SIMULATION OF FLOW IN THE LOWER CALCASIEU RIVER FROM THE SALTWATER BARRIER TO BURTON LANDING NEAR MOSS LAKE, LOUISIANA

By George J. Arcement, Jr.

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CONVERSION FACTORS AND ABBREVIATIONS

For the convenience of readers who prefer to use metric (International System) units rather than the inch-pound units used in this report, values may be converted by using the following factors:

Multiply inch-pound units	By	To obtain metric units
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square foot (ft^2)	0.09294	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) as follows: °F = 1.8 X °C + 32.

Sea level: In this report "sea level" refers to the 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 "Sea Level Datum of 1929."

SIMULATION OF FLOW IN THE LOWER CALCASIEU RIVER FROM THE SALTWATER BARRIER TO BURTON LANDING NEAR MOSS LAKE, LOUISIANA

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ABSTRACT

Water movement in the lower Calcasieu River is a function of the configuration of the stream system, freshwater inflow, tidal action, and wind action. Tidal action is the dominant factor in water movement in the river.

The U.S. Geological Survey one-dimensional branch-network surface-water flow model was used to simulate discharge for a 15-mile reach of the lower Calcasieu River from the saltwater barrier at Lake Charles, La., to Burton Landing near Moss Lake. The flow model uses a weighted, four-point, implicit finite-difference approximation for solution of the unsteady flow equations.

The flow model was calibrated using five sets of discharge measurements made at the external boundaries of the study reach; average percent error between observed and simulated discharge for the calibration runs was 13.8 percent. The flow model was verified using three sets of discharge measurements; average percent error for the verification runs was 29.6 percent. The average error for all of the model runs was 25.2 percent. The computed discharge for the model runs ranged from 59,000 to -51,100 cubic feet per second. Computed discharges are very sensitive to changes in the flow-resistance coefficient and to changes in the boundary data.

INTRODUCTION

The lower Calcasieu River is a very important factor in the development of the Lake Charles area and is the major source of water for thermoelectric plants, petrochemical industries, seafood industries, and rice farmers. The river provided 227 Mgal/d (million gallons per day) of surface water in 1985, most of which was for cooling in thermoelectric plants and for rice irrigation (D.L. Lurry, U.S. Geological Survey, written commun., 1985). Consequently, there is considerable interest in the hydraulic characteristics of the lower Calcasieu River, especially by managers and officials who regulate the discharge of effluents.

Purpose and Scope

The purpose of this report is to present information on a method to compute continuous discharge for the lower Calcasieu River from the saltwater barrier to Burton Landing near Moss Lake.

Application of the usual stage-discharge relation for determining discharge from stage data is not appropriate to this study reach because of the effects of tides and wind on the river and the influence of the saltwater barrier above Lake Charles. Therefore, the U.S. Geological Survey one-dimensional branch-network surface-water flow model was tested as a method to compute continuous discharge for this study reach.

Approach

Stage data were recorded from May 1984 to September 1986 for the lower Calcasieu River at the saltwater barrier and Burton Landing near Moss Lake, which are the external boundaries of the study reach. Discharge measurements were made during this period on the lower Calcasieu River at the railroad bridge above Interstate 10 (I-10) and Burton Landing near Moss Lake.

This stage and discharge information, along with other parameters that define the geometry of the stream system, were used to calibrate the U.S. Geological Survey's one-dimensional branch-network surface-water flow model. The flow model computes continuous discharge at several locations within the study reach.

Acknowledgments

This study has been supported by a cooperative agreement between the U.S. Geological Survey and the Louisiana Department of Environmental Quality, Office of Water Resources.

DESCRIPTION OF STUDY AREA

The lower Calcasieu River extends from about 10 mi (miles) north of the city of Lake Charles to about 35 mi south where it enters the Gulf of Mexico. Figure 1 shows this area which covers parts of Calcasieu and Cameron Parishes. The study area for this report is the lower Calcasieu River from the saltwater barrier to below Moss Lake at Burton Landing, about 15 mi downstream (fig. 2). Terrain in the southwestern part of Louisiana consists of almost-level coastal plains. Extensive coastal marshes begin south of Lake Charles and cover much of Cameron Parish. Elevations in the area range from 25 ft (feet) above sea level in Calcasieu Parish to sea level in parts of both parishes.

HYDROLOGIC CONDITIONS

Water movement in the lower Calcasieu River is a function of the configuration of the stream system, freshwater inflow, tidal action, and wind action. The configuration of many of the waterways, particularly the 40-foot deep ship channel, permits water to easily move in or out of the river. Headwater streamflows, which must pass through the saltwater barrier, had a maximum flow at Kinder of 182,000 ft^3/s (cubic feet per second) on May 19, 1953, for the period of record (1938-85), but generally average about 2,500 ft^3/s. Reduced streamflows occur during the period June through November. The minimum streamflow, 136 ft^3/s, was recorded on August 15, 1956 (Carlson and others, 1984).

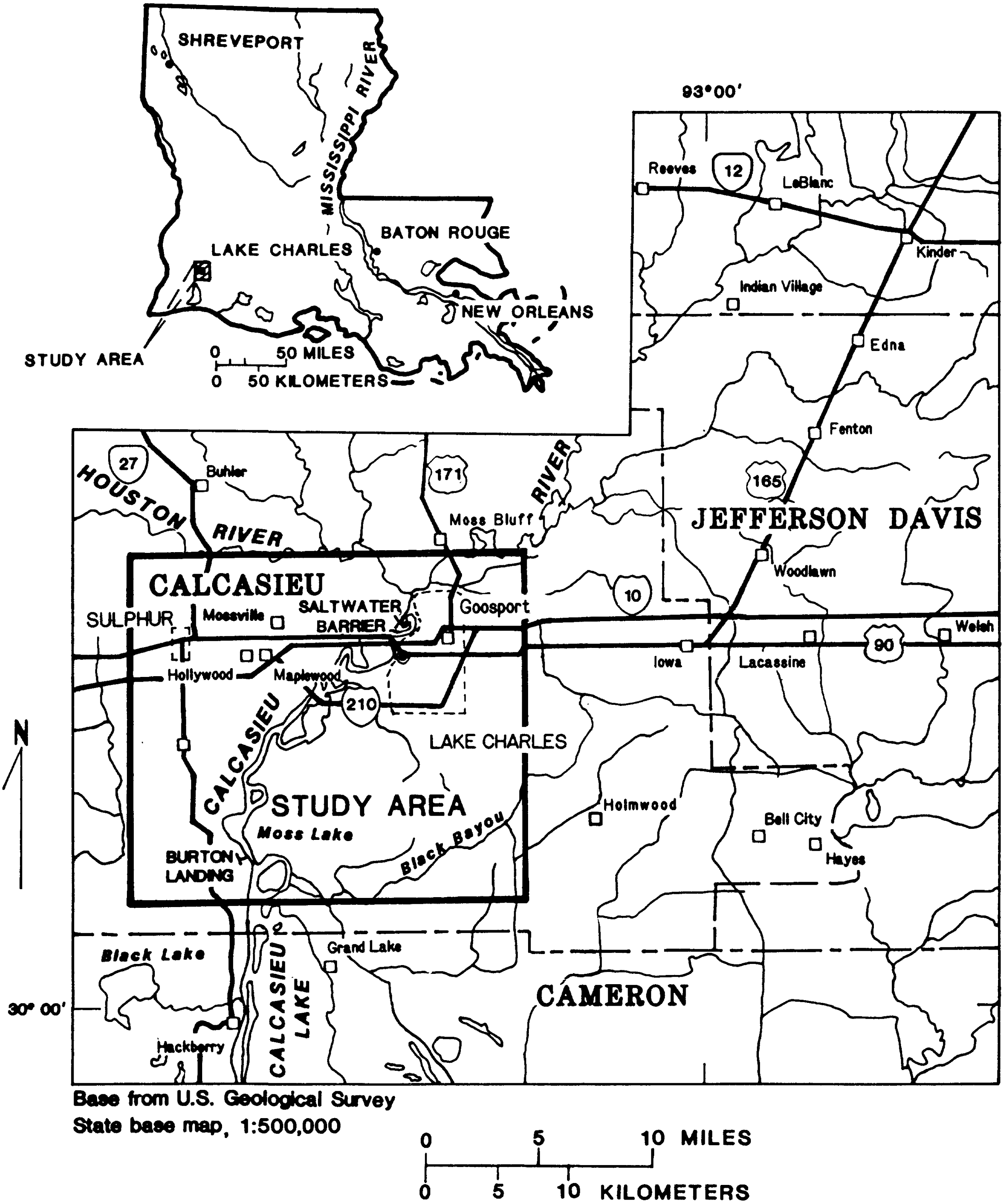


Figure 1.--Location of lower Calcasieu River study area.

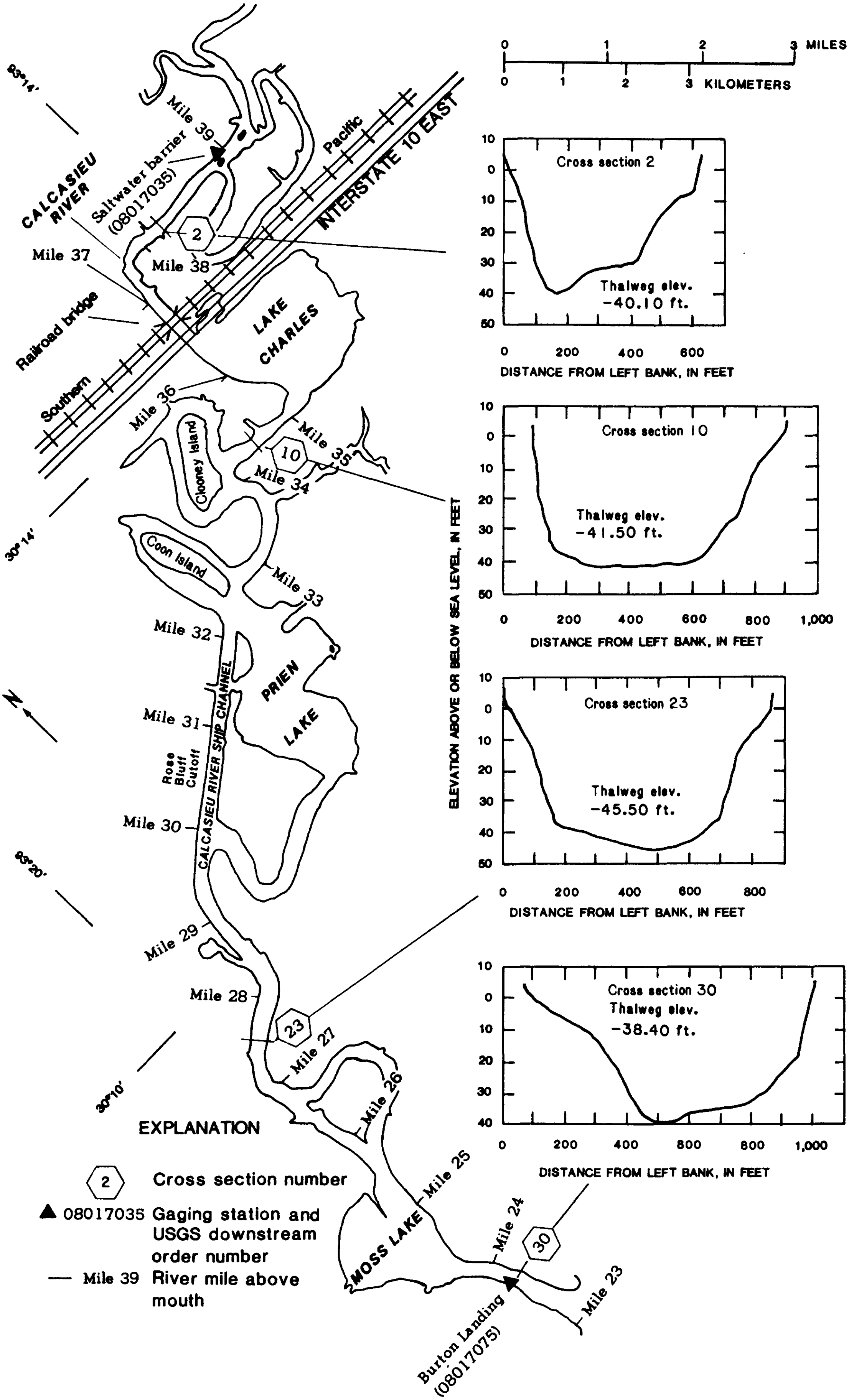


Figure 2.--Location of study reach, gaging stations, and representative cross-sectional geometry.

To permit the access of deep-draft ocean going vessels to Lake Charles, the Calcasieu ship channel was completed in 1968 to a depth of 40 ft and width of 400 ft. There are also several mooring and turning basins along with the ship channel.

Because of the 40-foot deep ship channel, gulf waters move freely inland into the lower Calcasieu River. With low headwater inflow into the lower Calcasieu River, the water is predominately salty with a gradient change from brackish water at the surface to saltwater at the bottom. Freshwater flushing does occur temporarily during high headwater inflows.

The saltwater barrier, completed in 1968, is located on the Calcasieu River just north of Lake Charles. The barrier is designed to minimize the movement of saltwater into the stream channels north of Lake Charles. The barrier consists of flood and navigation control structures. The flood control structure has a gated spillway with five tainter gates, each 25 ft high and 40 ft wide. The bottom elevation of the gates is 20.8 ft below sea level. The navigation control structure has one pair of steel sector gates in a concrete bay, 69 ft high and 56 ft wide. The sill is at 13.8 ft below sea level. The barrier is operated to maintain an upstream gage height of 2.5 ft above sea level.

The lower Calcasieu River with its associated lakes and waterways provides considerable storage area throughout the study area. Between Burton Landing near Moss Lake and the railroad bridge near I-10 at Lake Charles, there are several tributaries and cutoffs, and three lakes: Moss Lake, Prien Lake, and Lake Charles; 1.0, 1.53, and 1.74 mi^2 (square miles), respectively (Shampine, 1970).

Tidal action is the dominant factor in water movement in the lower Calcasieu River. Three kinds of tides can occur: diurnal, having one high and one low water event in a tidal day; semidiurnal, with two high water and two low water events in a tidal day; and mixed, usually of a semidiurnal nature but with relatively large differences between adjacent high and low water events. Figure 3 shows each of these tidal patterns for the lower Calcasieu River at the saltwater barrier. In the Gulf of Mexico, and in the lower Calcasieu River, a diurnal tide pattern is dominant. The diurnal range of the tide at the mouth is about 2 ft. Tidal action is detectable to the vicinity of Phillips Bluff near Kinder on the lower Calcasieu River (about mile 86 from the mouth).

The manner in which streamflow of the lower Calcasieu River responds to tidal action can be interpreted from data obtained from stage recorders. However, some flow characteristics need to be mentioned. On an approaching high tide, the water surface rises toward a peak elevation; however, upstream flow continues for some time after the peak has been reached. The same condition occurs for low tide; after the low tide elevation has been reached, downstream flow will continue for some time. During an intensive survey of June 1984, these flow conditions continued for about 2 hours after the high and low tides had been reached.

A condition also occurs where there is flow upstream and downstream in the same vertical of a cross section. Figures 4 and 5 show that the condition

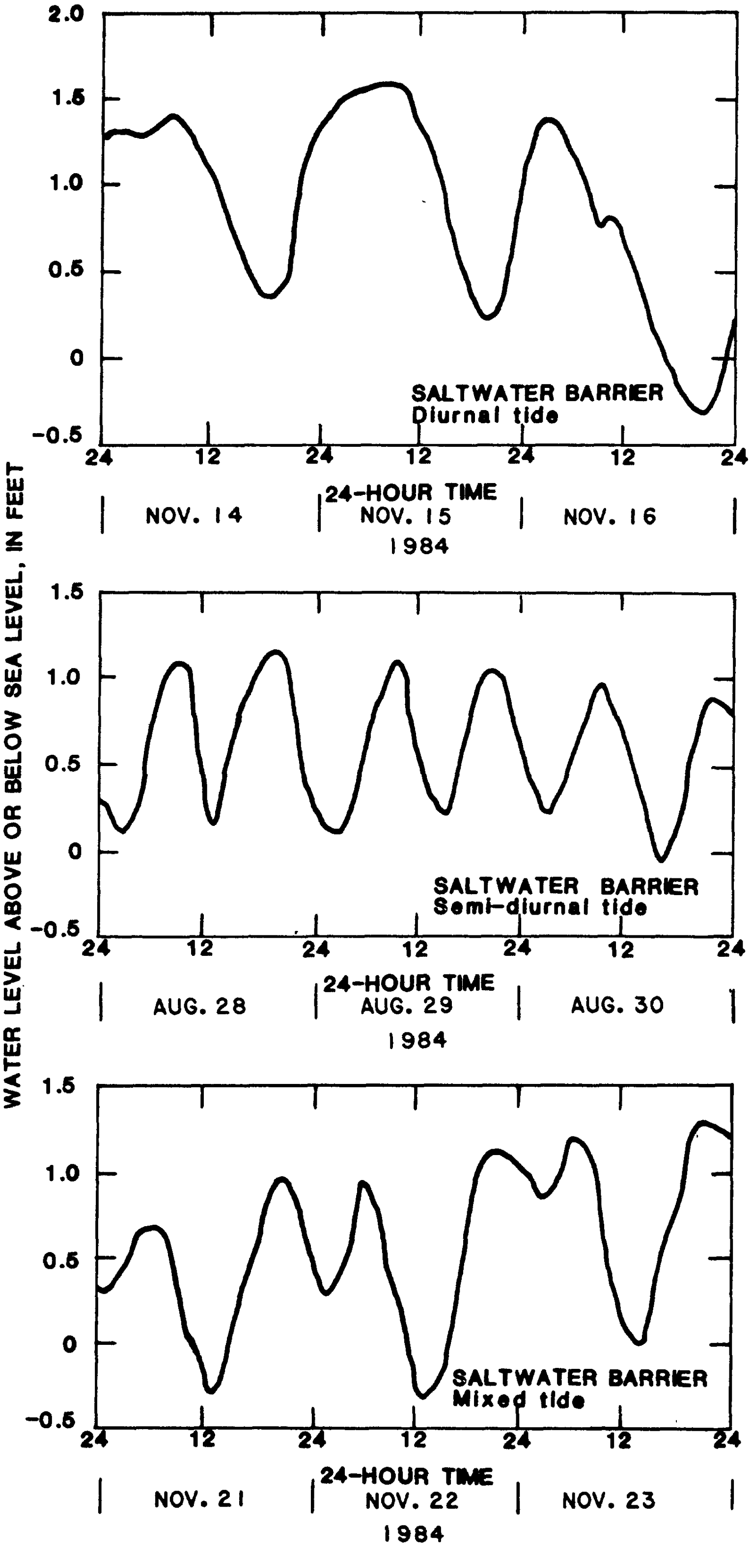


Figure 3.--Examples of diurnal, semidiurnal, and mixed tide patterns for lower Calcasieu River at saltwater barrier.

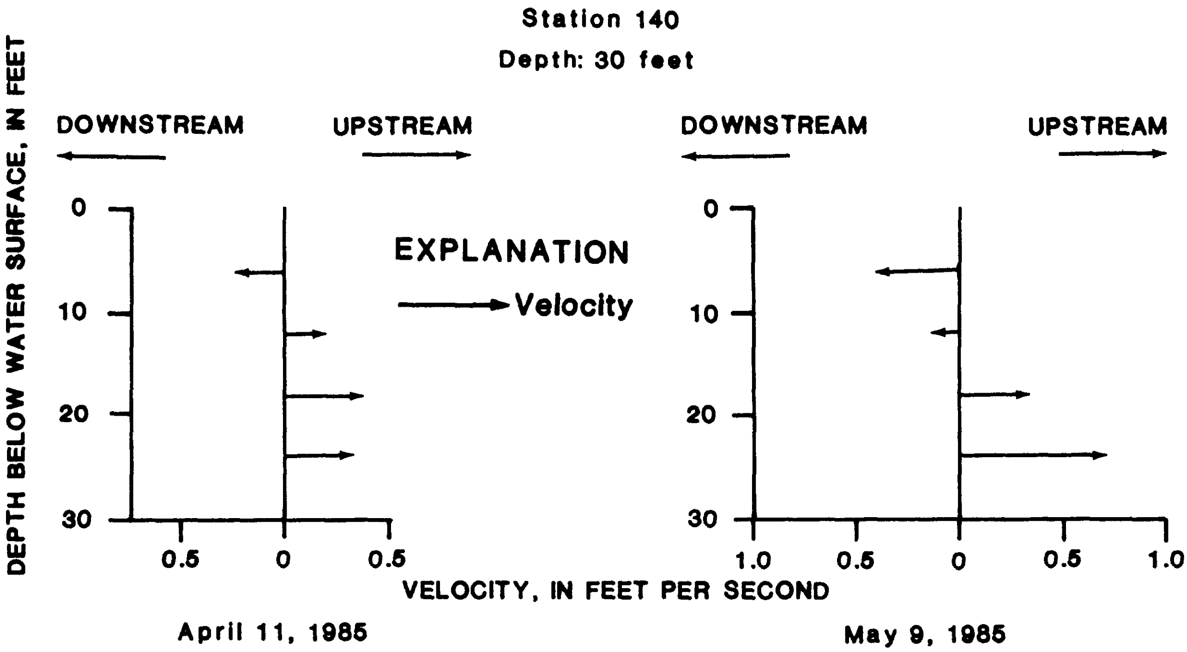


Figure 4.--Measured velocity profiles showing direction and magnitude of flow of lower Calcasieu River at station 140 along cross section at railroad bridge above Interstate 10.

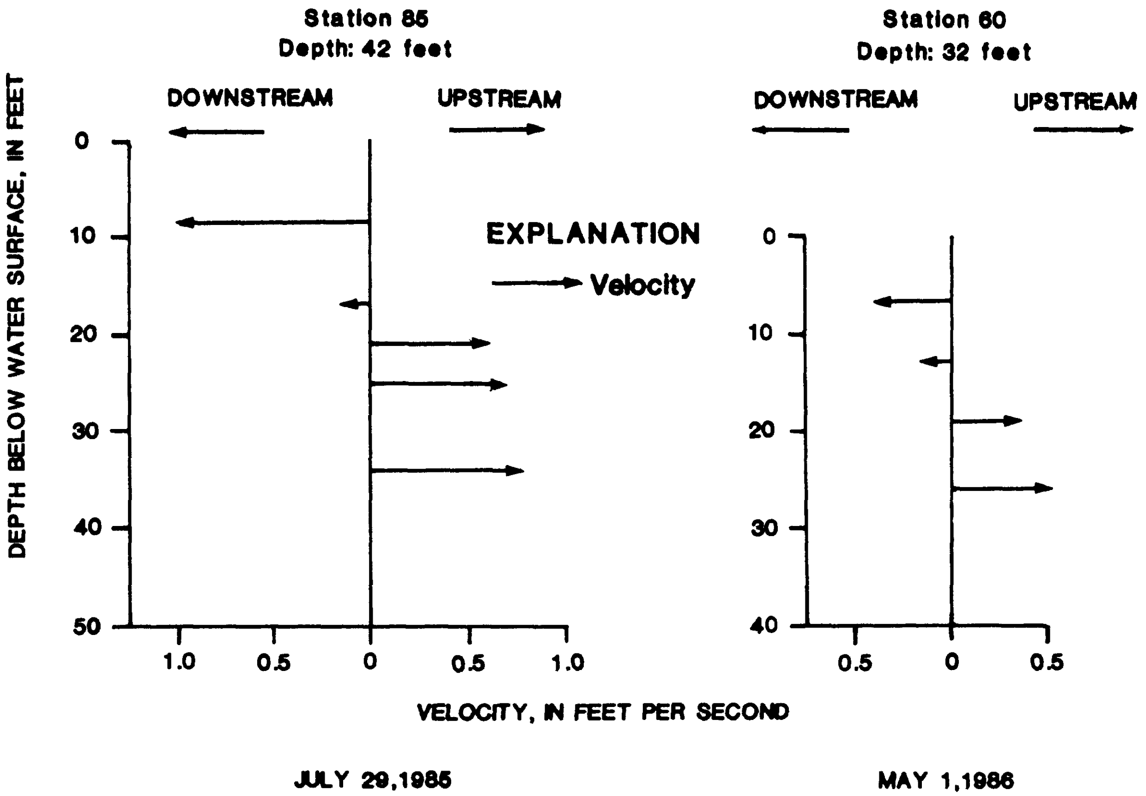


Figure 5.--Measured velocity profiles showing direction and magnitude of flow of lower Calcasieu River at stations 85 and 60 along cross section at Burton Landing near Moss Lake.

occurs at two measurement locations on the river, at the railroad bridge above I-10 at Lake Charles and at Burton Landing near Moss Lake. At the railroad bridge, a null flow point can be detected between 6 and 12 ft in depth for the velocity profile measurement on April 11, 1985. The flow at 6 ft and above is in the downstream direction, and the flow at 12 ft and below is in the upstream direction. For the May 9, 1985, velocity profile, the null point is between 12 and 18 ft in depth, with the flow at 12 ft and above in the downstream direction and 18 ft and below in the upstream direction. At Burton Landing, the null point is detected between 17 and 21 ft in depth for the velocity profile of July 29, 1985, with the flow at 17 ft and above in the downtream direction and 21 ft and below in the upstream direction. For the May 1, 1986, velocity profile, the null point is between 13 and 19 ft in depth, with the flow at 13 ft and above in the downstream direction and 19 ft and below in the upstream direction.

DESCRIPTION OF BRANCH-NETWORK SURFACE-WATER FLOW MODEL

The U.S. Geological Survey branch-network surface-water flow model, developed and documented by Schaffranek and others (1981), is intended for operational use and is applicable to any channel (branch) or system of channels (network of branches) subject to backwater flow, unsteady flow, or both whether caused by ocean tides, flood waves, seiches, wind, or regulation. It may be implemented after data for the appropriate channel geometry and initial conditions descriptive of a prototype are obtained and when sequences of synchronous, precisely timed, boundary-value data are provided at its external boundaries. The model is designed to efficiently compute unsteady one-dimensional flow and water-surface elevation (stage) in either singular or interconnected channels. In general, a prototype waterway may be as simple as one channel with an appropriate set of boundary-value data defined at its extremities or as complex as a system of interconnected channels offering multiple flow paths and requiring boundary-condition definition at several external boundary locations. A typical network is composed of branches (reaches) and segments (subreaches).

The branch-network flow model is based on the one-dimensional, nonlinear partial-differential equations governing unsteady flow in channels for which the dependent variables are flow and stage. It uses a weighted, four-point, implicit finite-difference scheme to solve for the dependent variables in the unsteady flow equations. The application of the model is subject to the basic assumptions and limitations inherent in the formulation of the equations. The development of the model, including the basic assumptions and limitations, is described by Schaffranek and others (1981). For the lower Calcasieu River study reach the assumptions that flow is substantially homogeneous in density and that a uniform velocity distribution prevails throughout any cross section are not always valid. During the period of tide changeover, stratified flow conditions and density variances do occur.

To implement the branch-network flow model it is necessary to accurately describe the prototype system under investigation. This includes the branch and junction locations, the branch and segment lengths, the cross-sectional geometry, and the roughness properties that affect the channel conveyance. Some of these data are readily available through direct field measurements. Others require initial approximation and subsequent refinement throughout the model calibration and verification processes.

The selection of network junctions determines the sequence used by the model to simulate the flow of the river (fig. 6). Locations at which two or more channels join or where tributary inflow must be accommodated are internal junctions. Model-computed boundary conditions supplemented by model-computed flows are applied at these locations. Junctions at which a single branch is defined are external junctions which are the extremities of the network. User-supplied boundary conditions (stage or discharge) are required at these locations. Channel reaches between junctions are called branches which can be further subdivided into segments. The variability of geometric and hydraulic factors, as well as computational considerations, are the basis on which the subdivision of branches into segments are determined. Cross-sectional geometry is used to define all segments and points.

Branch and segment lengths can be determined by field surveys or by measuring along the channel thalweg as depicted on topographic maps or marine charts. Cross-sectional information consists of stage-area and stage-width tables. The required cross-sectional geometry can be approximated from hydrographic-survey charts or measured directly by standard hydrographic-survey techniques.

In addition to the channel and cross-sectional properties, definitions of the flow-resistance coefficient is required. The flow-resistance coefficient is a function of the physical and hydraulic properties of the channel and is a difficult parameter to determine. In a channel or network in which approximate steady-flow conditions occur, a flow-resistance coefficient equivalent to Manning's n may be used for unsteady-flow computation. In the branch-network flow model, the flow-resistance coefficient is approximated by Manning's n and can be varied as a function of the water temperature, discharge, flow depth, Froude number, or Reynolds number.

Initial conditions and boundary values are required for computation of flow by the branch-network flow model. Initial conditions consist of stage and discharge data at the end points of all segments. Data for initial conditions can be obtained directly by field measurements, computed from previous simulations, approximated from some other source, or estimated.

User-defined boundary conditions occur at the external junctions of the network, that is, at a junction consisting of a single connecting branch. Boundary values may be specified by either a stage or discharge hydrograph or described by a unique stage-discharge relation. Assignment of internal-boundary conditions at internal junctions is accomplished automatically by the branch-network flow model.

The success of any flow model depends on the accuracy of the prototype data used for calibration. Prototype data consist of a time series of measured discharges, together with concurrently recorded stage data at external boundary locations in the modeled reach. In the calibration process, the model parameters such as the flow-resistance coefficient are adjusted to accurately represent the prototype system for the range of flows expected.

All aspects of a particular model schematization are subject to adjustment during the calibration process. Reach lengths and channel geometry are measurable. Therefore, they generally are not altered during calibration. However, timing errors in the recorders or a datum error in the stage data, are subject to review and correction.

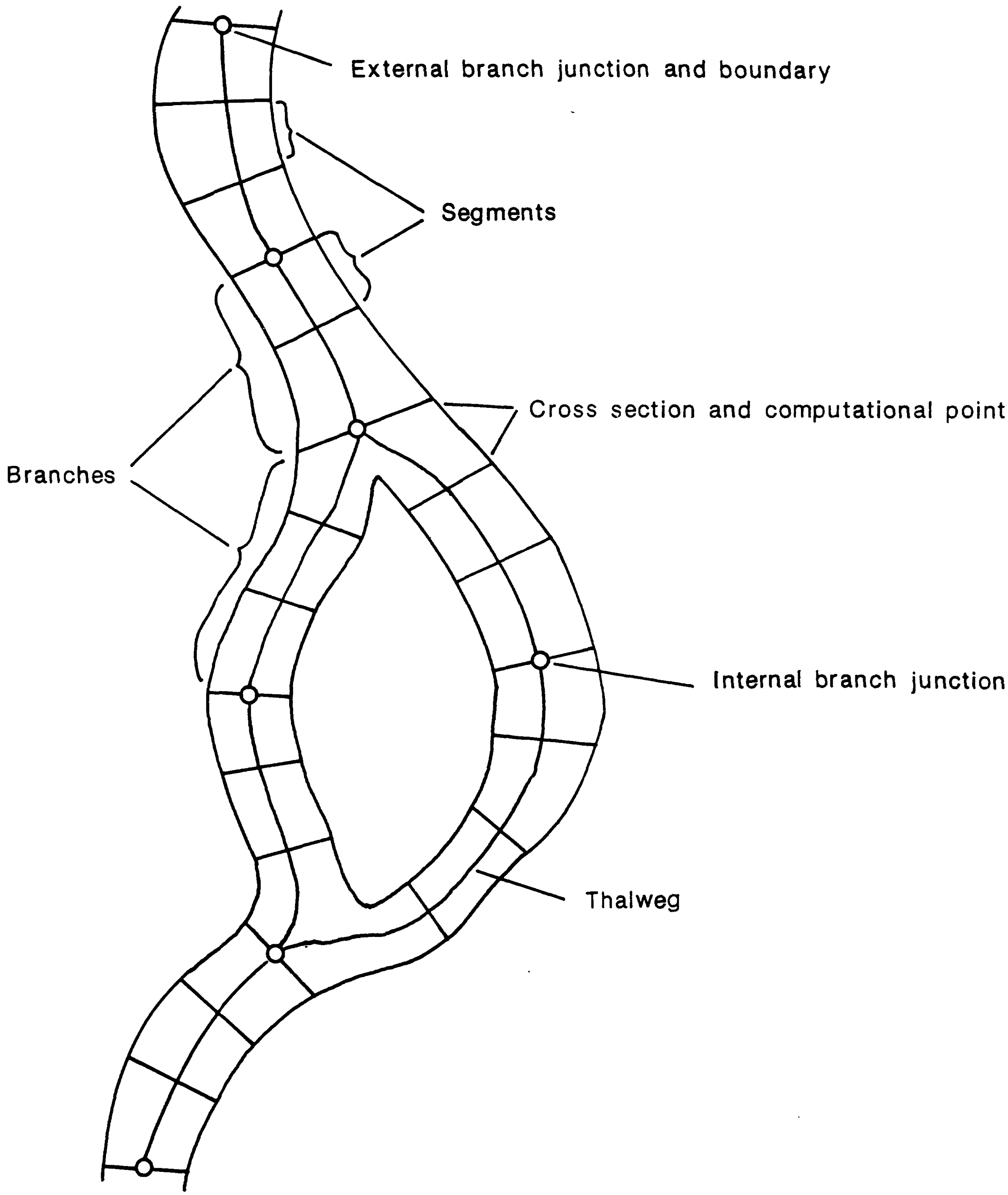


Figure 6.--Hypothetical layout for branch-network flow model.

DATA COLLECTION

Several types of data sets are necessary to run and calibrate the branch-network flow model. These data sets include cross-sectional geometry, stage data, and discharge measurements.

Figure 7 shows the cross-sectional network established to define the lower Calcasieu River model reach. Distances between cross-sections along the channel reach were measured from topographic maps. Cross-sectional depths were obtained with a fathometer, and widths were taken from topographic maps for lakes and were measured for channel cross sections. Figure 2 shows several representative measured cross sections.

Stage data are being recorded hourly at stream-gaging stations on the lower Calcasieu River below the saltwater barrier (08017035) and at Calcasieu River at Burton Landing near Moss Lake (08017075) (fig. 2). These two stations are the external junctions of the study reach. Contraband Bayou and Bayou d'Inde are the only tributaries entering the study reach and do not significantly affect the flow; therefore, they were not included in the model development.

Wind data are being recorded at the stream-gaging station on the Calcasieu River near Moss Lake. Wind speed and direction are being recorded hourly.

A series of discharge measurements (table 1) were made on the lower Calcasieu River at the railroad bridge upstream of the I-10 bridge at Lake Charles and at Burton Landing near Moss Lake. A series of discharge measurements on the river were also made during an intensive survey on June 19-20, 1984 (table 1). The majority of these discharge measurements were made using a directional current meter which measures direction of velocity in relation to magnetic north and magnitude of velocity. Some of the high flow measurements were made using a Price AA[1] current meter.

SCHEMATIZATION OF THE FLOW MODEL

The branch-network flow model was used to compute continuous discharge at several locations in this reach of the lower Calcasieu River. The study reach, 15 mi long, was represented by 29 computation points as shown in the schematic in figure 7. The reach was divided into 13 branches for flow simulations.

Flow was routed through the ship channel and the lakes. This was required to account for the storage conditions of the lakes. The model reach started at the saltwater barrier at mile 39, was then divided at mile 36.4 at Lake Charles, and reconnected at mile 35. The reach continues for 2.8 mi and divides again at mile 32.2, with flow going through the ship channel and Prien Lake and reconnecting at mile 29.2. The reach then continues for 3.7 mi to Moss Lake, where it again divides at mile 25.5, reconnects at mile 24.0, and ends 0.4 mi downstream at Burton Landing at mile 23.6.

[1] Use of the brand name in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey or the Louisiana Department of Environmental Quality, Office of Water Resources.

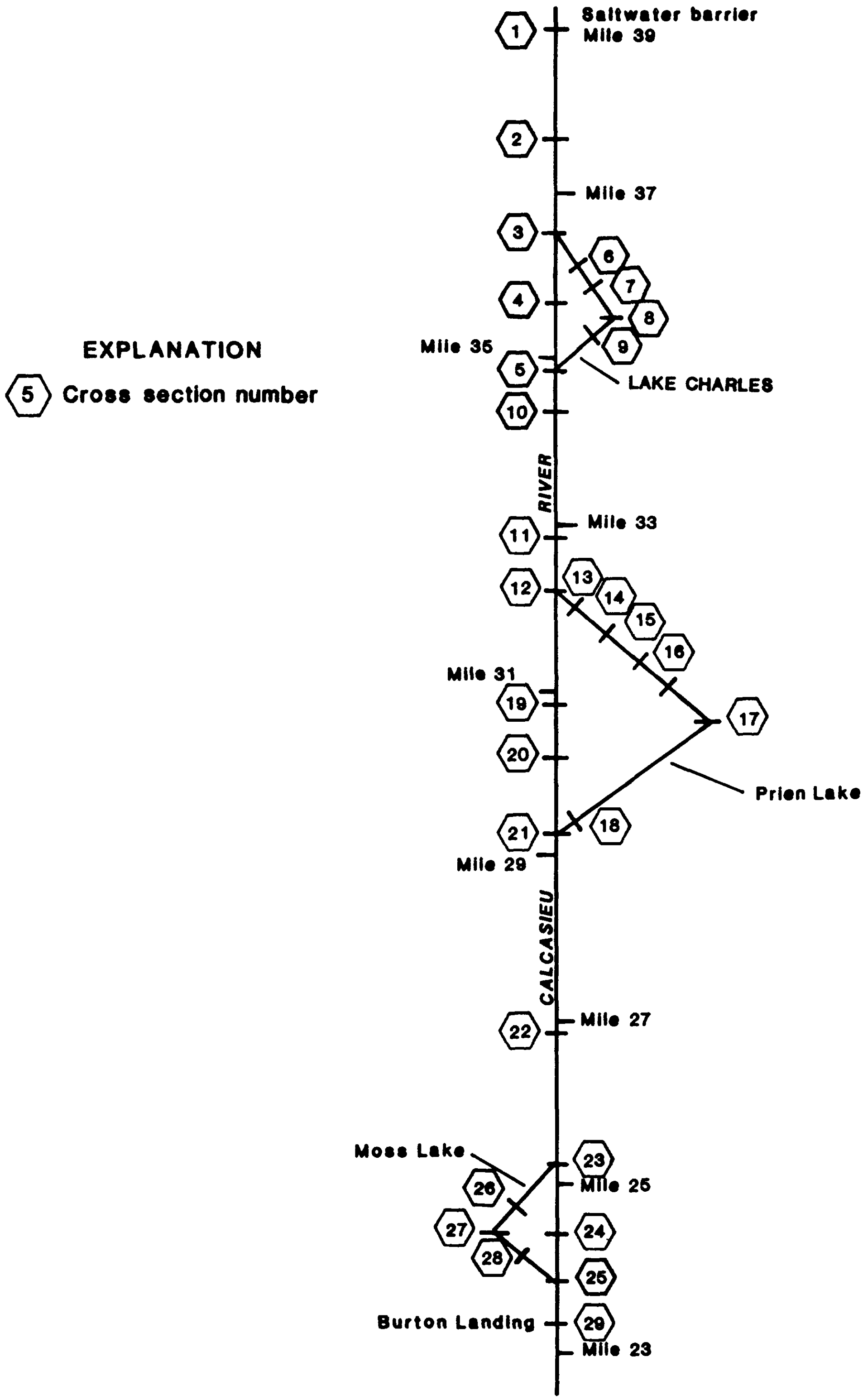


Figure 7.--Schematic of the lower Calcasieu River used for simulation of flow from the saltwater barrier to Burton Landing.

Table 1.--List of discharge measurements made on the lower Calcasieu River at the railroad bridge above Interstate 10 and Burton Landing near Moss Lake

[ft^2, square feet; ft/s, feet per second; ft^3/s, cubic feet per second; RRB, railroad bridge; DVM, directional velocity meter; Down, downstream; Up, upstream; BL, Burton Landing; AA, Price AA current meter[1]]

Site	Date	Time	Type velocity meter	Upstream flow Area (ft^2)	Upstream flow Velocity (ft/s)	Upstream flow Discharge (ft^3/s)	Downstream flow Area (ft^2)	Downstream flow Velocity (ft/s)	Downstream flow Discharge (ft^3/s)	Net flow (ft^3/s)	Direction of flow
RRB	6-19-84	0515	DVM	4,240	0.39	1,670	9,720	1.11	10,800	9,130	Down
RRB	6-19-84	0700	DVM	1,940	.30	583	12,800	1.03	13,200	12,600	Down
RRB	6-19-84	0800	DVM	4,550	1.89	8,590	9,810	1.96	19,200	10,600	Down
RRB	6-19-84	1000	DVM	11,100	.33	3,620	3,680	.24	880	2,740	Up
RRB	6-19-84	1100	DVM	13,700	.20	2,740	1,270	.02	20	2,720	Up
RRB	6-19-84	1200	DVM	15,100	.19	2,880	------	----	------	2,880	Up
RRB	6-19-84	1315	DVM	15,100	.19	2,810	------	----	------	2,810	Up
RRB	6-19-84	1800	DVM	3,220	.15	480	11,900	.43	5,130	4,650	Down
RRB	6-19-84	1915	DVM	1,650	.37	610	13,300	.42	5,650	5,040	Down
RRB	6-19-84	2130	DVM	592	.12	70	14,400	.53	7,620	7,550	Down
RRB	6-19-84	2215	DVM	410	.10	40	14,600	.37	5,420	5,380	Down
RRB	6-19-84	2300	DVM	2,040	.03	60	13,000	.37	4,750	4,690	Down
BL	6-19-84	1130	DVM	21,900	.84	18,500	------	----	------	18,500	Up
BL	6-19-84	2015	DVM	1,970	.06	120	20,200	.43	8,700	8,580	Down
RRB	6-20-84	0100	DVM	------	----	------	14,400	.56	8,020	8,020	Down
RRB	6-20-84	0530	DVM	600	----	300	13,800	.91	12,600	12,300	Down
RRB	10-24-84	1100	AA	------	----	------	16,400	2.93	48,100	48,100	Down
BL	10-24-84	1430	AA	------	----	------	26,600	1.77	45,200	45,200	Down
RRB	10-24-84	1645	AA	------	----	------	16,400	2.56	42,000	42,000	Down
RRB	3-21-85	1145	AA	------	----	------	15,900	1.36	21,700	21,700	Down
BL	4-10-85	0930	DVM	26,100	1.24	32,300	------	----	------	32,300	Up
RRB	4-11-85	1600	DVM	7,110	.31	2,190	6,380	.19	1,230	960	Up
BL	4-11-85	1030	DVM	26,800	.72	19,200	------	----	------	19,200	Up
BL	5- 9-85	0930	DVM	25,700	1.17	30,000	------	----	------	30,000	Up
RRB	5- 9-85	1315	DVM	7,610	.39	2,950	5,910	.34	2,030	920	Up
BL	6- 5-85	0800	DVM	23,200	1.27	29,400	------	----	------	29,400	Up
RRB	6- 5-85	1015	DVM	12,200	.27	3,310	1,290	.20	260	3,050	Up
BL	7-29-85	1445	DVM	5,010	.73	3,660	17,800	.64	11,400	7,790	Down
RRB	7-30-85	1145	DVM	9,250	.23	2,130	4,520	.30	3,050	920	Down
BL	5- 1-86	1300	DVM	22,300	1.48	33,000	------	----	------	33,000	Up
BL	5- 1-86	1445	DVM	22,300	.82	18,400	------	----	------	18,400	Up
BL	5- 1-86	1630	DVM	22,100	.30	4,330	------	----	------	4,330	Up
BL	5- 2-86	0615	DVM	------	----	------	21,000	.74	15,500	15,500	Down
BL	5- 2-86	0745	DVM	------	----	------	20,000	.49	9,880	9,880	Down
BL	5- 2-86	0930	DVM	------	----	------	19,600	.36	7,030	7,030	Down

[1] Use of the brand name in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey or the Louisiana Department of Environmental Quality, Office of Water Resources.

CALIBRATION AND VERIFICATION

Flow simulations (runs) were made for 3- or 4-day periods, providing 2 days of warm-up time for the model prior to actual calibration and verification. Eight sets of discharge measurements, ranging from 48,100 to -32,300 ft^3/s, that were used to calibrate and verify the flow model are shown in table 1.

Stage data, in hourly intervals, were input as external boundary conditions below the saltwater barrier and at Burton Landing. The model linearly interpolated between the hourly stage values to accommodate simulation of flow at a 15-minute time step. Cross-sectional data were input into the model in a stage-area-width format to simulate the 29 measured cross-sectional locations used.

The flow-resistance coefficient was approximated initially as Manning's n. It was determined that a variable flow-resistance coefficient as a function of discharge, at least, would be needed in the model. Flow-resistance coefficients computed using Mannings equation were plotted against the corresponding measured discharge, and a curve was fitted to the data using the method of least squares. Figure 8 shows the relation of flow-resistance coefficient to absolute discharge. The data indicate that the flow-resistance coefficient increases as discharge decreases. The flow-resistance coefficient ranged from 0.014 to 0.36. The high flow-resistance coefficient existed for very low discharge, when flow can be either positive or negative anywhere in the reach because of tidal and wind effects. At times the flow will be in both directions at the same cross section as described earlier; however, this condition is not simulated by the model. The model is calibrated during this condition to compute net discharge. The highest flow-resistance coefficient occurs when the stratified flow occurs and cannot be considered equivalent to Manning's n but necessary for calibration for this particular flow condition.

Calibration runs for the model were made using five sets of discharge measurements shown in table 2. The flow-resistance coefficient was adjusted during the calibration runs to achieve the best results. A comparison of measured discharge to computed discharge is also shown in table 2. The average percent error for the calibration runs was 13.9 percent, excluding the measurement made on May 9, 1985, at the railroad bridge above I-10.

Three verification runs were made using the discharge measurements shown in table 3. No adjustments were made to the model after calibration. A comparison of measured discharge to computed discharge is also shown in table 3. The average percent error for the verification runs was 29.6 percent, excluding the measurement made on July 30, 1985, at the railroad bridge above I-10.

The average error for all of the model runs was 25.2 percent. Although the error may seem high, the model does simulate the flow conditions well considering the complexity of the hydraulic conditions for the lower Calcasieu River. Figures 9 through 16 show stage hydrographs at the saltwater barrier and Burton Landing. Also shown in these figures are the computed discharge hydrographs from the model and the measured discharge for these sites. The computed discharge for the hydrographs ranged from 59,500 to -51,100 ft^3/s in the eight data sets. The higher percentage of error is associated with the lower discharge as it approaches zero flow. A comparison of measured discharge to computed discharge shows an average error of 18.5 percent for measurements above 10,000 ft^3/s and below -10,000 ft^3/s and an average error of 30.3 percent for those between $\pm 10,000$ ft^3/s. The error may be because of accuracy limitations in the discharge measurements that may be caused by the low velocities and method used, or they may be associated with slight timing errors in stage data. Also, at low discharge the flow stratification problem exists. Figures 9 to 16 also show the time delay relation between the peak stage and peak discharge during the flood tide and ebb tide phases of the tide cycle.

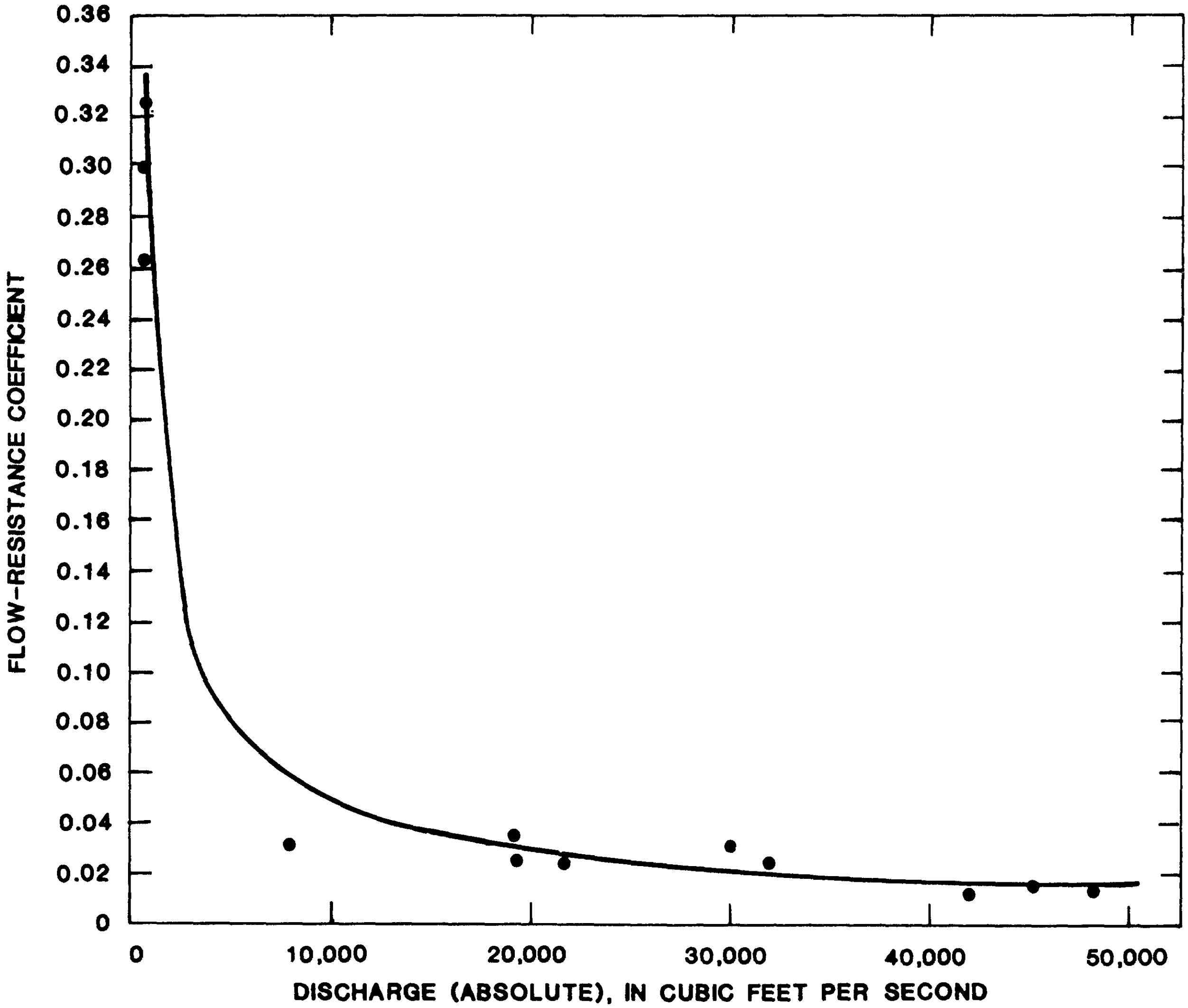


Figure 8.--Relation of flow-resistance coefficient to measured discharge (absolute discharge).

Additional discharge measurements will be made to verify continuous calibration of the flow model and wind data will be added to further refine the model. Also, additional discharge measurements within the study reach would further define the flow-distribution pattern through the ship channel and lakes.

Table 2.--Errors associated with calibration of the branch-network flow model for lower Calcasieu River

[RRB, railroad bridge; BL, Burton Landing]

Set	Site	Date	Time	Measured discharge, Q_m	Computed discharge, Q_c	Percent difference $\frac{Q_m - Q_c}{Q_m} \times 100$
				cubic feet per second		
1	RRB	10-24-84	1100	48,100	33,500	30.4
1	BL	10-24-84	1430	45,200	52,500	-11.9
1	RRB	10-24-84	1645	42,000	39,700	5.5
2	RRB	3-21-85	1145	21,700	20,600	5.1
3	BL	4-10-85	0930	-32,300	-33,700	-4.3
3	BL	4-11-85	1030	-19,200	-20,600	-7.3
4	BL	5- 9-85	0930	-30,000	-22,100	26.3
4	RRB	5- 9-85	1315	-920	391	(a)
5	BL	6- 5-85	0800	-29,400	-22,400	23.8
5	RRB	6- 5-85	1015	-3,050	-2,730	10.5

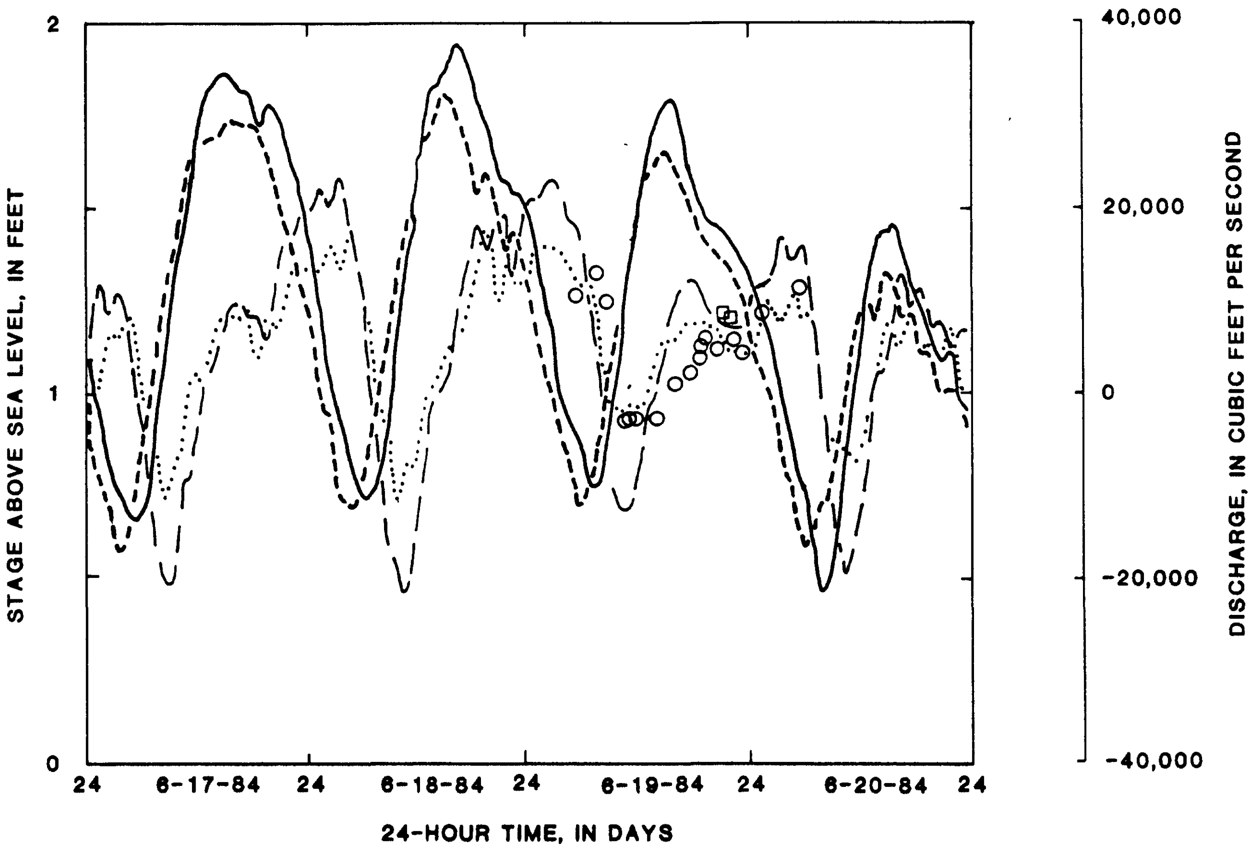
[a] Not used in computation of percent error.

Table 3.--Errors associated with verification of the branch-network flow model for lower Calcasieu River

[RRB, railroad bridge; BL, Burton Landing]

Set	Site	Date	Time	Measured discharge, Q_m	Computed discharge, Q_c	Percent difference $\frac{Q_m - Q_c}{Q_m} \times 100$
				cubic feet per second		
6	BL	7-29-85	1445	7,790	3,510	54.9
6	RRB	7-30-85	1145	920	4,350	(a)
7	BL	5- 1-86	1300	33,000	-30,800	6.7
7	BL	5- 1-86	1445	-18,400	-24,200	-31.5
7	BL	5- 1-86	1630	-4,330	-4,280	1.2
7	BL	5- 2-86	0615	15,500	14,100	9.0
7	BL	5- 2-86	0745	9,880	12,200	-23.5
7	BL	5- 2-86	0930	7,030	3,310	52.9
8	RRB	6-19-84	0515	9,130	12,000	-31.4
8	RRB	6-19-84	0700	12,600	9,700	23.0
8	RRB	6-19-84	0800	10,600	5,640	46.8
8	RRB	6-19-84	1000	-2,740	-1,940	29.2
8	RRB	6-19-84	1100	-2,720	-3,040	-11.8
8	BL	6-19-84	1130	-18,500	-12,900	30.3
8	RRB	6-19-84	1200	-2,880	-2,100	27.1
8	RRB	6-19-84	1315	-2,810	-1,270	54.8
8	RRB	6-19-84	1800	4,650	6,770	-45.6
8	RRB	6-19-84	1915	5,040	6,790	-34.7
8	BL	6-19-84	2015	8,580	7,770	9.4
8	RRB	6-19-84	2130	7,550	5,400	28.5
8	RRB	6-19-84	2215	5,380	4,160	22.7
8	RRB	6-19-84	2300	4,690	3,320	29.2
8	RRB	6-20-84	0100	8,020	4,190	47.8
8	RRB	6-21-84	0530	12,300	8,850	28.0

[a] Not used in computation of percent error.



EXPLANATION

——— Stage at railroad bridge above Interstate 10

– – – – Stage at Burton Landing near Moss Lake

·········· Computed discharge at railroad bridge above Interstate 10

—— —— Computed discharge at Burton Landing near Moss Lake

○ Measured discharge at railroad bridge above Interstate 10

□ Measured discharge at Burton Landing near Moss Lake

Figure 9--Stage, computed discharge, and measured discharge for the lower Calcasieu River at the railroad bridge above Interstate 10 and at Burton Landing near Moss Lake, June 17-20, 1984.

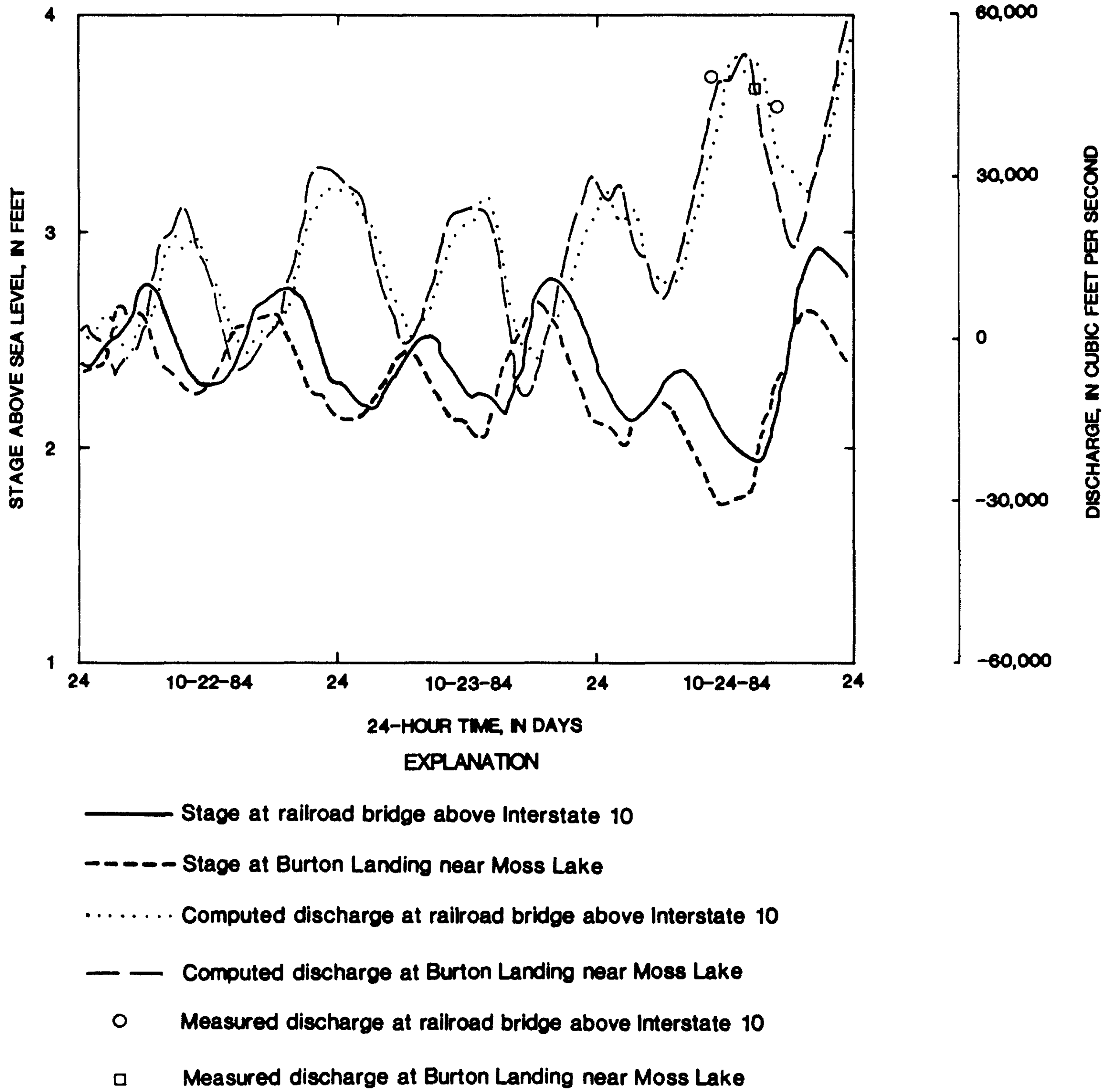


Figure 10.--Stage, computed discharge, and measured discharge for the lower Calcasieu River at the railroad bridge above Interstate 10 and at Burton Landing near Moss Lake, October 22-24, 1984.

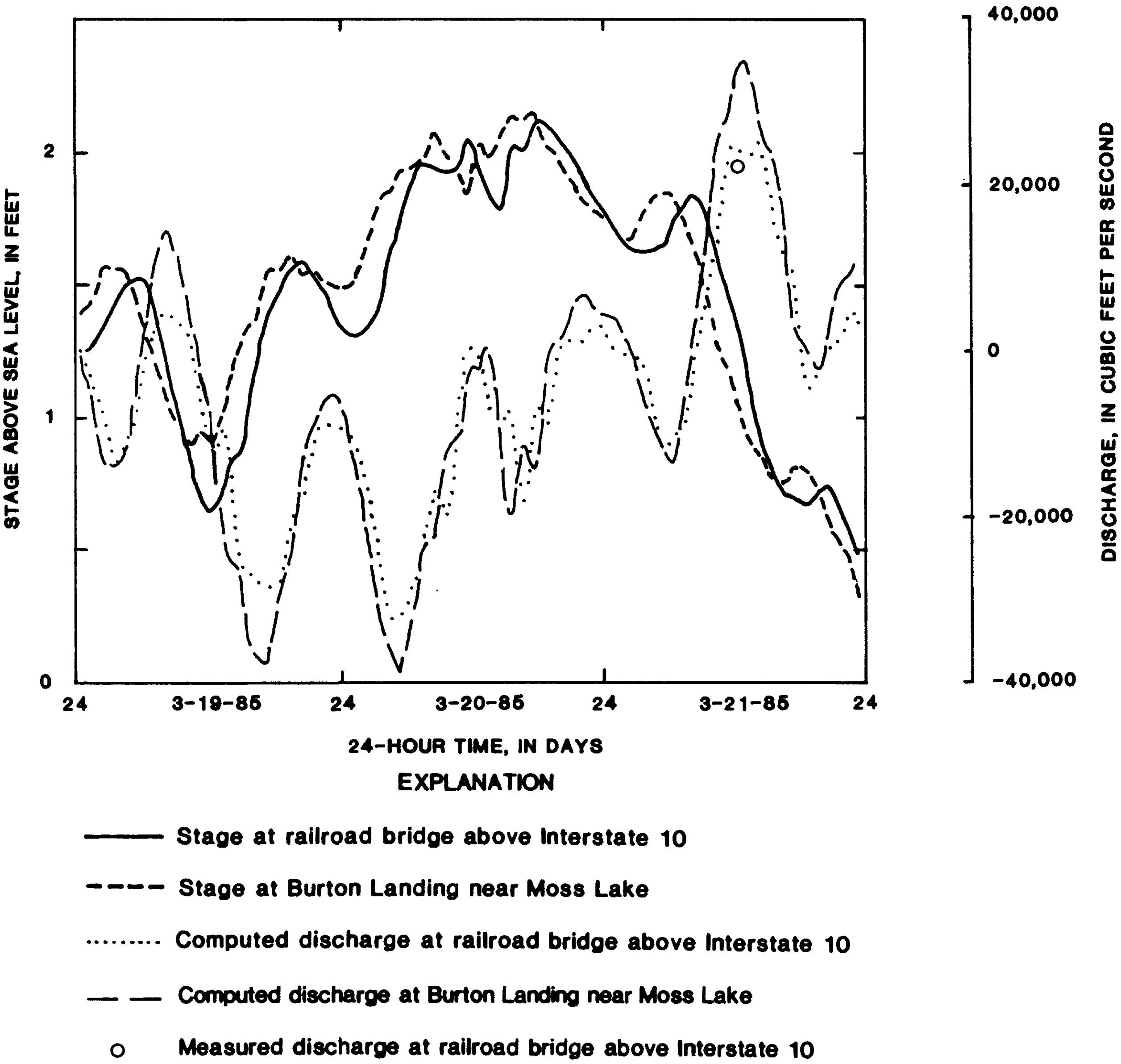


Figure 11.--Stage, computed discharge, and measured discharge for the lower Calcasieu River at the railroad bridge above Interstate 10 and at Burton Landing near Moss Lake, March 19-21, 1985.

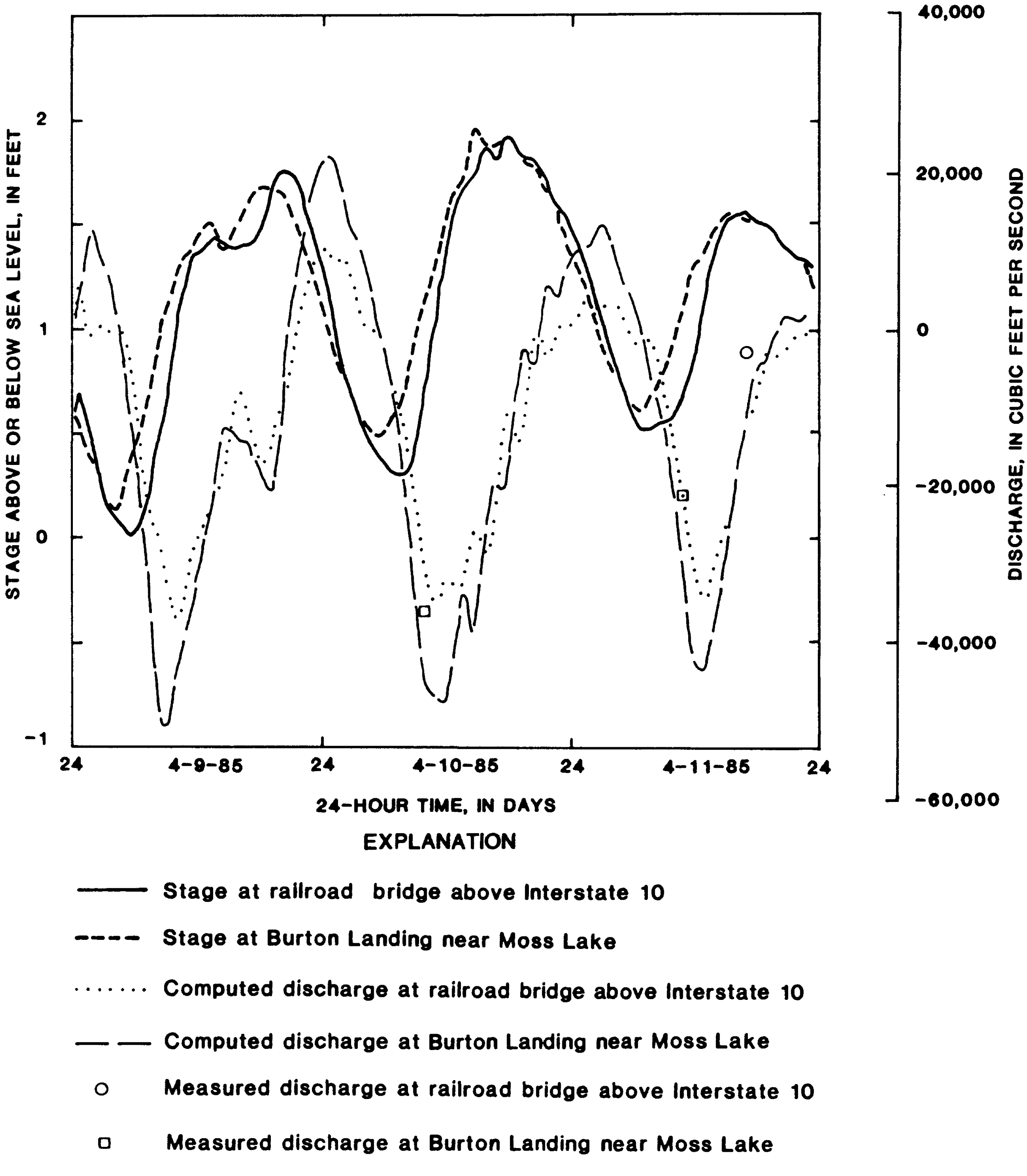


Figure 12.--Stage, computed discharge, and measured discharge for the lower Calcasieu River at the railroad bridge above Interstate 10 and at Burton Landing near Moss Lake, April 9-11, 1985.

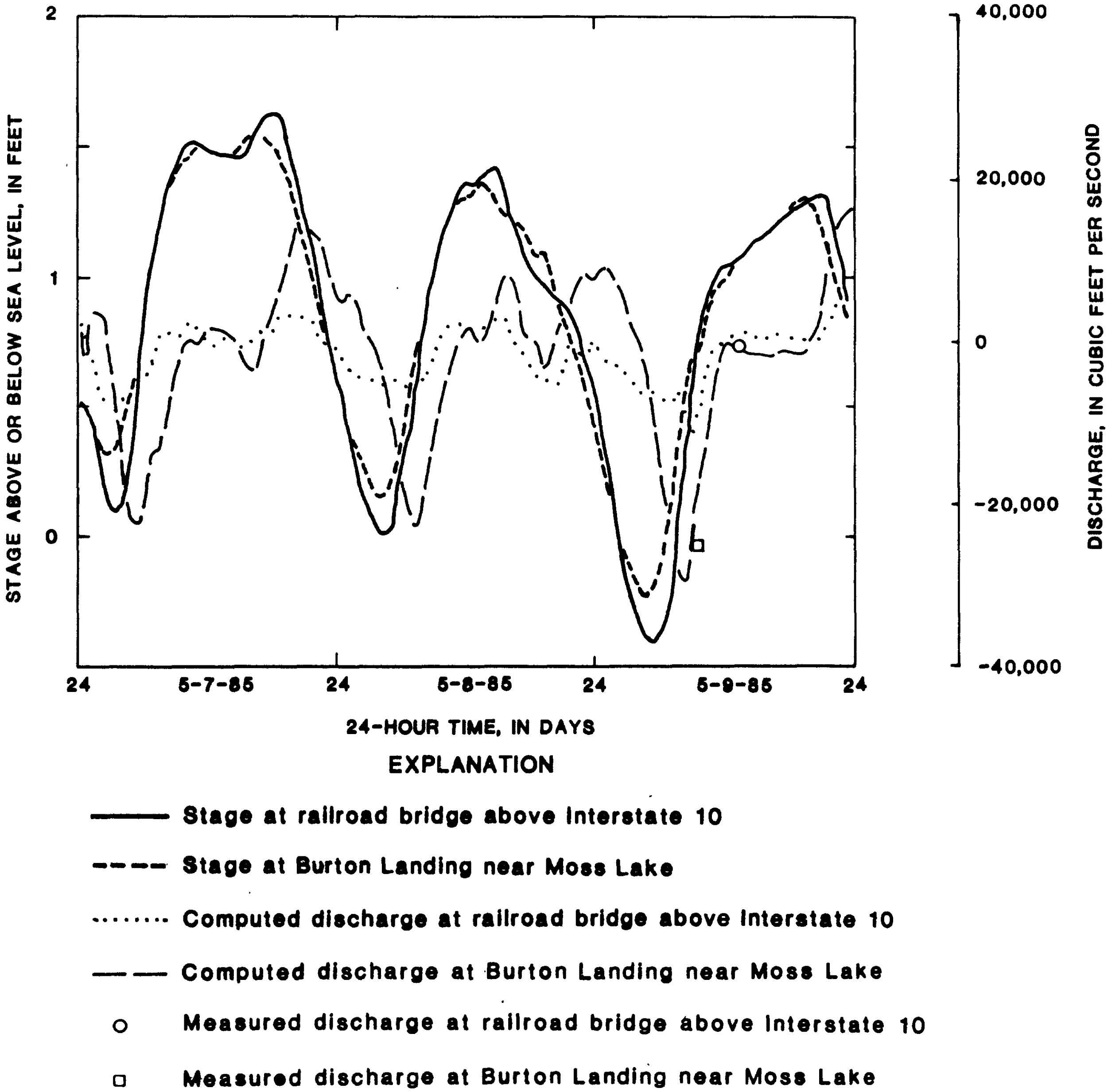
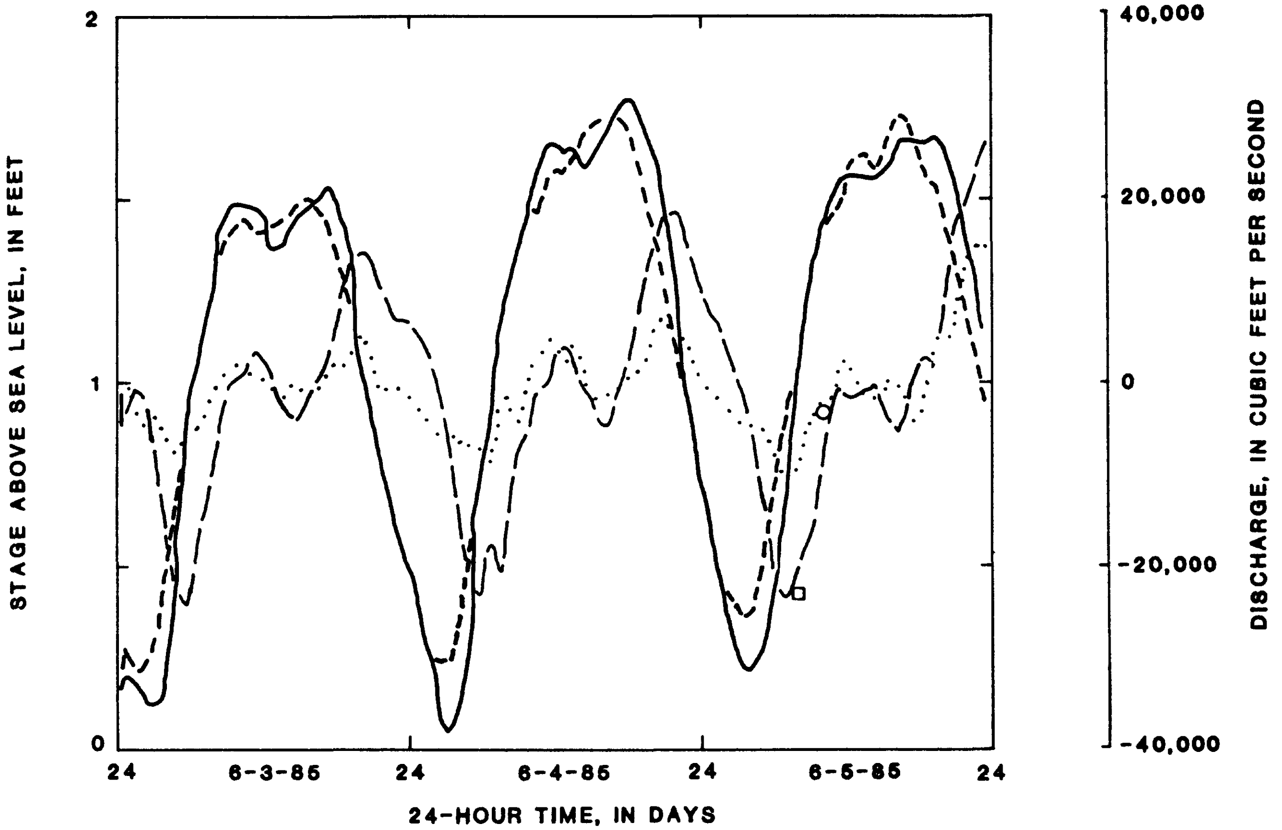


Figure 13.--Stage, computed discharge, and measured discharge for the lower Calcasieu River at the railroad bridge above Interstate 10 and at Burton Landing near Moss Lake, May 7-9, 1985.



EXPLANATION

——— Stage at railroad bridge above Interstate 10

- - - - Stage at Burton Landing near Moss Lake

······· Computed discharge at railroad bridge above Interstate 10

—— —— Computed discharge at Burton Landing near Moss Lake

○ Measured discharge at railroad bridge above Interstate 10

□ Measured discharge at Burton Landing near Moss Lake

Figure 14.--Stage, computed discharge, and measured discharge for the lower Calcasieu River at the railroad bridge above Interstate 10 and at Burton Landing near Moss Lake, June 3-5, 1985.

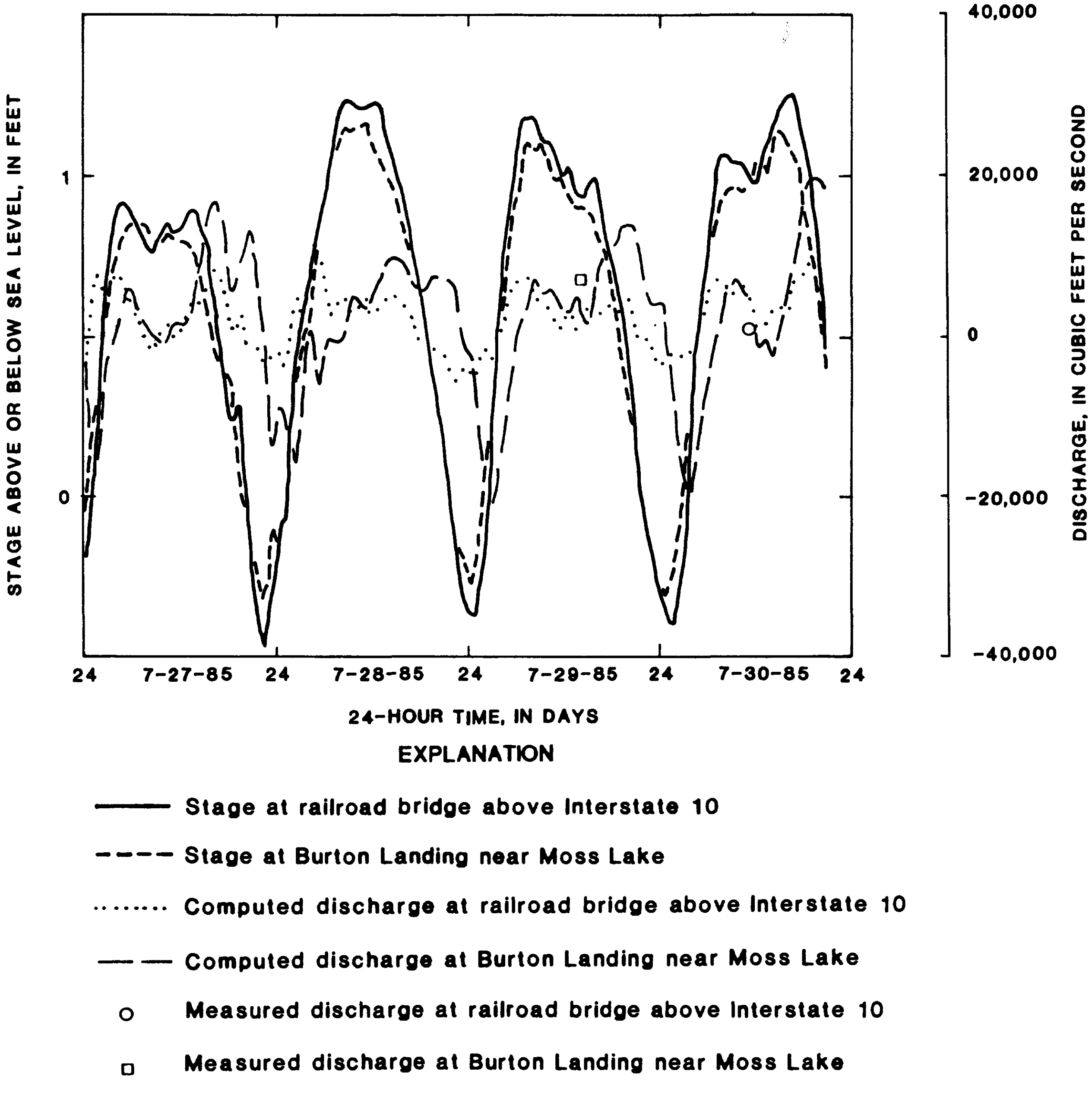
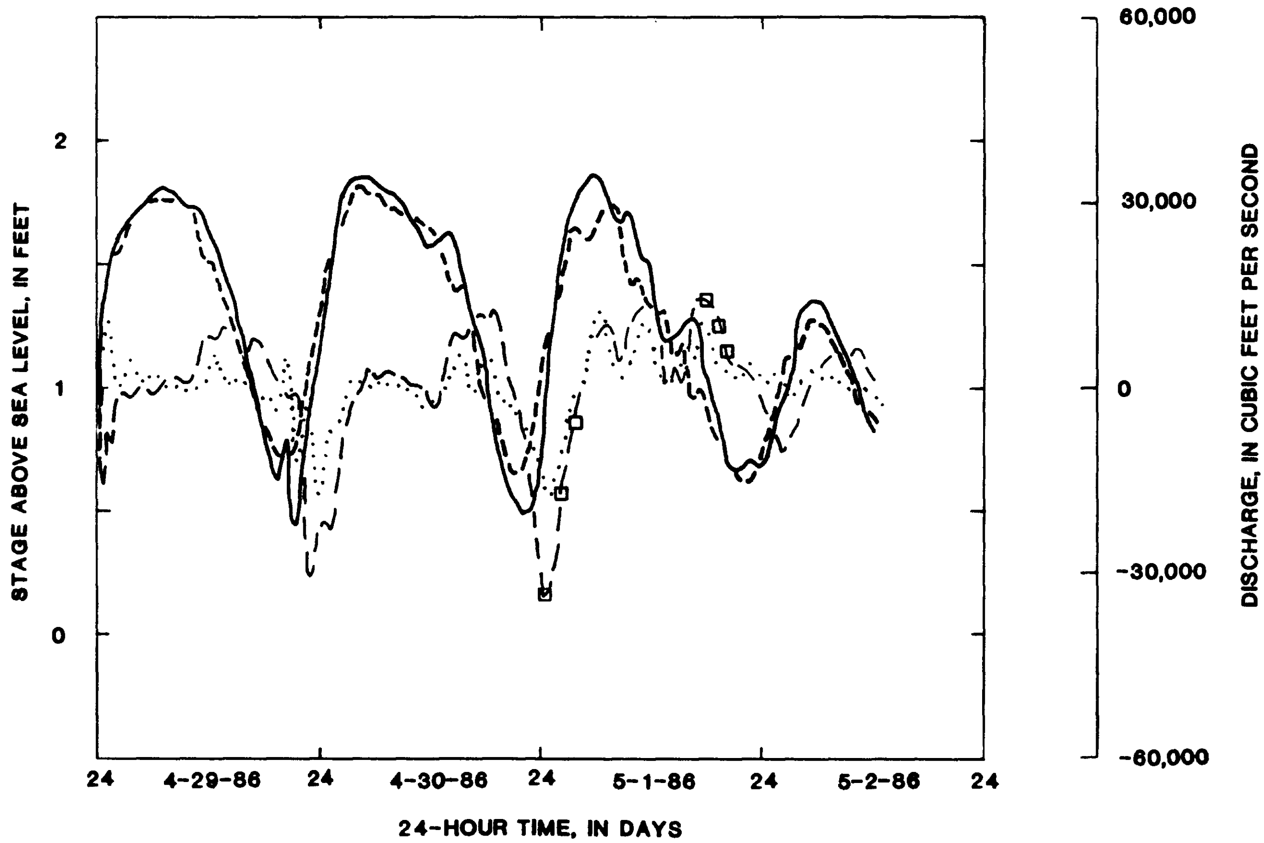


Figure 15.--Stage, computed discharge, and measured discharge for the lower Calcasieu River at the railroad bridge above Interstate 10 and at Burton Landing near Moss Lake, July 27-30, 1985.



EXPLANATION

——— Stage at railroad bridge above Interstate 10

- - - - Stage at Burton Landing near Moss Lake

······· Computed discharge at railroad bridge above Interstate 10

— — Computed discharge at Burton Landing near Moss Lake

□ Measured discharge at Burton Landing near Moss Lake

Figure 16.--Stage, computed discharge, and measured discharge for the lower Calcasieu River at the railroad bridge above Interstate 10 and at Burton Landing near Moss Lake, April 29-May 2, 1986.

SENSITIVITY ANALYSIS

A sensitivity analysis of controlling parameters was performed on the flow model. The analysis permits model users to determine the extent to which uncertainty in the input parameters results in uncertainty in the predicted discharge. Three parameters were considered in this sensitivity analysis: (1) the effects of computational time-step size, (2) variation in flow-resistance coefficients, and (3) errors in boundary-value data.

These experiments were conducted using data collected during October 22-24, 1984. Flow was routed through the study reach for this period using different time-step sizes. There was little or no noticeable difference in the discharge hydrographs computed with a 10-, 15-, 30-, or 60-minute time step.

Knowledge of the effects of the flow-resistance coefficient on the computed discharge is essential for understanding the flow model. If the flow-resistance coefficient is reduced, discharge and rate of travel are increased. A high value for the flow-resistance coefficient decreases discharge and rate of travel.

The flow-resistance coefficient was made a function of discharge to improve the simulations. The variation of the discharge hydrograph using different fixed flow-resistance coefficients provided an indication that the model was very sensitive to the flow-resistance coefficient. Data set 1 was used to determine the differences in discharge at Burton Landing near Moss Lake and the Railroad Bridge near I-10 by varying the flow-resistance coefficient by ±10 and ±20 percent. Figure 17 shows the difference in discharge at Burton Landing by varying the flow-resistance coefficient 0.015 by ±20 percent. A 10-percent change in the flow-resistance coefficient changed the discharge by about 4 percent; a -10-percent change caused discharge to vary by about 22 percent; and a 20-percent and -20-percent change caused discharge to vary by about 14 percent and 44 percent, respectively.

The flow model assumes that the cross-sectional geometry used is fixed (no scour or fill). Measured cross sections of the study reach were input as the cross-sectional geometry. Because there is little scouring or filling taking place in the study reach, the assumption of a fixed cross-sectional boundary seems reasonable.

Errors in boundary data will adversely affect the solution of the flow model. Increasing the water-surface slope (fall) by varying the downstream boundary data by -0.05 ft (approximately 5 percent of the mean range of the tidal stage) results in a change of discharge of about 65 percent. The opposite is true when decreasing the water-surface slope by increasing the downstream boundary data by 0.05 ft; there is a change in discharge of about -45 percent. Figure 18 shows the difference in discharge at Burton Landing by varying the downstream boundary by ±0.05 ft for data set 1. Errors in boundary data will be magnified in the solution of the flow model.

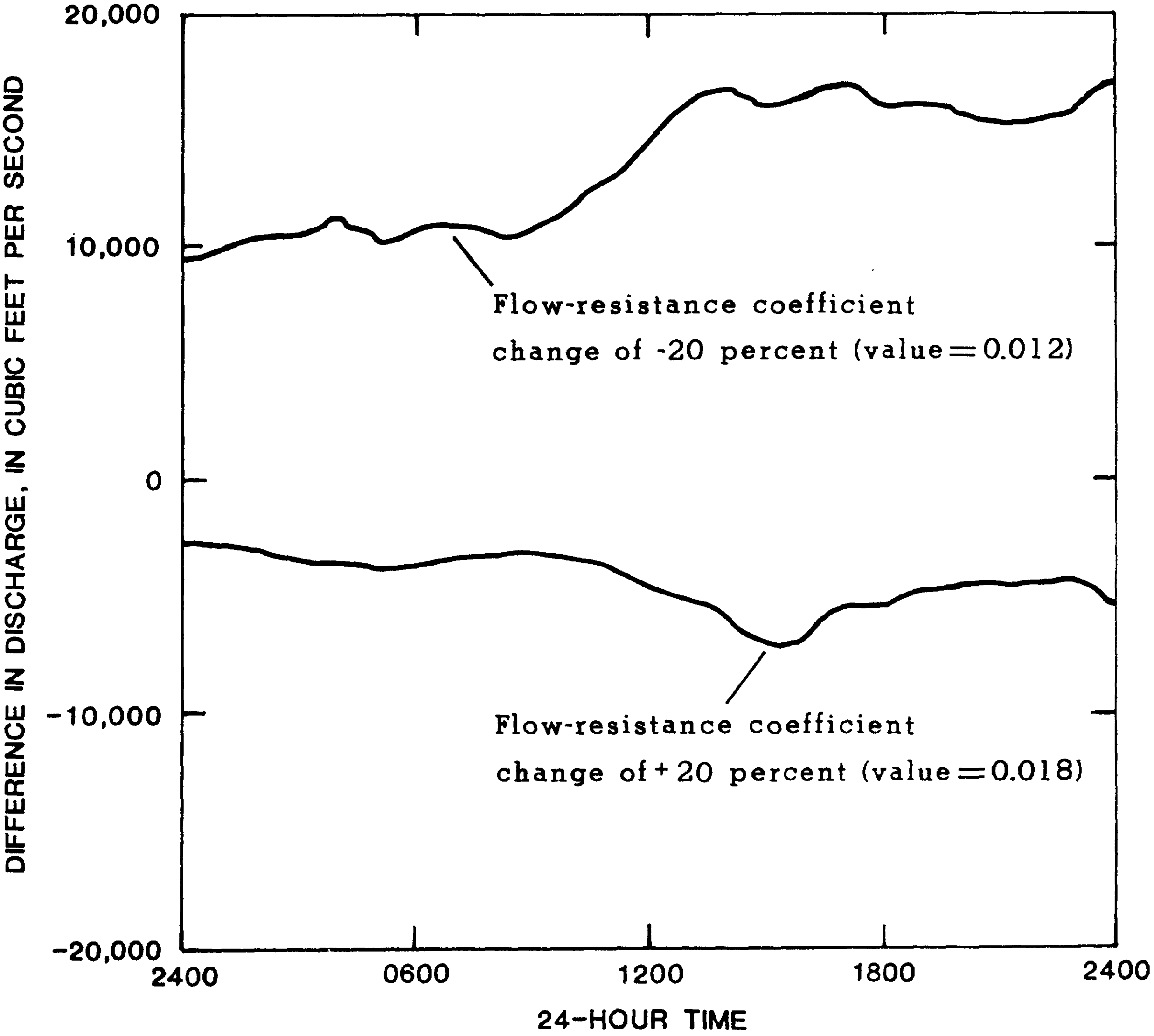


Figure 17.--Difference in discharge for the lower Calcasieu River at Burton Landing near Moss Lake for October 24, 1984, computed by varying the flow-resistance coefficient by ±20 percent from a fixed value of 0.015.

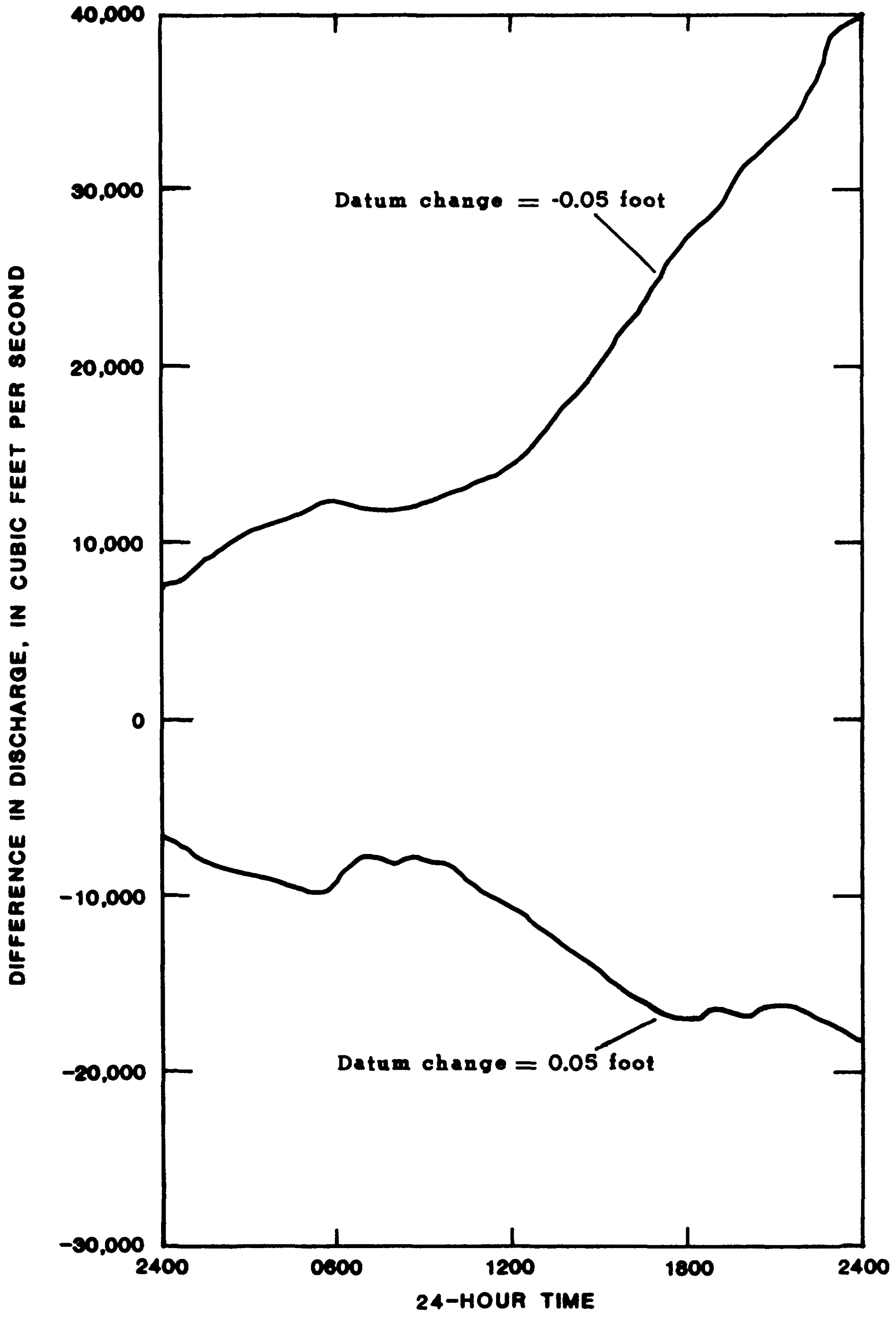


Figure 18.--Difference in discharge for the lower Calcasieu River at Burton Landing near Moss Lake for October 24, 1984, computed by varying the downstream boundary data by ±0.05 foot.

SUMMARY

Water movement in the lower Calcasieu River is a function of the configuration of the stream system, freshwater inflow, tidal action, and wind action. Tidal action, the dominant factor in water movement in the river occurs in three patterns: diurnal, the dominant pattern; semidiurnal; and mixed.

The U.S. Geological Survey's one-dimensional branch-network flow model was used to simulate discharge for a 15-mi reach of the lower Calcasieu River from the saltwater barrier at Lake Charles, La., to Burton Landing near Moss Lake. The flow model uses a weighted, four-point, implicit finite-difference approximation for solution of the unsteady flow equations governing flow in open channels. The functional form of the flow-resistance coefficient, varying resistance coefficient with discharge, was derived from measured data. The entire study reach was represented in the model by 29 cross sections.

The flow model was calibrated using five sets of discharge measurements made at the external boundaries of the study reach; average percent error between observed and simulated discharge for the calibration runs was 13.8 percent. The flow model was verified using three sets of discharge measurements; average percent error for the verification runs was 29.6 percent. The average error for all of the model runs was 25.2 percent.

The eight computed discharge hydrographs indicate that the flow model accurately simulates the flow, and computed discharges ranged from 59,500 to -51,100 ft^3/s. A comparison of measured discharge to computed discharge shows an average error of 18.5 percent for measurements above 10,000 ft^3/s and below -10,000 ft^3/s and an average error of 30.3 percent for those between $\pm$10,000 ft^3/s.

A sensitivity analysis of the flow model was run by varying the time-step size, flow-resistance coefficient, and boundary data. Computed discharges are very sensitive to changes in the flow-resistance coefficient and input boundary data.

The flow model does provide a tool to help analyze the hydraulic characteristics of the lower Calcasieu River. Additional discharge measurements will be made to further verify the calibration of the flow model. Wind data will be added to further refine the model. Also, additional discharge measurements within the study reach would further define the flow-distribution pattern through the ship channel and lakes.

SELECTED REFERENCES

Carlson, D.D., Stallworth, G.R., Dantin, L.J., Stuart, C.G., 1984, Water resources data for Louisiana, water year 1984, v. 1: U.S. Geological Survey Water-Data Report LA-84-1, 601 p.

Louisiana Department of Transportation and Development, 1984, The Louisiana water resources study commissions report to the 1984 legislature: Office of Public Works Resources, 438 p.

Schaffranek, R.W., Baltzer, R.A., and Goldberg, D.E., 1981, A model for simulation of flow in singular and interconnected channels: U.S. Geological Survey Techniques of Water-Resources Investigations, book 7, chap. C3, 110 p.

Shampine, W.J., 1970 [1971], Gazetteer of Louisiana lakes and reservoirs: Louisiana Department of Public Works Basic Records Report No. 4, 31 p.

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