EXTENSION OF TRANSIENT-FLOW MODEL OF THE SACRAMENTO RIVER AT SACRAMENTO, CALIFORNIA

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations 80-30

Prepared in cooperation with the
CALIFORNIA DEPARTMENT OF WATER RESOURCES

50272-101

REPORT DOCUMENTATION PAGE

1. REPORT NO.

2.

3. Recipient's Accession No.

4. Title and Subtitle
EXTENSION OF TRANSIENT-FLOW MODEL OF THE SACRAMENTO RIVER AT SACRAMENTO, CALIFORNIA

5. Report Date
July 1980

6.

7. Author(s)
Richard N. Oltmann

8. Performing Organization Rept. No.
USGS/WRI 80-30

9. Performing Organization Name and Address
U.S. Geological Survey
Water Resources Division
345 Middlefield Road
Menlo Park, California 94025

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C)
(G)

12. Sponsoring Organization Name and Address
U.S. Geological Survey
Water Resources Division
345 Middlefield Road
Menlo Park, California 94025

13. Type of Report & Period Covered
Final

14.

15. Supplementary Notes
Prepared in cooperation with the California Department of Water Resources

16. Abstract (Limit: 200 words)

The multiple-reach method-of-characteristics flow-simulation model that was successfully applied in 1976 to a 10.8-mile tide-affected reach of the Sacramento River from Sacramento to Freeport has been extended 10.5 miles farther downstream to Hood. The model reach was extended to improve the quality of the model's output during low-flow conditions for the streamflow station located at the upstream end of the reach, and to provide flow data at additional sites farther downstream toward the San Francisco Bay system. The extension of the reach, however, has not improved the quality of the model's low-flow output but it has provided flow data for sites farther downstream on the Sacramento River.

17. Document Analysis a. Descriptors
California, Computer Models, Flow Rates, Non-uniform Flow, Open Channel Flow, Stream Gages, Tidal Effects

b. Identifiers/Open-Ended Terms
Sacramento River, Sacramento-Hood Tidal Reach

c. COSATI Field/Group

18. Availability Statement
No restriction on distribution

19. Security Class (This Report)
UNCLASSIFIED

20. Security Class (This Page)
UNCLASSIFIED

21. No. of Pages
29

22. Price

(See ANSI-Z39.18)

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

EXTENSION OF TRANSIENT-FLOW MODEL OF THE SACRAMENTO RIVER AT SACRAMENTO, CALIFORNIA

By Richard N. Oltmann

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 80-30

Prepared in cooperation with the
California Department of Water Resources

July 1980

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

H. William Menard, Director

For additional information write to:

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

CONTENTS

ILLUSTRATIONS

TABLE

CONVERSION FACTORS

For readers who may prefer to use metric units (International System of Units) rather than inch-pound units, the conversion factors for the terms used in this report are listed below.

Multiply	By	To obtain
ft (foot)	0.3048	m (meter)
ft/s (foot per second)	0.3048	m/s (meter per second)
ft^3/s (cubic feet per second)	0.02832	m^3/s (cubic meters per second)
mi (mile)	1.609	km (kilometer)
mi^2 (square mile)	2.590	km^2 (square kilometer)
mi/h	1.609	km/h (kilometer per hour)

National Geodetic Vertical Datum of 1929 is a vertical datum derived from the average sea level over a period of many years at 26 tide stations along the Atlantic, Gulf of Mexico, and Pacific Coasts and as such does not necessarily represent local mean sea level at any particular place. To establish a more precise nomenclature, the term "NGVD of 1929" is used in place of "Sea Level Datum of 1929" or "mean sea level."

EXTENSION OF TRANSIENT-FLOW MODEL OF THE SACRAMENTO RIVER AT SACRAMENTO, CALIFORNIA

By Richard N. Oltmann

ABSTRACT

The multiple-reach method-of-characteristics flow-simulation model that was successfully applied in 1976 to a 10.8-mile tide-affected reach of the Sacramento River from Sacramento to Freeport has been extended 10.5 miles farther downstream to Hood. The model reach was extended to improve the quality of the model's output during low-flow conditions for the streamflow station located at the upstream end of the reach, and to provide flow data at additional sites farther downstream toward the San Francisco Bay system. The extension of the reach, however, has not improved the quality of the model's low-flow output but it has provided flow data for sites farther downstream on the Sacramento River.

INTRODUCTION

Purpose and Approach

The multiple-reach method-of-characteristics flow-simulation model has been used successfully on a tide-affected reach of the Sacramento River since February 1976. The model was applied to a 10.8-mile reach of the river from Sacramento to Freeport (fig. 1) to improve the flow record for the Sacramento River at Sacramento stream-gaging station (station 11447500). The application of the model to the Sacramento-to-Freeport reach is documented by Oltmann (1979). Readers are referred to Oltmann (1979) for a more comprehensive discussion of concepts, equations, and procedures pertaining to the model.

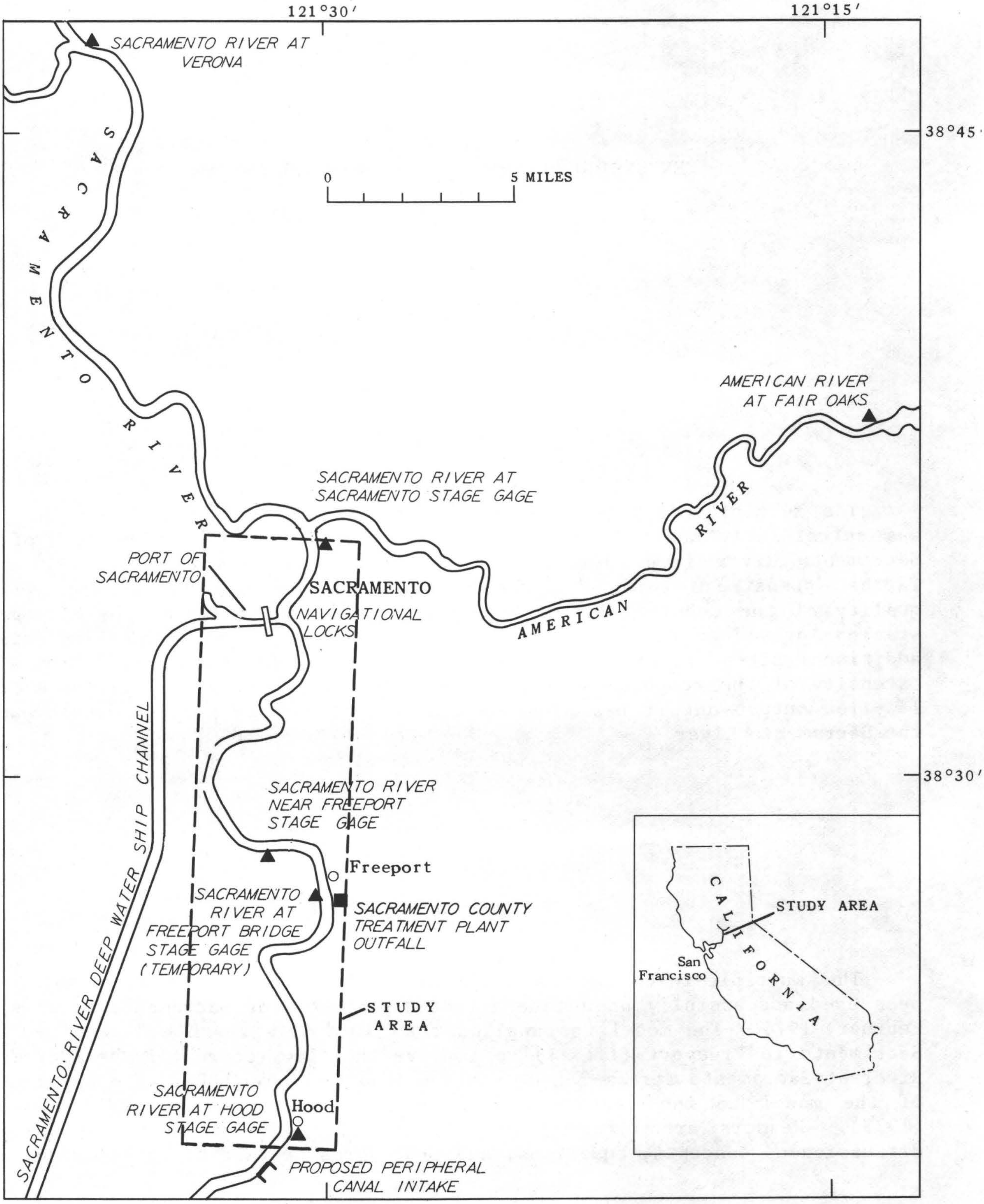

FIGURE 1.--Location of Sacramento River study area.

The purpose of the study presented in this report is (1) to improve the quality of the model's simulated low flows at the Sacramento River at Sacramento stream-gaging station, and (2) to provide flow-characteristics data for sites farther downstream toward the San Francisco Bay system. The approach taken was to extend the reach of the Sacramento-to-Freeport model 10.5 mi downstream to Hood. The study included (1) collecting and processing additional data on channel geometry and stage, and (2) using these data in conjunction with discharge measurement data to calibrate the extended model.

The study was made in cooperation with the California Department of Water Resources.

Reasons for Extension of Existing Model Reach

The Sacramento-to-Freeport model was subjected to a severe test during the 1976-77 drought, as the river's flow at the Sacramento stream-gaging station reached record minimums for the period of continuous streamflow record (1949-present). As a result of the extreme low flows, the tidal effect at Sacramento was pronounced, causing the flow to be more transient than usual. Some of the discharge measurement data that were collected during this period did not agree with the model's computed results. Because errors of a few hundredths of a foot in river stage can result in significant errors in the computed discharge during highly transient flow conditions, the difference between the computed and measured discharge was thought to be caused by errors in the river stage data. It was felt that by extending the model reach downstream, the accuracy of the model's computed low flows might be improved because the determination of river slope (hydraulic gradient) determined over the longer reach would be less sensitive to anomalies in measured river stages than the slope determined over the shorter reach. The California Department of Water Resources stream-gaging station at Hood, 10.5 mi downstream from the Freeport stage gage, was selected as the downstream end of the reach extension.

Extending the model to Hood would provide, for the first time, flow-characteristics data at the location of the outfall for the new Sacramento County regional sewage treatment plant at Freeport, and at the location of the State of California's proposed peripheral-canal intake near Hood (fig. 1).

DESCRIPTION OF RIVER REACH

The 21.3-mile reach of the Sacramento River to which the model was applied is located approximately 60 mi northeast of San Francisco, Calif. The reach has three primary stage-gaging stations (fig. 1). They are, starting at the upstream end of the reach, Sacramento River at Sacramento (11447500), Sacramento River near Freeport (11447650), 10.8 mi downstream from Sacramento, and the Sacramento River at Hood (11447652), 10.5 mi downstream from the Freeport gage. A temporary stage gage was operated between October 1976 and December 1977 at the Freeport Bridge, 2.5 mi downstream from the Freeport gage. This gage was installed to collect additional low-flow stage data within the reach during the drought period. The four stage gages are standard stilling-well installations equipped with float-driven digital recorders.

A daily streamflow record has been published for the Sacramento River at Sacramento gage since 1949. The drainage area at this gage is 23,502 mi^2. For the period of continuous streamflow record (1949-77), the daily mean discharge at the gage has ranged from 5,200 ft^3/s to 99,400 ft^3/s and has averaged 23,760 ft^3/s. During the drought period, the 1977 water-year discharge averaged only 7,610 ft^3/s, with a maximum daily mean discharge of only 13,700 ft^3/s. The stage-discharge relations at the Sacramento and Hood sites are affected by the tide when the streamflow is about 40,000 ft^3/s or less and 60,000 ft^3/s or less, respectively.

The river is channelized throughout the reach, with large areas of the levied riverbanks protected by riprap. Areas with no riprap are fairly free of flow-resisting vegetation. The river channel has a gentle uniform slope and is not very sinuous. The river bed is composed predominantly of sand-size material. During flows less than about 20,000 ft^3/s, 3- to 5-foot-high dunes are present on the riverbed; during higher flows the dunes decrease in height to 1 ft or less.

Figure 2 shows the relation between typical daily hydrographs of tide-affected discharge and stage for the upstream and downstream ends of the 21.3-mile reach (the discharge hydrographs were produced by the extended model). The differences in the extremes of the two discharge hydrographs show how the flow becomes more transient and is, therefore, more difficult to measure and compute as one travels downstream. The comparison of the two stage hydrographs shows that from about 0400 to 0700 hours and from 1500 to 1900 hours there was a negative hydraulic gradient (water surface was higher at Hood than at Sacramento), and, thus, a reversal of flow at Hood for these periods. A negative hydraulic gradient occurs for short periods when the river discharge at Sacramento is less than about 10,000 ft^3/s, which occurs about 15 percent of the time. The magnitude and duration of the negative hydraulic gradient is not usually sufficient to overcome the river's downstream momentum and cause flow reversal at Sacramento. During the 1977 drought, however, reverse flow was observed at Sacramento.

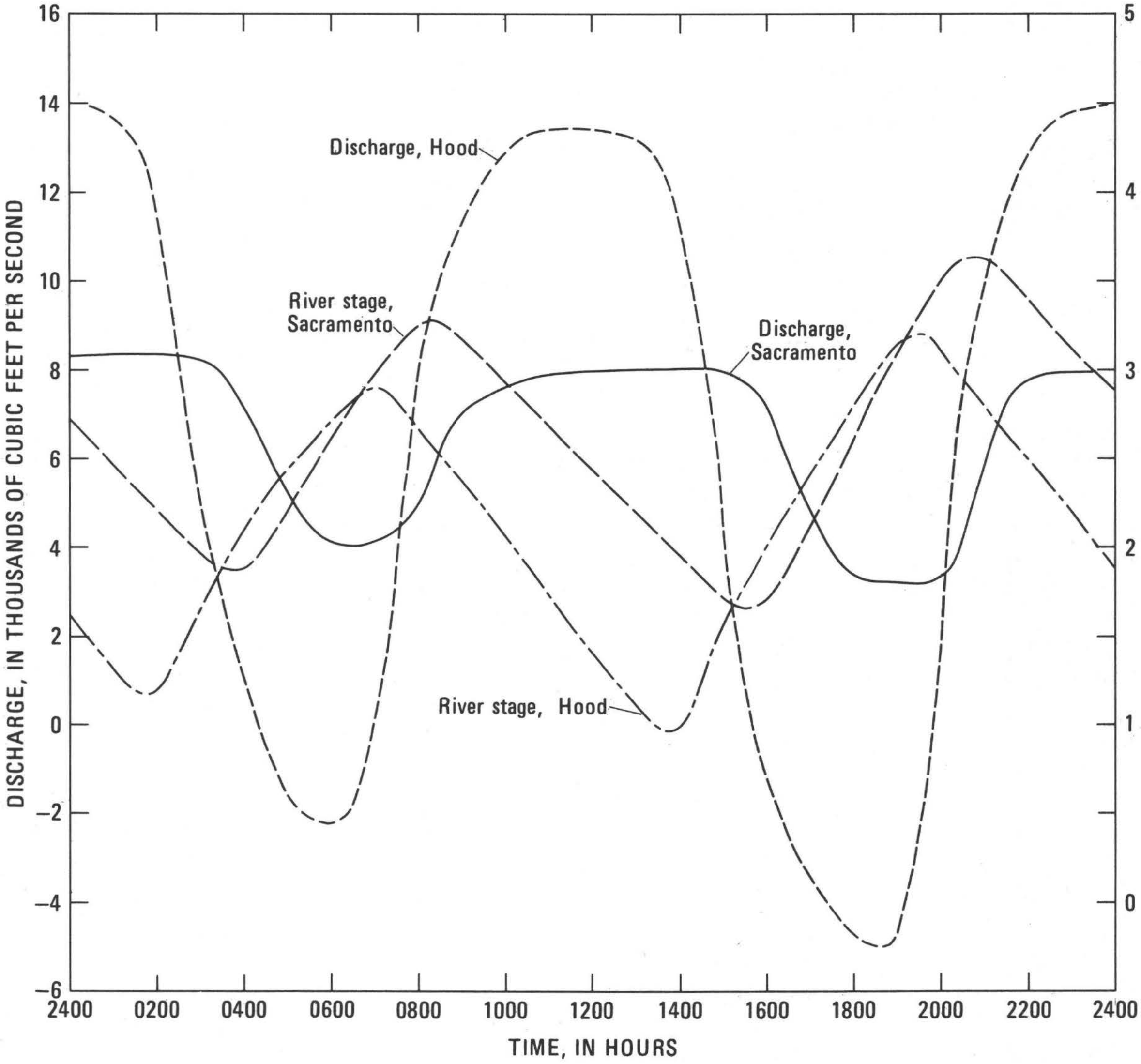

FIGURE 2.--Measured river stage and computed discharge hydrographs for Sacramento River at Sacramento and Sacramento River at Hood for September 15, 1977.

Spring tides, which have the largest tidal range, occur when the Sun, Moon, and Earth are directly or closely alined (new moon or full moon). Neap tides occur when the gravitational forces of the Sun and Moon upon the Earth are imposed at or near right angles and therefore tend to counteract each other. During neap tides the range between high and low tide is reduced. Figure 3 shows that under low-flow conditions water is stored within the Sacramento-to-Hood reach during spring tides and released from storage during neap tides. This temporary storage of water within the reach exists when daily mean flows at Sacramento are less than about 20,000 ft^3/s.

DESCRIPTION OF MODEL

The flow-simulation model that was applied to the Sacramento River was the multiple-reach method-of-characteristics digital-computer transient-flow simulation model developed by Lai (1967). This one-dimensional flow-simulation model is based on the equation of continuity (conservation of mass) and the equation of motion (conservation of momentum). These two partial differential equations are transformed into characteristic equations and are solved by using finite-difference approximations with a specified time interval (Lai, 1967). The assumptions used in this numerical model are: (1) Velocity is uniform in any given channel cross section; (2) water density in the channel is substantially homogeneous; (3) channel slope is mild and uniform over the reach; (4) the reach does not have a high degree of sinuosity; (5) reach geometry is relatively simple; and (6) the flow resistance coefficient used with unsteady flow is the same as that for steady flow. For a further explanation of the unsteady-flow equations and the method of characteristics, refer to Lai and Onions (1976) or Oltmann (1979).

Input data to the model include a depth-versus-area and a depth-versus-top width table describing the channel geometry, length of reach, mean channel bottom elevation at the ends of the reach, and a relation between discharge and flow-resistance coefficient (eta). The notation, eta, is used by Lai in place of Manning's n because eta accounts for schematization inaccuracies as well as being a flow resistance coefficient. The primary difference between the model used on the Sacramento River (version 27) and that described by Lai and Onions (1976) (version 13) is in the treatment of eta. Version 13 treats eta as a constant, but version 27 has the capability of varying eta either as a linear or quadratic function of discharge.

The driving force of the model is synchronized stage data collected at 15-minute intervals at the ends of the reach. These stage data, along with the length of the reach, define the hydraulic gradient. For a further explanation of the input data collection and processing, refer to Oltmann (1979).

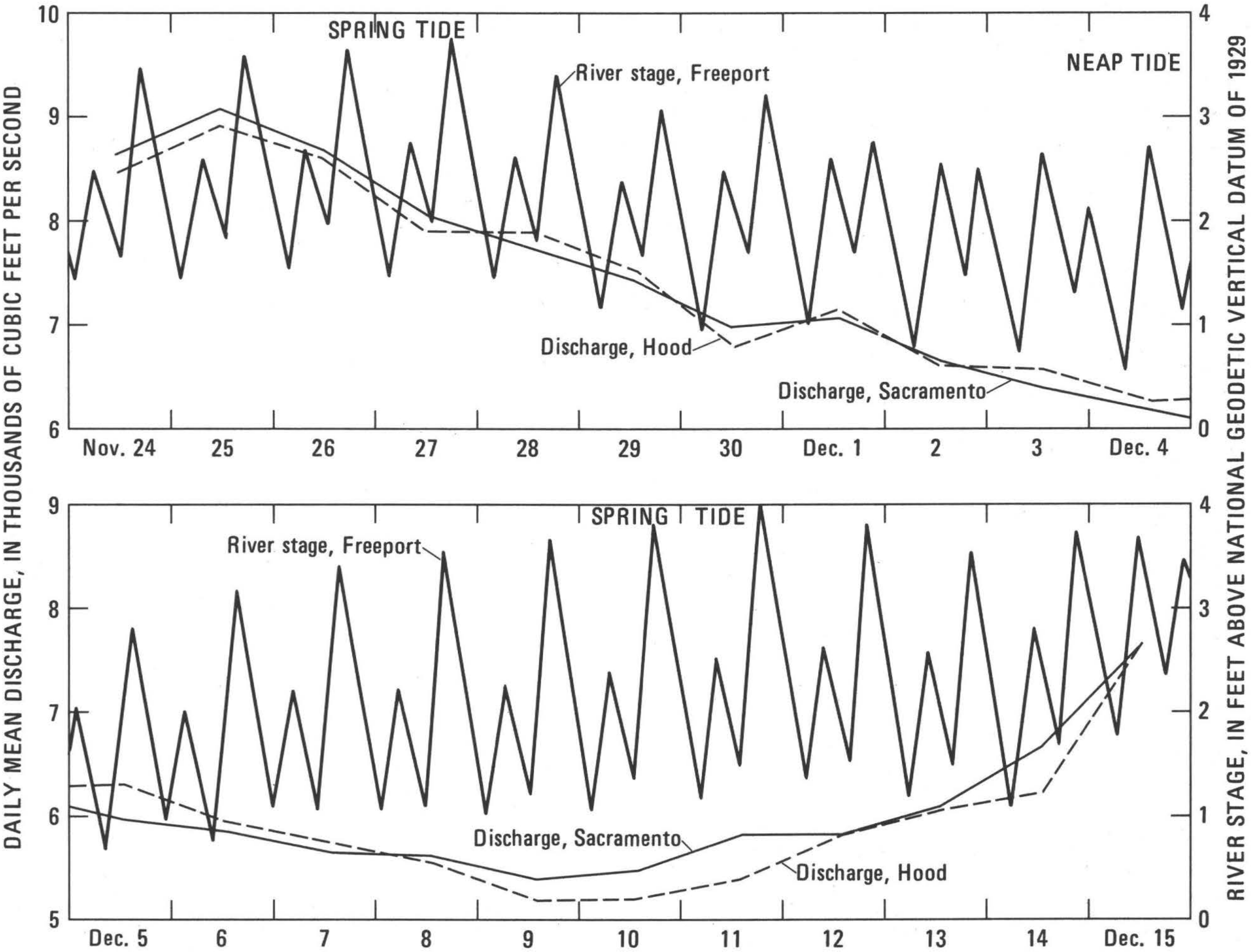

FIGURE 3.--Computed daily mean discharges at Sacramento and Hood and measured stage at Freeport for November 24 to December 15, 1977.

If the channel to which the model is to be applied is not uniform throughout the reach with respect to channel geometry or flow resistance, it can be subdivided into a series of shorter but approximately uniform subreaches. The model is then applied as a multiple-reach model. The channel in the Sacramento-to-Freeport reach was suitable for a single-reach model. A multiple-reach model requires input of channel geometry data and an eta-versus-discharge relation for each subreach. The driving force of synchronized stage data is applied only at the ends of the entire reach. Each subreach functions as a separate single-reach model with stage data (driving force) at the junction of two subreaches estimated by quadratic extrapolation from previously computed stage elevations at that point. The two discharges computed from the two subreaches for their common junction must agree within a user-specified tolerance. If the specified tolerance is exceeded, the estimated stage at the junction is varied and the two discharges recomputed until continuity at the junction is achieved (Lai and Onions, 1976; Oltmann, 1979).

The model has eight output options. The options include stage and discharge hydrographs, computed versus observed stage and discharge hydrographs, 15-minute discharge or daily mean discharge tables, a summation of positive and negative discharge for each day, and a comprehensive table of 15-minute discharge, stage, and velocity.

EXTENSION AND CALIBRATION OF MODEL

The initial steps to extend the model were to collect stage data at Hood and channel geometry data for the Freeport-to-Hood reach. A precision temperature-compensated timer was connected to the existing digital recorder at the Hood gage. The timer was set to synchronize Hood's stage data record with the stage data recorded at the Sacramento and Freeport gages. Survey level lines were run from the Freeport gage to the Hood gage in order to reference the stage readings to a common datum. Sixteen channel cross sections were surveyed and processed in the same manner as was done for the Sacramento-to-Freeport reach (Oltmann, 1979).

The model was calibrated by adjusting parameters until the differences between measured and computed discharge were minimized for both ends of the reach throughout the entire range of discharge. Discharge data were available at the Sacramento gage because the flow is measured every 6 to 8 weeks to verify the Sacramento-to-Freeport model. Because the Sacramento-to-Freeport model is verified by measurements on a routine basis throughout the range of flow, computed discharges from the model were also used for calibration of the upstream end of the Sacramento-to-Hood model. Four tidal-cycle measurements, which consist of a set of conventional discharge measurements made over a full or partial tidal cycle, were made at Hood and used for calibration of the downstream end of the model. High-flow calibration (minimal or no tide effect) for the downstream end of the model was performed by assuming continuity throughout the reach and adjusting the model during a nearly steady high-flow condition until the computed daily mean discharges for Hood agreed with the daily mean discharges computed for Sacramento.

Calibration began with dividing the reach into two subreaches, Sacramento-to-Freeport (upstream subreach) and Freeport-to-Hood (downstream subreach). The model was applied as a multiple-reach schematization. Plots of depth versus area for each subreach showed almost identical slopes. This indicates that the channel is fairly uniform throughout the entire 21.3 mi. Subsequently, the model was applied as a single-reach model over the entire Sacramento-to-Hood reach. Computed discharges from the two model configurations for a common period were very similar. The computer time, however, was 28 percent longer for the multiple-reach run than for the single-reach run. The multiple-reach schematization was abandoned, and the calibration effort continued using only the Sacramento-to-Hood single-reach schematization.

After numerous adjustments and computer runs, it was found that both ends of the model could be fairly well calibrated for the low-flow range. However, when the flow increased, the calibration at the downstream end of the reach could not be attained without destroying either the calibration at the upstream end or the low-flow calibration at both ends of the reach. The same results were produced with the multiple-reach schematization. This problem was overcome by using an extrapolation procedure described by Lai and Onions (1976). This procedure, which increases the model's numerical solution to second-order accuracy, provided calibration throughout the discharge range at both ends of the 21.3-mile reach.

Results of Calibration

Figures 4 to 9 and table 1 show part of the discharge data that were used for calibration of the Sacramento-to-Hood model and the comparison with the model's computed discharge. Figures 4 to 9 were drafted from model output line-printer plots that had measured discharge added manually. The final calibration eta-versus-discharge relation, ($eta = 2.650 \times 10^{-2} + 3.567 \times 10^{-8} Q + 5.667 \times 10^{-13} Q^2$) ranged from 0.0265 to 0.0343.

Figures 4 and 5 compare instantaneous (15-minute interval) discharges at Sacramento computed by the Sacramento-to-Hood model and the Sacramento-to-Freeport model with measured discharges. The two models produced similar hydrograph plots for Sacramento throughout a tide cycle except when the flow decreased because of flood tide. During this period, 0800 to 1130 hours (fig. 4), the Sacramento-to-Freeport model computed less discharge than the Sacramento-to-Hood model. The measurements made on December 15, 1976, were initially used to calibrate the Sacramento-to-Freeport model (Oltmann, 1979, fig. 4), and the measurements made on November 16, 1977, were used as verification of that calibration.

TABLE 1. - Daily mean discharges at Sacramento and at Hood computed by the Sacramento-to-Freeport model and the Sacramento-to-Hood model

Date	Computed daily mean discharge (cubic feet per second)			Percentage difference	
	Sacramento-to-Freeport model	Sacramento-to-Hood model			
	Sacramento $\bar{Q}_1$	Sacramento $\bar{Q}_2$	Hood $\bar{Q}_3$	$\frac{\bar{Q}_2-\bar{Q}_1}{\bar{Q}_1} \times 100$	$\frac{\bar{Q}_3-\bar{Q}_2}{\bar{Q}_2} \times 100$
1977: Nov. 29	7,420	7,430	7,520	+0.1	Not computed; channel storage in the reach at this magnitude of discharge because of tidal variations
30	7,010	6,980	6,780	-0.4	
Dec. 1	7,030	7,040	7,160	+0.1	
2	6,660	6,650	6,620	-0.2	
3	6,440	6,400	6,580	-0.6	
4	6,240	6,200	6,280	-0.6	
5	6,010	5,960	6,300	-0.8	
6	5,860	5,820	5,960	-0.7	
7	5,650	5,630	5,760	-0.4	
1977: Dec. 20	20,200	20,100	20,900	-0.5	
21	16,200	16,300	16,400	+0.6	
22	13,400	13,600	13,800	+1.5	
23	11,800	11,900	12,100	+0.8	
24	15,600	15,800	14,700	+1.3	
1978: Jan. 10	32,500	32,500	31,500	0	-3.1
11	38,000	38,000	37,500	0	-1.3
12	43,000	43,200	41,600	+0.5	-3.7
13	51,900	52,200	50,500	+0.6	-3.3
14	57,900	58,800	57,100	+1.6	-2.9
1978: Feb. 14	67,600	67,500	67,400	-0.1	-0.1
15	66,900	66,800	66,700	-0.1	-0.1
16	66,000	65,800	65,700	-0.3	-0.1
17	64,300	64,100	64,200	-0.3	+0.2
1978: Mar. 8	79,100	79,100	78,400	0	-0.9
9	79,300	79,200	78,700	-0.1	-0.6

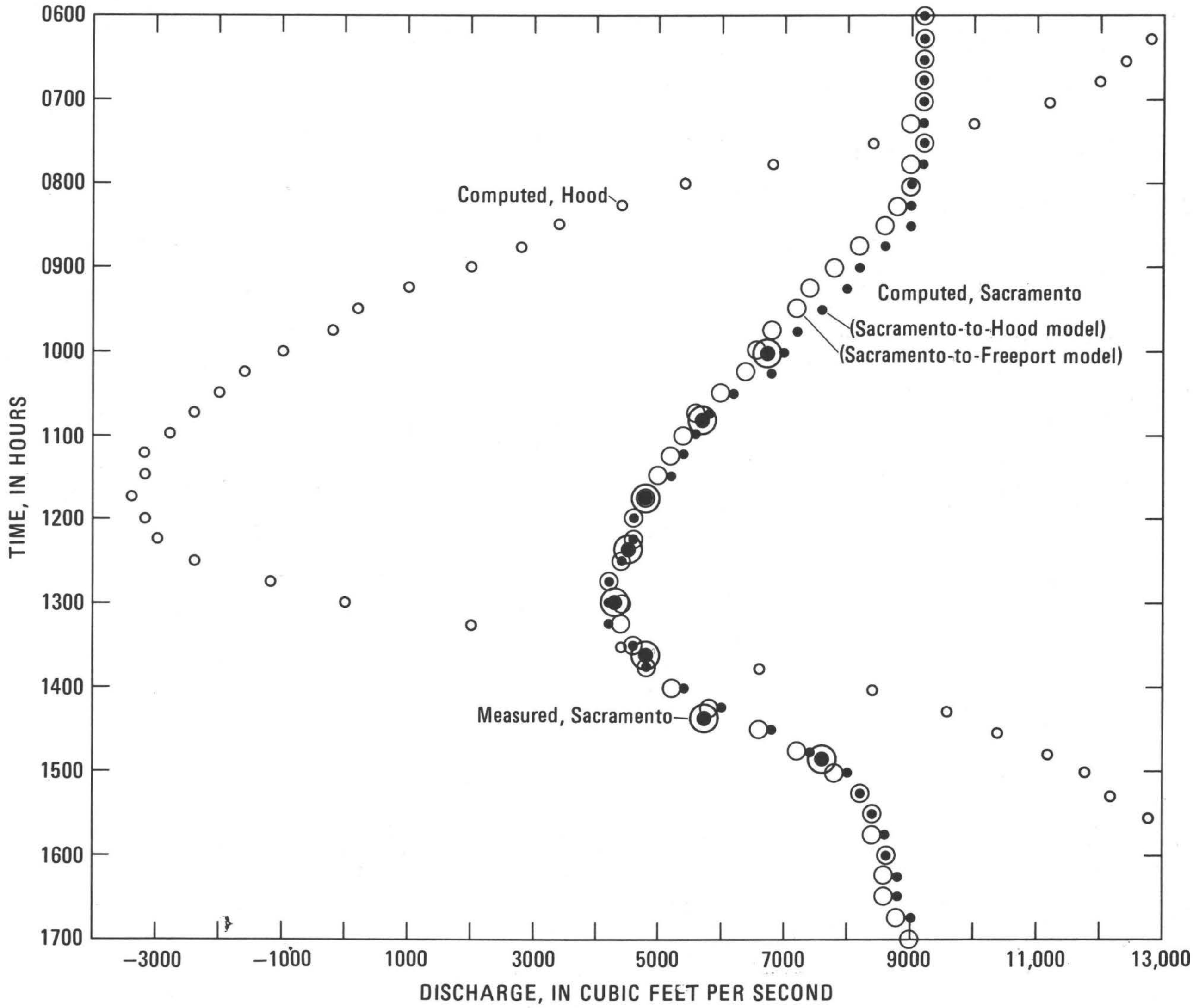

FIGURE 4.--Computed and measured discharge of the Sacramento River at Sacramento and computed discharge at Hood, December 15, 1976.

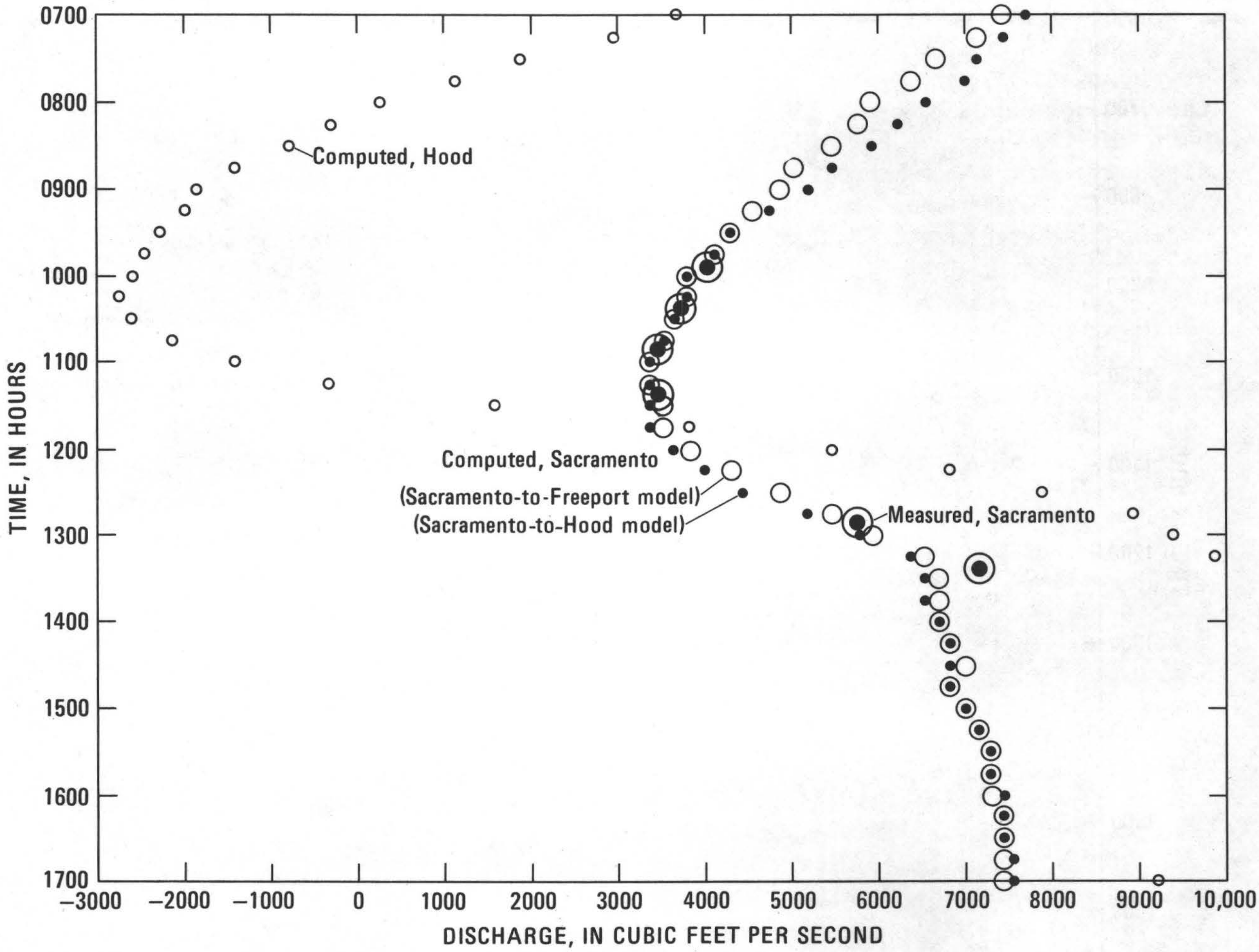

FIGURE 5.--Computed and measured discharge of the Sacramento River at Sacramento and computed discharge at Hood, November 16, 1977.

Figures 6 to 9 compare computed instantaneous discharges with the only available discharge measurements at Hood. The results are not as good as expected. The goal for calibration was to have the computed discharge hydrograph split 90 percent of the 29 discharge measurements by ±5 percent. Ten of the measurements exceeded the ±5 percent range. Five of the 10, however, are part of the August 14, 1978, tidal cycle measurement for which the computed discharge may be in error because of questionable input stage data. The other five discharge measurements were made during rapidly changing conditions and during reverse flow. The accuracy of measurements made under these conditions is questionable and will be discussed in the section on measuring transient flow. A calibration that would split the measurements of each tidal cycle could not be obtained. As a result, the model was calibrated to split the tidal cycle measurements with the computed discharges being either greater or less than all the measured discharges during a given tidal cycle. For example, the computed discharges for the tidal cycle measurement made on September 15, 1977, (fig. 6) are greater than the corresponding measured discharges.

Table 1 shows that the daily mean discharges at Sacramento computed by the Sacramento-to-Freeport model were duplicated within 1.6 percent by the Sacramento-to-Hood model. The tabulation also shows good continuity between the computed daily mean discharges at both ends of the reach for the Sacramento-to-Hood model. The January 10-14, 1978, period indicates about a 3-percent discrepancy between the daily mean discharges for Sacramento and Hood because the flood wave passes Sacramento before Hood. The February 14-17 and March 8-9, 1978, periods approach steady-state flow conditions and, therefore, the continuity between Sacramento and Hood is improved.

The calibration of the downstream end of the model appears good when looking at the continuity of daily mean discharges as shown in table 1. However, the computed hydrographs shown in figures 6 to 9 create questions as to the accuracy of the calibration and of the discharge measurements. It is believed that refinement in discharge-measuring techniques and additional tidal cycle measurement data can improve the calibration of the downstream end of the extended model to the same level of accuracy as the upstream end.

Measuring Transient Flow

Discharge measurement data, which are used to define the magnitude and variation of flow with respect to the changing tide, are essential to the calibration and verification of a transient-flow model. Tidal cycle measurements at the Sacramento stream-gaging station for many years have been made from a boat attached to a cable suspended approximately 20 ft above the water surface. The suspension of the line allows small boats to pass the site safely and without interrupting the individual discharge measurements that compose a tidal-cycle measurement. To allow passage of large boats, the cable must be dropped to the river bed.

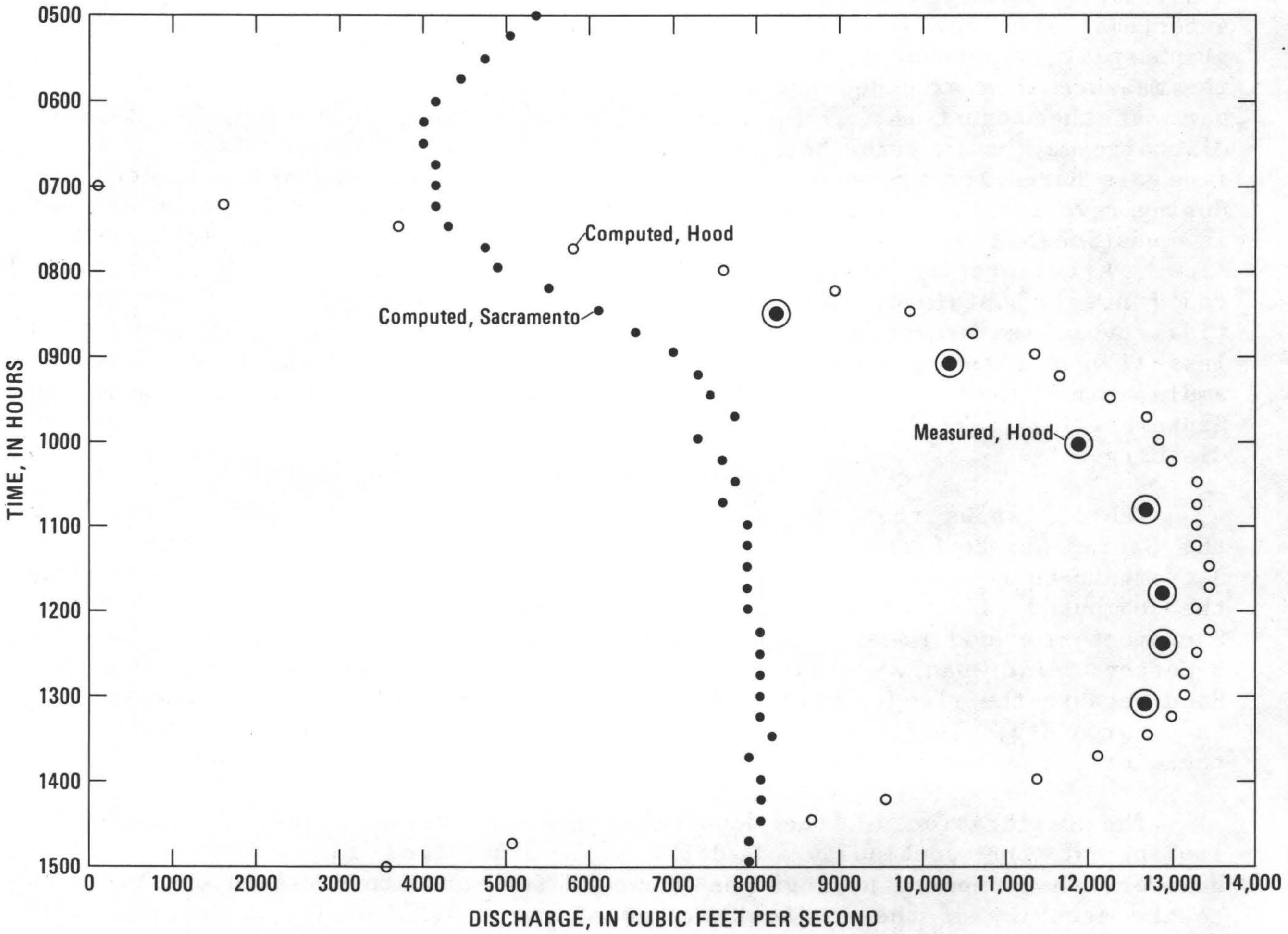

FIGURE 6.--Computed and measured discharge of the Sacramento River at Hood and computed discharge at Sacramento, September 15, 1977.

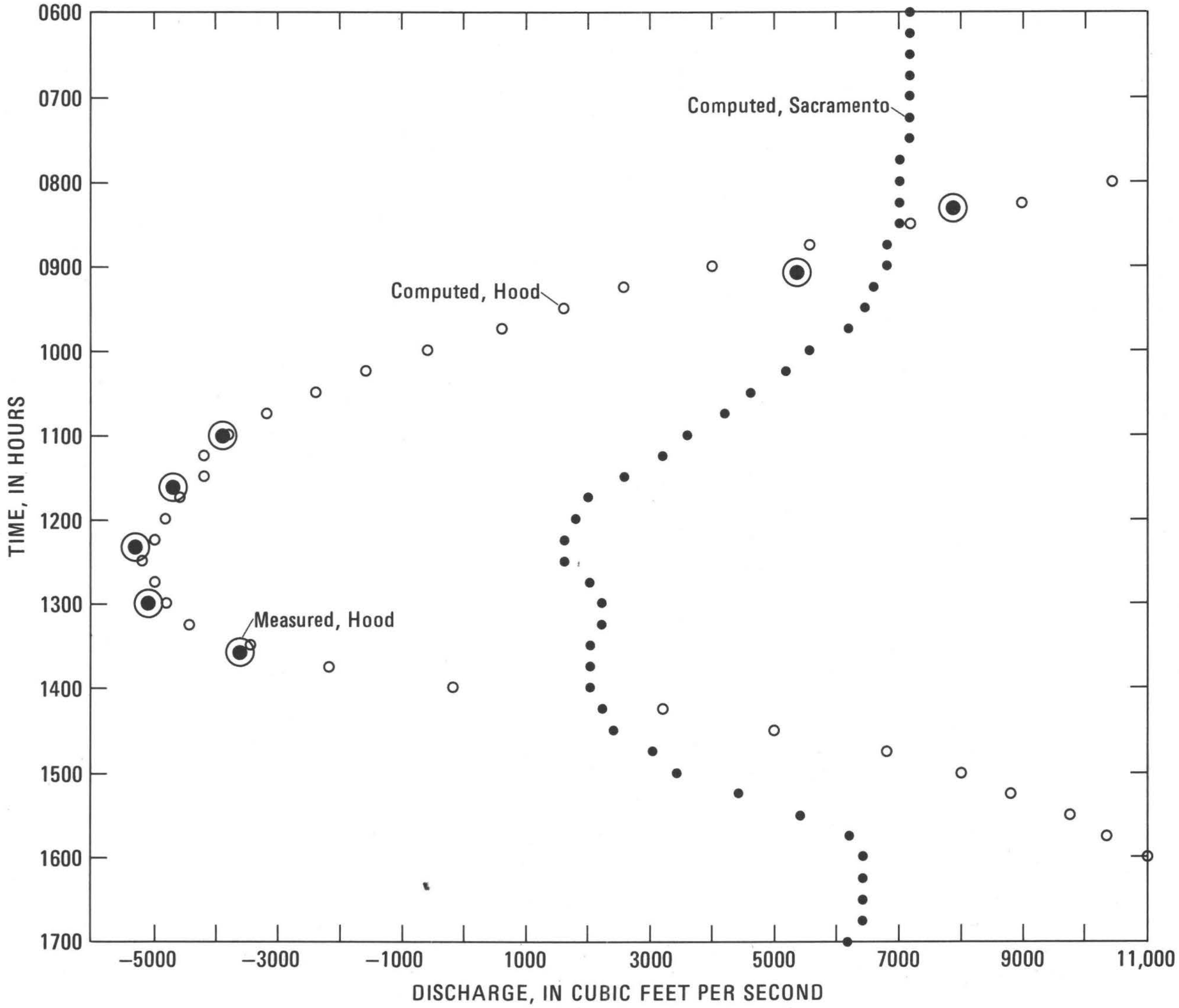

FIGURE 7.--Computed and measured discharge of the Sacramento River at Hood and computed discharge at Sacramento, October 20, 1977.

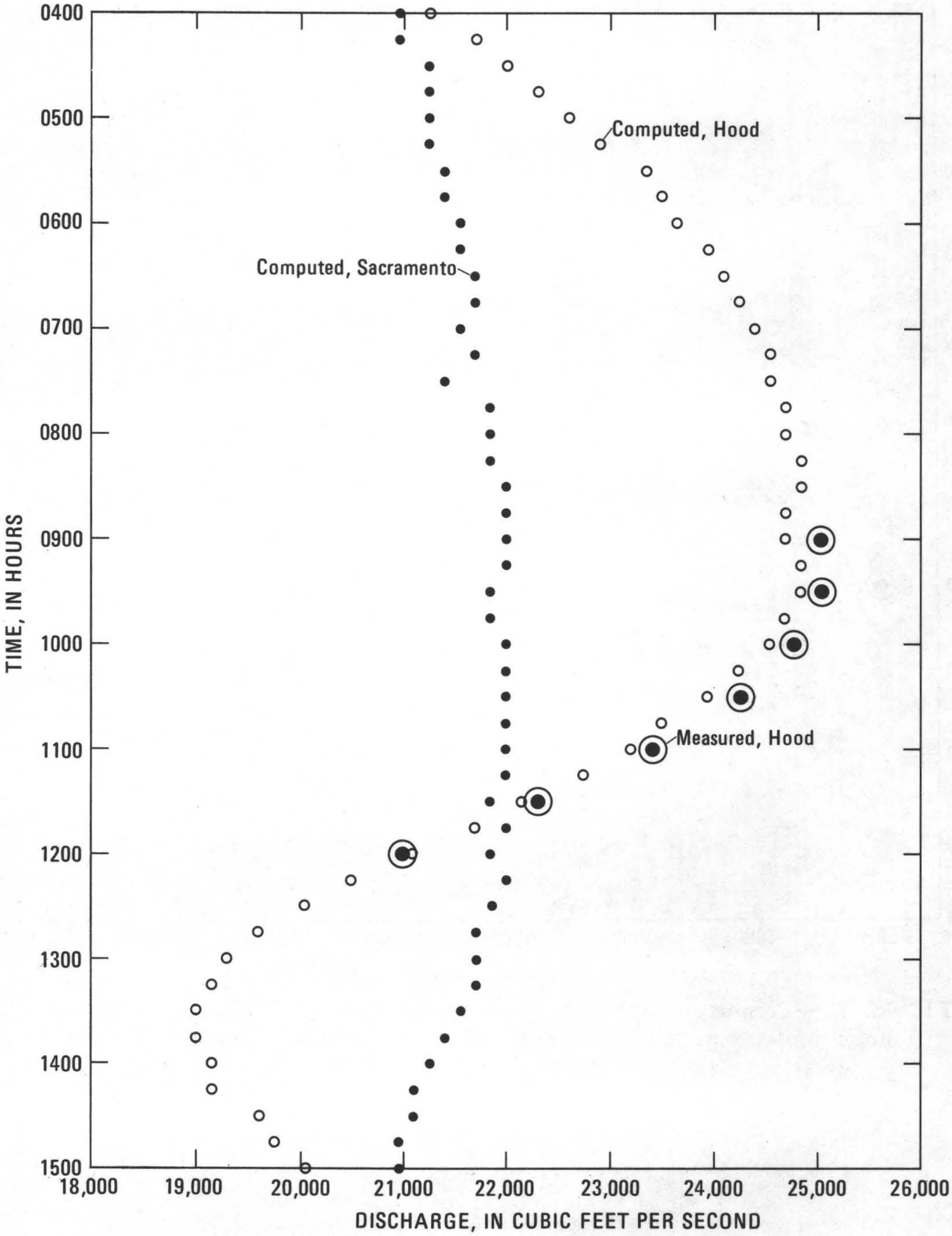

FIGURE 8.--Computed and measured discharge of the Sacramento River at Hood and computed discharge at Sacramento, May 18, 1978.

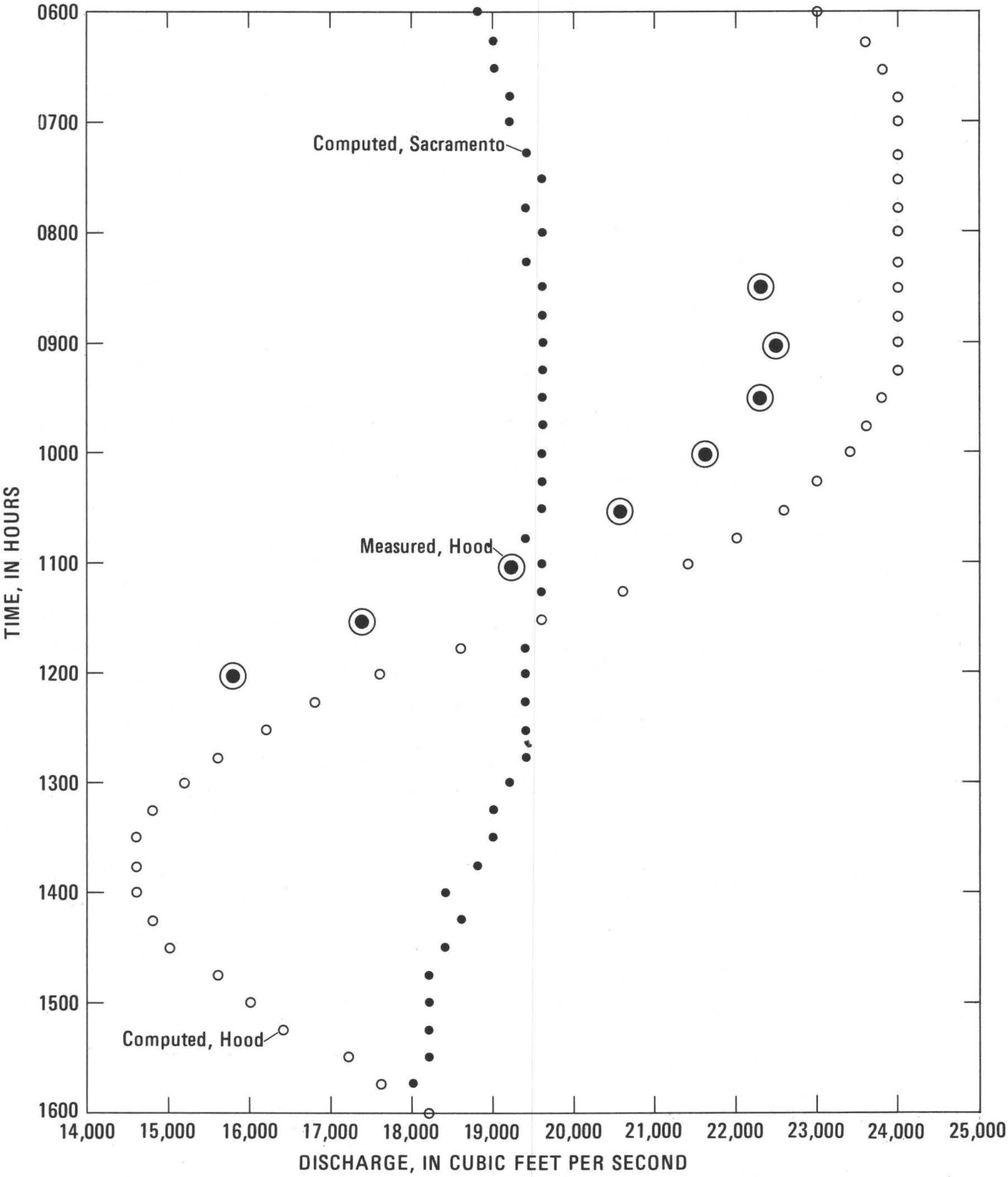

FIGURE 9.--Computed and measured discharge of the Sacramento River at Hood and computed discharge at Sacramento, August 14, 1978.

Because discharge is continually changing, the accuracy of transient-flow measurements depends on the amount of time it takes to complete a discharge measurement. Therefore, the interruption of dropping the cable during a measurement to allow passage of a boat can affect the accuracy of the measurement. The more rapidly the flow is changing, the more critical is the measuring time. For example, the accuracy of a measurement at Hood starting at 1400 hours (fig. 2), when the flow was about 11,000 ft^3/s, and ending 1 hour later, when the flow was about 4,000 ft^3/s, would be questionable. In order to reduce the time factor, two measuring boats are attached to the suspended cable at Sacramento to measure highly transient flows.

Measuring the flow of the Sacramento River at Hood presented problems that required modifying established measuring techniques. Hood, located downstream from Sacramento and, therefore, closer to the ocean, experiences greater tide effect and more rapidly changing flow than Sacramento (fig. 2). Thus, the amount of time it takes to make a discharge measurement is critical. There were no cable suspension facilities at Hood for making discharge measurements, so a standard boat-measurement cable was suspended across the river approximately 3 ft above the water surface. In order to decrease the measuring time, two boats were attached to the cable. Heavy boat traffic required frequent drops and subsequent resuspension of the cable during many of the measurements. The presence of the low cable also constituted a serious navigational hazard. After making two sets of measurements, the low cable was replaced with 10 buoys. The locations of these buoys within the measuring section was determined by analyzing the distribution of flow as defined by the two sets of cable measurements. Each of the previous cable measurements consisted of 24 subsection discharges computed by using the standard 0.2/0.8-depth velocity readings. Many of these cable measurements were recomputed, using only the velocity readings at the 10 buoy locations. The recomputed discharges were within ±1 percent of the original cable measurements.

The measurements using buoys consisted of taking the depth and 0.2/0.8-depth velocity readings over a period of time at each buoy, using three roving measuring boats. For each visit to a buoy, a minimum of two 0.2/0.8-depth velocity readings were taken. With the buoy locations at centroids, subsection discharges were computed and plotted versus time to construct a subsection hydrograph (fig. 10). The two subsection hydrographs in figure 10 are examples of the maximum and minimum scatter conditions that were obtained from the two measurements that were made at Hood. The scatter in the subsection discharge points probably indicates pulsating flow because of eddies and turbulence caused by sand dunes on the riverbed.

The instantaneous discharge for the river at a given time within the measuring period was determined by summing the 10 subsection discharges obtained from the hydrographs. The measured data points shown in figures 8 and 9 were computed in this manner. The buoy approach eliminated the hazard of the cable and the probable measurement error because of the greater time necessary to complete a conventional measurement.

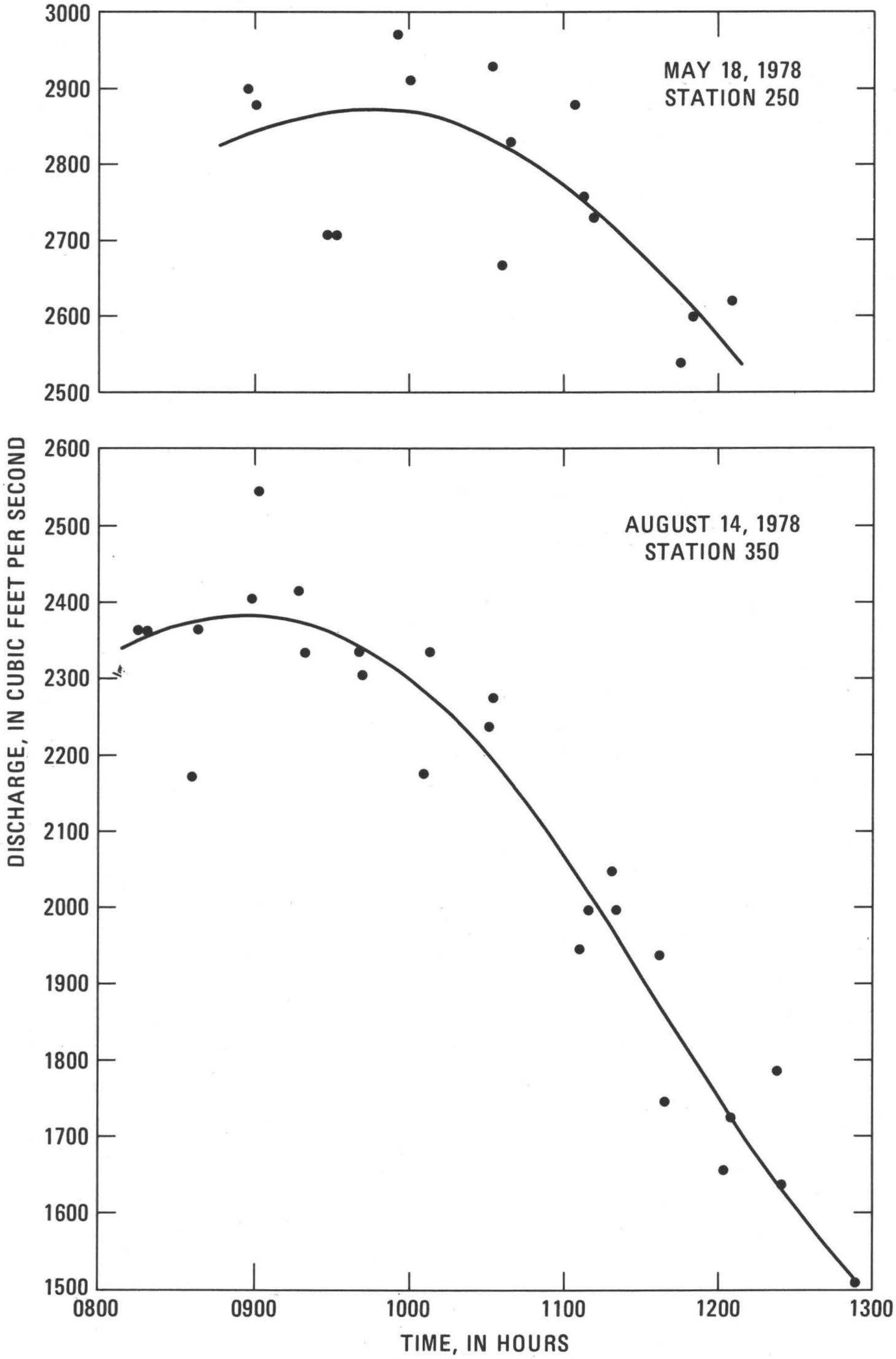

FIGURE 10.--Subsection discharge hydrographs, Sacramento River at Hood.

In addition to the time factor when measuring transient flows, there are also problems of wind and boat traffic. Wind has two effects upon the accuracy of the measurement. Because the measurements are made from a boat that is connected by ropes to the suspended cable, the boat tends to yaw during windy conditions, adding an erroneous longitudinal velocity vector to the desired stream velocity vector. Wind also causes waves, as does boat traffic, which creates a vertical motion of the boat that adds an erroneous vertical velocity vector to the desired stream velocity vector. A study by Kallio (1966) indicated that vertical motion of 0.4 ft/s when attempting to measure a stream velocity of 0.5 ft/s with a Price[1] velocity meter can result in a +10 percent error in recorded velocity. The effects of these two erroneous velocity vectors increase as the stream velocity decreases.

A set of low-flow measurements (fig. 11) made April 13, 1977, showed that as flow decreased, the difference between measured discharge and computed discharge increased. Wind conditions on that day were not favorable and were considered to be one of the factors causing the difference. Wind velocity, recorded 4.5 mi south of Sacramento, was 15 mi/h at 1300 hours on April 13, 1977. It was later discovered that the model's computed output could also be affected by wind; thus, another possible cause for the difference. The effect of wind on the model will be discussed in the next section. The possibility that the model was not calibrated for low flows in this range was eliminated by comparing the model's output with a set of low-flow measurements made under ideal weather conditions (fig. 12). Another set of measurements which verify the model's calibration within this range is shown in figure 4.

In 1977, reverse flow of the Sacramento River was observed at Sacramento. No attempt to measure the magnitude of reverse flow was made, as the velocity was less than 0.2-0.3 ft/s. Reverse flow was measured, however, at Hood (fig. 8). The Price velocity meters were observed to slowly oscillate ±10° from the normal direction of flow at a depth of about 3 ft. Because the direction of flow at greater depths could not be determined with the available equipment, the velocities at 0.8-depth settings were assumed to be normal to the measuring cross section. The accuracy of the reverse-flow measurements is, therefore, questionable.

---

[1]The use of a brand name in this report is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.

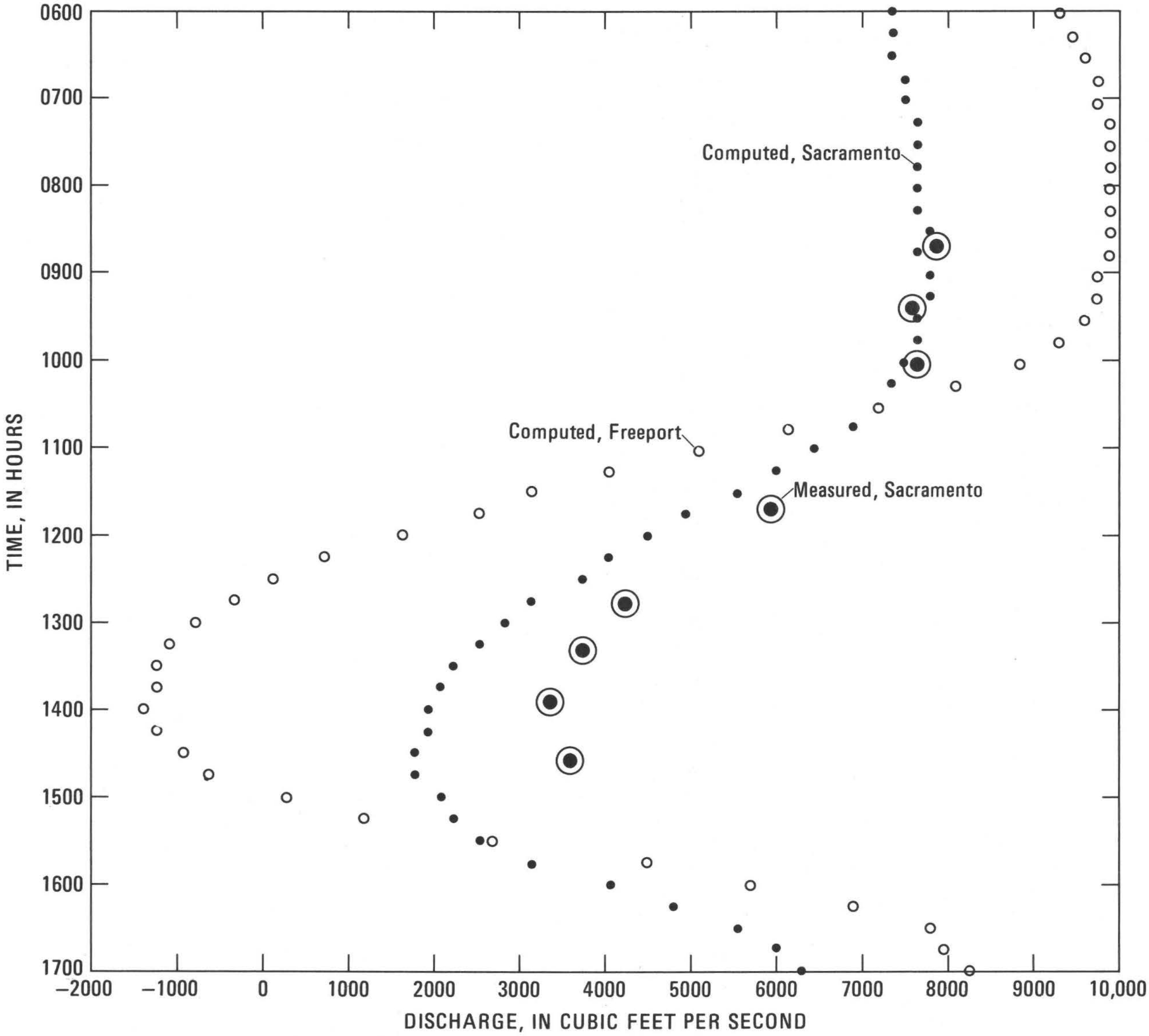

FIGURE 11.--Computed and measured discharge of the Sacramento River at Sacramento and computed discharge at Freeport during period of adverse conditions (windy), April 13, 1977.

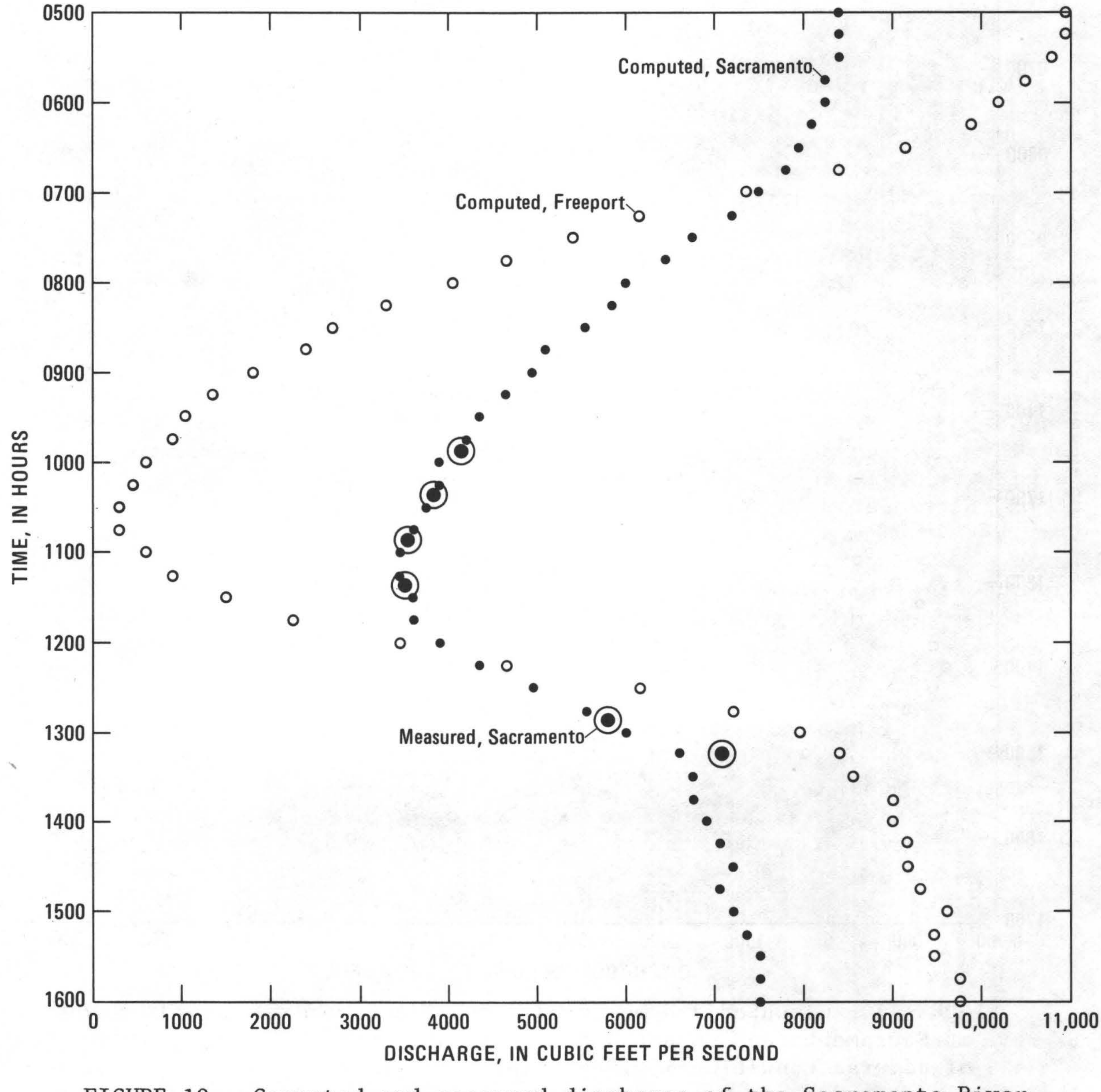

FIGURE 12.--Computed and measured discharge of the Sacramento River at Sacramento and computed discharge at Freeport during period of nearly ideal conditions, November 16, 1977.

Effects of Wind upon the Model's Output

Wind was found to affect the accuracy of the model's results during extreme low-flow conditions. This became evident when the Sacramento-to-Freeport model's daily mean discharges for the months of March and April 1977 were compared with wind data and the summation of corresponding daily mean discharges at Sacramento River at Verona (station 11425500), 19.6 mi upstream of the Sacramento station (fig. 1), and the American River at Fair Oaks (station 11446500), 22.8 mi upstream from the Sacramento station. The Fair Oaks gage is on the only tributary between the Sacramento and Verona stations. During periods of strong winds, the daily mean discharge hydrograph computed by the model showed less discharge (maximum error about 20 percent) when compared to the summation hydrograph. Wind velocities during these periods averaged about 15 to 20 mi/h; the corresponding daily mean discharges were about 5,200 to 6,500 ft^3/s. When the flow is very low, as the flow was during these months, a 0.01-foot error in defining the hydraulic gradient can produce large percentage errors in computed discharge. Because exposure to the wind of the Sacramento and Freeport stations differs by about 90°, it is believed that the wind may cause water to pile up at one station and not the other. During "pile-up," a gage does not record the actual cross-sectional water-surface elevation for the river at that point and, therefore, does not define the actual hydraulic gradient that is driving the flow past the gage.

It was felt that the extension of the model to Hood would improve the low-flow output of the model because exposure to the wind at the Sacramento and Hood gages was almost identical. Figure 13 shows, however, that the Sacramento-to-Hood model produced nearly the same results as the Sacramento-to-Freeport model. This implies either that only the recorded stage at the Sacramento station is affected or that the models are not affected. If the models were not affected, the difference between the computed and measured discharge would be caused by the wind effect upon the measurements. The difference, however, is too large to be totally attributed to measurement error. The author believes that the difference is a combination of the two wind effects.

There is no provision within the model to account for wind effects. Because the combination of extreme low flows and high winds seldom occurs, modification of the model is not warranted. Future plans, however, include installation of an anemometer at the Freeport station in an attempt to learn more about the effects of the wind upon the model.

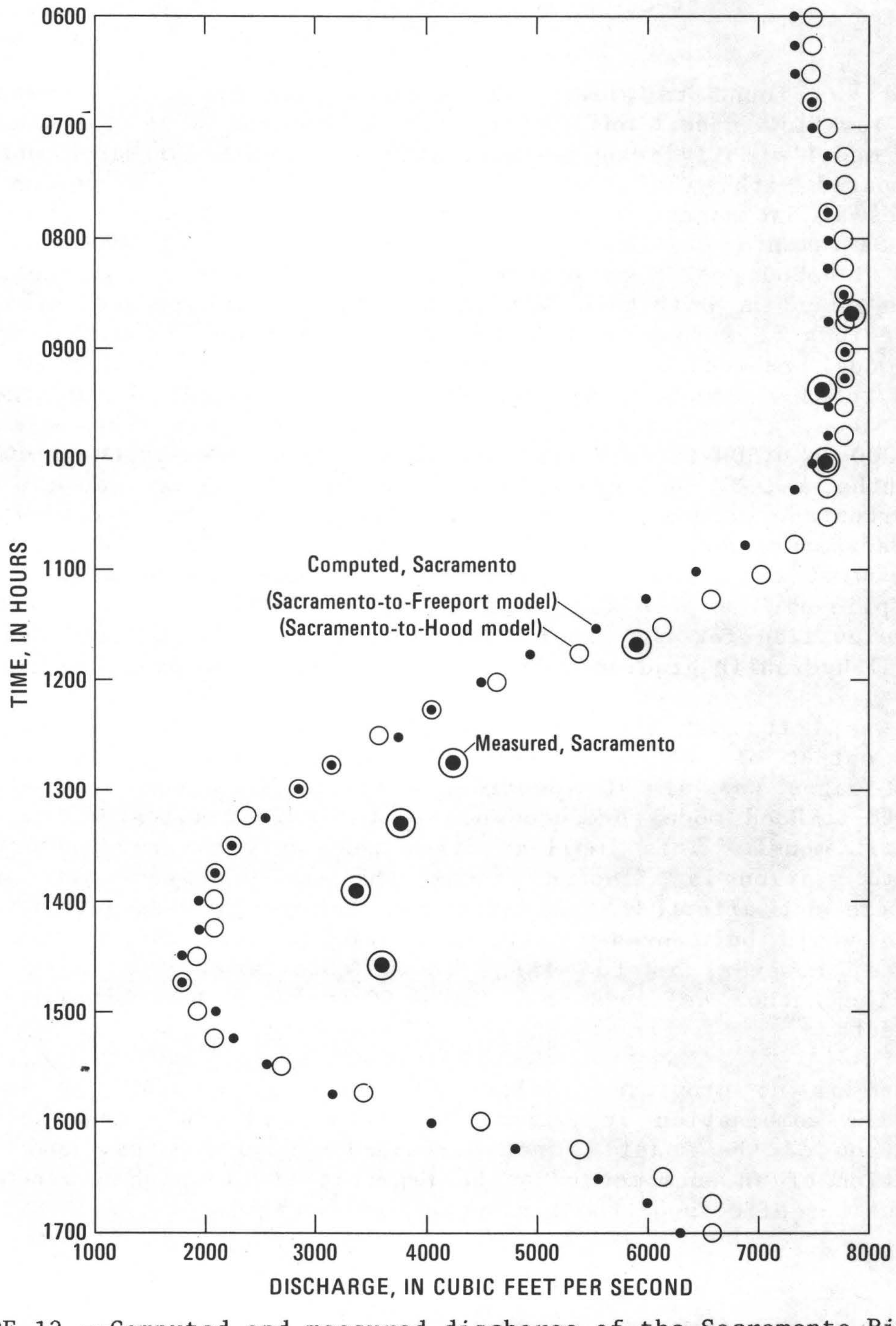

FIGURE 13.--Computed and measured discharge of the Sacramento River at Sacramento during period of adverse conditions (windy), April 13, 1977.

SUMMARY

The Sacramento-to-Freeport model was extended 10.5 mi downstream to Hood to improve the model's output of low flows at the upstream end of the reach and to provide flow-characteristics data for sites farther downstream from Freeport. The extension, however, did not improve the accuracy of the computed low flows. Errors in measured river stage, which define the hydraulic gradient for the reach, were considered the probable cause for error in the model's output of low flows. It was believed that extending the model would correct the problem because a more accurate river slope could be determined over a longer reach. The extended model results, however, were similar when compared to the Sacramento-to-Freeport model results.

The error in the two models' output of low flows was determined to be related to wind. The wind affected the accuracy of the discharge measurements and the models' computed low flows. The model has no provisions for wind; however, the combination of extreme low flows and high winds seldom occurs. Investigation into the effects of wind will continue.

The calibration of the extended model at the downstream end of the model reach is not considered as good as the calibration of the upstream end because only a limited number of discharge measurements were made and used for calibration of the downstream end. In addition, the accuracy of the discharge measurements is questionable. With the possible refinement of discharge-measuring techniques and the collection of additional tidal cycle measurement data, the accuracy of the extended model should be improved.

REFERENCES CITED

Kallio, N. A., 1966, Effect of vertical motion on current meters: U.S. Geological Survey Water-Supply Paper 1869-B, p. B7-B9.

Lai, Chintu, 1967, Computation of transient flows in rivers and estuaries by the multiple-reach method of characteristics: U.S. Geological Survey Professional Paper 575-D, p. D273-D280.

Lai, Chintu, and Onions, C. A., 1976, Computations of unsteady flows in rivers and estuaries by the method of characteristics: U.S. Geological Survey Computer Contr., 202 p., available only from U.S. Department of Commerce, Natlional Technical Information Service, Springfield, Va., 22151, as report PB-253 785/AS.

Oltmann, R. N., 1979, Application of transient-flow model to the Sacramento River at Sacramento, California: Menlo Park, Calif., U.S. Geological Survey Water-Resources Investigations 78-119, 23 p.

GPO 689-143