HYDROLOGIC INVESTIGATIONS OF THE LOWER CALCASIEU RIVER, LOUISIANA

By Max J. Forbes, Jr.

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CONVERSION FACTORS AND ABBREVIATIONS

For the convenience of readers who may 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 unit	By	To obtain metric unit
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square foot (ft^2)	929.0	square centimeter (cm^2)
	0.09294	square meter (m^2)
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon (gal)	3.785	liter (L)
gallon per minute (gal/min)	0.06308	liter per second (L/s)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
	1,233	cubic meter (m^3)
mile per hour (mi/h)	1.609	kilometer per hour (km/h)

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 "Mean Sea Level of 1929."

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ABSTRACT

Water movement in the lower Calcasieu River, a tidal estuary, is a function of the physical configuration of the river-estuary system, freshwater inflow, tidal action, and wind action. The configuration of many of the waterways and particularly the 40-foot deep ship channel permits large amounts of water to easily move into or out of the river. Freshwater inflows, though large at times, generally are low; minimum and maximum flows at Kinder are 136 and 182,000 ft^3/s (cubic feet per second), respectively, and average and median flows are 2,500 and 1,030 ft^3/s, respectively.

Tidal action, the dominant long-term factor in water movement, occurs in three patterns, diurnal, semi-diurnal, and mixed; diurnal is dominant. Measurements in June 1984 indicated that about 75 percent of the gulf water moving into the lower Calcasieu River on an incoming tide is stored in Calcasieu Lake and other waterways south of Burton Landing, and that about 5 percent of the tidal inflow reaches the Lake Charles area. Studies of tidal lag time indicated that about 80 percent of the total incoming tidal-cycle time required for a tidal peak to move from Cameron to Indian Bayou is expended in moving the peak through the Cameron to Burton Landing reach.

Winds are generally southerly; average speed is about 8.7 miles per hour. Wind can cause dramatic changes in water movement and stage over a relatively short period of time. The maximum and minimum water-surface elevations at Cameron, caused primarily by wind, were 10.53 feet (Hurricane Audrey in 1957) above and 5.3 feet (1984) below sea level, respectively.

The potential for mechanical reaeration, a function of velocity and depth, is low (on a unit volume basis) in the deep and slow-moving waters of the lower Calcasieu River. Calculation of reaeration coefficients in tidal streams is hampered by the unsuitability of the river for the use of conventional calculation methods, such as tracer dye studies, that are dependent on sustained and one-directional streamflow.

INTRODUCTION

The lower Calcasieu River is no longer natural in either configuration or in the quality of its waters. The potential for additional changes in the use of the river concerns local, State, and Federal agencies, institutes of learning, and interest groups. Some of this group of concerned organizations are carrying out functions mandated by law, regulating certain aspects of the water environment. Others are interested in the flow system and are studying the lower Calcasieu River so that future planners will have information on which to base decisions. Still others are concerned with maintaining the natural environment in this wetland area. All organizations worked together to keep the benefits of the river and lakes available to future generations. Appendix 1 presents a list of organizations and a summary of ongoing activities that concern the hydrology of the lower Calcasieu River.

Early interest in the water resources of the lower Calcasieu River were associated with shipping and rice farming. The lower Calcasieu River near Lake Charles was deep and wide enough to accommodate many of the oceangoing vessels of the time. A major obstacle was a sand-bar in the river at the south end of Calcasieu Lake. To alleviate this problem a shallow channel (5 ft and later 13 ft deep) was cut through the bar in the late 1800's to permit access of vessels.

Rice farming requires large amounts of water for flooding fields. Prior to modern well drilling techniques permitting the use of ground water, surface waters were heavily used. Large pumping plants were built along the lower Calcasieu River north of Lake Charles to supply the farmers. Today only three pumping plants provide water from the river or tributaries to farmers.

Development of petroleum-based industries began in the first third of the 20th century, requiring large amounts of water for processing and waste removal. Several of these industries were located in Lake Charles where water and other necessary raw materials were available, as well as suitable land and transportation.

Recreational boating is high on the list of today's users of the lower Calcasieu River, and fishermen and water skiers have easy access to waterways. The fishing industry was developed in the Cameron area where quick access to the Gulf of Mexico and reasonable access to the roads and railroads of Lake Charles were available, and where the necessities of a home port could be established.

In the 1900's, a sizable fur industry developed in the marshes south of Lake Charles. Marshes that provide habitat for fur-bearing animals are dependent on the fluctuation of waters that typifies the coastal estuarine environment.

Purpose and Scope

The purpose of this report is to present a summary of hydrologic data and to describe surface-water features and processes in the lower Calcasieu River. Information is included on stream discharge at different flow conditions, tidal characteristics (types, magnitude, record maximum and minimum readings, gage datum details, and timing of tides within the system), and wind characteristics (prevailing directions, variation with season, and magnitude). Also included are descriptions of dredged channels, controls, tributaries and distributaries, representative channel cross sections (dredged and natural), and details of openings between the ship channel and Calcasieu Lake. A section addresses the computation of discharge in the reach between the saltwater barrier and Burton Landing at Moss Lake. Another section discusses reaeration in tidal rivers and suggests a technique for computing reaeration coefficients in such rivers.

Most surface-water data used for this investigation are on file at the U.S. Geological Survey; some stage data were obtained from the U.S. Army Corps of Engineers. Tide tables and wind data were extracted from reports of the National Oceanic and Atmospheric Administration (1985a, 1985b). Predictions of tide elevations in the lower Calcasieu are based on data collected at the Galveston, Texas, Tide Reference Station, and the description of wind characteristics is based on data collected at the Lake Charles airport.

Acknowledgments

A special mention of thanks is due those persons of the Data Collection Unit, Coastal Engineering Section, Hydraulic and Hydrologic Branch, U.S. Army Corps of Engineers, New Orleans District, who provided extensive records of stage data for the Calcasieu River. Representatives of the Louisiana Departments of Environmental Quality and Wildlife and Fisheries provided essential information on the study area and made available their equipment and facilities. Employees of the Southern Pacific Transportation Company, Lake Charles, provided access to the railroad bridge above Interstate 10 (I-10) and cooperated with bridge operations during a number of discharge measurements made from the bridge. The study was conducted by the U.S. Geological Survey, in cooperation with the Louisiana Department of Environmental Quality, Office of Water Resources.

GENERAL DESCRIPTION

The headwaters of the Calcasieu River are in the uplands of Vernon Parish, and the river flows southward in an eastward-trending arc through parts of Rapides, Allen, and Jefferson Davis Parishes. Near Kinder the stream leaves the uplands and enters the coastal plain at the northeastern corner of Calcasieu Parish. At the gaging station west of Kinder, the Calcasieu River is relatively shallow. Only a few miles downstream, the stream enters the tidal province. Figure 1 shows the drainage of the Calcasieu River and its tributaries.

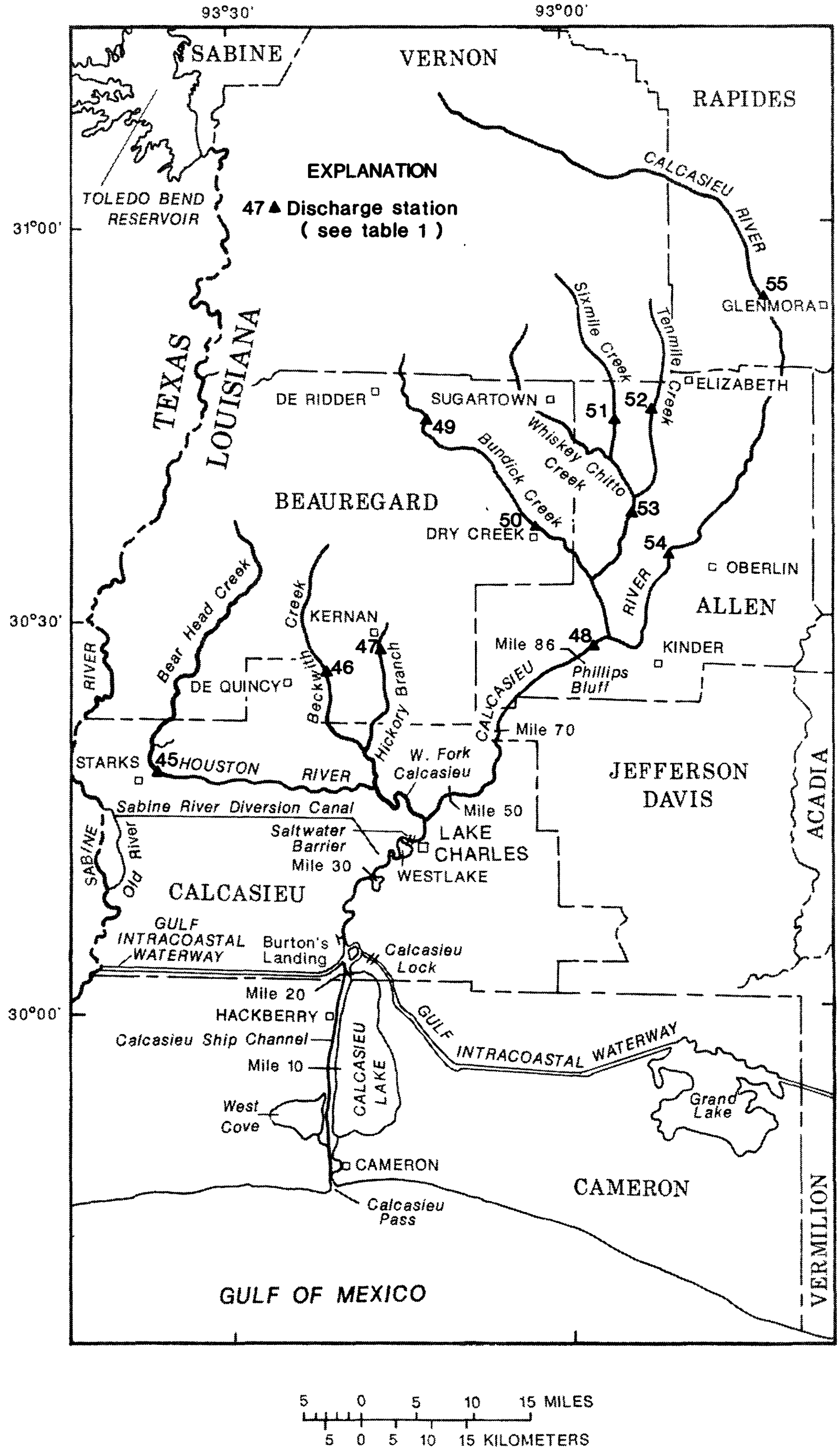

Figure 1.--Drainage of the Calcasieu River and associated waterways.

The lower Calcasieu River, for purposes of this report, extends from about 10 mi north of the city of Lake Charles to the Gulf of Mexico (fig. 2). The terrain in this part of southwestern Louisiana is a flat almost-level coastal plain. Extensive coastal marshes begin south of Lake Charles and cover much of Cameron Parish. Land surface elevations in the study area range from about 25 ft above sea level in Calcasieu Parish to zero or less in parts of both parishes. The Calcasieu River with its associated lakes and waterways provides considerable water surface throughout the study area. Dominant surface-water areas are Calcasieu Lake, Lake Charles, Prien Lake, the ship channel from the city of Lake Charles to the Gulf of Mexico, and the Gulf Intracoastal Waterway.

The climate of the area is generally subtropical with a strong maritime character, influenced to a large degree by the large amount of water surface and the proximity of the gulf. Throughout the year these influences affect the relative humidity and temperature, decreasing the range between extremes as compared to more inland sites. Air temperatures of record range from a minimum of -16°C in 1899 to 41°C in 1930; however, freezing or below freezing temperatures normally occur only about 11 days per year, and summer temperatures rarely exceed 38°C. The prevailing wind is from the south during much of the year, and winds are usually light. Rainfall (based on data collected from 1947 to date at the rain gage at Lake Charles) is heavy, averaging about 56 in/yr. Rainfall is reasonably distributed throughout the year and generally is less during October. All other months, except March, have an average total of more than 4 in. of rainfall, with the total for July often more than 7 in. Almost all rainfall is of the convective and air mass types, showery and brief. In winter months nearly continuous frontal rains can persist for a few days. Extremes in precipitation occur during all seasons. Notable seasonal rainfall totals (National Oceanic and Atmospheric Administration, 1985b) for a 24-hour period include: 4.75 in. in March 1951; 16.01 in. in June 1947; 10.22 in. in August 1962; and 10.00 in. in November 1961. Since 1900, the centers of five hurricanes have passed very near the city of Lake Charles.

HISTORICAL ACTIVITY AFFECTING THE HYDROLOGY OF THE LOWER CALCASIEU RIVER

Throughout the history of the lower Calcasieu River, there have been efforts to improve accessibility and usability of the river. In the mid-1800's, the channel through Calcasieu Lake had a maximum depth of 13 ft and a 3-foot depth existed at the bar at the northern end of Calcasieu Pass (between the Gulf of Mexico and Calcasieu Lake). In 1871, the U.S. Army Corps of Engineers made its first report of the navigation situation of the Calcasieu River. As a result, a channel 5 ft deep by 80 ft wide was established through the bar. From 1871 to the late 1930's, the channel was maintained and deepened to a final depth of 13 ft.

To permit the access of deeper-draft vessels to Lake Charles and to avoid the maintenance of a deeper channel through Calcasieu Lake, the Lake Charles Deep Water Channel (30 ft deep by 125 ft wide) between the Sabine and Calcasieu Rivers was completed between 1937 and 1940. This channel was along the route of the present-day Gulf Intracoastal Waterway. Thus, the old route through Calcasieu Lake was bypassed.

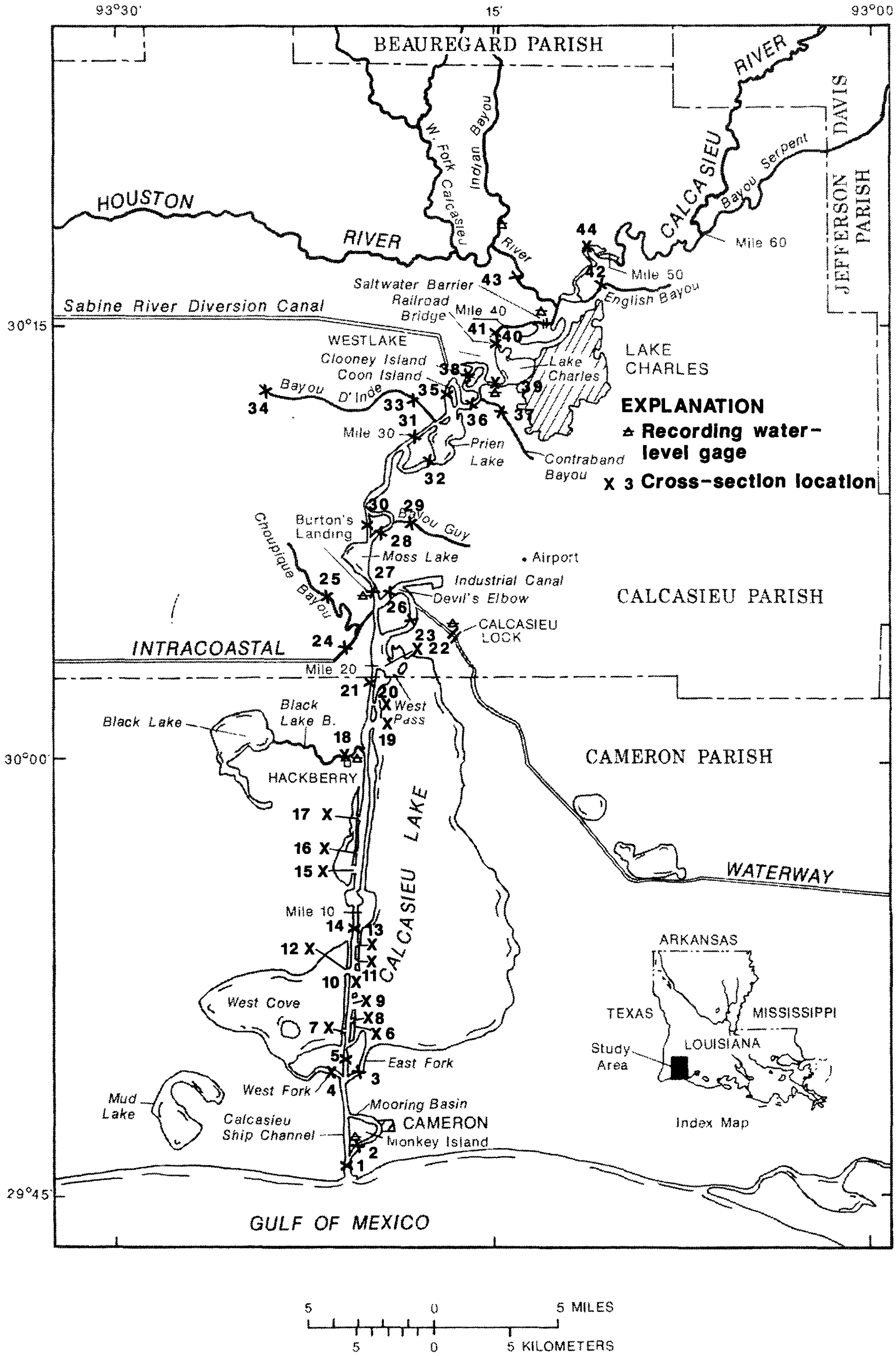

Figure 2.--Study area of the lower Calcasieu River.

The Lake Charles Deep Water Channel was replaced in 1941 by parts of the first Calcasieu Ship Channel, completed from the gulf to Lake Charles at a depth of 30 ft and a width of 250 ft. Figure 2 shows the route of the channel, which bordered Calcasieu Lake to the west and created Monkey Island at Cameron. In 1953, the channel was deepened to 35 ft; in 1968, the channel was deepened and widened to 40 ft by 400 ft, respectively. The mooring basin (fig. 2) located just upstream from Cameron was expanded to a width, length, and depth of 350, 2,000, and 40 ft, respectively.

Additional off-channel work was done during the stages of development of the Ship Channel. A 35-foot deep by 250-foot wide channel was completed around Clooney Island in 1953. In 1968, this channel was deepened and widened to 40 ft by 400 ft, respectively, and a 40-foot deep by 200-foot wide channel was constructed on the west side of the Coon Island loop and included a turning basin (750 ft wide, 1,000 ft long, and 40 ft deep) at the end of that channel (north end of the loop). Also in 1968, a 35-foot deep by 250-foot wide channel with an upstream-end turning basin 750 wide and 1,000 ft long was extended up the west side of Lake Charles (the lake) to a point about 1,000 ft south of the railroad bridge. A channel about 35 ft deep by 300 ft wide was dredged in Contraband Bayou to a point about 2,600 ft from the Calcasieu River. In addition to turning basins mentioned, since about 1953, a primary basin has been maintained at the juncture of the outflow channel from Prien Lake and the Ship Channel. Since 1968, dimensions are 1,000 by 1,000 ft with a depth of 40 ft. In addition to these activities, a 12-foot deep by 200-foot wide channel around Monkey Island at Cameron, connecting the ship channel at each end, has been maintained since 1968.

The Industrial Canal (fig. 2) was established in 1978 by dredging from the ship channel through the bend in Devil's Elbow and eastward to a point about 2.75 mi from the ship channel. The connecting channel is 40 ft deep and 400 ft wide. A turning basin with dimensions of 1,400 by 1,600 ft and depth of 40 ft is located at the end of the canal.

The Gulf Intracoastal Waterway crosses the Calcasieu River channel just north of Calcasieu Lake and about 20 mi from the gulf. The waterway is maintained at a depth of 12 ft and a width of 125 ft. Calcasieu Lock, located on the waterway about 2.5 mi east of the Calcasieu Ship channel, was completed in 1952 and controls saltwater movement eastward into the Grand Lake area.

The Calcasieu River saltwater barrier, completed in 1968, is located on the river just north of Lake Charles (fig. 2). As the name implies, the barrier is designed to minimize the movement of saltwater into the deep and numerous channels upstream. In constructing the barrier, a loop of the river was closed at one point and the barrier structure was placed across the neck of the loop. The barrier consists of flood and navigation control structures, operating side by side. The flood control structure consists of a spillway with five tainter gates, each 25 ft high by 40 ft wide. The bottom elevation of the gates is 20.0 ft below sea level, and thus a total opening of 4,000 ft^2 exists with water surface at sea level and with all gates open. The navigation control structure has one pair of steel sector gates in a concrete bay 56 ft wide and 69 ft in length. The bottom elevation of the bay is at 13.8 ft below sea level, and thus about 770 ft^2 of opening area exists with the water surface at sea level. The barrier is operated to maintain a stage of 2.5 ft (about 1 ft above sea level) on the upstream side of the structure.

HYDROLOGIC FEATURES AND PROCESSES

Water movement in the lower Calcasieu River, a tidal estuary, is a function of the configuration of the hydrologic system, freshwater inflow, tidal action, and wind action.

Physical Characteristics

To further define the physical characteristics of the lower Calcasieu River, a series of cross sections of waterways is presented in figures 3 through 18. Several sections of the ship channel are included to show the magnitude of the volume of water in the system in terms of widths and depths. In these channels, cross-sectional areas are large, and flow velocities normally are small. Cross sections of tributaries and adjacent waterways are included to help describe flow paths to and from the dominant ship channel. Cross sections of channels between the ship channel and Calcasieu Lake are included to delineate available flow paths between these bodies of water. Appendix 2 is a cross reference of numbers given to cross sections during an intensive survey in 1984 and cross-section numbers used in this report.

Freshwater Inflow to the Lower Calcasieu River

Figure 1 shows the network of streams that provide freshwater flow to the lower Calcasieu River and the location of continuous-record gaging stations of the U.S. Geological Survey. Streamflow characteristics for these stations are described in tables 1 and 2. Table 1 shows the 7-day 10-year lowflow[1], a frequently used streamflow parameter in waste dilution computations and wastewater permit considerations; streamflow frequency and duration statistics; and maximum and minimum flows of record for the streams at these sites.

Relatively low streamflows occur during June through November (table 2), with the lowest flows for most streams normally occurring in October; these lowest flows generally coincide with the low rainfall of October. Also the flow of Whisky Chitto Creek contributes more than 75 percent of the average flow for the gaging station, lower Calcasieu River near Kinder, although Whisky Chitto Creek contributes less than a third of the drainage area of the Calcasieu River at that point.

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[1] An average flow representing seven consecutive days will be equal to or less than the 7-day 10-year low flow at intervals averaging 10 years, or the probability is 1 in 10 that this average flow will be equal to or less than the 7-day 10-year low flow in any one climatic year (April-March).

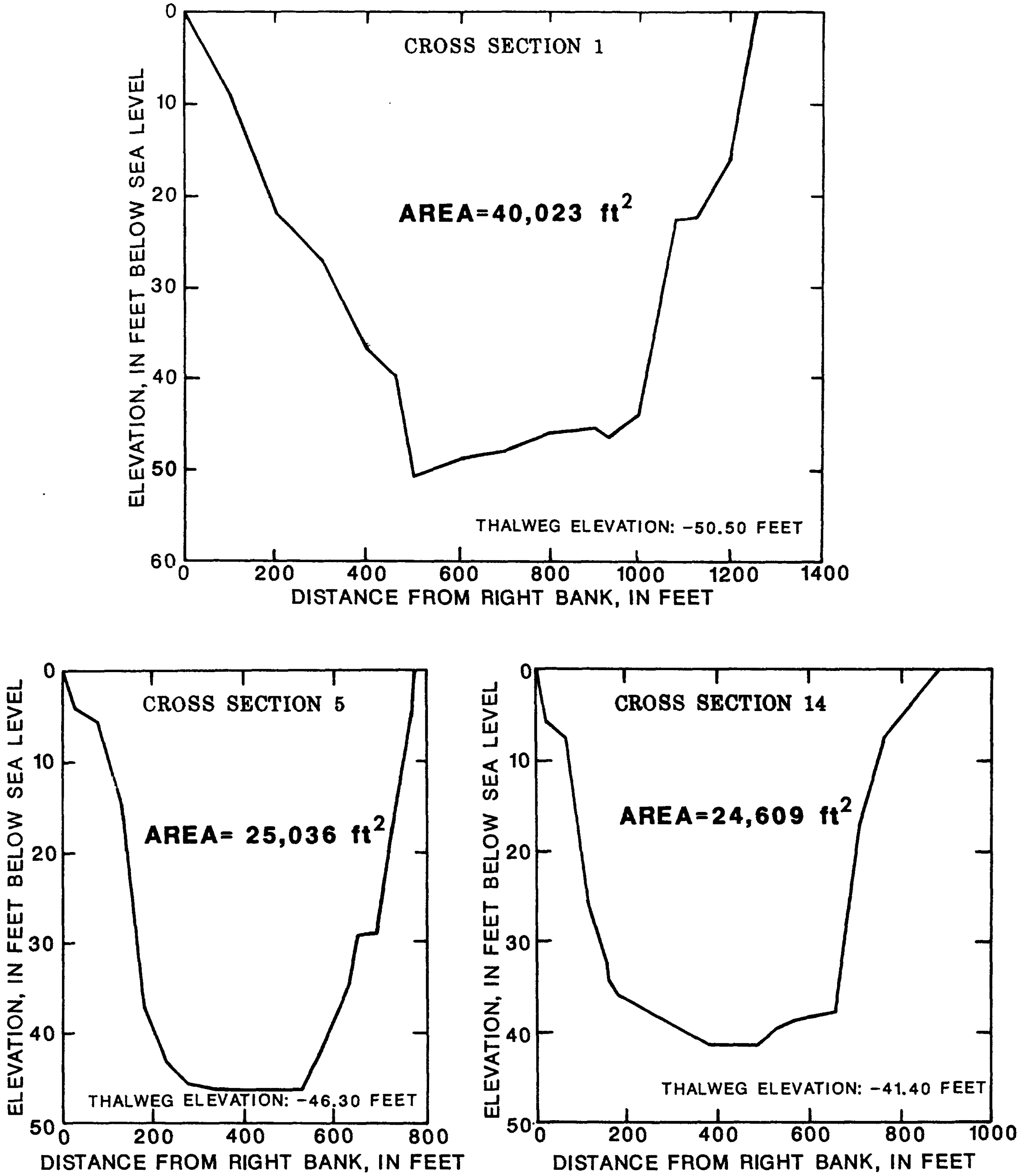


Figure 3.--Cross sections of Calcasieu Ship Channel for sites 1, 5, and 14. (See fig. 2 for locations.)

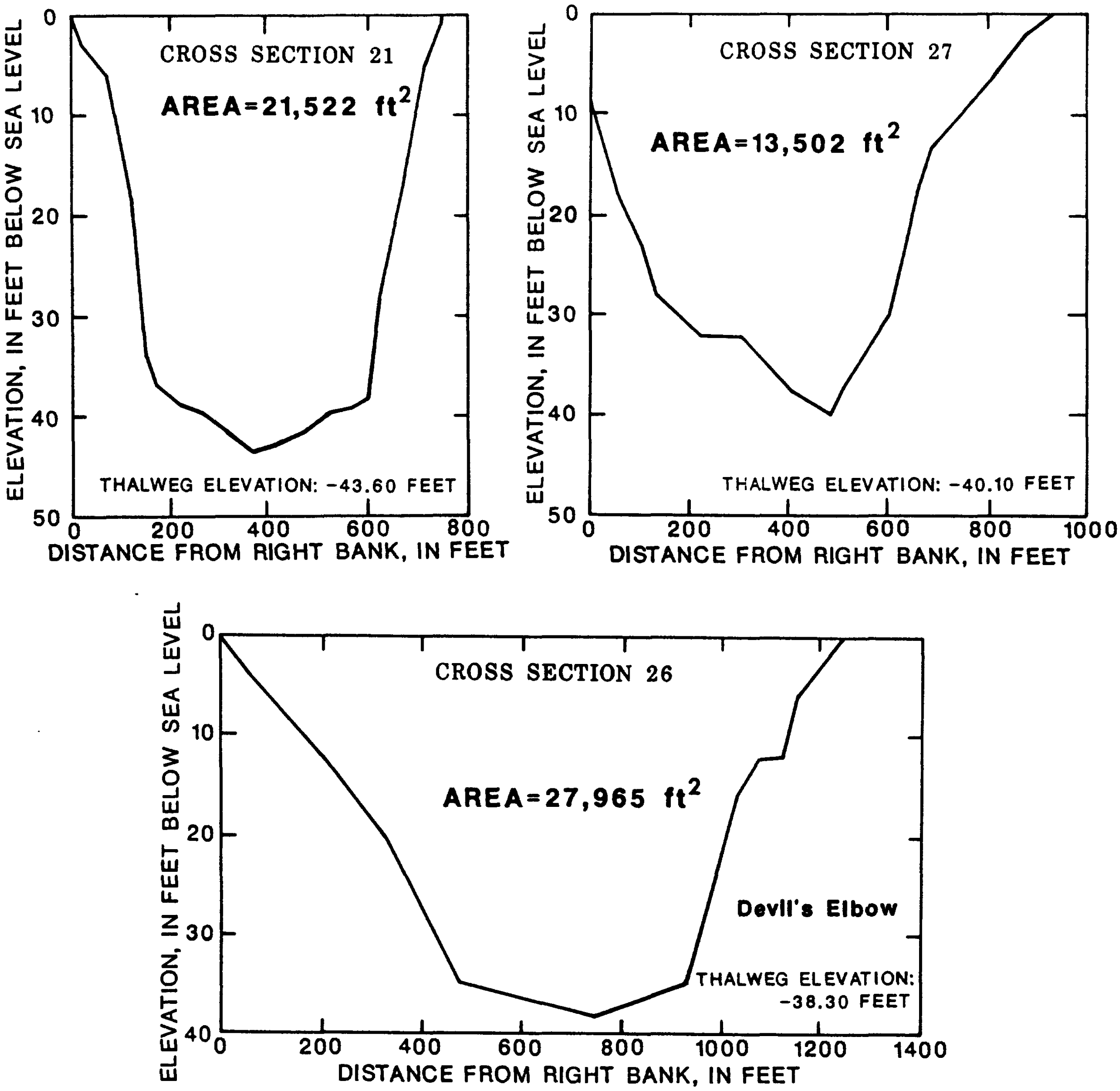


Figure 4.--Cross sections of Calcasieu Ship Channel for sites 21, 26, and 27. (See fig. 2 for locations.)

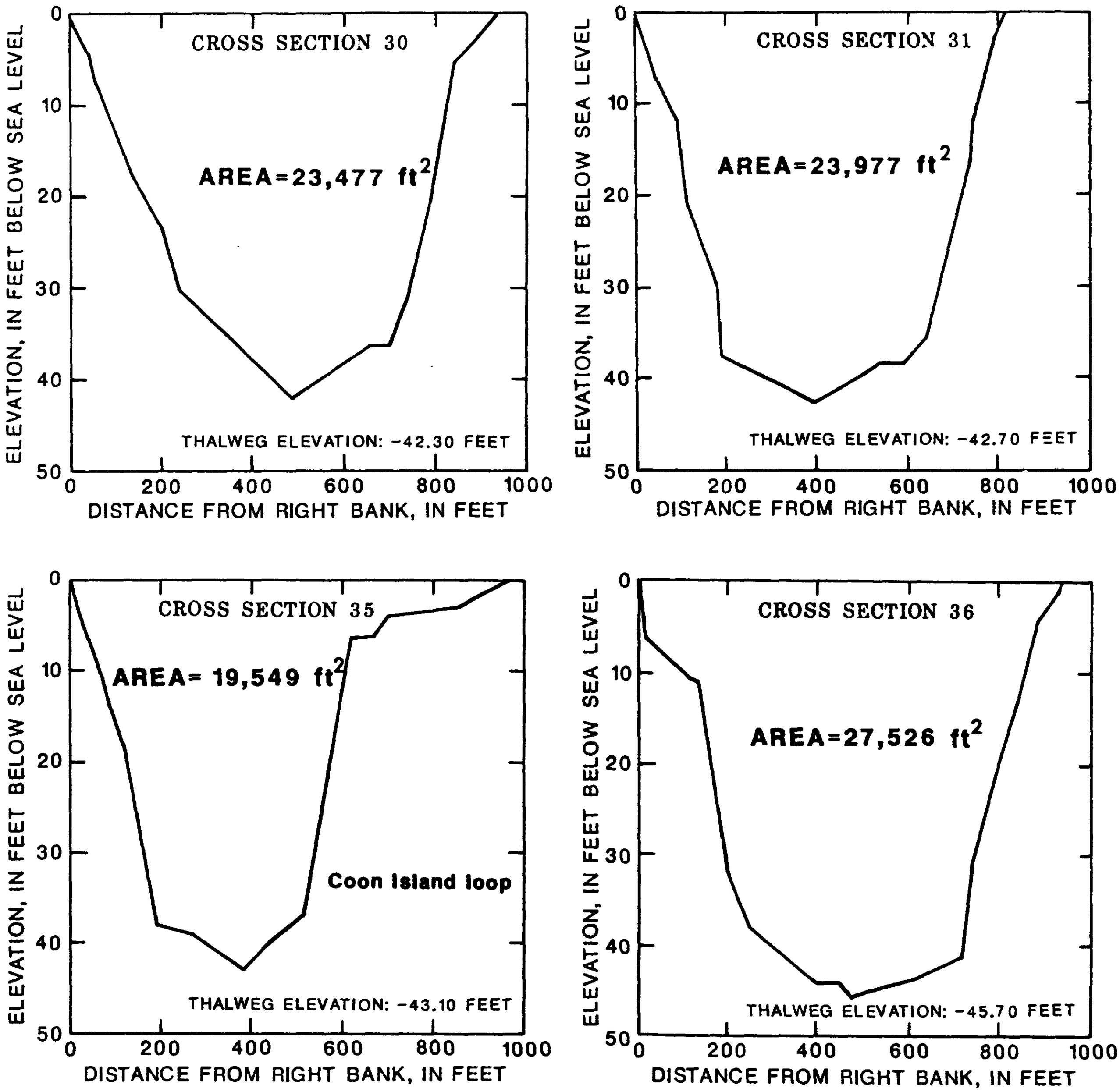
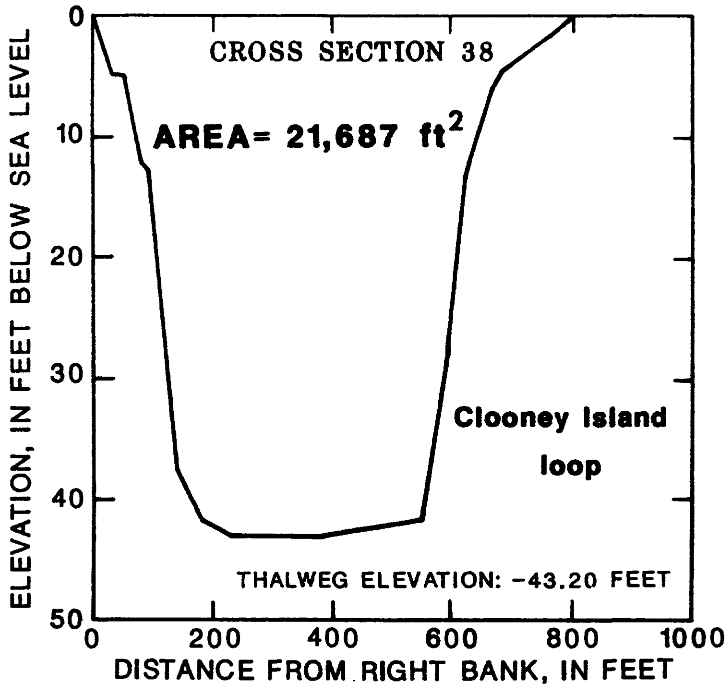


Figure 5.--Cross sections of Calcasieu Ship Channel for sites 30, 31, 35, and 36. (See fig. 2 for locations.)



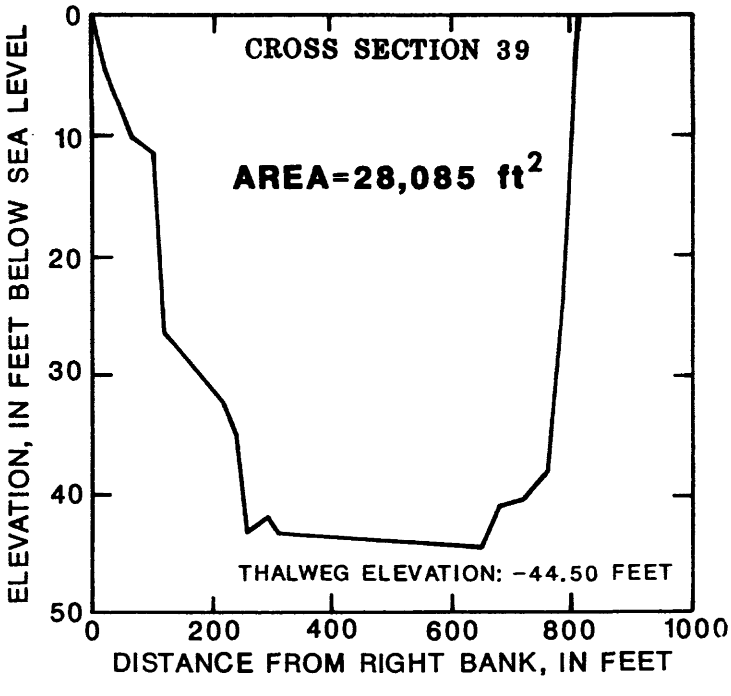


Figure 6.--Cross sections of Calcasieu Ship Channel for sites 38 and 39. (See fig. 2 for locations.)

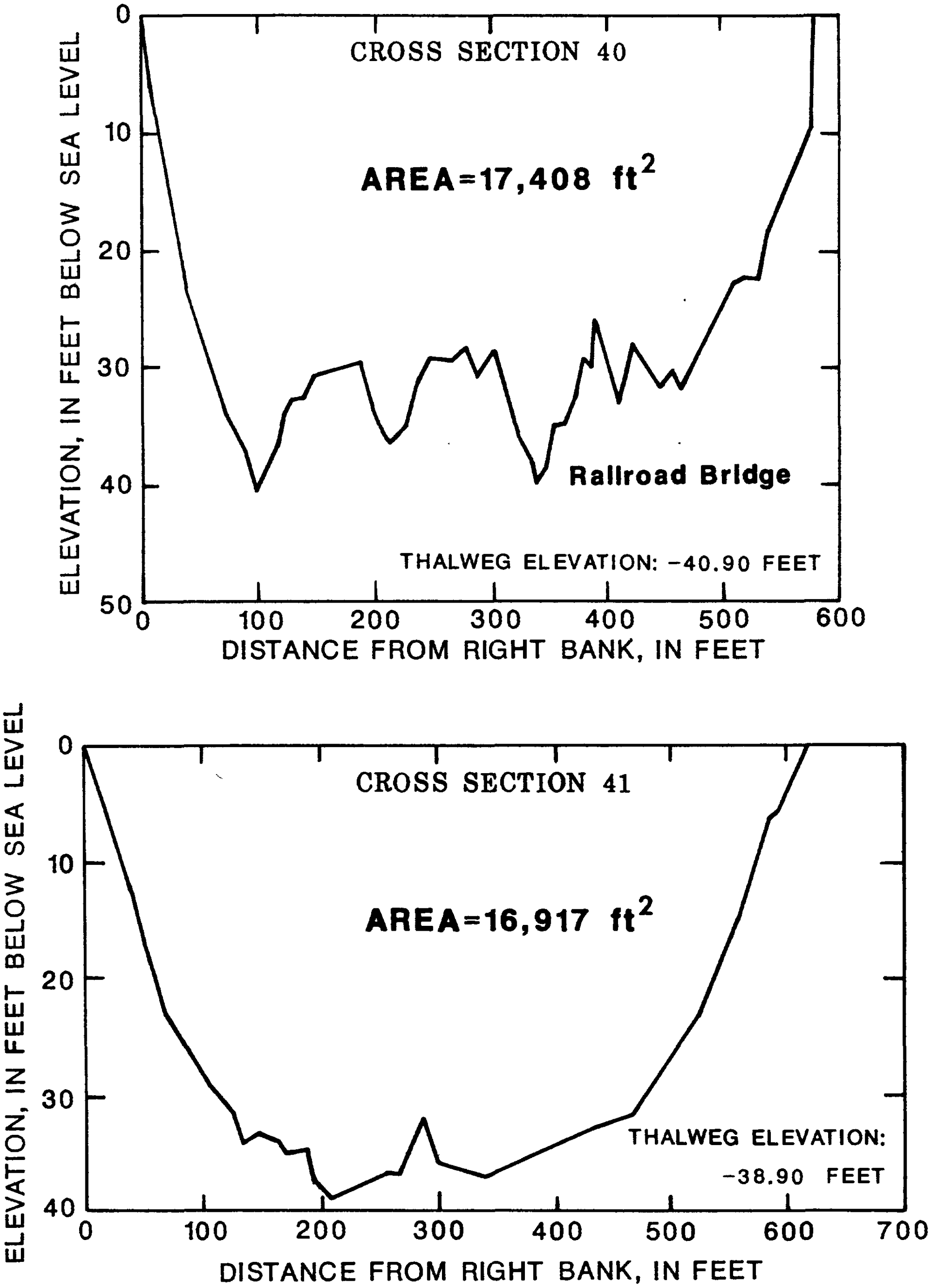


Figure 7.--Cross sections of Calcasieu Ship Channel for sites 40 and 41. (See fig. 2 for locations.)

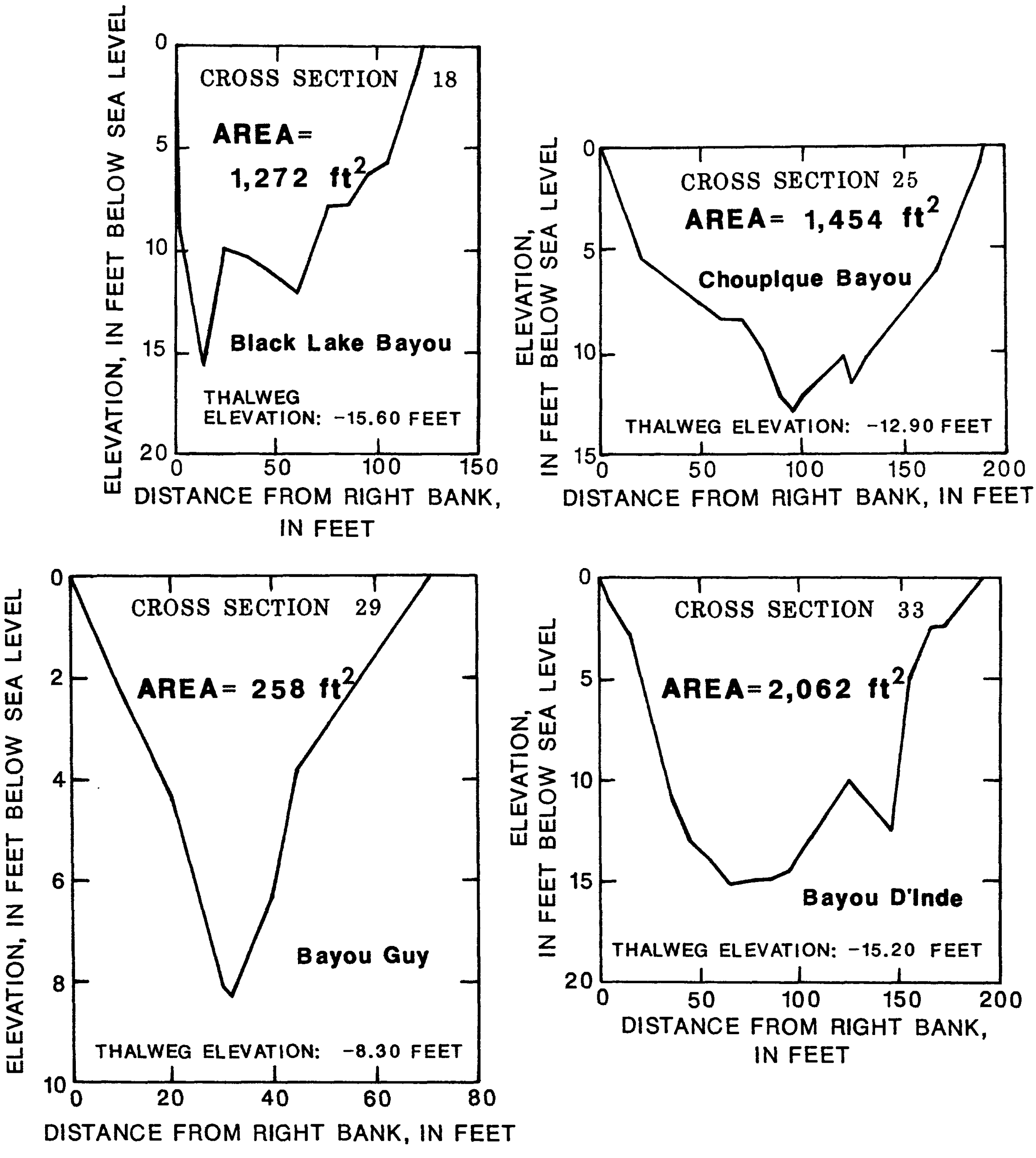


Figure 8.--Cross sections of tributaries to lower Calcasieu River for sites 18, 25, 29, and 33. (See fig. 2 for locations.)

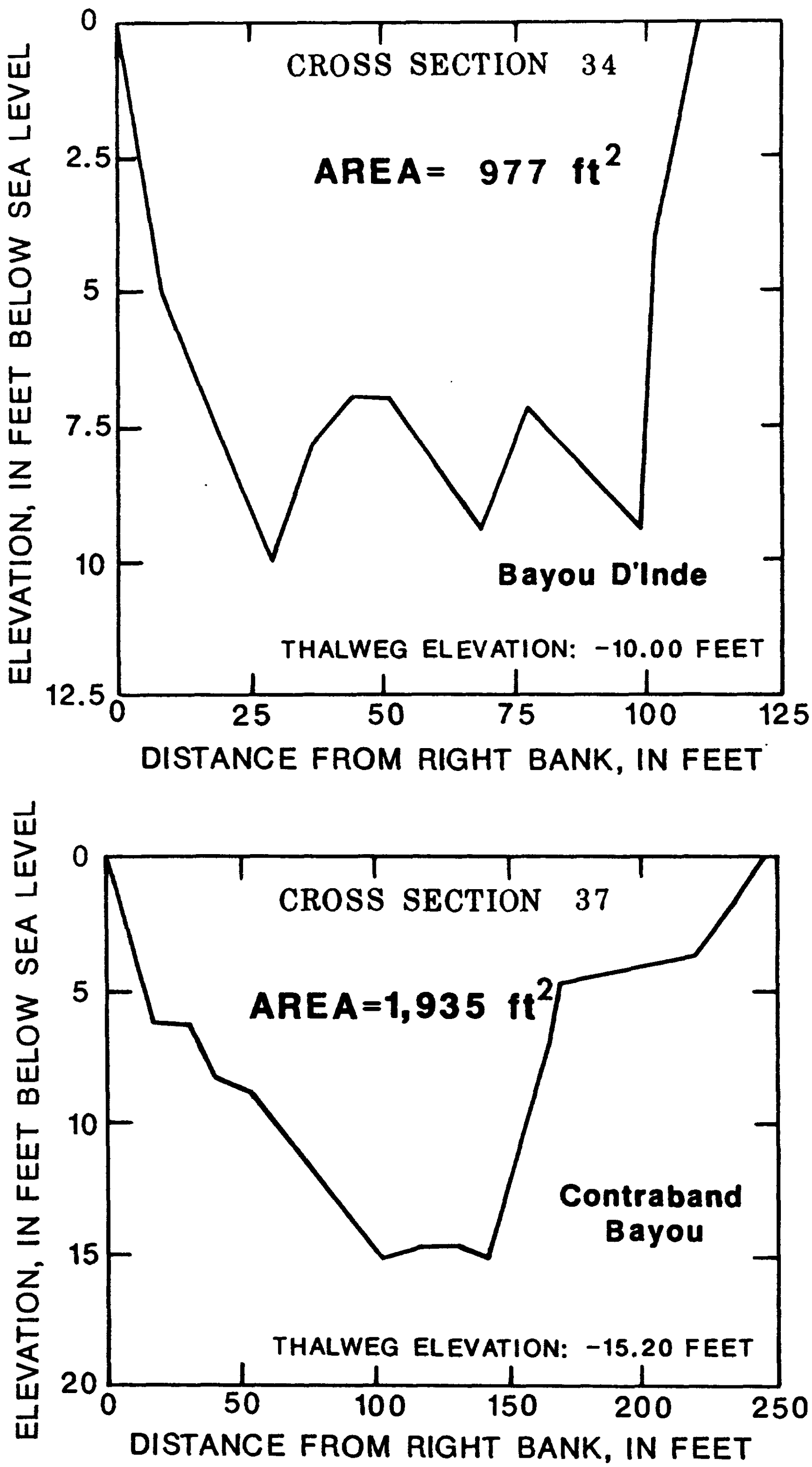


Figure 9.--Cross sections of tributaries to lower Calcasieu River for sites 34 and 37. (See fig. 2 for locations.)

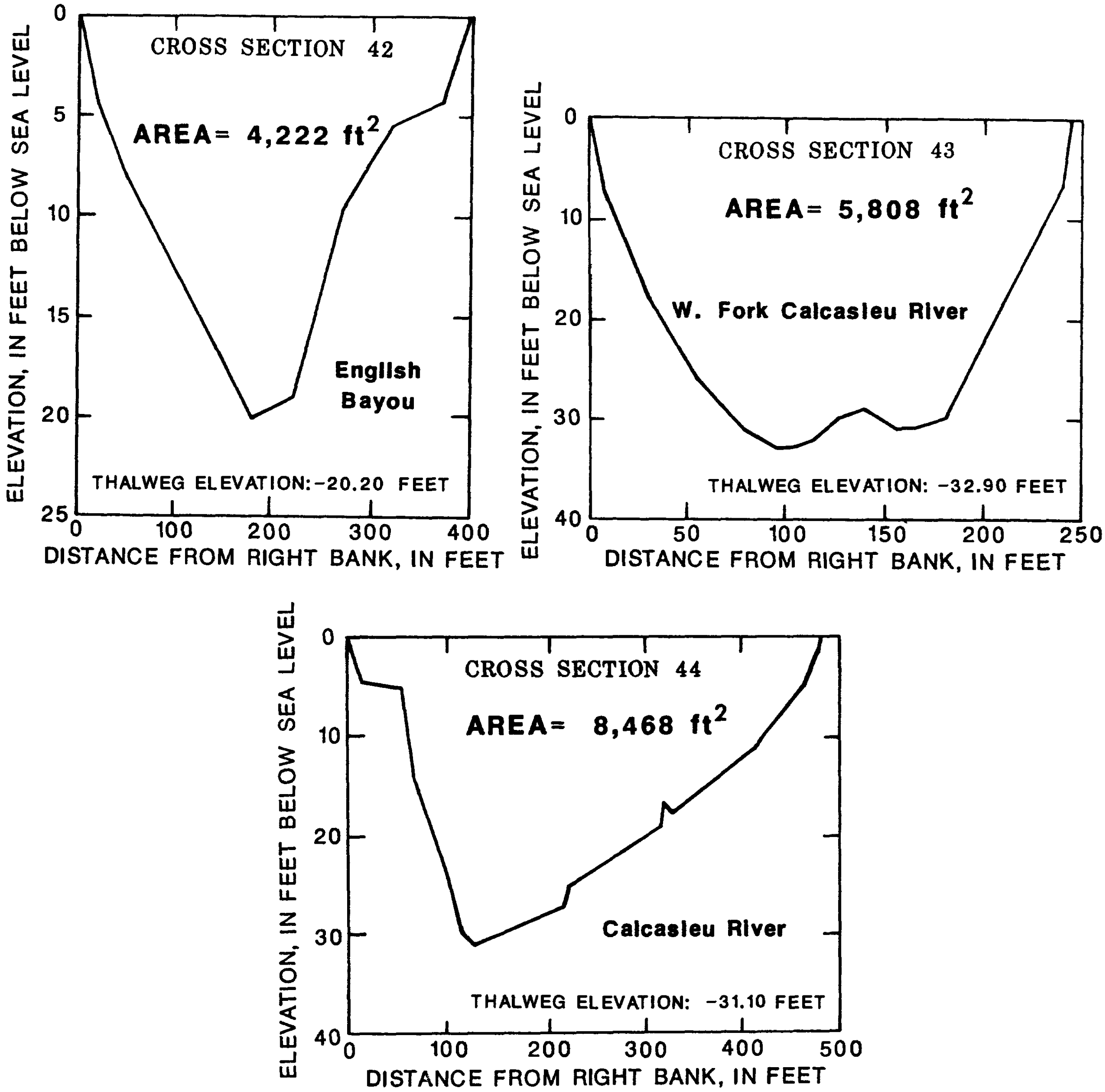


Figure 10.--Cross sections of tributaries to lower Calcasieu River for sites 42, 43, and 44. (See fig. 2 for locations.)

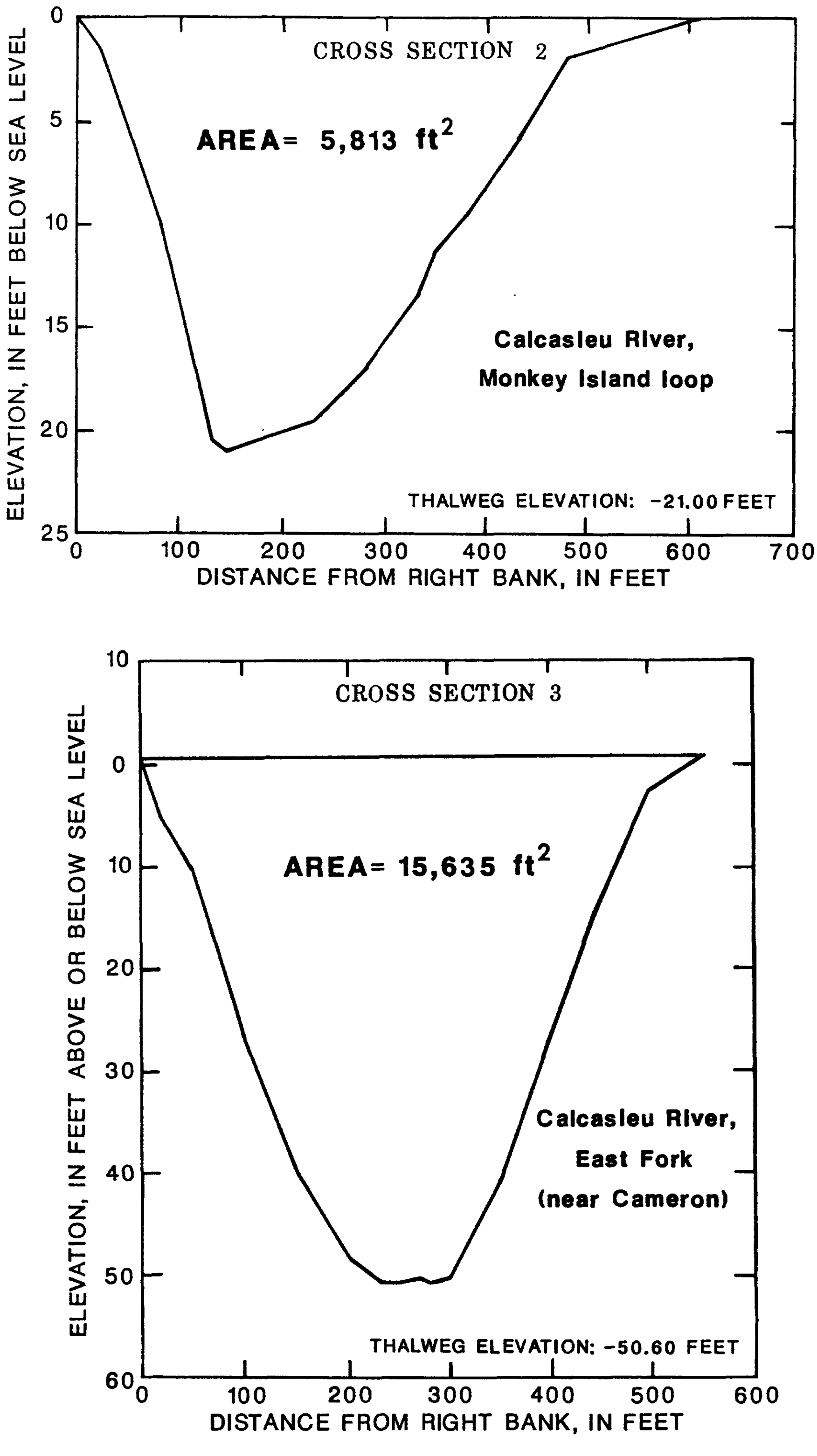


Figure 11.--Cross sections of waterways adjacent to Calcasieu Ship Channel for sites 2 and 3. (See fig. 2 for locations.)

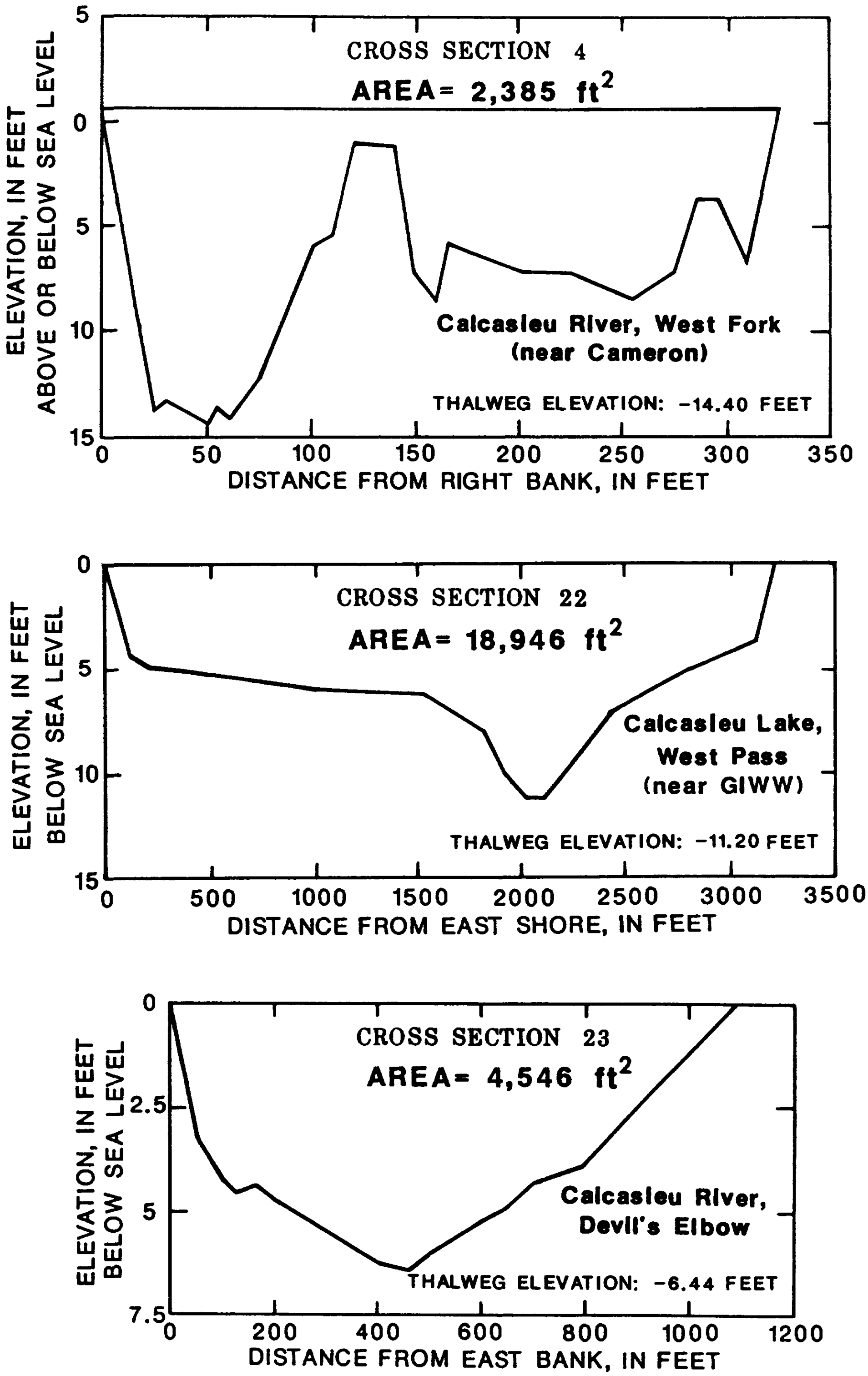


Figure 12.--Cross sections of waterways adjacent to Calcasieu Ship Channel for sites 4, 22, and 23. (See fig. 2 for locations.)

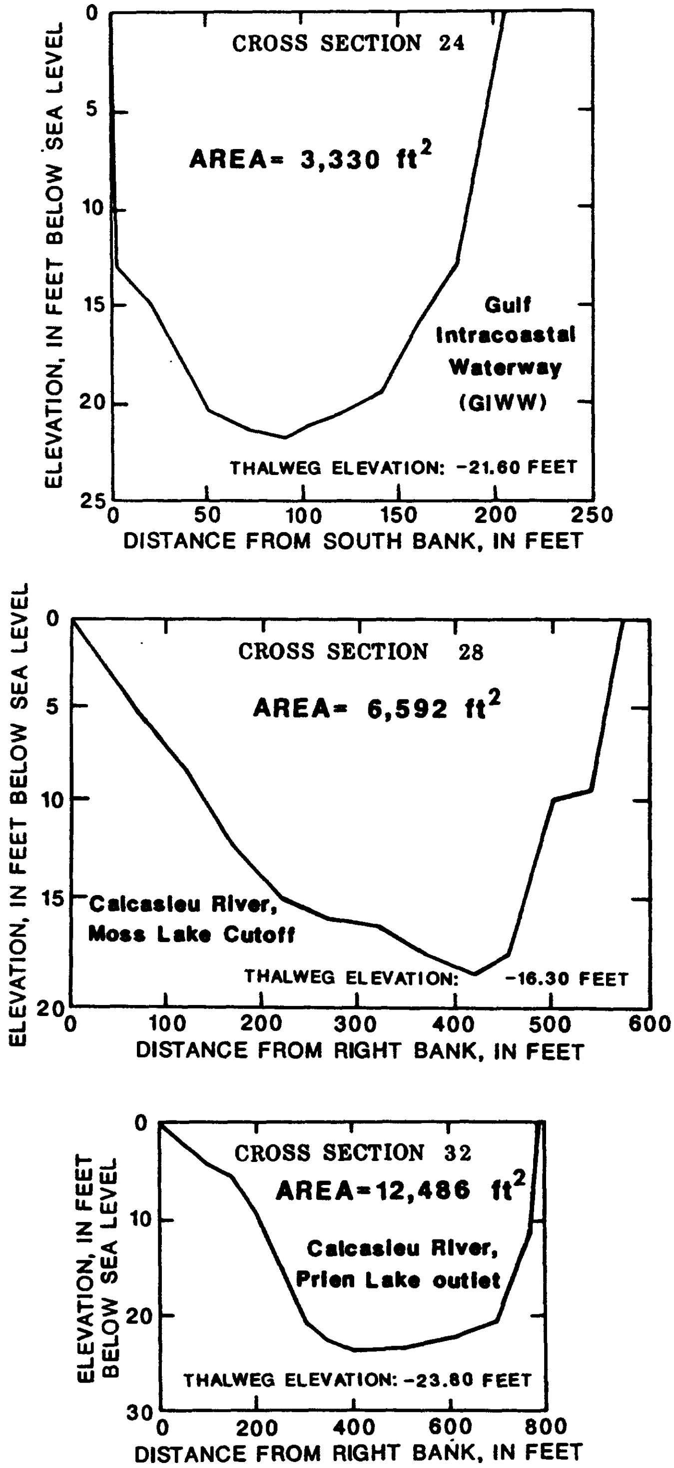


Figure 13.--Cross sections of waterways adjacent to Calcasieu Ship Channel for sites 24, 28, and 32. (See fig. 2 for locations.)

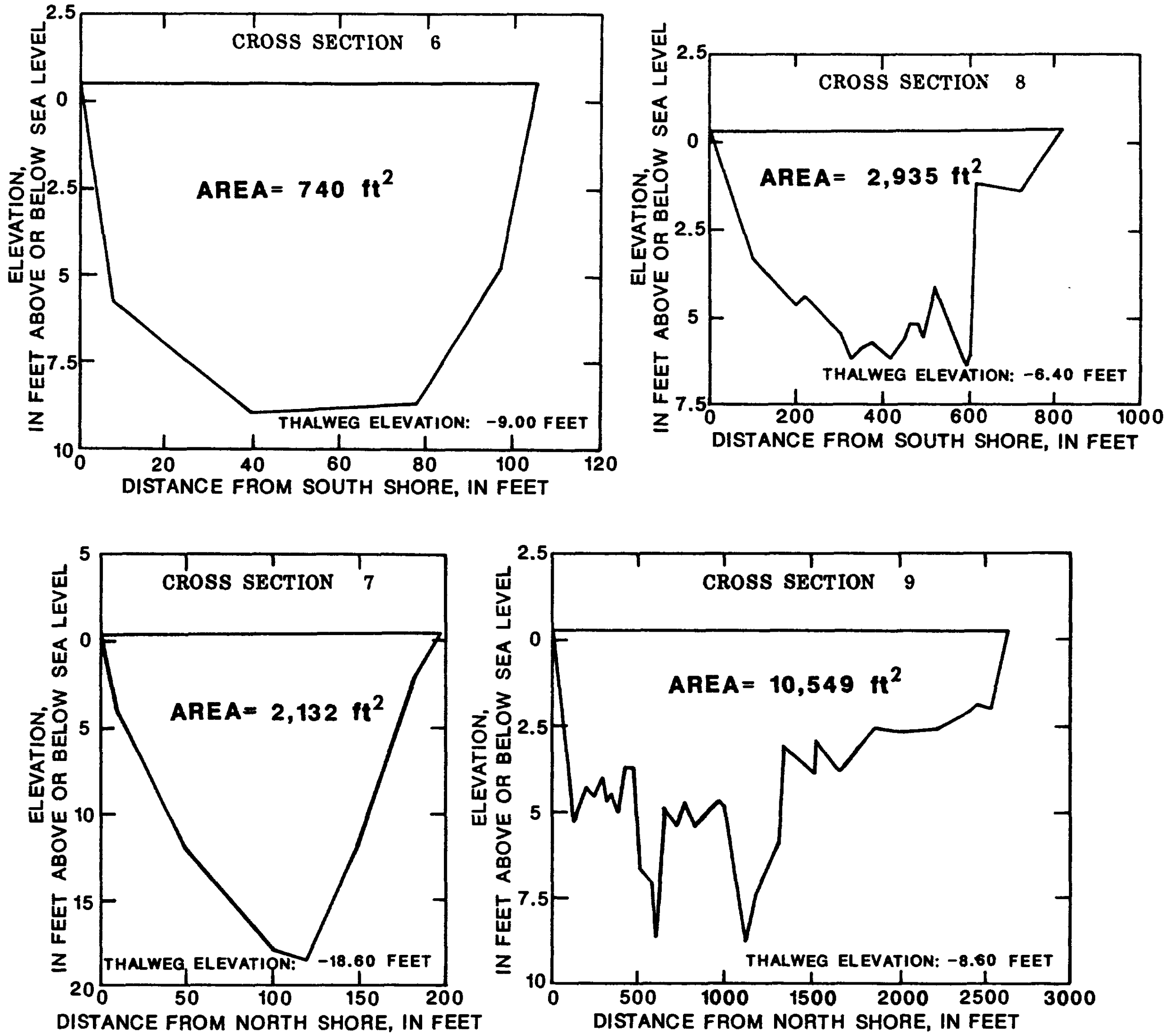


Figure 14.--Cross sections of openings between Calcasieu Ship Channel and Calcasieu Lake for sites 6, 7, 8, and 9. (See fig. 2 for locations.)

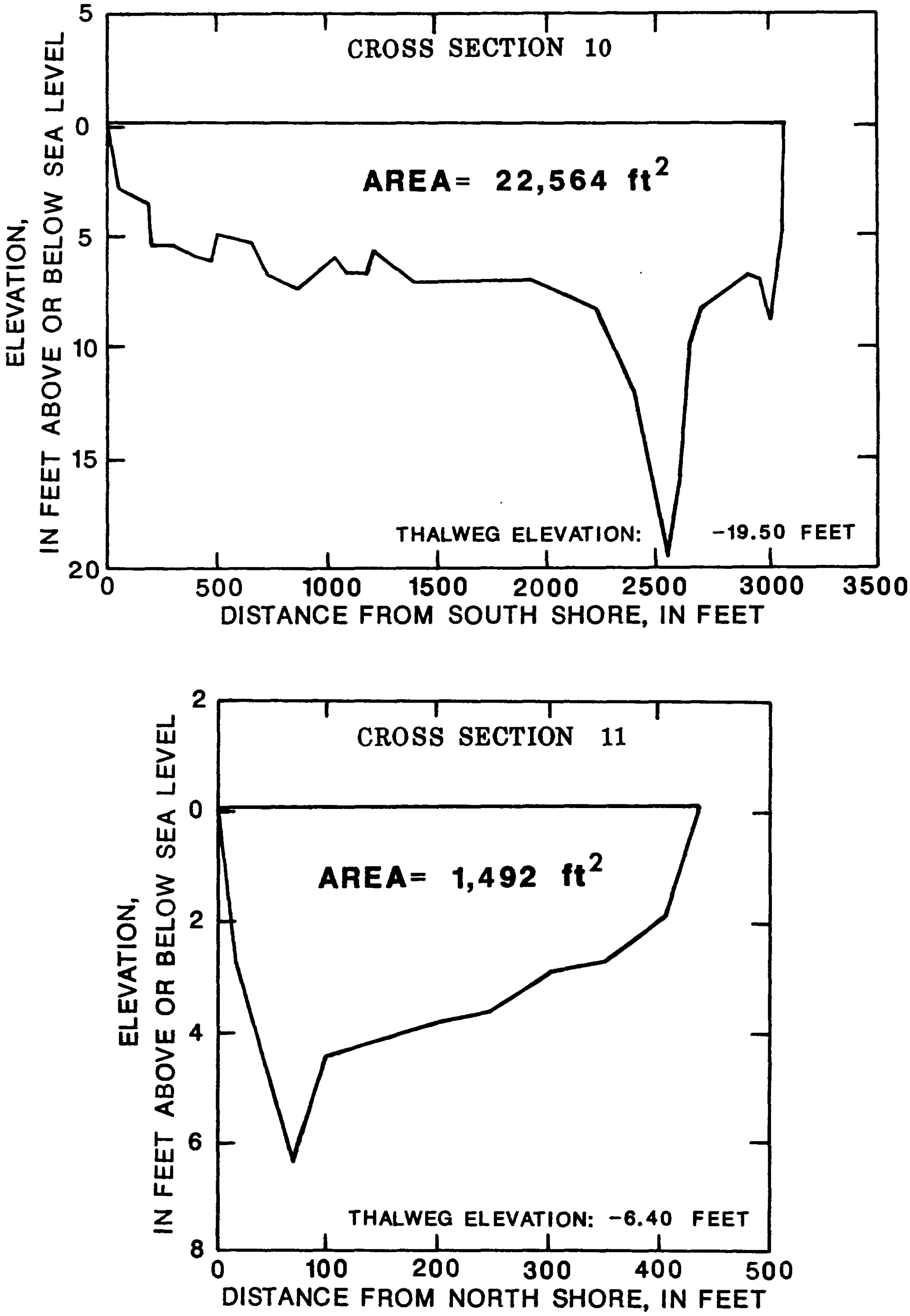


Figure 15.--Cross sections of openings between Calcasieu Ship Channel and Calcasieu Lake for sites 10 and 11. (See fig. 2 for locations.)

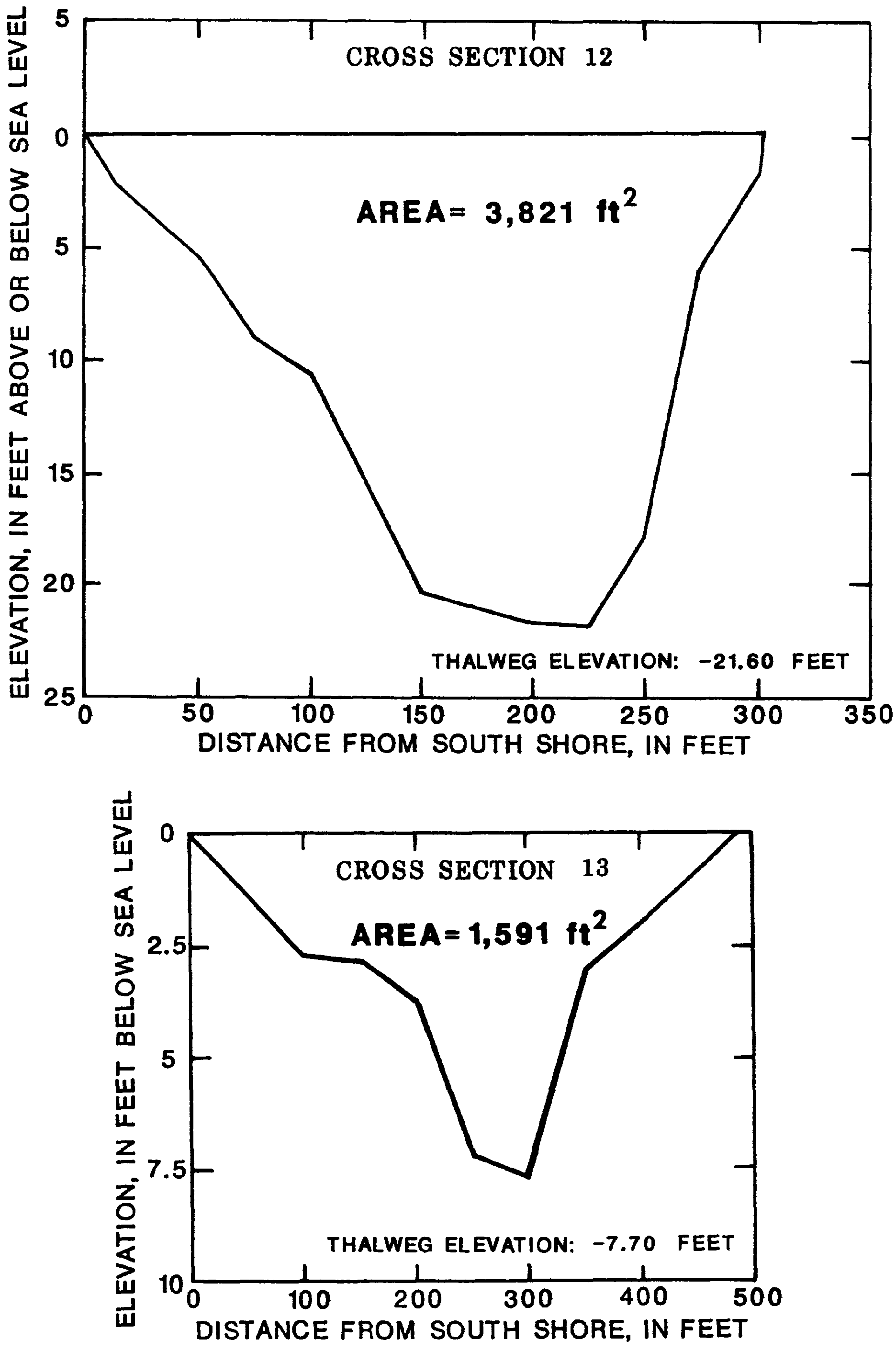
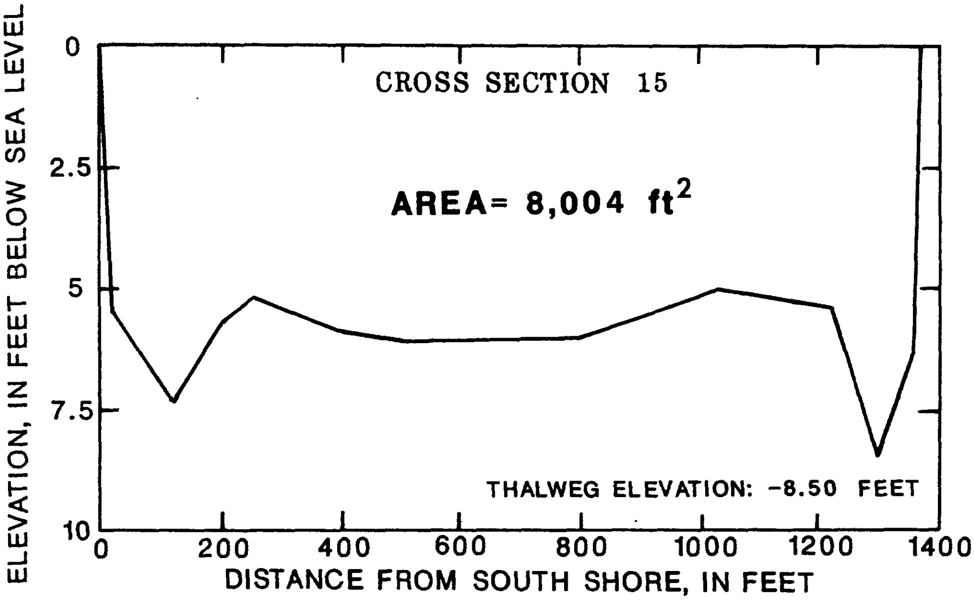


Figure 16.--Cross sections of openings between Calcasieu Ship Channel and Calcasieu Lake for sites 12 and 13. (See fig. 2 for locations.)



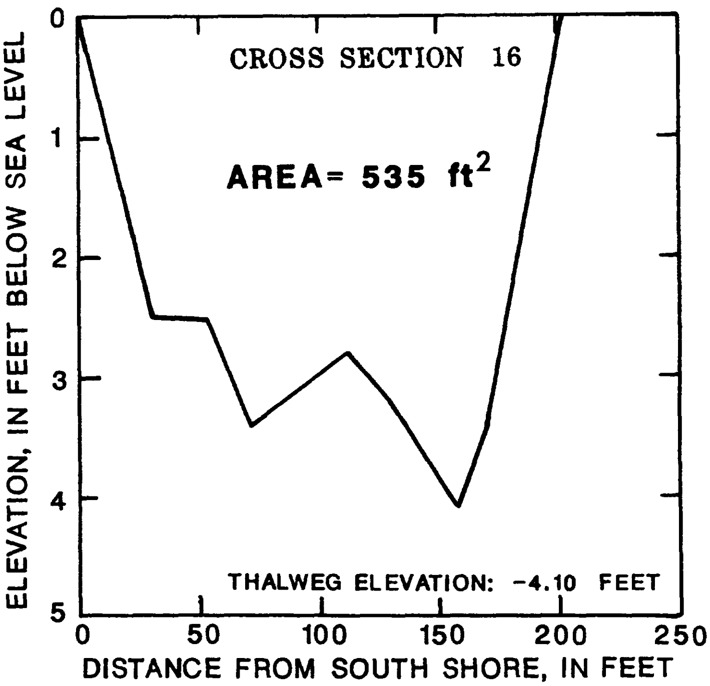


Figure 17.--Cross sections of openings between Calcasieu Ship Channel and Calcasieu Lake for sites 15 and 16. (See fig. 2 for locations.)

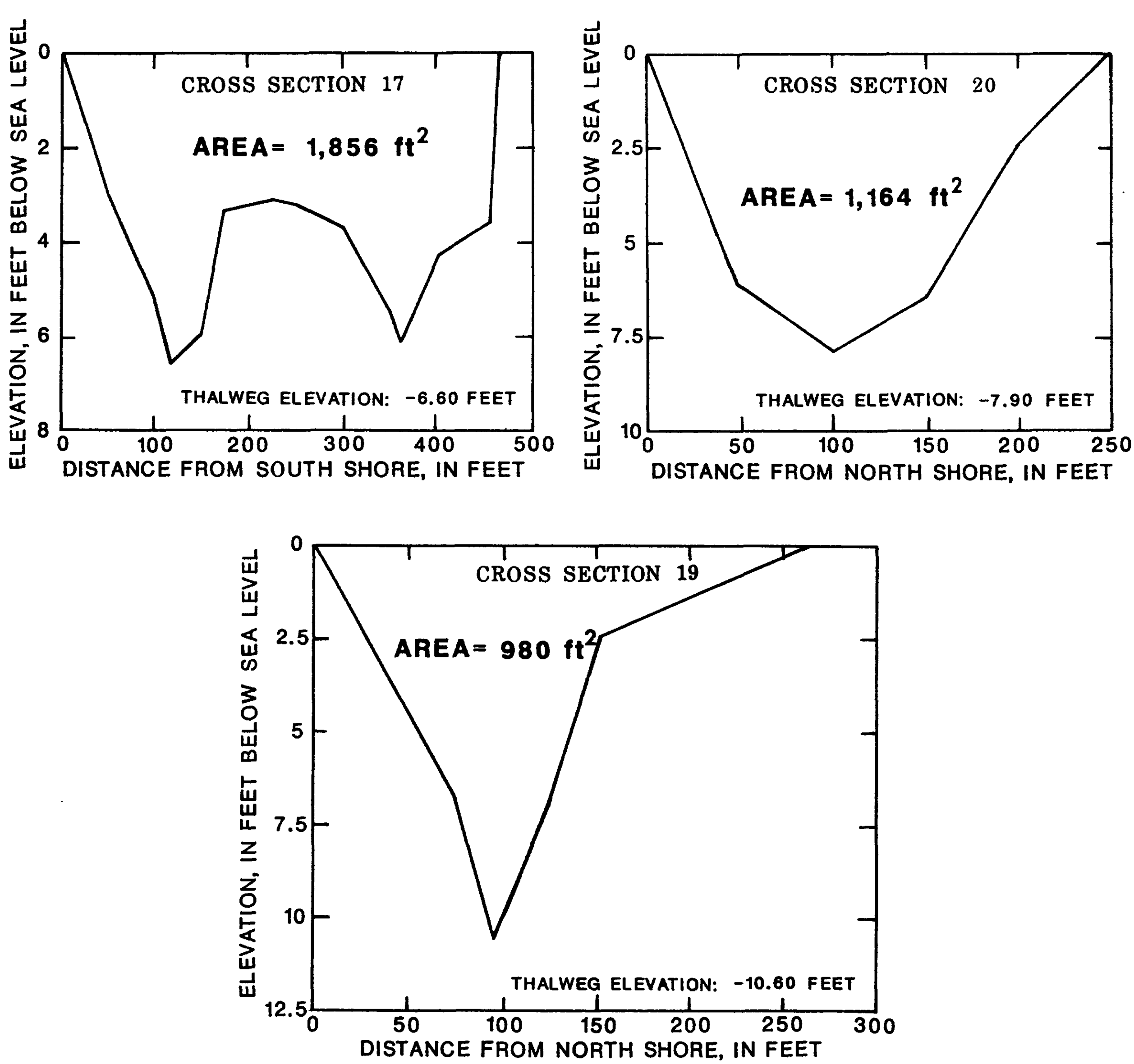


Figure 18.--Cross sections of openings between Calcasieu Ship Channel and Calcasieu Lake for sites 17, 19, and 20. (See fig. 2 for locations.)

Flow in the Lower Calcasieu River

On June 19 and 20, 1984, an intensive survey of streamflow and water-quality characteristics of the lower Calcasieu River and tributaries was conducted by the U.S. Geological Survey and the Louisiana Department of Environmental Quality. During that survey, 65 discharge measurements were made at selected locations. Table 3 shows the results of measurements made during the incoming tide of June 19. Table 4 shows the results of measurements made during the outgoing tide of June 19-20, 1984. Table 5 shows the results of the 20 measurements made at the railroad bridge above I-10 on June 19-20, 1984.

Table 1.--Site information and flow statistics (frequency and duration) for continuous-record streamflow stations in the Calcasieu River basin

Map no.	Station no.	Station name	Drainage area (square miles)	Period of record	Maximum flow	Minimum flow	7-day low flows 2-year	7-day low flows 10-year	7-day low flows 20-year	Percent of time flows 10	30	50	70	90
					(cubic feet per second)									
55	08013000	Calcasieu River near Glenmora	499	[a]1943-	59,900	15	26.9	18.2	16.6	1,950	521	165	61.3	30.0
54	08013500	Calcasieu River near Oberlin	753	1922-25 1938-	72,800	30	54.4	36.6	33.7	3,050	1,020	330	124	61.0
51	08014000	Sixmile Creek near Sugartown	171	1956-65	6,770	34	53.2	36.4	32.5	548	179	106	72.7	47.8
52	08014200	Tenmile Creek near Elizabeth	94.2	1949-65	31,900	7.2	14.2	9.7	8.5	278	65.0	33.4	22.0	15.4
53	08014500	Whisky Chitto Creek near Oberlin	510	1939-	144,000	88	152	111	103	1,820	645	371	236	159
49	08014800	Bundick Creek near De Ridder	120	1956-79	17,200	8.8	17.2	13.1	12.4	379	106	59	33.3	19.9
50	08015000	Bundick Creek near Dry Creek	238	1939-70	37,000	20	57.4	31.5	25.9	833	251	138	93.6	63.5
48	08015500	Calcasieu River near Kinder	1,700	1922-25 1938-57 1957-	182,000	136	298	203	186	6,120	2,270	1,030	538	319
46	08016400	Beckwith Creek near DeQuincy	148	1945-	13,800	.1	1.5	.3	.2	593	94	27.3	9.2	2.7
47	08016600	Hickory Branch at Kernan	82.2	1945-57	6,850	0	0	0	0	316	32.0	6.7	1.4	2
45	08016800	Bear Head Creek near Starks	177	1956-	19,100	0	0	0	0	705	120	27.6	5.2	.2

[a] Open period indicates currently active station.

Table 2.--Annual and monthly average flow for continuous-record streamflow stations in the Calcasieu River basin

Map no.	Station no.	Annual	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
		Average flows (cubic feet per second)												
55	08013000	728	1,423	1,583	1,183	1,090	1,072	338	179	154	180	135	393	1,053
54	08013500	1,150	2,009	2,310	1,892	1,760	1,659	674	388	375	330	244	628	1,551
51	08014000	228	342	362	390	276	125	137	122	90.8	172	103	228	374
52	08014200	125	164	264	173	173	242	64.9	48.0	39.8	46.8	30.8	77.8	175
53	08014500	814	1,165	1,319	1,106	1,052	1,172	599	436	438	380	332	617	1,108
49	08014800	164	298	259	236	195	134	102	78.7	63.8	100	63.9	151	278
50	08015000	358	499	598	445	463	494	307	200	215	165	120	312	453
48	08015500	2,577	4,104	4,556	3,767	3,750	3,881	1,867	1,137	1,129	882	784	1,371	3,727
46	08016400	199	358	390	262	260	258	125	91.9	70.2	95.7	67.0	101	318
47	08016600	127	201	290	198	206	225	97.0	53.1	47.0	27.7	23.4	22.1	136
45	08016800	236	458	429	292	282	236	118	95.1	51.5	147	124	148	427

Table 3.--Discharge measurements for lower Calcasieu River during incoming tide, intensive survey of June 19, 1984 (except site 40)

[ft^2, square feet; ft/s, foot per second; ft^3/s, cubic feet per second; Up, upstream; Down, downstream; dashes indicate the heading does not apply]

		Upstream flow			Downstream flow				
Site no.	Time	Area (ft^2)	Velocity (ft/s)	Discharge (ft^3/s)	Area (ft^2)	Velocity (ft^2)	Discharge (ft^3/s)	Net flow (ft^3/s)	Direction
1	0650	41,496	1.71	71,100	------	----	-----	------	Up
2	0650	6,231	.98	6,090	------	----	-----	------	Up
5	0750	25,685	2.11	54,300	------	----	-----	------	Up
14	0815	18,942	.71	13,500	6,130	0.09	581	13,000	Up
18	0955	975	.63	610	------	----	-----	------	Up
22	1100	16,085	.52	8,340	2,025	.21	424	7,920	Up
21	0940	20,946	.58	12,100	1,144	.10	114	12,000	Up
24	0950	3,403	.99	[a]3,370	------	----	-----	------	Up
25	1030	18	.23	4	1,335	.46	612	608	Down
27	1138	21,889	.85	18,500	------	----	-----	------	Up
26	1140	8,469	.25	[a]2,120	19,193	.21	3,940	1,820	Down
28	1320	6,305	.27	1,700	1,059	.18	193	1,500	Up
29	1400	368	.14	52	------	----	-----	------	Up
30	1310	17,559	.47	8,220	7,195	.16	1,160	7,050	Up
31	1217	23,471	.35	8,320	------	----	-----	------	Up
32	1510	4,735	.16	738	9,111	.11	1,040	303	Down
33	1335	------	----	------	1,601	.20	316	------	Down
34	1220	------	----	------	786	.10	77	------	Down
36	1347	25,896	.25	6,480	1,996	.06	125	6,360	Up
39	1505	18,054	.15	2,720	9,464	.35	3,290	572	Down
37	1432	1,189	.11	125	400	.02	8	117	Up
38	1504	6,664	.09	587	14,109	.13	1,770	1,180	Down
40	See table 5 for measurements.								
42	1628	1,831	.32	593	2,273	.08	172	421	Up
43	1630	4,734	.14	672	809	.04	30	642	Up
44	1725	1,230	.13	163	6,945	.25	1,740	1,580	Up

[a] Upstream is away from ship channel.

In the natural (pre-1871) condition, the bar at the north end of Calcasieu Pass acted to hold water in the river and Calcasieu Lake and to slow saltwater movement upstream. When high-water conditions occurred in the lower Calcasieu River, freshwater flushing occurred. The effects of this flushing prolonged the freshness of water in Calcasieu Lake because of the damming effect of the bar.

Table 4.--Discharge measurements for lower Calcasieu River during outgoing tide, intensive survey of June 19-20, 1984 (except site 40)

[ft², square feet; ft/s, foot per second; ft³/s, cubic feet per second; Down, downstream; Up, upstream; dashes indicate the heading does not apply]

		Upstream flow			Downstream flow				
Site no.	Time	Area (ft^2)	Velocity (ft/s)	Discharge (ft^3/s)	Area (ft^2)	Velocity (ft^2)	Discharge (ft^3/s)	Net flow (ft^3/s)	Direction
1	1610	------	----	-----	41,245	0.87	36,000	------	Down
2	1638	------	----	-----	6,176	.73	4,490	------	Down
5	1720	------	----	-----	28,855	1.04	26,800	------	Down
14	1749	8,012	0.24	1,940	17,159	.30	5,160	3,220	Down
18	2345	213	.30	64	757	.70	527	463	Down
22	2140	800	.03	24	17,310	.25	4,410	4,390	Down
21	1850	5,303	.26	1,380	17,216	.61	10,500	9,150	Down
24	2052	------	----	-----	3,439	.62	2,120	------	Down
25	1900	1,288	.23	294	85	.08	7	287	Up
27	2020	1,972	.06	122	20,151	.43	8,700	8,580	Down
26	1945	19,186	.22	[a]4,210	6,652	.31	2,090	2,120	Up
28	2145	4,692	.22	1,030	2,648	.02	53	979	Up
30	2300	5,536	.30	1,660	19,306	.49	9,530	7,820	Down
31	2122	5,109	.11	571	18,776	.33	6,160	5,590	Down
32	0400	4,085	.15	613	9,111	.13	1,180	571	Down
33	2039	------	----	-----	1,601	.24	380	------	Down
36	0020	4,432	.25	1,120	23,096	.37	8,560	7,440	Down
37	2210	443	.12	54	972	.11	105	51	Down
39	0000	1,958	.06	113	24,345	.40	9,820	9,710	Down
40	See table 5 for measurements.								
44	0210	6,146	.38	2,360	1,910	.34	649	1,720	Up

[a] Upstream is away from ship channel.

Since the bar was removed, and particularly since the 40 ft depth has been established, water from the gulf is free to move inland, and freshwater flushing during high streamflows is temporary. Because of the relatively low streamflow of the Calcasieu River, a saltwater wedge does not occur as in streams with large amounts of freshwater flowing downstream as tidal action drives saltwater upstream. Freshwater and saltwater mixing occurs in much of the lower Calcasieu River.

Table 5.--Discharge measurements for lower Calcasieu River (site 40) at Lake Charles during intensive survey of June 19-20, 1984

[ft^2, square foot; ft/s, foot per second; ft^3/s, cubic foot per second; Down, downstream; Up, upstream; dashes indicate the heading does not apply]

		Upstream flow			Downstream flow					
Date	Time	Area (ft^2)	Velocity (ft/s)	Discharge (ft^3/s)	Area (ft^2)	Velocity (ft/s)	Discharge (ft^3/s)	Net flow (ft^3/s)	Direction	Parallel flow area (ft^2)[a]
6-19	0522	4,238	0.39	1,670	9,723	1.11	10,800	9,100	Down	733
6-19	0700	1,944	.30	583	12,779	1.03	13,200	12,600	Down	-----
6-19	0800	4,554	1.88	8,590	9,810	1.96	19,200	10,600	Down	359
6-19	0910	574	.09	52	14,059	1.05	14,800	4,500	Down	125
6-19	0955	11,147	.32	3,620	3,682	.24	882	2,700	Up	-----
6-19	1100	13,739	.20	2,740	1,270	.02	25	2,700	Up	-----
6-19	1203	15,074	.19	2,880	------	----	------	-----	Up	-----
6-19	1321	15,143	.19	2,810	------	----	------	-----	Up	-----
6-19	1509	6,971	.18	1,300	7,929	.14	1,090	196	Up	336
6-19	1630	4,707	.10	493	9,825	.13	1,320	831	Down	704
6-19	1706	4,004	.16	719	11,151	.20	2,180	1,460	Down	-----
6-19	1800	3,221	.15	480	11,881	.43	5,130	4,650	Down	-----
6-19	1915	1,650	.33	604	13,252	.42	5,650	5,040	Down	-----
6-19	2000	------	----	-----	13,622	.35	4,850	-----	Down	1,240
6-19	2130	92	.12	72	14,438	.53	7,620	7,550	Down	-----
6-19	2210	410	.11	45	14,599	.37	5,420	5,390	Down	-----
6-19	2300	2,039	.03	61	12,970	.37	4,750	4,690	Down	-----
6-20	0056	------	----	-----	14,351	.56	8,020	-----	Down	628
6-20	0300	2,868	1.37	3,940	9,944	.75	7,470	3,540	Down	-----
6-20	0925	600	.48	288	13,814	.91	12,600	12,300	Down	300

[a] Area affected by flows along cross section; net result is no flow.

Some flow characteristics in the river channels can be described by the results of the survey of June 1984. Headwater flow conditions (indicated by the flow at the gaging station, Calcasieu River near Kinder) are shown in the table below and represent one of the factors affecting water movement; other dominant factors are tide and wind. Flow time from Kinder to Lake Charles varies from about 1.5 days at higher flows to about 3 days at lower flows, and, consequently, on June 19-20, 1984, headwater flows in the Lake Charles area were about equal to flows near Kinder on June 17-18, 1984.

Daily discharge (average), USGS gaging station, Calcasieu River near Kinder

June 1984 (day)	Discharge (cubic feet per second)	June 1984 (day)	Discharge (cubic feet per second)
15	4,390	21	1,540
16	3,800	22	1,400
17	3,200	23	1,210
18	2,390	24	1,170
19	1,910	25	1,250
20	1,620		

Headwater flow and wind conditions of 4 to 11 mi/h during the period of the intensive survey (June 19-20, 1984) had no significant effect on discharges measured. Discharge measurements were made on an incoming tide with the intention of measuring at each site at the time that a similar condition of tide was occurring. Results of these measurements are shown in tables 3 and 8. A discharge of 71,100 ft^3/s was measured at the mouth of Calcasieu River (site 1, fig. 2). As water moved upstream, part moved around Monkey Island and rejoined the main flow at the north end of the Monkey Island loop. Old channels (east to Calcasieu Lake, west to West Cove) carried appreciable amounts of water. The flow at site 5 (fig. 2), upstream from these channels, was 54,300 ft^3/s, indicating that about 25 percent (16,800 ft^3/s) of the flow entering the mouth of the river went through these two channels with an average velocity of about 0.9 ft/s.

Between sites 5 and 14 (fig. 2) there are several openings between the ship channel and adjacent parts of Calcasieu Lake. These openings have a total cross-sectional area of about 48,600 ft^2 at a water-surface elevation of sea level. During the survey of June 1984, about 41,300 ft^3/s(discharge of 54,300 ft^3/s at site 5 minus discharge of 13,000 ft^3/s at site 14) moved into the lake through these openings. Average velocity for this flow was about 0.8 ft/s. At the upper end of Calcasieu Lake (site 22), about 7,920 ft^3/s or about 11 percent of the flow measured at site 1 flowed from the lake into the ship channel.

The data and comparisons presented here represent only one set of observations of a system that is constantly changing. However, some observations concerning the hydrology of the lower Calcasieu River can be made from what is available. Gulf tides force large amounts of water up the lower Calcasieu

River where most of that water goes into storage in Calcasieu Lake and adjacent waterways. The surface area of the lake is about 67 mi^2 (Barrett, 1970). Gages at Cameron and Hackberry showed that the elevation of the Calcasieu Lake increased by about 0.8 ft during the high tide of June 19, 1984. An area-depth calculation indicates that about 1.5×10^9 ft^3 of water went into storage in about 8 hours (the duration of the tidal rise). During this period, it is reasoned that upstream discharge increased from 0 to some maximum value, with an average flow for the period between the minimum and maximum upstream flow values. An average flow to accomplish the calculated storage would be about 52,000 ft^3/s. Comparison of discharges indicates that about 50,000 ft^3/s was leaving the main channel and going into storage in Calcasieu Lake. This value was calculated by subtracting the sum of the discharge measurements at sites 14 and 22 (13,000 + 7,900 ft^3/s) from the measurement at site 1 (71,000 ft^3/s). This indicates that an upstream flow of 50,000 ft^3/s would have been expected to occur during the tidal cycle.

Based on available data, approximately 25 percent (18,500 ft^3/s) of the flow at site 1 was measured at site 27 (Burton Landing near Moss Lake), immediately above the confluence of the Gulf Intracoastal Waterway and Calcasieu Ship Channel. The discharge remaining in the system downstream from Burton Landing can be computed by subtracting the discharge of 18,500 ft^3/s for site 27 from the discharge of 71,000 ft^3/s for site 1. The computed discharge of 52,500 ft^3/s compares favorably with the average flow to produce the storage in Calcasieu Lake.

Several tributaries, cutoff river loops, and three lakes (Moss Lake, Prien Lake, and Lake Charles) are located between Burton Landing and the railroad bridge above I-10. These bodies of water provide storage for relatively large amounts of the water that move upstream past Burton Landing. The maximum upstream discharge was about 2,900 ft^3/s at the railroad bridge above I-10 (about 4 percent of the flow at site 1). While coincidence may play a part in the similarity, about 75 percent of the tidal flow was indicated as being stored downstream from Burton Landing, and about 80 percent of the time for the tidal peak to traverse the Cameron-Indian Bayou reach was expended in the Cameron-Burton Landing reach.

On the outgoing tide of June 19 and 20, 1984, control of the sequencing of measurements (to follow the tide out) was not as effective as for the incoming tide (tables 5 and 8). However, several similarities with the patterns of the incoming measurements were noted. The discharge at site 27 was again about 25 percent of the discharge at site 1; the discharge at site 5 was again about 75 percent of the discharge at site 1; and the flow from the ship channel into Calcasieu Lake at site 22 was about 12 percent of the discharge at site 1 (incoming percentage was about 11). During the measurements, water moved through measurement cross-sections in many directions, with upstream and downstream components, and occasionally parallel to the cross sections. Such flow patterns are characteristic of tidally influenced water bodies (tables 3-5 and 8).

Diversion of Water from the Sabine River

In 1981, the Sabine River Diversion Canal went into operation, diverting water from the Old River loop of the Sabine River west of Lake Charles into the industrial area of Westlake (fig. 1). The canal, about 25 mi long, was developed to provide water for farmers along the canal's route and to provide supplemental freshwater to industries in the Lake Charles area. Three 54 in. pumps, each with a horsepower rating of 600, a capacity of 50,000 gal/min, and a lift of 33 ft, move water into the gravity canal. The average pumping rate for the 1986 calendar year was about 47 ft^3/s. The table below shows the amount of water used from the Sabine River Diversion Canal in the 1986 calendar year:

Month	Agricultural use	Industrial use
	(million gallons)	
January	170.25	1,091.32
February	107.97	1,058.97
March	213.25	1,051.23
April	245.79	1,106.66
May	224.36	1,247.32
June	213.65	1,327.34
July	254.50	1,452.52
August	206.89	1,459.49
September	264.67	1,189.42
October	173.53	1,359.90
November	130.03	1,069.03
December	114.72	1,327.58
Subtotals	2,319.61	14,740.78
Grand total	17,060.39	

These data are included to more fully describe the uses and sources of surface water in the area of the lower Calcasieu River. The total number of acres irrigated was 2,557.9. Agricultural use is not metered and is estimated at 2.75 acre-ft of water for the growing season. Monthly use is based on estimated percentages for the months irrigation water was taken. Losses are prorated into both uses to make use totals equal to withdrawal totals.

Diversion of Water from the Lower Calcasieu River

The primary uses of water taken from the lower Calcasieu River are for irrigation and industrial cooling. Irrigation use is primarily for rice irrigation. Water use figures from the 1985 survey are tabulated in the following table (Lurry, 1987):

Parish	Irrigation use (average, based on full year rather than the growing season)
	(million gallons per day)
Allen----------------	9.0
Beauregard-----------	2.2
Calcasieu[1]-----------	57.0
Cameron--------------	44.0
Jefferson Davis------	99.0
Total-----------	211.2
	Industrial use (average)
Calcasieu[1]-----------	132.0
Cameron--------------	22.0
Total-----------	154.0

[1] Does not include water from the Sabine River Diversion Canal.

Tide Characteristics

Waters of the lower Calcasieu River are subject to tides of the Gulf of Mexico. The diurnal range of tide at the mouth is about 2 ft, with a mean level about 0.2 ft sea level. Tidal action is detectable to the vicinity of Phillips Bluff on the Calcasieu River (about mile 86). Three kinds of tides can occur: diurnal, having one high water and one low water event in a tidal day; semi-diurnal, with two high water and two low water events in a tidal day; and mixed, usually of a semi-diurnal nature but with relatively large differences between adjacent high and low water events. In the Gulf of Mexico, and in the lower Calcasieu River, a diurnal tide pattern predominates. Extreme high and low water levels in the lower Calcasieu River are produced by storm and wind effects, and are discussed in the section on "Wind Characteristics."

Figures 19 through 24 show tidal patterns for recording water-level gages in the lower Calcasieu River for the different tide types. In figures 19 and 21 the diurnal pattern is evident during the period November 14-16, 1984. The range of tide elevations at Cameron is about 1.9 ft. A time lag of about 9 hours occurred between the high tide peaks of November 14, at Cameron and Hackberry; this is a time lag rate of about 30 min/mi of distance between the gages. Much lower time lag rates are computed between gages above Hackberry. The Hackberry-Gulf Intracoastal Waterway-Calcasieu Lock area reach had a time lag rate of about 10 min/mi; the Gulf Intracoastal Waterway-Lake Charles reach had a time lag rate of about 4 min/mi; no discernible lag between Lake Charles and the saltwater barrier was observed. During this period the flood (tainter) gates at the barrier were closed. The navigational gate was opened for 2 hours on November 14, 5 hours on November 15, and 13 hours on November 16. This operation is evident on the Indian Bayou gage record, with decreases in

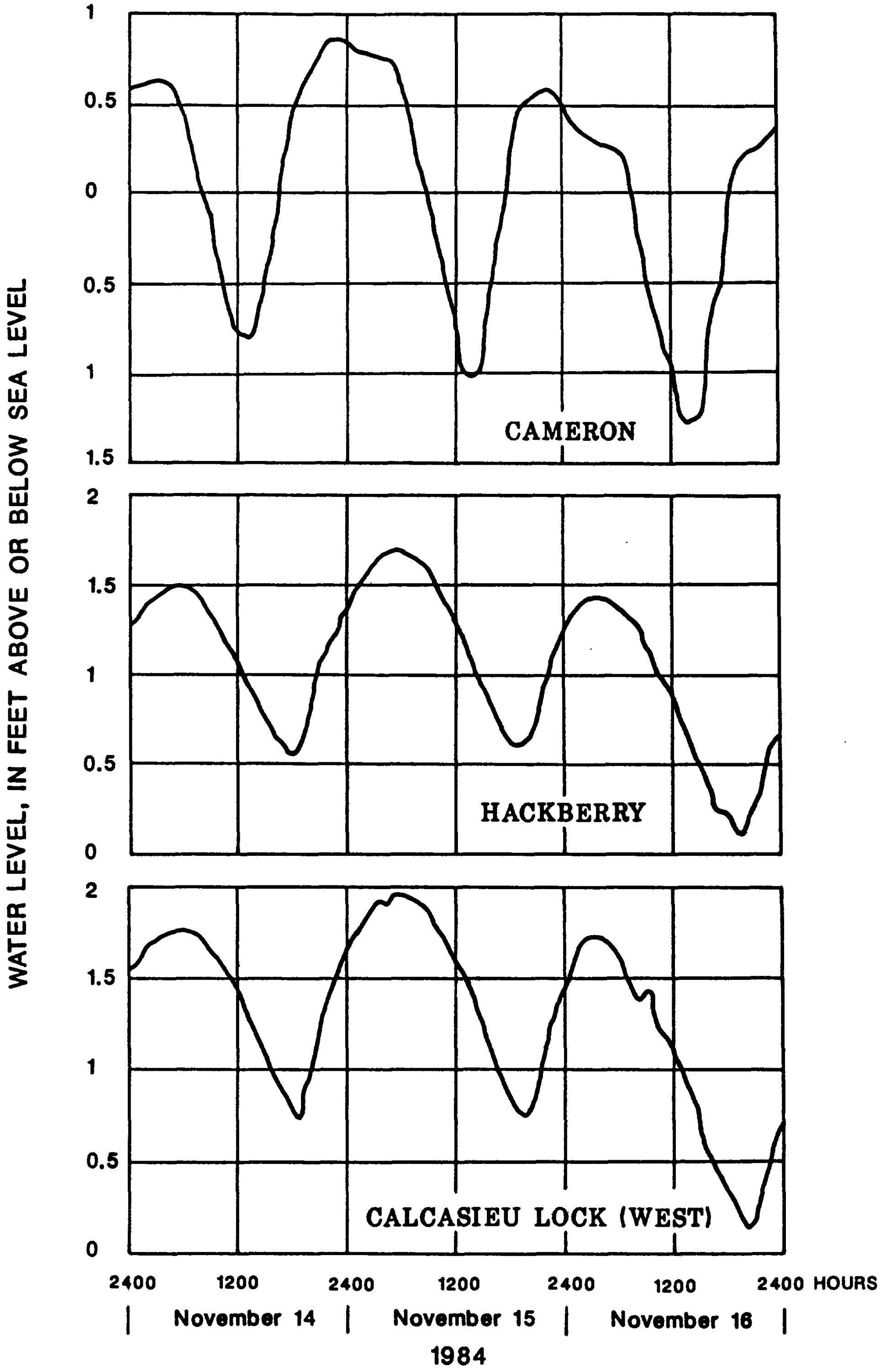


Figure 19.--Diurnal tide elevations for lower Calcasieu River at Cameron, Hackberry, and Calcasieu Lock (West), November 14-16, 1984.

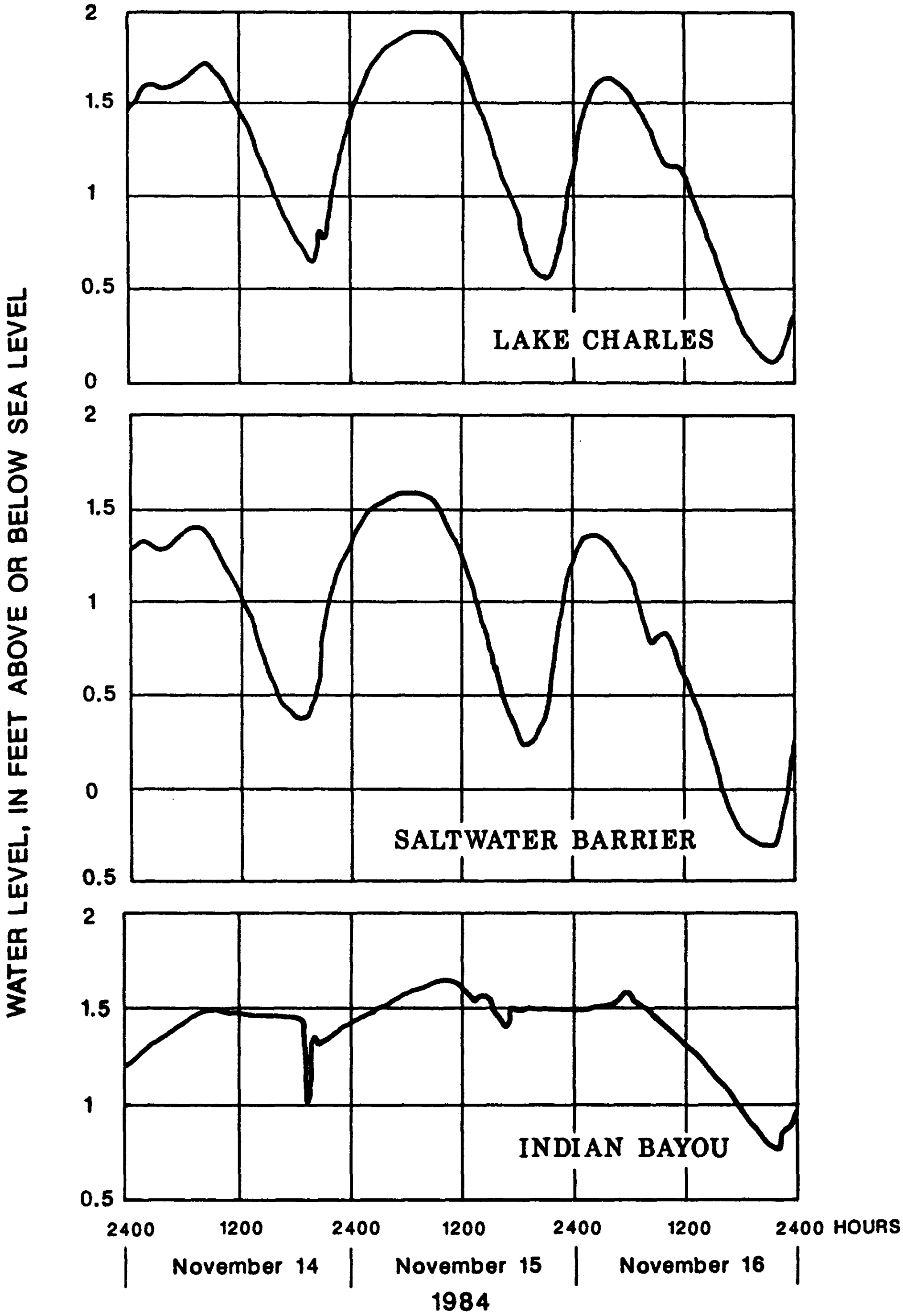


Figure 20.--Diurnal tide elevations for lower Calcasieu River at Lake Charles, saltwater barrier, and Indian Bayou, November 14-16, 1984.

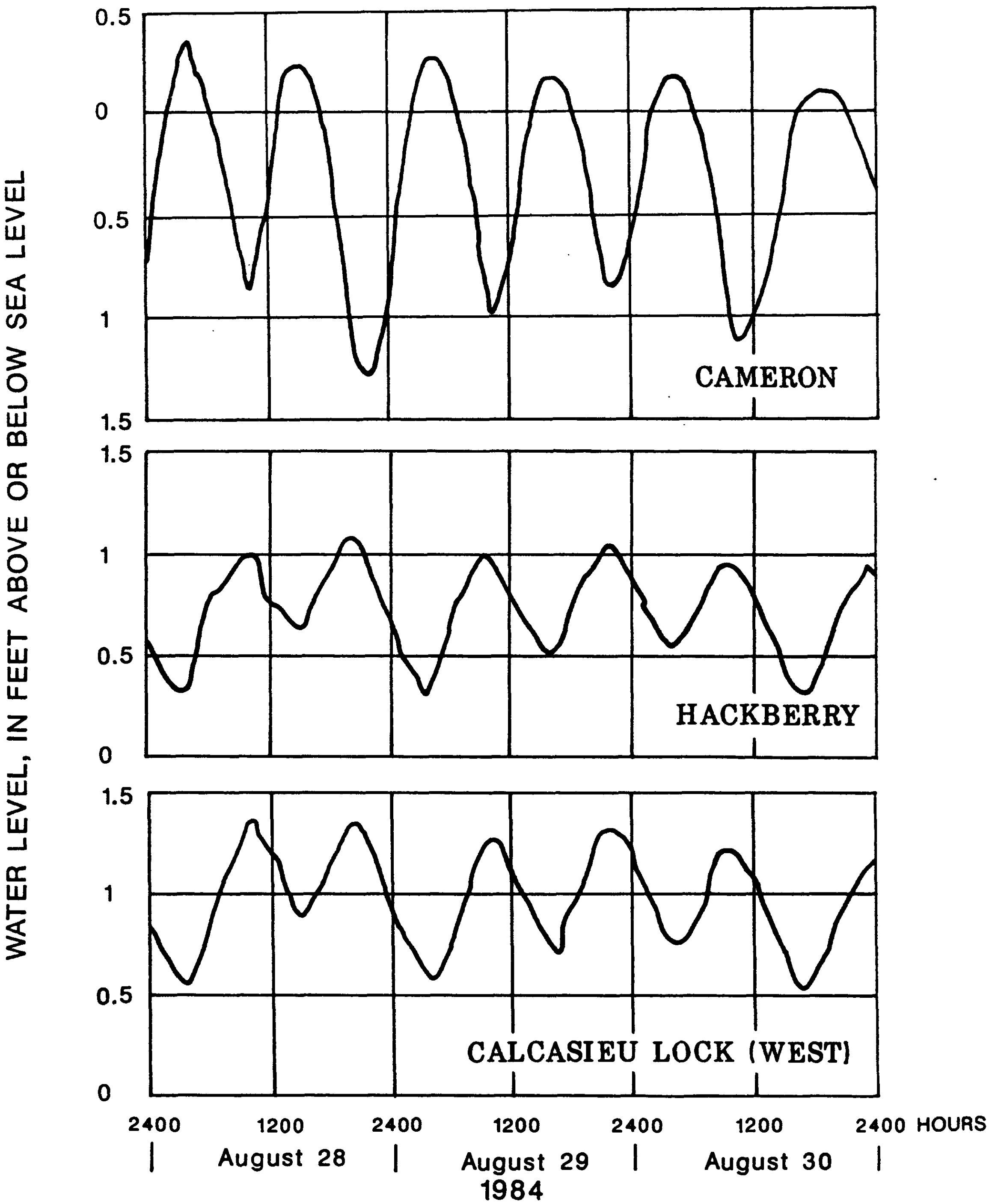


Figure 21.--Semi-diurnal tide elevations for lower Calcasieu River at Cameron, Hackberry, and Calcasieu Lock (West), August 28-30, 1984.

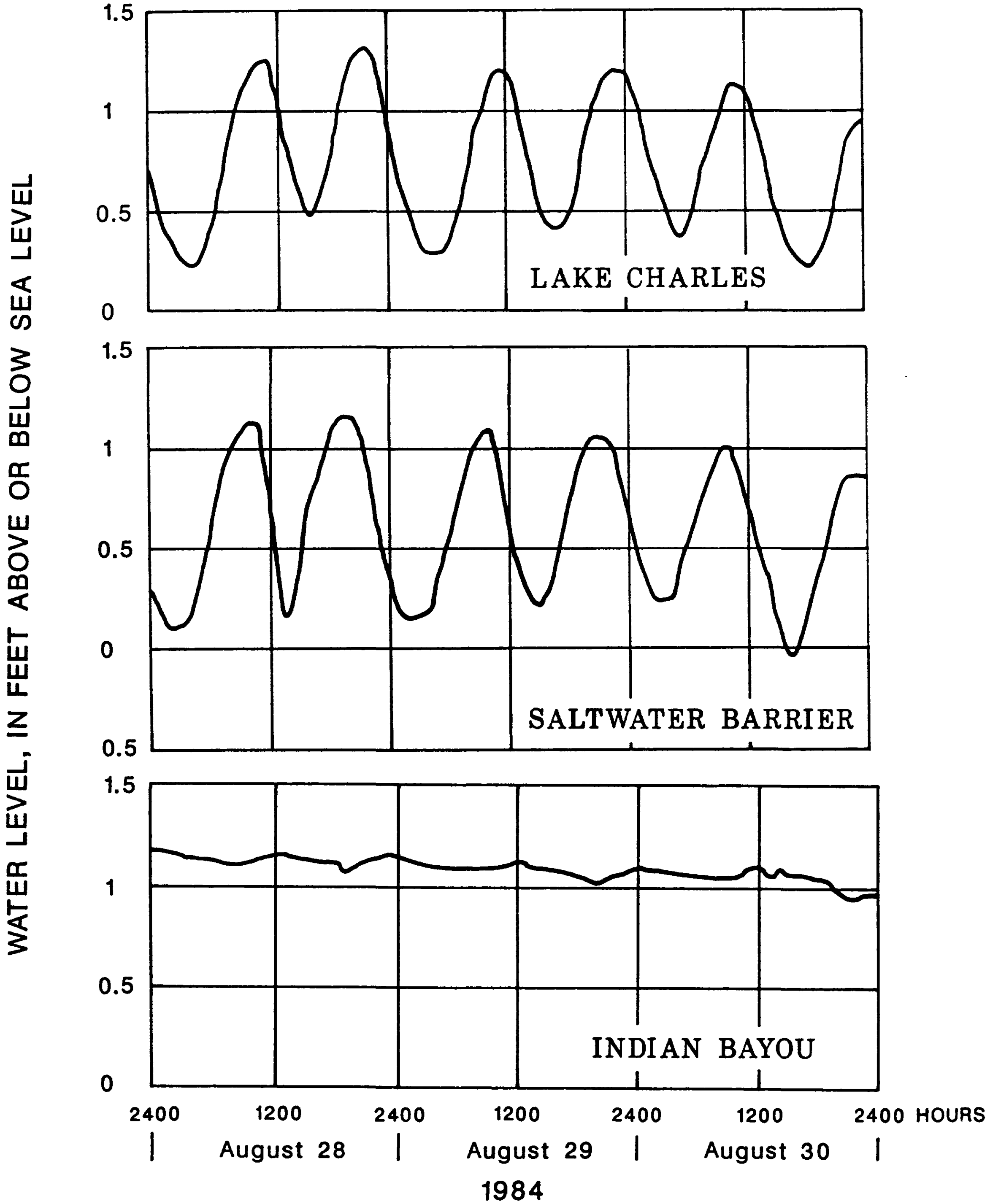


Figure 22.--Semi-diurnal tide elevations for lower Calcasieu River at Lake Charles, saltwater barrier, and Indian Bayou, August 28-30, 1984.

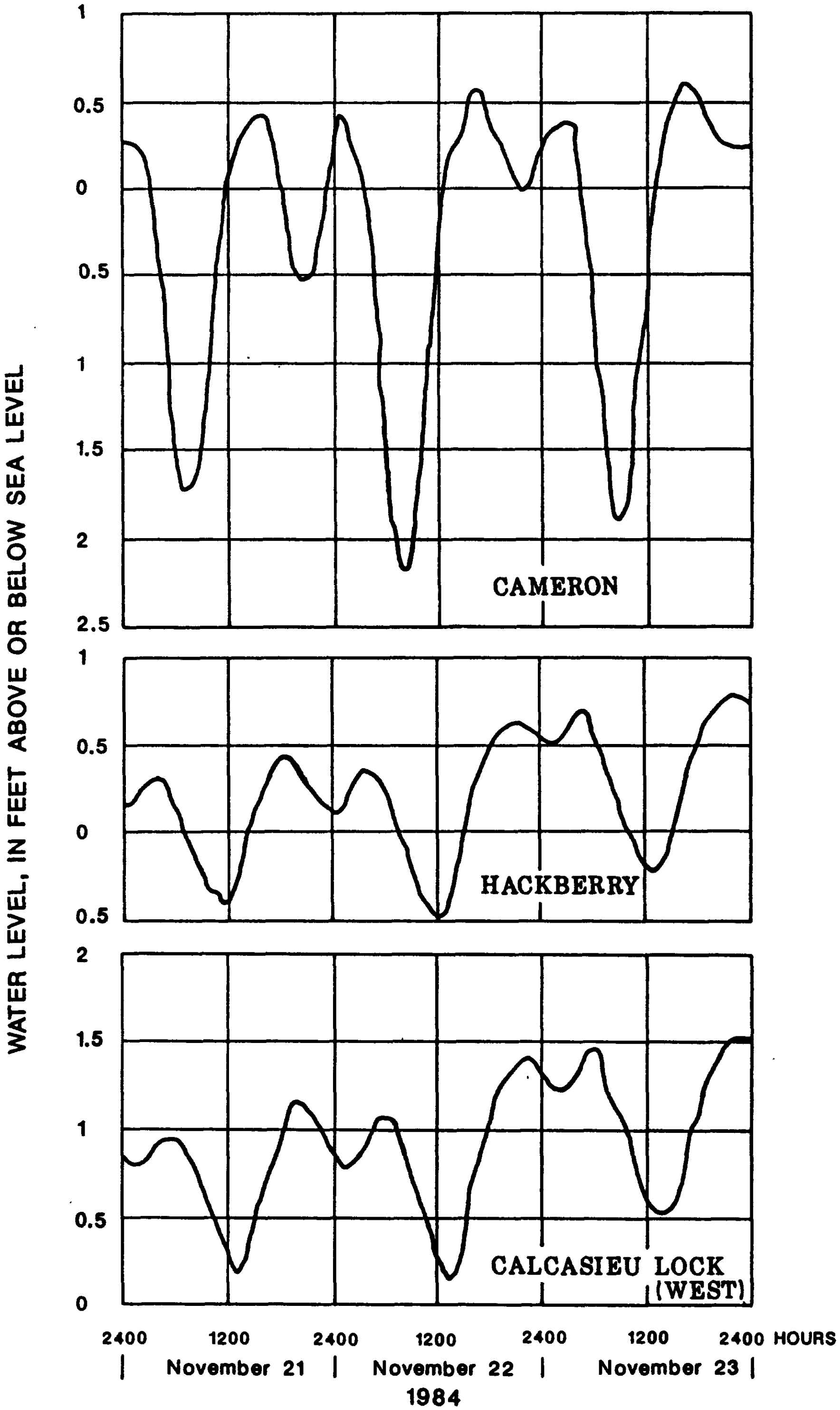


Figure 23.--Mixed tide elevations for lower Calcasieu River at Cameron, Hackberry, and Calcasieu Lock (West), November 21-23, 1984.

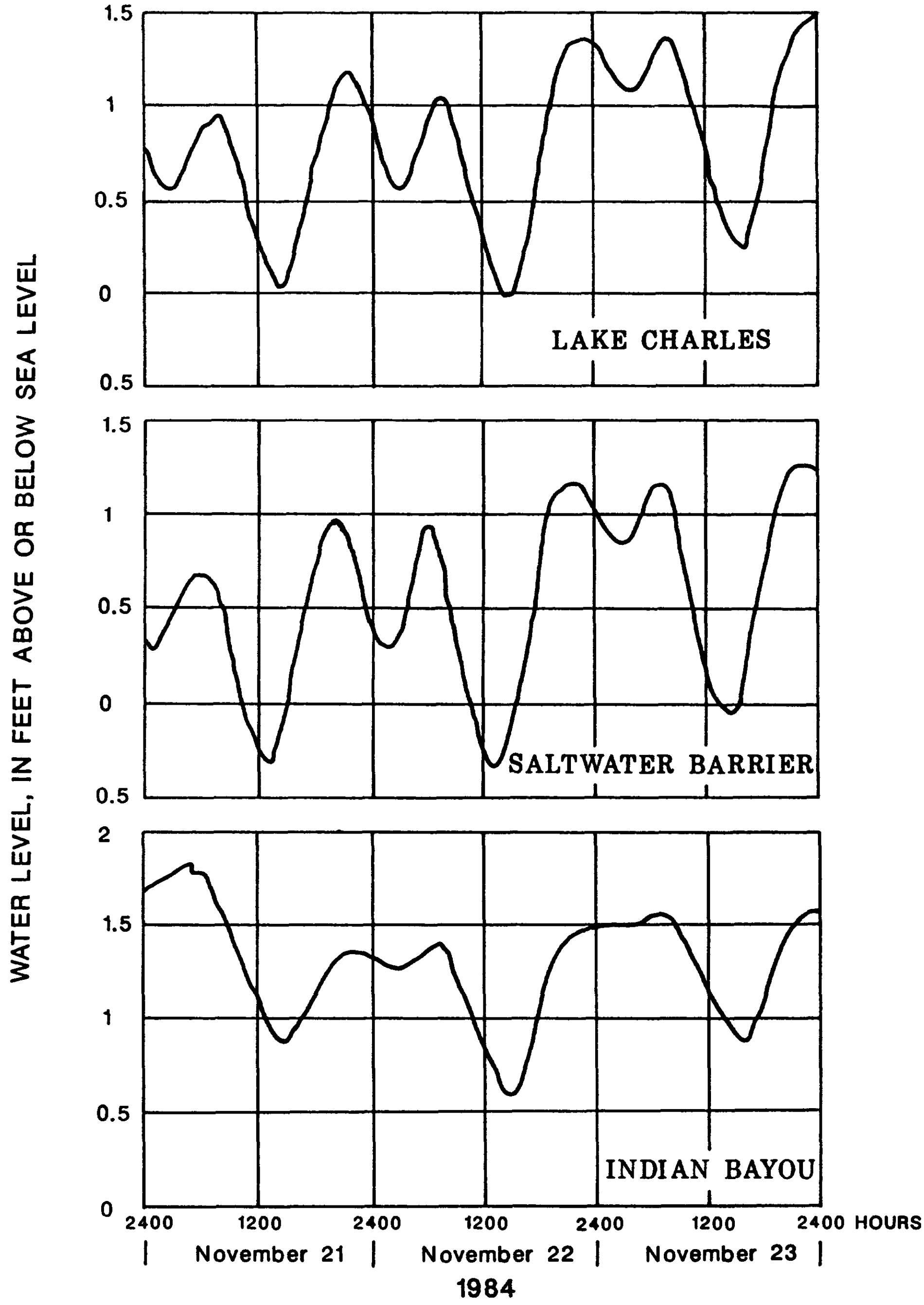


Figure 24.--Mixed tide elevations for lower Calcasieu River at Lake Charles, saltwater barrier, and Indian Bayou, November 21-23, 1984.

stage for short periods on November 14 and 15 with a much longer and lower decrease on November 16. Southerly winds with generally less than average (8.7 mi/h) speed were recorded on November 14 and 15; a shift to northerly winds occurred on November 16, and wind speed ranged from 5 to 14 mi/h.

Figures 21 and 22 show the semi-diurnal tidal pattern during August 28-30, 1984; the range of tide elevations at Cameron for the high tide of about 0400 hours on August 29 is about 1.6 ft. Time lags between gages for this period show a shortening (as compared to the diurnal pattern) because of the two-tide-a-day pattern. The overall time lag between Cameron and Indian Bayou was about 8.5 hours. Both the navigational and flood gates at the saltwater barrier were closed for this period. Of interest is the evident trace on the Indian Bayou gage of the high and low tide points in spite of the closure of the barrier; a likely explanation is leakage through the barrier, either in the overbank section between the navigation and flood gates or an incomplete gate closure, that allowed sufficient water movement to show the tide pattern. There is additional evidence of water movement through the barrier in the slow leak down of the water above the barrier as indicated by the gradual decrease of stage (from about 1.2 ft to about 0.9 ft in 3 days). Winds varied from northerly to southerly during the period with no definite pattern established; wind speed ranged from 0 to 13 mi/h.

Mixed tide characteristics are shown in figures 23 and 24 for November 21-23, 1984. These figures clearly show the semi-diurnal nature with the relatively wide (2.8 ft) range for the high tide of about 1600 hours on November 22. Time lags for this period were similar to those of the August period. The flood gates at the barrier were open 10 ft (half open) for the entire period, and the navigational gates were open for about 15 hours each day during the period. The Indian Bayou gage, though damped by the barrier, showed the mixed tide trace in shape and magnitude. Winds during the period were northerly, and wind speed ranged from 4 to 13 mi/h.

The time required for a peak to traverse the Cameron-Gulf Intracoastal Waterway reach was about 80 percent (76, 78, and 81) of the total traverse time (Cameron-Indian Bayou). Calcasieu Lake, in storing large amounts of water on the incoming tide, also slows the rate of movement of the tidal wave. Upstream from the lake, relatively small amounts of water are stored and the tidal wave moves faster.

The manner in which water of the lower Calcasieu River responds to tidal action is well documented in the records of water-level recorders. Some characteristics of this response show that at an approaching high tide, the water surface rises toward a peak; downstream flow, however, continues for some time after the peak stage is reached. During the survey of June 1984, downstream flow continued on the surface for about 2 hours after the high-tide peak had been reached at that point. However, upstream flow was occurring beneath the downstream flowing surface layer. Figure 25 shows this condition occurring at two measurement locations on the lower Calcasieu River, the railroad bridge above I-10 and Burton Landing near Moss Lake for measurements in April and May 1985. A flow division (upstream-downstream) point was detected between about 6.5 and 13 ft in depth on the April 11, 1985, measurement and between about 13 and 20 ft in depth on the May 9, 1985, measurement. For the measurement at Burton Landing near Moss Lake on July 29, 1985, the flow division occurred between about 18.5 and 25 ft in depth. The angles shown above the vertical sections indicate the direction with respect to magnetic north for each of the velocity observations and the angle of the cross-section measurement. A similar but reversed condition occurred as a low tide approached. Upstream flow continued for a time after the lowest stage was reached. Knowledge of these occurrences is important to observers who wish to measure a specified flow condition (upstream or downstream). Water-surface elevation and movement are partial indicators of what is happening, but do not always accurately define the flow condition.

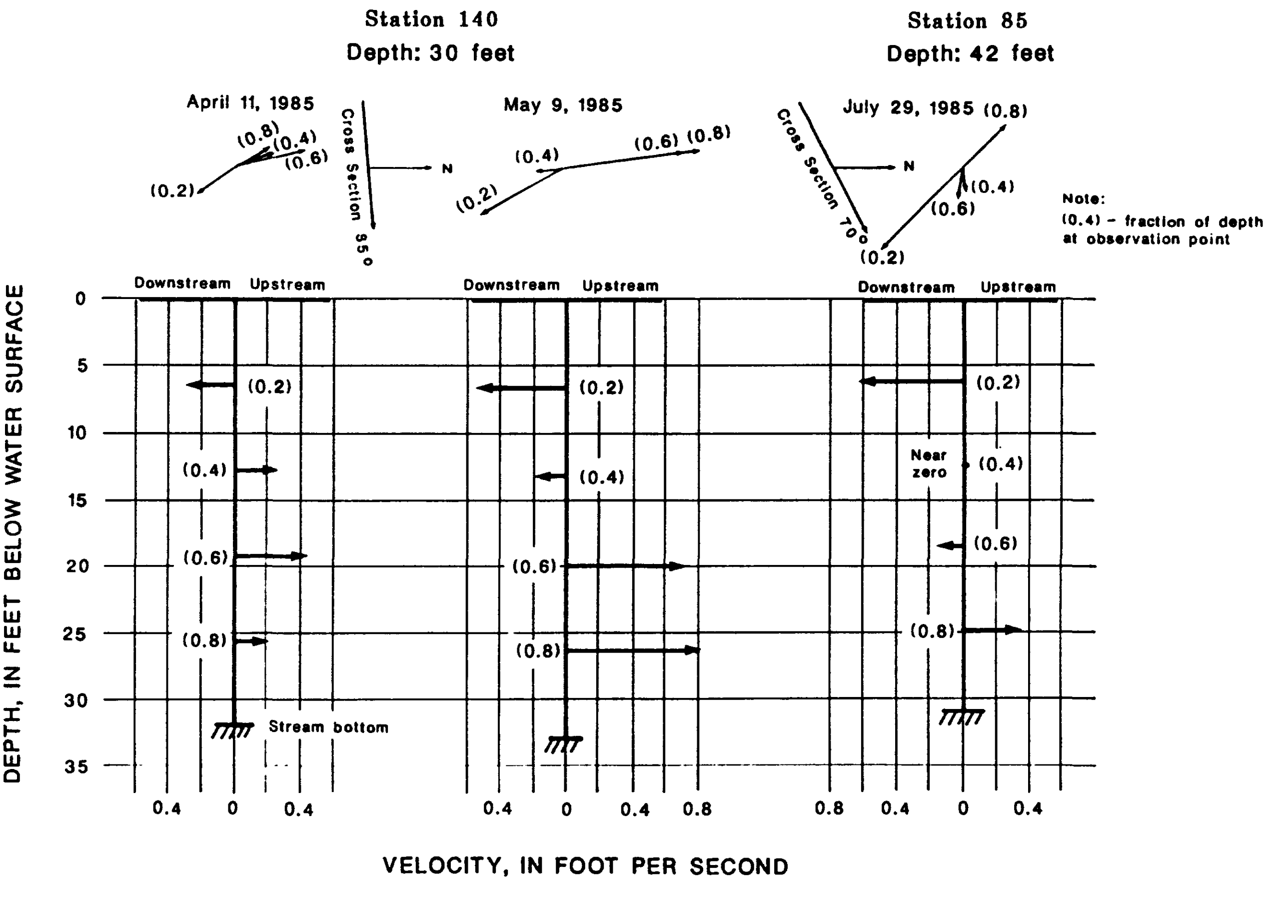


Figure 25.--Velocity profiles showing direction and magnitude of flow of lower Calcasieu River along cross sections at railroad bridge above Interstate 10 (station 140) and Burton Landing near Moss Lake (station 85).

Predictions of tide elevations and timing for specified sites can be made from tide tables published by the National Oceanic and Atmospheric Administration (1985a). For the lower Calcasieu River, the site for which predictions can be made is Calcasieu Pass, Pilot's Wharf (on the south side of Monkey Island at Cameron). Predictions for this site are based on the Galveston, Texas Tide Reference Station and have the following characteristics (National Oceanic and Atmospheric Administration, 1985a):

1. High water or tide occurs 2 hours 14 minutes before high tide at the reference station. (Example: Highwater for December 25, 1985, is predicted to occur at 1716 hours at the Galveston station; highwater is then predicted to occur at 1502 hours at Calcasieu Pass.)

2. High water or tide is 1.43 times the height[2] given for high water at the reference station. (Example: High water for Galveston for December 25, 1985, is predicted to be 1.2 ft; high water for Calcasieu Pass is then predicted to be 1.43 times 1.2 or 1.7 ft.)

3. Low water or tide occurs about 1 hour 24 minutes before low tide at the reference station.

4. Low water or tide is again 1.43 times the height[2] given for low water at the reference station.

Wind Characteristics

Although tidal action is the dominant factor in water movement in the lower Calcasieu River, wind action can substantially affect water movement. Examples of substantial changes induced by wind, are discussed below. The minimum water-surface elevation recorded for the water-level gage at the port of Lake Charles was 4.16 ft below sea level at 1230 hours on February 28, 1984; this occurred during a period of sustained northerly winds. Table 6 shows wind readings at the Lake Charles Airport (fig. 2) for the period in which the minimum water-surface elevation occurred; values given are averages for the 3-hour period noted. Streamflows into the area during this period (as indicated by flow records for the station near Kinder) were well below the average flow and had minimal effect on the water-surface elevation. During this same event, the water surface at Cameron reached 5.3 ft below sea level.

The fastest mile observed on February 27 was 28 mi/h, blowing from 310 degrees; the fastest mile observed on February 28 was 25 mi/h, blowing from 300 degrees. The fastest mile is the highest recorded speed at which a mile of wind passes a station; it is a measure of both speed and duration. Fastest miles of record are in general produced by sustained winds of higher velocity.

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[2] Heights given are with reference to Mean Lower Low Water (Gulf Coast Low Water Datum). These and other pertinent tidal parameters are defined in the National Oceanic and Atmospheric Administration (1985a).

Table 6.--Wind direction and speed at Lake Charles Airport, February 26-29, 1984

Date (1984)	Time	Wind Direction[1] (degrees)	Wind Speed (miles per hour)
Feb. 26-------	0600	130	10
	0900	110	10
	1200	140	19
	1500	180	23
	1800	280	8
	2100	210	7
	2400	230	10
Feb. 27-------	0300	260	15
	0600	270	15
	0900	290	16
	1200	310	20
	1500	310	24
	1800	310	20
	2100	310	16
	2400	310	14
Feb. 28-------	0300	270	13
	0600	300	15
	0900	300	19
	1200	290	18
	1500	300	17
	1800	310	14
	2100	310	8
	2400	300	7
Feb. 29-------	0300	320	7
	0600	290	6
	0900	350	8

[1] Direction from which wind is blowing.

The wind direction column in table 6 shows a shift of direction taking place between 1500 and 1800 hours on February 26, from a generally southeasterly direction to a generally northwesterly direction, and thereafter exceeding the average speed at this site (8.7 mi/h, National Oceanic and Atmospheric Administration, 1985b) for about 45 hours. The effect of this period of sustained high winds is seen in the records for water-surface elevations at gages in the area (figs. 26 and 27). On the Cameron trace, the predicted values of low and high tide are plotted to indicate water levels expected without the effects of wind.

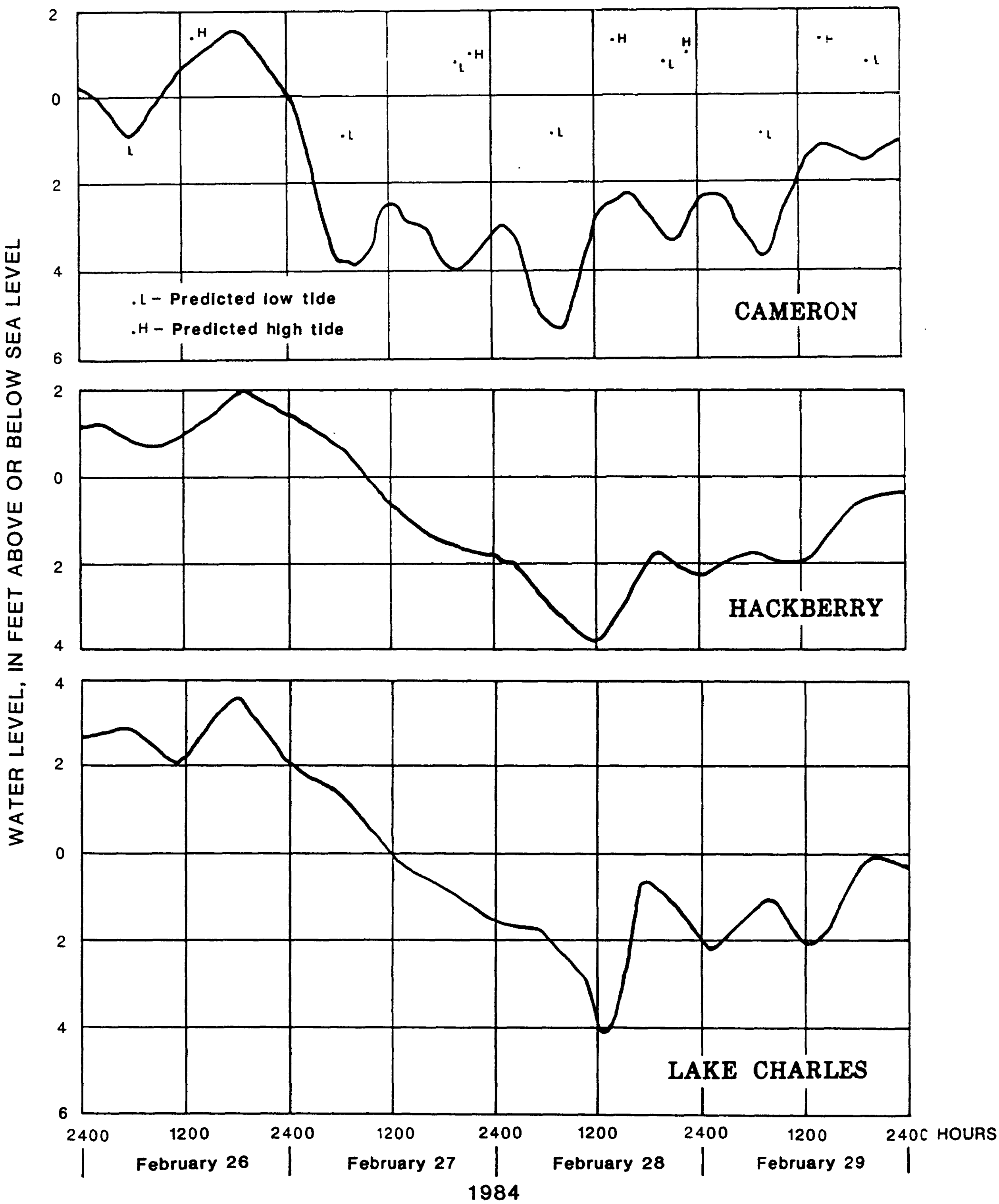

Figure 26.--Water-surface elevations for lower Calcasieu River at Cameron, Hackberry, and Lake Charles, sustained northerly winds, February 26-29, 1984.

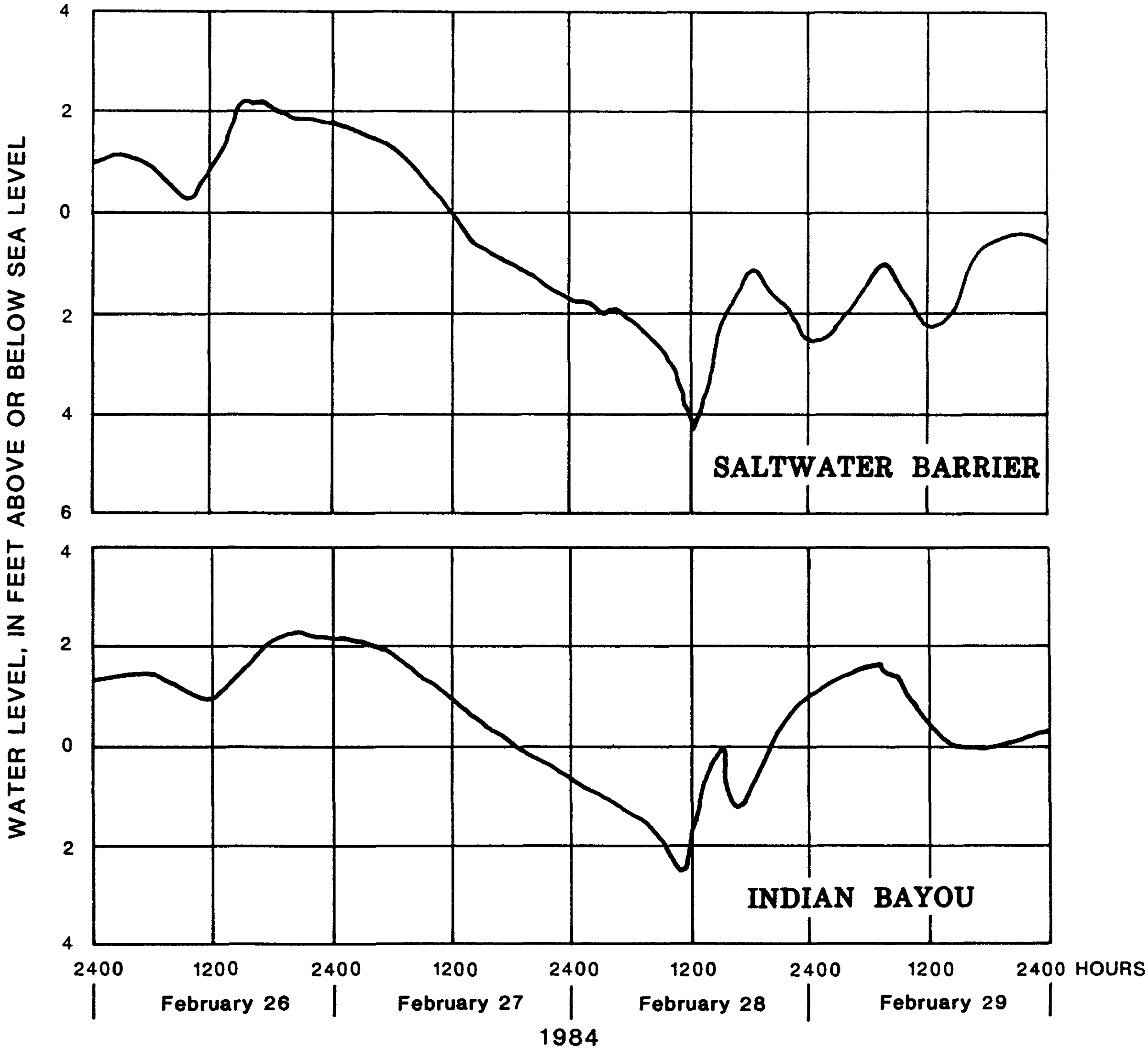

Figure 27.--Water-surface elevations for lower Calcasieu River at saltwater barrier and Indian Bayou, sustained northerly winds, February 26-29, 1984.

Winds from the south can drive the gulf water into the lower Calcasieu River and hold that water in the river and lakes. While the maximum water elevation at Cameron was the result of hurricane winds and tides (10.53 ft above sea level, June 27, 1957), southerly winds have produced much-above-average water-surface elevations. In March of 1973, southerly winds caused such a condition. Headwater flows into the lower Calcasieu River (again indicated by the gaging station at Kinder) did not produce the high elevations. The fastest mile observed during this period was 40 mi/h, with the wind blowing from 180 degrees. Tabulated below are wind readings at the Lake Charles Airport for a period of relatively high water-surface elevations.

Date (1973)	Time	Wind	
		Direction[1] (degrees)	Speed (miles per hour)
Mar. 23--	0600	070	10
	0900	100	16
	1200	110	17
	1500	100	18
	1800	050	24
	2100	090	20
	2400	090	22
Mar. 24--	0300	100	20
	0600	110	24
	0900	130	32
	1200	180	27
	1500	240	17
	1800	270	10
	2100	260	7
	2400	270	11

[1] Direction from which wind is blowing.

The above table shows a period on March 23 when winds were generally from the southeast. On March 24 the wind shifted more to the south and for about 30 hours, winds blew from the southern quadrants (90-270 degrees) with an average speed of about 22 mi/h (almost three times the average speed for this site). The effect of this period of sustained high southerly winds is seen in the records of water-surface elevations at several gages in the area (fig. 28). As was done for the low water conditions shown in figure 27, the predicted values of high and low tide for the gage at Cameron are shown for comparison. For the Hackberry gage, magnitude and direction of wind at selected times are shown to illustrate the effect of wind.

The dramatic effects of wind action on the lower Calcasieu River are caused, for a large part, by the large expanses of open water in the lakes, especially Calcasieu Lake. With a length of about 16 mi and roughly orientated north-south, Calcasieu Lake acts, in southerly or northerly winds, like a giant pump to either force gulf water upstream or to force water downstream through Calcasieu Pass into the gulf, lowering water-surface elevations throughout the river and lakes to the north. In either instance, the large cross-sectional areas of the ship channel (about 20,000 ft^2) promote rapid movement of water, and the waters of the system respond rapidly to wind.

The prevailing wind flow in the Lake Charles area is from a southerly direction during much of the year. Almost 80 percent of hourly speed observations during the year is 12 mi/h or less. Table 7 shows average wind conditions by month for the period 1951-80, with information on the fastest mile.

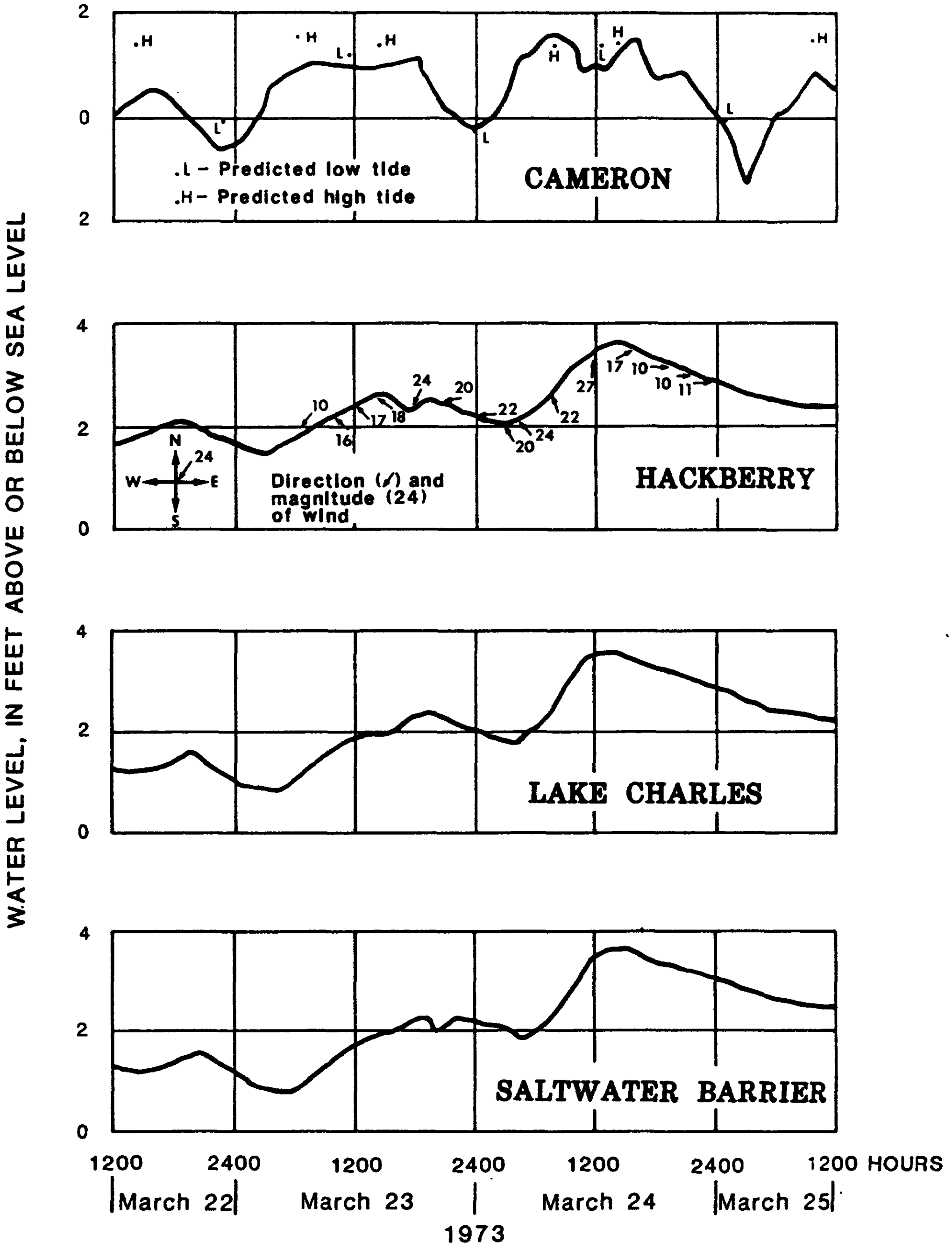

Figure 28.--Water-surface elevations for lower Calcasieu River at Cameron, Hackberry, Lake Charles, and saltwater barrier, sustained southerly winds, March 22-25, 1974.

Table 7.--Monthly average wind direction, speed, and fastest mile at Lake Charles Airport, 1951-80

Month	Prevailing direction[1]	Average speed (miles per hour)	Fastest mile: Direction[1] (degrees)	Fastest mile: Speed (miles per hour)	Fastest mile: Year
January---	North-------------	10.2	320	58	1962
February--	South-------------	10.4	250	40	1971
March-----	South-------------	10.7	180	40	1973
April-----	South-------------	10.3	060	44	1973
May-------	South-------------	8.9	320	43	1973
June------	South-southwest---	7.5	160	35	1974
July------	South-southwest---	6.5	120	35	1974
August----	South-southwest---	6.1	110	46	1964
September-	East-northeast----	7.2	000	40	1971
October---	East-northeast----	7.6	270	33	1973
November--	East-northeast----	9.0	320	35	1975
December--	South-------------	8.7	320	58	1962

[1] Direction from which wind is blowing.

Reaeration

Reaeration is a necessary process that helps to maintain the quality of stream water, and dissolved-oxygen (DO) concentration is a widely used measure of the quality of a stream. When any oxygen-using process takes place in the stream, the DO concentration is reduced, the reduction being dependent on the DO concentration at the beginning of the process, the volume of the oxygen-using materials in contact with the stream, and the type and manner of introduction of the biodegradable materials.

Countering the reduction of oxygen in the stream is the process of reaeration, in which water in contact with oxygen absorbs that oxygen. Water contains a finite amount of oxygen; that amount is defined as occurring at the saturation concentration of the water and occurs when the oxygen in the water reaches equilibrium with the adjacent oxygen-containing atmosphere. The saturation concentration is a function of water temperature, barometric pressure, and salinity. An exception to the previous discussion occurs when oxygen-producing plants in the water create a more than saturated condition in the water (super saturation).

When an oxygen-using process reduces the DO concentration, the countering reaeration process is driven by the oxygen deficit, the difference between the saturation DO concentration (Cs) and the actual DO concentration (C). To properly assess reaeration in the oxygen-recovery process, the time rate of change of oxygen between C and Cs must be determined. A widely used relation, $r = K_2(Cs-C)$ states that the time rate of change of oxygen concentration (r) is equal to a coefficient (K_2) times the deficit (Cs-C). The reaeration coefficient, K_2, is a function of the physical characteristics of the water body (surface area, depth, surface motion, temperature, and any other factor that affects the exposure of water molecules to atmospheric oxygen). K_2 can be thought of as a measure of the oxygen-transfer potential. If conditions are such as to inhibit oxygen transfer, K_2 is relatively small; if favorable transfer conditions exist, K_2 is relatively large.

The oxygen deficit of a given point in a stream is relatively easy to determine. Tables for saturation concentrations are available, with inputs of temperature and atmospheric pressure providing good values of Cs. Actual C values can be measured relatively inexpensively and with reasonable accuracy. The determination of K_2 can vary from relatively easy to relatively impossible.

This report discusses three generally accepted techniques of determining K_2: the dissolved-oxygen balance technique, the disturbed equilibrium technique, and the tracer technique. The dissolved-oxygen balance technique consists of measuring all of the oxygen movement processes (positive and negative) occurring in a stream study reach, except reaeration. By comparing the reach-entering oxygen conditions, considering the within-reach oxygen movement processes, with the reach-leaving oxygen conditions, a reaeration coefficient can be computed that would balance the oxygen loss-gain equation. When the uncertainties of measuring all of the oxygen movement processes are considered, the accuracy of the computed reaeration coefficient would not be great.

The disturbed equilibrium technique was developed for measuring K_2 in small streams. The technique is basically an oxygen-balance computation, but done at two different oxygen levels, one natural and one induced. The second oxygen level is created chemically, usually by adding sodium sulfite plus a cobalt ion catalyst. The cost of creating this second oxygen level limits this technique to small streams. In the computations at both oxygen levels, all oxygen depletion processes are grouped and the oxygen sources considered are photosynthesis and reaeration. The depletion processes, photosynthesis, K_2, change in temperature, and Cs are assumed to be constant in the reach; some of these assumptions are questionable.

The tracer technique involves the injection of a gas that behaves like oxygen in the mass transfer at the air-water interface but does not participate in other chemical or biological processes. Thus, the mechanical part of reaeration can be observed in the loss of the gas to the atmosphere. Sampling is done to measure that loss. The assumption is made that the gain of oxygen by water (reaeration) occurs in the same manner as the loss of the gas by the water. With the results of the analysis of samples, a reaeration coefficient can be calculated.

Several empirical prediction equations for determining K_2 have been developed. These are generally of the form

$$K_2 = A(\theta)^{T-20} \frac{U^W}{H^j},$$

where:

- A = a constant obtained from a regression analysis of experimental data;
- θ = generally the 1.0241 suggested by Elmore and West (1961) in their work on the effect of water temperature on reaeration;
- T = water temperature in degrees Celsius;
- U = average stream velocity in the cross section, in feet per second;
- H = average depth of the cross section, in feet; and
- w, j = either chosen from the regression equation, or chosen for dimensional homogeneity of the prediction equation.

Some of the more widely used equations that may be applicable in the deep channels of the lower Calcasieu River are those proposed by Churchill and others (1962), and O'Connor and Dobbins (1958). The Churchill and others (1962) equation,

$$K_2 = 5.026(1.0241)^{T-20} \frac{U^{0.969}}{H^{1.673}},$$

was based on observed reaeration rates below dams from which oxygen deficient water was released, and on what is considered to be the most extensive and reliable set of field data available. The O'Connor and Dobbins (1958) equation,

$$K_2 = \frac{(D_m U)^{0.5}}{H^{1.5}},$$

includes D_m, the molecular diffusion coefficient and is based on the theories of turbulent flow and the rate of renewal of saturated surface waters.

When considered for application in the lower Calcasieu River, each technique or equation has one or more criteria that cannot be met in the physical system. The measurement of the various input parameters for the oxygen-balance technique would not be accurate enough to assure realistic K_2 determinations. This is, however, a basic problem with using the technique in many locations. Use of the disturbed equilibrium technique would not be appropriate in large streams, from aspects of economy and practicality. For tracer studies, an assumption is made that there is reasonable and sufficient flow. A time-of-travel study conducted in May 1978, with dye injected about 2 mi downstream from the outlet of Lake Charles, indicated that at a flow rate of 455 ft^3/s at Kinder the tracer dye cloud moved less than 4 mi in 7 days. The dye was in very low concentrations in the ship channel, Coon Island loop, and Prien Lake. At one time, traces of the dye were found in Clooney Island loop about 1 mi upstream from the injection site. This problem with sustained flow negates the tracer technique in reaeration studies in this waterbody, except at higher flow rates where K_2 values would not be applicable to the lower flow rates.

Empirical equations use terms of velocity and depth that are assumed to remain reasonably constant long enough to give K_2 credence in its units of per day. That constancy is not achieved for any appreciable length of time in the tidal reaches of the lower Calcasieu River where reaeration information is needed.

The physical and hydrologic characteristics of the lower Calcasieu River (deep channels, tidal action, gulf-wind action, relatively low headwater flows) negate the conventional application of the techniques and equations mentioned earlier. However, variations of these procedures may produce reasonable and usable measures of reaeration until time and effort produces specialized procedures for determining reaeration characteristics in such tidal bodies of water.

Consultation with Ron Rathbun (U.S. Geological Survey, oral commun., 1985), an expert in reaeration, expressed the possibility of using selected empirical equations for the computation of reaeration coefficients if the criterion for relatively constant velocity conditions can be met. Therefore, reliable velocity is the key to determination of reaeration characteristics.

Following this section, an application of the branch-network flow model in the lower Calcasieu River is discussed. The model is being calibrated and seems capable of computing downstream and upstream flows. Flows of a mixed nature (downstream and upstream simultaneously) that are known to occur at both the Burton Landing near Moss Lake and Lake Charles railroad bridge, sites 27 and 40, respectively, cause problems that will be approached through defined paths in the calibration process. When these problems are resolved, velocity can be calculated at a number of cross sections on a 15-minute basis.

An objective of another project concerning hazardous substances in the lower Calcasieu River is to install multi-depth flowmeter at the railroad-bridge site to further define the periods when mixed flows take place. This information would complement the branch-network flow modeling calibration. Again, velocity would be available on a 15-minute basis.

Another approach that may produce reliable velocities for use in reaeration equations and which is being investigated involves the calculation of discharge in a stream segment for a period of time during which the change in velocity can be assumed to be relatively constant. This approach is described in ISO Standards Handbook 16 (International Organization for Standardization, 1983) as the "Method of Cubature." A change in volume for the segment is computed, using changes in water-surface elevation from water-level recorders at each end of the segment and the surface area of the segment. This volume change may occur on a flood or ebbtide, and the flow to produce the change will be directional (upstream or downstream). To this is added algebraically the change in volume created by changes in water-surface elevation in the reaches upstream from the segment to the limit of tidal influence. This calculation involves the location of a point of zero tidal effect on the river, the fluctuation of the upstream segment gage, and the stream-surface area between the point of zero tidal effect and upstream gage. The net change in volume added algebraically to the upland flow volume during the time period represents the volume of water that flowed through the cross section of interest during the specified time period.

A flow rate, in ft^3/s, to produce the change in volume is computed, and that flow rate is passed through the cross section at the downstream end of the segment and where the reaeration coefficient is desired. This passage, VOLUME/AREA, produces an average velocity term that is then used to compute the reaeration coefficient. This technique will be further studied for applicability under a variety of flow and tide conditions. Another area to be studied is the deviation, in the deep channels of the Calcasieu River, of the dissolved-oxygen concentration from the typical dissolved-oxygen concentration experienced when the empirical equations were developed. This area will be studied with the thought of adjusting selected empirical equations for the deep channels of this and other similar rivers.

APPLICATION OF THE BRANCH-NETWORK FLOW MODEL IN THE LOWER CALCASIEU RIVER

As a part of the activity in the lower Calcasieu River, and to provide flow information in that part of the river having most of the industrial development, a reach of the Calcasieu River between the saltwater barrier and Burton Landing near Moss Lake was selected for application of the U.S. Geological Survey branch-network surface-water flow model, developed and documented by Schaffranek and others (1981).

A model reach was instrumented as follows:

Saltwater barrier.--Water surface follower (float) driving a digital punch recorder, 60 minute punch interval on 16 channel paper tape. Stage only is recorded at this location.

Burton Landing near Moss Lake.--Water surface follower (float), and Gill anemometer and microvane, driving a digital punch recorder, 60 minute punch interval on 16 channel paper tape, through a U.S. Geological Survey mini-monitor (for multi-parameter use). Stage, wind direction, and wind speed are recorded at this location. See appendix 3 for additional information on these sites.

Figure 29 shows the network as established in the Calcasieu River model reach. Cross sections were obtained with a fathometer. Distances along the channel were taken from topographic maps; widths were taken from topographic maps for lake cross sections and were measured for channel cross sections. To assist in calibration of the model, a series of measurements were made; the results of these measurements are shown in table 8. Results of modeling are being produced for flow conditions in which there is one-directional flow, either upstream or downstream, associated with incoming or outgoing tide. During tidal changes (transitions between tides), flow occurs in both directions (fig. 19). The model is being adjusted to handle this condition, and to better simulate the one-directional flow situation.

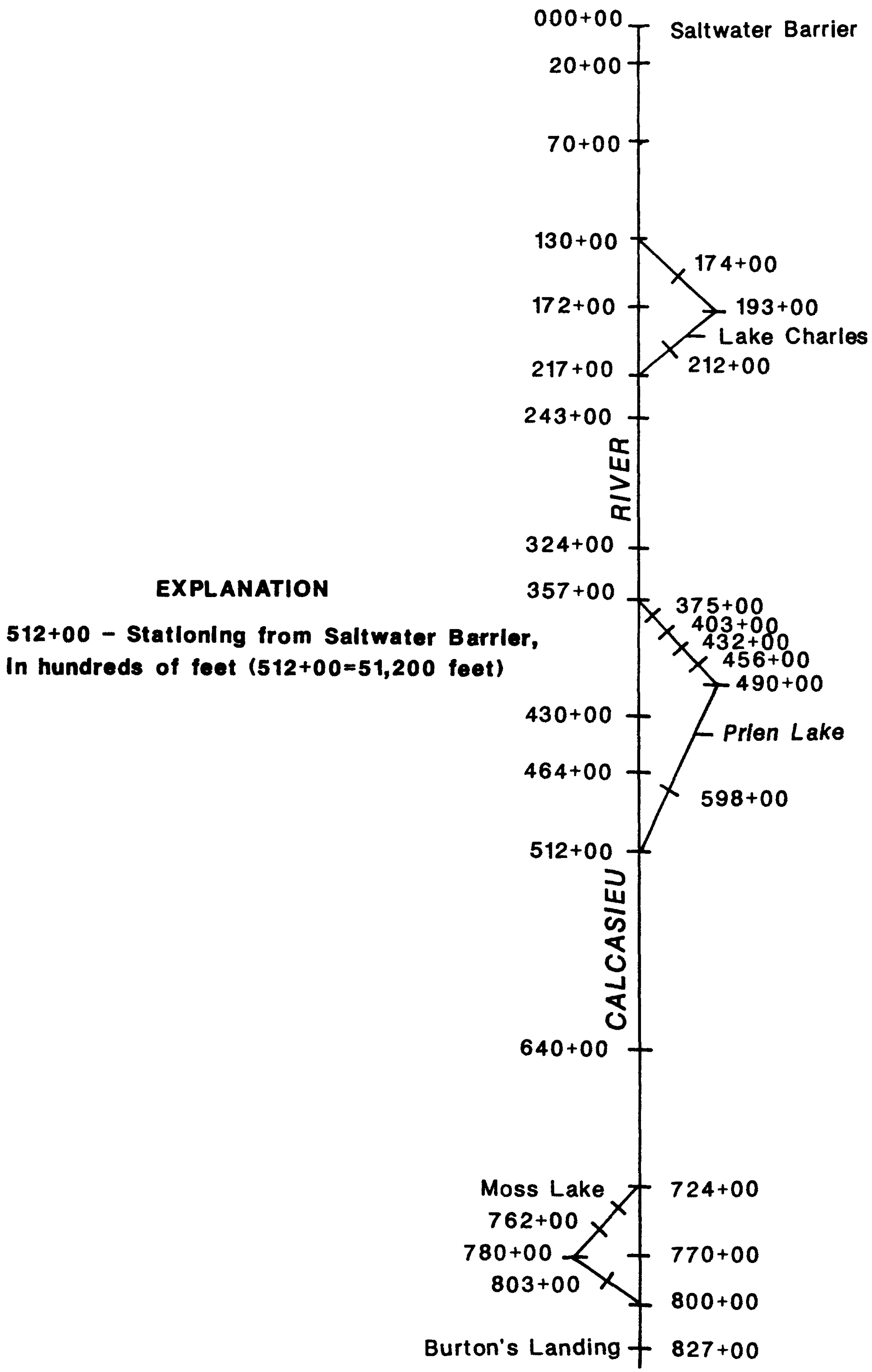

Figure 29.--Schematic of the lower Calcasieu River used for application of the branch-network flow model.

Table 8.--Discharge measurements used to calibrate the branch-network flow model

[ft^2, square feet; ft/s, foot per second; ft^3/s, cubic feet per second; Down, downstream; Up, upstream]

Site no.	Date	Time	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^2)	Downstream flow Discharge (ft^3/s)	Net flow (ft^3/s)	Direction
40	10-24-84	0940	------	------	------	16,400	2.93	48,100	48,100	Down
27	10-24-84	1335	------	------	------	25,600	1.77	45,200	45,200	Down
40	10-24-84	1600	------	------	------	16,400	2.56	42,000	42,000	Down
27	3-21-85	0800	------	------	------	25,500	1.20	30,500	30,500	Down
40	3-21-85	1100	------	------	------	15,900	1.36	21,700	21,700	Down
27	4-10-85	0825	------	------	------	26,100	1.24	32,300	32,300	Down
27	4-11-85	1007	26,800	0.72	19,200	------	-----	------	19,200	Up
40	4-11-85	1450	7,100	.31	2,190	6,380	.19	1,230	960	Up
27	5- 9-85	0830	25,700	1.17	30,000	------	-----	------	30,000	Up
40	5- 9-85	1215	7,610	.39	2,950	5,910	.34	2,030	920	Up
27	6- 5-85	0730	23,200	1.27	29,400	------	-----	------	29,400	Up
40	6- 5-85	0950	12,284	.27	3,310	1,290	.20	260	3,050	Up
27	7-29-85	1400	5,010	.73	3,660	17,720	.65	11,500	7,790	Down
40	7-30-85	1100	9,250	.23	2,130	4,520	.67	3,050	920	Down

NEED FOR ADDITIONAL STUDIES

This report presents the results of studies carried out in the lower Calcasieu River during 1984 and 1985. In several areas, further studies to more completely define the hydrology of the river are needed. In considering this subject, planned studies in the ongoing project "Analysis of the Occurrence, Movement, and Fate of Selected Hazardous Substances in the Lower Calcasieu River" are taken into consideration; the suggested needs are exclusive of the plans of that project. The needs listed below are prioritized.

1. Completion of branch-network flow modeling: Instrumentation for the planned modeling has been in place and operating for about 30 months. Results have been produced and calibration continues. Difficulty has been experienced with simultaneous two-directional flows (upstream and downstream) at tide changes. Work on calibration and solution to specific difficulties will continue.

2. Flow patterns at selected locations: Flow patterns of the lower Calcasieu River have been addressed in a general manner. There is a need for more information on flow patterns for selected sites. Some of the sites mentioned below have general interest; others were selected as sensitive locations with respect to potential spills. Sites specified at this time include: Calcasieu River upstream from the saltwater barrier, ship channel-Gulf Intracoastal Waterway junction, Contraband Bayou, Bayou D'Inde, Clooney and Coon Island loops, deep spots in Lake Charles and Prien Lake, and other sensitive sites. While tracer dye studies in the past have not produced the desired level of information because of very low-flow conditions, the tracer-dye technique is suggested for the flow pattern studies. However, a higher headwater flow condition is needed to move the tracer enough to define flow patterns. This definition is not likely to be quantitative in terms of time of travel, but will provide information on patterns of flow.

3. Evaluation of previous modeling activity in the lower Calcasieu River: A number of studies of the river have included flow and quality modeling. A review of the results of these studies would increase understanding of the lower Calcasieu River and improve the initial starting position for future modeling studies. Modeling activities have been conducted in recent years by the Louisiana Department of Environmental Quality, the U.S. Army Corps of Engineers, McNeese State University, and the U.S. Geological Survey.

SUMMARY AND CONCLUSIONS

Water movement in the lower Calcasieu River, a tidal estuary, is a function of the physical configuration of the river-estuary system, freshwater inflow, tidal action, and wind action. Changes in the configuration of the lower Calcasieu River from the natural river of the mid-1800's to the current form have had a major impact on the hydrology of the river. The 40-foot deep ship channel has the capacity to affect the movement of large amounts of water in a relatively short time.

Average freshwater inflow, however, at the nearest gaging station to Lake Charles (Kinder) is only about 2,500 ft^3/s, a small amount compared to the large amounts flowing into and out of the river during tide changes. The minimum and maximum flows near Kinder are 136 and 182,000 ft^3/s, respectively. However, the median flow near Kinder is only 1,030 ft^3/s, indicating that there are long periods of low freshwater flow in the lower Calcasieu River.

The distinct saltwater wedge commonly found in tidally affected streams does not usually form in the lower Calcasieu River because headwater streamflow is not great enough during most of the year to force itself over the incoming saltwater. Thus, mixing of freshwater and saltwater normally occurs with very little stratification.

Gulf tidal action is the dominant force moving water into and out of the lower Calcasieu River; the river experiences diurnal, semi-diurnal, and mixed tidal patterns, with the diurnal pattern being dominant. Measurements in June 1984 indicated that about 75 percent of ordinary tidal inflow is stored in Calcasieu Lake and other waterways south of Burton Landing, and about 5 percent of ordinary tidal inflow reaches the Lake Charles area. Studies of tidal lag time indicated that about 80 percent of the total incoming tidal-cycle time required for a tidal peak to move from Cameron to Indian Bayou is expended in moving the peak through the Cameron to Burton Landing reach.

Wind action can cause dramatic changes in water movement and stage over a relatively short period of time; extreme examples have occurred during the five hurricanes that centered on this area. The maximum and minimum water-surface elevations at Cameron, caused primarily by wind, were 10.53 ft (Hurricane Audrey in 1957) above and 5.3 ft (1984) below sea level, respectively. More common high winds from the south have caused water-surface elevations of about 2 ft above sea level at Cameron and about 4 ft in the Lake Charles area. Northerly winds produce, at times, very low water-surface elevations in the lower Calcasieu River. During these conditions, wind moves down the broad expanses of river channels and pushes water southward, forcing water out of the mouth of the river and lowering water levels. Such a wind in February 1987 caused the water-surface elevation at Lake Charles to reach a low of 4 ft below sea level.

The potential for mechanical reaeration, a function of velocity and depth, is low (on a unit volume basis) in the deep and slow-moving waters of the lower Calcasieu River. Techniques and equations (such as tracer dye studies that are dependent on sustained and one-directional streamflow) commonly used to estimate reaeration coefficients are not directly applicable in this river. The most promising approach appears to be the determination of average velocities for short time periods when water movement can be assumed to be relatively constant, and the use of these velocities in empirical equations to compute reaeration coefficients. Two techniques presently being examined could provide the short duration velocities required; the branch-network flow model is being applied in the saltwater barrier-Burton Landing near Moss Lake reach and can produce discharges (on a 15-minute basis); a volumetric discharge computation is being examined that could produce velocities on a hourly basis.

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GLOSSARY

Gulf Coast Low Water Datum--a chart datum.--Specifically, the tidal datum designated for the coastal waters of the gulf coast of the United States. It is defined as Mean Lower Low Water when the type of tide is mixed and Mean Low Water when the type of tide is diurnal.

Mean Lower Low Water--a tidal datum.--The average of the lowest low water height for each tidal day observed over the National Tidal Epoch. For stations with shorter series (less than 19 years), simultaneous observational comparisons are made with a control station in order to derive the equivalent of a 19-year datum.

Mean Low Water--a tidal datum.--The average of all the low water heights observed over the National Tidal Datum Epoch. For shorter series, a computation as described above in Mean Lower Low Water is followed.

National Tidal Epoch--a specific 19-year Metonic cycle.--The Metonic cycle was defined by the fifth century B.C. astronomer, Meton, as occurring between occasions when the full and new moon occur on the same day. The absolute length of the cycle is 235 lunations. A lunation or synodical month, is the period between two successive new moons and averages 29 days, 12 hours, 44 minutes, and 2.8 seconds in length.

Appendix 1.--Organizations with hydrologic activities in the lower Calcasieu River

[The following information is provided to assist those interested in or conducting investigations in the Calcasieu River basin]

Organization	Comments
State	
1. Louisiana Department of Environmental Quality Office of Water Resources Water Pollution Control Division P.O. Box 44091 Baton Rouge, Louisiana 70804-4091 Telephone: (504) 342-6363	Conducts water-quality surveys in connection with determining waste load allocations. Issues permits for discharges to waterways. Studies recently completed in the lower Calcasieu River include nonpoint sources; water quality, such as ammonium nitrogen transformations; sediment oxygen demand; and fisheries use-attainability (evaluating ability of the estuary to sustain different species).
2. Louisiana Department of Transportation and Development, Office of Public Works District 7 P.O. Box 1399 Lake Charles, Louisiana 70602 Telephone: (318) 439-2406	Provides technical assistance to local governments in matters of drainage, flood control, and navigation. Conducts drainage improvement projects, generally on non-navigable streams.
3. Louisiana Department of Transportation and Development, Sabine River Diversion System P.O. Box 2324 Sulphur, Louisiana 70664-2324 Telephone: (318) 439-2406	Operates the Sabine Diversion Canal to supply farmers and industrial users in the Lake Charles area.
4. Louisiana Department of Wildlife and Fisheries, Office of Coastal and Marine Resources, Seafood Division P.O. Box 15570 Baton Rouge, Louisiana 70895 Telephone: (504) 342-5876	Engaged in monitoring and appraisal of seafood resources, including habitats. Study of ecosystem of Calcasieu River and Calcasieu Lake conducted for the U.S. Department of Energy by McNeese State University was administered by the Department of Wildlife and Fisheries.
Federal	
1. U.S. Coast Guard Supervisor, Marine Safety Detachment 150 Marine Street Lake Charles, Louisiana 70601 Telephone: (318) 433-3765	Works in water pollution prevention and response, maritime safety (responsible for navigational aids in Calcasieu Ship Channel), and search and rescue.
2. U.S. Army Corps of Engineers New Orleans District Chief, Hydraulics and Hydrology Branch, LMNED-H P.O. Box 60267 New Orleans, Louisiana 70160-0267 Telephone: (504) 862-2420	Operates water-level recorders on lower Calcasieu River, operates saltwater barrier and Calcasieu Lock, and maintains ship channel (depth and width). Conducted study on effect of deepening Calcasieu Ship Channel to 45, 50, and 55 ft.
3. U.S. Department of Energy Chemist 1000 Independence Ave. SW Washington, D.C. 20585 Telephone: (202) 252-4410 or -4730	Initiated study of ecosystem of Calcasieu River and Calcasieu Lake to be conducted by McNeese State University.
4. U.S. Environmental Protection Agency Chief, Water Quality Management Branch, 6W-Q 1201 Elm Street Dallas, Texas 75270 Telephone: (214) 767-2668	Responsible for implementation of the Clean Water Act. Works with State agencies on water-quality programs. Issues National Pollution Discharge Elimination System (NPDES) permits.

Appendix 1.--Organizations with hydrologic activities in the lower Calcasieu River--Continued

Organization	Comments
Federal--Continued	
5. U.S. Environmental Protection Agency Environmental Service Division College Station Road Athens, Georgia 30613 Telephone: (404) 546-2294	Provides technical support for the U.S. Environmental Protection Agency, Atlanta Regional Office (and for other regions on request). Provided support in sediment oxygen demand determinations during the intensive survey of June 1984.
6. U.S. Geological Survey Water Resources Division P.O. Box 66492 Baton Rouge, Louisiana 70896 Telephone: (504) 389-0281	Operates water-level recorders in the Calcasieu River basin. Analyzes water samples for water-quality constituents. Conducted hydrologic study of the lower Calcasieu River. Presently conducting study of hazardous substances in water of lower Calcasieu River.
7. National Oceanic and Atmospheric Administration Chief, Hazardous Material Response Branch Office of Oceanography and Marine Services, Ocean Assessment Division 7600 Sand Point Way NE BIN C15700 Seattle, Washington 98115 Telephone: (206) 562-6317	Conducted study of hazardous materials in lower Calcasieu River.
8. National Oceanic and Atmospheric Administration National Ocean Service Estuarine and Ocean Physics Branch Chief, Tide and Current Predictions Section N/OMA132 6001 Executive Blvd. Rockville, Maryland 20852 Telephone: (301) 443-8060	Provides tide predictions and information on tide gages operated by the National Oceanic and Atmospheric Administration.
Other	
1. McNeese State University Department of Biological and Environmental Sciences P.O. Box 923 Lake Charles, Louisiana 70609 Telephone: (318) 437-5675	In cooperation with U.S. Department of Energy conducted study of the ecosystem of the Calcasieu River and Calcasieu Lake system.

Appendix 2.--Cross reference of numbers assigned to sites in the intensive survey of June 19-20, 1984 and numbers assigned to sites in this report

[The table shows cross-section numbers used during the intensive survey of June 19-20, 1984, and the corresponding numbers assigned in this report. Other numbers assigned in this report refer to cross sections used to illustrate flow conditions at other times than during the intensive survey]

Intensive survey number	Report number
1	1
2	2
3	5
4	14
5	18
6	22
7	21
8	24
9	25
10	27
11	26
12	28
13	29
14	30
15	31
16	32
17	33
18	34
19	36
20	35
21	39
22	37
23	38
24	40
25	42
26	43
27	44

Appendix 3.--Description of gaging stations on the lower Calcasieu River

[Benchmarks referred to are described in the National Oceanic and Atmospheric Administration (1985a) publication Vertical Geodetic Control, Quads 290931 (December 1983) and 300932 (May 1984); ft, feet; MLG, Mean Low Gulf; mi, miles]

Location	Recorder	Operated by	Comments
1. Cameron-Pilot's Wharf, south side of Monkey Island	Automatic, zero of gage set at 0.78 feet below sea level, referenced to Benchmark P212, Quad 290931, sequence no. 052, line 101	U.S. Army Corps of Engineers New Orleans District (station number 73650)	Checks in 1982 of Benchmark P212 revealed an updating of elevation from 7.54 ft (1965) to 5.95 ft, a correction of -1.59 ft. To convert gage readings to sea level, subtract 2.37 ft, [0.78 ft (datum correction) plus 1.59 (benchmark correction)].
2. Hackberry-American Oil Company Wharf, west side of ship channel, about 900 ft south of mouth of Black Lake Bayou	Automatic, zero of gage set to 0.55 ft below sea level, referenced to Benchmark G211, Quad 300932, sequence no. 143, line 103	U.S. Army Corps of Engineers New Orleans District (station number 73600)	Checks in 1982 of Benchmark G211 revealed an updating of elevation from 6.59 ft (1965) to 6.13 ft, a correction of -0.46 ft. To convert gage readings to sea level, subtract 1.01 ft, [0.55 ft (datum correction) plus 0.46 ft (benchmark correction)].
3. Calcasieu Lock west-near lock operator's house at west end of lock on Gulf Intracoastal Waterway, about 2.2 mi from Calcasieu ship channel	Automatic, zero of gage set to 0.81 ft below sea level, referenced to Benchmark G226, Quad 300932, sequence no. 187, line 104	U.S. Army Corps of Engineers New Orleans District (station number 76960)	Benchmark G226 has an elevation of 6.785 ft above sea level (1982). Levels of April 10, 1985, indicate that the conversion of gage readings to sea level involves the subtraction of 1.96 ft.
4. Burton Landing near Moss Lake-lower Calcasieu River, west bank, at north end of sheet pile bulwark	Automatic, zero of gage set to 5.42 ft above sea level, referenced to Benchmark Q356, Quad 300932, sequence no. 130, line 103	U.S. Geological Survey Louisiana District (station number 08017075)	Benchmark Q356, established in 1981, has an elevation of 9.622 ft above sea level (1982). Levels of April 1985 indicate that the conversion of gage readings to sea level involves the subtraction of 5.42 ft.
5. Lake Charles-south side (east bank) of lower Calcasieu River, east end of port wharf near Coast Guard dock, about 1 mi downstream from Lake Charles	Automatic, zero of gage set to 0.59 ft below sea level, referenced to Benchmark 876 7816 Tidal 4, Quad 300932, sequence no. 148, line 104	U.S. Army Corps of Engineers New Orleans District (station number 73550)	Benchmark 876 7816 Tidal 4 has an elevation of 8.730 ft (1982) above sea level. Levels of January 1985 indicate that the conversion of gage readings to sea level involves the subtraction of 1.76 ft.

Appendix 3.--Description of gaging stations on the lower Calcasieu River--Continued

Location	Recorder	Operated By	Comments
6. Saltwater barrier-lower Calcasieu River, north side (west bank) and west end of navigation channel (gated) in barrier, about 2.6 mi upstream from Lake Charles	(1) U.S. Army Corps of Engineers, automatic, zero of gage set to sea level (1965) (2) U.S. Geological Survey, automatic, zero of gage set are to both recorders referenced to Benchmark 10 V 29 LADTD, Quad 300932, sequence no. 250, line 108	(1) U.S. Army Corps of Engineers, New Orleans District (station number 73473) (2) U.S. Geological Survey Louisiana District (station number 08017036)	Benchmark 10 V 29 LADTD has an elevation of 10.995 sea level (1982). Levels of January 1985 indicate that the conversion of gage readings to sea level for both recorders involves the subtraction of 1.54 ft.
7. Indian Bayou at bridge northwest of Lake Charles, and 1,500 ft upstream from the confluence of Indian Bayou and the West Fork Calcasieu River	Automatic, zero of gage set to sea level, referenced to Benchmark 10 V 33 LADTD, Quad 300932, sequence no. 257, line 108	U.S. Army Corps of Engineers New Orleans District (station number 73460)	Checks in 1982 of Benchmark 10 V LADTD revealed an updating of elevation from 17.657 ft (1968) to 17.052 ft, a correction of -0.605 ft. To convert gage readings to sea level, subtract 0.605 ft.
8. Kinder-Calcasieu River, at bridge on U.S. Highway 190 about 4 mi west of Kinder	Automatic, zero of gage set to 11.95 ft above sea level.	U.S. Geological Survey Louisiana District (station number 08015500)	