GRAPHICAL METHOD FOR ESTIMATING OCCURRENCE AND DURATION OF A CRITICAL LOW FLOW IN THE SACRAMENTO RIVER AT FREEPORT, CALIFORNIA

By Jerry G. Harmon

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 82-4001

Prepared in cooperation with

SACRAMENTO COUNTY

DEPARTMENT OF PUBLIC WORKS

May 1983

UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information,
write to:

District Chief
Water Resources Division
U.S. Geological Survey
2800 Cottage Way, Room W-2235
Sacramento, Calif. 95825

Copies of this report can be purchased
from:

Open-File Services Section
Western Distribution Branch
U.S. Geological Survey
Box 25425, Federal Center
Denver, Colo. 80225
Telephone: 303 234-5888

CONTENTS

ILLUSTRATIONS

TABLE

CONVERSION FACTORS

The inch-pound system of units is used in this report. For readers who prefer to use metric 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^3/s (cubic feet per second)	0.02832	m^3/s (cubic meters per second)
mi (miles)	1.609	km (kilometers)
mi/h (miles per hour)	1.609	km/h (kilometers per hour)
mi^2 (square miles)	2.590	km^2 (square kilometers)
Mgal/d (million gallons per day)	3785	m^3/d (cubic meters per day)

GRAPHICAL METHOD FOR ESTIMATING OCCURRENCE AND DURATION OF A CRITICAL LOW FLOW IN THE SACRAMENTO RIVER AT FREEPORT, CALIFORNIA

By Jerry G. Harmon

ABSTRACT

Sacramento County expected to begin operation of the Sacramento Regional Wastewater Treatment Plant in 1982. The California State Water Resources Control Board has ruled that the plant will not be allowed to release effluent into the Sacramento River when flow in the river is 4,000 cubic feet per second or less. Depending on tide condition, flows less than 4,000 cubic feet per second may occur either once or twice during each 24-hour 50-minute tide cycle when the daily mean flow is less than about 12,000 cubic feet per second. Daily mean flows less than 12,000 cubic feet per second occur about 28 percent of the time. Riverflow at the plant outfall is monitored by an acoustic streamflow-measuring system. Regulation of effluent released from the plant will normally be based on real-time flow data computed by the acoustic system. A graphical method for determining the occurrence and duration of flows of 4,000 cubic feet per second and less was developed as a backup system to be used if a temporary failure in the acoustic system occurs.

INTRODUCTION

Sacramento County expected to begin operation of the Sacramento Regional Wastewater Treatment Plant in 1982. Effluent from the plant will be released into the Sacramento River at Freeport, Calif. (fig. 1). The California State Water Resources Control Board has ruled that the plant will not be allowed to release effluent into the river when flow in the river is 4,000 ft^3/s or less.

Flow in the Sacramento River at Freeport is affected by tides when the flow is less than about 45,000 ft^3/s. Depending on tide condition, flows at Freeport can be less than 4,000 ft^3/s during one or two periods per day when the daily mean flow is less than about 12,000 ft^3/s. Based on the flow-duration curve (fig. 2) for the Sacramento River at Sacramento (1949-79), flows less than 12,000 ft^3/s occur about 28 percent of the time (daily mean flow of the Sacramento River at Freeport is considered equivalent to that of the Sacramento River at Sacramento, 10.8 miles upstream).

The Sacramento River at Freeport has a drainage area of 23,510 mi^2. Mean annual flow, based on 31 years of record at Sacramento, is 23,590 ft^3/s.

Flow in the Sacramento River at the plant outfall has been monitored on a real-time[1] basis since 1978 by an acoustic streamflow-measuring system installed by Sacramento County. The county will use data from the acoustic system to regulate effluent release from the plant. Because failure or malfunction in the acoustic system eliminates real-time flow data at the plant, a backup system is needed to prevent possible effluent-release violations. In October 1980, the U.S. Geological Survey, in cooperation with the Sacramento County Department of Public Works, began a study to develop an independent method to determine when flow at the plant outfall is 4,000 ft^3/s or less. Three methods were considered: (1) Installation of another acoustic streamflow-measuring system, (2) conversion of the Sacramento-to-Hood transient-flow model (Oltmann, 1980) to a real-time system, and (3) development of a graphical method. The graphical method was chosen because it was considered the most practical. This report describes the development, verification, and application of the graphical method.

---

[1]For the purpose of this report, real-time system is defined as a system which can produce the present streamflow value when the system is interrogated.

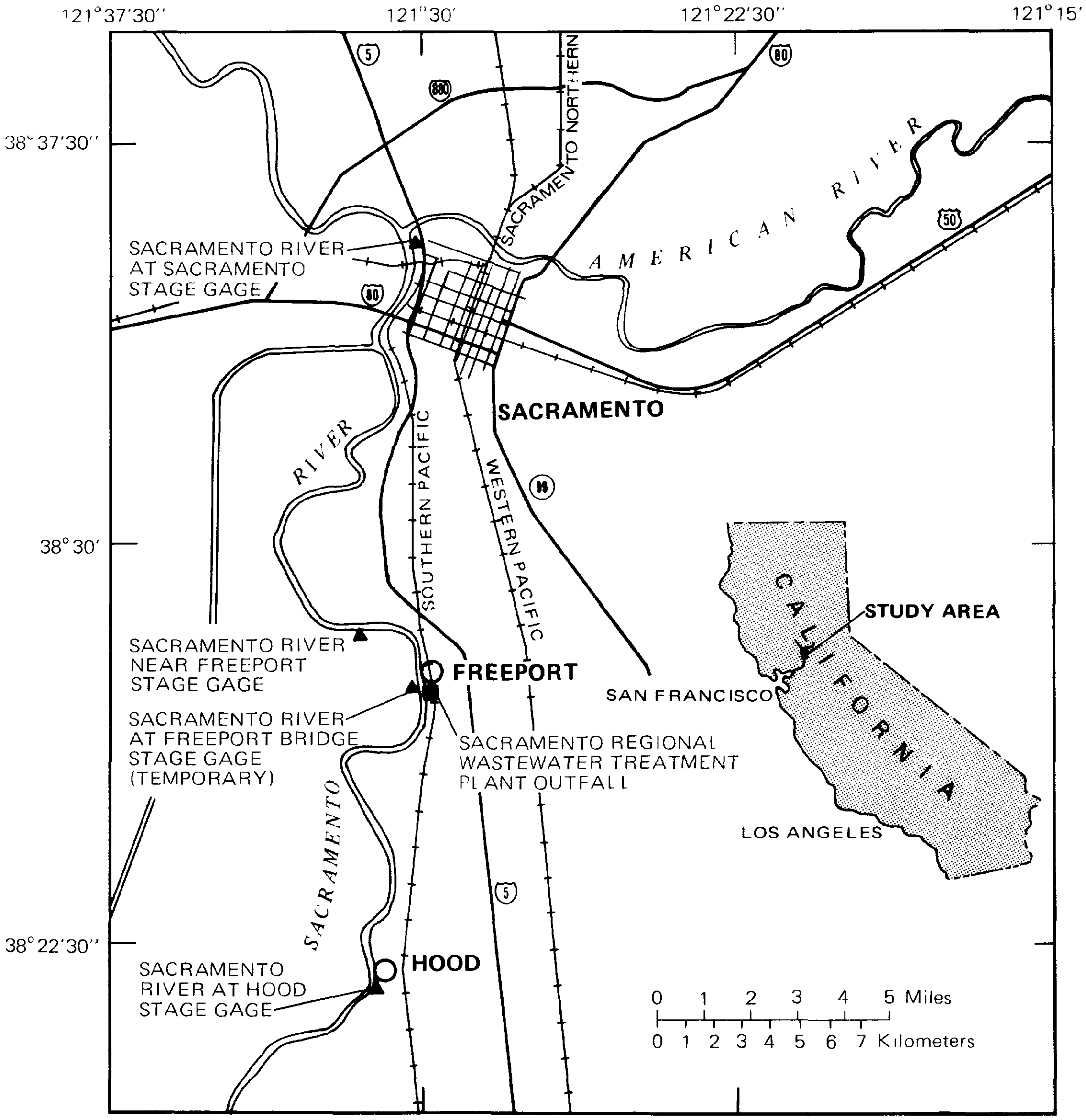


FIGURE 1.--Sacramento River study area.

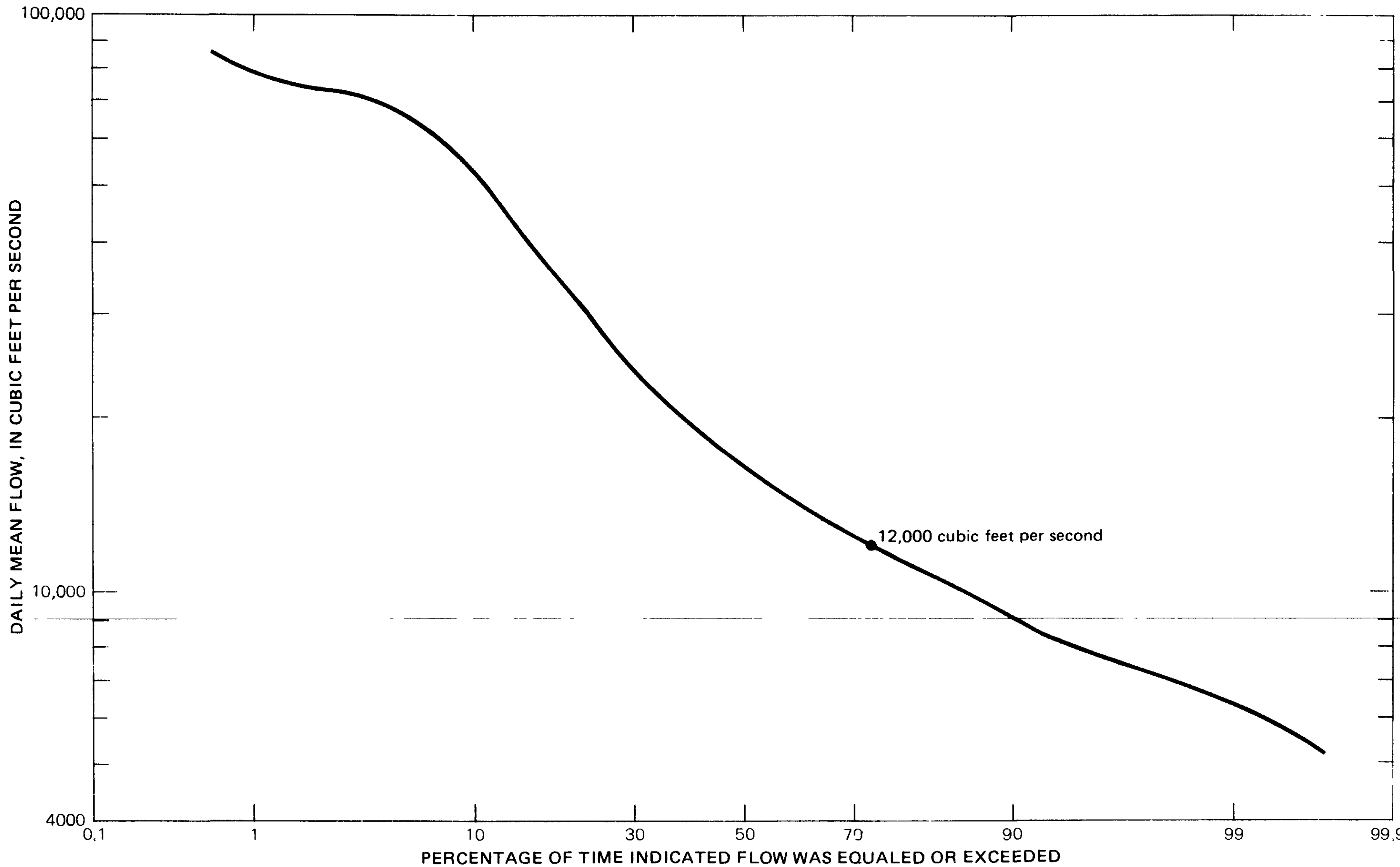


FIGURE 2.--Flow-duration curve for the Sacramento River at Sacramento, 1949-79.

ACOUSTIC STREAMFLOW-MEASURING SYSTEM

Because low flows in the Sacramento River at Freeport are affected by tides, a real-time monitoring system is required to determine when flows are 4,000 ft^3/s or less. In 1978 an acoustic streamflow-measuring system was installed at the Sacramento Regional Wastewater Treatment Plant outfall. Acoustic streamflow-measuring systems have been operated successfully at other sites (Smith and others, 1971). The acoustic system at Freeport was calibrated using current-meter measurements made by the Geological Survey. Periodic current-meter measurements continue to be made to verify the flows computed by the acoustic system.

Flows computed by the acoustic system at Freeport are transmitted to teletype machines in the treatment plant and in the Sacramento office of the Geological Survey. The teletype machines print date, time, stage, velocity, and flow at preselected intervals. Intervals of 10 minutes are usually used during periods of low flow. Daily mean flow is printed at the end of each day.

SOURCES OF DATA USED TO DEVELOP THE GRAPHICAL METHOD

Continual stage and flow data for low-flow periods at Freeport were required to develop the graphical method to predict the occurrence and duration of flows of 4,000 ft^3/s and less. The acoustic streamflow-measuring system at Freeport had not been in operation long enough to provide sufficient data to develop the graphical method; however, data from other sources were available. During the drought of 1976-77, the Geological Survey recorded river stage at Freeport, Sacramento, and Hood. Flows at Freeport for the drought period were computed by the transient-flow model described by Oltmann (1980). Stage data recorded at Sacramento and Hood are required to operate the transient-flow model. Flow data computed by the acoustic streamflow-measuring system and by the transient-flow model are nearly equivalent because both are calibrated to the same current-meter measurements. Because the accuracy of stage data recorded on windy days is questionable, stage and model-computed flow data were not used if the daily mean wind velocity was greater than 10 mi/h or if the maximum hourly wind velocity for the day was greater than 15 mi/h.

DEVELOPMENT OF THE GRAPHICAL METHOD

Method to Estimate Duration of a Critical Low Flow

A graph to estimate the duration of periods of flow of 4,000 ft^3/s or less was developed using stage and flow data for the Sacramento River at Freeport. Duration of the critical low-flow period depends on magnitude of daily mean flow and tide condition (spring tide, neap tide, or a condition between spring tide and neap tide). Depending on tide condition, flow at Freeport may decrease to 4,000 ft^3/s or less once or twice during a 24-hour 50-minute tide cycle when the daily mean flow is less than about 12,000 ft^3/s. The hydrograph through a tide cycle at Freeport includes two stage peaks and two associated flow troughs (fig. 3). Figure 3 shows the following sequence of events as they normally occur during a low-flow cycle: (1) stage trough, (2) flow decreases to 4,000 ft^3/s, (3) flow trough, (4) flow increases to 4,000 ft^3/s at about the time of the (5) stage peak, and (6) flow peak. The stage index for this study is the difference, in feet, from the stage trough to the subsequent stage peak.

The duration graph is based on a relation of stage index and daily mean flow to a time factor. The time factor is the number of 15-minute increments during which the flow was 4,000 ft^3/s or less. The time factor multiplied by 15 minutes is, therefore, the duration of the critical low-flow period.

After the data were plotted, lines establishing boundaries for bands of equal duration were drawn (fig. 4). To complete the graph for its intended use, the plotted data were replaced by printed values of duration in the appropriate bands (fig. 5).

Method to Estimate Occurrence of a Critical Low Flow

The method to estimate when flow in the Sacramento River at Freeport will decrease to 4,000 ft^3/s is based on a correlation of two events. This method assumes that the end of a critical low-flow period (t_2 in fig. 3) coincides with the time of a stage peak (S_2 in fig. 3). Based on 170 occurrences, plotted in figure 6, the end of the critical low-flow period occurs an average of 7 minutes before the subsequent stage peak. On 15 occasions the two events happened at the same time. The two events occurred no more than 15 minutes apart on 98 occasions. Stage peak occurred before flow increased to 4,000 ft^3/s on 65 occasions. Beginning time of a critical low-flow period can therefore be estimated by subtracting the estimated duration of the period from the projected time of a stage peak. The procedure is listed in the section "Application of the Graphical Method."

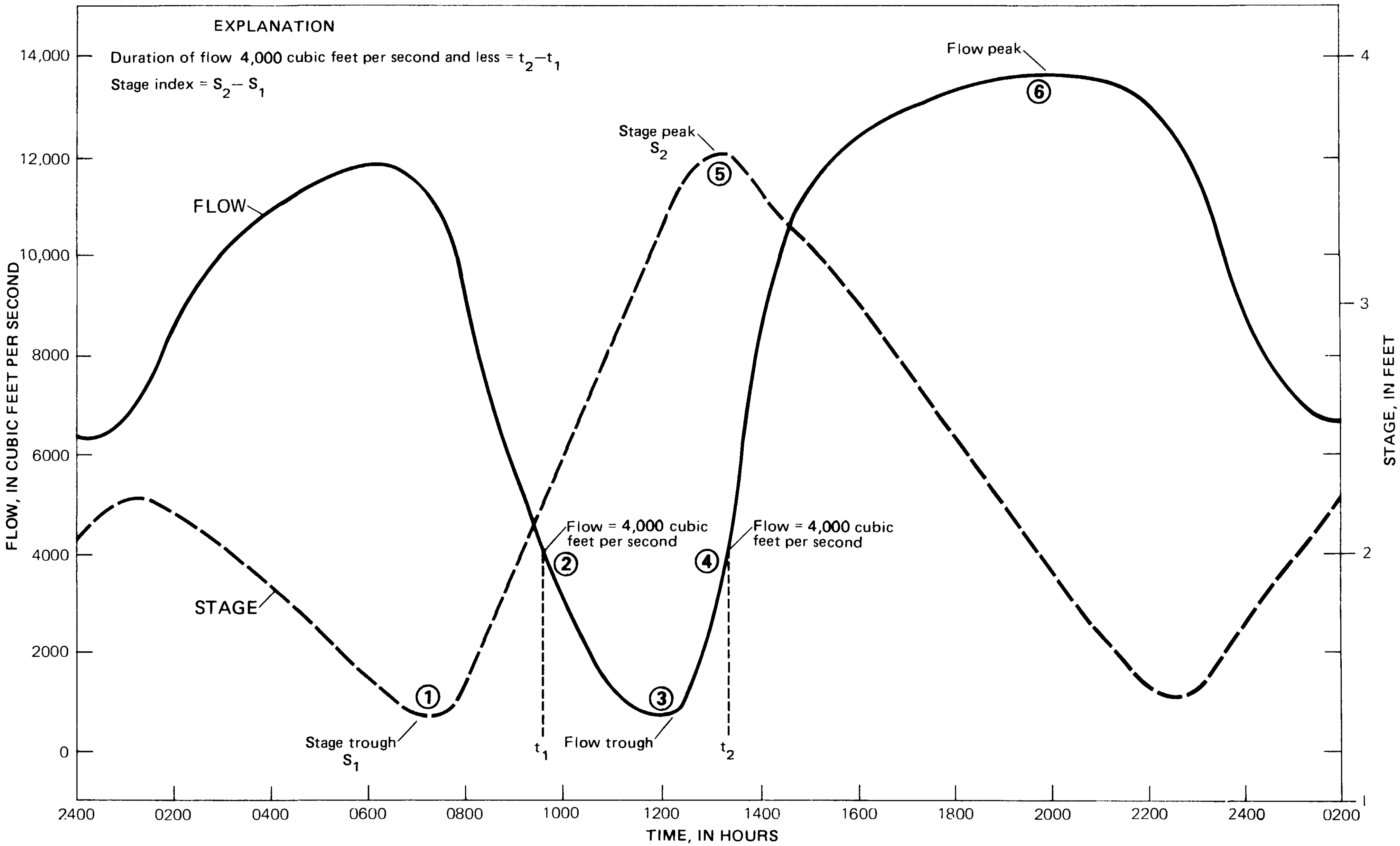
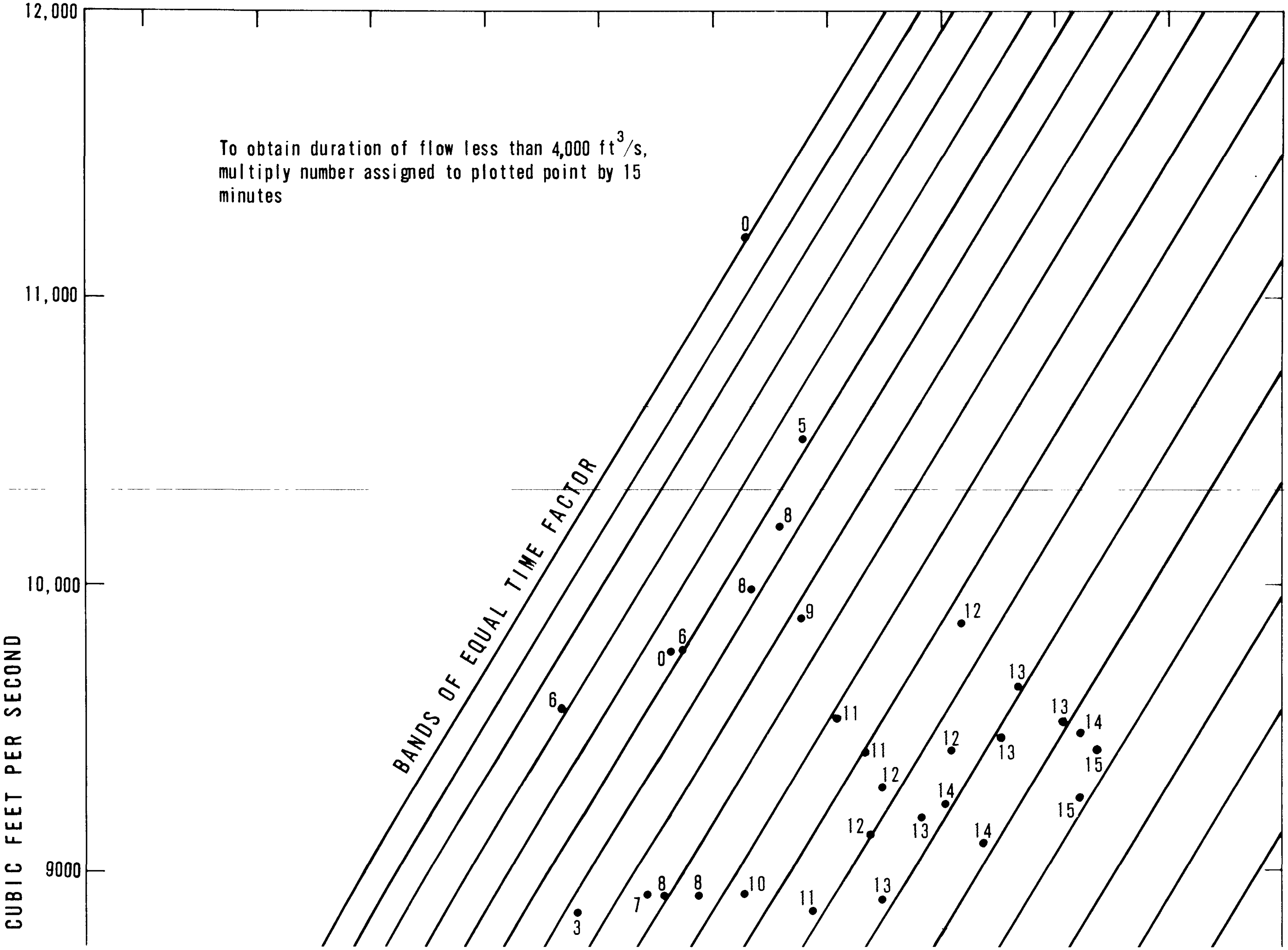


FIGURE 3.--Flow and stage of the Sacramento River at Freeport, January 14, 1977.


12,000
11,000
10,000
9000
CUBIC FEET PER SECOND
To obtain duration of flow less than 4,000 ft³/s, multiply number assigned to plotted point by 15 minutes
BANDS OF EQUAL TIME FACTOR

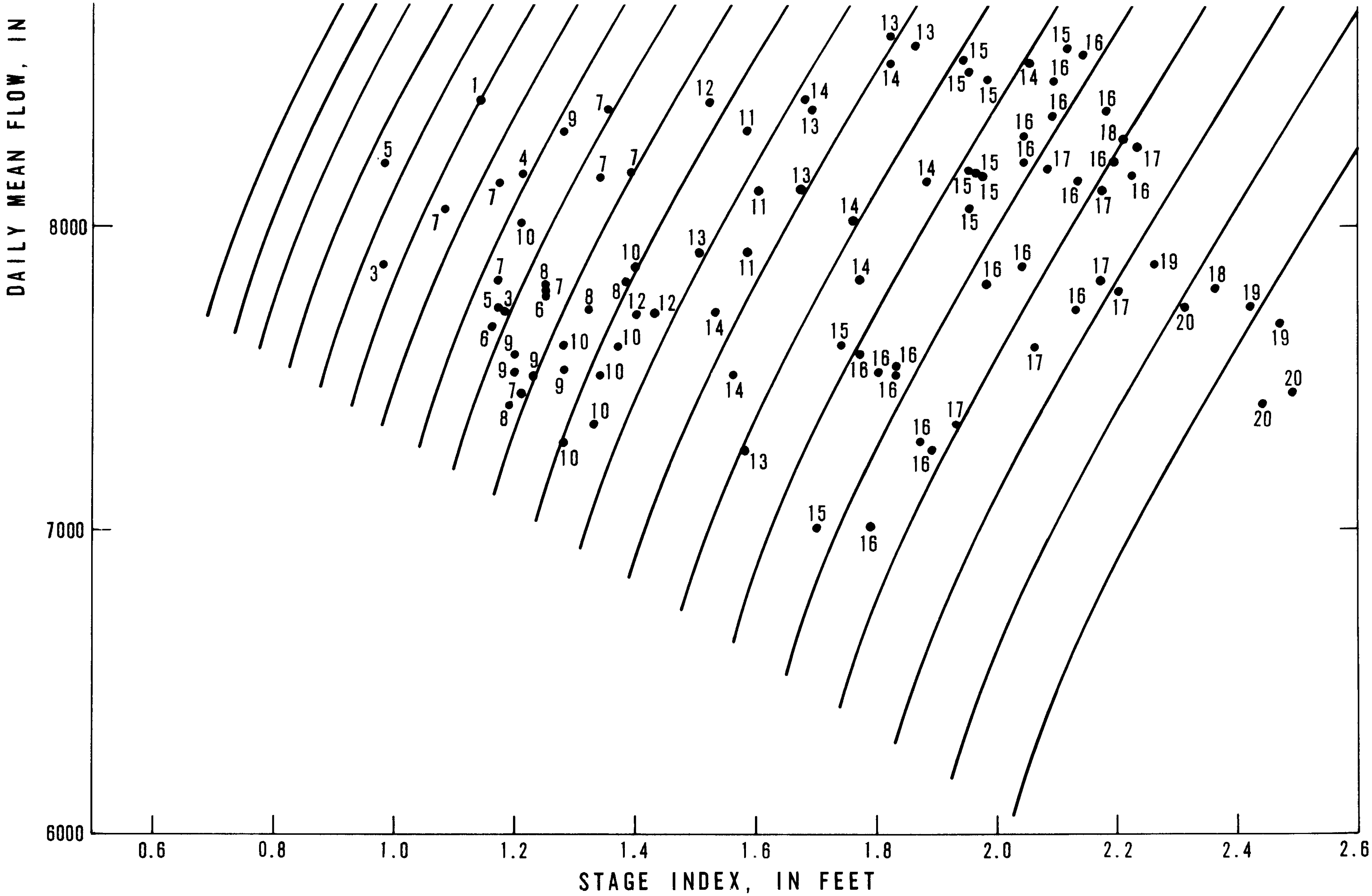
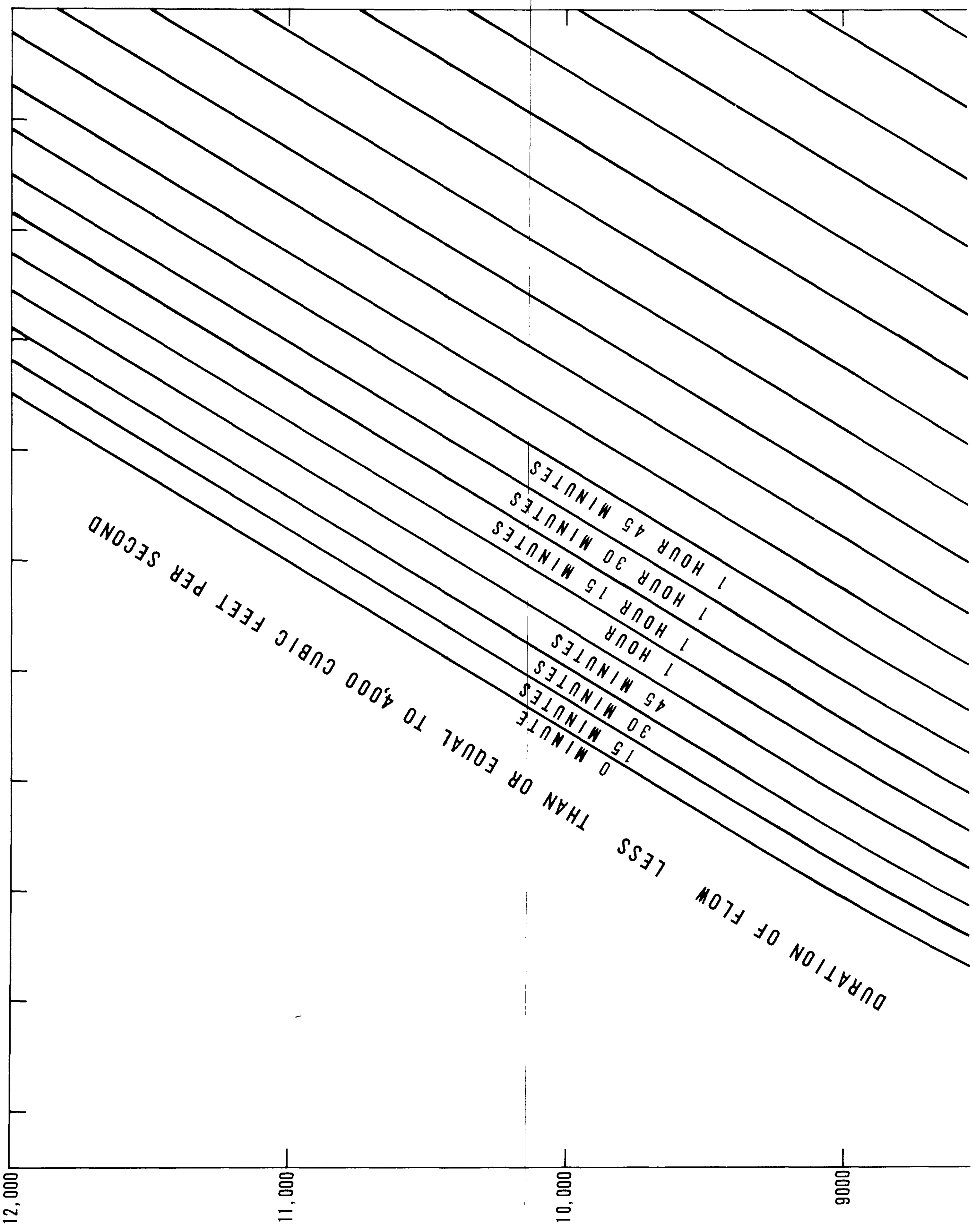


FIGURE 4.--Plotted data used to develop a relation of daily mean flow and stage index to duration of flow equal to and less than 4,000 cubic feet per second, Sacramento River at Freeport.


DURATION OF FLOW LESS THAN OR EQUAL TO 4,000 CUBIC FEET PER SECOND
0 MINUTE
15 MINUTES
30 MINUTES
45 MINUTES
1 HOUR
1 HOUR 15 MINUTES
1 HOUR 30 MINUTES
1 HOUR 45 MINUTES
12,000
11,000
10,000
9000
CUBIC FEET PER SECOND

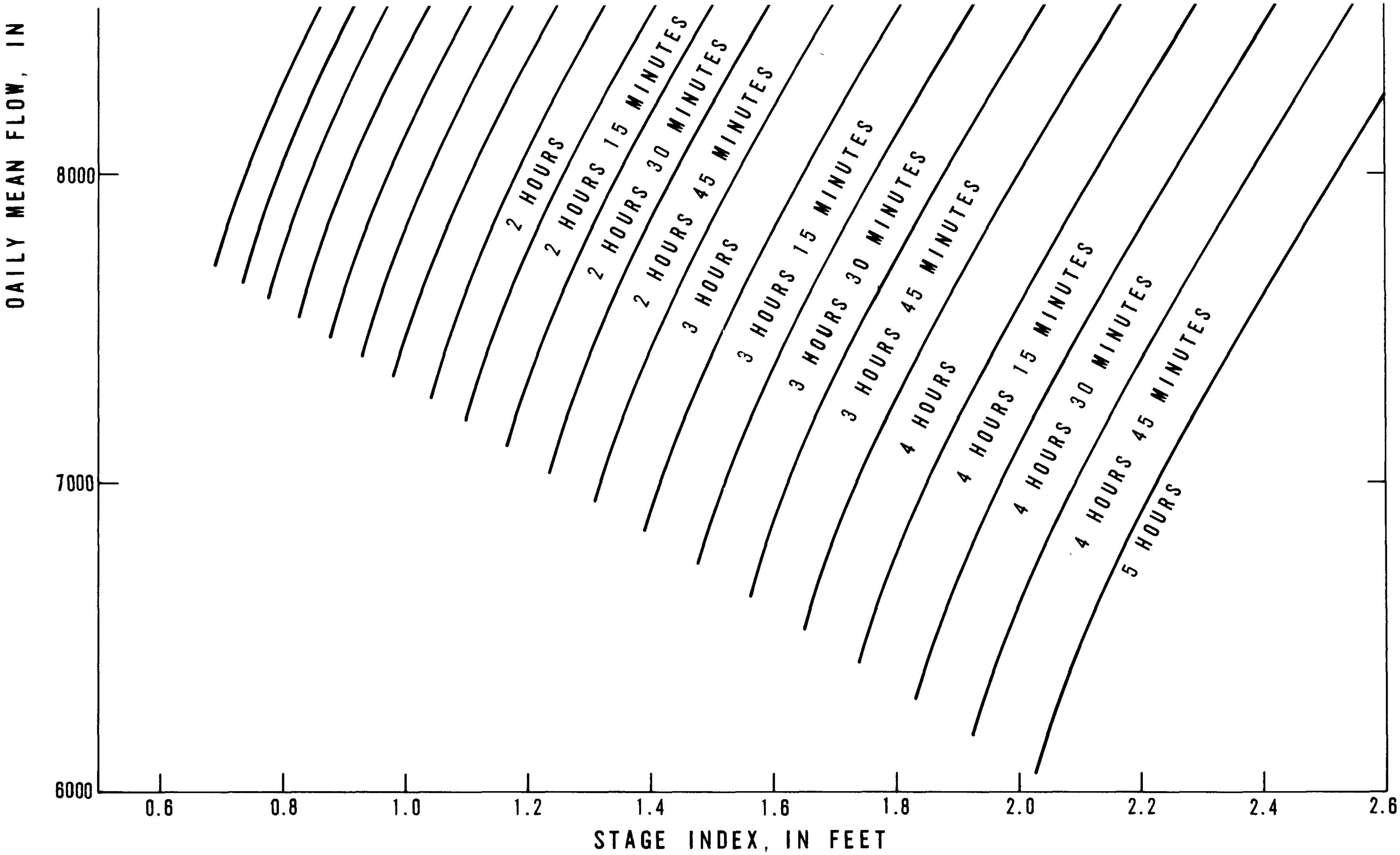


FIGURE 5.--Duration graph for flows equal to and less than 4,000 cubic feet per second, Sacramento River at Freeport.

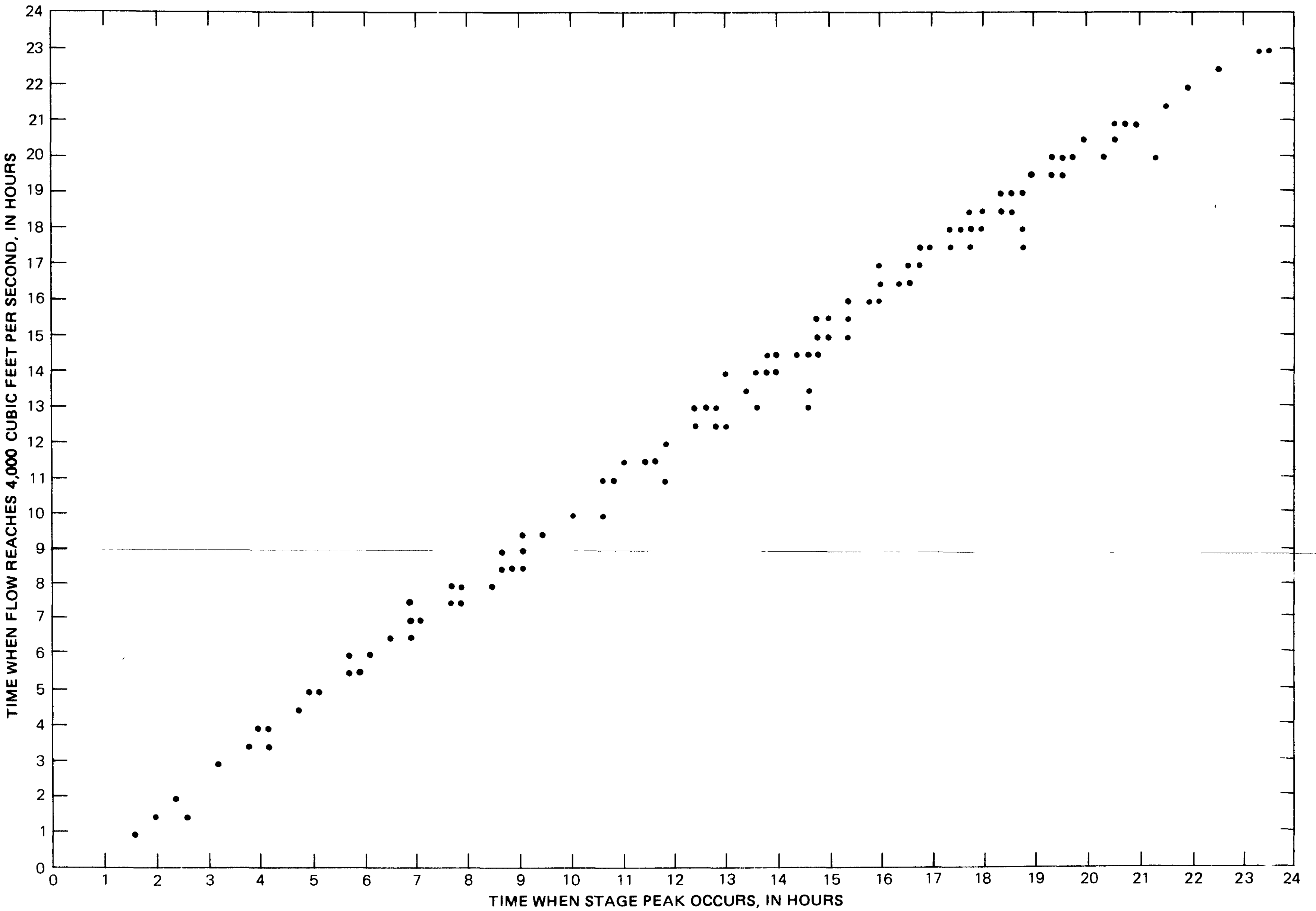


FIGURE 6.--Relation of time when flow reaches 4,000 cubic feet per second to time when stage peak occurs.

VERIFICATION OF THE DURATION GRAPH

Data from low-flow periods in 1980-81 were used to verify the duration graph (fig. 5) developed from 1976-77 data. The 1980-81 flow data for Freeport were computed by the transient-flow model because records from the acoustic streamflow-measuring system were not complete during the 1980-81 low-flow periods. The gage at the Freeport bridge was discontinued in 1977; stage indices for the 1980-81 low-flow periods were computed from stage data recorded 2 miles upstream from Freeport. A plus 0.12-foot stage-index correction was used based on comparison of synchronized stage data recorded at the two sites in 1976-77.

Estimated durations from the graph, based on computed stage indices and daily mean flows, were compared with computed durations in table 1. Of the 49 estimated durations, 29 are less than computed durations, 15 are more than computed durations, and 5 are the same. More than half the estimated durations are within 15 minutes of the computed durations. The average difference is 26 minutes.

APPLICATION OF THE GRAPHICAL METHOD

At Freeport a daily mean flow of 12,000 ft^3/s or less in the Sacramento River indicates the probable occurrence of one or two critical low-flow periods (flow less than 4,000 ft^3/s) during the 24-hour 50-minute tide cycle. Projected values of stage index and daily mean flow are required to use the graph to estimate the duration of a critical low-flow period. Projected time of a stage peak is required to predict the occurrence (time) of a critical low-flow period.

Projected times of stage peaks and projected stage indices are obtained from a Freeport stage recorder operating independently of the acoustic streamflow-measuring system. Projected daily mean flow is available by telephone from the California Department of Water Resources in Sacramento. The projected daily mean flow is based on stage-discharge relations at upstream gages and seasonal consumptive-use factors.

The occurrence and duration of critical low flows are estimated as follows:

Step 1. Project the time of the next stage peak by adding 24 hours 50 minutes to the time of the recorded corresponding stage peak of the previous day. This will be the estimated time of the end of the critical low-flow period.

Step 2. From the corresponding events recorded the previous day, compute the stage index by subtracting trough stage from peak stage as shown in figure 3.

Step 3. Obtain the projected daily mean flow from California Department of Water Resources.

Step 4. Plot stage index and daily mean flow on the duration graph (fig. 5). From the band where the point plots, read the duration.

Step 5. Subtract the duration from the time projected in step 1. The result is the estimated beginning time of the critical low-flow period.

TABLE 1.--*Comparison of computed and estimated durations of flow equal to and less than 4,000 cubic feet per second, Sacramento River at Freeport*

Date		Time, in hours, computed flow decreased to 4,000 ft^3/s	Duration of flow less than 4,000 ft^3/s			
			Computed from transient-flow model		Estimated from figure 5	
			Hours	Minutes	Hours	Minutes
1980						
Oct.	19	1255	2	30	2	
	20	1335	2	15	2	30
	21	0105	2	15	2	30
	21	1330	3		2	45
	22	0150	2	30	2	45
	22	1355	3	30	3	15
	23	0305	2	15	3	
	23	1435	3	15	3	45
	29	1935	2	30	3	
	30	1010	2	30	2	
	30	2115	1	45	2	
	31	1050	3		2	30
	31	2235	1	45	1	15
Nov.	1	1135	3		2	45
1981						
Jan.	15	1105	2	45	2	15
	16	1135	3		3	
	17	1220	3	15	3	
	18	1320	3		3	
Apr.	17	0335	2		1	45
	17	1555	2		0	45
	18	0315	3	15	2	15
	18	1645	1	30	1	45
	19	0130	2	45	1	45
	29	0155	0	45	0	
	30	0200	2		2	15
	30	1440	0	30	0	
June	2	0315	3		2	45
	3	0340	3	15	3	
	4	0425	3	30	3	15
	4	2125	0		1	30
	5	0500	3	45	3	30
	5	2050	2	15	2	30
	6	0610	3	15	2	45
	6	2110	3	15	3	15
	7	0735	2	45	2	
	7	2220	2	30	3	
	11	0035	2	30	2	30
	12	0125	2	15	2	15
	13	0120	2	45	2	
	14	0155	2	15	2	
	15	0235	2	30	2	45
	16	0235	3	15	3	
	17	0300	3	15	2	30
	18	0325	3	45	3	15
	18	1940	1	30	1	45
	19	0350	3	45	3	15
	19	1935	2	45	2	30
	20	0435	3	45	3	15
	20	2040	1	45	2	45

SOURCES OF ERROR

Durations used to develop the duration graph were obtained from printouts of flows computed by the transient-flow model for 15-minute intervals. Because many of the computed flows were close to 4,000 ft^3/s at a 15-minute interval, some interpolation was required. All durations used to develop the graph were calculated to the nearest 15 minutes.

Projected daily mean flow usually differs by less than 4 percent from the daily mean flow computed by the acoustic streamflow-measuring system. The difference is rarely more than 7 percent. When daily mean flows are less than 12,000 ft^3/s, day-to-day changes in the daily mean flows are gradual.

Stage index from the corresponding part of the previous day's tide cycle usually differs from the current stage index by less than 0.2 feet.

Projected time of a stage peak is based on an average tide cycle of 24 hours 50 minutes. From the data used to develop the duration graph, times of corresponding stage peaks were within 10 minutes of the average value 62 percent of the time and within 25 minutes 88 percent of the time.

Accuracy of the relation of a stage peak to the occurrence of the critical low flow was discussed in the section "Development of the Graphical Method."

SUMMARY

In order to comply with State of California regulations, Sacramento County must stop releasing effluent from the Sacramento Regional Wastewater Treatment Plant to the Sacramento River at Freeport when riverflow at the release point is 4,000 ft^3/s or less. Periods of flow less than 4,000 ft^3/s occur during the tide cycle when daily mean flows are less than about 12,000 ft^3/s. Daily mean flows are less than 12,000 ft^3/s about 28 percent of the time. Riverflow is monitored on a real-time basis at the plant outfall by an acoustic streamflow-measuring system. A backup system will be required if a failure in the acoustic system occurs when the daily mean flow is less than 12,000 ft^3/s. A graphical method, independent of the acoustic system, was developed to estimate the occurrence and duration of periods of flow less than 4,000 ft^3/s. A duration graph was developed and verified, using recorded river stage and model-computed flow data. Using the graphical method, estimated duration of periods of flow less than 4,000 ft^3/s is obtained by applying a projected daily mean flow and a projected stage index to the duration graph. The projected time of a stage peak indicates the end of a period of flow less than 4,000 ft^3/s. Subtracting the estimated duration from the projected time of the stage peak gives the predicted beginning time of the period of flow less than 4,000 ft^3/s.

REFERENCES CITED

Oltmann, R. N., 1980, Extension of transient-flow model of the Sacramento River at Sacramento, California: U.S. Geological Survey Water-Resources Investigations 80-30, 29 p.

Smith, Winchell, Hubbard, L. L., and Laenen, Antonius, 1971, The acoustic streamflow-measuring system on the Columbia River at The Dalles, Oregon: U.S. Geological Survey Open-File Report, 60 p.