STREAM DISCHARGE RATING CURVES FOR THE FALL RIVER, ROCKY MOUNTAIN NATIONAL PARK

WATER RESOURCES FIELD SUPPORT LABORATORY

WRFSL PROJECT REPORT NO. 83-5P

WATER RESOURCE FIELD SUPPORT LABORATORY
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Submitted to:

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PURPOSE

Discharge measurements were taken at the Fall River Bridge in Horseshoe Park, Rocky Mountain National Park, Colorado, for development of stream discharge rating curves. The rating curves were developed as part of sediment transport and geomorphic studies conducted by Colorado State University during the summer of 1983 to assess the response of the Fall River to the July 16, 1982 Lawn Lake dam failure. During the course of this research, an extensive record of stage readings has been compiled which enables a detailed history of discharge behavior to be put together, when combined with the rating curves. Stage readings have also been taken coincident to bedload discharge measurements, facilitating development of a sediment discharge rating curve.

GAGE SITE

The rating curves were developed from measurements taken at the upstream side of the Fall River Bridge, located in Horseshoe Park approximately two miles from the north entrance to Rocky Mountain National Park (Figure 1). The bridge site was chosen for its fortuitous combination of attributes, including:

1) proximity to the site of the sediment transport and geomorphic studies, so that consideration of inflows and outflows to the stream between the gage site and the research site was not necessary;

2) stabilized channel cross-section, due to presence of concrete bridge wing and abutment walls, and a rip-rapped channel bottom placed across the channel and extending from about 50 feet above the bridge to 30 feet below the bridge, placed to prevent excessive channel scour;

3) convenience for taking discharge measurements; and

4) convenience in obtaining stage readings for both geomorphologists and National Park Service personnel.

The upstream side of the bridge was chosen for three reasons: 1) flow was most tranquil at this side of the bridge, and channel slope was more gentle; 2) channel bottom appeared most stable, and 3) a gage staff could be mounted in a convenient location with a slackwater flow.

A gage staff (Figure 2) was bolted to the southwest wing wall by Park Service workmen on June 17, 1983.

PERIOD OF MEASUREMENT

Measurements used to obtain the rating curves were taken between June 7, 1983 and August 10, 1983. A wide variety of discharge levels were sought, and the days selected for discharge measurements reflected this objective. Peak runoff in the Fall River is due to snowmelt in the Roaring River basin, and the time period of the rating curve measurments included the latter part of the early snowmelt runoff period, the peak runoff period, and the recessional snowmelt runoff period running into the low flow period of late summer. This is discussed further in the Results section of this report.

MEASUREMENT TECHNIQUES

Measurements were taken using cup-type rotary current meters, commonly referred to as Price meters. Several meters and measurment techniques were employed, being necessitated by flow conditions and equipment availability and breakdowns. Wading, with meter mounted on a wading rod, proved satisfactory for low and moderate flows of up to about 250 cubic feet per second (Figure 3). A cable-mounted meter suspended from the bridge deck using a winch and crane was necessary for high discharges (Figure 4). Various combinations of instruments and measurment techniques were used in data collection (Table 1; these are subsequently referenced by number in Table 2).

RESULTS

A summary of the gaging results is given in Table 2. When plotted (Figure 5), the data is seen to delineate the general form of the snowmelt dominated hydrograph. Peak flows in the neighborhood of 400 cfs occurred around the 20th of June. Thundershowers observed during the high flow period appeared to have little effect on discharge, but a daily rise of discharge that reached a peak in late afternoon or evening was observed. For each day that two discharge measurements were taken, the second measurement yielded a higher discharge than the first. This is the expected behavior of a snowmelt runoff stream.

A plot of stage versus discharge (Figure 6) shows a significant scatter such that a single linear or quadratic discharge rating curve would not be well correlated to all of the data points. Reasoning provides at least three explanations for this scatter: 1) the river underwent variations of scour and deposition at the gage site commensurate to and generative of the data; 2) the scatter is mainly due to measurement error; 3) the river underwent general trends of scour and deposition which further analysis of the data may reveal. Such analysis is required to differentiate between the possible explanations.

Of the measurement techniques used to obtain data, all should yield adequate or better results with the possible exception of Method 3 (Table 1). The uncertainty of this method is significantly greater than the other methods due to the subjectivity inherent in the integration of instantaneous velocities over time by eye. It is also seen that this point is somewhat anomalous to the others in the data set; removal of this point from the discharge-rating curve determination appears justifiable.

Two notable morphological trends were observed during the course of measurement which help to explain trends in the data. First was a lateral shifting of the channel immediately upstream of the bridge accompanied by erosion of the left bank and redirection and shifting of the zone of maximum velocity. Second was scour at the gaging

cross-section. The trend of scour is evident throughout the cross-section. Plots of bed elevation versus time at 5.5, 9.5, 13.5, 17.5 and 21.5 feet from left bank (Figure 7a through 7e) all show degradation occurring in June during the rising limb and peak of the hydrograph (Figure 5). Scour averaged about 1.2 feet during the June period, and about 0.4 feet during the recessional limb of the hydrograph in July and early August.

Scour occurred at the site despite the presence of the rip-rap blanket. The blanket was composed of angular rock and was dumped directly onto the sandy riverbed with no intermediate gravel filter. Silts and sands were scoured through the interstices and voids in the rip-rap blanket even though the rip-rap itself was competent under the lower flow conditions. This was the primary mechanism of scour. Additionally, some of the rip-rap was mobilized during high flows, as was observed during the course of measurement. Cobbles as big as four inches in diameter were found to be rolling along the bed. Besides the lowering of the bed due directly to the loss of this rock, there is subsequent degradation resulting from additional exposure of the finer materials of the sublayer to the flow.

The zone of strongest current was found to shift from the right bank side of the stream near midstream toward the left bank in early June, back toward the right bank in late June, to mid-channel in early July, and toward the right bank in early August, Table 3. The

The shifting was a response to meandering tendencies and streambank erosion by the channel immediatley upstream of the bridge. The stream had a visible tendency to straighten during high flows; also, the greatest streambank erosion occurred during this time, due in part to bank sloughing and due in part to impact from floating debris.

The shifting of the zone of strongest current influenced scour activity at the gage site. The maximum velocity traversed the mid-channel portion of the stream, between approximately 8 feet and 20 feet from left bank, during the rising limb of the hydrograph in June. As a result, scour was fairly constant at about one foot of degradation across the mid-channel portion of the stream during this period, and there was less degradation along either side. Further degradation along the channel banks occurred subsequently, probably due in part to slope instability of the steep underwater side slopes created by the mid-channel scour activity. Later in the summer, shoaling occurred along the left bank after the zone of strongest current shifted toward the right bank. This scour and shoaling activity in turn caused shifts in the stage-discharge relationship.

DISCHARGE RATING CURVES

In order to derive stage-discharge correlations, least squares regressions were tested for the data. A simple statistics software package developed at Penn State University, MINITAB, was utilized to obtain the regression equations.

Various combinations of linear and polynomial regressions were tested, using different subsets of the data points. From these it was apparent that the measurement of June 17, previously noted as being of dubious value, was incongruous to the rest of the data set. Coefficients of determination were significantly improved with that measurement removed as an outlier. Also, the regression equations were found to be erroneous at low discharges without a zero discharge data point. Using Figure 7, zero discharge was estimated to occur at -1.10 feet gage height. With this point tying down one end of the regression curve, and the outlier removed, satisfactory discharge rating curves were obtained.

Two rating curves were found to yield the most satisfactory results. A separate rating curve to be used on and before June 17, 1983 was found to be necessary due to the degradation that occurred during this period. A linear regression based on the data points prior to that date yielded a coefficient of determination of 99.0 percent, adjusted for 3 degrees of freedom, see Appendix, Table A1. The regression equation is

$$Q = (194.0)\ H - 269.0 \qquad (1)$$

where Q is discharge in cubic feet per second and H is the gage height in feet. Both coefficients are found to be significant predictors at the 99.95 percent level, as indicated by the large t-ratios. The

standard deviation of discharge about the regression line is only 6.4 cubic feet per second. The equation ought to be useful for gage heights between about 1.5 and 3.0 feet, and discharges between about 40 and 350 cfs.

For measurements subsequent to June 17, 1983 a polynomial regression was found to be most satisfactory, Table A2. The regression equation is

$$Q = (19.4)\, H^2 + (50.6)\, H + 34.4 \qquad (2)$$

with a coefficient of determination of 90.1 percent, adjusted for 6 degrees of freedom. Testing of the null hypothesis for the Q-axis intercept yields rejection at the 75 percent level of confidence; the null hypothesis for the coefficients of gage height in the equation are rejected at the 90 percent level of confidence. Thus the equation is least certain at the lowest discharge levels, which is as expected. The equation is probably best applied at gage heights above 0.8 feet or so. Extrapolation of the curve below the stage/discharge level of the lowest observed data points used in the regression analysis is always prone to relatively greater levels of uncertainty. The standard deviation of discharge about the polynomial regression curve is 40 cfs.

Both of the recommended discharge rating curves are plotted in Figure 8.

CONCLUSIONS

A stream gaging program initiated to develop stage/discharge relationships on the Fall River in the summer of 1983 yielded satisfactory results. Two discharge rating curves were developed, being necessitated by scouring at the gage site during the peak snowmelt runoff period in June. A linear regression of discharge upon gage height was found to be a very good predictor of observed discharges for the period prior to June 17. A polynomial regression yielded satisfactory results for discharges subsequent to June 17.

FIGURES

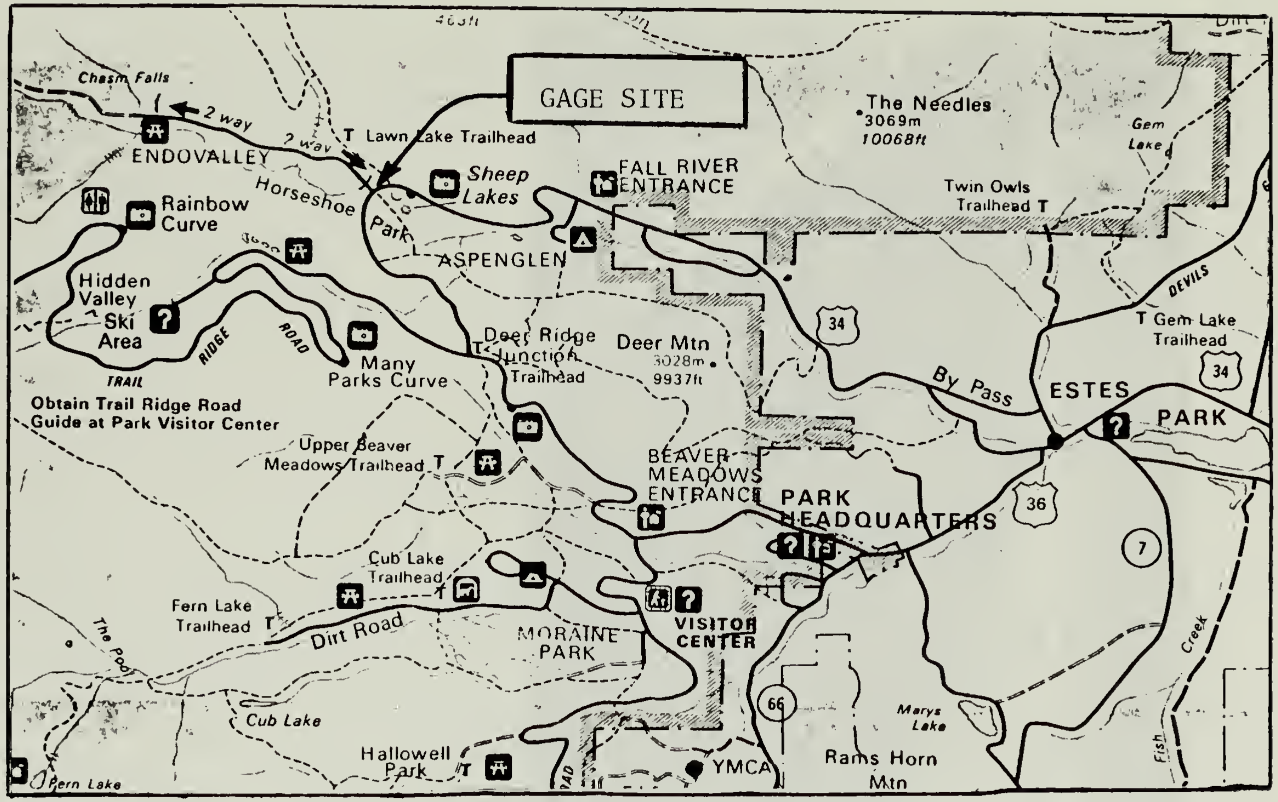

Figure 1. Gage site location.

Figure 2. Gage site at Horseshoe Park. The gage staff is visible on the wing wall.

Figure 3a. Stream gaging using wading rod with rotary cup meter.

Figure 3b. Rod-mounted Type AA #T01581 rotary cup meter with Swoffer Model 2200 fiber optic tachometer.

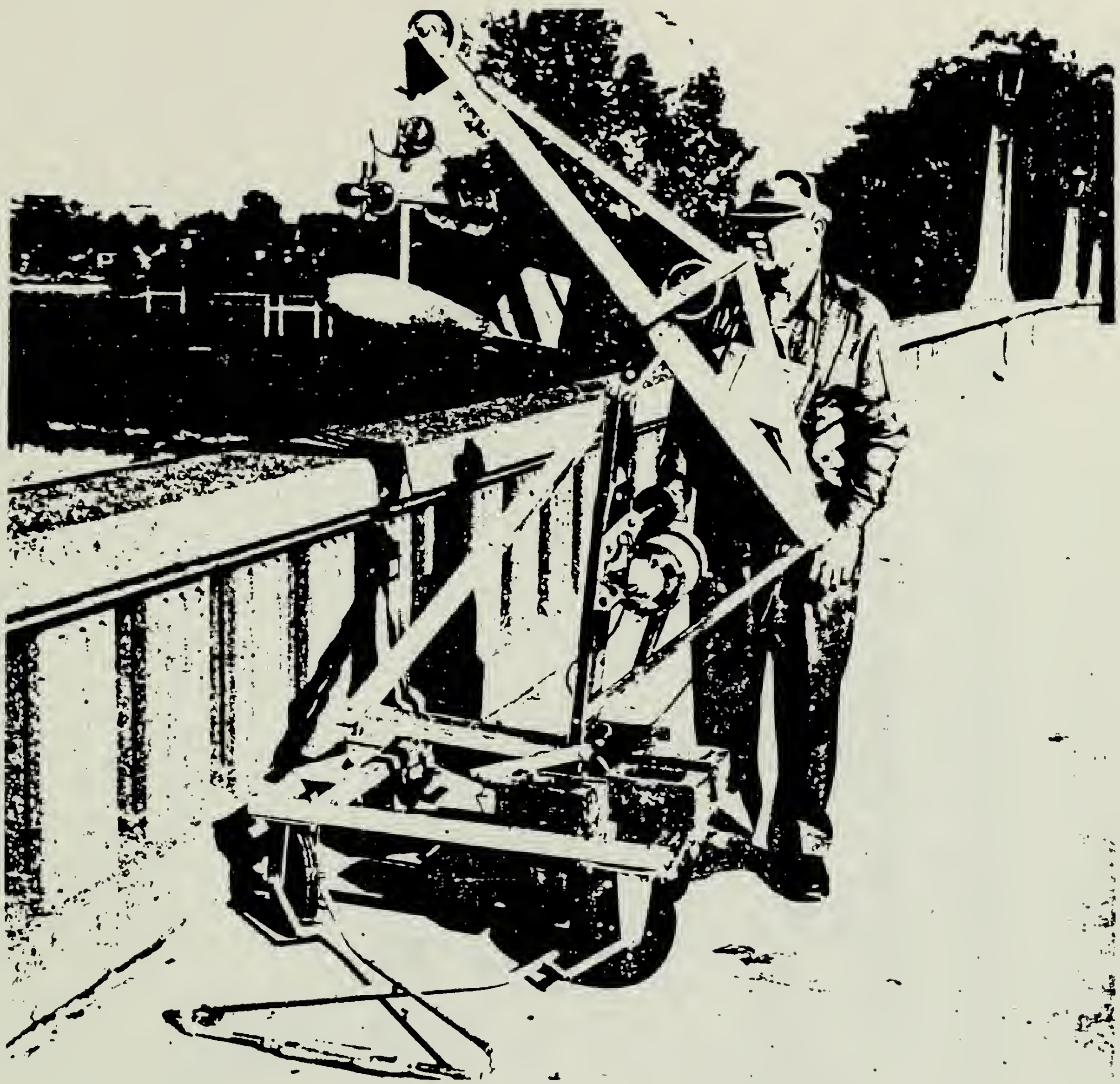

Figure 4. USGS Type-A crane with cable-mounted current meter and reel, similar to the setup used for the present discharge measurements.

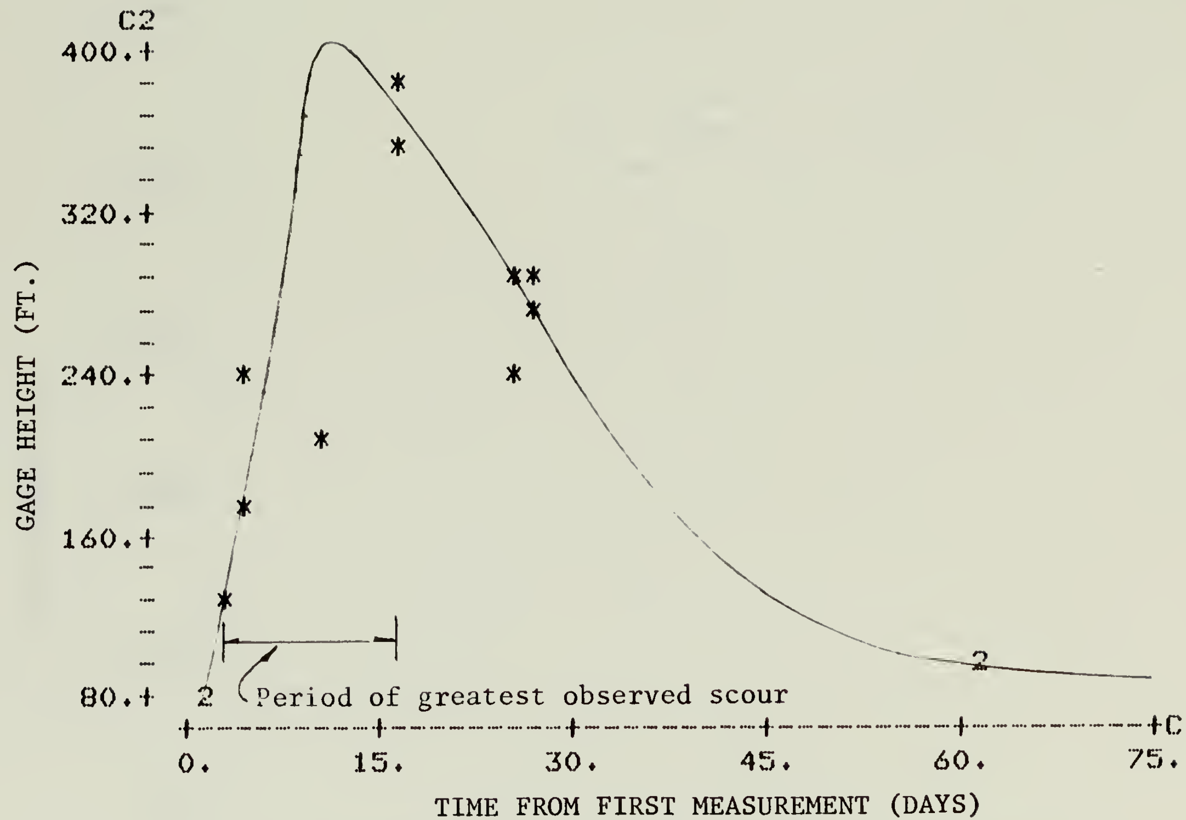

Figure 5. Generalized hydrograph for Fall River runoff, summer 1983.

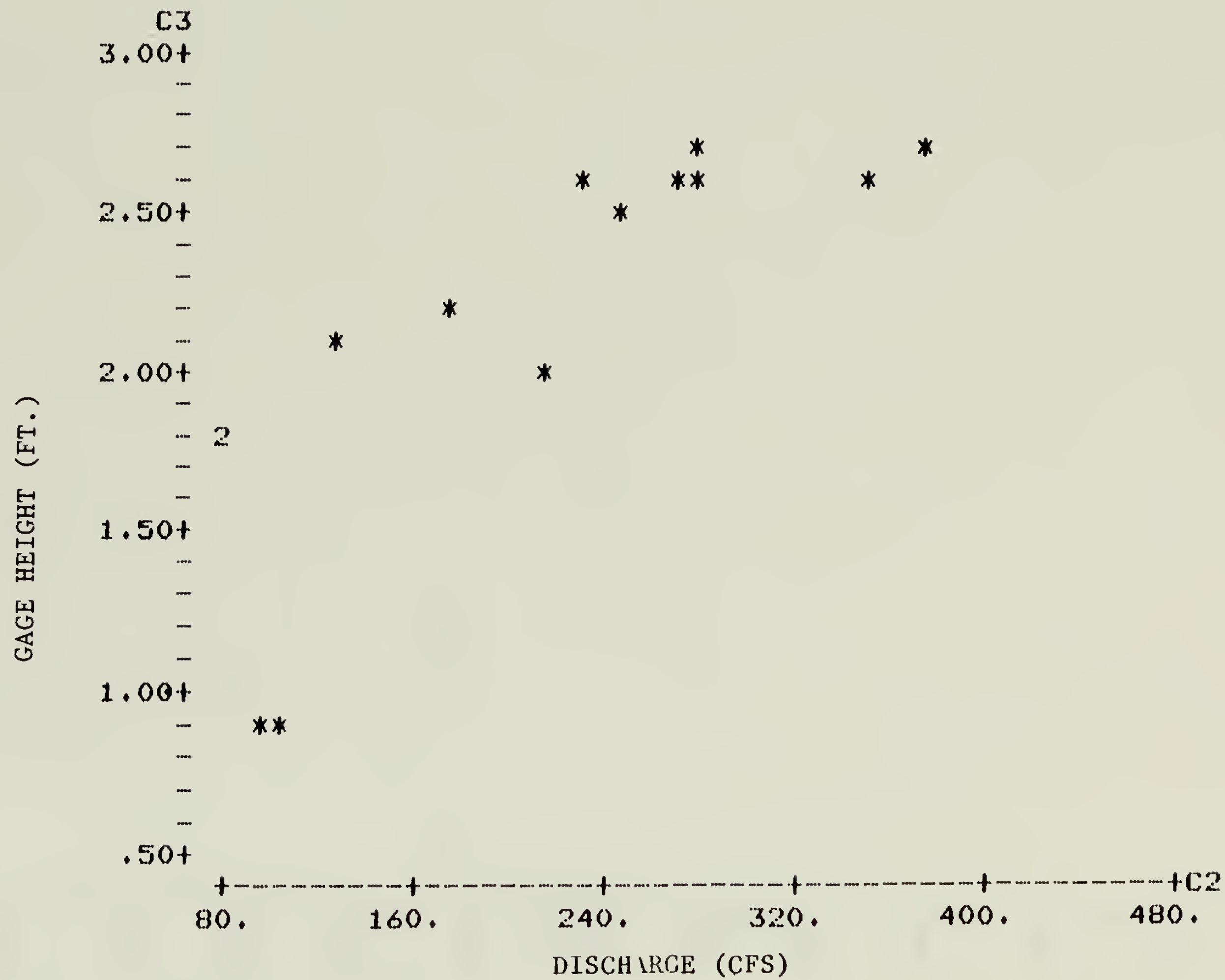

Figure 6. Stage/Discharge relationship for all data points.

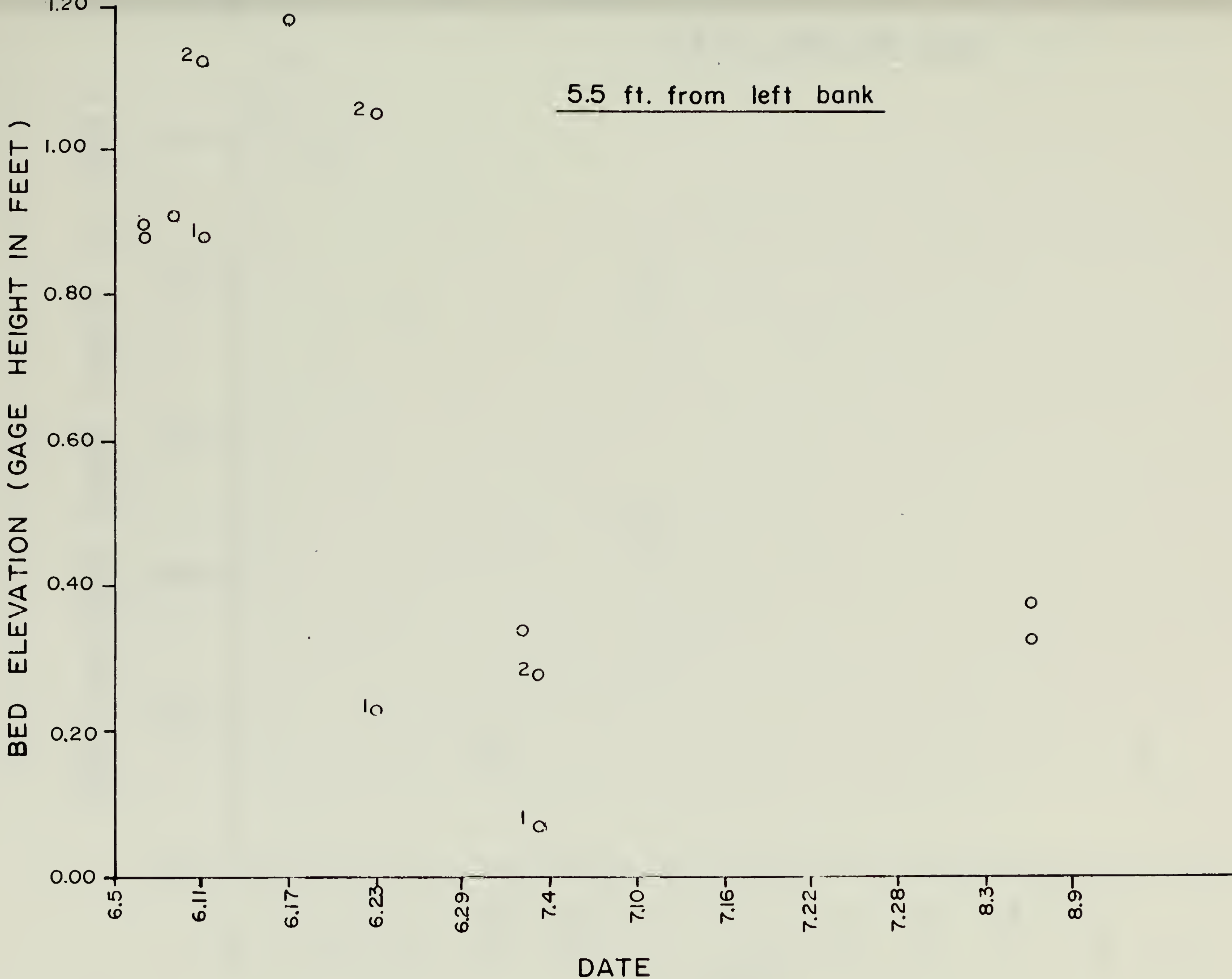

Figure 7a. Gage height of bed elevation over time, 5.5 feet from left bank.

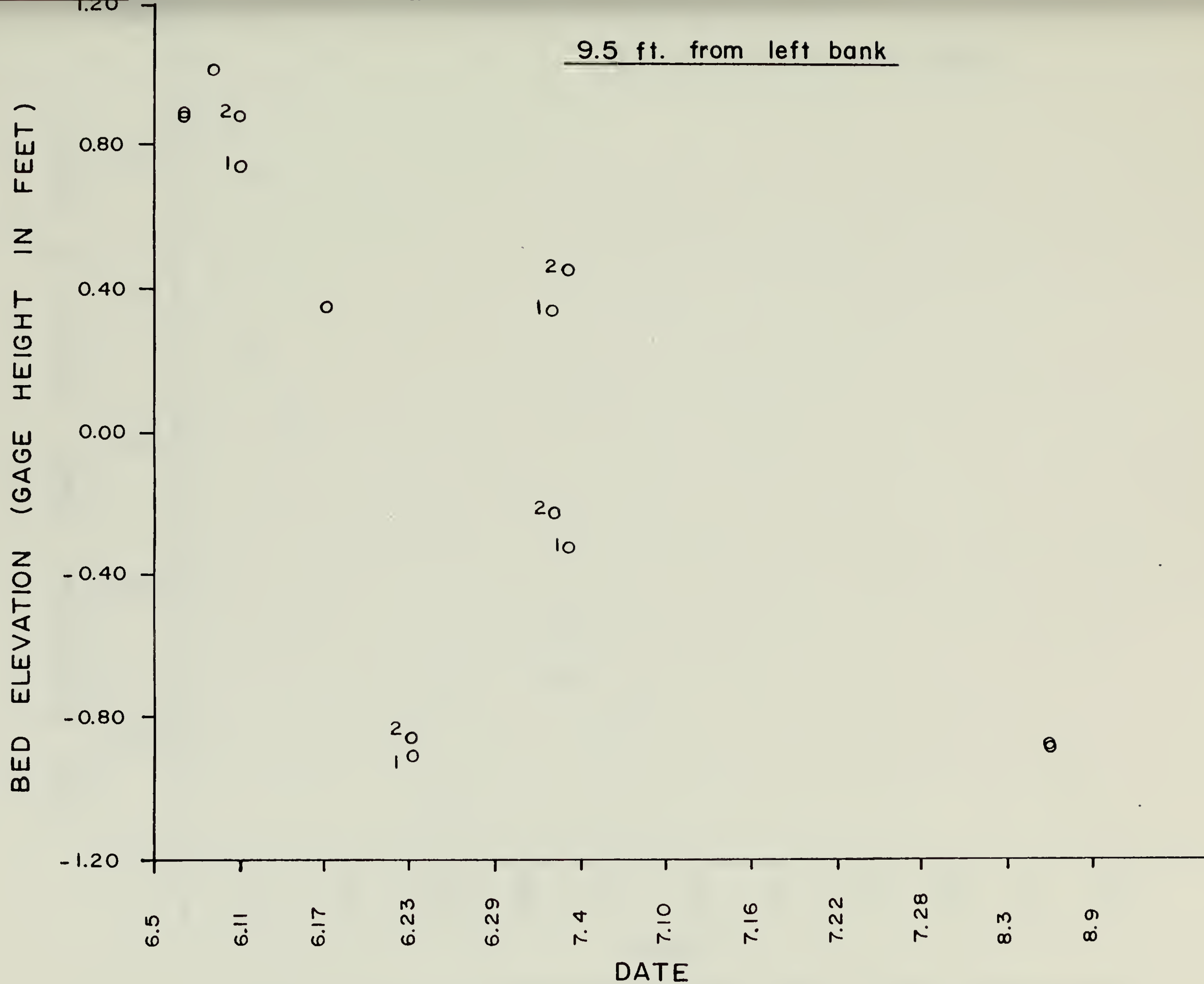

Figure 7b. Gage height of bed elevation over time, 9.5 feet from left bank.

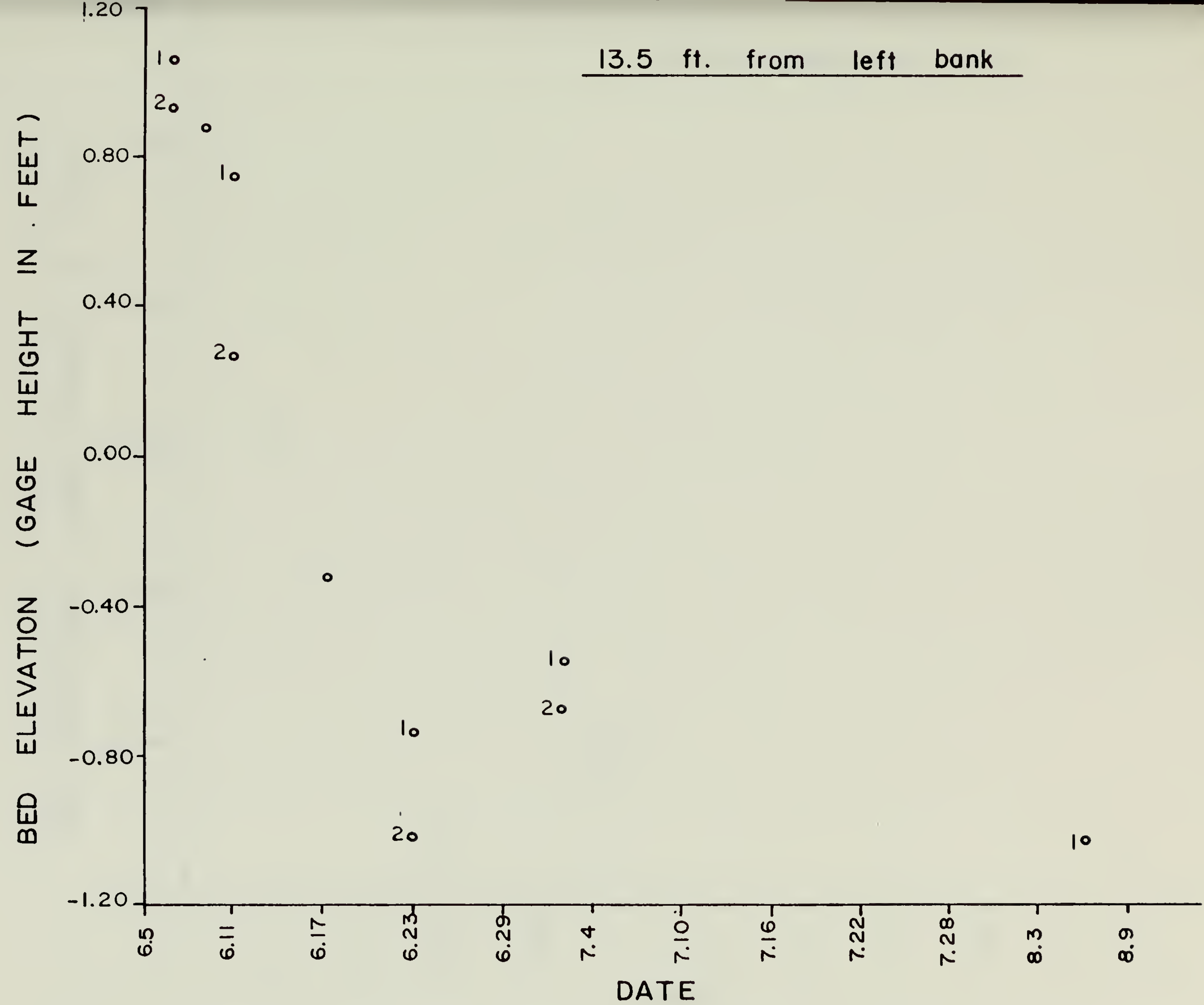

Figure 7c. Gage height of bed elevation over time, 13.5 feet from left bank.

2o

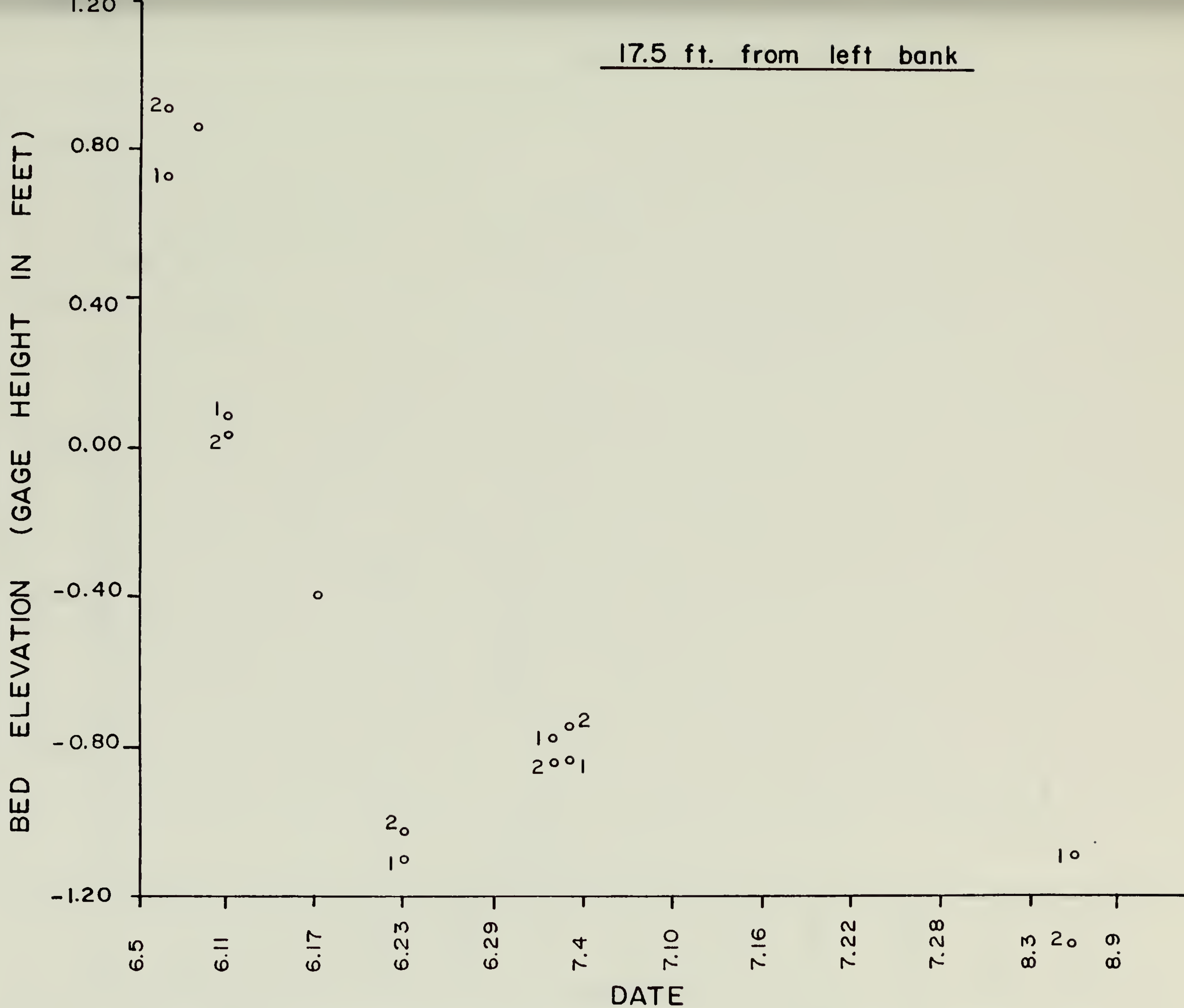

Figure 7d. Gage height of bed elevation over time, 17.5 feet from left bank.

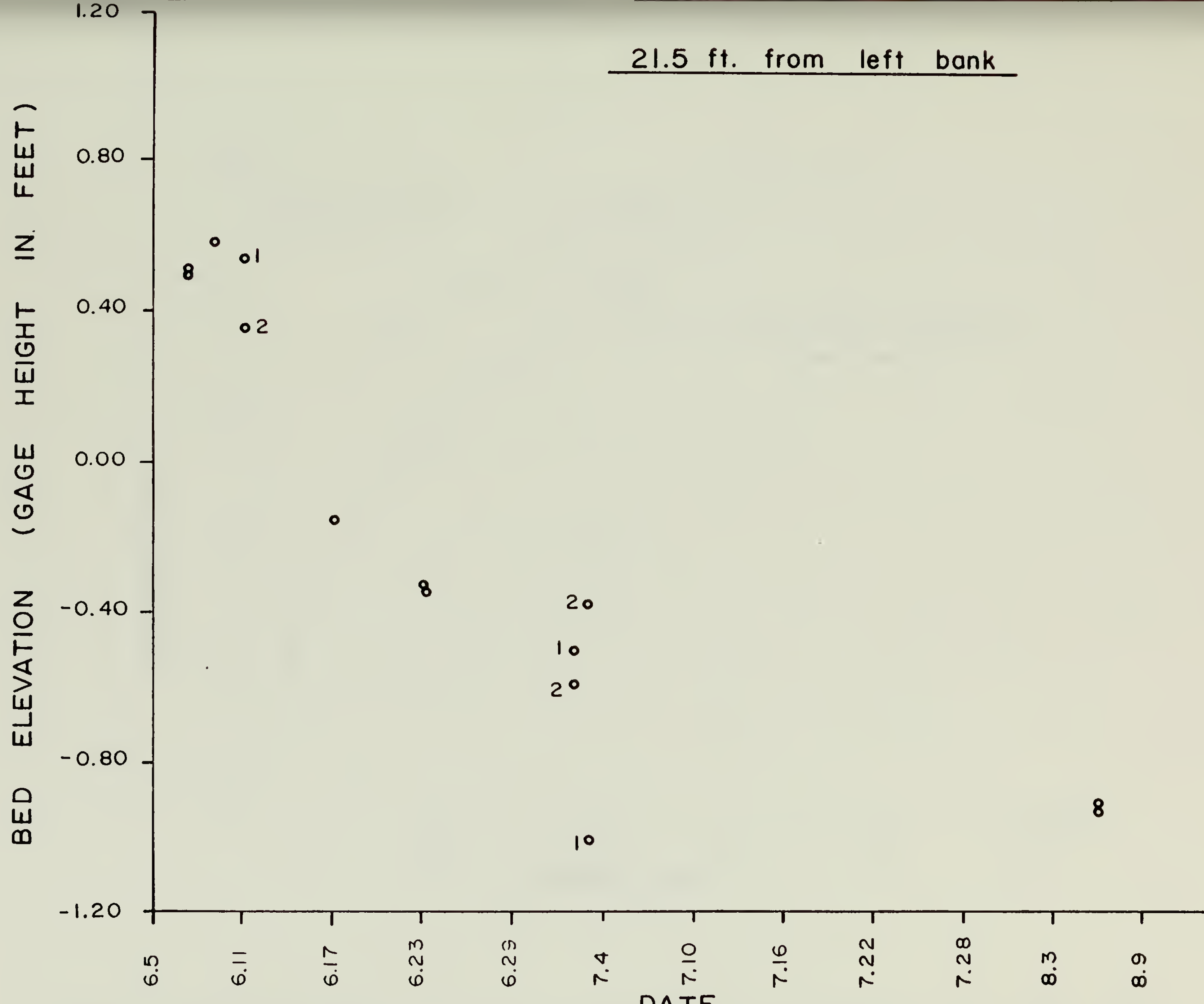

Figure 7e. Gage height of bed elevation over time, 21.5 feet from left bank.

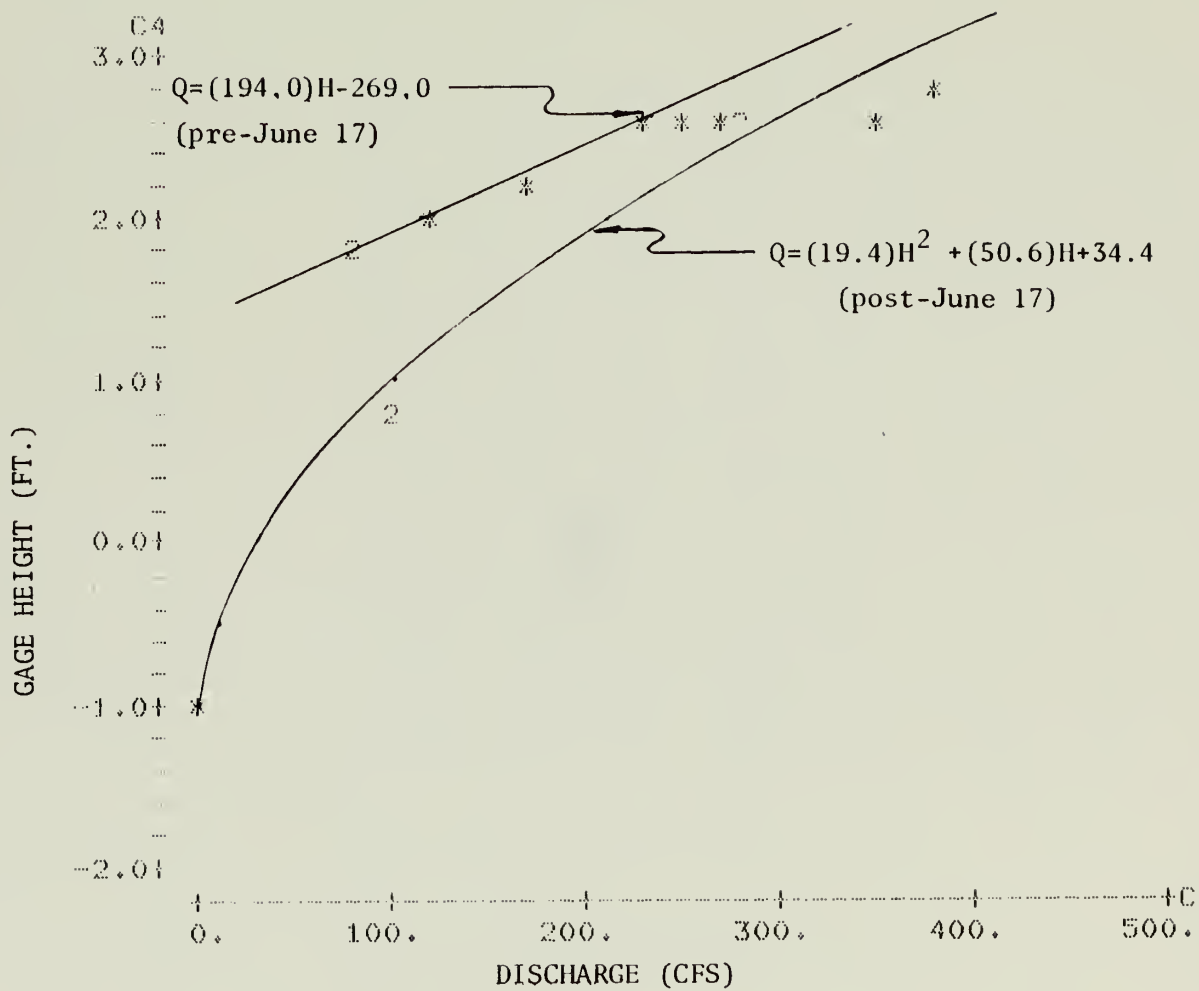

Figure 8. Discharge rating curves for the Fall River at the Horseshoe Park bridge, Rocky Mountain National Park for summer, 1983.

TABLES

Table 1
Gauging Methods

Description	Method No.
Rod-mounted Gurley #TA2298 rotary cup meter. Clicks counted while wading.	1
Rod-mounted Type AA #T01581 rotary cup meter. Sec and Rev read from Swoffer Model 2200 fiber optic tachometer while wading.	2
Rod-mounted Gurley #TR2433 rotary cup meter. Velocity averaged by eye using direct reading velocity-calibrated analog-display Gurley voltmeter giving instantaneous velocities. While wading.	3
Cable-suspended Type AA #T01581 rotary cup meter. Sec and Rev read from Swoffer Model 220 fiber optic tachometer. Current meter suspended from bridge using a sounding weight.	4
Combination of Methods 2 and 4. Wading done in shallower side portions of stream; cable used mid-stream.	5
Cable-suspended Gurley #TA2298 rotary cup meter. Current meter suspended from bridge using a sounding weight. Clicks counted.	6
Combination of Methods 1 and 6. Wading done in shallower side portions of stream; cable used mid-stream.	7
Combination of Methods 2 and 6. Wading done in shallower side portions of stream; cable used mid-stream.	8

Table 2
Summary of Stream Gauging Data

Date	Meas. No.	Discharge (cfs)	Gage Height(ft)	Area (ft^2)	Mean Vel. (fps)	Mean Depth (ft)	Mean Froude No.	Method No.
83.6.7.	1	77.7	1.76	23.3	3.33	0.93	0.61	1
"	2	80.7	1.82	22.7	3.56	0.91	0.66	1
83.6.9.	1	124.	2.06	28.8	4.38	1.15	0.71	1
83.6.11.	1	172.	2.24	38.3	4.50	1.53	0.64	2
"	2	233.	2.59	48.4	4.80	1.94	0.61	2
83.6.17.	1	213.	1.96	41.2	5.16	1.65	0.71	3
83.6.23.	1	352.	2.61	70.5	5.00	2.82	0.52	5
"	2	376.	2.75	72.8	5.16	2.91	0.53	5
83.7.2.	1	246.	2.54	65.5	3.75	2.62	0.41	7
"	2	280.	2.65	70.4	3.98	2.82	0.42	7
83.7.3.	1	271.	2.60	70.2	3.86	2.80	0.41	8
"	2	282.	2.66	68.5	4.11	2.74	0.44	8
83.8.7.	1	98.5	0.89	34.2	2.88	1.67	0.39	1
"	2	100.	0.88	35.9	2.79	1.75	0.37	1

Table 3
Zone of Maximum Velocity

Measurement	Distance from Left Bank (ft)
83.6.7. #1	15.5
83.6.7. #2	17.5
83.6.9.	16.5
83.6.11. #1	11.5
83.6.11. #2	9.5 to 15.5
83.6.17.	17.5
83.6.23. #1	15.5
83.6.23. #2	15.5
83.7.2. #1	9.5 and 13.5
83.7.2. #2	13.5
83.7.3. #1	9.5
83.7.3. #2	9.5
83.8.6. #1	16.0
83.8.6. #2	14.0

Width of channel at gage site is 25.0 feet. The distance shown is the center of the maximum velocity of three point moving averages across the stream.

APPENDIX

REGRESSION STATISTICS

Data points for the regression:

ROW	DISCHARGE Q(CFS)	GAGE HEIGHT H(FT.)
1	77.700	1.76000
2	80.700	1.82000
3	124.000	2.06000
4	172.000	2.24000
5	233.000	2.59000

THE REGRESSION EQUATION IS
Y = - 269. + 194. X1

	COLUMN	COEFFICIENT	ST. DEV. OF COEF.	T-RATIO = COEF/S.D.
	--	-269.25	20.21	-13.33
X1	C2	194.235	9.551	20.34

THE ST. DEV. OF Y ABOUT REGRESSION LINE IS
S = 6.443
WITH (5- 2) = 3 DEGREES OF FREEDOM

R-SQUARED = 99.3 PERCENT
R-SQUARED = 99.0 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

DUE TO	DF	SS	MS=SS/DF
REGRESSION	1	17170.48	17170.48
RESIDUAL	3	124.54	41.51
TOTAL	4	17295.03	

DURBIN-WATSON STATISTIC = 2.45

Y = DISCHARGE
X1= GAGE HEIGHT

Table A1. Linear regression statistics for prediction of discharge from stage for measurements taken on or before June 11, 1983. This regression equation is recommended for the stage/discharge rating curve for the period preceding and including June 17.

Data points used in the regression:

ROW	DISCHARGE	GAGE HEIGHT
1	0.000	-1.10000
2	352.000	2.61000
3	376.000	2.75000
4	246.000	2.54000
5	280.000	2.65000
6	271.000	2.60000
7	282.000	2.66000
8	98.500	.89000
9	100.000	.88000

```
THE REGRESSION EQUATION IS
Y =     34.4 +   50.6 X1 +   19.4 X2
```

	COLUMN	COEFFICIENT	ST. DEV. OF COEF.	T-RATIO = COEF/S.D.
	--	34.38	26.83	1.28
X1	C2	50.61	22.71	2.23
X2	C5	19.39	10.02	1.93

```
THE ST. DEV. OF Y ABOUT REGRESSION LINE IS
S = 40.13
WITH (    9- 3) =    6 DEGREES OF FREEDOM

R-SQUARED = 92.6 PERCENT
R-SQUARED = 90.1 PERCENT, ADJUSTED FOR D.F.
```

ANALYSIS OF VARIANCE

DUE TO	DF	SS	MS=SS/DF
REGRESSION	2	120307	60154
RESIDUAL	6	9664	1611
TOTAL	8	129971	

FURTHER ANALYSIS OF VARIANCE
SS EXPLAINED BY EACH VARIABLE WHEN ENTERED IN THE ORDER GIVEN

DUE TO	DF	SS
REGRESSION	2	120307
C2	1	114281
C5	1	6027

ROW	X1 C2	Y C1	PRED. Y VALUE	ST.DEV. PRED. Y	RESIDUAL	ST.RES.
1	-1.10	0.0	2.2	40.1	-2.2	-1.45 X

X DENOTES AN OBS. WHOSE X VALUE GIVES IT LARGE INFLUENCE.

DURBIN-WATSON STATISTIC = 1.42

Y = DISCHARGE   X1 = GAGE HEIGHT   X2 = GAGE HEIGHT SQUARED

Table A2. Polynomial regression statistics for measurements taken on and following June 23, 1983. This regression equation is recommended for the discharge rating curve for the period following June 17.