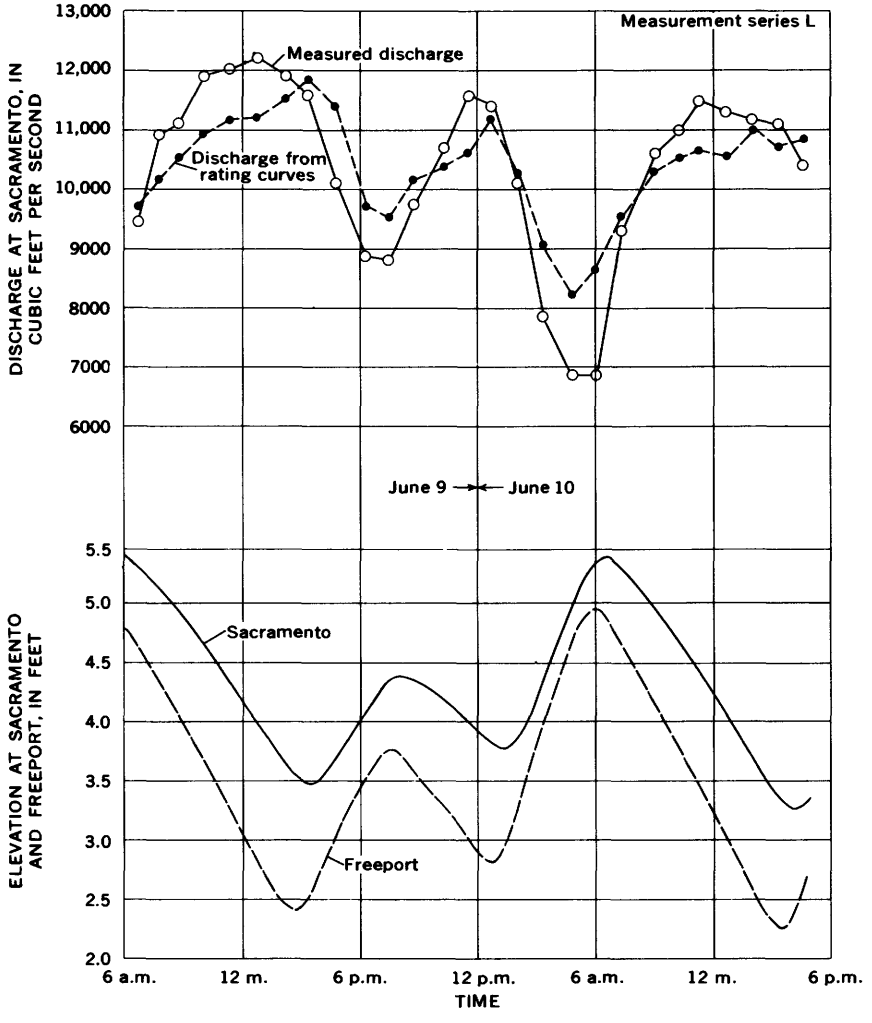

FIGURE 12.—Stage and discharge of Sacramento River, June 9–10, 1960.

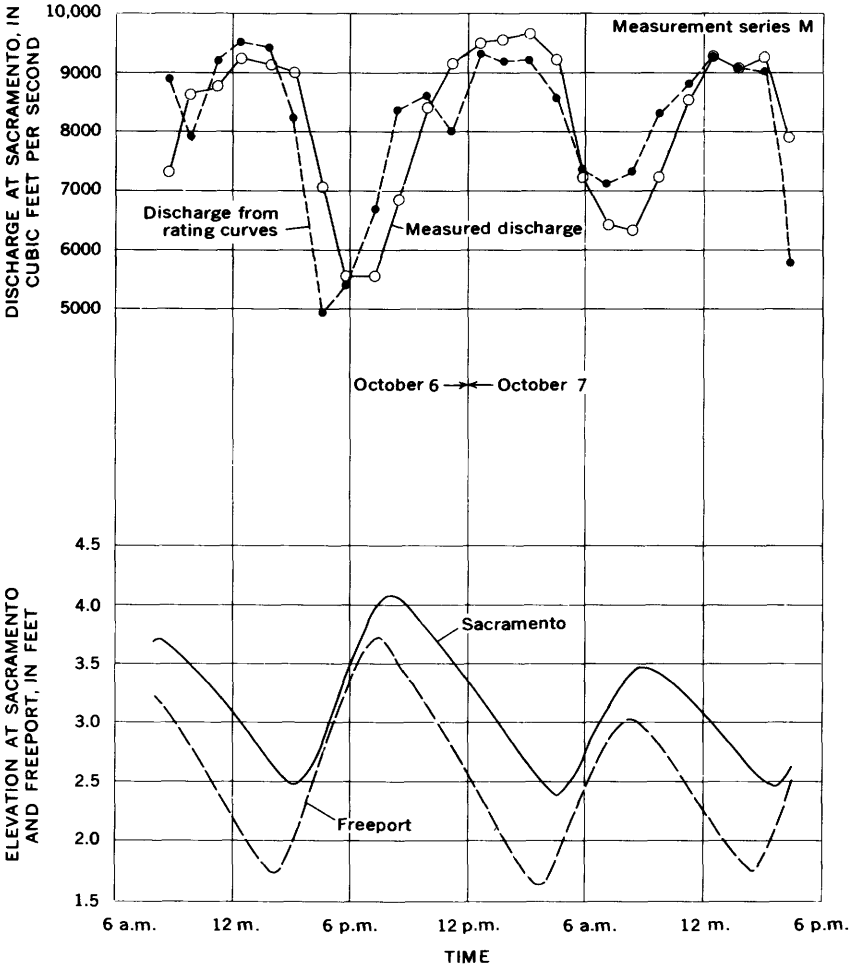

FIGURE 13.—Stage and discharge of Sacramento River, October 6–7, 1960.

TABLE 2.—*Sacramento River measurements*

Measurement No.	Date	Clock time	Measured discharge (cfs)	Stage at Sacramento (feet)	Fall, Sacramento to Freeport (feet)	Rate of change of stage (feet per 15 minutes)			Discharge from rating curves (cfs)	Percent error of discharge obtained from rating curves
						At Sacramento	At Freeport	Mean in reach		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Series A, August 27–28, 1957										
A- 1	Aug. 27	7:36 a.m.	8,160	4.28	0.48	+0.04	−0.04	0	8,400	+3
2	do	9:10	9,350	4.21	.73	−.04	−.07	−.055	9,200	−2
3	do	10:18	10,630	4.04	.83	−.04	−.08	−.06	9,800	−9
4	do	11:44 a.m.	10,760	3.78	.94	−.05	−.07	−.06	10,150	−6
5	do	1:12 p.m.	10,580	3.46	1.02	−.05	−.07	−.06	10,200	−4
6	do	2:20	11,340	3.23	1.09	−.06	−.05	−.055	10,400	−8
7	do	3:42	10,800	2.97	.85	−.03	+.10	+.035	9,780	−9
8	do	5:02	8,980	3.10	.41	+.07	+.11	+.09	8,330	−7
9	do	6:08	8,150	3.50	.31	+.11	+.12	+.115	8,070	−1
10	do	7:41	7,430	4.06	.29	+.08	+.07	+.075	7,600	+2
11	do	8:41	7,850	4.33	.51	+.03	−.05	−.01	8,580	+9
12	do	10:06	9,420	4.25	.73	−.04	−.05	−.045	9,500	+1
13	do	11:20 p.m.	10,090	4.07	.85	−.04	−.07	−.055	9,900	−2
14	Aug. 28	12:44 a.m.	10,560	3.80	.95	−.05	−.05	−.05	10,330	−2
15	do	1:59	10,890	3.55	1.01	−.05	−.06	−.055	10,330	−5
16	do	3:19	10,700	3.30	1.06	−.05	−.03	−.04	11,000	+3
17	do	4:45	10,320	3.11	.70	0	+.10	+.05	9,830	−5
18	do	6:00	8,900	3.34	.44	+.075	+.095	+.085	8,630	−3
19	do	7:25	8,380	3.79	.41	+.07	+.07	+.07	8,450	+1
20	do	8:43	8,480	4.09	.54	+.03	−.02	+.005	8,800	+4
21	do	10:05	9,710	4.05	.76	−.03	−.05	−.04	9,580	−1
22	do	11:28 a.m.	10,460	3.85	.87	−.04	−.06	−.05	9,900	−5
23	do	12:39 p.m.	10,430	3.66	.97	−.04	−.07	−.055	10,200	−2
24	do	2:00	11,020	3.39	1.04	−.06	−.06	−.06	10,230	−7
25	do	3:23	10,640	3.11	1.06	−.05	−.04	−.045	10,280	−3
26	do	4:47 p.m.	10,290	2.93	.58	0	+.12	+.06	9,030	−12
Series B, October 28–29, 1957										
B- 1	Oct. 28	11:00 a.m.	18,400	6.22	1.45	+0.025	+0.01	+0.02	18,130	−1
2	do	12:16 p.m.	18,750	6.30	1.53	+.005	−.015	−.005	17,910	−4
3	do	1:38	18,480	6.30	1.65	−.01	−.02	−.015	18,380	−1
4	do	3:13	18,840	6.21	1.75	−.02	−.03	−.025	18,560	−1
5	do	4:28	18,770	6.12	1.77	−.02	−.02	−.02	18,760	0
6	do	5:54	19,290	6.03	1.67	−.01	+.02	+.005	18,920	−2
7	do	7:05	18,680	6.04	1.39	+.02	+.08	+.05	18,700	0
8	do	8:27	17,610	6.21	1.20	+.045	+.045	+.045	17,070	−3
9	do	9:42	17,690	6.40	1.27	+.01	+.02	+.015	16,610	−6
10	do	11:04 p.m.	17,750	6.49	1.43	+.01	−.02	−.005	17,340	−2
11	Oct. 29	12:43 a.m.	18,560	6.45	1.62	−.01	−.04	−.025	17,980	−3
12	do	1:46	18,170	6.38	1.72	−.02	−.04	−.03	18,490	+2
13	do	3:09	18,920	6.25	1.81	−.03	−.04	−.035	18,700	−1
14	do	4:24	18,810	6.12	1.89	−.02	−.05	−.035	19,150	+2
15	do	5:44	19,290	5.97	1.94	−.03	−.04	−.035	19,300	0
16	do	7:02	19,050	5.84	1.93	−.02	−.02	−.02	19,480	+2
17	do	8:26	18,530	5.73	1.70	−.01	+.05	+.02	19,380	+5
18	do	9:46	18,270	5.78	1.45	+.02	+.06	+.04	18,330	0
19	do	11:05 a.m.	17,780	5.93	1.37	+.03	+.03	+.03	17,410	−2
20	do	12:12 p.m.	17,790	6.05	1.39	+.01	+.02	+.015	17,200	−3
21	do	1:41	18,040	6.14	1.51	0	−.02	−.01	17,380	−4
22	do	3:03	18,410	6.13	1.64	−.01	−.025	−.02	17,850	−3
23	do	4:23	18,520	6.06	1.71	−.02	−.03	−.025	18,110	−2
24	do	5:43	18,240	5.97	1.74	−.015	−.015	−.015	19,300	+6
25	do	7:24 p.m.	18,150	5.88	1.65	−.01	+.03	+.01	18,890	+4

TABLE 2.—*Sacramento River measurements*—Continued

Measurement No.	Date	Clock time	Measured discharge (cfs)	Stage at Sacramento (feet)	Fall, Sacramento to Freeport (feet)	Rate of change of stage (feet per 15 minutes)			Discharge from rating curves (cfs)	Percent error of discharge obtained from rating curves
						At Sacramento	At Freeport	Mean in reach		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Series C, December 10–11, 1957										
C- 1	Dec. 10	8:18 a.m.	13,460	4.95	1.07	+0.035	+0.035	+0.035	13,970	+4
2	do	9:06	13,410	5.05	1.08	+.03	+.02	+.025	13,660	+2
3	do	9:50	13,550	5.13	1.13	+.02	+.01	+.015	14,310	+6
4	do	11:18 a.m.	14,090	5.18	1.25	0	−.02	−.01	14,220	+1
5	do	12:27 p.m.	14,190	5.16	1.36	−.01	−.03	−.02	14,700	+4
6	do	1:50	14,670	5.07	1.46	−.03	−.03	−.03	14,860	+1
7	do	3:17	13,990	4.95	1.44	−.02	0	−.01	15,300	+9
8	do	4:34	14,080	4.88	1.08	0	+.11	+.055	14,650	+4
9	do	5:42	12,690	5.01	.73	+.06	+.09	+.075	12,480	−2
10	do	7:09	11,970	5.37	.69	+.06	+.04	+.05	11,700	−2
11	do	8:20	12,730	5.59	.90	+.03	+.02	+.025	13,070	+3
12	do	9:40	13,480	5.64	1.12	0	−.04	−.02	13,580	+1
13	do	11:00 p.m.	14,050	5.57	1.29	−.025	−.045	−.035	14,270	+2
14	Dec. 11	12:25 a.m.	14,270	5.41	1.40	−.03	−.05	−.04	14,700	+3
15	do	1:48	14,790	5.22	1.48	−.035	−.05	−.04	14,950	+1
16	do	3:04	14,550	5.04	1.56	−.035	−.05	−.04	15,150	+4
17	do	4:24	14,460	4.86	1.61	−.04	−.03	−.035	15,450	+7
18	do	6:01	14,490	4.64	1.47	−.025	+.04	+.01	15,600	+8
19	do	7:01	14,020	4.58	1.14	0	+.08	+.04	14,180	+1
20	do	8:24	12,910	4.72	.90	+.04	+.04	+.04	12,580	−3
21	do	9:35	12,570	4.91	.88	+.04	+.02	+.03	12,350	−2
22	do	11:03 a.m.	12,480	5.09	1.04	+.01	−.01	0	12,950	+4
23	do	12:24 p.m.	13,390	5.11	1.21	0	−.04	−.02	13,660	+2
24	do	1:36	13,840	5.05	1.32	−.02	−.04	−.03	14,040	+1
25	do	2:53	13,630	4.94	1.39	−.02	−.04	−.03	14,330	+5
26	do	4:18	13,680	4.81	1.39	−.02	0	−.01	14,750	+8
27	do	5:19 p.m.	13,700	4.74	1.16	−.01	+.07	+.03	14,200	+4
Series D, July 16–17, 1958										
D- 1	July 16	6:59 a.m.	12,600	6.04	1.00	−0.025	−0.045	−0.035	12,780	+1
2	do	8:22	14,100	5.88	1.15	−.02	−.06	−.04	13,530	−4
3	do	9:47	15,000	5.68	1.33	−.04	−.07	−.055	14,190	−5
4	do	10:23 a.m.	14,900	5.56	1.38	−.05	−.06	−.055	14,350	−4
5	do	12:38 p.m.	15,500	5.11	1.56	−.05	−.07	−.06	14,790	−5
6	do	1:35	15,500	4.92	1.64	−.04	−.06	−.05	15,300	−1
7	do	3:02	14,800	4.63	1.69	−.05	−.05	−.05	15,200	+3
8	do	4:23	14,600	4.39	1.34	−.02	+.10	+.04	15,420	+6
9	do	5:44	13,500	4.51	.95	+.04	+.08	+.06	13,310	−1
10	do	7:10	12,500	4.85	.87	+.10	+.06	+.08	13,570	+9
11	do	8:25	12,100	5.09	.98	+.02	0	+.01	12,820	+6
12	do	9:52	14,000	5.14	1.20	−.02	−.04	−.03	13,330	−5
13	do	11:10 p.m.	14,200	5.05	1.33	−.02	−.05	−.035	14,000	−1
14	July 17	12:39 a.m.	14,300	4.87	1.44	−.03	−.05	−.04	14,350	0
15	do	2:21	14,500	4.64	1.30	−.02	+.10	+.04	15,510	+7
16	do	3:15	13,700	4.64	.93	+.02	+.13	+.075	13,800	+1
17	do	4:35	12,200	5.01	.63	+.10	+.10	+.10	12,000	−2
18	do	5:37	11,500	5.40	.62	+.08	+.10	+.09	12,180	+6
19	do	7:00	11,800	5.78	.79	+.04	−.03	+.005	11,770	0
20	do	8:19	13,800	5.78	1.07	−.015	−.055	−.035	12,980	−6
21	do	9:38	14,200	5.61	1.21	−.05	−.08	−.065	13,130	−8
22	do	11:11 a.m.	14,700	5.35	1.34	−.04	−.08	−.06	13,820	−6
23	do	12:23 p.m.	14,800	5.12	1.48	−.04	−.08	−.06	14,350	−3
24	do	1:36	14,700	4.90	1.56	−.05	−.06	−.055	14,700	0
25	do	3:00	15,000	4.58	1.63	−.05	−.06	−.055	14,700	−2
26	do	5:10 p.m.	14,500	4.26	1.22	−.01	+.10	+.045	14,600	+1

TABLE 2.—*Sacramento River measurements*—Continued

Measurement No.	Date	Clock time	Measured discharge (cfs)	Stage at Sacramento (feet)	Fall, Sacramento to Freeport (feet)	Rate of change of stage (feet per 15 minutes)			Discharge from rating curves (cfs)	Percent error of discharge obtained from rating curves
						At Sacramento	At Freeport	Mean in reach		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Series E, October 21-22, 1958										
E-1	Oct. 21	10:05 a.m.	13,490	3.89	1.40	−0.03	+0.06	+0.015	14,270	+6
2	do	11:05 a.m.	13,470	3.85	1.11	0	+.03	+.04	13,150	−2
3	do	12:30 p.m.	12,320	4.07	.85	+.07	+.09	+.08	12,620	+2
4	do	1:53	12,080	4.50	.78	+.07	+.06	+.065	12,040	0
5	do	3:05	11,990	4.75	.93	+.03	−.01	+.01	12,120	+1
6	do	4:30	13,300	4.77	1.12	−.01	−.04	−.025	12,850	−3
7	do	5:45	13,150	4.66	1.11	−.03	−.06	−.045	12,250	−7
8	do	7:13	12,880	4.45	1.33	−.04	−.06	−.05	12,980	+1
9	do	8:34	13,300	4.25	1.41	−.04	−.05	−.045	13,300	0
10	do	9:35	13,060	4.08	1.42	−.04	−.02	−.03	13,450	+3
11	do	11:10 p.m.	12,880	3.92	.93	+.01	+.10	+.055	12,400	−4
12	Oct. 22	12:30 a.m.	11,470	4.17	.69	+.07	+.08	+.075	11,180	−3
13	do	2:00	11,760	4.61	.80	+.06	+.01	+.035	11,620	−1
14	do	3:10	12,490	4.81	1.02	+.03	−.02	+.005	12,470	0
15	do	4:25	13,280	4.82	1.20	−.01	−.04	−.025	13,160	−1
16	do	5:40	13,710	4.73	1.34	−.03	−.05	−.04	13,560	−1
17	do	7:10	14,270	4.55	1.47	−.03	−.05	−.04	14,150	−1
18	do	8:27	13,790	4.35	1.55	−.04	−.05	−.045	14,200	+3
19	do	9:48	13,900	4.13	1.58	−.04	−.01	−.025	14,560	+5
20	do	11:11 a.m.	14,050	3.97	1.17	0	+.10	+.05	14,000	0
21	do	12:30 p.m.	12,110	4.11	.76	+.06	+.11	+.085	12,040	−1
22	do	1:41	12,210	4.46	.64	+.08	+.09	+.085	11,360	−7
23	do	2:57	12,710	4.87	.68	+.08	+.03	+.055	11,330	−11
24	do	5:04 p.m.	12,580	5.13	1.09	0	−.04	−.02	12,850	+2
Series F, December 8-9, 1958										
F-1	Dec. 8	11:00 a.m.	13,900	4.38	1.35	−0.02	+0.07	+0.025	14,940	+7
2	do	12:15 p.m.	13,500	4.39	.81	+.045	+.125	+.085	12,860	−5
3	do	1:37	12,000	4.76	.51	+.09	+.11	+.10	10,740	−10
4	do	3:00	10,900	5.26	.44	+.095	+.075	+.085	10,000	−8
5	do	4:27	11,300	5.69	.82	+.035	−.045	−.005	11,870	+5
6	do	5:50	13,100	5.69	1.09	−.01	−.05	−.03	13,160	0
7	do	7:06	13,800	5.55	1.22	−.04	−.06	−.05	13,400	−3
8	do	8:30	14,100	5.34	1.35	−.03	−.07	−.05	14,100	0
9	do	9:44	15,100	5.13	1.47	−.05	−.06	−.055	14,440	−4
10	do	11:07 p.m.	14,500	4.90	1.56	−.05	−.07	−.06	14,550	0
11	Dec. 9	12:29 a.m.	14,600	4.65	1.63	−.045	−.04	−.04	15,110	+3
12	do	1:43	14,100	4.45	1.39	−.035	+.07	+.02	15,150	+7
13	do	3:03	12,900	4.45	.94	+.035	+.08	+.06	13,240	+3
14	do	4:17	12,300	4.68	.86	+.06	+.035	+.05	12,470	+1
15	do	5:40	12,400	4.91	1.00	+.03	0	+.015	12,900	+4
16	do	6:55	12,900	4.96	1.18	−.01	−.03	−.02	13,240	+3
17	do	8:33	12,800	4.89	1.37	−.015	−.055	−.035	14,000	+9
18	do	9:30	14,300	4.79	1.44	−.025	−.045	−.035	14,270	0
19	do	10:43 a.m.	13,600	4.63	1.48	−.03	−.035	−.03	14,520	+7
20	do	12:25 p.m.	13,800	4.47	1.06	0	+.11	+.055	13,920	+1
21	do	1:34	12,000	4.61	.63	+.07	+.11	+.09	11,580	−4
22	do	2:55	11,300	5.10	.51	+.09	+.12	+.105	11,130	−2
23	do	4:26	10,600	5.63	.60	+.06	+.02	+.04	10,900	+3
24	do	5:49 p.m.	12,200	5.81	.97	−.01	−.05	−.03	12,530	+3

TABLE 2.—*Sacramento River measurements*—Continued

Measurement No.	Date	Clock time	Measured discharge (cfs)	Stage at Sacramento (feet)	Fall, Sacramento to Freeport (feet)	Rate of change of stage (feet per 15 minutes)			Discharge from rating curves (cfs)	Percent error of discharge obtained from rating curves
						At Sacramento	At Freeport	Mean in reach		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Series G, April 23–24, 1959										
G- 1	Apr. 23	7:25 a.m.	8,440	4.23	0.64	−0.06	−0.06	−0.06	8,890	+5
2	do	8:20	9,650	4.04	.67	−.06	−.08	−.07	8,840	−8
3	do	9:52	9,490	3.69	.82	−.06	−.07	−.065	9,460	0
4	do	11:10 a.m.	9,260	3.38	.94	−.07	−.08	−.075	9,700	+5
5	do	12:37 p.m.	9,320	3.02	1.02	−.07	−.08	−.075	10,180	+9
6	do	2:03	9,160	2.64	1.05	−.06	−.04	−.05	9,820	+7
7	do	3:10	8,640	2.39	.73	−.03	+.09	+.03	9,590	+11
8	do	4:25	6,600	2.48	.27	+.04	+.11	+.075	6,600	0
9	do	5:47	6,740	2.92	.25	+.08	+.08	+.08	6,600	−2
10	do	7:15	7,410	3.38	.37	+.06	0	+.03	6,650	−10
11	do	8:28	8,070	3.45	.65	−.02	−.04	−.03	8,750	+8
12	do	9:40	8,800	3.30	.75	−.04	−.05	−.045	9,050	+3
13	do	11:02 p.m.	9,120	3.09	.84	−.05	−.06	−.055	9,210	+1
14	Apr. 24	12:37 a.m.	8,970	2.80	.94	−.05	−.04	−.045	9,580	+7
15	do	1:41	9,420	2.61	.76	−.03	+.10	+.035	9,580	+2
16	do	3:00	7,640	2.71	.13	+.09	+.16	+.125	5,520	−28
17	do	4:23	5,090	3.52	.11	+.17	+.14	+.155	6,050	+19
18	do	5:41	4,060	4.30	.11	+.14	+.14	+.14	6,250	+54
19	do	7:46	6,300	5.09	.60	0	−.09	−.045	9,280	+47
20	do	8:33	8,490	4.95	.66	−.05	−.06	−.055	9,450	+11
21	do	9:41	9,540	4.71	.79	−.05	−.08	−.065	10,000	+5
22	do	11:05 a.m.	9,940	4.39	.90	−.07	−.08	−.075	10,230	+3
23	do	12:18 p.m.	10,450	4.09	.98	−.07	−.08	−.075	10,420	0
24	do	1:42	10,610	3.71	1.06	−.07	−.08	−.075	10,460	−1
25	do	2:59	10,350	3.40	1.10	−.05	−.04	−.045	10,820	+5
26	do	4:23 p.m.	9,580	3.16	.54	0	+.09	+.045	8,830	−8
Series H, September 30 to October 1, 1959										
H- 1	Sept. 30	12:40 p.m.	10,660	2.92	0.96	−0.02	+0.07	+0.025	10,820	+2
2	do	1:50	10,000	2.92	.48	+.06	+.06	+.06	8,420	−16
3	do	3:13	8,510	3.33	.33	+.08	+.10	+.09	7,900	−7
4	do	4:28	8,050	3.67	.31	+.06	+.03	+.045	7,300	−9
5	do	6:00	8 630	3.93	.64	0	−.045	−.02	9,100	+5
6	do	7:10	9,870	3.83	.76	−.04	−.06	−.05	9,380	−5
7	do	8:22	10,390	3.68	.88	−.03	−.07	−.05	9,880	−5
8	do	9:52	11,020	3.45	1.02	−.05	−.07	−.06	10,290	−7
9	do	11:08 p.m.	11,290	3.19	1.09	−.05	−.03	−.04	10.630	−6
10	Oct. 1	12:26 a.m.	10,730	2.95	.94	−.03	+.05	+.01	10,500	−2
11	do	1:41	9,850	3.00	.47	+.08	+.10	+.09	8,820	−10
12	do	3:02	7,920	3.42	.32	+.105	+.12	+.11	8.150	+3
13	do	4:43	7,680	3.97	.43	+.045	0	+.02	8,240	+7
14	do	5:48	8,870	4.06	.40	−.01	−.04	−.025	7,620	−14
15	do	7:00	9,730	3.93	.76	−.035	−.05	−.04	9,830	+1
16	do	8:22	10,600	3.71	.90	−.06	−.07	−.065	9,840	−7
17	do	9:46	10,150	3.42	.99	−.045	−.075	−.06	10,100	0
18	do	11:10 a.m.	10.170	3.10	1.07	−.07	−.07	−.07	10,000	−1
19	do	12:20 p.m.	10,400	2.83	1.09	−.07	−.03	−.05	10,180	−2
20	do	1:46	9,630	2.63	.60	+.015	+.115	+.065	9,060	−6
21	do	3:06	7,800	2.95	.25	+.10	+.12	+.11	7,000	−10
22	do	4:25	6,940	3.52	.25	+.11	+.10	+.105	7,350	+6
23	do	5:47	6,800	3.92	.38	+.05	0	+.025	7,900	+16
24	do	7:08 p.m.	8,120	3.95	.68	−.03	−.08	−.055	8,960	+10

TABLE 2.—*Sacramento River measurements*—Continued

Measurement No.	Date	Clock time	Measured discharge (cfs)	Stage at Sacramento (feet)	Fall, Sacramento to Freeport (feet)	Rate of change of stage (feet per 15 minutes)			Discharge from rating curves (cfs)	Percent error of discharge obtained from rating curves
						At Sacramento	At Freeport	Mean in reach		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Series J, October 20–21, 1959										
J- 1	Oct. 20	9:39 a.m.	6,650	3.28	0.44	+0.02	−0.04	−0.01	7,570	+14
2	do	11:02 a.m.	7,770	3.22	.62	−.03	−.04	−.035	8,460	+9
3	do	12:21 p.m.	8,170	3.01	.70	−.05	−.06	−.055	8,520	+4
4	do	1:40	8,530	2.79	.79	−.04	−.06	−.05	8,800	+3
5	do	3:00	8,580	2.53	.74	−.055	0	−.03	8,620	0
6	do	4:26	7,560	2.46	.27	+.04	+.10	+.07	6,420	−15
7	do	5:44	5,840	2.97	.12	+.13	+.12	+.125	5,600	−4
8	do	7:06	4,890	3.56	.20	+.10	+.07	+.085	6,420	+31
9	do	8:22	5,420	3.89	.31	+.02	−.03	−.005	6,950	+28
10	do	9:44	7,600	3.83	.55	−.035	−.06	−.05	8,250	+9
11	do	10:58 p.m.	8,300	3.62	.66	−.05	−.065	−.06	8,620	+4
12	Oct. 21	12:24 a.m.	9,060	3.30	.75	−.05	−.07	−.06	8,890	−2
13	do	1:46	9,180	3.01	.84	−.06	−.06	−.06	9,110	−1
14	do	3:05	9,480	2.69	.90	−.08	−.07	−.075	9,000	−5
15	do	4:14	9,090	2.41	.93	−.055	−.055	−.055	9,090	0
16	do	5:42	9,180	2.12	.61	−.02	+.08	+.03	8,320	−9
17	do	7:00	7,750	2.24	.33	+.075	+.085	+.08	6,950	−10
18	do	8:20	6,500	2.64	.28	+.06	+.06	+.06	6,600	+2
19	do	9:38	6,440	2.97	.27	+.06	+.05	+.055	6,570	+2
20	do	10:58 a.m.	6,990	3.19	.49	0	−.04	−.02	7,720	+10
21	do	12:20 p.m.	7,740	3.09	.62	−.02	−.05	−.035	8,330	+8
22	do	1:46	8,460	2.90	.71	−.035	−.05	−.04	8,630	+2
23	do	3:00	8,920	2.73	.78	−.04	−.03	−.035	8,890	0
24	do	4:33 p.m.	8,410	2.54	.38	0	+.08	+.04	7,150	−15
Series K, January 14–15, 1960										
K- 1	Jan. 14	8:38 a.m.	10,600	4.12	0.79	−0.01	−0.03	−0.02	10,160	−4
2	do	10:02	11,200	4.03	.91	−.025	−.035	−.03	11,000	−2
3	do	11:00 a.m.	11,400	3.93	.99	−.03	−.045	−.04	11,100	−3
4	do	12:42 p.m.	11,300	3.71	1.05	−.035	−.03	−.03	11,100	−2
5	do	1:47	11,900	3.58	.88	−.01	+.075	+.03	11,520	−3
6	do	3:23	9,320	3.83	.41	+.07	+.12	+.095	8,990	−4
7	do	4:24	8,860	4.21	.44	+.08	+.09	+.085	9,310	+5
8	do	5:48	8,860	4.64	.37	+.08	+.01	+.045	8,350	−6
9	do	7:10	10,100	4.77	.67	−.03	−.05	−.04	9,890	−2
10	do	8:21	11,100	4.61	.77	−.04	−.06	−.05	10,000	−10
11	do	10:02	11,700	4.32	.95	−.05	−.07	−.06	10,650	−9
12	do	11:20 p.m.	11,900	4.05	1.04	−.05	−.07	−.06	10,890	−8
13	Jan. 15	12:58 a.m.	12,400	3.69	1.13	−.055	−.07	−.06	10,990	−11
14	do	1:48	12,200	3.50	1.18	−.07	−.07	−.07	10,930	−10
15	do	3:04	12,300	3.21	1.19	−.06	−.05	−.055	10,920	−11
16	do	4:18	11,700	3.01	.95	−.01	+.10	+.045	11,280	−4
17	do	5:38	10,600	3.12	.58	+.06	+.08	+.07	9,440	−11
18	do	7:00	9,920	3.46	.50	+.065	+.06	+.06	8,940	−10
19	do	8:26	9,540	3.73	.58	+.03	0	+.015	9,050	−5
20	do	9:49	10,700	3.73	.76	−.02	−.04	−.03	9,490	−11
21	do	11:02 a.m.	11,100	3.60	.89	−.035	−.075	−.055	9,820	−12
22	do	12:20 p.m.	11,100	3.40	.96	−.04	−.04	−.04	10,200	−8
23	do	1:46	11,100	3.22	1.00	−.03	−.01	−.02	10,550	−5
24	do	3:00 p.m.	10,800	3.10	.60	+.015	+.115	+.065	10,130	−6

TABLE 2.—*Sacramento River measurements*—Continued

Measurement No.	Date	Clock time	Measured discharge (cfs)	Stage at Sacramento (feet)	Fall, Sacramento to Freeport (feet)	Rate of change of stage (feet per 15 minutes)			Discharge from rating curves (cfs)	Percent error of discharge obtained from rating curves
						At Sacramento	At Freeport	Mean in reach		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Series L, June 9–10, 1960										
L–1	June 9	6:35 a.m.	9,430	5.33	0.68	−0.04	−0.08	−0.06	9,710	+3
2	do	7:43	10,900	5.13	.77	−.05	−.07	−.06	10,170	−7
3	do	8:44	11,100	4.94	.89	−.055	−.095	−.075	10,520	−5
4	do	10:00	11,900	4.65	.99	−.075	−.06	−.07	10,950	−8
5	do	11:21 a.m.	12,000	4.33	1.05	−.05	−.06	−.055	11,200	−7
6	do	12:42 p.m.	12,200	4.01	1.16	−.055	−.095	−.075	11,200	−8
7	do	2:08	11,900	3.65	1.20	−.06	−.03	−.045	11,520	−3
8	do	3:24	11,600	3.47	.95	0	+.10	+.05	11,870	+2
9	do	4:44	10,100	3.69	.62	+.07	+.09	+.08	11,410	+13
10	do	6:10	8,860	4.08	.56	+.05	+.06	+.055	9,710	+10
11	do	7:26	8,800	4.35	.59	+.03	0	+.015	9,540	+8
12	do	8:38	9,720	4.36	.76	−.01	−.05	−.03	10,170	+5
13	do	10:16	10,700	4.18	.88	−.03	−.05	−.04	10,400	−3
14	do	11:30 p.m.	11,600	4.00	.97	−.035	−.07	−.05	10,620	−8
15	June 10	12:40 a.m.	11,400	3.82	.99	−.02	0	−.01	11,200	−2
16	do	1:58	10,100	3.84	.54	+.07	+.13	+.10	10,250	+1
17	do	3:22	7,860	4.42	.36	+.10	+.12	+.11	9,090	+16
18	do	4:42	6,850	4.96	.27	+.09	+.10	+.095	8,260	+21
19	do	6:00	6,860	5.35	.39	+.045	0	+.025	8,680	+27
20	do	7:20	9,300	5.27	.61	−.02	−.05	−.035	9,580	+3
21	d0	8:57	10,600	4.98	.80	−.06	−.06	−.06	10,300	−3
22	do	10:10	11,000	4.70	.88	−.07	−.05	−.06	10,520	−4
23	do	11:16 a.m.	11,500	4.43	.94	−.07	−.045	−.06	10,680	−7
24	do	12:38 p.m.	11,300	4.07	1.03	−.06	−.10	−.08	10,560	−7
25	do	2:01	11,200	3.72	1.12	−.075	−.045	−.06	11,000	−2
26	do	3:13	11,100	3.40	1.10	−.065	−.04	−.05	10,720	−3
27	do	4:32 p.m.	10,400	3.27	.75	+.02	+.125	+.075	10,850	+4
Series M, October 6–7, 1960										
M–1	Oct. 6	8:37 a.m.	7,340	3.67	0.60	−0.05	−0.05	−0.05	8,910	+21
2	do	9:48 a.m.	8,670	3.49	.68	−.03	−.08	−.055	7,900	−9
3	do	11:06 a.m.	8,770	3.26	.81	−.06	−.05	−.055	9,230	+5
4	do	12:15 p.m.	9,250	3.01	.90	−.04	−.065	−.05	9,530	+3
5	do	1:52	9,170	2.68	.92	−.06	−.02	−.04	9,420	+3
6	do	3:00	9,010	2.49	.51	−.02	+.12	+.05	8,250	−8
7	do	4:30	7,100	2.82	.10	+.09	+.10	+.095	4,950	−30
8	do	5:36	5,550	3.32	.12	+.08	+.08	+.08	5,450	−2
9	do	7:05	5,500	3.92	.23	+.08	+.04	+.06	6,700	+22
10	do	8:20	6,880	4.08	.55	−.02	−.07	−.045	8,400	+22
11	do	9:42	8,420	3.84	.63	−.04	−.07	−.055	8,620	+2
12	do	11:04 p.m.	9,190	3.57	.72	−.06	−.06	−.06	8,050	−12
13	Oct. 7	12:27 a.m.	9,500	3.23	.83	−.05	−.055	−.05	9,310	−2
14	do	1:39	9,580	2.97	.89	−.07	−.07	−.07	9,200	−4
15	do	3:02	9,670	2.65	.93	−.065	−.055	−.06	9,210	−5
16	do	4:20	9,220	2.41	.61	−.03	+.10	+.035	8,590	−7
17	do	5:46	7,230	2.67	.32	+.09	+.10	+.095	7,370	+2
18	do	7:02	6,420	3.10	.29	+.08	+.085	+.08	7,120	+11
19	do	8:17	6,380	3.41	.35	+.045	0	+.02	7,360	+15
20	do	9:34	7,230	3.44	.58	−.03	−.04	−.035	8,320	+15
21	do	11:04 a.m.	8,580	3.24	.74	−.04	−.07	−.055	8,840	+3
22	do	12:26 p.m.	9,300	2.98	.83	−.035	−.045	−.04	9,260	0
23	do	1:38	9,100	2.77	.87	−.06	−.05	−.055	9,100	0
24	do	2:56	9,260	2.54	.71	−.03	+.07	+.02	9,020	−3
25	do	4:07 p.m.	7,930	2.55	.19	+.05	+.12	+.085	5,800	−27

The first criterion was met in all series of measurements except series K. Inspection of figure 11 shows that in measurement series K the derived discharges were consistently low. The error involved, however, was not very serious. The largest individual difference was −12 percent, and the average difference was −6 percent.

The graph in the upper right corner of plate 1 shows that the second criterion, requiring that derived discharges be unbiased throughout the entire range of measured discharge, was satisfied. Neither plus or minus differences predominate in any section of this graph.

The third criterion, relating to the maximum allowable difference of ±10 percent between derived and measured discharge, was not entirely fulfilled. Table 3, which summarizes the differences between derived and measured discharge, indicates that 89 percent of these differences do not exceed ±10 percent and that 95 percent of these do not exceed ±15 percent. The graph in the upper right corner of plate 1 shows that the larger differences occur in the low range of discharge. Some of the error can possibly be ascribed to poor synchronization of the two recording gages with the result that the gage heights used to define the independent variables are not actually simultaneous elevations of stage at each end of the reach. Some error may have been introduced by wind effect on water-surface elevations. The inescapable fact is that the relationship is inherently weak below 8,000 cfs. As indicated by figures 2–13, however, the large errors exist for no more than a few hours during any day, and the days containing these large errors occur only during the relatively uncommon periods of extremely low average discharge.

No attempt was made to compute the standard error of estimate of the correlation because of the uncertainty concerning the number of degrees of freedom lost in the correlation and because of the lack of complete independence of the individual discharges in each series of discharge measurements.

TABLE 3.—*Summary of differences between derived and measured discharge*

Range of error (percent)	Number of measurements with error in indicated range	Percentage of total number of measurements with error in indicated range
0–±10	268	89
±11–±15	18	6
±16–±20	4	1
Greater than ±20	12	4
Total	302	100

SUMMARY AND CONCLUSIONS

In this study an operational method was sought for determining the momentary discharge of tide-affected streams. By use of data for Sacramento River at Sacramento and by application of the coaxial method of graphical multiple correlation a relationship between discharge and the hydraulic parameters of stage, fall, and rate of change of stage was derived. The relationship, despite its imperfections, provides a satisfactory and practical method of rating this reach of river.

The method used, or some modification of it, should be applicable for deriving rating relationships for many streams, tidal or otherwise, that are subject to unsteady flow; the Geological Survey rating methods that have been used in the past are inadequate when accelerative forces present are too large to be ignored.

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