DEVELOPMENT OF CURVES THAT REPRESENT TRENDS IN SELECTED HYDRAULIC VARIABLES FOR THE SACRAMENTO RIVER AT BUTTE CITY, CALIFORNIA

by D. E. Burkham and Richard Guay

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JAMES G. WATT, Secretary

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Dallas L. Peck, Director

For additional information write to:

District Chief
Water Resources Division
U.S. Geological Survey
345 Middlefield Road
Menlo Park, Calif. 94025

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CONVERSION FACTORS

For readers who may prefer to use metric units rather than inch-pound units, the conversion factors for the terms used in this report are listed below:

Multiply	By	To obtain
ft (feet)	0.3048	m (meters)
ft/s (feet per second)	0.3048	m/s (meters per second)
ft^3/s (cubic feet per second)	0.02832	m^3/s (cubic meters per second)
mi (miles)	1.609	km (kilometers)

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. In this report, NGVD of 1929 is referred to as sea level.

The use of the Statistical Analysis System (SAS) in this report does not imply endorsement of the system by the U.S. Geological Survey.

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ABSTRACT

Streamflow records for the Sacramento River at Butte City, California, are used to develop curves that represent trends in discharges, stages, and velocities that are equaled or exceeded 95, 90, 75, 50, and 25 percent of the time.

INTRODUCTION

The U.S. Bureau of Reclamation has asked the U.S. Geological Survey to supply them with curves that represent trends, or lack of trends, in values of selected hydraulic variables for the Sacramento River at streamflow gage sites. Specifically, for each of the sites, they requested curves that represent trends in discharges, stages, and mean velocities that are equaled or exceeded 95, 90, 75, 50, and 25 percent of the time. The gage sites on the Sacramento River are as follows: Above Bend Bridge near Red Bluff, at Vina Bridge, at Hamilton City, at Ord Ferry, at Butte City, at Colusa, below Wilkins Slough, at Knights Landing, and at Verona.

The purpose of this report is to present a brief description of the procedure used to develop the requested curves for the Sacramento River at Butte City, Calif., (U.S. Geological Survey gaging station 11389000). Necessary for this description are brief discussions concerned with the development of equations that represent average stage-discharge and discharge-velocity relations, and concerned with the development of curves and equations that represent temporal shifts in these relations. Real data are used to develop the curves and equations. The data and curves are not analyzed for trends. However, a few cursory remarks are given that are concerned with the probable reasons for or amounts of changes in the different hydraulic variables. The procedure described herein is similar to that used to develop trend curves for discharges, stages, and mean velocities for the other gage sites for the Sacramento River.

A set of computer programs called SAS (Statistical Analysis System) was used to analyze and process data (Helwig and Council, 1979). Computer related acronyms are fully described in this report or in the report by Helwig and Council (1979).

The gaging station at Butte City is about 115 mi upstream and north of Sacramento, Calif. Datum of the gage is 2.92 ft below sea level. Records of daily streamflow for the site have been continuous since September 1938. From April 1921 to September 1938, records were obtained only during low-flow periods, usually in April through September. Streamflow records for April 1931 to February 1980 were used in the study.

The Sacramento River at the Butte City gage is tentatively characterized as a sand-bed river, but gravel is interbedded with the sand (Kresch, 1970, table 3). The clay-to-gravel banks of the river are unstable for long reaches in the vicinity of the gage (Brice, 1977). Changes in the river can occur rapidly in unstable reaches or slowly in reaches that are relatively stable.

The Sacramento River, which rises in the Cascade Range about 50 mi south of the northern boundary of California, flows through the Sacramento Valley, a structural trough filled with fluvial and marine sediments. The river's flow is affected by upstream reservoirs, power development, bypasses for flood control, diversion for irrigation, and return flow from irrigation. The largest deviations from natural flow probably have been due to regulation at Shasta Dam, beginning in December 1943, and to transbasin diversions from the Trinity River, beginning in April 1963. These developments have caused changes in the dominant rate of flow that is carried by the main channel.

TRENDS IN DISCHARGE

Curves representing trends in discharge for the Butte City site are developed by steps as follows:

1. Data values are developed for use in SAS. The terms QMEAS and DURQ are arbitrarily assigned to groups of data, called data sets.

2. Data sets QMEAS and DURQ are combined to give the set, QMDUR.

3. Using QMDUR and SAS procedure PLOT (Helwig and Council, 1979), a plot of instantaneous discharge versus time overlaid with plots of Q95, Q90, Q75, 050, and Q25 versus time is developed (fig. 1).

4. Trend curves for Q95, Q90, Q75, Q50, and Q25 are constructed by connecting appropriate points in figure 1.

The data set QMEAS contains station number, measurement number, date and starting time of measurement, gage height of water surface, measured discharge, width of water surface, cross-sectional area of flow, accuracy of measurement, type of measurement--boat, bridge, wading, cable--maximum depth, and distance of measurement site from gaging station. Some of these data, which were obtained directly from measurement notes in files of the U.S. Geological Survey, were used only for screening purposes. Only discharges less than 60,000 ft^3/s (bankful discharge) were used in the analyses.

The data set DURQ contains values of daily discharge that are equaled or exceeded 95, 90, 75, 50, and 25 percent of the time for 10-year periods. These values, called, respectively, Q95, Q90, Q75, Q50, and Q25, are obtained using the National Water Data Storage and Retrieval System--WATSTORE, Program A969 (Meeks, 1975) and Program G490 (Williams, 1975). Thirty values each for Q95, Q90, Q75, Q50, and Q25 for overlapping 10-year (progressive) periods were obtained for the study station. As previously indicated, these 150 values of data were used to develop the curves shown in figure 1. The first 10-year period is water years 1939-48 and the final period is water years 1968-77. Dates are represented by the date of the midpoint of the 10-year period.

The curves shown in figure 1 can be used to study trends in daily discharges for the Sacramento River in the vicinity of Butte City that are equaled or exceeded 95, 90, 75, 50, and 25 percent of the time. The instantaneous discharges that are shown in figure 1 can be used to study trends in discharge that is directly determined by measurement. The changes in trends in discharge that occurred after regulation began at Shasta Lake in 1943 and that occurred after the transbasin diversion from the Trinity River in 1964, can readily be seen in figure 1. The downward trend that began after 1970 is due to the drought in 1976 and 1977.

The daily discharge that is equaled or exceeded 95 percent of the time increased from about 2,400 ft^3/s in 1939-48 to about 7,200 ft^3/s in 1966-75, a 200-percent increase (fig. 2). The discharges that were equaled or exceeded 90, 75, 50, and 25 percent of the time also increased but the rate of increase was smaller. The flow-duration curves for 1939-48, 1954-63, and 1966-75, shown in figure 2, were developed directly from data produced in step 2.

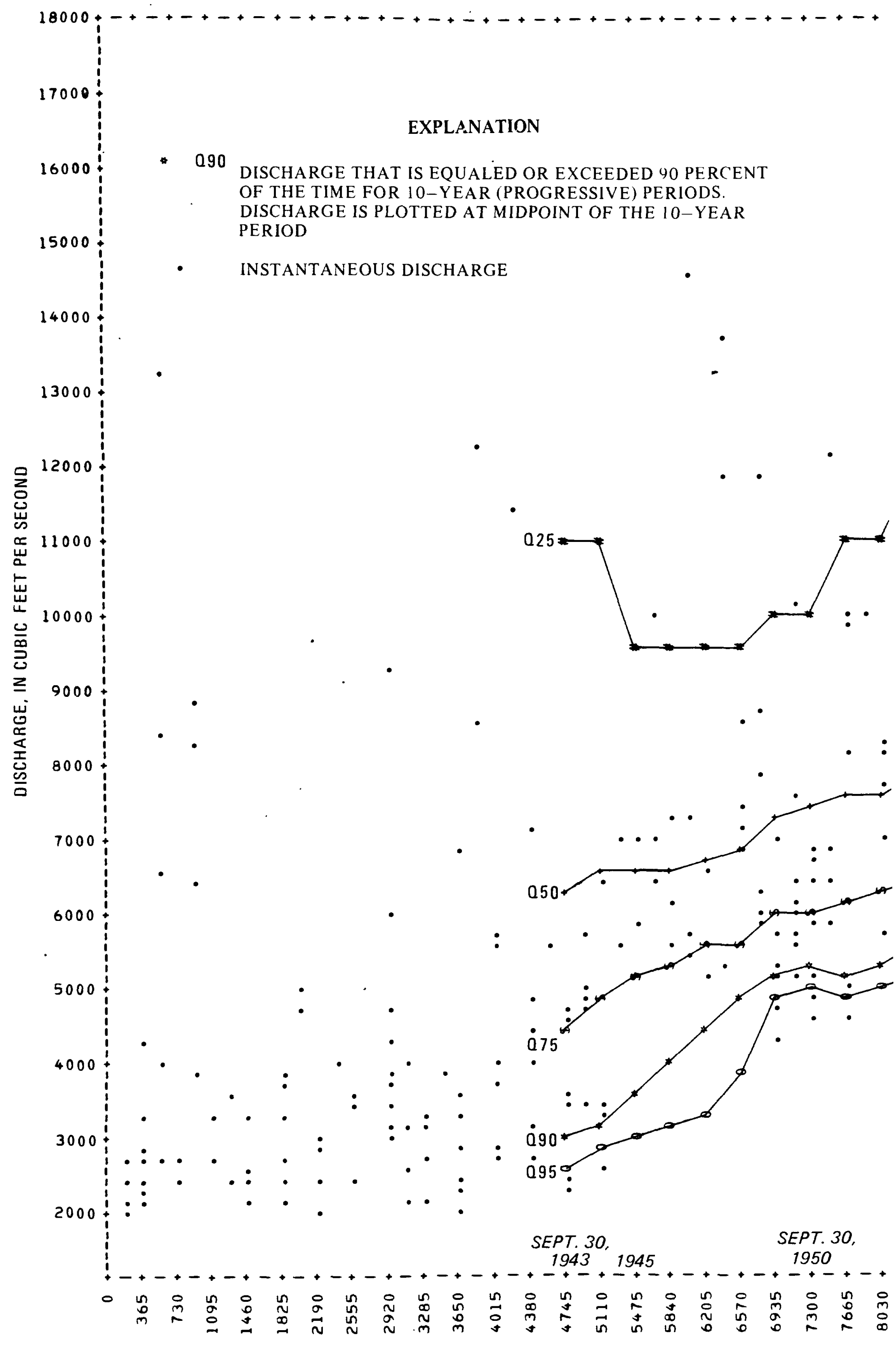
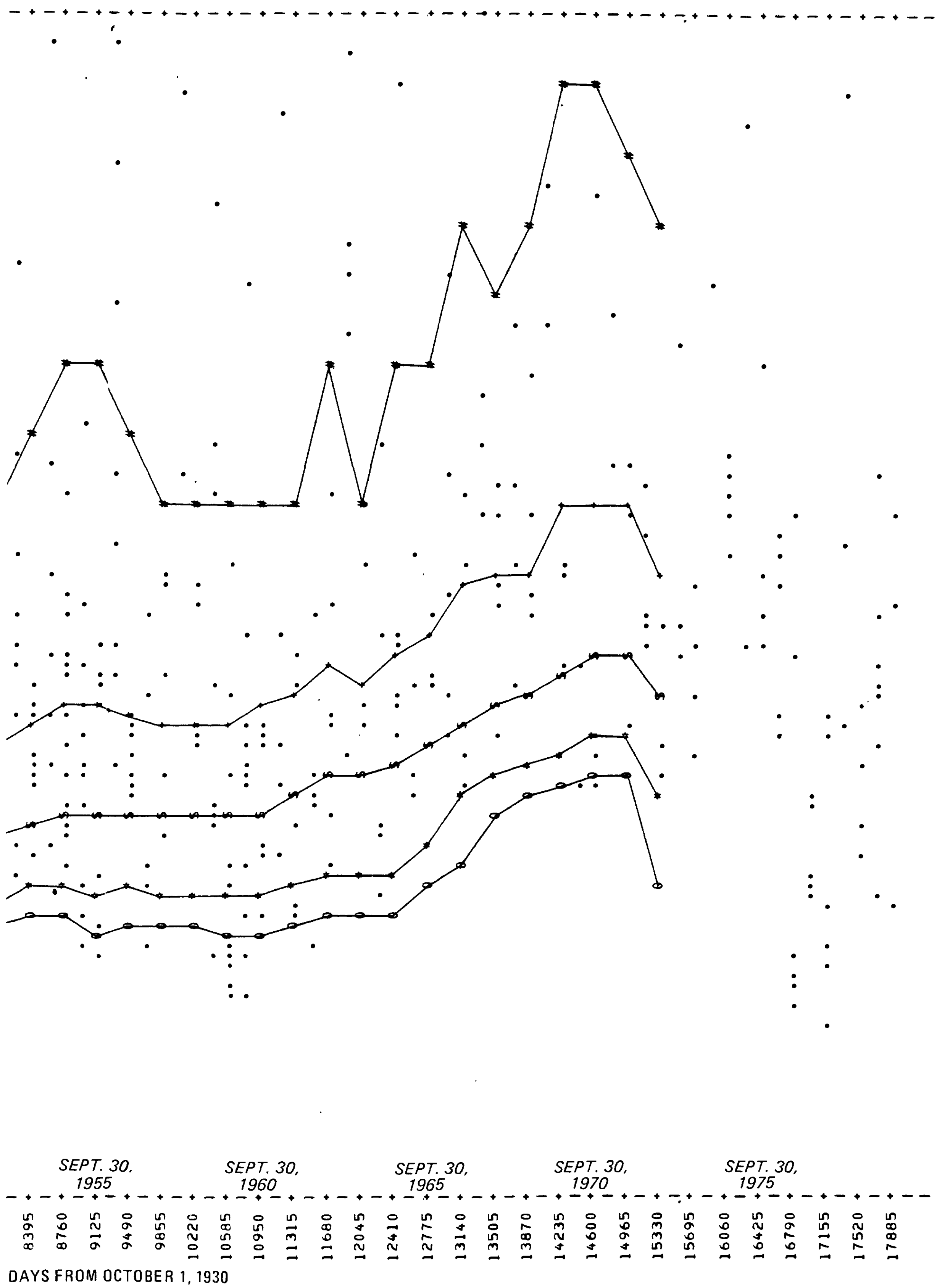


FIGURE 1.--Trend curves for



Q95, Q90, Q75, Q50, and Q25.

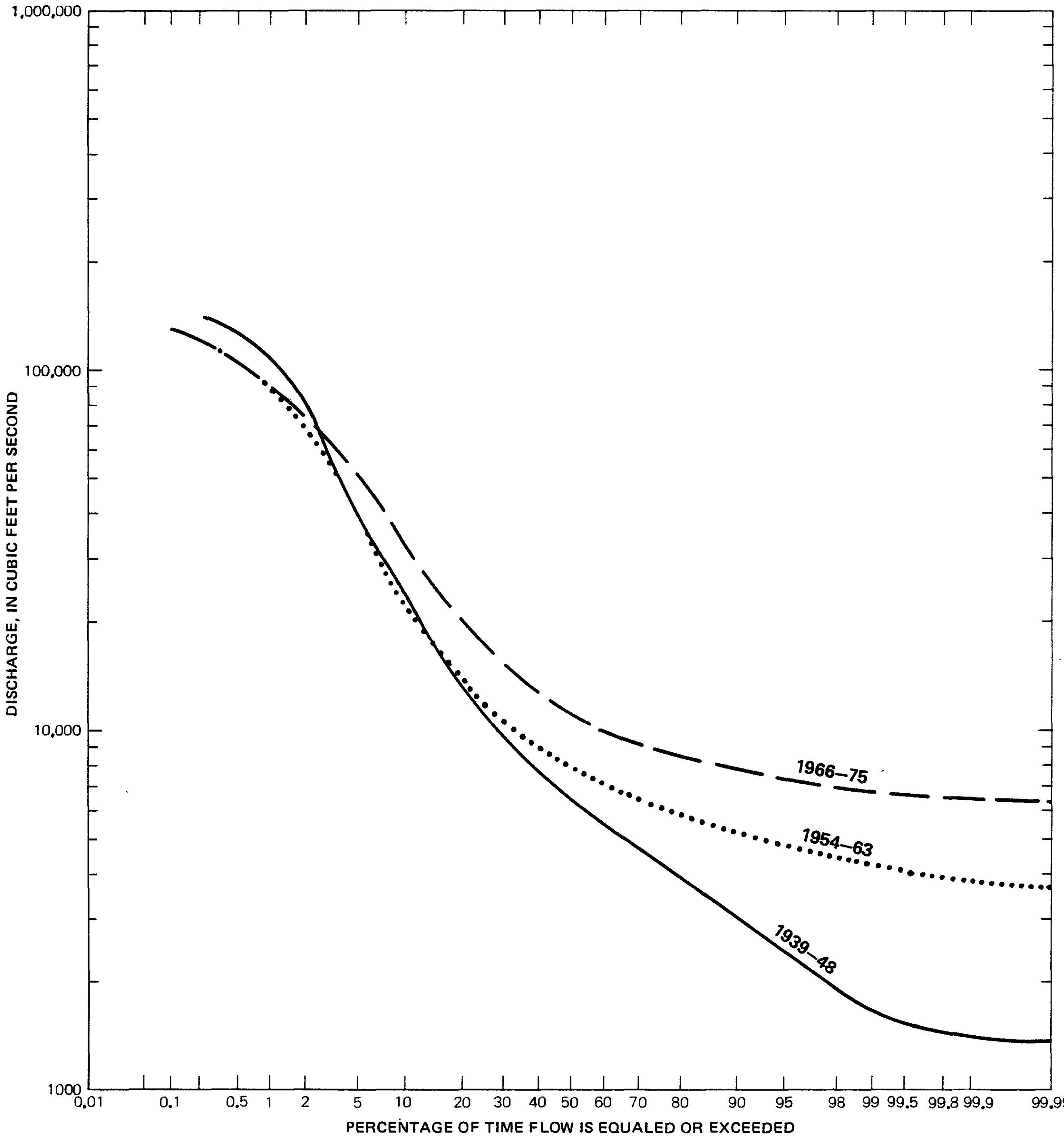


FIGURE 2.--Flow-duration curves.

TEMPORAL SHIFTS IN THE STAGE-DISCHARGE RELATION

A curve representing temporal shifts in the stage-discharge relation for the study site is developed by steps as follows:

1. Using QMEAS and the SAS procedure NLIN (Helwig and Council, 1979), an equation is developed that represents the average stage-discharge relation for the period 1931-77 (fig. 3).

2. Shifts in the stage-discharge relation developed in step 1 are determined.

3. Shifts determined in step 2 are plotted against stage (fig. 4) and against time (fig. 5).

4. A curve representing average trend is drawn on figure 5.

The model required in the SAS procedure NLIN is represented as $QM=A(GH-B)^{C}$, in which QM is discharge, A is a coefficient, GH is gage height or stage of water surface, B is a parameter, and C is an exponent. The NLIN procedure (Helwig and Council, 1979) uses iteration and least-square regression analyses to develop estimates for A, B, and C. The equation representing the average stage-discharge relation for the study station is:

$$\underline{QM} = 704.3(GH-66.48)^{1.47} \tag{1}$$

in which

$\underline{QM}$ = computed discharge, in cubic feet per second; and
GH = gage height or stage, in feet.

The number 66.48 represents, on an average, the apparent stage below which flow ceases. The standard error of estimate for equation 1 is 767 ft^3/s, which is about 8 percent of the mean of measured discharges in the QMEAS data set. Equation 1 is applicable to stages greater than 66.48 ft and less than bankful stage (fig. 3). All measurements of discharge less than 60,000 ft^3/s were used to develop equation 1.

Shifts in the stage-discharge relation (step 2) are determined by transposing equation 1 to give an equation for $\underline{GH}$ (equation 2), computing values for $\underline{GH}$ using equation 2 and measured values of discharge from QMEAS, and determining shifts, in feet, as the difference between $\underline{GH}$ and GH. Equation 2 is:

$$\underline{GH} = 0.0116(QM)^{0.68}+66.48. \tag{2}$$

Shift, in feet, is represented as:

$$\text{Shift} = \underline{GH}-GH. \tag{3}$$

The standard error of estimate for equation 2 is 0.55 ft.

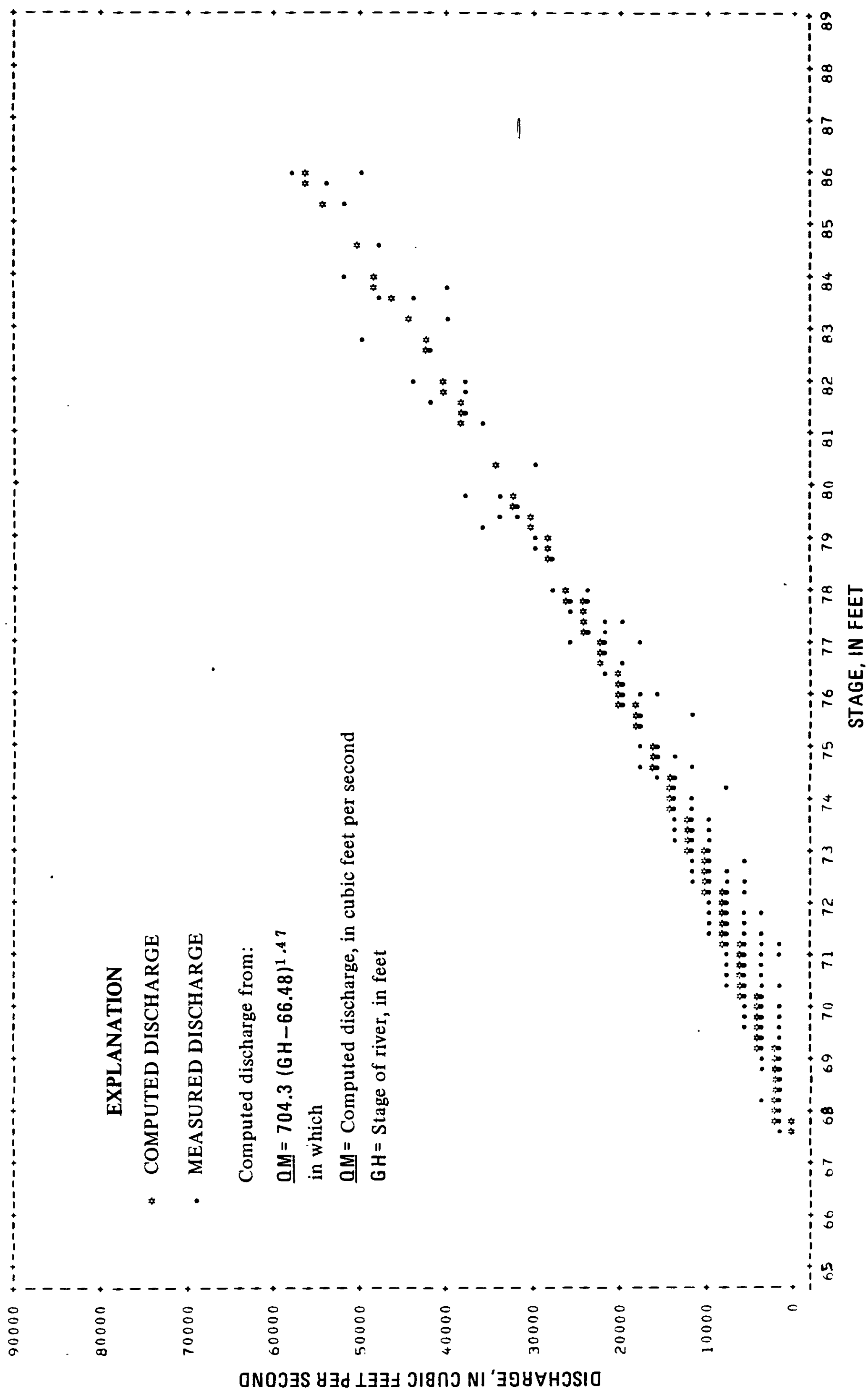


FIGURE 3.--Relations of stage to measured and computed discharges.

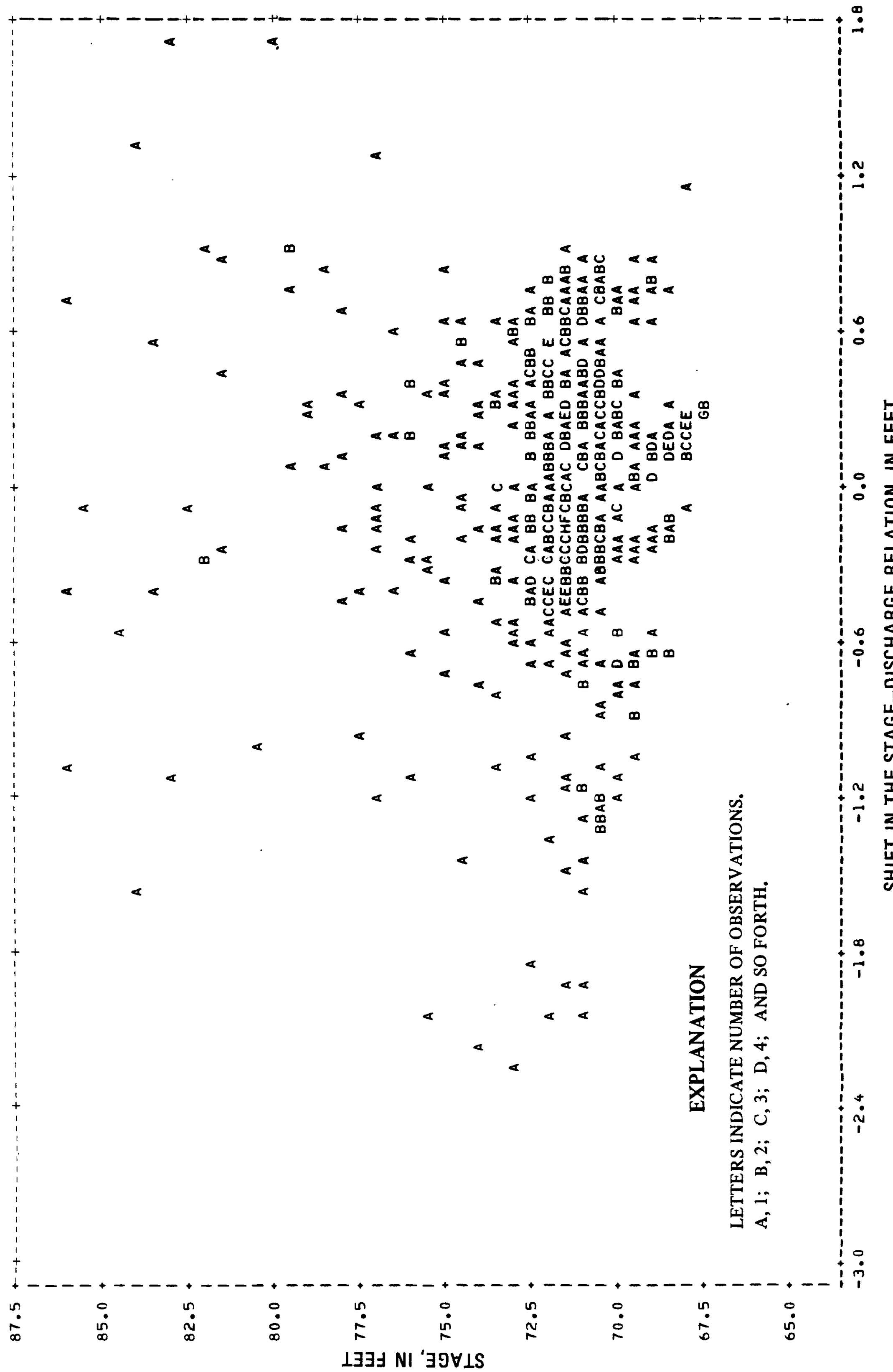


FIGURE 4.--Relation of shifts to stage.

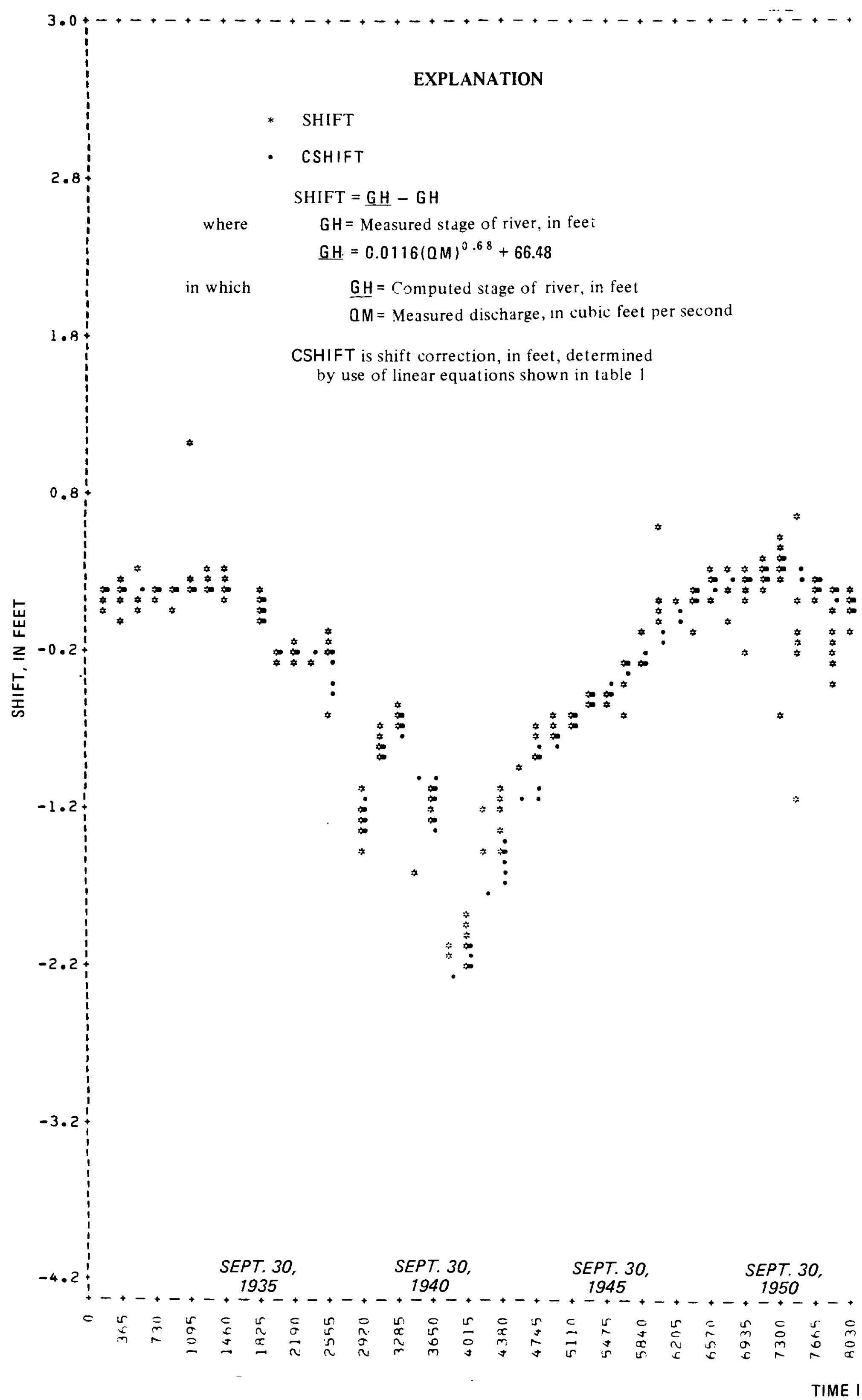
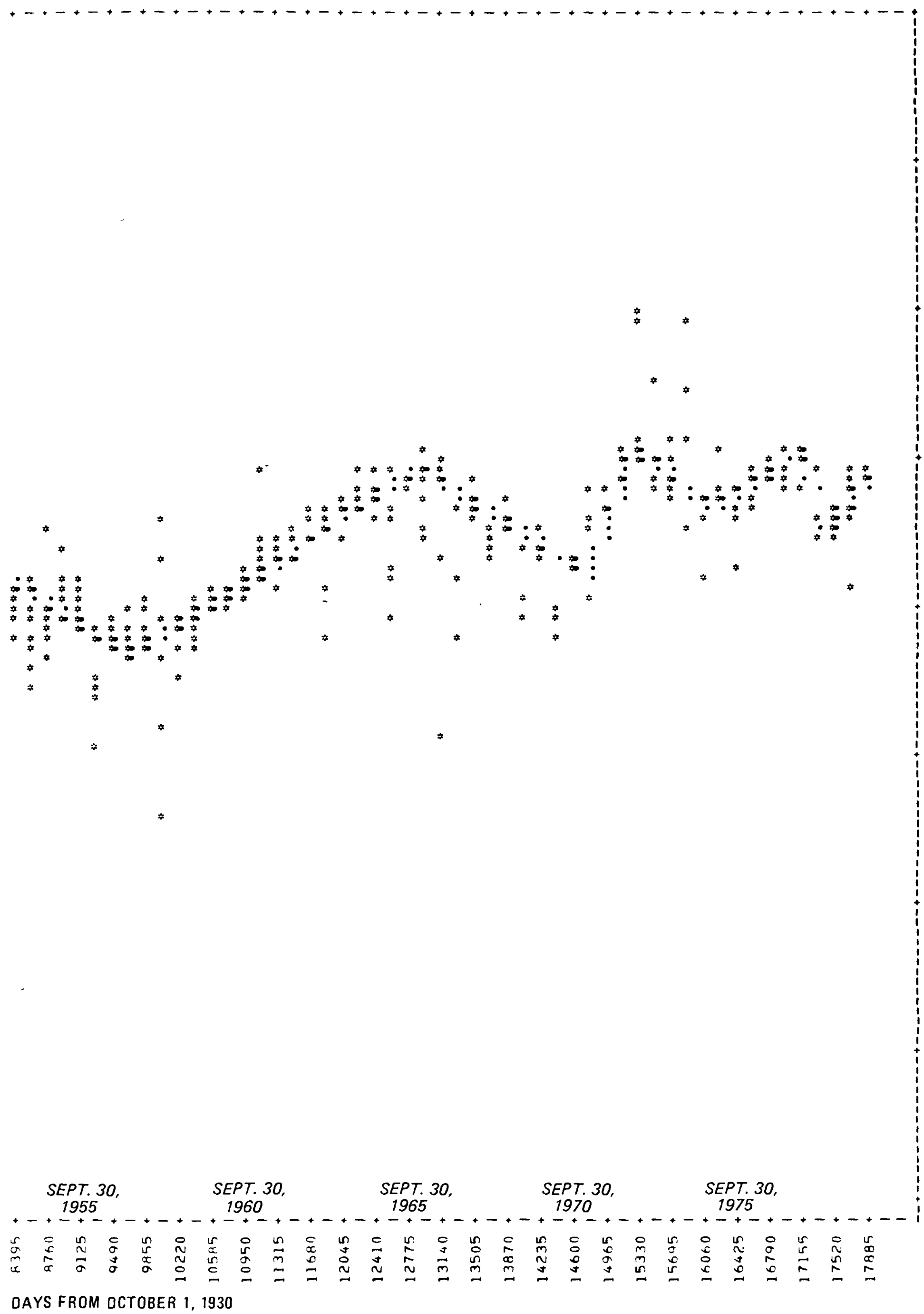


FIGURE 5.--Relation of shift, obtained as the



difference between GH and GH (equation 3), to time.

The graph showing the relation of shift to stage (step 3), or a graph showing the relation of ($\underline{QM}$-QM) to stage, is needed in order to verify that the model "$QM=A(GH-B)^C$" and equation 1 adequately represent the average stage-discharge relation for the study site. A need to modify the model would be indicated if the plotted shifts, shown in figure 4, were not approximately isometrically grouped around a shift of zero for the full range of stage being studied.

The trend curve, which was developed in steps 3 and 4, and shown in figure 5, can be used as a "tool" in investigations concerned with changes in the stage-discharge relation for the study site. Changes in the stage-discharge relation for the site apparently occurred in 1935, 1941, 1943, 1950, 1957, 1965, 1971, 1972, 1974, and 1977. An investigation to determine why these changes occurred is beyond the scope of this report. Changes such as those indicated, however, often coincide with or follow the occurrences of major floods.

The model, $QM = A(GH-B)^C$, can be used to represent the stage-discharge relation for many streams. It probably would have to be modified, however, for streams where two or more controlling conditions affect the stage-discharge relations. The model should be used only with caution, if ever, to represent the stage-discharge relation for sand-bed streams.

TRENDS IN STAGE

Curves showing trends in stage are developed by steps as follows:

1. Linear equations are developed for lines representing average trends in shifts that are shown in figure 5 (table 1).
2. Equation 2 is adjusted, using the shift-correction relations from step 1 above. The adjusted equation 4 represents an adjusted $\underline{GH}$, which is shown as $\underline{GHA}$.
3. A graph is developed that shows the relation between residuals, obtained by using the formula "residual = $\underline{GHA}$-GH," and time (fig. 6)
4. Values for stages that are equaled or exceeded 95, 90, 75, 50, and 25 percent of the time are determined on the basis of 10-year (progressive) periods. These values are called, respectively, GH95, GH90, GH75, GH50, and GH25.
5. A data set composed of QMEAS and values of GH95, GH90, GH75, GH50, and GH25 is developed.
6. The data set from step 5 is used to develop a graph showing a plot of stage versus time overlaid with plots of GH95, GH90, GH75, GH50, and GH25 versus time (fig. 7).
7. Trend curves for GH95, GH90, GH75, GH50, and GH25 are developed by connecting appropriate points in figure 7.

In step 1, equations representing shift (CSHIFT) were developed for 18 increments of time (table 1). These equations were used to determine a value for CSHIFT for each measurement in QMEAS.

Equation 4, referred to in step 2, is:

$$\underline{GHA} = 0.0116(QM)^{0.68} + 66.48\text{-}CSHIFT. \quad (4)$$

The standard error of estimate for equation 4 is 0.24 ft.

TABLE 1. - SAS statements for equations representing shifts in relations of stage to discharge, and discharge to velocity

---

SAS statements for linear equations that represent average trends in shifts (CSHIFTS) in the stage-discharge relation and for the limits on time (T)[1/].

```
IF T<1400 THEN CSHIFT=.22;
IF 1400<=T<1900 THEN CSHIFT=1.45-.00088*T;
IF 1900<=T<2300 THEN CSHIFT=-.20;
IF 2300<=T<2630 THEN CSHIFT= 7.82-.00348*T;
IF 2630<=T<3070 THEN CSHIFT=-5.83+.0017*T;
IF 3070<=T<3380 THEN CSHIFT= 4.35-.0016*T;
IF 3380<=T<3690 THEN CSHIFT= 9.80-.0032*T;
IF 3690<=T<4500 THEN CSHIFT=-7.80+.0015*T;
IF 4500<=T<6375 THEN CSHIFT=-3.69+.00062*T;
IF 6375<=T<7080 THEN CSHIFT=-.93+.00018*T;
IF 7080<=T<9450 THEN CSHIFT= 3.07-.00038*T;
IF 9450<=T<12700 THEN CSHIFT=-4.21+.00039*T;
IF 12700<=T<14550 THEN CSHIFT= 5.90-.000405*T;
IF 14550<=T<15060 THEN CSHIFT=-25.10+.001725*T;
IF 15060<=T<15950 THEN CSHIFT= 8.33-.000494*T;
IF 15950<=T<16950 THEN CSHIFT=-6.58+.00044*T;
IF 16950<=T<17180 THEN CSHIFT= 43.62-.002522*T;
IF 17180<=T<17875 THEN CSHIFT=-12.06+.0007194*T;
```

SAS statements for linear equations that represent average trends in shifts (SHV) in the discharge-velocity relation and for the limits on time (T)[1/].

```
IF 0<=T<1750 THEN SHV=0;
IF 1750<=T<3750 THEN SHV=.525-.000300*T   ;
IF 3750<=T<7000 THEN SHV=-1.826+.000326*T;
IF 7000<=T<7240 THEN SHV=.43;
IF 7240<=T<8050 THEN SHV= 4.45-.00055*T;
IF 8050<=T<10740 THEN SHV=.52-.0000669*T;
IF 10740<=T<12000 THEN SHV=-5.23+.000468*T;
IF 12000<=T<12880 THEN SHV=.39;
IF 12880<=T<14250 THEN SHV=5.94-.00043*T;
IF 14250<=T<16400 THEN SHV=-2.19+.000139*T;
IF 16400<=T<18000 THEN SHV=.10;
```

[1/] Time (T) is in days from October 1, 1930.

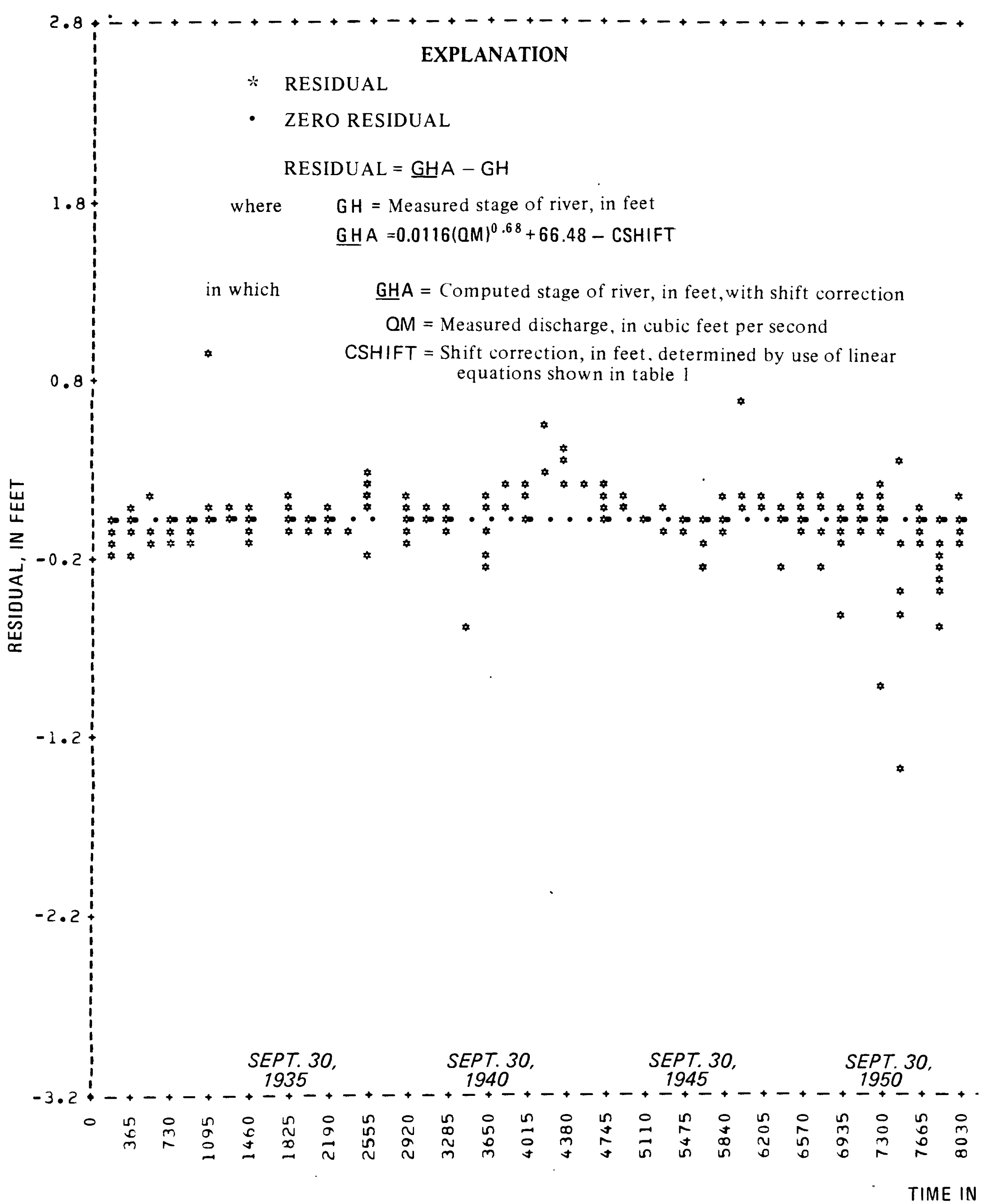
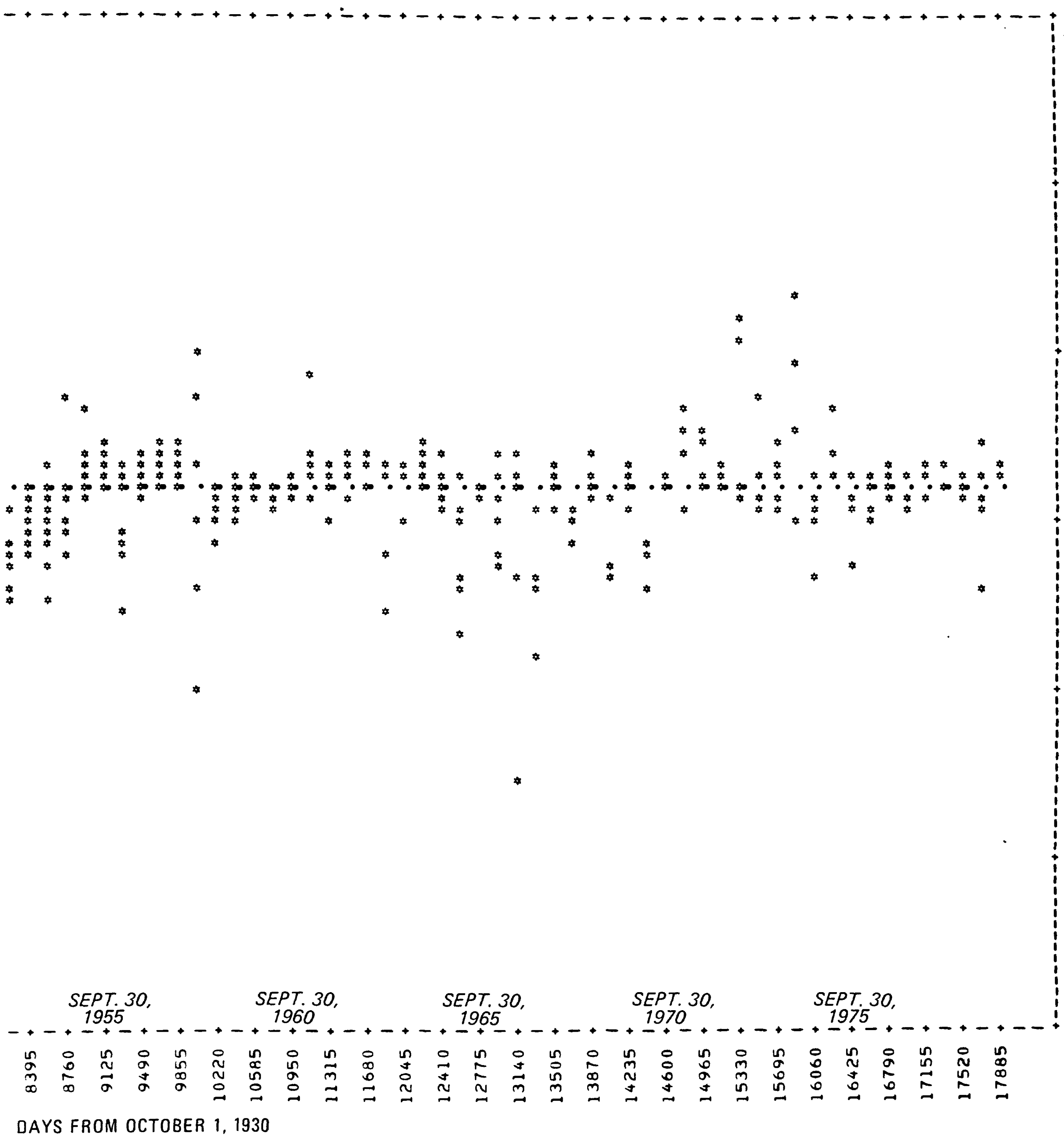


FIGURE 6.--Relation of residual, obtained



as the difference between GHA and GH, to time.

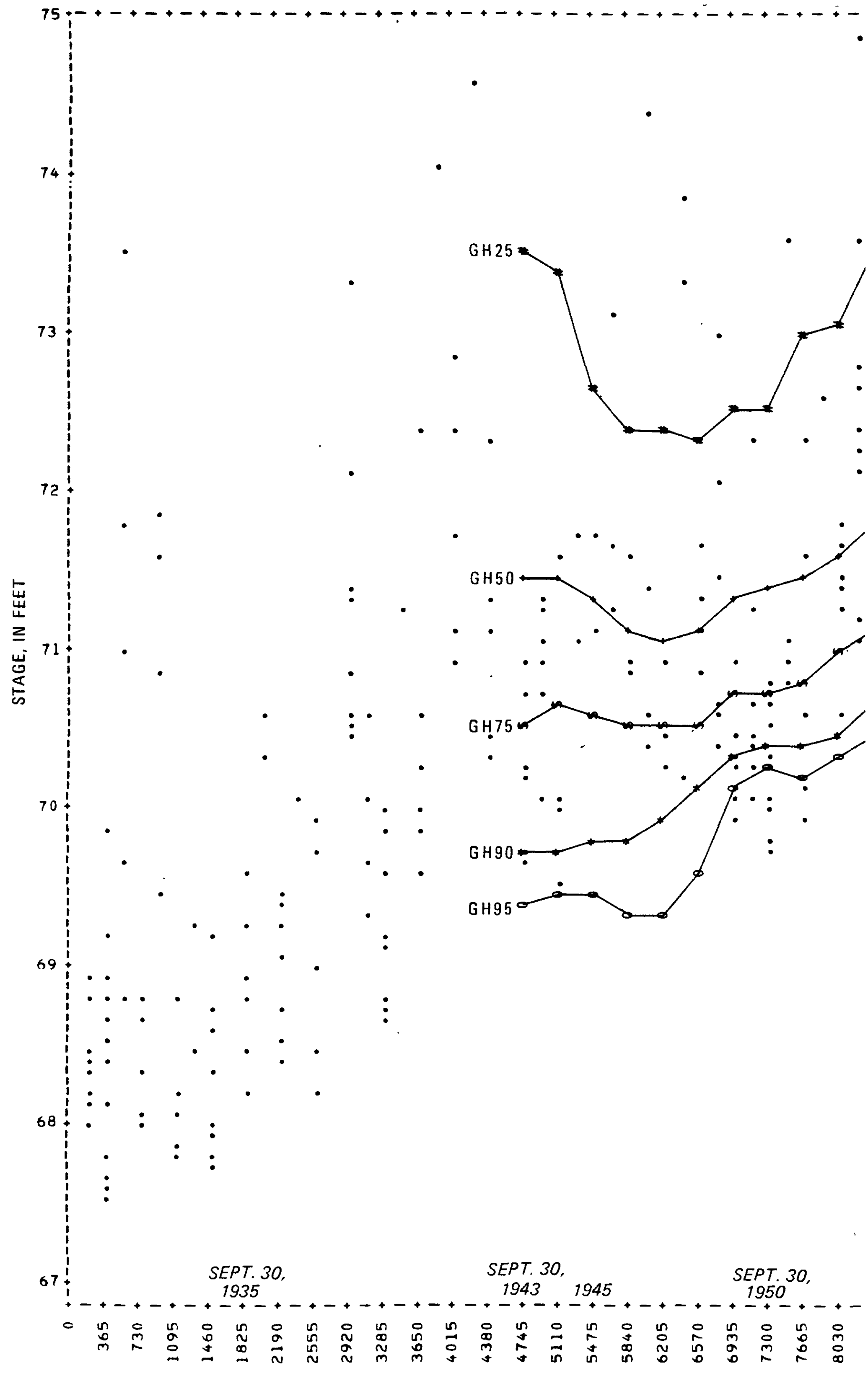
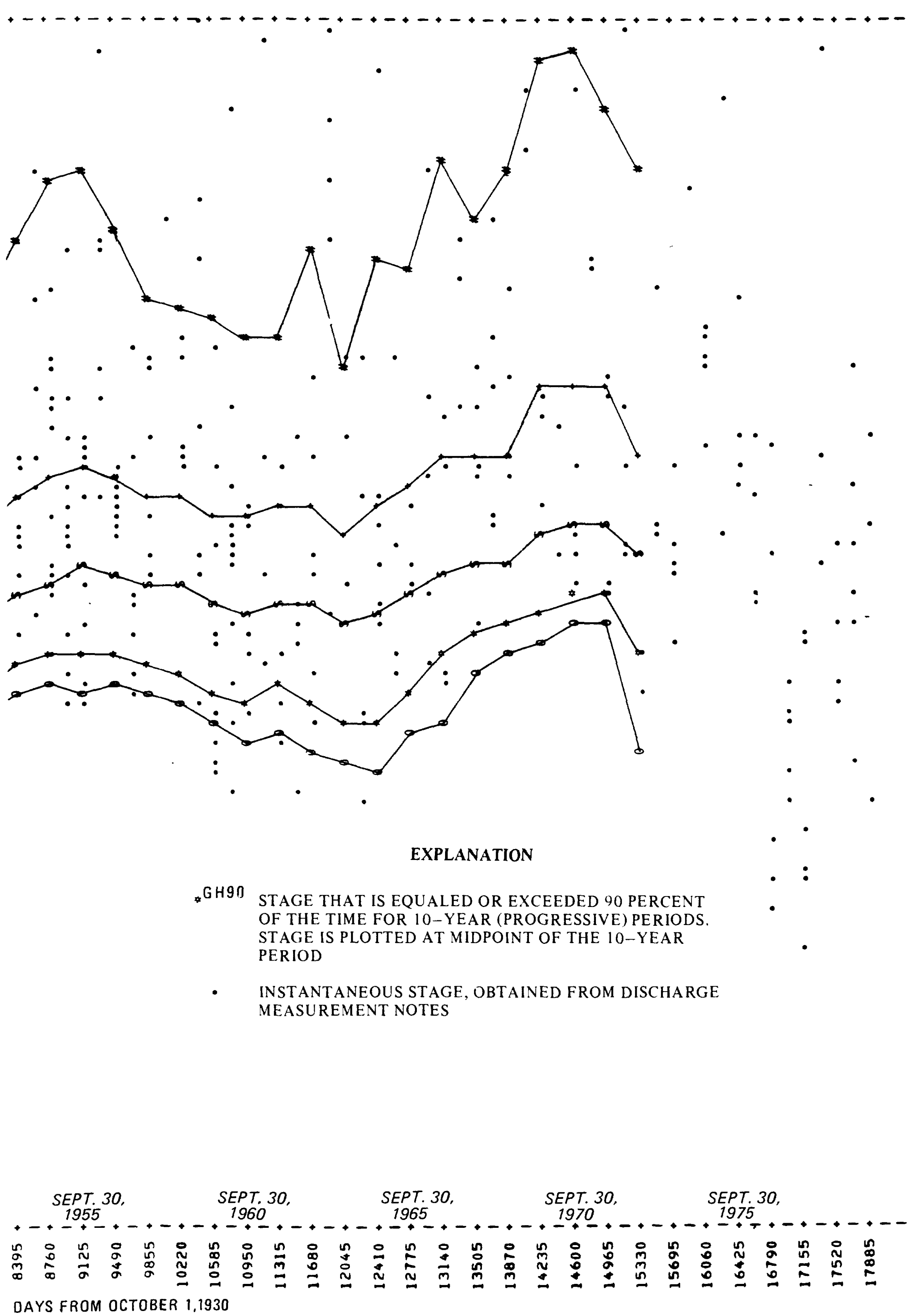


FIGURE 7.--Trend curves for



GH95, GH90, GH75, GH50, and GH25.

The graph given in figure 6 (step 3) is needed as a check to insure that equation 4 will not give biased results.

Equation 4 was used to directly estimate values of GH95, GH90, GH75, GH50, and GH25 from values of Q95, Q90, Q75, Q50, and Q25. An average value of CSHIFT was used to represent shift for each 10-year period. Average values of CSHIFT were determined from a table containing CSHIFTS and entered in the DURQ data set.

The curves shown in figure 7 can be used to study trends in stage of the Sacramento River in the vicinity of the Butte City gage. From 1939-48 to 1967-76, GH95, GH90, GH75, GH50, and GH25 apparently increased 1.5, 1.4, 1.1, 1.0, and 1.3 ft, respectively. Presumably, these increases, which average 1.3 ft, resulted mostly from regulation of flow.

TRENDS IN VELOCITY

The steps and procedures used to develop the stage-discharge relation, linear shift equations representing the stage-discharge relation, and trend curves for stage also were used, respectively, to develop the discharge-velocity relation (fig. 8), linear equations representing shifts in the discharge-velocity relation (table 1), and trend curves for velocity (fig. 9). Only data from discharge measurements made within 100 ft of the gage were used to develop velocity curves. The equation representing the discharge-velocity relation, without a shift adjustment, is:

$$\underline{V} = 0.00612\ (QM)^{0.644} \tag{5}$$

in which $\underline{V}$ equals computed velocity, in feet per second. With a shift correction, the equation is:

$$\underline{VA} = 0.00612\ (QM)^{0.644} + SHV \tag{6}$$

in which $\underline{VA}$ equals adjusted computed velocity, in feet per second, and SHV represents an adjustment, in feet per second. The standard error of estimate is 0.23 ft/s for equation 5 and 0.18 ft/s for equation 6.

The curves shown in figure 9 can be used to study trends in velocity of the Sacramento River at the Butte City gage. The parameters V95, V90, V75, V50, and V25 represent, respectively, mean daily velocities that are equaled or exceeded 95, 90, 75, 50, and 25 percent of the time. From 1939-48 to 1967-76, V95, V90, V75, V50, and V25 apparently increased 1.09, 1.05, 0.92, 0.89, and 0.91 ft/s, respectively. Presumably, these increases in velocity, which average 0.97 ft/s, are the result of the regulation of flow.

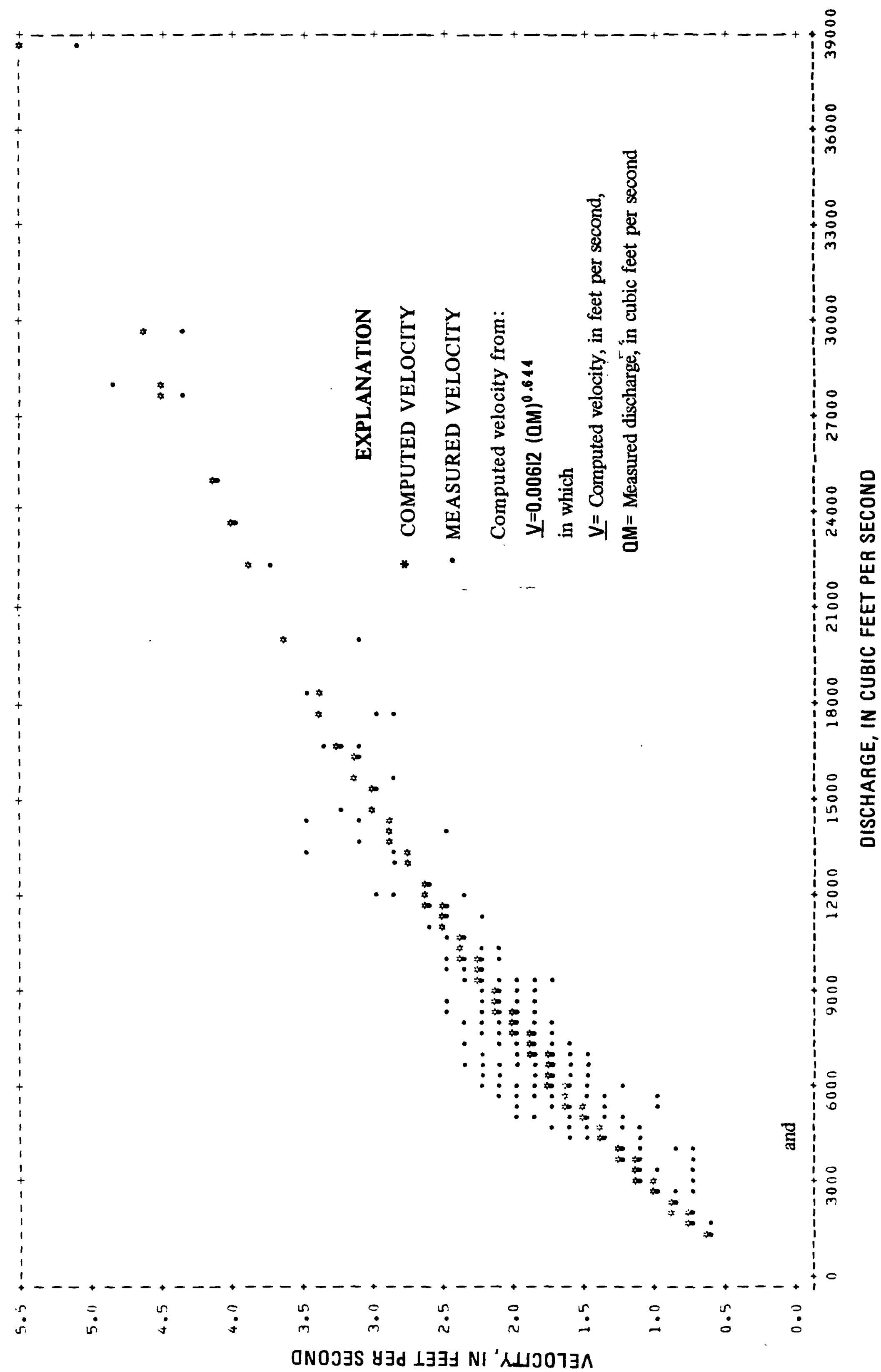


FIGURE 8.--Relation of discharge to measured and computed velocities.

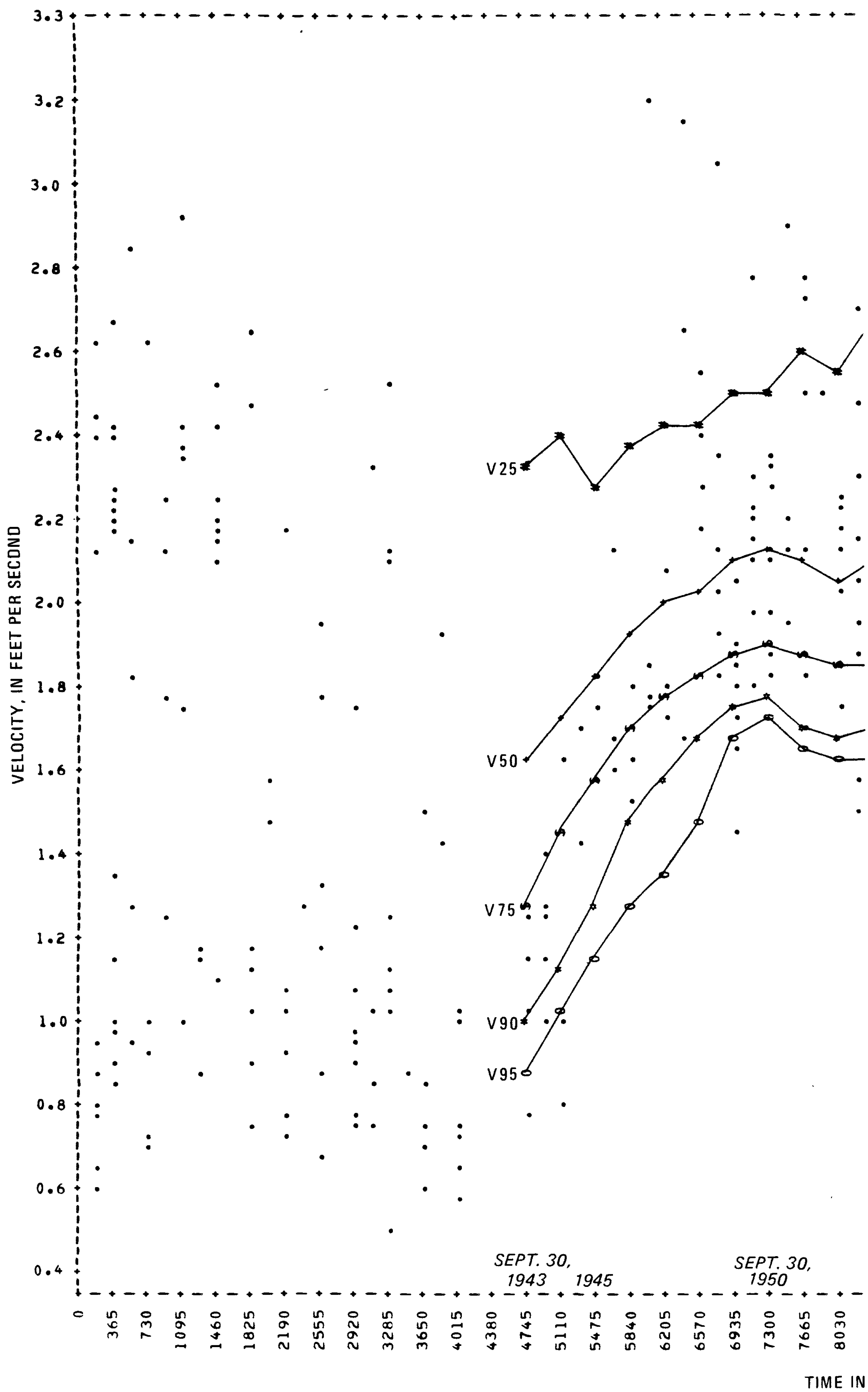
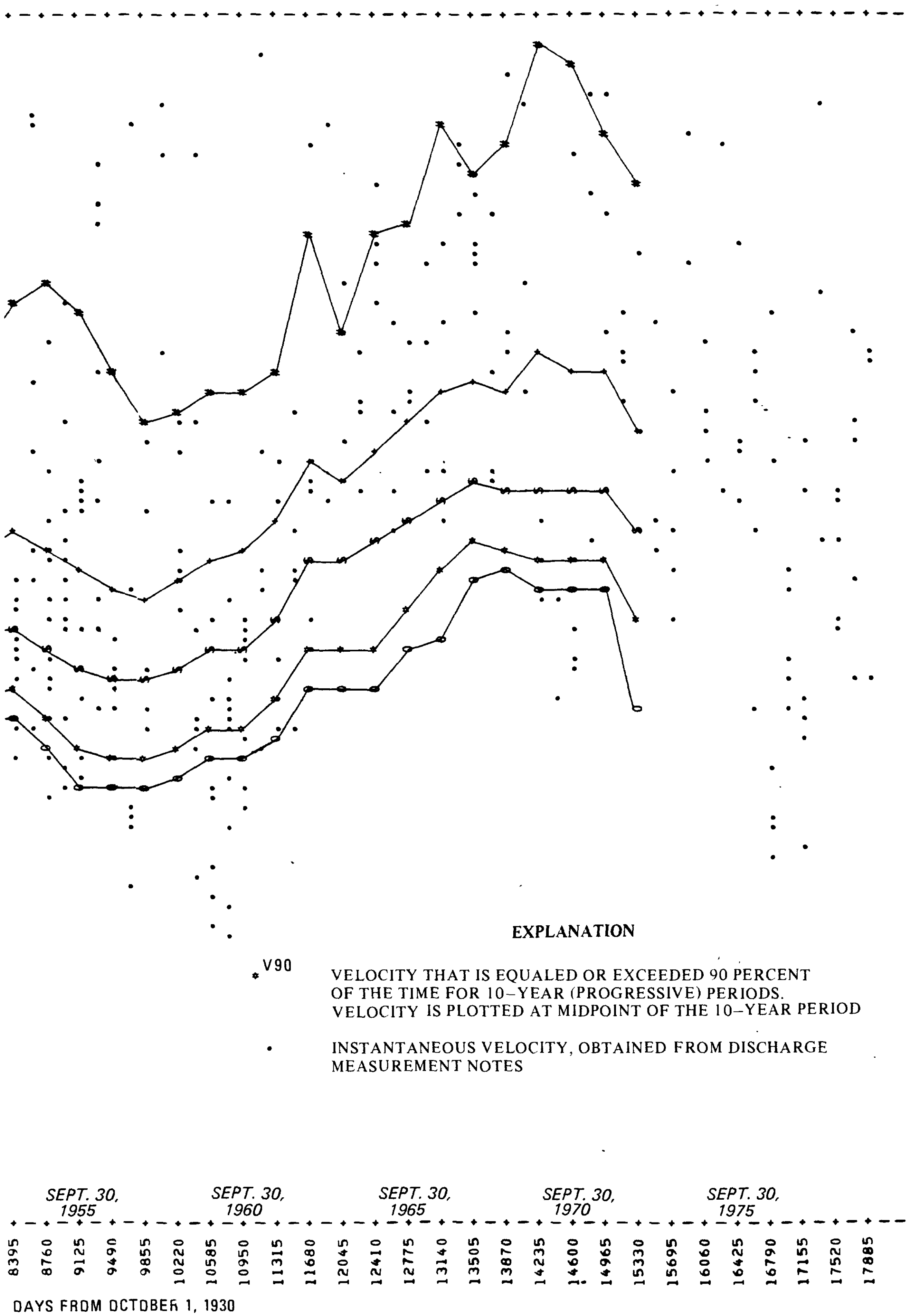


FIGURE 9.--Trend curves for



V95, V90, V75, V50, and V25.

The trend lines in figure 9 should be of special value to investigations that deal with the effects of changes in discharge on the erosion, transportation, and deposition of sediment in the Sacramento River. The capacity to transport sediment in a river is a function of the flow velocity raised to an exponent ranging from 3 to 6. The change in velocity for V95, V90, V75, V50, and V25, therefore, can cause changes in the capacity to transport sediment at the site on the Sacramento River by percentages ranging from 1,140 to 13,070, 875 to 7,650, 508 to 2,580, 372 to 1,383, and 270 to 728, respectively. The magnitude of these factors, however, may be misleading in regard to the total sediment yield at a site on the Sacramento River. For a given lengthy time period, a large percentage of the sediment yield at a station on the Sacramento River probably comes during floods. The sediment-carrying capacity during the peak of a major flood at the site may be larger than that for Q95 by more than 10 million percent. Thus, the changes in sediment yield resulting from alterations in Q95, Q90, Q75, Q50, and Q25 at the study site may be insignificant compared to the volume of sediment movement during floods.

SUMMARY

The procedure used to develop curves representing trends in discharge, stage, and mean velocity for the Sacramento River at Butte City, Calif., is described in this report. The curves are for discharges, stages, and mean velocities that are equaled or exceeded 95, 90, 75, 50, and 25 percent of the time.

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