Hydrological and Biological Studies of the Colorado River Delta, Texas

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HYDROLOGICAL AND BIOLOGICAL STUDIES OF THE COLORADO RIVER DELTA, TEXAS

by

Engineering and Environmental Systems Section

Texas Department of Water Resources

Espey, Huston and Associates, Inc.

Civil Engineering Department
University of Texas at Austin

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PREFACE

This report describes the results of a joint investigation by the U.S. Bureau of Reclamation, Department of the Interior, and the Texas Department of Water Resources. The purpose of this study was to investigate the physical, chemical and biological relationships in the Colorado River Deltaic marsh and to utilize this information to assess the impacts of alternative surface water development in the Colorado River Basin upon the delta. Partial funding was provided by the federal government as part of an appropriation for the Bureau of Reclamation's "Colorado Coastal Plains Study, Texas": a comprehensive investigation addressing the present and long-range water resource needs of the Colorado River Basin below Mansfield Dam. This federal study was authorized by P.L. 89-561, 89th Congress, and funds were appropriated to the Bureau of Reclamation by the 93rd Congress, with local sponsorship provided by the Lower Colorado River Authority.

DESCRIPTION OF THE REPORT

The purpose and scope of the study is provided in Chapter I, as well as a summary of the major findings.

A physical description of the Colorado River deltaic system, the flow exchange patterns in the delta and marsh habitat are included in Chapter II.

The development of the hydrodynamic simulation model including its formulation, application, calibration and verification for the Colorado River Delta is discussed in Chapter III.

Chapters IV and V, respectively, contain descriptions of the nutrient balance studies and the nutrient exchange studies for the delta.

The deltaic flow routing simulations and the effects of future water resources development upon the inflows into Matagorda Bay are presented in Chapter VI.

ACKNOWLEDGEMENTS

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A portion of the technical information incorporated in this report was provided through contractual agreements with Espey, Huston and Associates, Inc. and Dr. Neal Armstrong of The University of Texas at Austin, Department of Civil Engineering. Assistance in the collection of field data was provided by personnel of the U.S. Geological Survey, Water Resources Division, Houston Subdistrict.

Special thanks are due Mr. Emmett Gloyna of the U.S. Bureau of Reclamation for his assistance in the completion of this project.

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CHAPTER I

PURPOSE AND SUMMARY

BACKGROUND

The coastal region of Texas represents one of the most diverse and valuable accumulations of natural resources available to the State. Along approximately 400 miles of coastline are located six major estuarine systems and several smaller estuaries. These estuarine systems have a total surface area of more than 1.3 million acres including many large shallow bays behind barrier islands. Thousands of acres of adjacent marsh and bayous provide nursery habitat for juvenile forms of marine species and also produce nutrients for the estuarine systems. The ecosystems which have developed within these estuaries are in large part dependent upon the amount, as well as the seasonal and spatial distribution of inflows of freshwater and associated nutrients from the rivers. Natural and man-made resources of the bays and estuaries contribute multiple-use inputs into the Texas economy in the form of navigational networks, a natural source of ecological treatment for wastes, and a resource base for minerals, seafoods, and recreational opportunities.

The increasing water demands on Texas river basins have generated considerable public concern as to the fate of their respective estuaries and the important role which these systems play in the overall economy of Texas. Realizing the need for maintaining the resources of the Texas coastal systems, the Texas Water Development Board, now part of the Texas Department of Water Resources (TDWR), began a Bays and Estuaries Program in 1967 to collect biological and hydrological data for the purpose of developing a working knowledge of the relationships that exist among freshwater inflows, tidal exchange, nutrients, and biological productivity of the bays and estuaries. Concurrent with the biological and hydrological studies, the Board initiated a series of studies to determine the value or economic impact of the bays and estuaries on the State and local economies.

At the time these studies were begun, there were very little reliable data available on the estuaries of Texas. Although several limited programs were underway, they were largely independent of one another, the data collected under any one program were not comprehensive, and since sampling and measurements of physical parameters under different programs were not accomplished simultaneously, the resulting data could not be reliably correlated. Furthermore, the complexity of these estuarine environments precluded a simple, straight-forward approach to the problem. Thus, from necessity, the Bays and Estuaries Program became a multidisciplinary and comprehensive study which employs advanced techniques and state-of-the-art methodologies to develop information with which to solve the very complex "real world" problems associated with water resources and the living resources of the coastal environments.

In 1975 this program gained further recognition and emphasis with the passage of Senate Bill 137 by the 64th Legislature of the State of Texas. This legislation directs the Board, now TDWR, "to investigate the effects of freshwater inflows upon the bays and estuaries of Texas and to complete comprehensive studies regarding the development of methods of providing and maintaining the ecological environments thereof." Under this mandate the studies on the six major Texas estuarine systems are to be completed with published reports by December 31, 1979. This deadline has necessitated a vigorous schedule of ecological, hydrological, geological, and economic investigations. Since the Bureau of Reclamation has been engaged in a comprehensive study of the water resources of the Lower Colorado River Basin in connection with the water supply potential of the Colorado Coastal Plains, and since an important segment of the study is the assessment of the environment of the Colorado River Delta, with and without future water resources development, within the Lower Colorado River Basin, it was mutually beneficial for the two agencies to undertake a joint investigation.

OBJECTIVES

The objective of this report is to evaluate the present hydrological and biological characteristics of the Colorado River Delta and to assess the probable impact on the hydrological regime of the deltaic system of future water resources development in the Colorado River Basin.

SCOPE

To provide some of the information necessary for this evaluation, the hydrological and biological interrelationships were determined by (1) application of a mathematical model to simulate the hydrodynamic characteristics of the Colorado River Delta complex, (2) delineation of the marsh habitats, (3) investigation of the deltaic system nutrient balance, and (4) determination of the deltaic system nutrient exchange rates. The results of these investigations were then used in conjunction with data compiled by the TDWR hydrological studies of the Colorado River Basin to assess the impact of various future water storage reservoir development scenarios in the basin upon the freshwater inflows to Matagorda Bay.

SUMMARY

Description of the Colorado River Delta

The Colorado River Delta lies along the middle Texas Gulf Coast. The delta covers an area of approximately 4,000 acres and is divided almost equally by the river channel of the Colorado River. Prior to 1929, the Colorado River flowed directly into Matagorda Bay near the shoreline at Matagorda, Texas. The reclamation activities, however, removed log jams in the lower Colorado in 1929 thereby allowing an increased flow of cumulated silt downstream into Matagorda Bay. By the late 1930's, the delta formed a causeway across Matagorda Bay and the Colorado River flowed directly into the Gulf of Mexico. Flow patterns near the mouth of the Colorado River have been observed to be quite complicated with bi-directional flow occurring under some tidal and river flow conditions. Numeric simulations of the hydrodynamics in the area of the mouth of the Colorado River have indicated that significant quantities of water are exchanged between Matagorda Bay and the Gulf of Mexico via Tiger Island Cut.

It has been found that the Colorado River Delta is composed of approximately twelve zones of marsh vegetation. The most important marsh species, in terms of areal extent, are Spartina spartinae which predominates in over twenty-nine percent of the project area. The inundation of these areas allows for the exchange of nutrient materials from the delta into the surrounding water column which is in turn flushed into the Matagorda Bay waters. Model studies show that these areas are not inundated by riverine flows.

Development of a Hydrodynamic Model for the Colorado River Delta

To properly evaluate the transport of water and nutrients through a deltaic river marsh, it is necessary to describe and compute estimates of the complex tidal and freshwater inflow interactions. A mathematical model (set of equations) based upon the physical laws of conservation of mass and momentum was developed and applied to the Colorado River Delta. A mathematical model (a computerized mathematical representation of a prototype system) such as the one utilized to analyze the hydrodynamics of the Colorado River Delta, undergoes several stages of development before it is considered a satisfactory predictive tool for use in the assessment of environmental impacts upon a particular ecosystem as a result of external purturations, either natural or man-induced. In addition, a rigorous data acquisition program must be instituted in order to insure the availability of sufficient information with which to test the veracity of the physical and biological principles on which the model is based. A simplified flow diagram of the model development and application process is presented in Figure I.1.

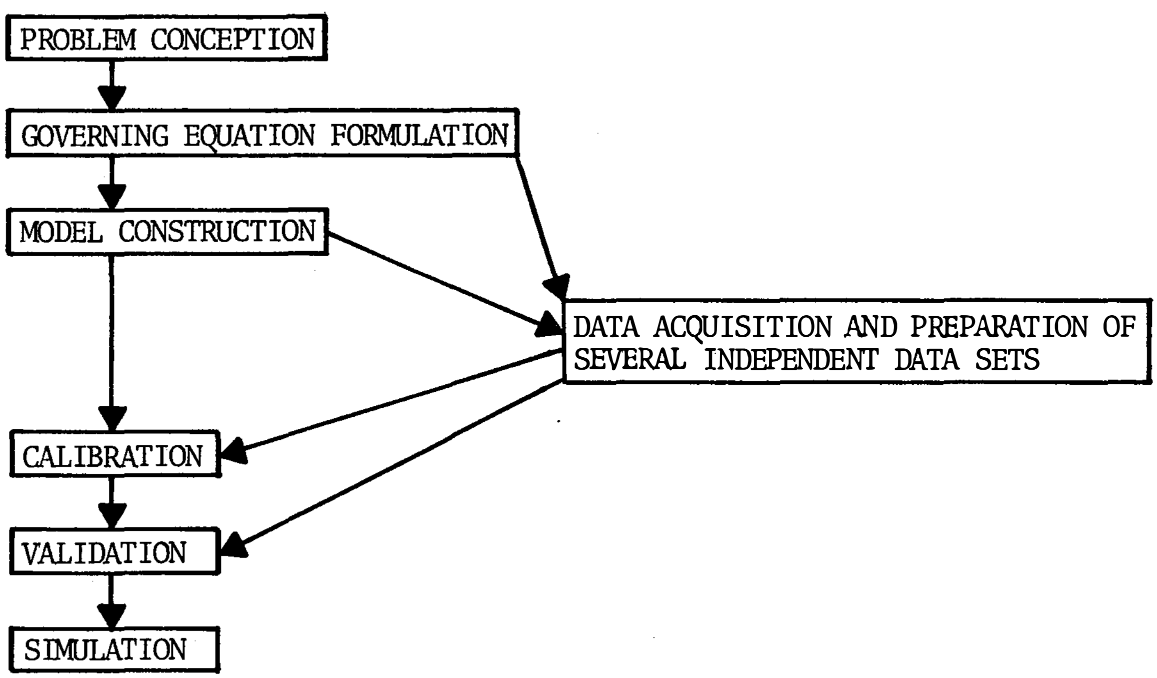


Figure I.1 Flow Diagram of Model Development

Model development begins with the selection of a specific problem, a general type of problem, or most likely a number of interrelated problems for which simple solutions are not currently available. The governing equations for each of the problems and their paths of interaction are arranged in such a manner as to form a congruous system of equations solvable through the application of ordinary solution techniques. These governing equations are then coded into algorithms, data input and output requirements determined and the necessary computer files created.

Prior to the next step in the model development, several independent sets of input and output data, as prescribed by the formulation and construction steps, must be gathered. The data should be sufficient to include the extremes of anticipated application of the model, and be of sufficient spatial extent and temporal duration to insure coverage of all boundary conditions and diurnal variations.

The calibration of the model consists of application of the model utilizing one or more of the input data sets, comparison of the simulated responses with the corresponding observed prototype responses, and adjustment of the input equation coefficients until the simulated and observed responses agree within some appropriate predetermined tolerances. If observed and simulated responses can not be drawn to agreement through the adjustment of the available coefficients, this indicates that either all of the governing equations were not included or ill-formulated in the formulation step or that there are errors in the model construction, i.e., a poorly constructed algorithm or the selection of an inappropriate solution technique, not all boundary conditions satisfactorily defined, etc.

Once a model has been satisfactorily calibrated, an independent set of input values (not previously used in the calibration process) are used and a new set of responses values simulated. These simulated responses are then compared with the corresponding observed response values. If the two responses agree within another predetermined tolerance the model is said to be "validated", i.e., future conditions for which comparative response data are not currently available may be simulated with a high degree of confidence. If a model fails to validate, it may still perform a reasonable simulation, however, the degree of response confidence is less.

The simulation step involves the application of possible purturbations to the model input values and analysis of the output to determine the effects upon the system.

The computer model, if properly applied and its output judiciously interpreted, can be a valuable analytical tool. However, as Kent Thornton of the U.S. Army Engineers Waterways Experiment Station includes in the preface of his formal reports, "No mathematical model will predict absolute values. For some variables, the predicted values may not be within an order of magnitude of observed field data. However, if the models are calibrated properly and the output interpreted with a knowledge and understanding of the model assumptions and limitations, trends may be predicted that provide valuable information about the nature and relative magnitude of impacts on a proposed activity."

The delta system is represented as a series of interconnected shallow channels which are subject to varying levels of flow inundation depending upon the tide and flow rates in the Colorado River. The representation of the delta includes the section of the Gulf of Mexico and Matagorda Bay adjacent to the delta and the Colorado River Channel up to Bay City, Texas.

The computations are based upon using a finite difference approximation to the equations which describe the governing physical relationships. The physical boundaries assumed in the mathematical model of the Colorado River Delta are the upstream river flow on the Colorado River at Bay City, tidal inputs in the Gulf of Mexico, Matagorda Bay, and East Matagorda Bay, and the waterway channel boundaries at the east and west ends of the Gulf Intracoastal Waterway (GIWW).

The correct coefficients for calibration of the hydrodynamic model, reflecting the delta's hydraulic characteristics, were determined by simulating the flow conditions and water inundation depths in the delta, comparing them with actual observed conditions, and adjusting the coefficients until adequate agreement between observed and simulated conditions was achieved. Two inflow studies, representing both low and high flow conditions, were conducted in 1977. The May 25-26 study represents a high flow condition, with the flow in the Colorado River averaging 5,000 cubic feet per second of flow. The low flow condition was observed during July 27-28, with the flow in the Colorado River averaging 670 cubic feet per second. These study cases served as low and high flow calibration cases with good results.

When the hydrodynamic model was used to simulate the observed conditions in these two historic events, in general, over the delta region the simulated water surface elevations appear to be in phase with the observed variation. However, consistently different magnitudes of the tidal elevation were found to occur. An elevation error of approximately 0.7 feet appeared to be fairly consistent over all simulated periods. This error is believed to be the result of tide gauge elevation datum errors of that magnitude.

The calibration simulations of the low flow condition in July 1977 resulted in a general agreement between the simulated and observed phases but again with a variation in the elevation, due primarily to suspected datum errors.

Agreement between simulated and measured flows recorded during the two field studies is not adequate at all locations. The phasing for the May period appears to be correct, however there is a definite shift in amplitude at some locations. The simulated flows in the July case reveal discrepancies in both phase and magnitude. It is believed that the flow velocity discrepancies can be attributed to the presence of density currents, i.e., bi-directional flows, which occur during low flow periods but this hypothesis cannot be accurately tested at this time due to the lack of suitable data. Mass balance analyses of the two simulation studies, however, indicate discrepancies which reinforce the possibility of bi-directional flow in the Colorado River Channel.

Nutrient Balance Studies

A major source of nutrients to the Texas Gulf Coast bays and estuaries is the deltaic regions located at the mouths of the major rivers. Samples were collected and analyzed to determine the nutrient contribution to the Matagorda Bay System from the Colorado River and Colorado River Delta. These samples were collected at the same time as the intensive flow studies recorded above.

Model computations and field observations confirmed that, with few exceptions, no part of the delta west of the river is inundated by freshwater overbanking from the Colorado River during flood events. All nutrients transported downstream by the river are contributed directly to either the Gulf of Mexico or Matagorda Bay.

A significant flood event occurring in April 1977 opened the mouth of the Colorado River to the Gulf of Mexico by flushing the silt and scouring the channel. The May 1977 study reflected this condition as hydrologic and nutrient concentration data indicated that over 75 percent of the total nitrogen, total phosphorus and total organic carbon contributed by the river was discharged into the Gulf of Mexico while the remainder entered Matagorda Bay through Culver Cut and Tiger Island Cut. Lower river discharges in July, in conjunction with a more constricted river mouth configuration, resulted in a greater percentage of nitrogen and phosphorus input into Matagorda Bay at Tiger Island Cut, but a lower total nutrient contribution than was observed during the previous field study.

Nutrient Exchange Studies

The nutrient sources in the Colorado River Delta contribute to the food-chain in Matagorda Bay only if sufficient inundation occurs to release the delta nutrients. To calculate the amount of nutrients released it is necessary to establish rates of nutrient exchange between the land area in the delta and the inundating waters through which the material is transferred. Utilizing marsh habitat reactor studies it was determined that the nutrient exchange rates for the predominant macrophytes in the Colorado River Delta were very similar in magnitude to the exchange rates for the other marsh systems in Texas. These rates indicate that particulate and carbonaceous material is generally exported from the deltaic systems, while inorganic nitrogen and phosphorus are consistently taken up by the system.

Future Condition Deltaic Flow Routings

Utilizing the hydrodynamic model, computation of flows into the delta were made under various reservoir development scenarios described in the TDWR Report "Present and Future Surface Water Availability in the Colorado River Basin, Texas" (TDWR, 1978). Typical tidal conditions were utilized as the driving Gulf tides for all simulated inflow conditions. The variation in the flow through Tiger Island Cut was computed using a distribution curve derived from the application of several flow and geomorphological scenarios. It was found that approximately 80 percent of the flow in the Colorado River above Tiger Island Cut was diverted through Tiger Island Cut at river flows of 2,000 ft^3/sec (cubic feet per second). This percentage of diverted flow decreased as the Colorado River flow rate increased to a flow rate of approximately 8,000 ft^3/sec. At flow rates greater than 8,000 ft^3/sec in the Colorado River, the diversion through Tiger Island Cut remained at a constant 62 percent.

CHAPTER II

DESCRIPTION OF THE COLORADO RIVER DELTAIC SYSTEM

GENERAL

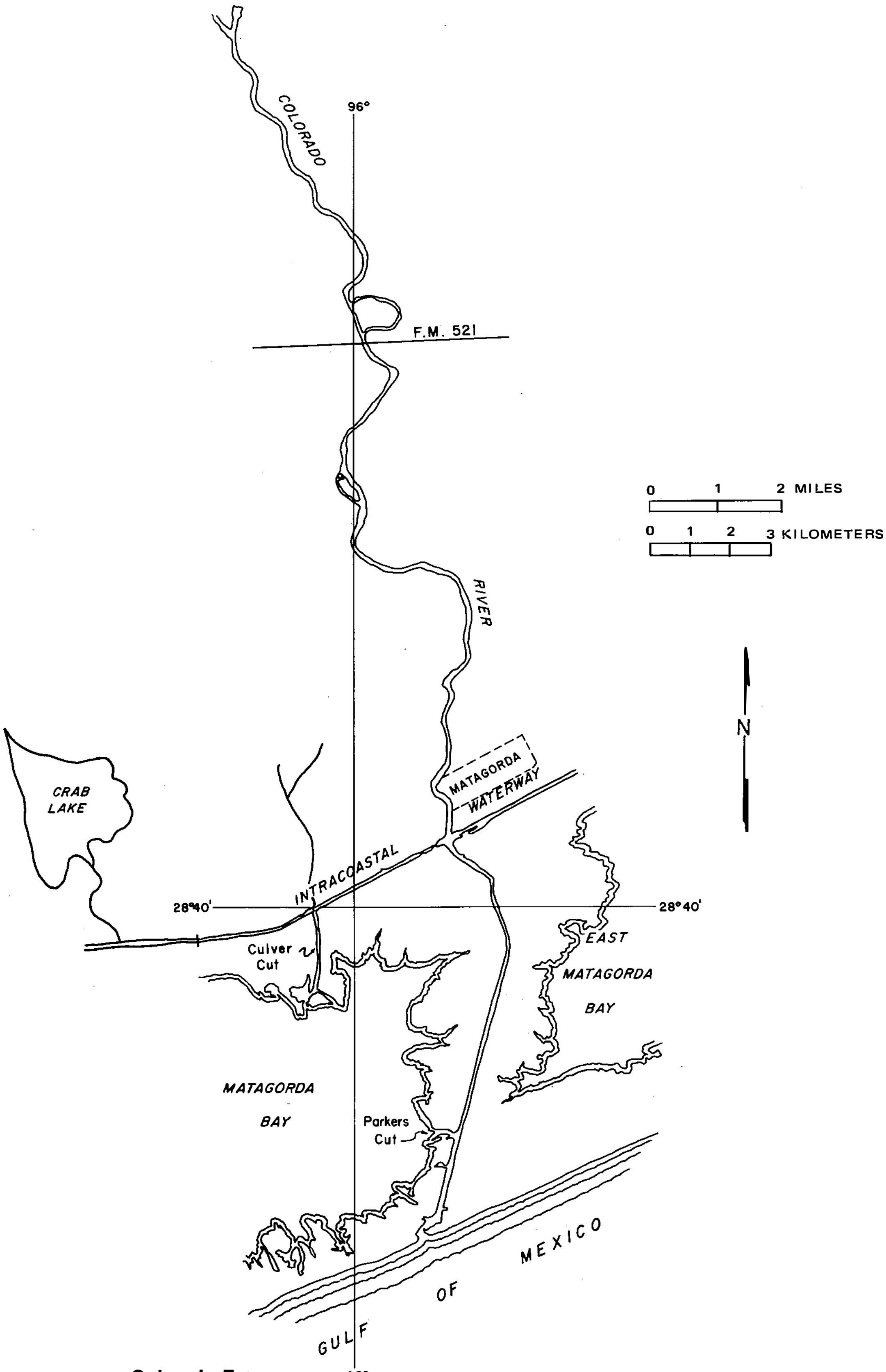
The Colorado River Deltaic System, as shown in Figure II.1 lies wholly within Matagorda County, Texas. Bounded on the north by Bay City, Texas and on the south by the Gulf of Mexico, the system includes portions of Matagorda Bay, East Matagorda Bay, the Matagorda Peninsula, the Gulf Intracoastal Waterway (GIWW), and all associated floodplain areas.

The Colorado River between Bay City, Texas and Matagorda, Texas is characterized by a well-defined channel of reasonably constant width and cross-sectional dimensions with a generally smooth meander pattern and one active oxbow. The river channel has been leveed for nearly the entire reach to heights varying from 10 to 25 feet above the mean water level. As a result, both flooding and infiltration derived from overland runoff are unlikely except during the most extreme hydrologic conditions.

Prior to 1930, the Colorado River flowed directly into Matagorda Bay near the mainland shore at Matagorda, Texas. The river channel above Matagorda was filled with tangled masses of logs and brush embedded in silt which restricted the water flow into the bay. In 1929, local conservation and reclamation districts cleared the channel by removing key logs which allowed the transportation of accumulated silt downstream by river currents and its subsequent deposition in Matagorda Bay. The rapid accumulation of materials in the bay enlarged the delta at the river mouth, and by 1930 the delta extended halfway across the bay to Matagorda Peninsula. In the mid-1930's, local interests dredged a straight channel from the river's mouth across Matagorda Bay and through Matagorda Peninsula to the Gulf of Mexico. Dredge material from this channel was placed on both sides to contain flood flows of the river. By the late 1930's, the delta had become a causeway across Matagorda Bay and the delta has been enlarged to a present area of approximately 4,000 acres.

Natural sediment deposition constricted the mouth of the river at Matagorda Peninsula, causing the delta area and upstream channel reaches near Matagorda to be prone to flooding during high flow periods. Local interests contracted Parker Dredging Company to dredge a channel from the river through the western delta bank into Matagorda Bay. This cut is known as Parker Cut (also called Tiger Island Cut).

The present deltaic system of the Lower Colorado River is a well defined system bounded on the north by the GIWW, which is maintained by the U.S. Corps of Engineers (USCE), and on the south by the Matagorda Peninsula and Gulf of Mexico. Dredge spoil is deposited on the causeway and commercial establishments have been located there as well. Thus, there are economic and social interests in the continued existence of the delta causeway.



Colorado Estuary

Figure II.1
COLORADO RIVER DELTA SYSTEM

Several active and inactive exchange points exist between the main channel of the Colorado River and both Matagorda Bay and East Matagorda Bay. However, most of these exchange points have been filled in with dredge spoil and become active only under severe flood events when overbanking occurs. Tiger Island Cut, the only exchange point maintained, provides the major exchange between the main channel of the Colorado River and Matagorda Bay.

The apparent sediment-formed regions of the Colorado River Delta do not become inundated under normal flow or moderate flood events due to the construction of levees within these regions. However, some of these areas are subject to inundation during occasional periods of strong southerly winds which result in water elevation setup.

Matagorda Bay is quite shallow in the vicinity of the Colorado River, with maximum water depths of approximately 5 feet. The bay has many small islands such as Dog Island Reef which rise only a fraction of a foot above normal high water levels. These areas are also subject to inundation during high tides when accompanied by strong southerly winds.

East Matagorda Bay is also quite shallow near the Colorado River delta with depths ranging from 1 to 5 feet, but no islands are located within the study boundaries. The delta regimes formed by formerly active exchange points between the Colorado River and East Matagorda Bay are of low relief and subject to periodic inundation by wind setup.

DELTAIC FLOW EXCHANGE PATTERNS

The mouth of the Colorado River forms a continually changing exchange point with the Gulf of Mexico. A combination of longshore drift and sediment deposition results in the silting of the river mouth during periods of low flow. Sediments can accumulate to levels sufficient to divert the majority of the Colorado River flow through Tiger Island Cut into Matagorda Bay. During high flow events, the momentum and velocity of the Colorado River flow are sufficient to scour the sediment deposits and to enlarge the river mouth exchange point with the Gulf of Mexico.

Flow patterns near the mouth of the Colorado River often become quite complicated, as was demonstrated by the application of the Texas Department of Water Resources (TDWR) Dynamic Estuary Model (DEM) to this system (Thorn and Smith, 1977). Thorn and Smith simulated flows above, below and through Tiger Island Cut under present channel conditions and under two proposed channel dredging conditions; one case with Tiger Cut at present conditions and the Colorado Mouth dredged and the other case with both Tiger Island Cut and the River Mouth dredged. A variety of Colorado River steady-state cases with flows ranging from 100 to 9,000 cfs were examined for each channel condition. Measured flow and tidal records obtained during the October 1972 U.S. Geological Survey (USGS) - TDWR intensive inflow/exchange study on the Lavaca/Matagorda Bay System were used to calibrate flow exchange between Matagorda Bay, the Colorado River, and the Gulf of Mexico.1/ The simulated flows resulting from this study were

1/ Smith, Robert E. 1973. Lavaca-Tres Palacios Estuary Intensive Inflow Study, October 16-19, 1972. U.S. Geological Survey, Houston Subdistrict, Houston, Texas.

preliminary estimates of the actual condition since the effects of Culver Cut, the GIWW and East Matagorda Bay were omitted.

Under present channel conditions, these simulations indicate that significant quantities of water are exchanged between Matagorda Bay and the Gulf of Mexico via Tiger Island Cut as a result of the tidal phase and amplitude variations between the two bodies. Given Colorado River flows as high as 2,000 cfs, water was predicted to flow in excess of 2,000 cfs from Matagorda Bay through Tiger Island Cut and into the Gulf of Mexico due to the difference in tidal elevation. An opposite tidal elevation alignment resulted in 4,100 cfs being forced from the Gulf into Matagorda Bay through Tiger Island Cut at the same Colorado River flow of 2,000 cfs.

These results indicate that the exchange between the Colorado River and Matagorda Bay through Tiger Island Cut is not a simple case of freshwater flowing from the Colorado River through the Cut into the Bay. The flow magnitude and direction varies over the tidal cycle as the tidal amplitudes in the Gulf and Matagorda Bay rise and fall. Thus, the exchange through Tiger Island Cut is a function of not only Colorado River flow, but also the difference in tidal amplitude between Matagorda Bay and the Gulf.

MARSH VEGETATION

The Colorado River Delta is comprised of approximately 12 zones of marsh vegetation, most of which were delineated by the Texas A&M Remote Sensing Center (RSC). The areal extent of each of these zones is shown in Sheets 1 and 2, located in the pocket of this report. The species composition, areal extent, and primary productivity estimates for each zone were determined by Adams and Tingley (1977).

Detailed descriptions of the various communities of marsh vegetation found in the Colorado River deltaic system were reported in a study by Espey, Huston and Associates, Inc. which was funded by TDWR (Adams and Tingley, 1977).

The results of their study are summarized in Sheets 1 and 2 (pocket) and Table II.1 through II.4. Table II.1 lists the most significant plant species in the Colorado Delta. Table II.2 gives the species composition by percentage for each of 12 vegetation zones. A range of zones having a variety of vegetation types are represented, including bare sand and mud flats, tidal marshes, irregularly flooded marshes, freshwater marshes, and uplands. Some of the zones which cover large areas are not uniform in composition. The percentages in Table II.2 are averages of each entire zone. Table II.3 lists production values (as dry weight) as reported in studies of the important marsh plants occurring in the Colorado Delta.

Table II.4 shows the areal extent of each vegetation zone and an estimate of its annual above-ground net primary production (ANP). ANP estimates in Table II.4 are derived from the percentage composition values in Table II.2 and the species production values in Table II.3. For example, Zone 1 (456.3 hectares) is comprised of 30 percent Spartina spartinae (gulf cordgrass) and 30 percent S. patens (salt-meadow cordgrass) (Table II.2). ANP values for these two species are 1,695 and 1,329 g/m^2, respectively (Table II.3). ANP of S. spartinae in Zone 1 is (0.30) x (456.3 hectares) x (1,695 g/m^2). ANP for S. patens in Zone 1 as a whole (ignoring water, mud flats, other vegetation, etc.)

Table II.1 Important Plant Species Occurring in the Colorado River Delta

Species Code	Scientific Name	Common Name
BAMA	*Batis maritima*	Saltwort
BOFR	*Borrichia frutescens*	Sea ox-eye daisy
DISP	*Distichlis spicata*	Saltgrass
JURO	*Juncus roemerianus*	Rush
MOLI	*Monanthochloe littoralis*	
PHCO	*Phragmites communis*	Common reed
SAVI	*Salicornia virginica*	Glasswort
SCMA	*Scirpus maritimus*	Salt-marsh bulrush
SPAL	*Spartina alterniflora*	Smooth cordgrass
SPPA	*Spartina patens*	Saltmeadow cordgrass
SPSP	*Spartina spartinae*	Gulf cordgrass
TYSP	*Typha* sp.	Cat-tail

Table II.2 Plant Species Composition of Marsh Vegetation Zones[1], Colorado River Delta

Vegetation Zone[2]		BAMA	BOFR	DISP	JURO	MOLI	PHCO	SAVI	SCMA	SPAL	SPPA	SPSP	TYSP	Soil/ Water	Other Vegetation
1	SPSP/SPPA	0	0	0	0	0	0	0	0	0	0	30	0	30	10
2	(Sand/mud)	0	0	0	0	0	0	0	0	0	0	0	0	100	0
3	BAMA/MOLI	15	5	5	0	10	+	10	5	+	+	+	0	50	0
4	BAMA/SAVI	40	21	2	0	1	+	30	6	+	0	±	0	0	0
5	(Upland)	0	+	+	0	0	0	+	0	0	0	+	0	0	100
6	SPSP/SPPA	0	5	5	0	0	0	0	0	0	15	45	0	0	30
7	DISP/SCMA	0	4	60	0	0	4	0	20	0	0	0	0	0	12
8	SPSP	0	0	0	5	0	0	0	5	0	0	85	0	0	5
9	SCMA/DISP	0	3	15	3	0	6	0	70	0	0	0	3	0	0
10	SPAL	+	0	0	0	0	0	+	20	80	0	0	0	0	0
11	TYSP	0	0	0	8	0	12	0	8	0	0	0	65	0	7
12	PHCO	0	0	0	0	0	85	0	0	0	0	0	10	0	5

1/ Data are estimated areal cover percentages by species. Contributions of less than 1 percent are denoted by the symbol +.

2/ The 4-letter species codes are made up of the first two letters of the genus and species as listed in Table II.1.

TABLE II.3

ANNUAL ABOVE GROUND NET PRIMARY PRODUCTION (ANP) VALUES FOR IMPORTANT MARSH PLANT SPECIES

Species/Zone	ANP g(dry)/M^2
BAMA	422
BOFR	843
DISP	1,102
JURO	499
MOLI	942
PHCO	2,984
SAVI	393
SCMA	1,097
SPAL	1,084
SPPA	1,329
SPSP	1,695
TYSP	1,336

TABLE II.4

AREAL EXTENT AND ESTIMATES OF
ANNUAL ABOVEGROUND NET PRIMARY PRODUCTION (ANP)
OF MARSH VEGETATION ZONES

Zone	Description	Hectares	ANP $g(dry)/m^2$	ANP Metric Tons/Zone
1	SPSP/SPPA	456.3	907	4,140
2	(Sand/Mud)	(605.7)	---	---
3	BAMA/MOLI	624.7	349	2,180
4	BAMA/SAVI	2,308.5	561	12,952
5	(Upland)	(1,450.2)	---	---
6	SPSP/SPPA	2,030.7	1,059	21,510
7	DISP/SCMA	280.2	1,033	2,895
8	SPSP	446.3	1,521	6,787
9	SCMA/DISP	336.1	1,193	4,010
10	SPAL	1,181.7	1,087	12,845
11	TYSP	266.1	1,354	3,603
12	PHCO	86.9	2,671	2,321
TOTALS/(Average)		8,017.5	(913)	73,243

equals the sum of the ANP values for S. spartinae and S. patens.

The major marsh species in the Delta in terms of areal extent are Spartina spartinae, which predominates in almost 3,000 ha (29 percent of the area); Spartina patens, which is a dominant species in almost 2,500 ha; Batis maritima and Salicornia spp., which are dominant in almost 3,000 ha; and Spartina alterniflora, which predominates in almost 1,200 ha. The S. alterniflora zone represents the only important intertidal marsh, and as such, it probably contributes a much greater amount of usable energy to the estuary than any of the other zones. With the exception of occasional events such as floods and hurricanes that result in flushing nutrient rich "plugs" of material from the intertidal marshes, more of the detritus of the relatively productive higher marsh zones is converted into peat rather than being exported on a regular basis to the estuary.

CHAPTER III

DEVELOPMENT OF A HYDRODYNAMIC MODEL OF THE COLORADO RIVER DELTA

FORMULATION OF HYDRODYNAMIC MODEL

As a prerequisite to the evaluation of nutrient transport through deltaic river marshes, it is necessary to describe the complex interaction between tidal inundation and the routing of freshwater flow from the river through the marsh systems. The preliminary modeling effort of Thorn and Smith (1976) demonstrated the complex nature of the hydrodynamics of the Colorado River Delta. To provide the capability of a more detailed analysis, Espey, Huston and Associates, Inc., under contract to TDWR, applied an existing one-dimensional hydrodynamic model to the deltaic system of the Colorado River (Sullivan and Hauck, 1978).

The deltaic system that was modeled consists of areas of low refief with narrow, interconnected channels, some of which flow only at higher water levels. The system is fed above by inflow from a river, and is terminated below by an open-water area usually a bay or the Gulf of Mexico. From the open-water area the system is tidally forced, and the effects of tides (and meteorological water level variations as well) propagate well into the deltaic system. For practical purposes, the region included in the model extends from the river above the tidal influence to beyond the delta mouth to the first point in the open-water area at which a tidal record is available. Within the delta, lateral areas contiguous to the channels are flooded and dewatered with the rise and fall of the water levels. Some channels with higher bed levels flow only intermittently, depending upon the height of the water.

The basic hydraulic characteristic of such a delta system is that the momentum of the flow pattern is concentrated in the longitudinal axis of the channel. This characteristic prevails even when inundation of the floodplain occurs, because the inundated areas function principally as storage of water volume and carry relatively little longitudinal momentum. There is, of course, a water level above which the flow pattern becomes two-dimensional (both longitudinal and lateral components). However, for moderate levels of inundation, the application of a one-dimensional section-mean model with confluence and difluence of channels is appropriate.

The principal factors governing the flow in this type of deltaic system which were incorporated in the model include the following:

(1) physiography, i.e., the relative locations, depths, cross-sectional areas and bed elevations of the conveyance channels and lateral floodplains;

(2) freshwater inflows, and internal diversions or additions of water;

(3) bed friction, measured in this work by Manning's n; and

(4) water level variation at the mouth of the delta.

Freshwater inflow and water level variation at the delta mouth and included embayments are introduced as boundary conditions. For this study, the direct effect of wind stress upon currents within the delta was neglected. However, meteorological effects such as wind, rainfall, temperature, etc. are implicitly incorporated in the water level variation at the delta mouth boundary (since this represents the response of the embayment to meteorological factors). The basic equations and numerical solution of the mathematical model and adaptions necessary to allow simulation of the Colorado Delta system are discussed in the work by Sullivan and Hauck (1978).

The equations of longitudinal momentum conservation, and continuity for one-dimensional tidal flow, neglecting Coriolis acceleration and the surface wind stress term can be written as

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\frac{(Q^2)}{A} + gA\frac{\partial H}{\partial x} + \frac{gn^2 Q|Q|}{2.22\, A\, R^{4/3}} = 0 \qquad [III.1]$$

$$\frac{\partial H}{\partial t} + \frac{1}{B}\frac{\partial Q}{\partial x} - \frac{Qf}{As} = 0 \qquad [III.2]$$

where

Q = flow in conveyance channel (function of time and longitudinal position)

A = cross-section area of conveyance channel

H = water level (referenced to a standard datum)

R = hydraulic radius

n = Manning's roughness parameter

B = lateral width

As = surface area (including lateral storage)

Qf = discharge into channel

g = gravitational acceleration

x = distance, longitudinal direction

t = time

z = channel bottom elevation (referenced to a standard datum)

Equations [III.1] and [III.2] constitute a set of two equations with the two unknowns Q and H, each a function of both x and t. Figure III.1 displays the estuary cross-section and the definition of variables. Note that the momentum equation is employed in its full nonlinear form.

The basic equations, [III.1] and [III.2] are solved by the method of finite differences in which the derivatives in the equations are replaced by finite-difference approximations and the solution is obtained by solving the resulting algebraic equations. In order to do this, the delta/river is segmented into discrete sections and variables are defined at the center or ends of these sections in such a way as to maximize the accuracy of the finite difference approximation (that is, a "staggered" system of computational nodes is employed). Variable definition is shown schematically in Figure III.2. Simultaneous solution of the finite difference form of equations [III.1] and [III.2] for discrete values of x and t yield values of Q and H at each segment throughout the time period desired.

The segment surface area, As, is allowed to vary with time as a means of accounting for watering and dewatering of marshes and floodplains, thus accounting for the additional water storage volume in the floodplain. To incorporate this concept into the model in a reasonable manner, two values of the surface area, As_1 and As_2, are required for each section. Internally the model calculates a channel surface area which is the average width of the channel multiplied by its length. The second surface area, As_2, represents the area that becomes inundated when the average streambank elevation is exceeded, including the channel surface area, As_1. The value of As_2 can normally be planimetered from a topographic map. Depending upon the water elevation and its relation to the streambank elevation for a section, As_1 or As_2, as appropriate, is selected and used in the computer calculations of water height.

It should be noted that the conveyance channel width, B, does not change when inundation of the lateral storage area occurs. That is, the model implicitly assumes that the majority of the longitudinal flow, Q, occurs in the conveyance channel even when water elevations are such that the banks of the conveyance channel are inundated, and consequently B is not altered to include additional width due to flooding. Furthermore, as soon as the bank elevation of a section is exceeded by the water level, the lateral storage area becomes entirely inundated with a thin sheet of water. Obviously, the elevation of the lateral storage area is not completely uniform as the above statement would indicate; however, this assumption is not greatly in error in deltaic and coastal areas of Texas due to the low flat relief.

Boundary conditions are required at the upper and lower limits of the system in question and may be a specification of either Q or H as a function of time. In practice the lower boundary, i.e. toward the bay mouth, is taken to coincide with the location of a recording tide gauge so that H, as a function of time, is immediately available as recorded tide data. The upper condition may also be H(t), if the position coincides with a recording tide gauge. For the Colorado Delta, the upper conditions were specified by flow with Q = 0 = Qf, where Qf is the flow measured at a USGS streamflow gauge or calculated from a stage-discharge relationship.

In order to accurately simulate the deltaic system, some features are included in the general mathematical model that require some explanation. These features were necessary to account for salt-water barriers (or locks), and transient channels (normally dry channels subject to flow during high flow and/or

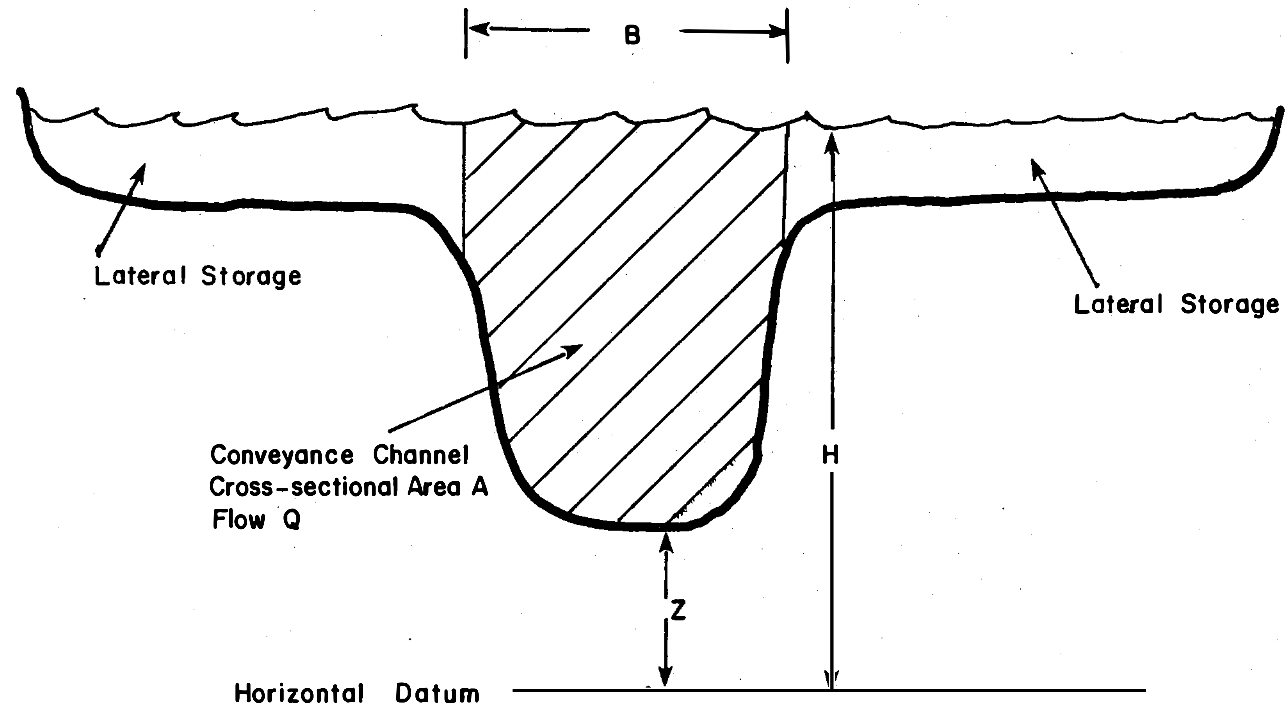


Figure III.1 DEFINITION OF VARIABLES IN CROSS-SECTION

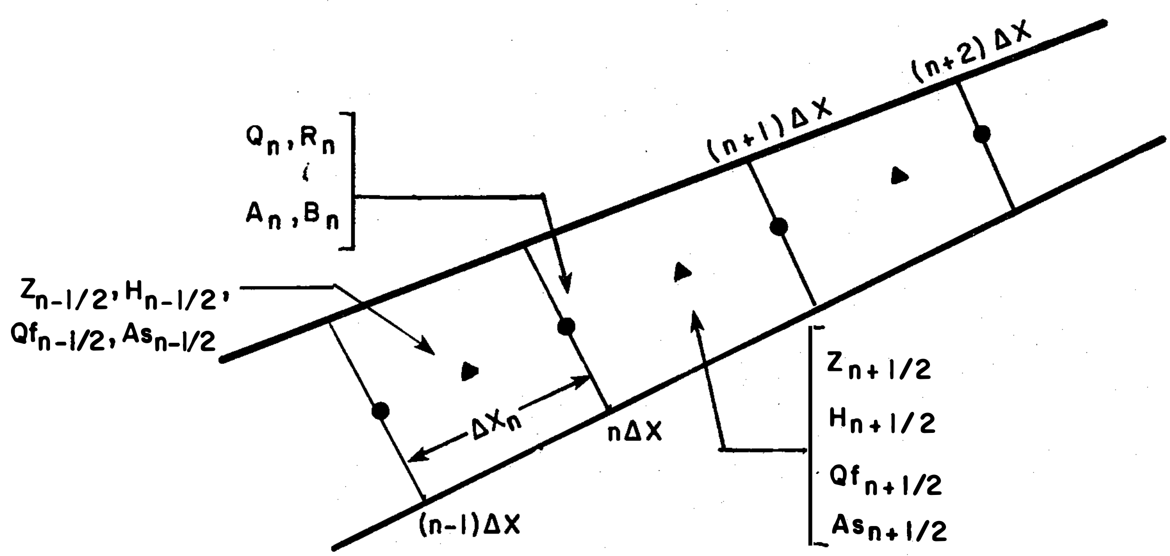


Figure III.2 VARIABLE DEFINITION IN FINITE-DIFFERENCE SEGMENTATION FOR HYDRODYNAMIC MODEL high tide conditions).

Salt-water barriers (or locks) are assumed to operate under two conditions: gates open and gates closed. When the gates are open, the gate is assumed to offer insignificant resistance to channel flow and calculations proceed as if the gate did not exist. However, if the gate is closed, flow is not allowed to pass the gate except by overtopping the gate. Flow is defined as occurring past the closed gates only at those times when the water level on either one or both sides of the gate exceeds the bank elevation of the surrounding channel or gate top (the lower of the two elevations) by two-tenths of a foot (0.2 ft). Due to computational instabilities and the fact that the governing equations in the model are not meant to describe extremely shallow flow conditions, a minimum flow depth of 0.2 ft is determined to be necessary to initialize flow. (It is reasonable to assume that any flow resulting from depths less than 0.2 ft is not a significant source of simulation error). Two locks exist in the Colorado River Delta on the Intracoastal Waterway (GIWW), one on either side of the Colorado River intersection with the GIWW.

Also, in the Colorado River Delta, at sufficiently high water levels, flow may occur between two waterbodies which are separated by dry land at lower water levels. These transient channels are modeled in an identical manner to closed locks. Flow does not occur through transient channels until the water level on one or both sides of the transient channel exceed the transient channel bottom elevation by 0.2 ft.

The development of the finite difference equations, description of the numerical solution of the equations, and the programming techniques are presented in detail in Sullivan and Hauck, 1978.

MODEL SEGMENTATION

The location of boundaries to the modeled system is a function of both model input requirements and data availability. In addition, system boundaries serve to isolate the objective hydrologic system from adjacent hydrologic systems, and since transport across longitudinal boundaries of overbank areas is assumed negligible by the model, the appropriate location of system boundaries becomes imperative.

There exists six boundaries to the system. There is the upstream river inflow boundary at Bay City on the Colorado River. Three tidal input boundaries exist; one in each the Gulf of Mexico, Matagorda Bay, and East Matagorda Bay. The remaining two channel boundaries are the east and west ends of the GIWW, as it is included in the system.

Choice of the Matagorda Bay boundary position was influenced by the location of USGS tide gauge 08162515 and the desire to include all exchange channels between Matagorda Bay and the GIWW which are appreciably influenced by Colorado River flows (gauge 08162515 is located approximately 12,000 ft. west of Tiger Island Cut). Flow measurements on the reach of the GIWW west of the Colorado River have indicated that the region influenced by Colorado River flows extends westward only as far as Culver's Cut. Thus a system boundary was located to the west of Culver's Cut approximately 18,000 feet from the junction of the Colorado River and the GIWW.

The East Matagorda Bay system boundary position was also placed to accomodate an exchange channel between the East Matagorda Bay and the GIWW. The USGS tide gauge 08117985 is located well within the system boundary and, thus, was not a factor in the boundary location. The boundary is located approximately 36,000 feet east of the junction of the Colorado River and the GIWW.

The Gulf of Mexico tidal input boundary was located solely to satisfy model input requirements. No tide gauges exist within this area. For periods having records the tide gauge located on the south jetty of the Matagorda Bay Entrance Channel could have been used, but for time periods having no records at this tide gauge, it would have been necessary to develop data from an alternate source. An examination of the tidal records for USGS gauges 08162515 and 08162508 (located approximately 200 feet north of Tiger Island Cut on the Colorado River), under steady-state conditions, indicate very close agreement in tidal amplitudes. However, the tides at the Matagorda Bay gauge lag the tides at Colorado River gauge by three hours. Therefore, the Gulf of Mexico tidal input data were derived by applying a minus three hour correction factor to records obtained from the Matagorda Bay tide gauge. These adjusted tide data were used as input at the Gulf of Mexico boundary which is located 6,000 feet into the Gulf directly out from the mouth of the Colorado River.

The upstream boundary of the Colorado River deltaic system selected for this modeling effort was the USGS flow gauge located at Bay City. This is the nearest upstream, non-tidally influenced, flow gauge for which data were available. Therefore, the streamflow data at this location are used in the model.

The locations of the GIWW, Matagorda Bay, East Matagorda Bay, Gulf of Mexico, and riverine system boundaries along with the segmentation used in this modeling effort are depicted in Figures III.3 and III.4. Tide gauge and streamflow gauge locations are also shown on these figures. Segments 1-44 define the riverine and Gulf of Mexico portions of the system. Segment 2 is utilized as the input segment for the Gulf driving tide and freshwater inflows are input to Segment 44 at Bay City. Segments 5, 8 and 12 serve as junction sections for Tiger Island Cut, a transient channel to East Matagorda Bay and the GIWW intersection, respectively.

Segments 45 through 56 define East Matagorda Bay and its associated areas of overbanking. Segment 46 serves as the tidal input segment. Segment 56 includes a transient channel between the Colorado River and the East Matagorda Bay (junctions with Segment 8 on Colorado River) which becomes active only under extreme flood conditions. Segment 57 is an unnamed cut connecting the GIWW to East Matagorda Bay. Segments 58 through 69 cover the portion of the GIWW included in this modeling effort. Segment 64 is the intersection of the Colorado River and the GIWW. Segment 68 intersects Culver Cut, which in turn intersects Segment 73 in Matagorda Bay. Segments 70 through 82 define Matagorda Bay and associated overbank areas. Segments 80 and 83 define Culver Cut and Tiger Island Cut, respectively. Since there is a mathematical relationship between segment length and computation timestep (Sullivan and Hauck, 1978), segment lenghts were selected to allow the use of a timestep (45 seconds) which would maintain computational accuracy without use of an inordinate amount of computer time and storage.

The model construction requires that all junction sections within the delta (junctions and intersections) be doubly numbered. The first number refers to the first meeting of the junction section when segmenting in an upstream

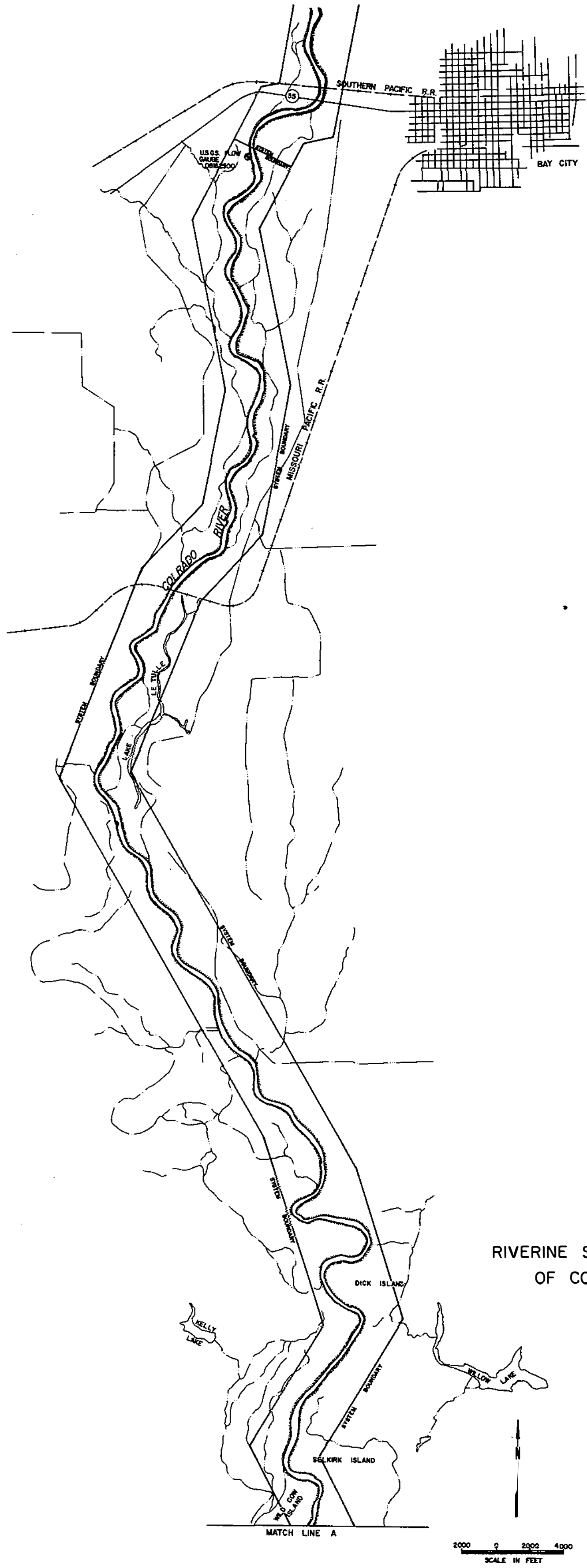


Figure III.3

RIVERINE SYSTEM BOUNDARIES
OF COLORADO DELTA

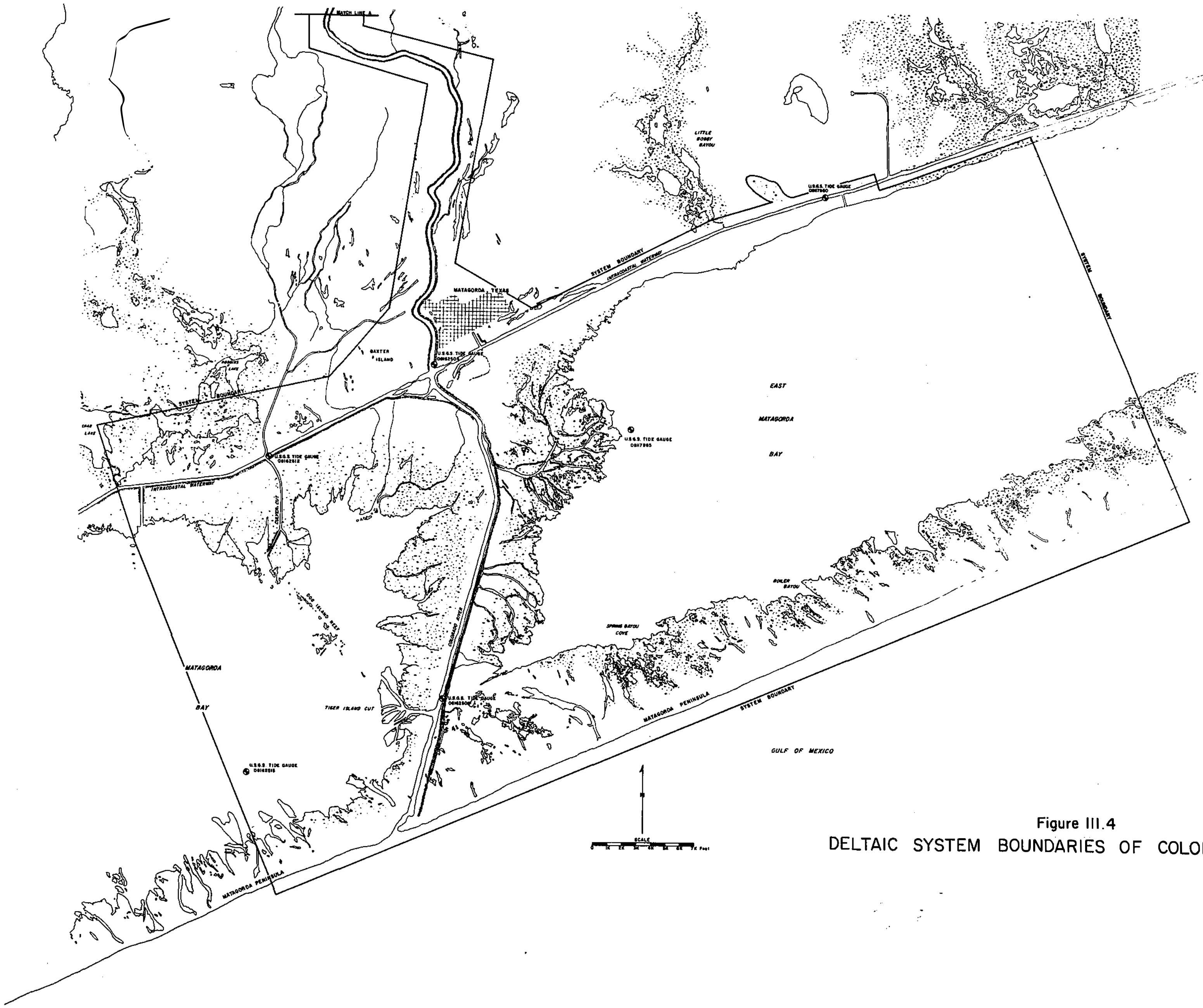


Figure III.4
DELTAIC SYSTEM BOUNDARIES OF COLORADO DELTA

direction; the second number refers to the second meeting. Segments 5/84, 8/56, 48/57, 68/81, 73/79 and 76/82 are all junction or intersection sections and thus have two segment numbers. The differencing techniques utilized at these locations is different from those used with standard channel segments (Sullivan and Hauck, 1978).

MODEL CALIBRATION AND VERIFICATION

The data base necessary for the development, calibration and verification of the simulation model consists of the physiographic details of the system, measured Gulf tides, measured tides at discrete points throughout the system, measured freshwater inflows, estimates of runoff from ungaged areas, and industrial withdrawals and return flows. Such a compilation of data for a specified period of time is referred to as a "data package", and it is through the successive application of the model to several independent data packages that the model is calibrated and verified. The continued operation of the model with new data packages is also necessary to establish model reliability, to obtain confidence in its usage and to make finer adjustments and modifications necessary to provide good simulations for a broad range of conditions. Maximum confidence exists for simulations involving prototype conditions similar to those used for calibration and verification. It is for this reason that the model should be operated for as many different data packages as possible.

Physiographic data are required for each section to describe channel shape and size of floodplain. The input data required are the following: channel width and average channel depth at the upstream end of the section, total area subject to inundation, Manning's n (roughness coefficient), channel length, average channel depth, and bank elevation. For the Colorado River Delta, these data were obtained from surveys conducted by the United States Army Corps of Engineers (USCE) for the proposed Mouth of the Colorado River Project and were supplemented with data gathered by TDWR. The data consisted of depth profiles across conveyance channels at selected locations and level transects across the floodplain at selected lines.

From the survey results and charts, the channel width and cross-sectional area could be determined. With the cross-sectional area and width information the average depth of the channel at the end of the section was determined. Bank elevations, which are the depths at which overbanking occurs and inundation of the surrounding floodplain results, were determined from the appropriate USGS quadrangle map. The channel length and total surface area subject to inundation of each section was measured from appropriate USGS 7 1/2-minute or 15-minute quadrangle maps. Finally, the average section depth was taken as the average of the channel depths at both ends of the section.

The Manning's roughness coefficient "n" was determined by experimentation within the range of values appropriate for the bed-type of the deltaic channels. Based on the results of several computer simulations for a range of freshwater flow and tidal conditions, one value of "n" for each section was selected. The values of "n" in the final segmentation ranged from 0.015 to 0.022. In general, the values of "n" in the bay and marsh areas were set at 0.015, while the value of "n" increased gradually in the upstream direction from 0.015 to 0.022 for the sections of the upper reach of the Colorado River.

In addition to those tide gauges mentioned earlier that were used for definition of boundary conditions, four additional tide gauges are maintained within the delta and their records were used for model verification purposes. The gauges are: 08162512 located on the GIWW at Culver Cut, 08117950 located on the GIWW five miles east of the Colorado River, 08162504 located on the east bank of the Colorado River at Matagorda, Texas and 08162508 located on the east bank of the Colorado River approximately 200 feet north of Tiger Island Cut (Figures III.3 and III.4).

To supplement the existing data base and to provide detailed information on the time history of tidal velocities and tidal prisms at selected locations in the system, two comprehensive inflow/exchange studies were conducted in the field. Hourly measurements of flow velocities were made at the six locations shown in Figure III.5. Measuring stations were positioned in each of the major channels where flow exchange was thought to occur. Four stations were located to monitor the exchange between the Colorado River and the GIWW, Matagorda Bay via Tiger Island Cut, and the Gulf. These stations, A through D, were respectively located in the river channel above the GIWW, in the river channel above Tiger Island Cut, in Tiger Island Cut and in the river channel just inside the mouth. Station E was located in Culver Cut above the GIWW to monitor exchange between the GIWW and the adjacent marsh area north of the GIWW. This station was eliminated after the first field study due to a lack of measurable exchange occurring between the channel and surrounding marsh. To monitor the exchange between Matagorda Bay, the adjacent marsh areas, and the GIWW via Culver Cut, Station F was located in Culver Cut below the GIWW (Figure III.5).

Due to time and budget limitations only two inflow/exchange studies could be conducted. Since the primary objective of each study was to obtain hydrological data for mathematical modeling of the delta it was desirable to conduct these under different but "typical" flow regimes if at all possible. Historic data were used in the selection of the times at which to collect data for the inflow/exchange studies. For the period 1951 through 1976, the months of the highest flows in the Colorado River have been May and June, while the lowest occur in July and August. Thus, the studies were conducted on 25-26 May 1977 and 27-28 July 1977 to coincide with these flow regimes.

The first field study commenced at 1100 hours on 25 May 1977 with velocity measurements recorded hourly for a 25-hour period at all six locations. The data recorded in the river at Station A, just above the GIWW, indicates that the river flow was sufficient to prevent flow reversal due to tidal action throughout the tidal cycle. The measured flow ranged from a high of 7,188 ft^3/sec to 4,103 ft^3/sec with a mean of 5,020 ft^3/sec.

The second field study began at 1600 hours on 27 July 1977 and continued for 25 hours with velocity measurements recorded hourly at five locations. Station E was dropped from the sampling program since the results of the May study indicated little exchange occurred at this location. The data taken at Station A during this study indicate that flow reversal occurred twice during the tidal cycle. The flow ranged from a maximum of 2,610 ft^3/sec downstream to 2,650 ft^3/sec upstream with a mean of 669 ft^3/sec in the downstream direction.

The mean monthly discharges for May and July at Bay City, Texas over the period 1951 through 1976 were 4,541 ft^3/sec and 1,611 ft^3/sec, respectively. Mean discharges calculated from flow data measured at Station A located on the Colorado River at Matagorda during the two inflow/exchange studies were 5,020 ft^3/sec for the 25-26 May study and 669 ft^3/sec for the 27-28 July study. Both

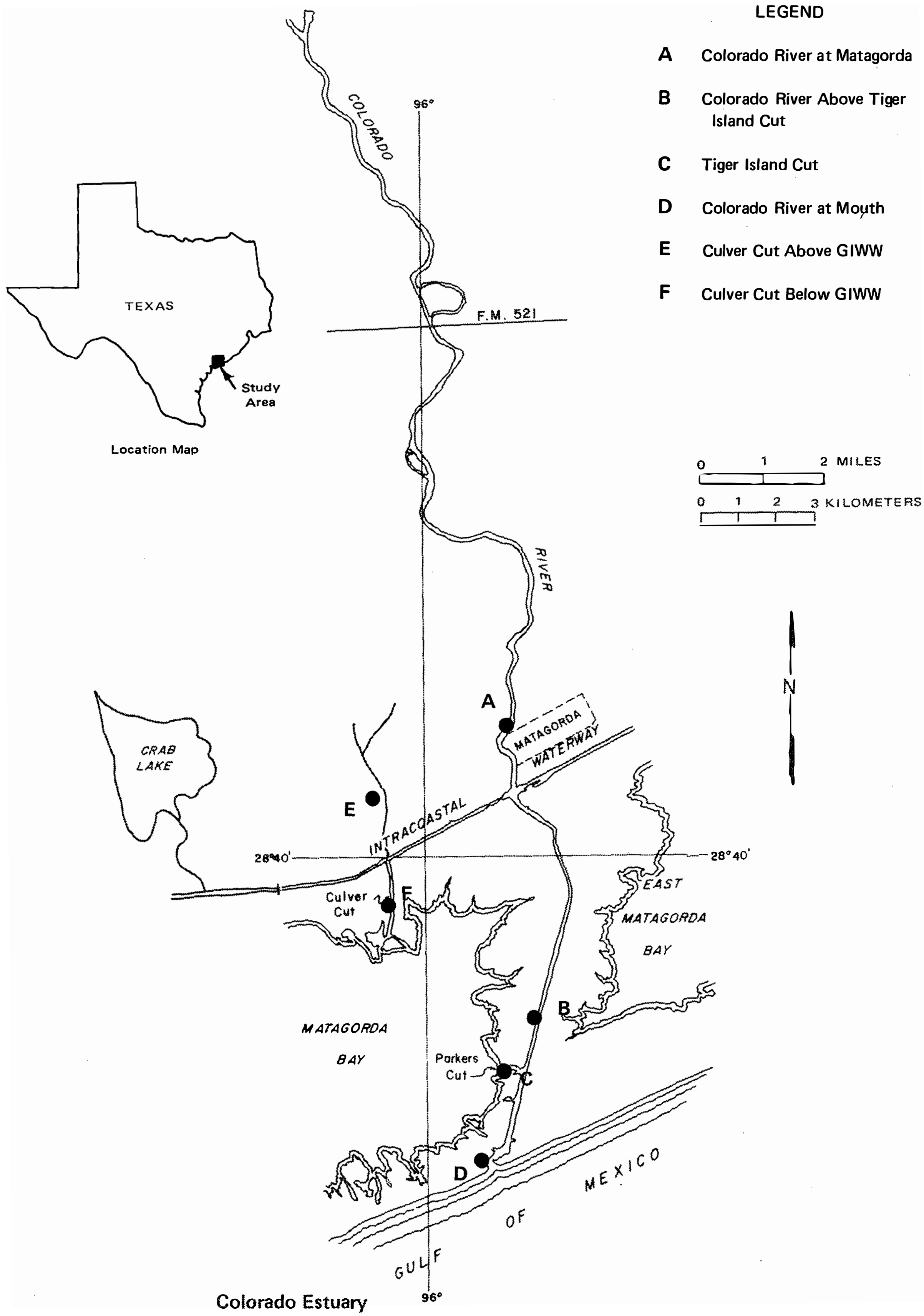


Figure III.5
SAMPLING SITES, COLORADO RIVER DELTA

means were well within one standard deviation of the mean discharges at Bay City over the 1951 through 1976 period of record, indicating that the conditions under which these studies were conducted could be considered representative.

The hydrodynamic model was operated for the two inflow/exchange study periods. The first case simulated was the period 18-26 May 1977, and the second case simulated was the period 20-28 July 1977. The Colorado River flow measured at Bay City and the tides recorded by the tide gauges in Matagorda Bay, the Colorado River above Tiger Island Cut, and East Matagorda Bay during these two periods were used to drive the model. Under the flow conditions present during these two periods, the locks on the GIWW located near Matagorda would be left open and were assumed so throughout both simulation periods.

During the first case simulated, the Colorado River flows measured at Bay City varied from 4,675 ft^3/sec to 5,900 ft^3/sec with a mean flow of 5,370 ft^3/sec. Daily mean flows for the simulation period are presented in Table III.1. The driving tides as recorded by the USGS gauges in Matagorda Bay and East Matagorda Bay are quite dissimilar and are presented in Figure III.6.

Comparison of simulated and measured water surface elevations on the Colorado River at Matagorda (Figure III.7) shows that the phasing appears to be correct; however, the mean simulated elevations exceed the observed elevations by a fairly consistent 0.3 foot. At Culver Cut (Figure III.8) the simulated elevations closely mimic the available observed data in phase, but are higher in elevation by a constant 0.7 foot. This datum appears to be fairly consistent for all simulated periods. The datum correction applied by the USGS to tide records for Culver Cut was 0.7 foot (substracted from the observed values). This correction factor is consistent with those used by the USGS in studies of 25-26 May and 27-28 July 1977 and with those utilized by the TDWR in field physiographic studies. However, the apparent consistency of the variation, combined with other idiosyncrasies observed in the July data, indicate that a datum correction of 0.7 foot to the measured data at Culver Cut may not be necessary. Simulated and observed water surface elevations on the GIWW east of the Colorado River (Figure III.9) are also in agreement with respect to phase. However, the simulated water surface elevations are about 0.4 foot lower than those measured by the USGS. This 0.4 foot variation also seems to persist for all other simulated periods.

Above Tiger Island Cut (Figure III.10) simulated and measured elevations are in close agreement with respect to phase and amplitude. The maximum elevation error observed is approximately 0.2 foot. Water surface elevations for Tiger Island Cut and the Colorado River mouth below Tiger Island Cut are presented in Figures III.11 and III.12. No validation data were available for these locations. They were included in this report to demonstrate the subtle elevation differences between the two locations which result in the flow patterns depicted in Figures III.13 through III.15.

Figure III.13 shows the temporal flow variations upstream of Tiger Island Cut plus the net flow (on the vertical axis "ebb" indicates flow toward the Gulf and "flood" indicates flow into the Colorado River from the Bay and Gulf). A simple mass balance indicates that under these relatively high flows, approximately 20 percent of the Colorado River flow is diverted into the GIWW at Matagorda. Inspection of Figure III.14 indicates that though the exchange flows through Tiger Island Cut are sizable, ranging up to 8,000 ft^3/sec in either direction, the net average flow between the two bodies is only 650 ft^3/sec being

TABLE III.1

FLOW RECORDS FOR COLORADO RIVER
AT BAY CITY, TEXAS (SEGMENT 44)

18-26 May 1977

DATE	(ft^3/sec)*
18 May	5,120
19 May	4,920
20 May	4,690
21 May	4,970
22 May	5,860
23 May	5,930
24 May	5,780
25 May	5,730
26 May	5,310

*Flows from USGS gauge on Colorado River at Bay City

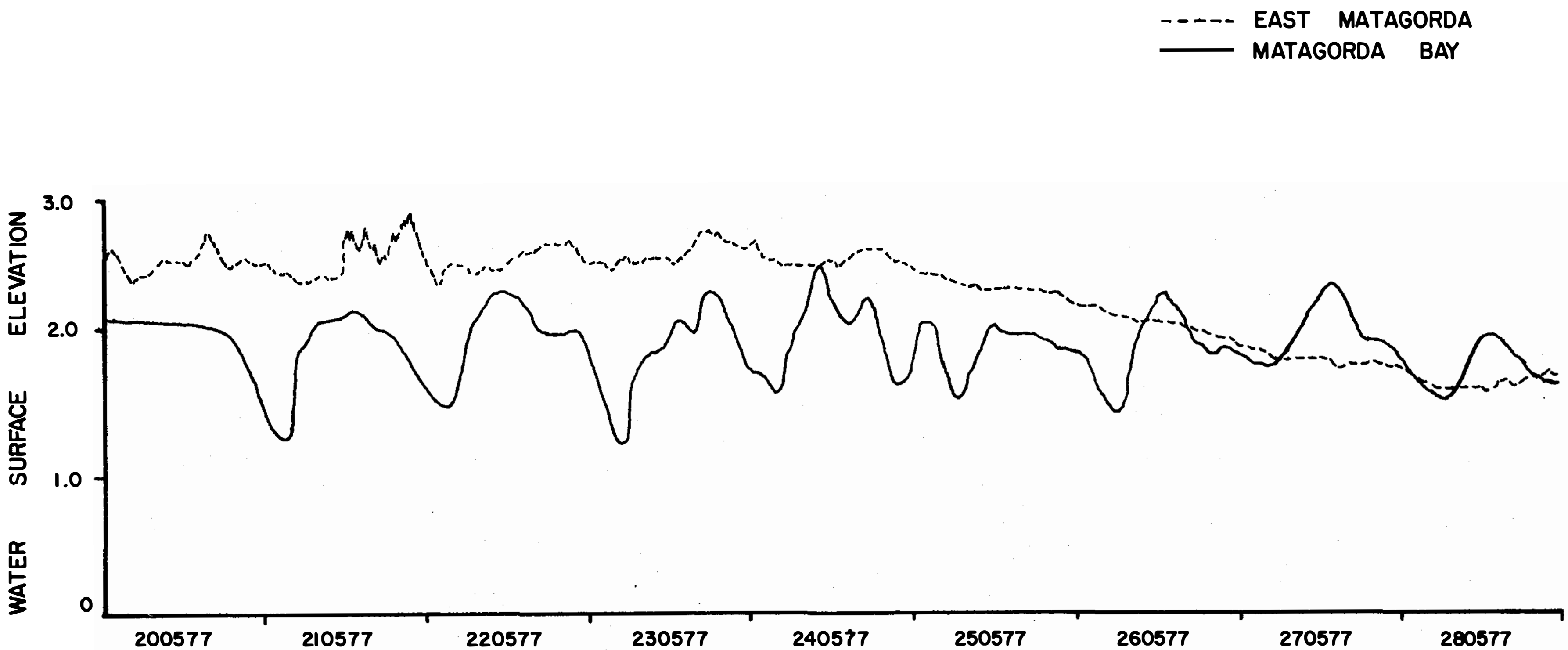


Figure III.6

INPUT TIDES – MAY SIMULATIONS

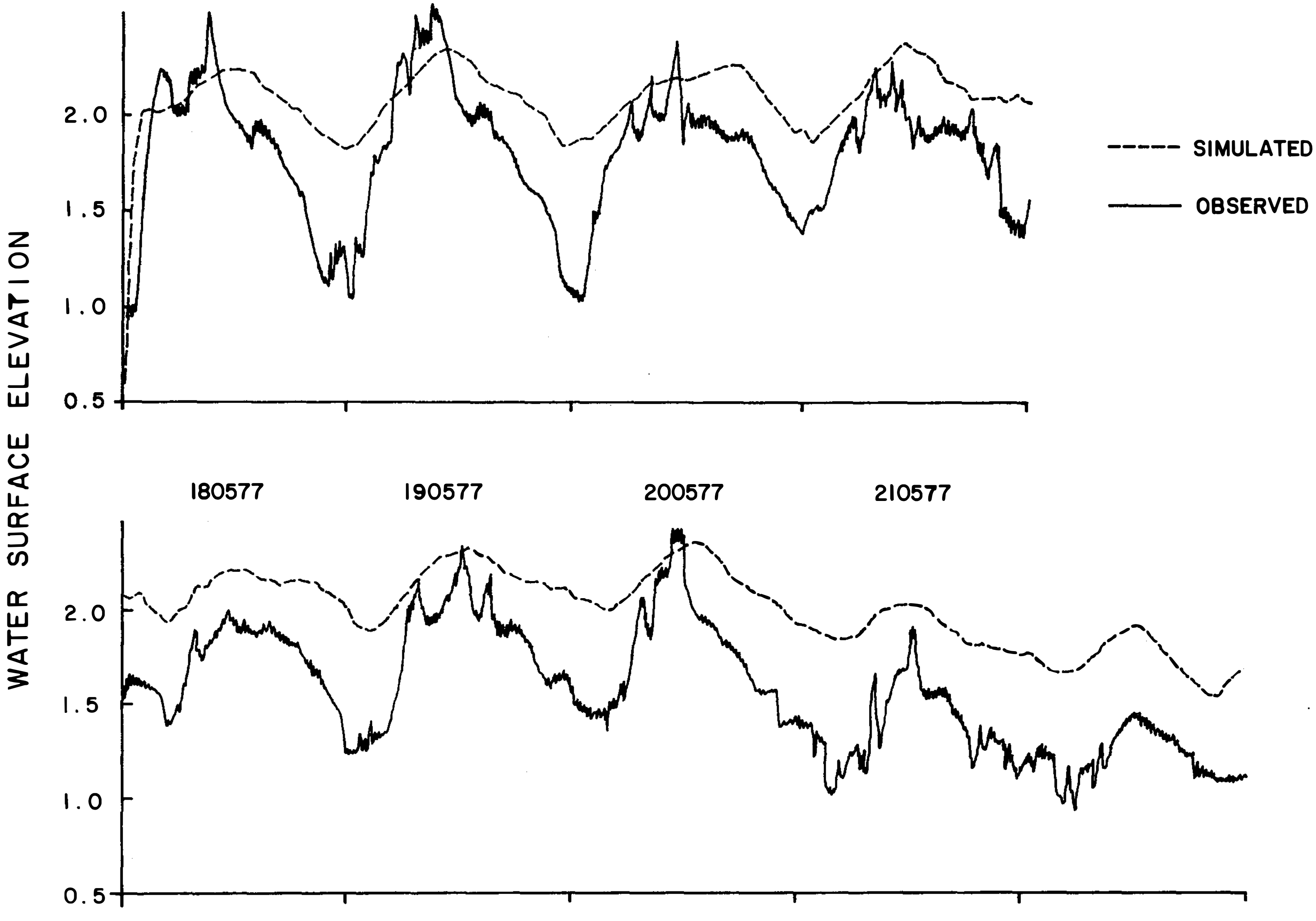


Figure III.7

TIDAL ELEVATION RECORD AT MATAGORDA

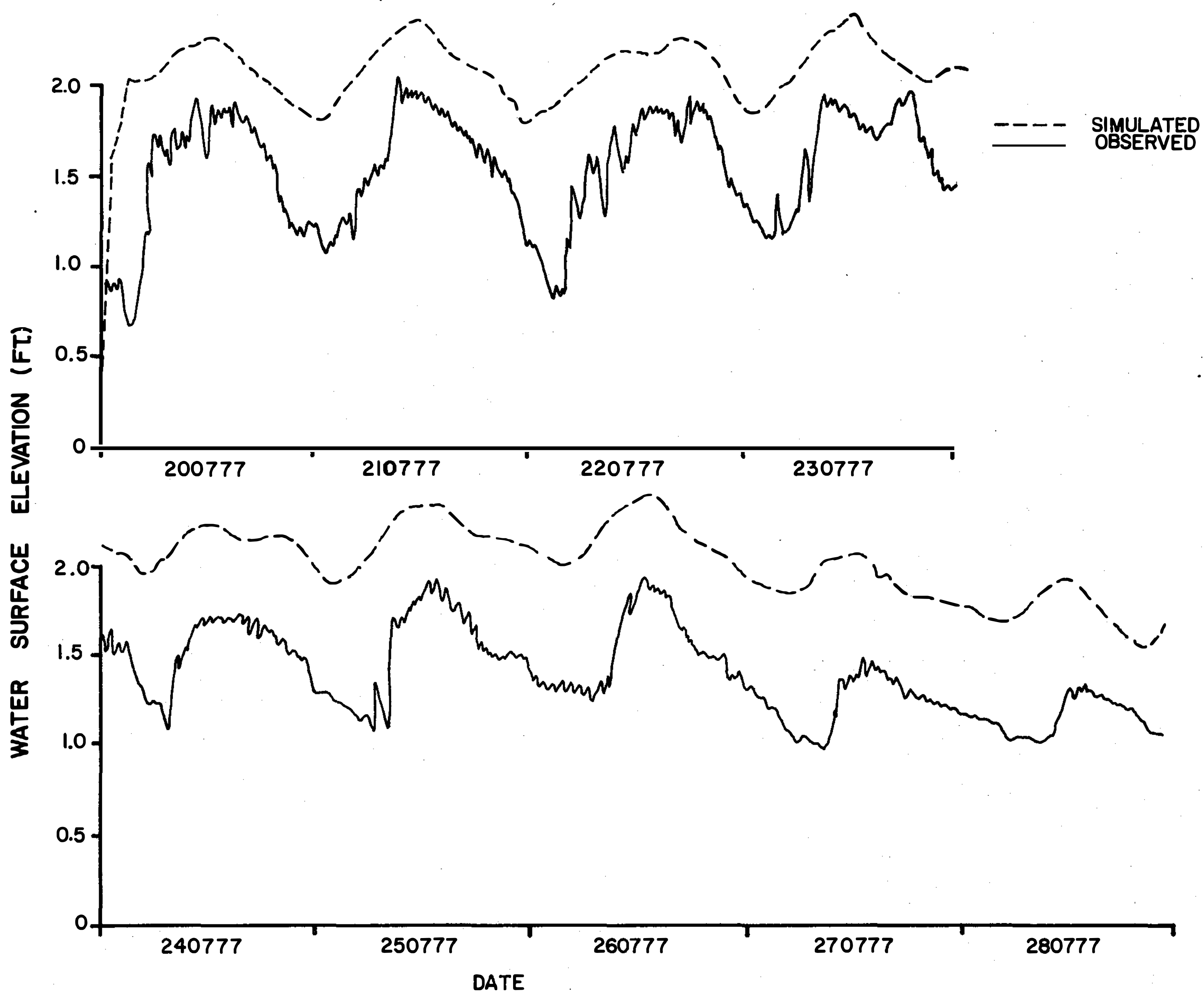


Figure III.8

TIDAL ELEVATION RECORD AT CULVER CUT

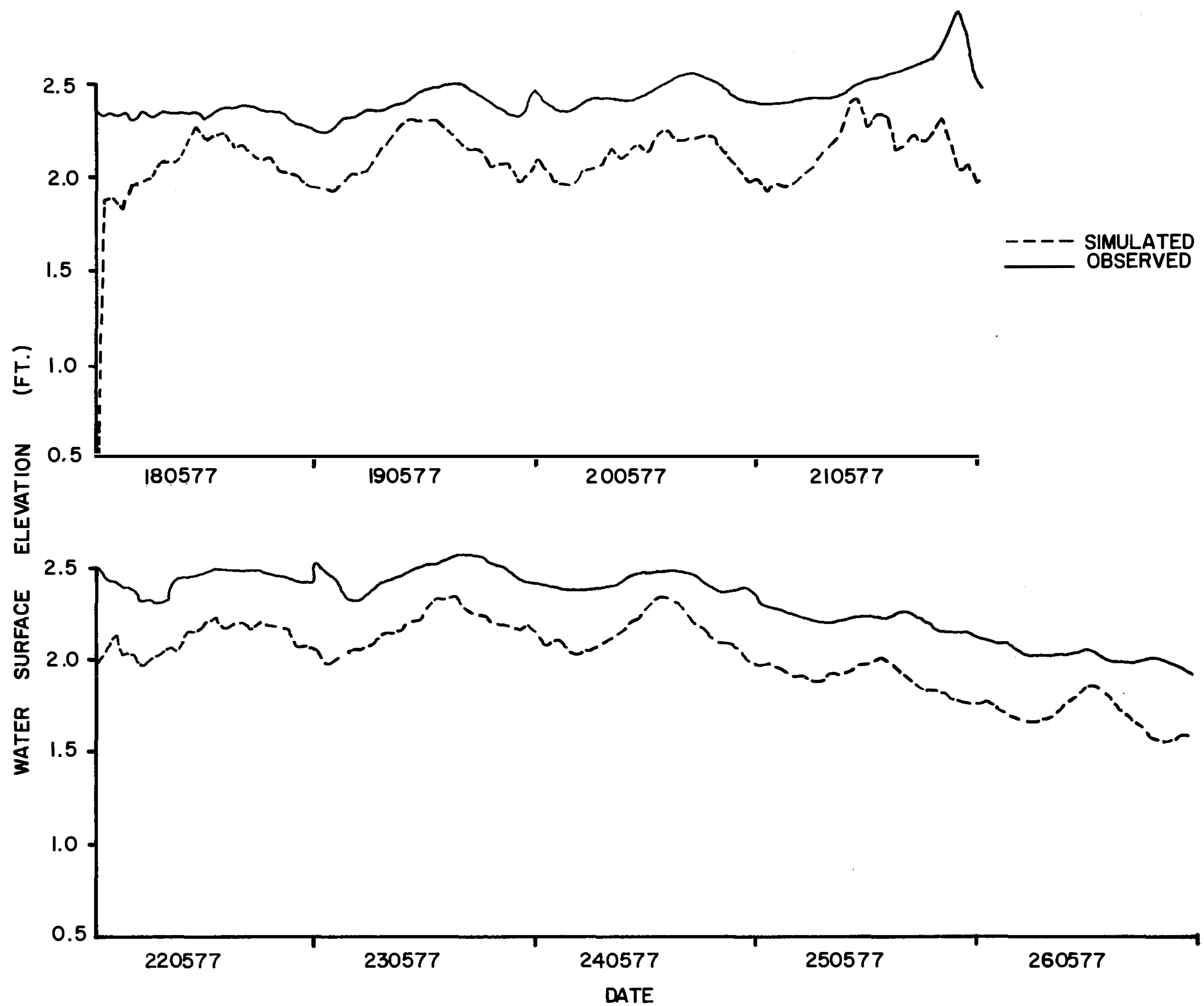


Figure III.9

TIDAL ELEVATION RECORD AT ICWW EAST OF MATAGORDA

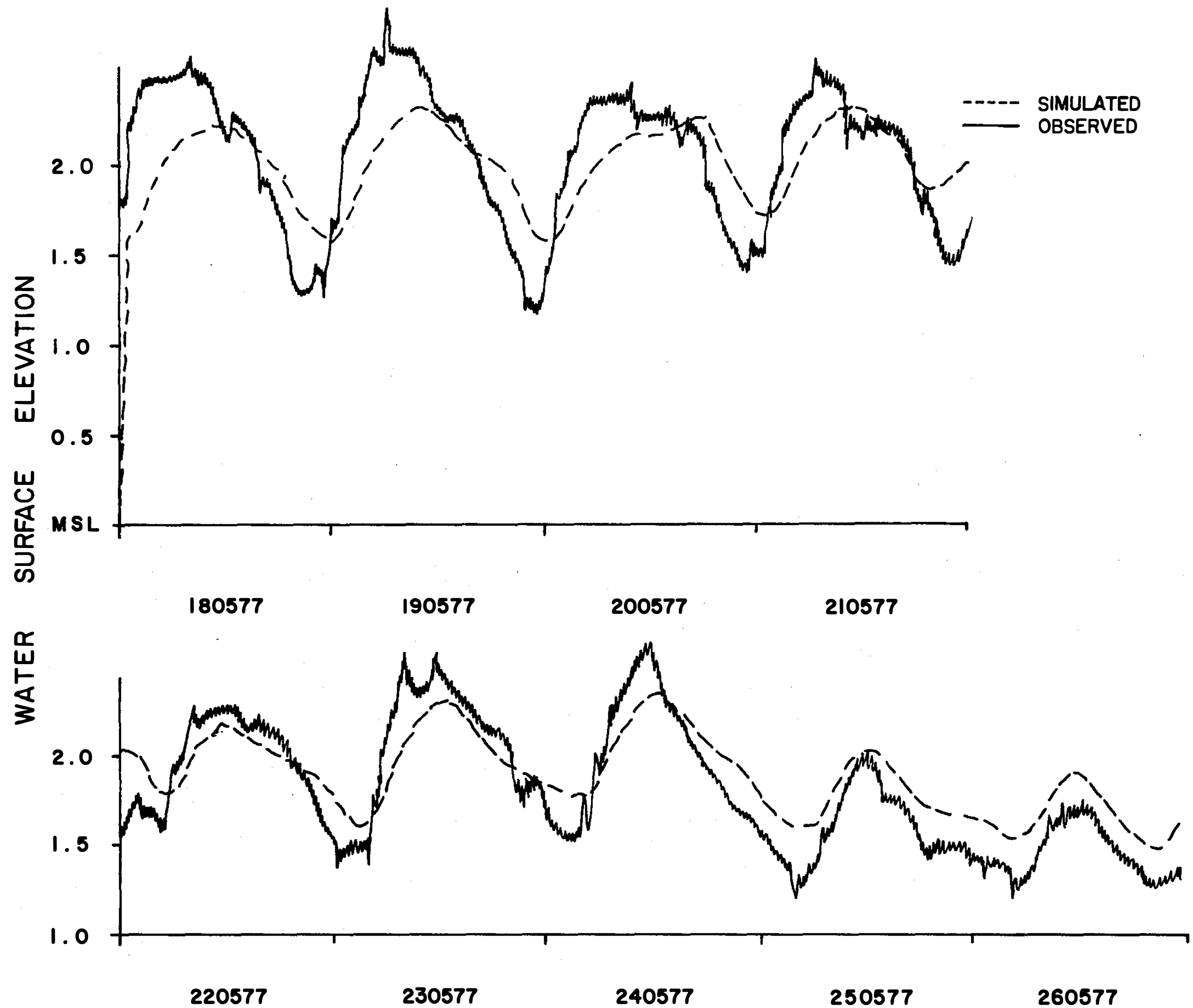


Figure III.10

TIDAL ELEVATION RECORD ABOVE TIGER ISLAND CUT

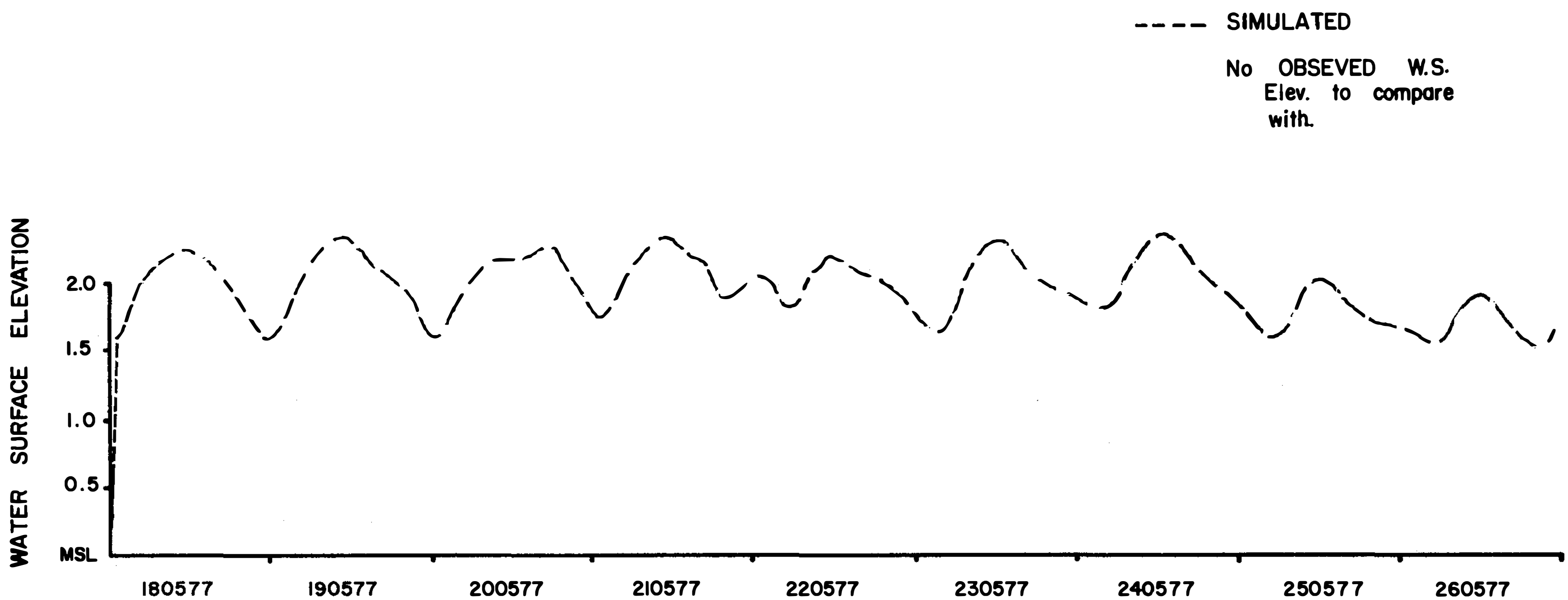


Figure III.11

TIDAL ELEVATION RECORD AT TIGER ISLAND CUT

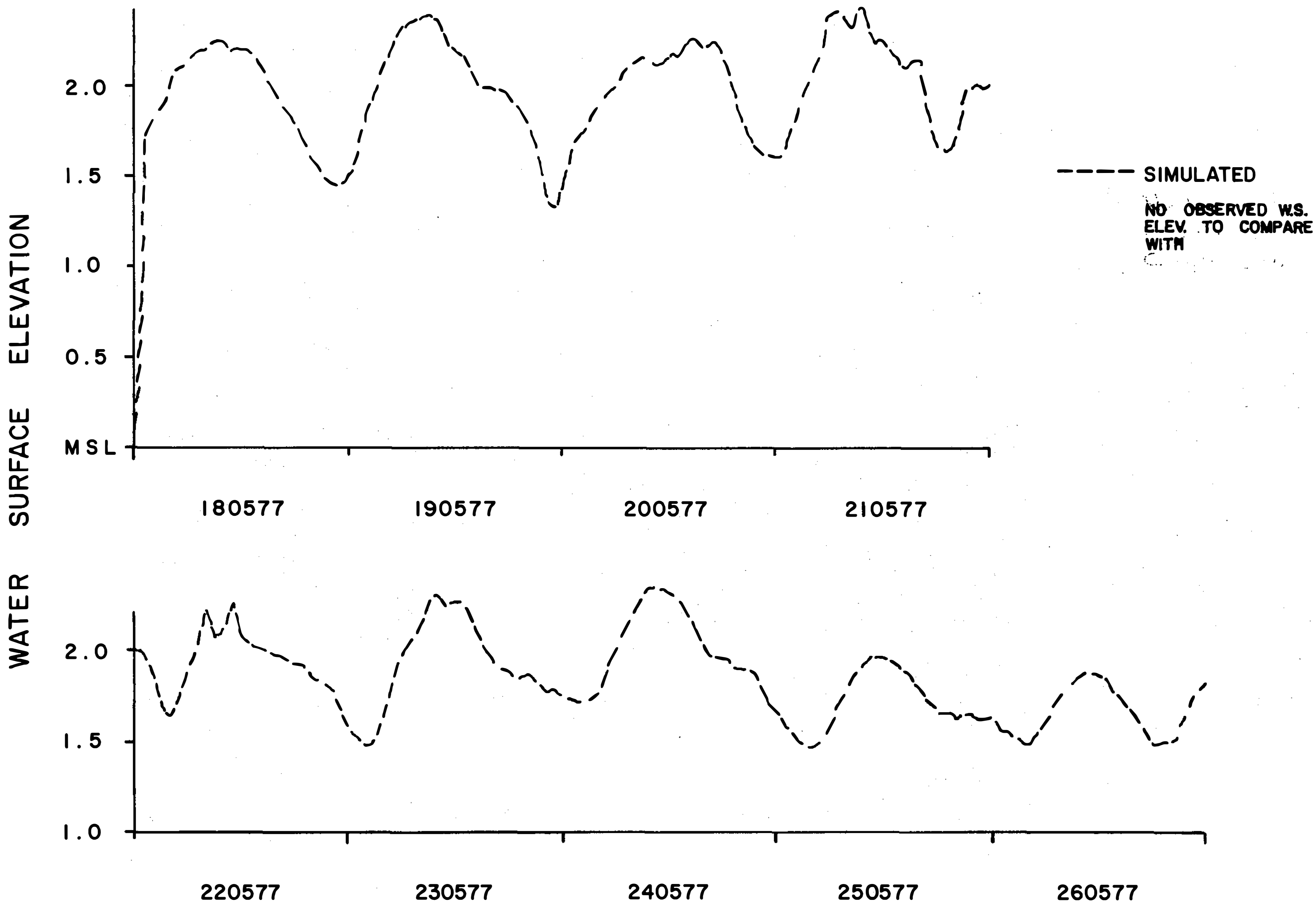


Figure III.12

TIDAL ELEVATION RECORD AT COLORADO MOUTH

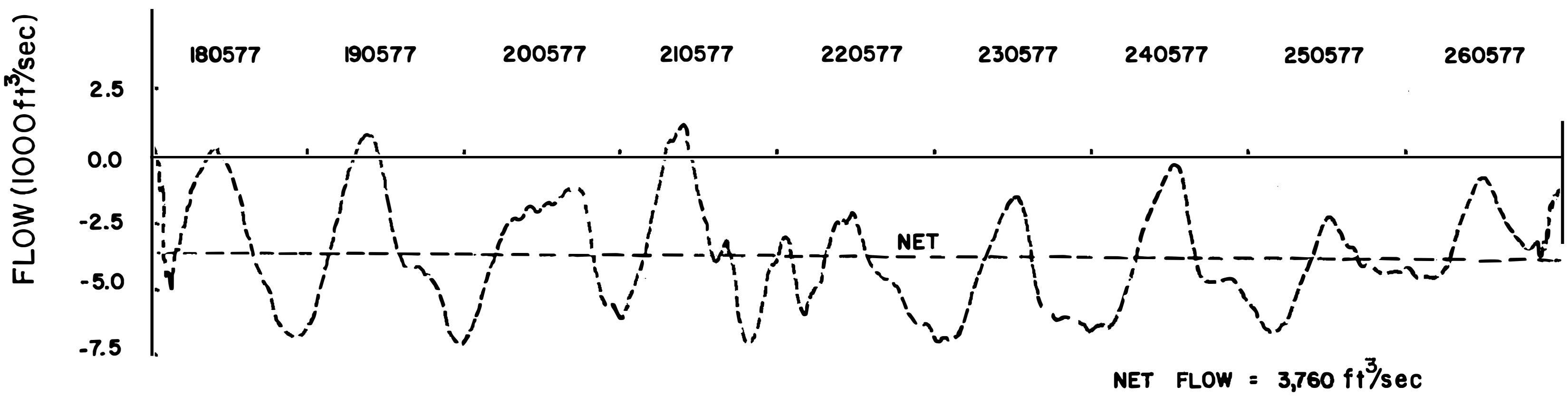
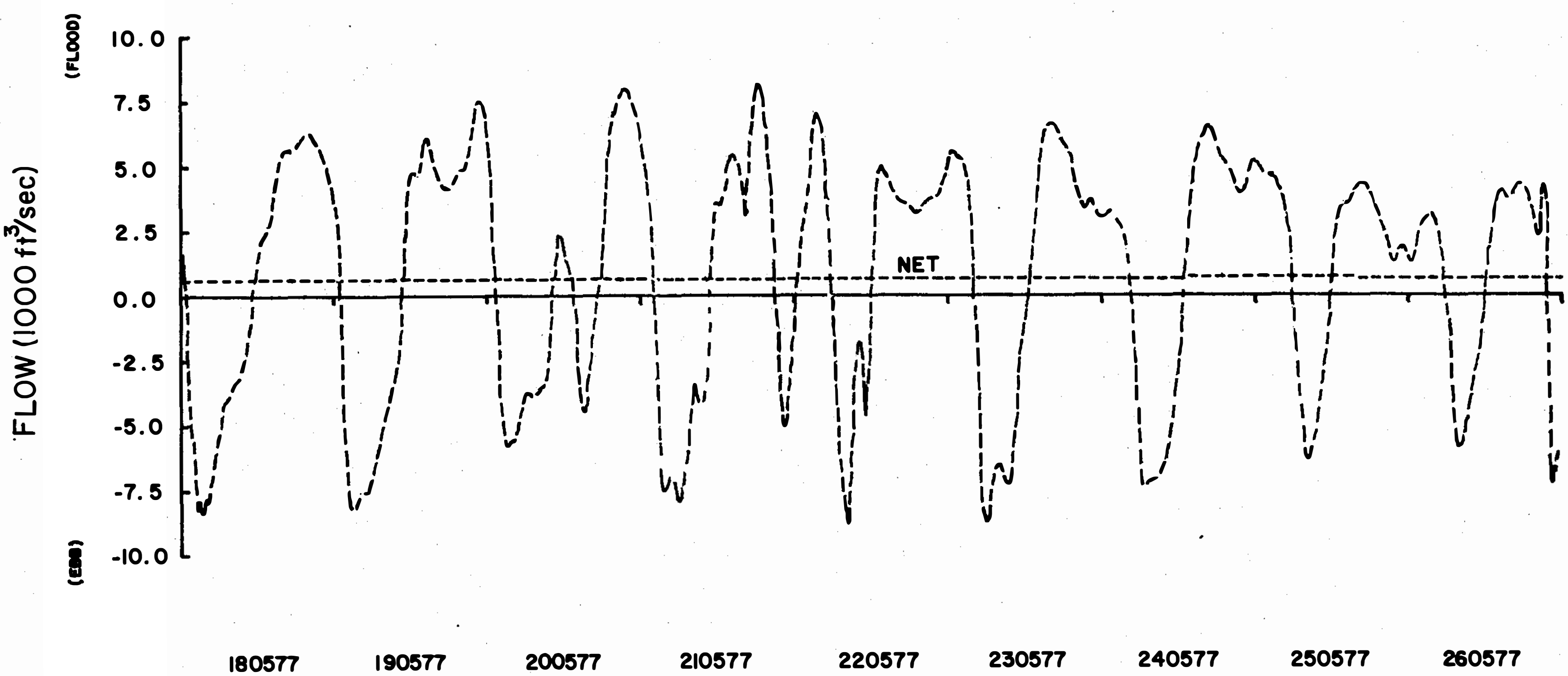


Figure III.13

FLOW ABOVE TIGER ISLAND CUT



NET FLOW = 650 ft^3/sec

Figure III.14

SIMULATED

FLOW AT TIGER ISLAND CUT

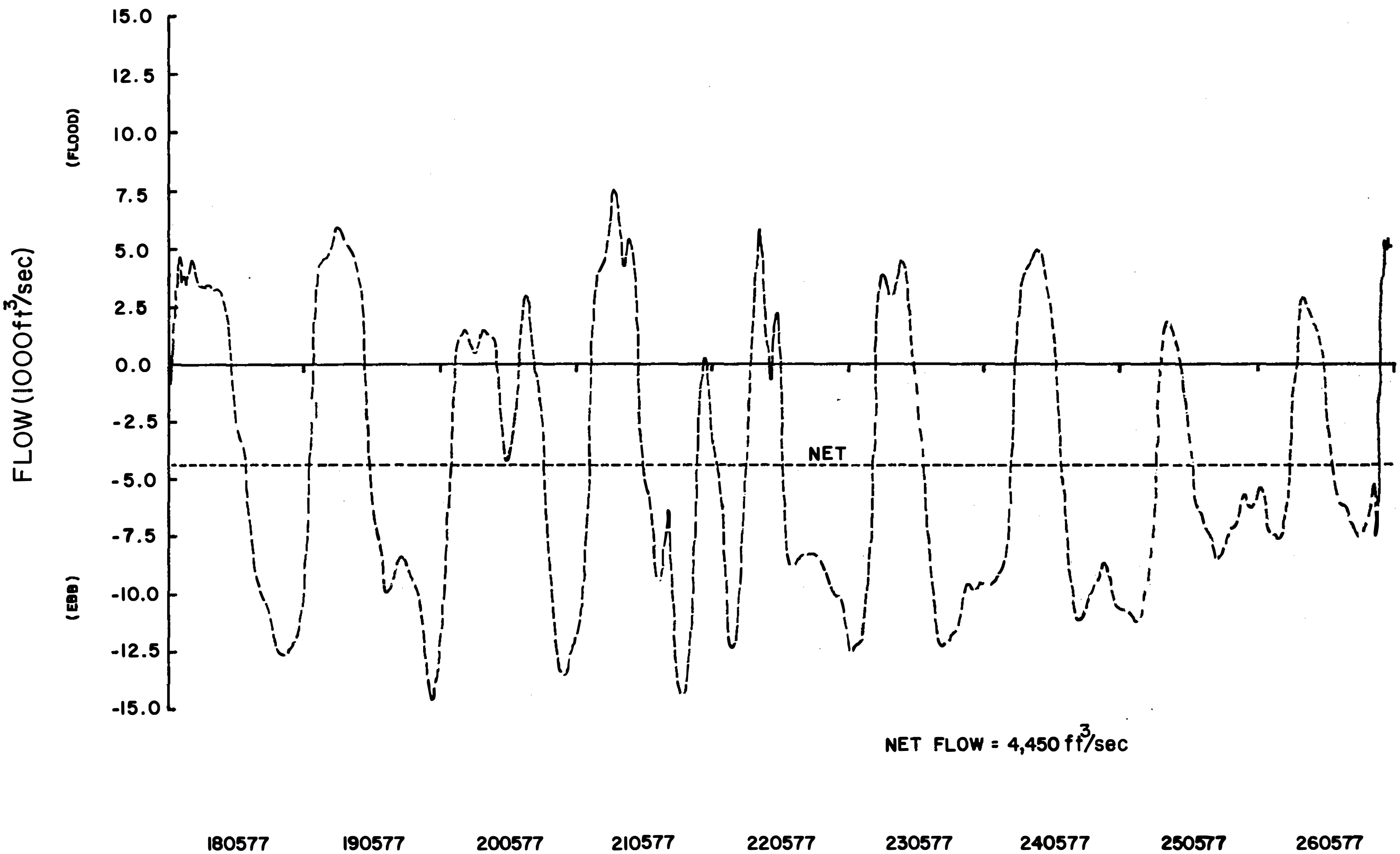


Figure III.15

SIMULATED

FLOW AT COLORADO MOUTH

contributed to the Colorado River by Matagorda Bay. Figure III.15 shows the simulated exchange flow patterns at the Colorado River mouth for the mean river flow of 5,370 ft^3/sec. A comparison of the flows through Tiger Island Cut and the Colorado River mouth exemplifies the tremendous volume of water that is exchanged between Matagorda Bay and the Gulf.

Table III.2 contains a segment-by-segment summary of the simulated activities within the delta. Included are: net flows for the last day of simulation, the overbank area associated with each segment, a flooding indicator (1 = overbank area flooded, 0 = overbank area did not flood), and the total time the overbank area of each segment was inundated during the simulation period. The riverine portions of the Colorado Delta did not inundate under the May observed flows. The levees along the river prevent flooding except under extreme flow conditions; likewise, the marsh areas of East Matagorda Bay and the GIWW east of Matagorda remained inundated throughout the entire simulation period.

The marsh areas to the north of the GIWW and west of Matagorda and all marsh areas associated with Matagorda Bay inundated for varying periods of time during the simulations using May data. Figure III.16 shows the areas inundated during the simulation period. The marsh areas north of the GIWW remained inundated for the longest period (approximately 65 percent of the simulation period) and the areas to the west of Culver Cut the least time (40 percent of the simulation period). Inspection of the tidal input data and bank elevations within the flooded regions suggests that high tides are the principal cause of inundation. The bank elevations of segments 67 through 84 were established at 2.0 feet above MSL. The driving tide in Matagorda Bay is above this elevation during much of the simulation period. The simulated depth of inundation of these segments corresponds to the difference between tide elevation and bank elevation, further confirming tidal activity as the principal inundation factor.

During the second case simulated, the measured Colorado River flows ranged from 850 ft^3/sec to 1,700 ft^3/sec with a mean daily flow of 1,402 ft^3/sec, approximately one-fourth of those encountered in the simulations using may data. Daily mean flows for the period are presented in Table III.3. The driving tides for this simulation period are presented in Figure III.17. Again, Matagorda Bay and East Matagorda Bay tides are nonrelated, exhibiting entirely different periods and amplitudes.

Comparison of simulated and observed water surface profiles at Matagorda demonstrate reasonable agreement (Figure III.18). Phase correlations are quite good, however, amplitude variations of about 0.4 foot are apparent throughout the simulation period.

At Culver Cut, simulated and observed amplitudes and phases are in close agreement (Figure III.19). However, the previously mentioned 0.7 foot tide gage datum error is again apparent. Measured water surface elevations, after application of the 0.7 foot datum correction factor, fall below 0.0 foot MSL on 25, 26 and 27 July. Comparison of Matagorda Bay tides and observed water surface elevations on the Colorado River at Matagorda show positive values on these days indicating a definite downward water surface gradient toward Culver Cut from both directions. This is further evidence that the 0.7 foot datum correction applied to the measured data is not necessary. Simulated values for the GIWW east of Matagorda (Figure III.20) demonstrate considerably more tidal influence than was actually observed. The mean water surface elevation appears to be consistently lower than the tide records of the USGS, as was the case with the

TABLE III-2

FINAL SUMMARY FOR MAY SIMULATION
(- indicates downstream)

Segment	Net Flow Last Day (ft^3/sec)	Overbank Area (Acres)	Flooding Indicator (If Flooding Occurred)	Time Inundated (Hours)
1	-4763.042	1469.	0	.00
2	-3444.792	0.	0	.00
3	-3588.040	0.	0	.00
4	-3678.042	0.	0	.00
5	-3067.876	52.	0	.00
6	-3068.069	20.	0	.00
7	-3067.888	19.	0	.00
8	-3067.326	17.	0	.00
9	-3066.441	13.	0	.00
10	-3065.279	0.	0	.00
11	-3063.940	13.	0	.00
12	-5405.687	23.	0	.00
13	-5404.422	0.	0	.00
14	-5402.921	4.	0	.00
15	-5401.598	2.	0	.00
16	-5399.645	0.	0	.00
17	-5396.933	0.	0	.00
18	-5394.933	2.	0	.00
19	-5392.934	10.	0	.00
20	-5390.974	8.	0	.00
21	-5388.509	1.	0	.00
22	-5386.438	6.	0	.00
23	-5384.520	7.	0	.00
24	-5382.595	13.	0	.00
25	-5380.870	1.	0	.00
26	-5378.729	8.	0	.00
27	-5376.520	25.	0	.00
28	-5373.536	12.	0	.00
29	-5370.835	14.	0	.00
30	-5368.200	5.	0	.00

(Continued)

TABLE III-2 (Cont'd)

Segment	Net Flow Last Day (ft^3/sec)	Overbank Area (Acres)	Flooding Indicator (If Flooding Occurred)	Time Inundated (Hours)
31	-5365.372	20.	0	.00
32	-5362.333	13.	0	.00
33	-5359.136	11.	0	.00
34	-5355.594	12.	0	.00
35	-5351.425	0.	0	.00
36	-5347.807	10.	0	.00
37	-5344.169	6.	0	.00
38	-5340.462	0.	0	.00
39	-5336.682	1.	0	.00
40	-5332.846	28.	0	.00
41	-5328.871	0.	0	.00
42	-5324.860	7.	0	.00
43	-5320.808	7.	0	.00
44	.000	8.	0	.00
45	-4253.952	1266.	0	.00
46	-3946.101	293.	0	.00
47	-3660.680	339.	0	.00
48	-1564.303	381.	0	.00
49	-1285.463	333.	0	.00
50	-999.702	287.	0	.00
51	-706.717	333.	0	.00
52	-421.694	51.	0	.00
53	-216.419	688.	0	.00
54	-80.608	1100.	0	.00
55	.000	636.	0	.00
56	.000	17.	0	.00
57	-1820.924	381.	0	.00
58	-1815.457	0.	0	.00
59	-1811.030	0.	0	.00
60	-1807.025	0.	0	.00
61	-1803.945	0.	0	.00

(Continued)

TABLE III-2 (Concluded)

Segment	Net Flow Last Day (ft^3/sec)	Overbank Area (Acres)	Flooding Indicator (If Flooding Occurred)	Time Inundated (Hours)
62	-1802.391	0.	0	.00
63	-1801.693	0.	0	.00
64	541.661	23.	0	.00
65	541.932	10.	0	.00
66	542.962	2.	0	.00
67	545.232	181.	1	137.45
68	-2.745	300.	1	137.40
69	.000	702.	1	137.64
70	.000	710.	0	.00
71	8.861	131.	1	103.51
72	17.530	200.	1	103.50
73	579.721	267.	1	103.48
74	588.537	119.	1	103.43
75	-13.201	210.	1	103.36
76	-4.967	159.	1	103.30
77	-1.329	505.	1	103.28
78	.000	1309.	1	103.51
79	-553.043	267.	1	103.48
80	-551.017	0.	0	.00
81	.000	300.	1	137.40
82	611.129	210.	1	103.36
83	611.058	0.	1	94.65
84	.000	52.	1	87.20

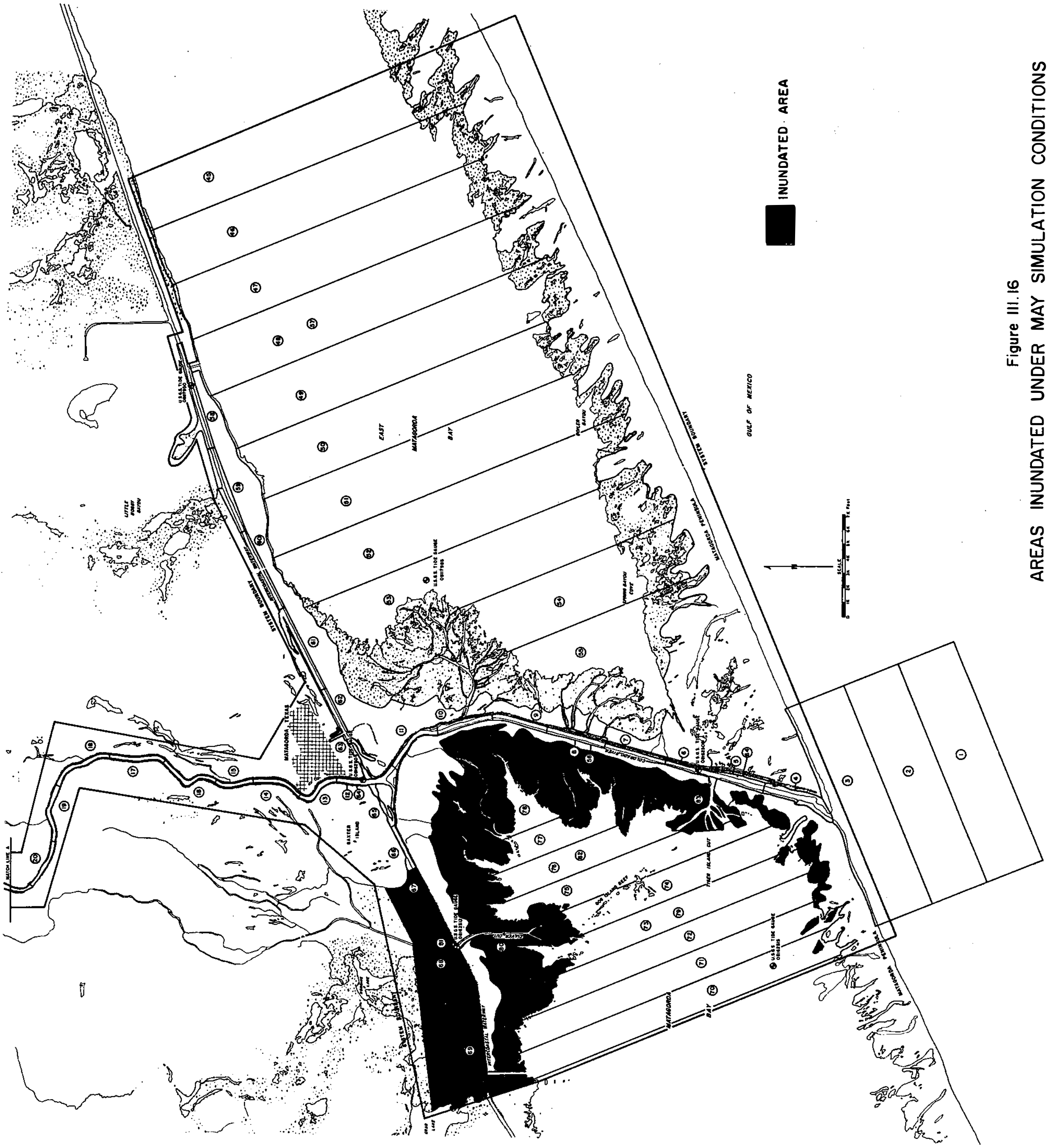


Figure III.16
AREAS INUNDATED UNDER MAY SIMULATION CONDITIONS

TABLE III.3

FLOW RECORDS FOR COLORADO RIVER
AT BAY CITY, TEXAS (SEGMENT 44)

20-28 July 1977

DATE	(ft^3/sec)*
20 July	1,400
21 July	1,530
22 July	1,640
23 July	1,670
24 July	1,600
27 July	1,160
28 July	835

*Flows from USGS gauge on Colorado River at Bay City

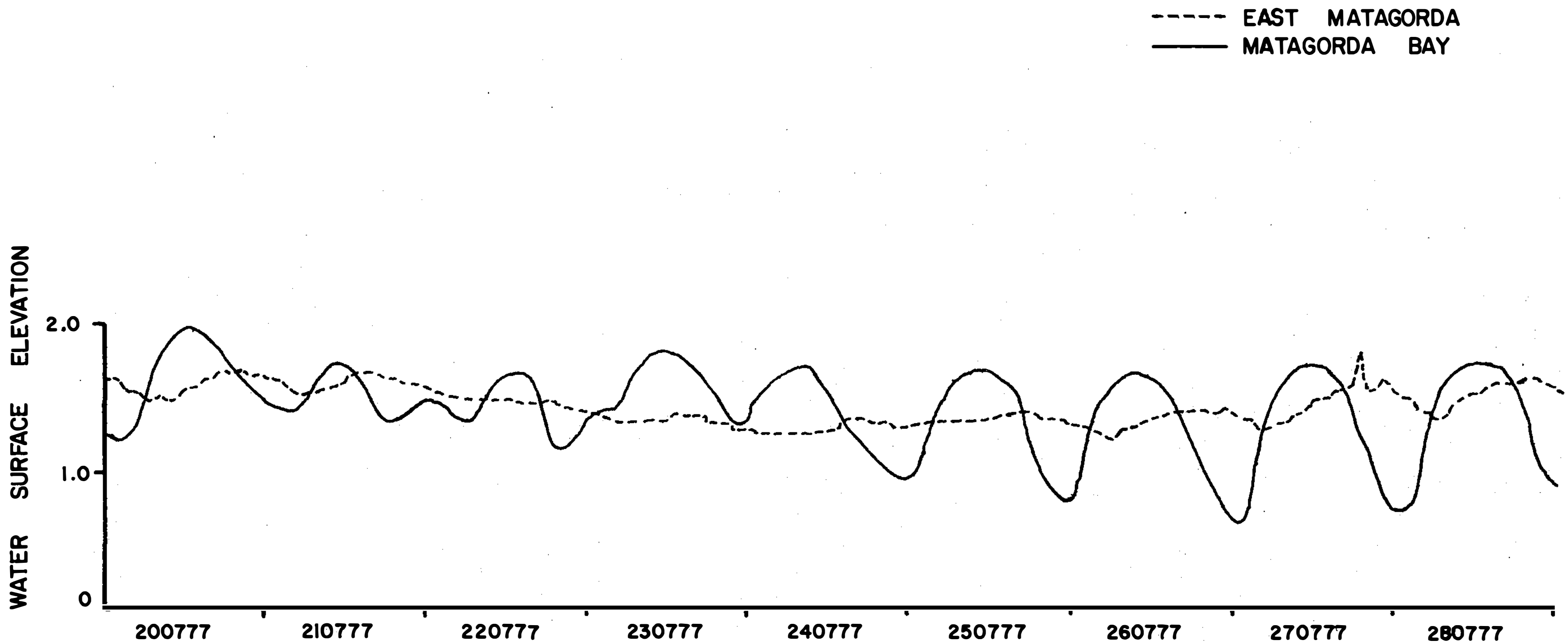


Figure III.17

INPUT TIDES — JULY SIMULATIONS

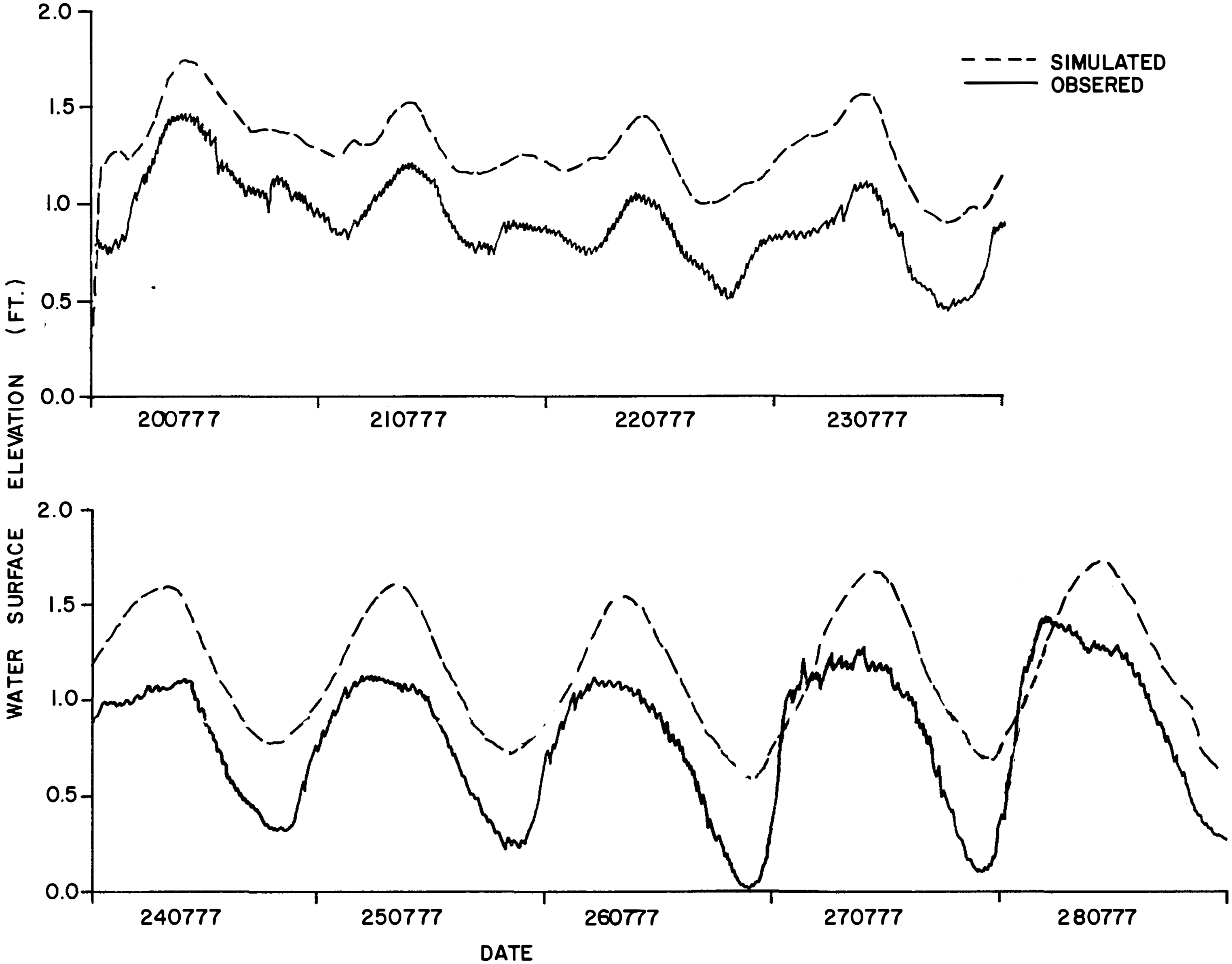


Figure III.18

TIDAL ELEVATION RECORD AT MATAGORA

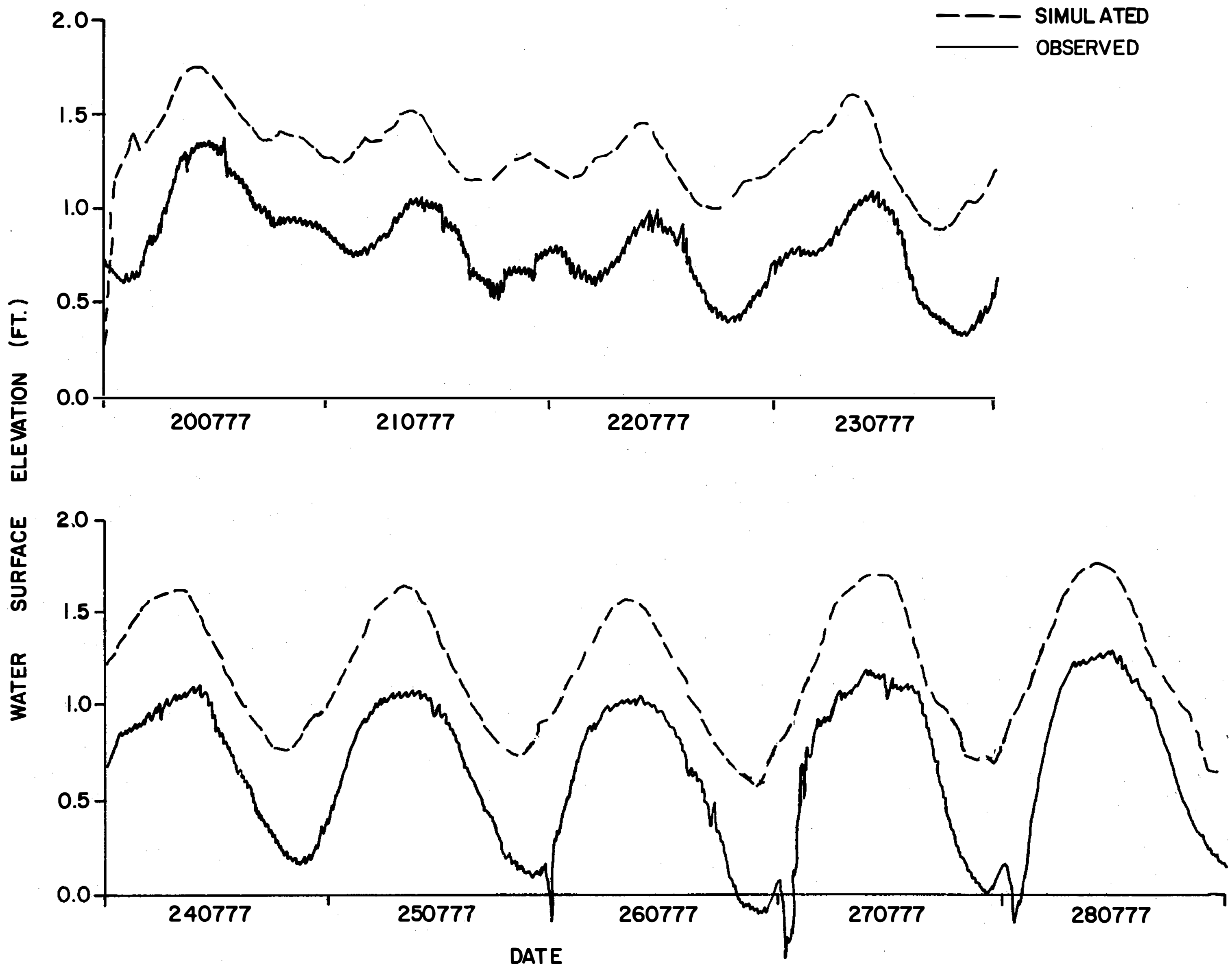


Figure III.19

TIDAL ELEVATION RECORD AT CULVER CUT

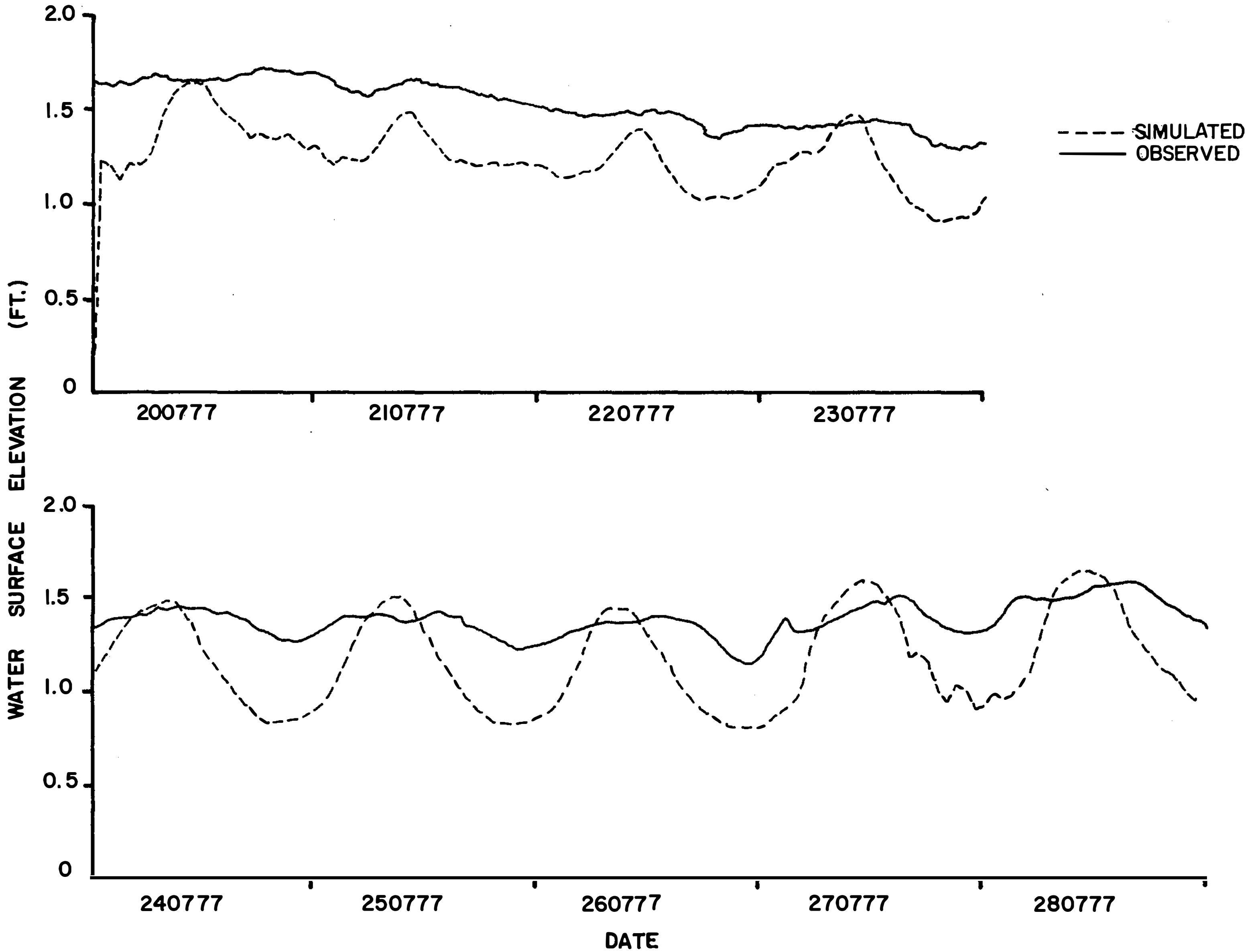


Figure III.20

TIDAL ELEVATION RECORD AT ICWW EAST OF MATAGORDA

May simulations, indicating a datum correction is possibly needed for this gauge.

Above Tiger Island Cut (Figure III.21) the model again closely corresponds to the observed water surface elevations. At these lower flows, the observed elevations are slightly lower than the measured validation values (maximum deviation of 0.2 foot), however, the phasing is nearly exact.

Inspection of the simulated flow and elevation data for Tiger Island Cut and below Tiger Island Cut (Figures III.22 through III.26) show that the net flow above Tiger Island Cut is in an upstream direction with approximately 70 percent of the total flow recorded above Tiger Island Cut being contributed by the Gulf of Mexico and 30 percent being contributed by Matagorda Bay. This net upstream flow, most likely, is the cause for propogation of tidal influence to the GIWW.

Flows for the July steady-state simulation period are considerably lower than for the May simulations as are the input tides for both Matagorda Bay and East Matagorda Bay, averaging about 1.0 through 1.5 foot lower (Table III.4). As a result, no flooding occurred within the delta throughout the simulation period.

The agreement between simulated flows and the measured flows recorded during the two field studies is not good at all locations. The phasing for the May data appears to be correct, but there is a definite shift in amplitude at some locations. The simulated flows for the July case show discrepancies in both phase and amplitude. Some of the difficulties with amplitude agreement could be due to the problems with the tide gauge datums. Also an inspection of the raw data indicates that some of the velocity profiles are typical of conditions influenced by density currents, however, the flow data were obtained using a Price Current Meter that was not equipped to indicate direction of flow so this hypothesis could not be strictly tested. The best agreement between simulated and observed flow is obtained when the river base flow is highest which coincides with the least likely chance of occurrence of bi-directional flows, i.e., the observed surface flow is in one direction while the subsurface flow is occurring in the opposite direction.

If a mass balance is carried out for the delta system using the flow data acquired during the two field studies, other inconsistencies arise (Table III.5). Since the flow in the GIWW on either side of the Colorado River was not measured, a complete mass balance cannot be obtained, but enough data are available to demonstrate the possibility of bi-directional flow.

During the period 1200 hours 25 May through 1200 hours 26 May, a total of 470 million ft^3 of water entered the delta system from the river at Station A. At Station B the volume increased to 546 million ft^3 indicating a contribution of 76 million ft^3 from the GIWW. A net volume of 378 million ft^3 entered the Gulf at Station D indicating a loss of 168 million ft^3 from the river delta. The measured volumetric discharge through Tiger Island Cut at Station C was 126 million ft^3 into Matagorda Bay or approximately 75 percent of the volume of water lost between Stations B and D. It is possible that a portion of the remaining 25 percent could have remained in storage in the river channel due to a rise in stage between Stations B and D. However, for the entire amount to remain in the river channel an estimated rise in stage of over 13 feet would be required which would cause overbanking to occur below Tiger Island Cut and no overbanking was observed in this area during the study.

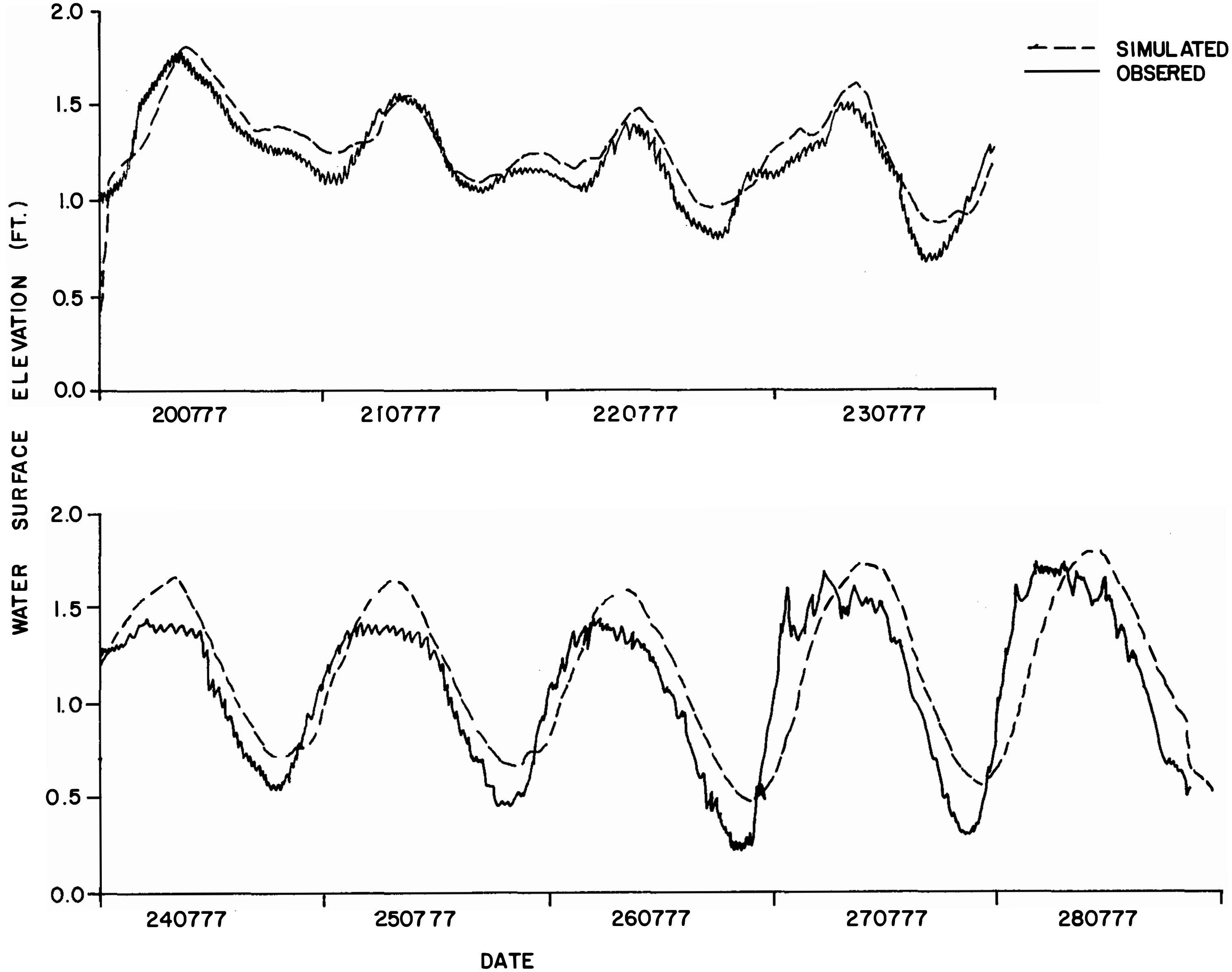


Figure III.21

TIDAL ELEVATION RECORD ABOVE TIGER ISLAND CUT

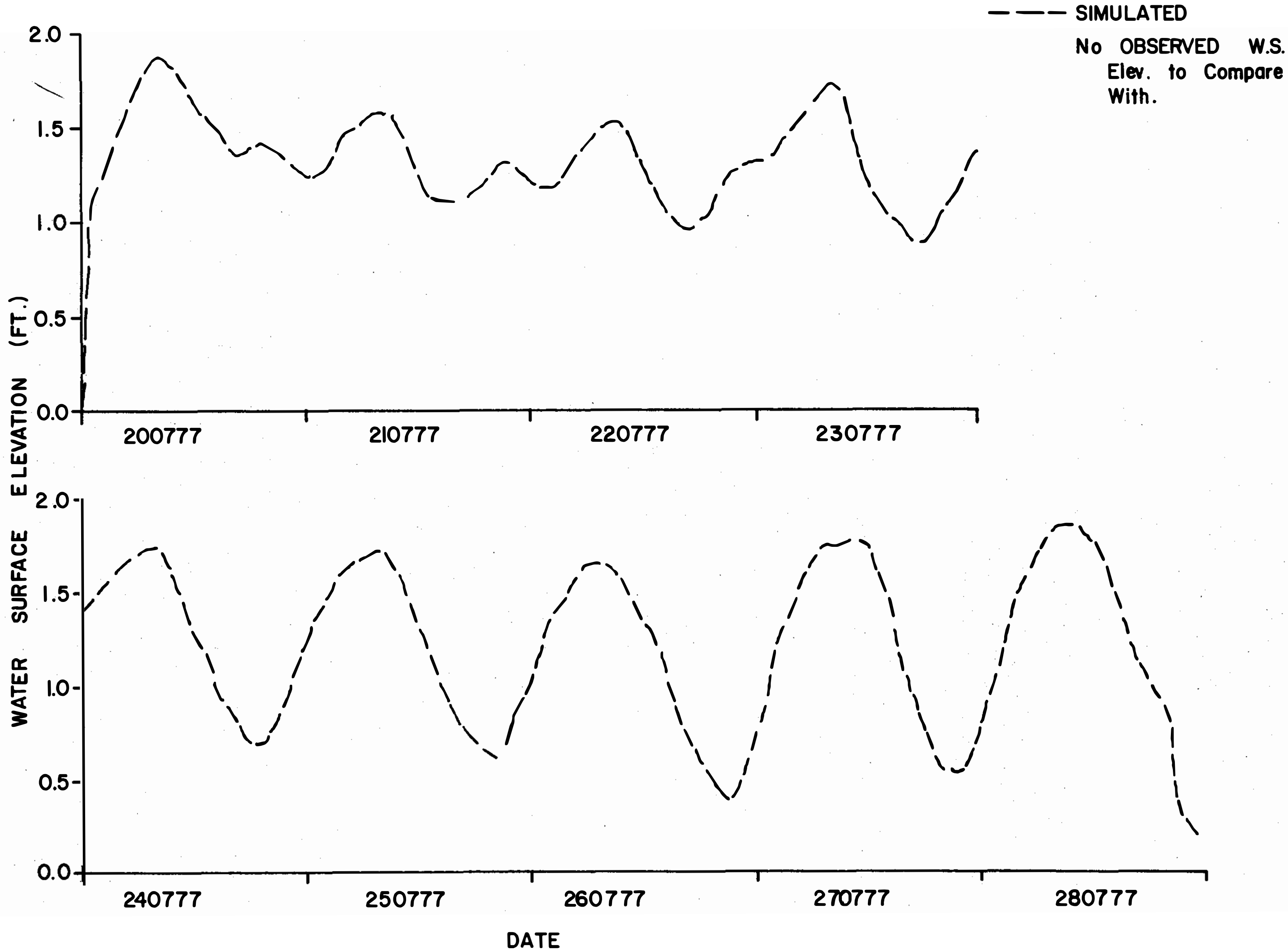


Figure III.22

TIDAL ELEVATION RECORD AT TIGER ISLAND CUT

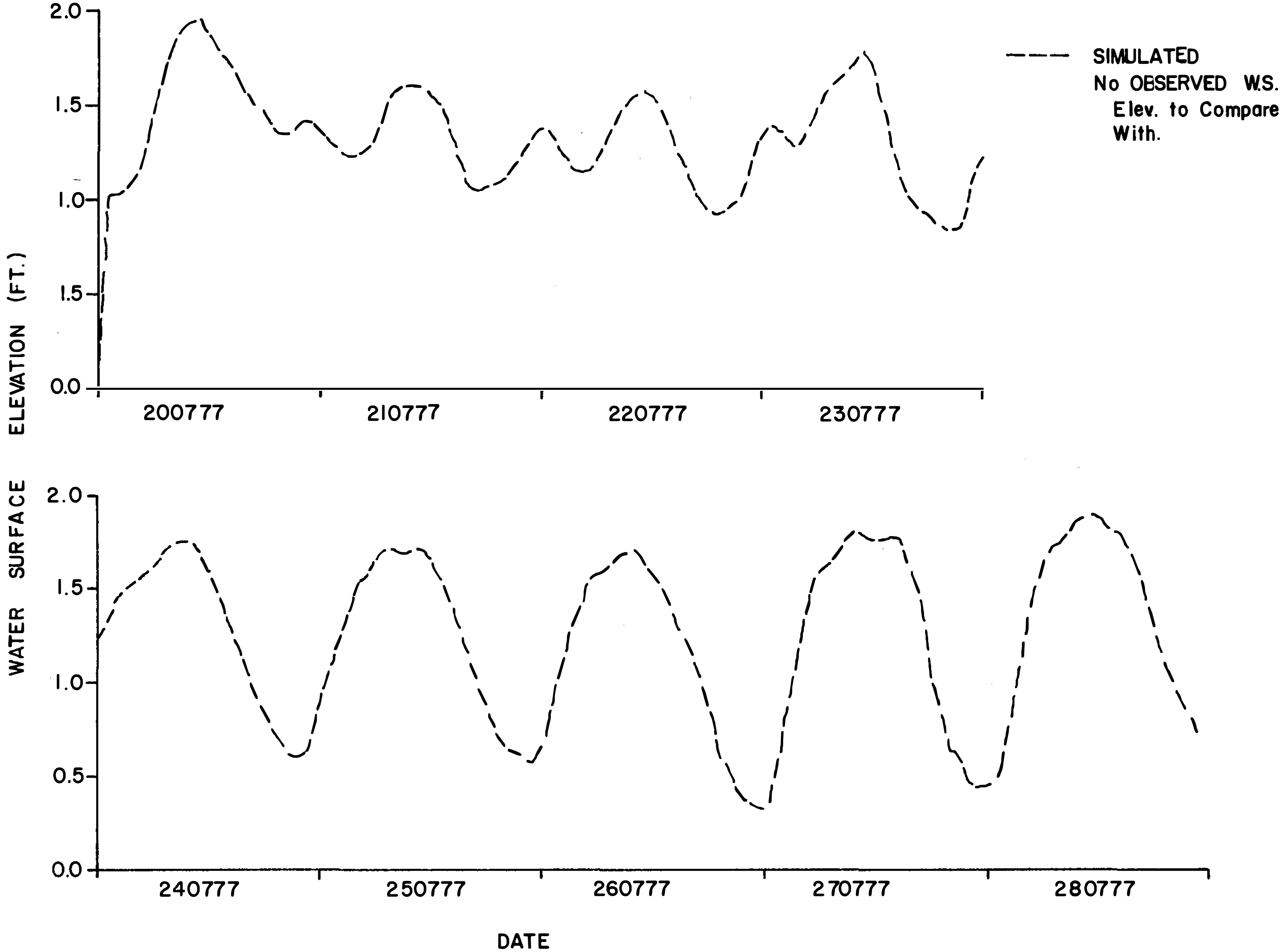


Figure III.23

TIDAL ELEVATION RECORD AT COLORADO MOUTH

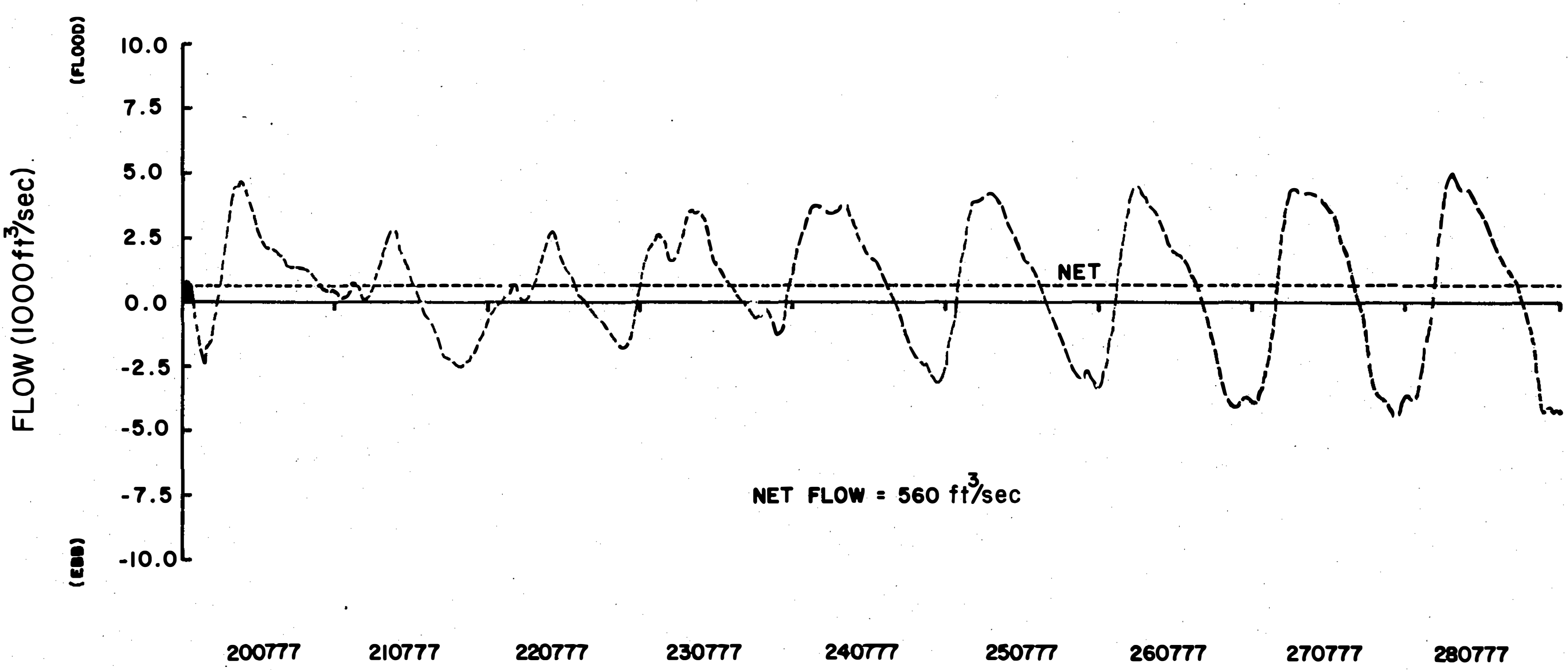
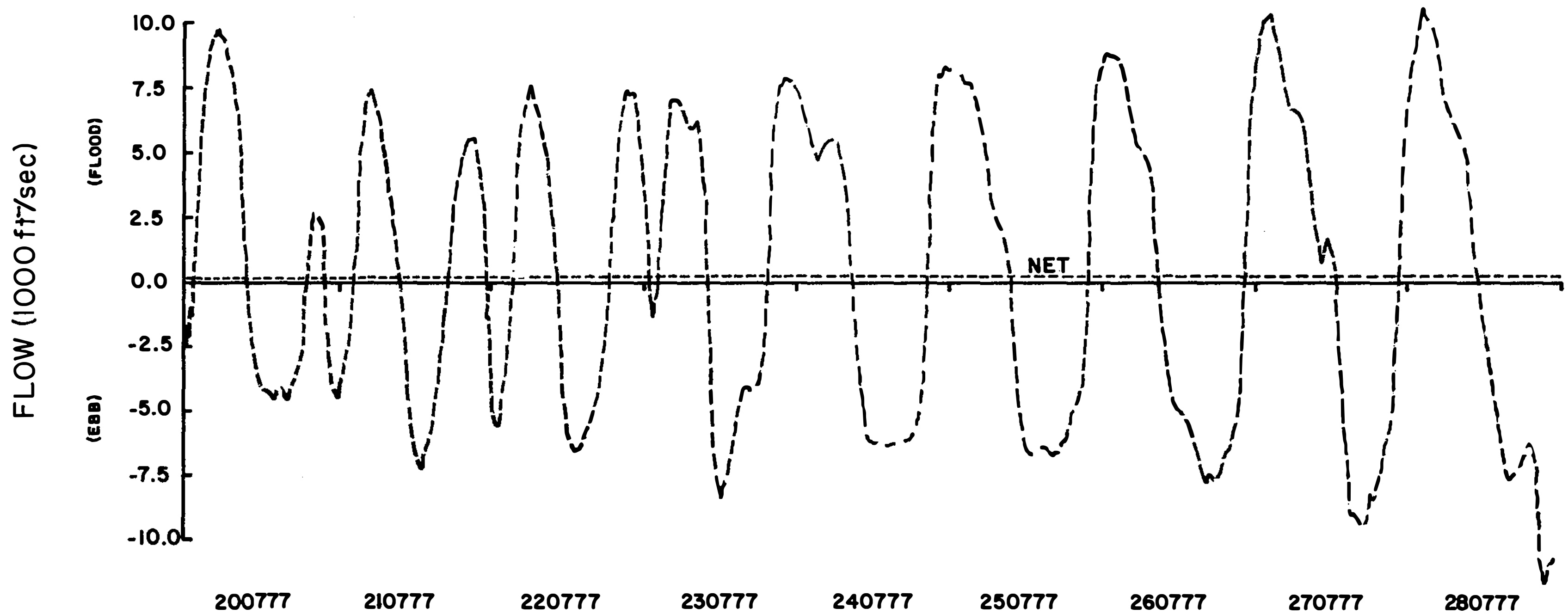


Figure III.24

SIMULATED

FLOW ABOVE TIGER ISLAND CUT



NET FLOW = 170 ft^3/sec

Figure III.25

SIMULATED

FLOW AT TIGER ISLAND CUT

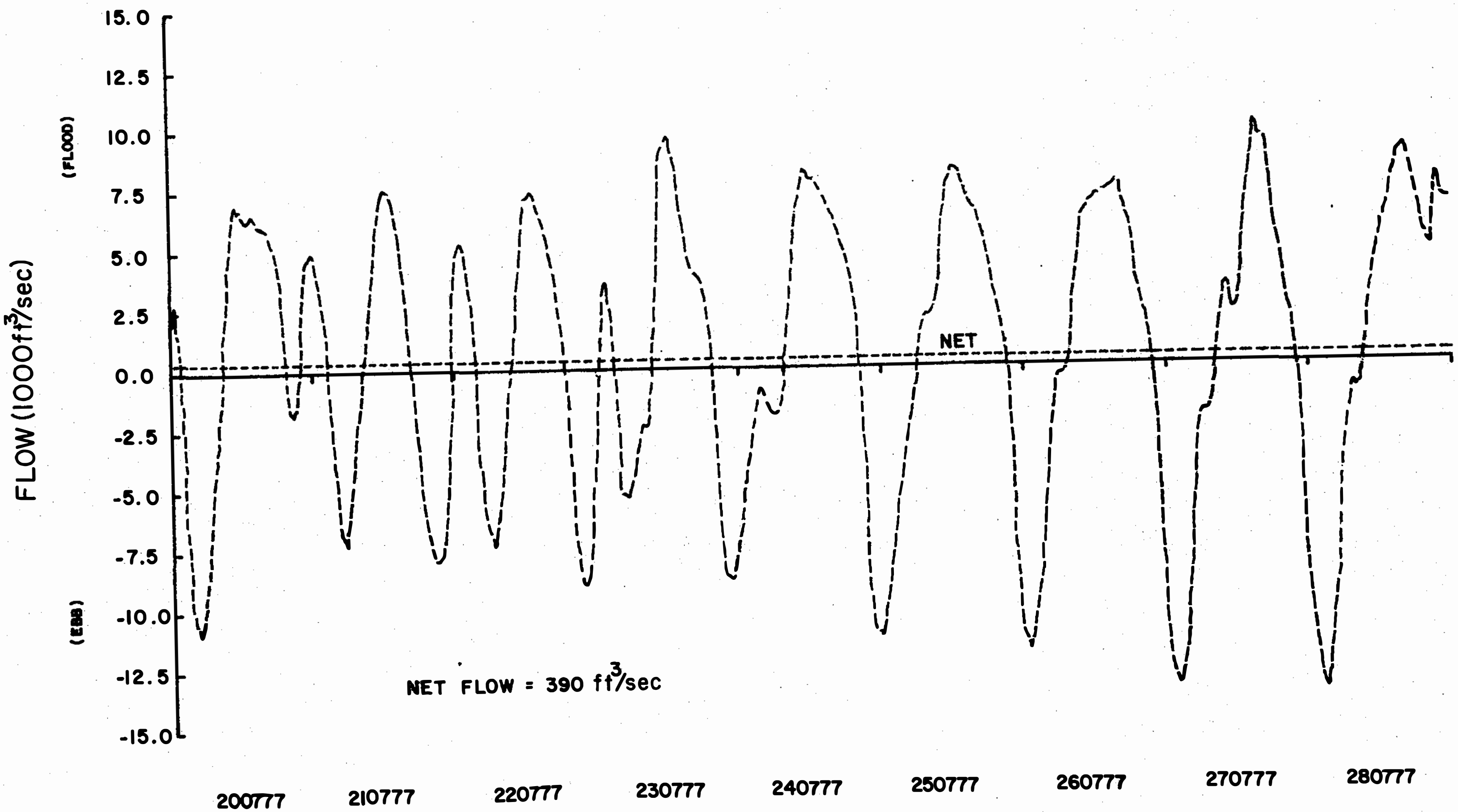


Figure III.26

SIMULATED

FLOW RECORD AT COLORADO MOUTH

TABLE III-4

FINAL SUMMARY FOR JULY SIMULATION
(- indicates downstream)

Segment	Net Flow Last Day (ft^3/sec)	Overbank Area (Acres)	Flooding Indicator (If Flooding Occurred)	Time Inundated (Hours)
1	986.444	1469.	0	.00
2	775.844	0.	0	.00
3	562.941	0.	0	.00
4	429.470	0.	0	.00
5	516.951	52.	0	.00
6	517.962	20.	0	.00
7	519.102	19.	0	.00
8	520.057	17.	0	.00
9	520.831	13.	0	.00
10	521.457	0.	0	.00
11	521.906	13.	0	.00
12	-876.773	23.	0	.00
13	-876.507	0.	0	.00
14	-876.209	4.	0	.00
15	-875.969	2.	0	.00
16	-875.661	0.	0	.00
17	-875.327	0.	0	.00
18	-875.133	2.	0	.00
19	-874.964	10.	0	.00
20	-874.807	8.	0	.00
21	-874.607	1.	0	.00
22	-874.412	6.	0	.00
23	-874.192	7.	0	.00
24	-873.916	13.	0	.00
25	-873.646	1.	0	.00
26	-873.318	8.	0	.00
27	-872.968	25.	0	.00
28	-872.454	12.	0	.00
29	-871.953	14.	0	.00
30	-871.454	5.	0	.00

(Continued)

TABLE III-4 (Cont'd)

Segment	Net Flow Last Day (ft^3/sec)	Overbank Area (Acres)	Flooding Indicator (If Flooding Occurred)	Time Inundated (Hours)
31	-870.928	20.	0	.00
32	-870.400	13.	0	.00
33	-869.899	11.	0	.00
34	-869.436	12.	0	.00
35	-869.024	0.	0	.00
36	-868.788	10.	0	.00
37	-868.728	6.	0	.00
38	-869.033	0.	0	.00
39	-869.764	1.	0	.00
40	-870.843	28.	0	.00
41	-872.218	0.	0	.00
42	-873.771	7.	0	.00
43	-875.422	7.	0	.00
44	.000	8.	0	.00
45	-1210.614	1266.	0	.00
46	-1221.114	293.	0	.00
47	-1260.297	339.	0	.00
48	582.115	381.	0	.00
49	507.823	333.	0	.00
50	416.364	287.	0	.00
51	308.307	333.	0	.00
52	192.790	51.	0	.00
53	103.454	688.	0	.00
54	39.530	1100.	0	.00
55	.000	636.	0	.00
56	.000	17.	0	.00
57	-1898.067	381.	0	.00
58	-1899.595	0.	0	.00
59	-1900.713	0.	0	.00
60	-1901.558	0.	0	.00

(Continued)

TABLE III-4 (Concluded)

Segment	Net Flow Last Day (ft^3/sec)	Overbank Area (Acres)	Flooding Indicator (If Flooding Occurred)	Time Inundated (Hours)
61	-1902.067	0.	0	.00
62	-1902.231	0.	0	.00
63	-1902.246	0.	0	.00
64	-503.205	23.	0	.00
65	-503.115	10.	0	.00
66	-502.702	2.	0	.00
67	-501.901	181.	0	.00
68	-1.021	300.	0	.00
69	.000	702.	0	.00
70	-1738.373	710.	0	.00
71	-1334.068	131.	0	.00
72	-957.296	200	0	.00
73	-1086.409	267.	0	.00
74	-755.425	119.	0	.00
75	-501.821	210.	0	.00
76	-214.263	159.	0	.00
77	-82.678	505.	0	.00
78	.000	1309.	0	.00
79	498.332	267.	0	.00
80	499.755	0.	0	.00
81	.000	300.	0	.00
82	78.232	210.	0	.00
83	85.694	0.	0	.00
84	.000	52.	0	.00

The data obtained during the period 1600 hours 27 July through 1600 hours 28 July show further discrepancies. According to this data a net total volume of 60 million ft^3 entered the delta system from the river at Station A. At Station B the volume decreased to 52 million ft^3 indicating a loss of 8 million ft^3 to the GIWW. A net volume of 76 million ft^3 was measured entering the Gulf at Station D indicating a gain of 24 million ft^3 from Matagorda Bay to the river through Tiger Island Cut, however, the measured data showed that 19 million ft^3 entered Matagorda Bay from the river through Tiger Island Cut. This indicates a definite error in the recorded flow direction or the presence of bi-directional flow. This phenomenon tends to occur at low flow rates such as the period of slack tide or low river base flow in the presence of density stratification. Therefore, there is a probable error in the measured flow data for the flows at either Station C or D. The simulation results and the measured tide data indicate the error is probably at the river mouth, Station D. Thus, with no valid observed flow data available for the delta it is impossible to make definately classify the model as "calibrated" or "uncalibrated" with respect to flow. However, with the excellent agreement achieved between simulated and observed water surface elevations throughout the delta and given the interrelationship of flow and water surface elevation, the author feels that simulated net flows are reasonable estimates of the actual time-averaged conditions.

The period 12-29 April 1977 was chosen for simulation of flood flow conditions. Table III.6 presents the daily flow recorded by the USGS flow gauge located near Bay City for this period. The peak flow was 49,100 ft^3/sec which occurred on 23 April and the mean flow for the period was 28,500 ft^3/sec.

Under high flow conditions, such as these, the gates on the navigation locks of the GIWW, located to the east and west of the Colorado River-GIWW intersection would be closed. These gates were assumed to be closed throughout the simulation period.

The driving tide records for Matagorda Bay and East Matagorda Bay are shown in Figure III.27. The Matagorda Bay tides appear semidiurnal early in the simulation period (12-15 April), changing to diurnal during the remainder of the simulation period (16-29 April). The East Matagorda Bay tides are very steady throughout the simulation period at about +2.0 feet MSL and demonstrate no discernible period. The locations of the USGS tide gauges in the area, used for model driving tide inputs, are sufficiently remote from the Colorado River to insure that they are not significantly influenced by flood waters.

Comparison of simulated and measured water surface elevations at the Matagorda City gauge (Figure III.28) indicates close agreement throughout most of the simulation period. However, the predicted elevations are in excess of those measured, by approximately 1 1/2 feet during the peak flow period, 22-24 April.

Inspection of the measured gauge readings at Culver Cut and the GIWW (Figures III.29 and III.30, respectively) confirms the assumption of closed lock gates throughout the major portion of this storm as the water surface elevations at these stations reflect little influence of the high flows. Simulated values at Culver Cut continue to exceed the measured values by as much as 0.9 foot but tide phase and amplitude is satisfactorily replicated. The simulated values for the GIWW east of the Colorado River demonstrate the inverse, averaging about 0.3 foot below measured values as occurred in the steady simulations.

Above Tiger Island Cut (Figure III.31) the simulated and observed water

TABLE III.6

FLOW RECORDS FOR COLORADO RIVER
AT BAY CITY, TEXAS (SEGMENT 44)

12-29 April 1977

DATE	(ft^3/sec)*
12 April	1,850
13 April	1,500
14 April	1,460
15 April	1,470
16 April	1,670
17 April	9,480
18 April	25,200
19 April	25,900
20 April	29,900
21 April	34,300
22 April	43,600
23 April	49,100
24 April	47,400
25 April	27,300
26 April	40,500
27 April	17,000
28 April	12,000
29 April	9,030

*Flows from USGS gauge on Colorado River at Bay City

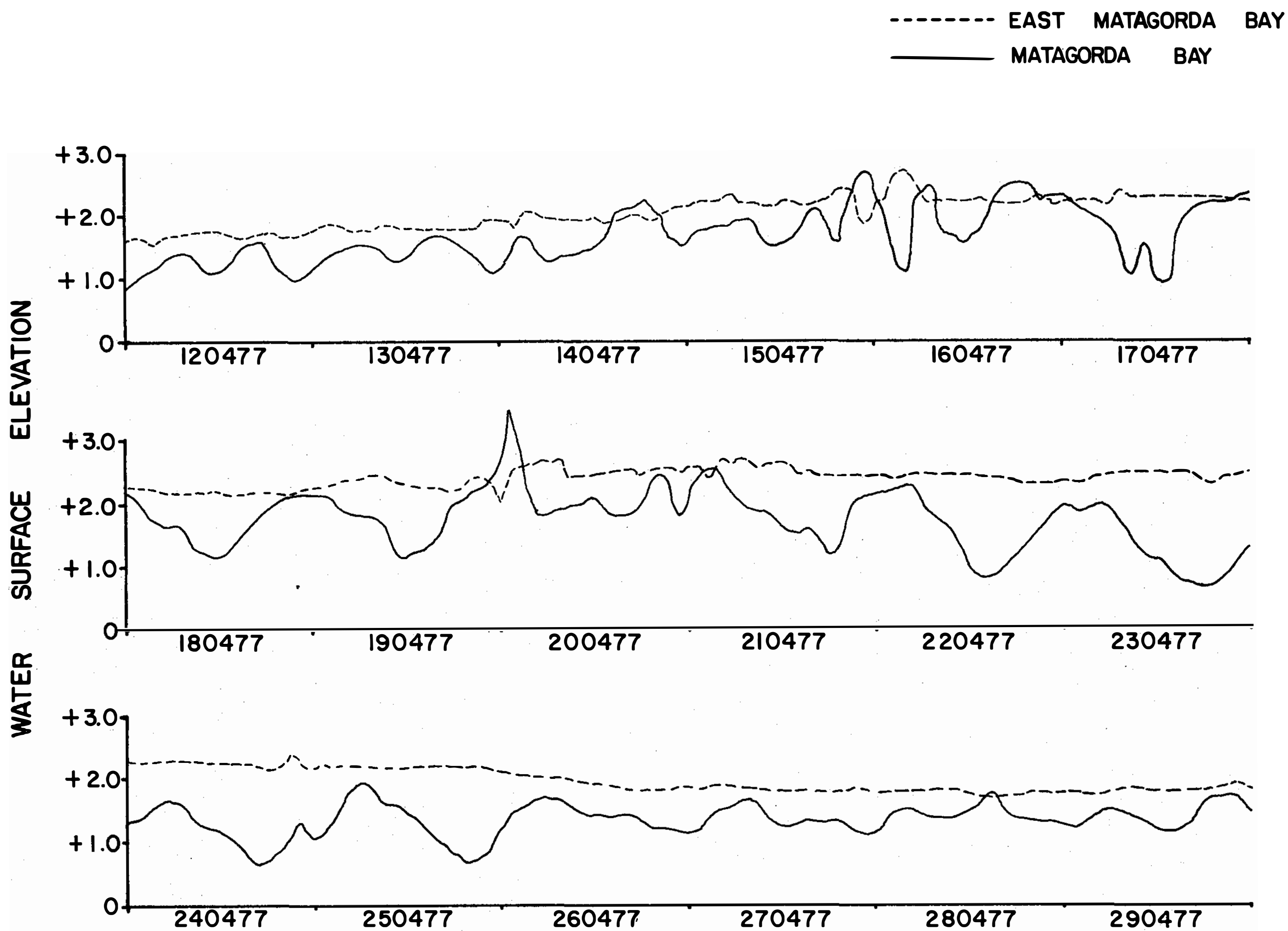


Figure III.27

INPUT TIDES — FLOOD SIMULATIONS

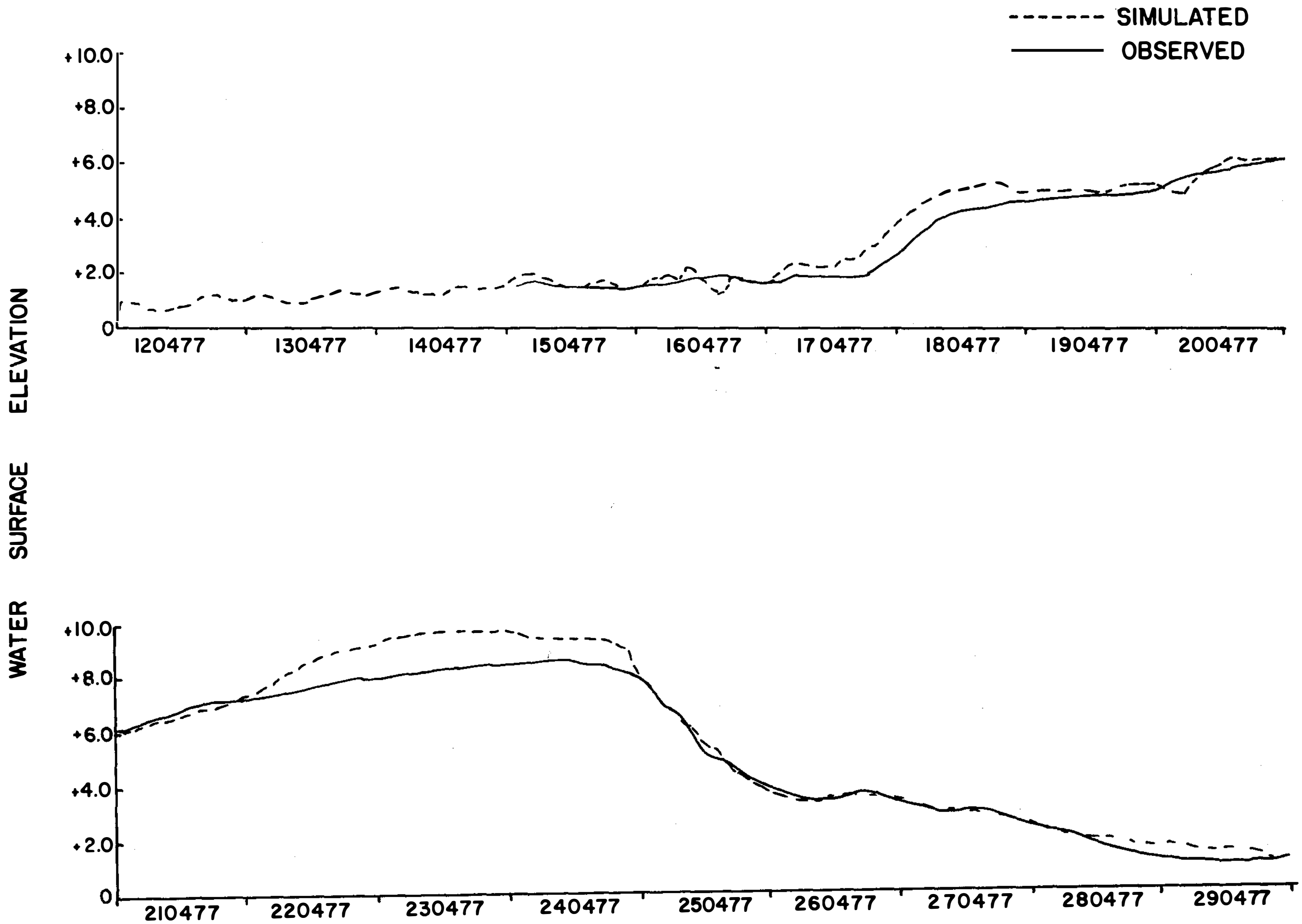


Figure III.28

TIDAL ELEVATION RECORD AT MATAGORDA

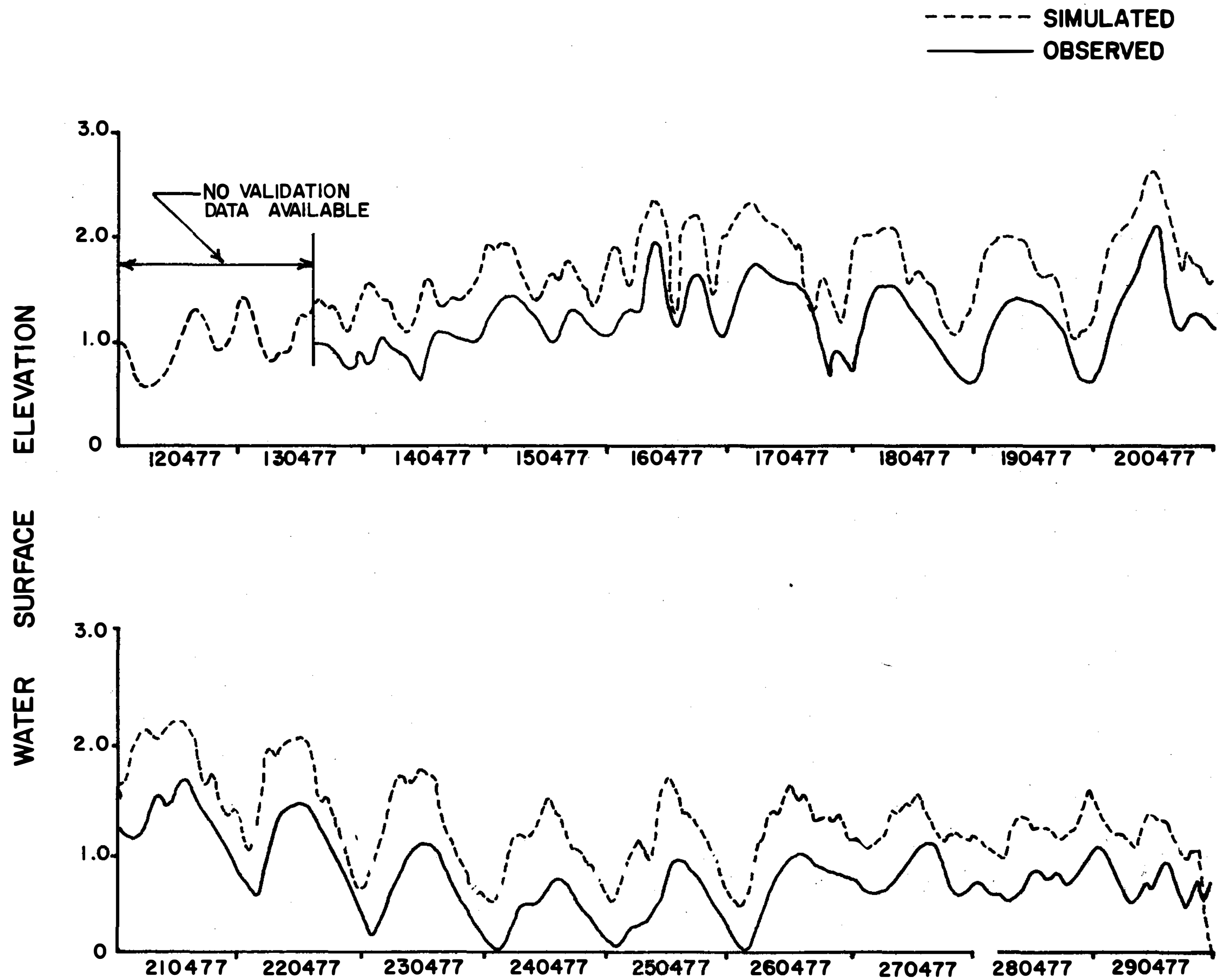


Figure III.29

TIDAL ELEVATION RECORD AT CULVER CUT

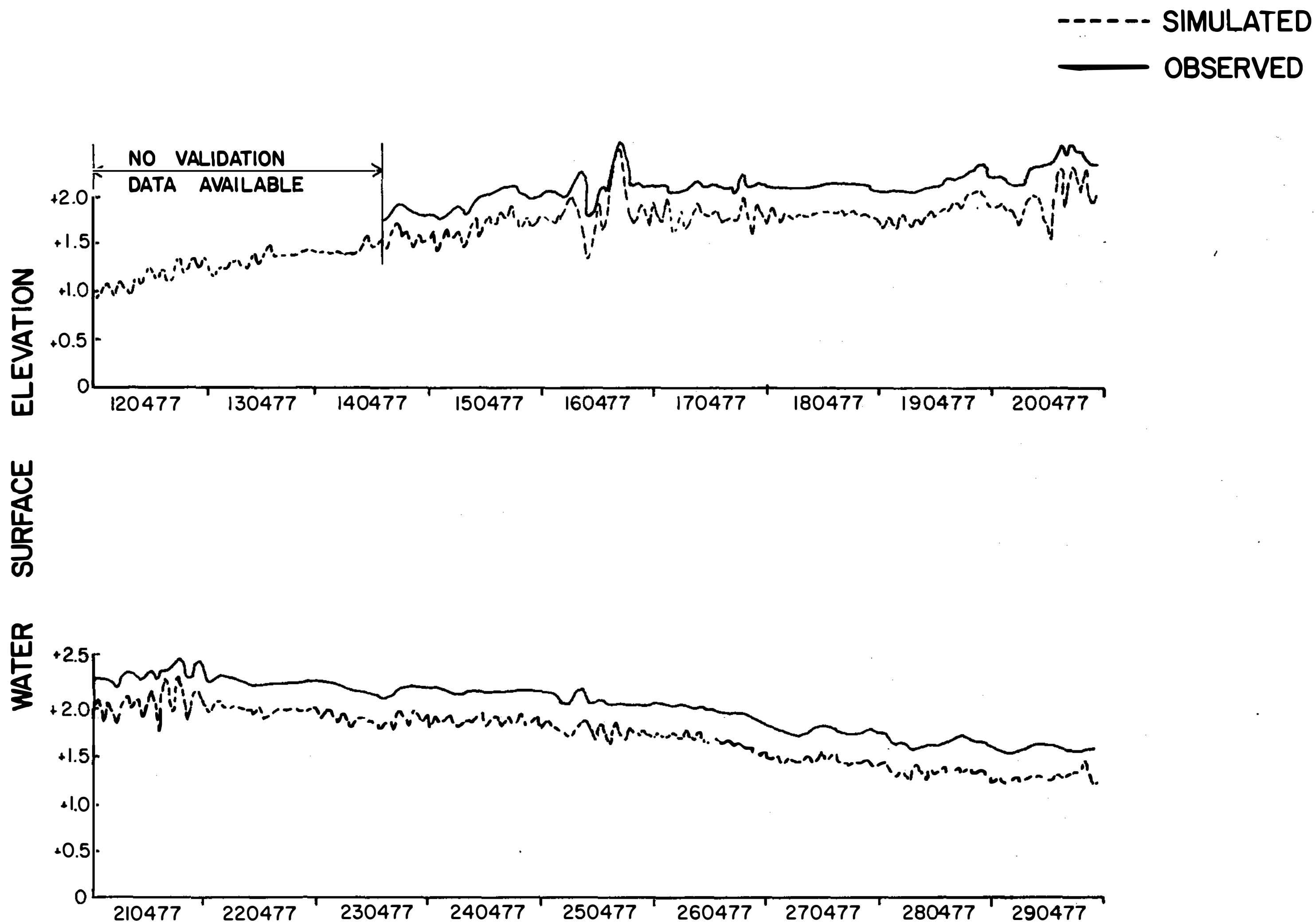


Figure III.30

TIDAL ELEVATION RECORD AT ICWW EAST OF COLORADO RIVER

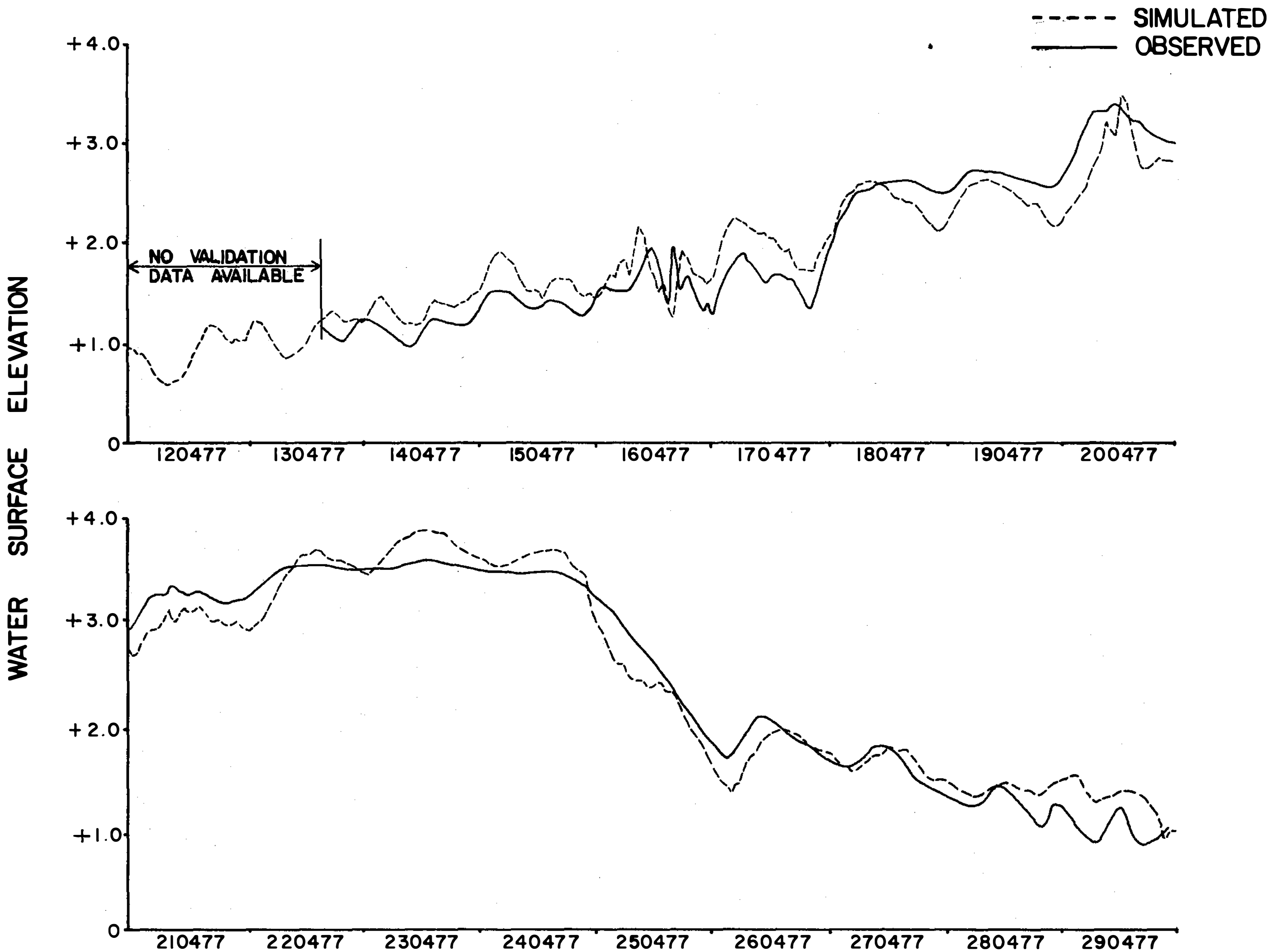


Figure III.31

TIDAL ELEVATION RECORD ABOVE TIGER ISLAND CUT

elevations are in very close agreement. The simulated values reflect a slightly higher tidal influence than was measured during the peak of the flood but the phasing is quite consistent. No validation data were available for flow patterns at Tiger Island Cut or at the mouth of the Colorado River. The simulated elevations and flows for these locations, for the flood case, are presented in Figures III.32 through III.36, respectively.

During the flood event, 17-29 April, flow patterns at Tiger Island Cut differ from those observed during the steady-state simulations. Instead of net flow from Matagorda Bay into the Gulf through Tiger Island Cut, water enters Matagorda Bay at a net rate of 8,650 ft^3/sec from the Colorado River. The simulated flow split at Tiger Island Cut is approximately 33 percent to 67 percent, with one-third of the total net flow entering Matagorda Bay and two-thirds entering the Gulf of Mexico under current physiographic river mouth conditions.

These results are not entirely consistent with those reached by Thorn and Smith (1976). Their flow split at Tiger Island Cut appeared to range from 50/50 with 9,000 ft^3/sec of Colorado River flow and a dredged river mouth to 84/16 with 7,000 ft^3/sec of river flow and 1973 channel mouth conditions. With both Tiger Island Cut and the Colorado River mouth dredged, the flow split simulated by Thorn and Smith was 70/30 in favor of Tiger Island Cut. Thus, the Thorn and Smith report indicates a far higher river contribution to Matagorda Bay by the Colorado River than was indicated in the current modeling effort. However, the river flow for this flood greatly exceeds any flows considered in the TDWR report since their work did not allow for inundation at high flows. Also, the flow area at the mouth was probably much greater during the flood due to scour. So direct comparison of flow distribution may not be appropriate.

Last day flow and tidal inundation summaries for the simulated flood are presented in Table III.7. Both input flows and driving elevations vary widely throughout the simulation period. Inspection of the input data indicates that the maximum flows occur during a period of very low tides in Matagorda Bay and the Gulf of Mexico and that maximum tidal elevations occur early in the simulation period during low flow, near steady-state conditions, at the start of the flood. The simulated output shows that the maximum depths of inundation of the marsh areas of Matagorda Bay are 0.4 to 0.5 foot, and that these periods of inundation and depths of inundation can be predicted from inspection of the observed Matagorda Bay tides. Further, no flooding at all is observed within the delta during the maximum flow period of the flood. Figure III.37 shows the areas inundated during the simulation period. Segments 67, 68 and 69 remain inundated for the longest period; however, this only amounts to 16 percent of the total model run-time.

SUMMARY

The Colorado River Delta is a complex system with many variables which causes detailed computer simulation modeling of the actual system to be difficult. The existence of possible circular circulation patterns involving Culver Cut, the GIWW, the Colorado River, Tiger Island Cut and Matagorda Bay further complicate a system beset by the influence of two unrelated tidal forces, and probable bi-directional flow within its principal exchange channels. The delta model, however, does a credible job of reproducing observed water surface elevation variations throughout the system, when subjected to low, moderate and flood freshwater inflows. Validation of hourly flows was not

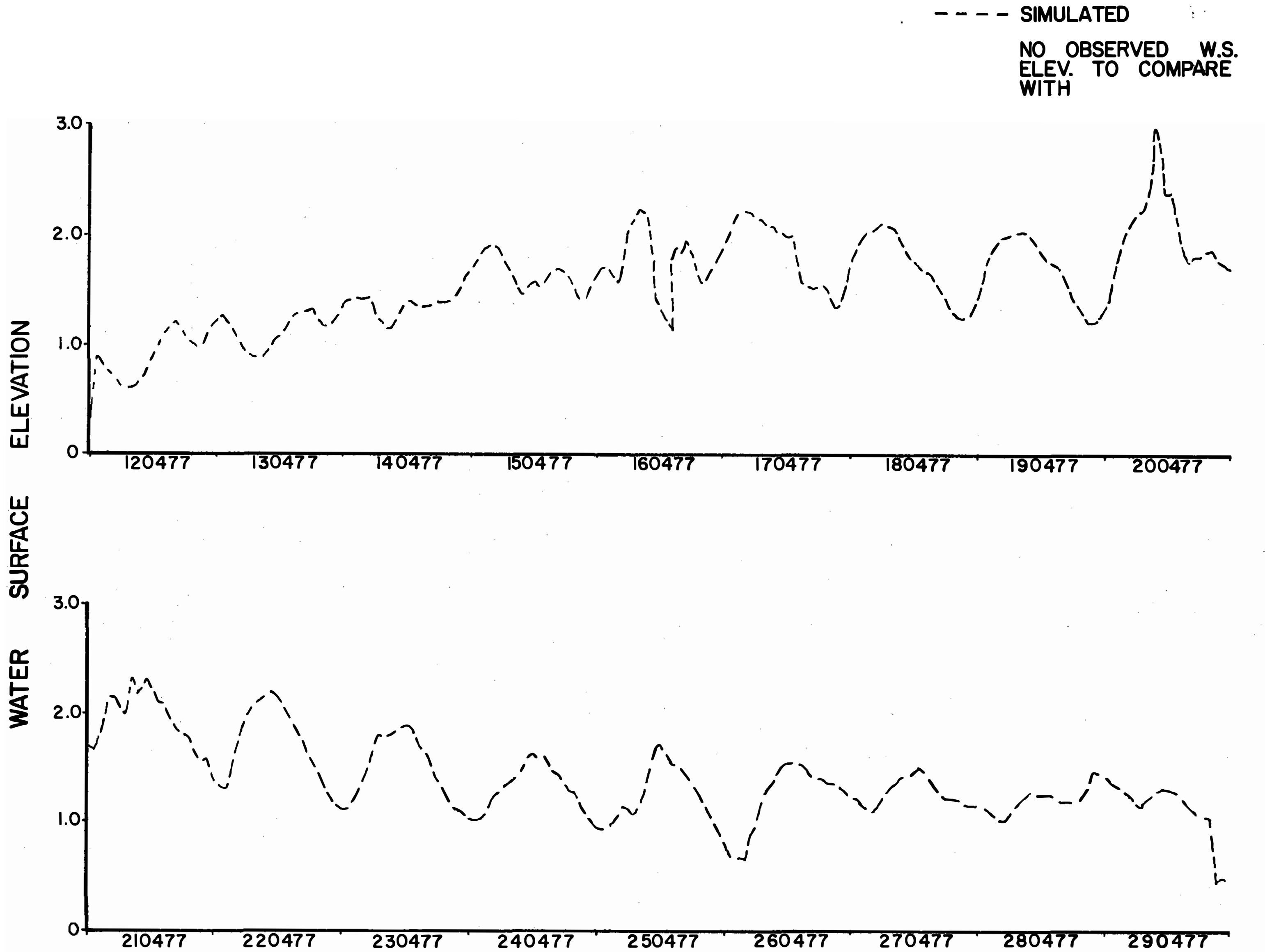


Figure III.32

TIDAL ELEVATION RECORD AT TIGER ISLAND CUT

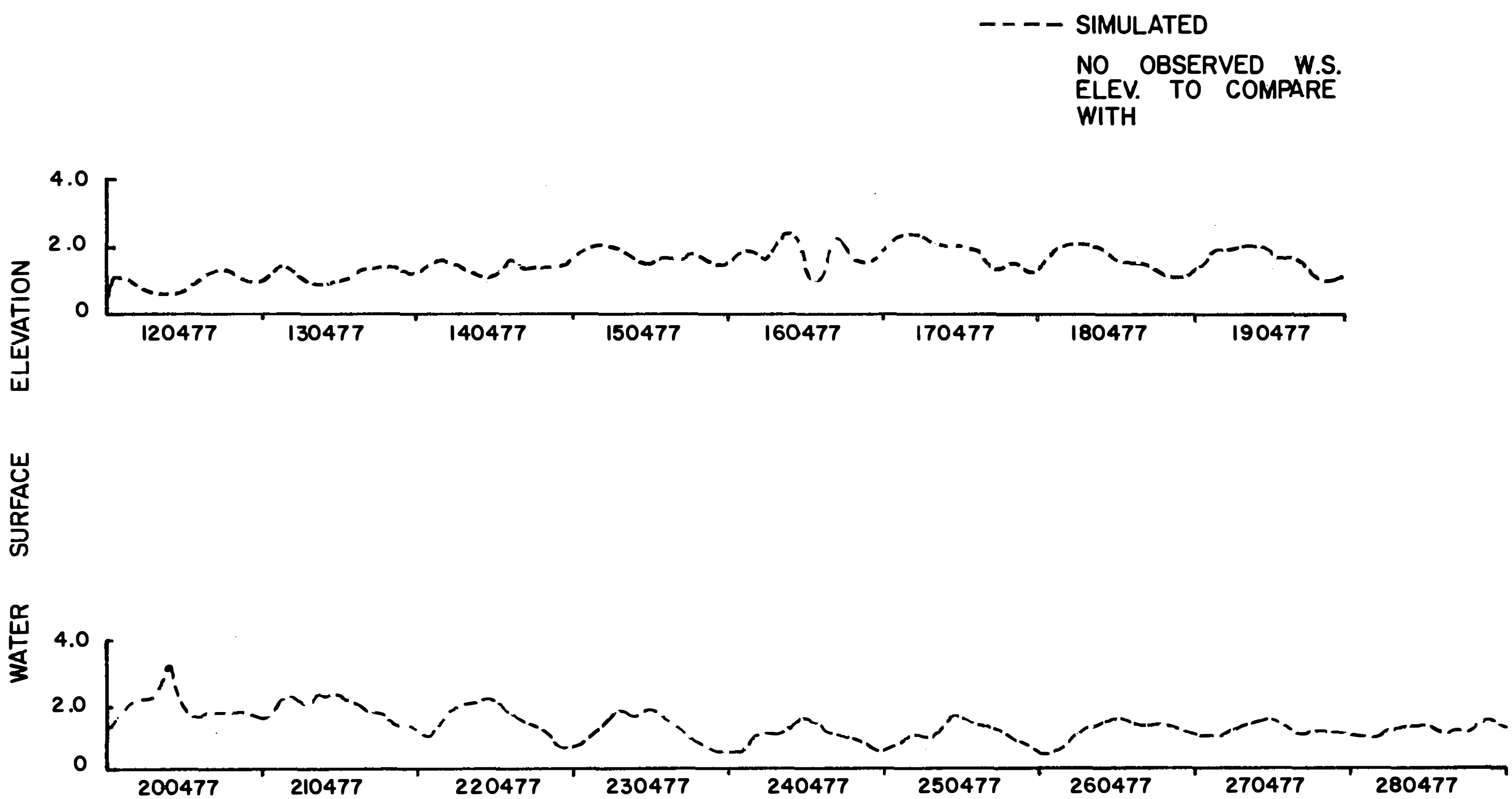


Figure III.33

TIDAL ELEVATION RECORD AT COLORADO MOUTH

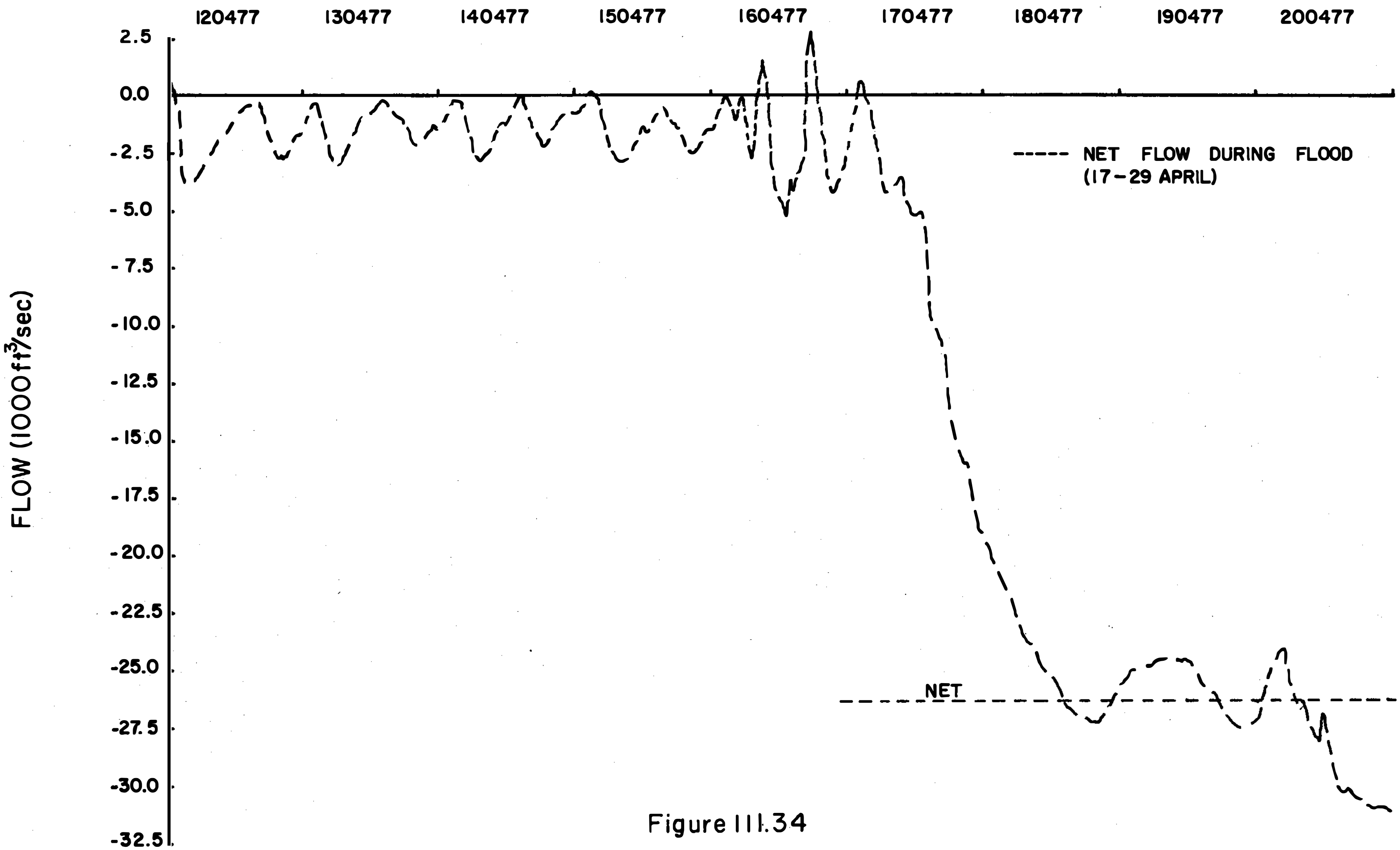


Figure III.34

SIMULATED

FLOW ABOVE TIGER ISLAND CUT

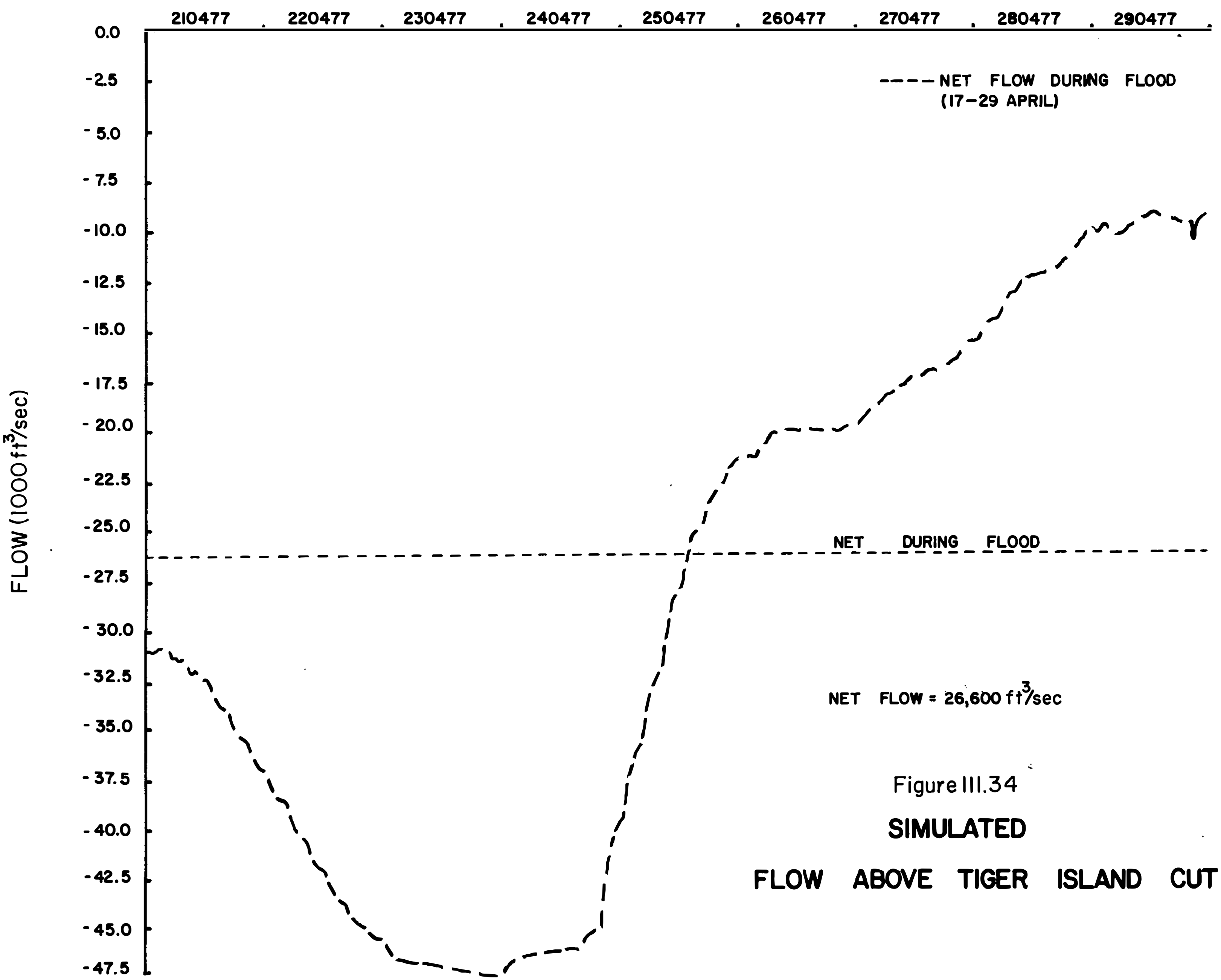


Figure III.34

SIMULATED

FLOW ABOVE TIGER ISLAND CUT

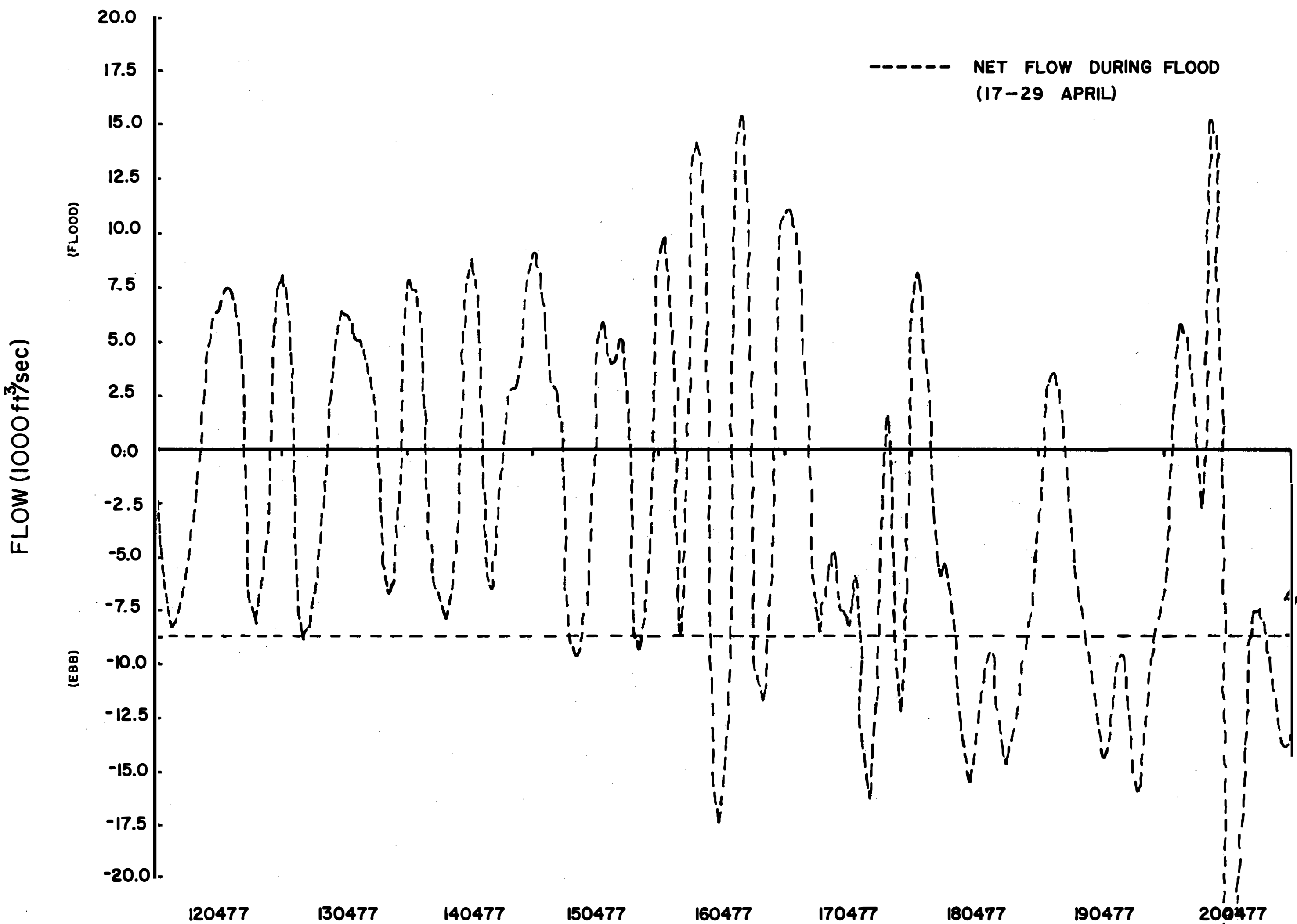
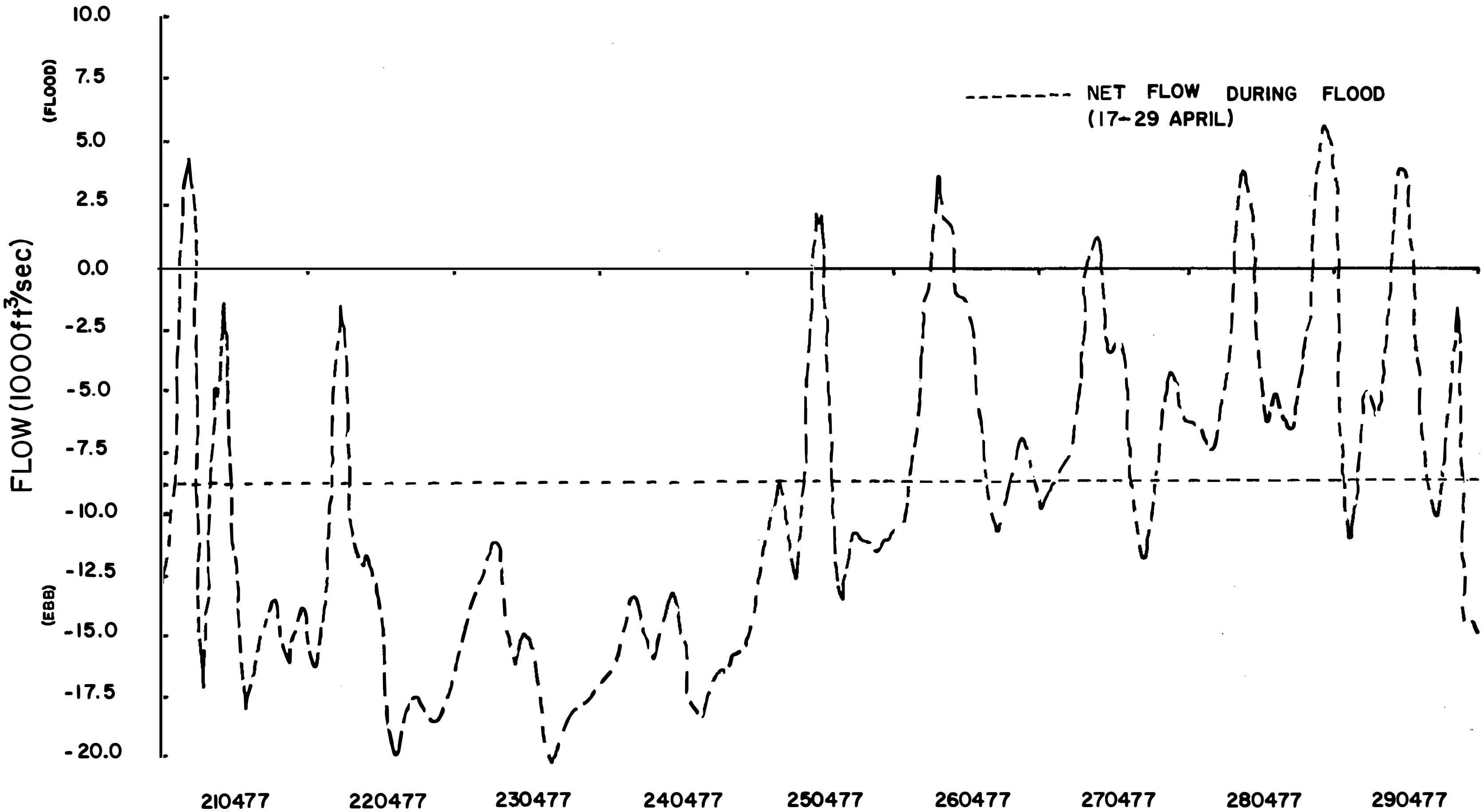


Figure III.35

SIMULATED FLOW AT TIGER ISLAND CUT

NET FLOW = 8,650 ft³/sec



NET FLOW = 8,650 ft^3/sec

Figure III.35

SIMULATED

FLOW AT TIGER ISLAND CUT

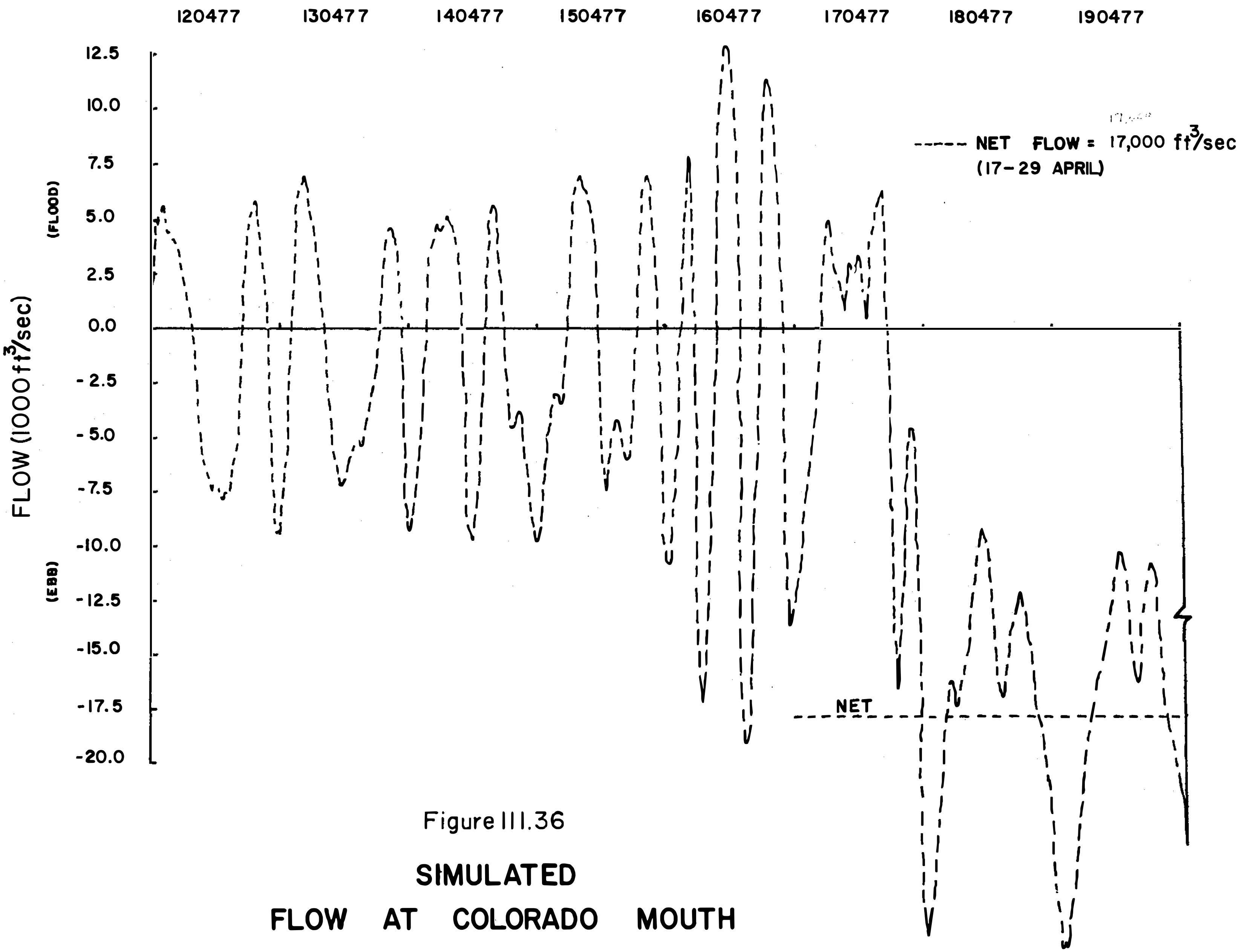


Figure III.36

SIMULATED

FLOW AT COLORADO MOUTH

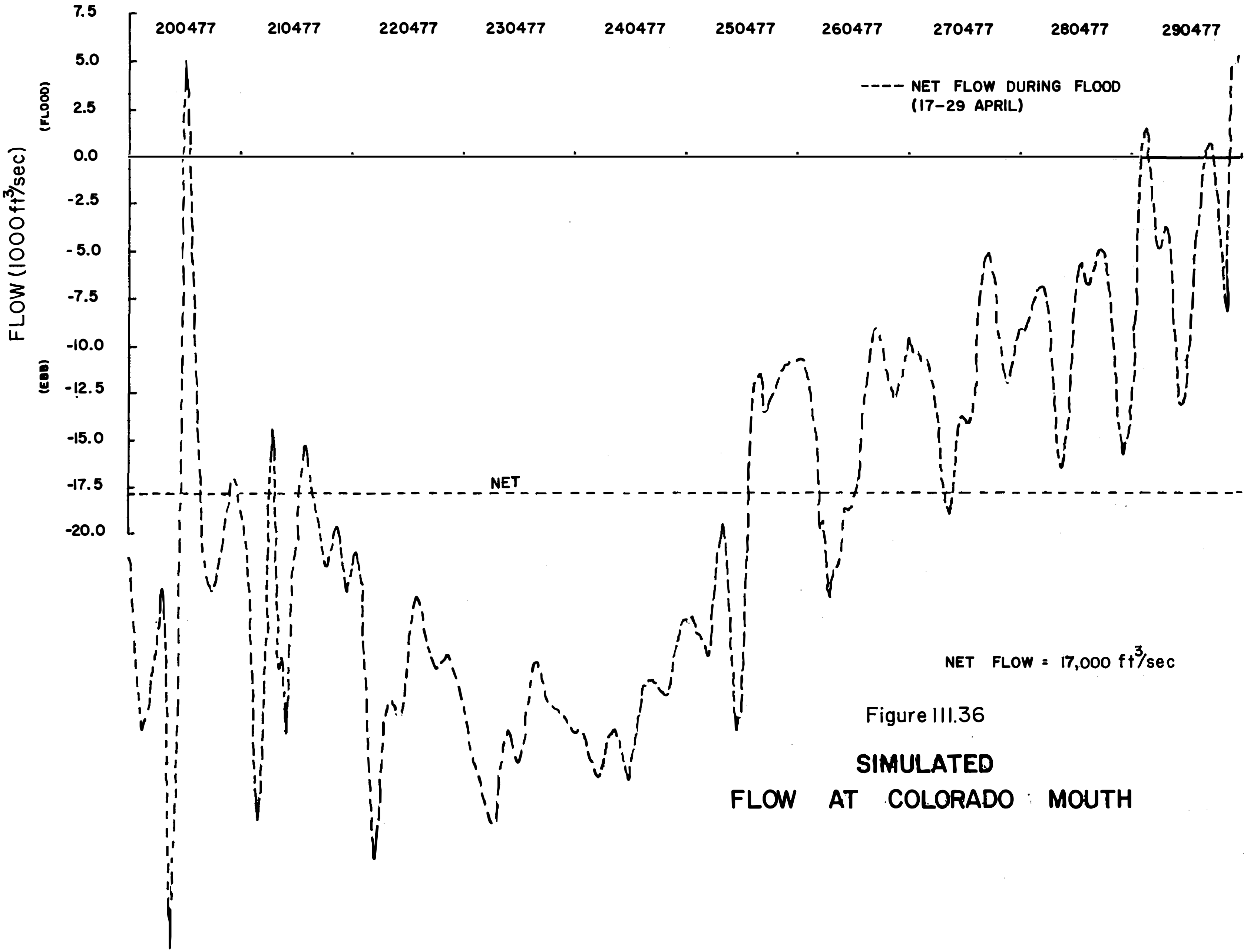


Figure III.36

SIMULATED
FLOW AT COLORADO MOUTH

TABLE III-7

FINAL SUMMARY FOR FLOOD SIMULATION
(- indicates downstream)

Segment	Net Flow Last Day (ft^3/sec)	Overbank Area (Acres)	Flooding Indicator (If Flooding Occurred)	Time Inundated (Hours)
1	-4814.225	1469.	0	.00
2	-4660.056	0.	0	.00
3	-4512.259	0.	0	.00
4	-4421.026	0.	0	.00
5	-9610.374	52.	0	.00
6	-9604.867	20.	0	.00
7	-9597.967	19.	1	54.76
8	-9591.083	17.	1	55.43
9	-9583.987	13.	1	51.74
10	-9576.414	0.	1	39.24
11	-9568.961	13.	0	.00
12	-9544.638	23.	0	.00
13	-9538.536	0.	0	.00
14	-9531.614	4.	0	.00
15	-9525.897	2.	0	.00
16	-9518.087	0.	0	.00
17	-9508.044	0.	0	.00
18	-9500.816	2.	0	.00
19	-9493.552	10.	0	.00
20	-9486.289	8.	0	.00
21	-9476.980	1.	0	.00
22	-9469.100	6.	0	.00
23	-9461.859	7.	0	.00
24	-9454.844	13.	0	.00
25	-9449.133	1.	0	.00
26	-9442.595	8.	0	.00
27	-9436.054	25.	0	.00
28	-9427.295	12.	0	.00
29	-9419.425	14.	0	.00
30	-9411.938	5.	0	.00

(Continued)

TABLE III-7 (Cont'd)

Segment	Net Flow Last Day (ft^3/sec)	Overbank Area (Acres)	Flooding Indicator (If Flooding Occurred)	Time Inundated (Hours)
31	-9404.291	20.	0	.00
32	-9396.609	13.	0	.00
33	-9388.960	11.	0	.00
34	-9380.767	12.	0	.00
35	-9371.185	0.	0	.00
36	-9362.808	10.	0	.00
37	-9354.465	6.	0	.00
38	-9346.318	0.	0	.00
39	-9338.342	1.	0	.00
40	-9330.427	28.	0	.00
41	-9322.315	0.	0	.00
42	-9314.169	7.	0	.00
43	-9305.962	7.	0	.00
44	.000	8.	0	.00
45	-513.484	1266.	0	.00
46	-492.727	293.	0	.00
47	-467.221	339.	0	.00
48	-414.736	381.	0	.00
49	-360.455	333.	0	.00
50	-293.570	287.	0	.00
51	-215.253	333.	0	.00
52	-132.711	51.	0	.00
53	-70.288	688.	0	.00
54	-26.757	1100.	0	.00
55	.000	636.	0	.00
56	.000	17.	0	72.26
57	-13.090	381.	0	.00
58	-9.893	0.	0	.00
59	-6.835	0.	0	.00
60	-3.515	0.	0	.00

(Continued)

TABLE III-7 (Concluded)

Segment	Net Flow Last Day (ft^3/sec)	Overbank Area (Acres)	Flooding Indicator (If Flooding Occurred)	Time Inundated (Hours)
61	.000	0.	0	.00
62	10.410	0.	0	.00
63	14.879	0.	0	.00
64	-1.412	23.	0	.00
65	.000	10.	0	.00
66	17.606	2.	0	.00
67	56.266	181.	1	70.36
68	-51.556	300.	1	69.89
69	.000	702.	1	70.44
70	-10007.232	710	0	.00
71	-9195.955	131.	1	52.28
72	-8442.290	200.	1	52.34
73	-7516.516	267.	1	52.36
74	-6860.162	119.	1	52.48
75	-987.730	210.	1	52.85
76	-420.148	159.	1	53.16
77	-160.913	505.	1	53.39
78	.000	1309.	1	54.83
79	-190.733	267.	1	52.36
80	-159.263	0.	0	.00
81	.000	300.	1	69.89
82	-5216.133	210.	1	52.85
83	-5198.485	0.	1	55.36
84	.000	52.	1	75.56

Figure III.37
AREAS INUNDATED UNDER FLOOD SIMULATION CONDITIONS

successful due to the suspected bi-directional flow patterns existing in the observed data. However, tidally averaged flows do replicate well, which is important for long term planning purposes.

CHAPTER IV

NUTRIENT BALANCE STUDIES

Nutrient inputs into the bays and estuaries is a major factor influencing the productivity of commercial, sport and other fishery resources of these systems. Other than oceanic nutrients brought in during tidal exchange, the only other sources for estuarine enrichment are those nutrients of terrestrial origin. These are brought in as a result of freshwater flows, either sheet runoff from immediately adjacent land areas or more importantly, where river systems with large basin areas drain thousands of acres. Since, with few exceptions, ocean water is relatively nutrient-poor, the vast majority of the nutrients which support an estuarine system are brought in with the freshwater inflow. Another factor which contributes to the success of estuarine productivity is the sediment brought downstream along with nutrients. This sediment is usually deposited in an alluvial fan-shaped delta that may spread over many square miles and offers a relatively shallow habitat that supports growth of periphyton and vascular plants. These conditions offer food, shelter and habitat space for fishes and crustaceans, as well as a myriad of benthic organisms. The dilution of seawater with freshwater also provides physical environment that promotes the growth and well-being of the juveniles of many marine species, especially shrimp and crabs, as well as many fishes.

To determine the nutrient contribution of the Colorado River to the Matagorda Bay System, water samples were collected at the six sampling locations used for flow measurements (Figure IV.1). These samples were analyzed for nutrient concentration (carbon, nitrogen and phosphorus) in the University of Texas Department of Environmental Health Engineering Laboratories in Austin, using the procedure described in Armstrong, et. al., 1975. At the same time physical water quality parameters (temperature, pH, conductivity, and dissolved oxygen) were measured <u>in situ</u> at each site. The measurements and samples were taken at three-hour intervals over a 25-hour period. Measurements of the physical water quality parameters were taken at the surface and bottom, while in general, the water samples for laboratory chemical analysis were collected at mid-depth. At times when surface and bottom conductivity were vastly different, both surface and bottom samples were taken.

For the analysis of the water data for water quality parameters, it was necessary to determine a means of handling concentration values that were below the sensitivity threshold of the laboratory detection procedures. This problem was encountered several times during analysis of nitrogen species contribution. It was resolved by assuming threshold sensitivity values in those instances where concentrations were too low to be detected accurately. In the subsequent analysis of the May data the reader should be aware that the nutrient input rates for the nitrogenous species are to be considered as absolute maximum values and to bear in mind that the actual values may be somewhat less; i.e., the assumption stated in the preceeding sentence would be expected to bias the data upward and thus lead to a result that is on the high side.

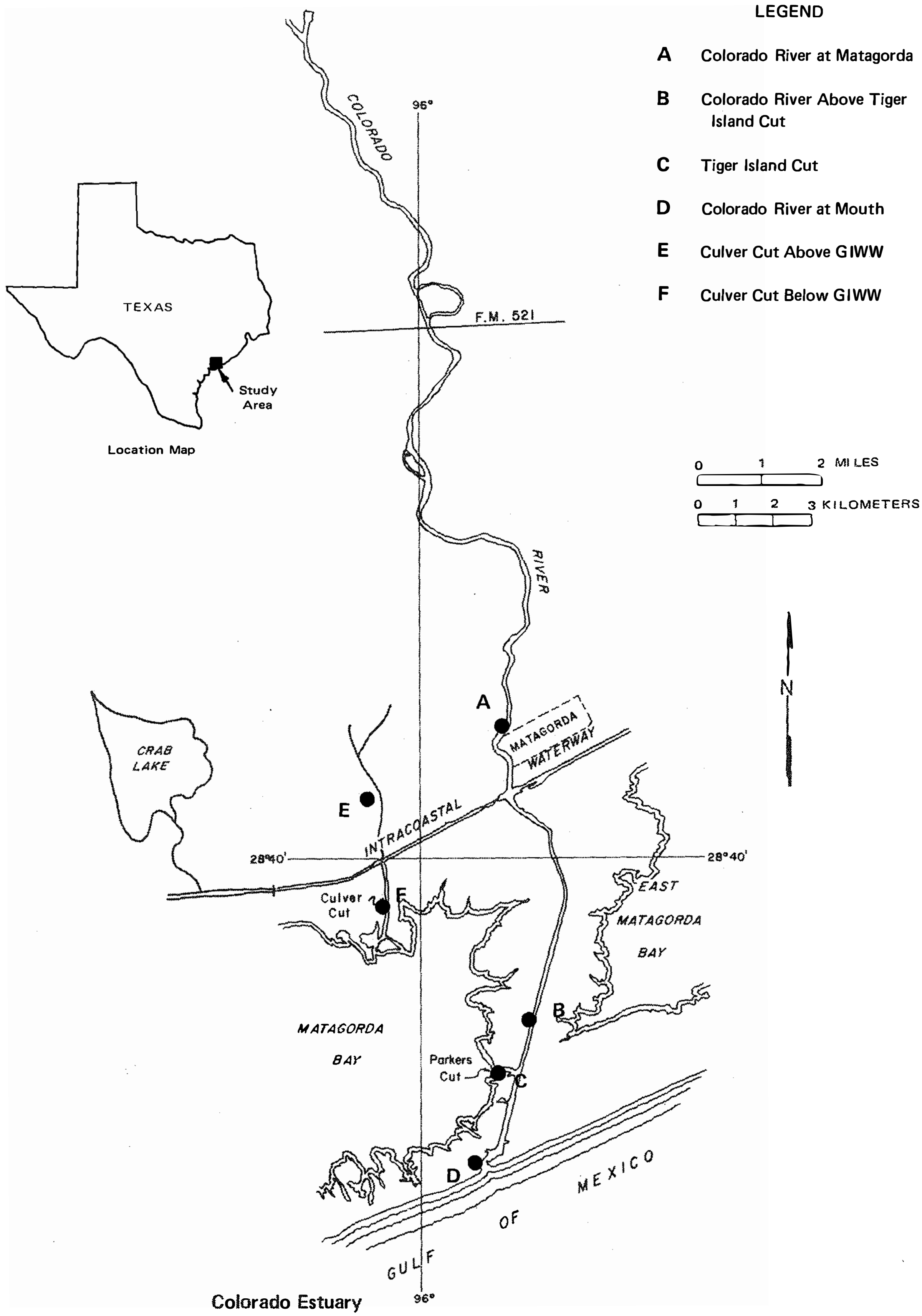


Figure IV.1.—Sampling Locations for Flows and Water Quality in the Colorado River Delta

During the May 1977 study the mean flow at Bay City of 5,400 ft^3/sec was high enough to prevent flow reversal in the river channel above Tiger Island Cut, but even under these high flow conditions the delta exhibited the characteristics of a "salt wedge" type estuary, i.e., a layer of lighter, less saline waters overlying a denser, more saline layer. This is readily evident by noting the difference between top and bottom salinity concentrations depicted in Figures IV.2, IV.3 and IV.4. This top to bottom salinity gradient existed during flood tides, but with the exception of the Colorado River at Matagorda (Station A), began to break down as bottom layers became less saline during ebb flows. However, the dissolved oxygen concentration levels at all sampling locations showed no diel (day and night) variation and remained relatively high (6.5 - 8.0 ppm) throughout the study. There was little, if any gradient in oxygen concentration from top to bottom.

With the exception of a slightly higher level of ammonia in the bottom samples at Station A (Figures IV.5 and IV.6) there appeared to be no significant differences in concentrations between top and bottom samples for any of the following water quality parameters, Total phosphate phosphorus (Total PO_4-P), orthophosphate phosphorus (PO_4-P), total organic carbon (TOC), total kjeldahl nitrogen (TKN-N), ammonia nitrogen (NH_4-N), and nitrate and nitrite nitrogen (NO_3-N, NO_2-N). Nor does there appear to be any correlation of nutrient concentrations with flow direction. Concentrations of TKN-N, NO_2-N and NO_3-N were low throughout the study and, in many instances, were so low that the laboratory apparatus and methods used were not sensitive enough to accurately detect them. Corresponding phosphorus levels were relatively high (Figures IV.7, IV.8, IV.9, IV.10, IV.11, IV.12, IV.13 and IV.14). The differences between the phosphorus concentrations of filtered versus unfiltered samples indicates that a large portion (roughly two-thirds) occurred in particulate form. The occurrence of relatively high phosphorus levels in conjunction with very low nitrogen levels suggests that during the study period nitrogen may have been a limiting nutrient for biological activity. Total organic carbon (TOC) concentrations were somewhat suspect since in many cases the concentrations measured from filtered samples were greater than those from unfiltered samples, indicating possible contamination in the field or the laboratory (Figures IV.15, IV.16, IV.17, IV.18, IV.19, IV.20, IV.21 and IV.22). These data seem to indicate that the total organic carbon occurred predominantly in the dissolved state.

The total nutrient transport can be determined by multiplying the nutrient concentration measured during each time interval by the total flow for that time interval. The total transport of each of the nutrient species at each sampling location during the May study is presented in Table IV.1 through Table IV.6. The net transport of each of the nutrient species at each sampling location is presented in Table IV.7. A total of 6,660 kg (14,700 lbs) of nitrogen, over half of which occurred in organic form; 5,610 kg (12,400 lbs) of phosphorus; and 102,896 kg (226,900 lbs) of total organic carbon entered the delta from the river above the GIWW. Based on mass balance calculations, 6,146 kg (13,600 lbs) of nitrogen, 3,253 kg (7,200 lbs) of phosphorus, and 142,556 kg (314,000 lbs) of total orgnaic carbon was exported from the delta (Table IV.8). Over three quarters of each nutrient (75 percent - 80 percent) leaving the delta was discharged into the Gulf of Mexico. The remaining 20 to 25 percent was discharged into Matagorda Bay primarily through Tiger Island Cut with some additional contribution (4 percent - 6 percent) from Culver Cut. As a result, 513 kg (1,100 lbs) nitrogen, 640 kg (1,400 lbs) phosphorus, and 31,758 kg (70,000 lbs) total organic carbon entered the waters of Matagorda Bay from the Colorado River Delta during the May study period. Based on these data the river was a net contributor

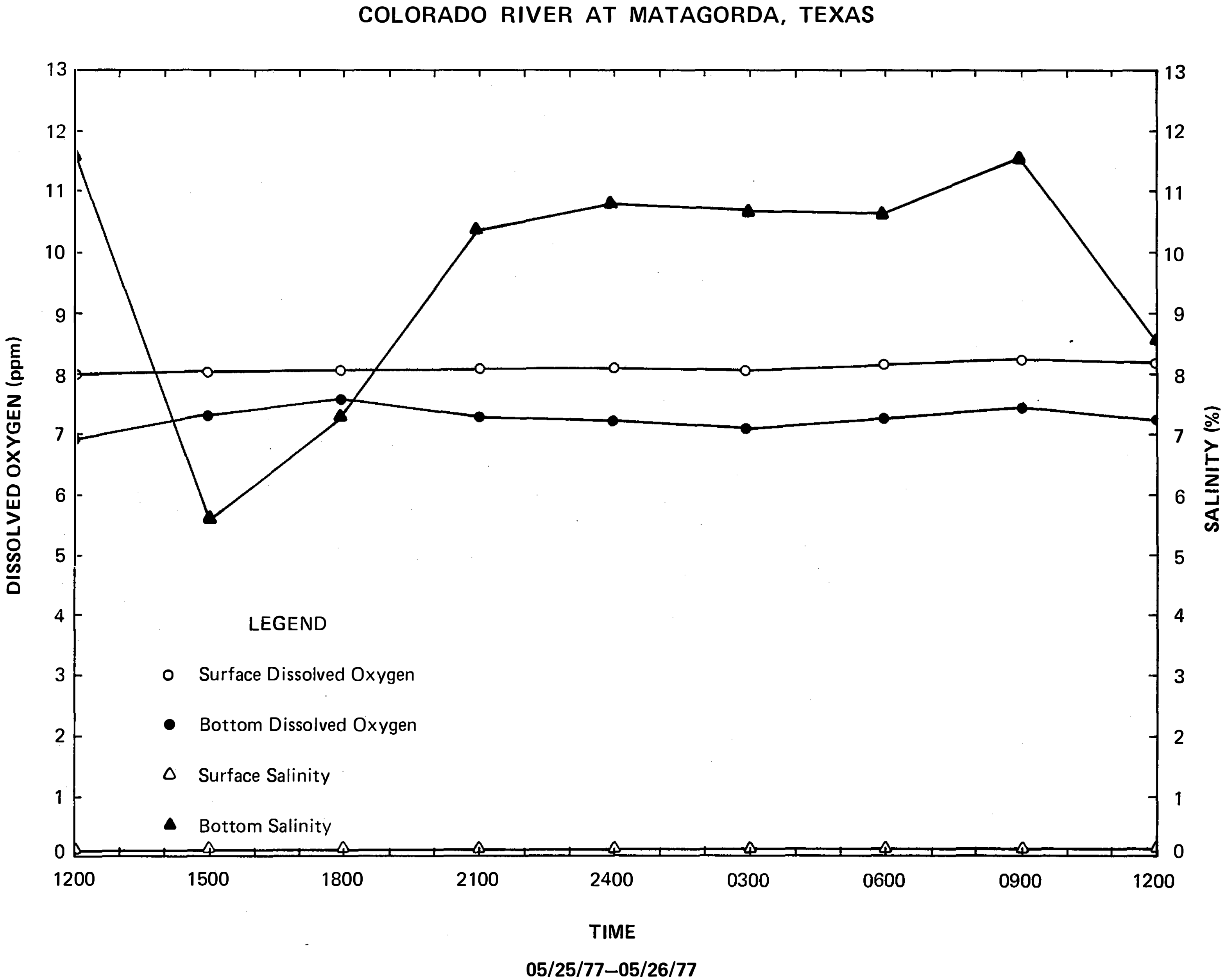


Figure IV.2.–Surface and Bottom Dissolved Oxygen and Salinity at Station A During the May 1977 Inflow/Exchange Study

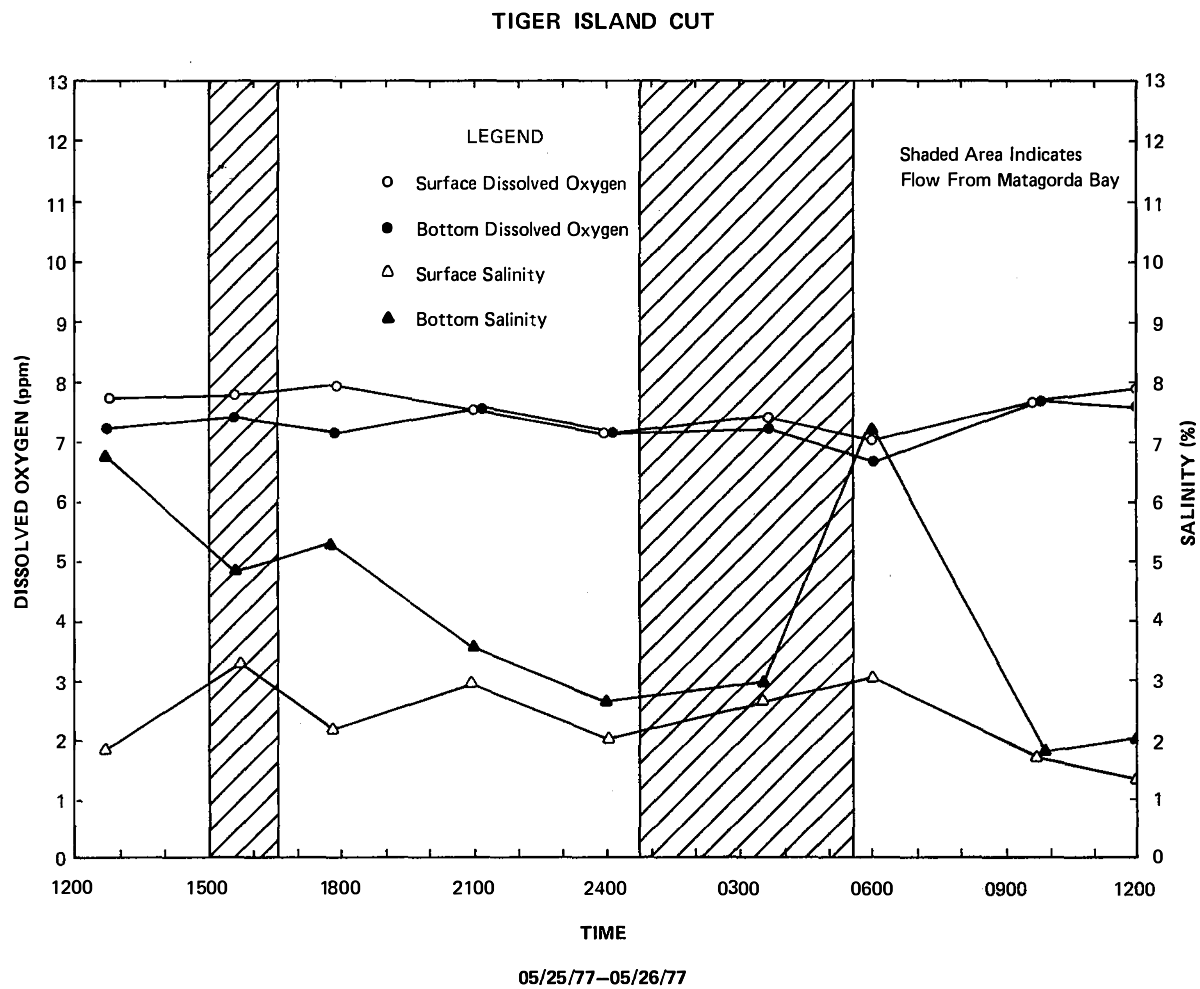


Figure IV.3.—Surface and Bottom Dissolved Oxygen and Salinity at Station C During the May 1977 Inflow/Exchange Study

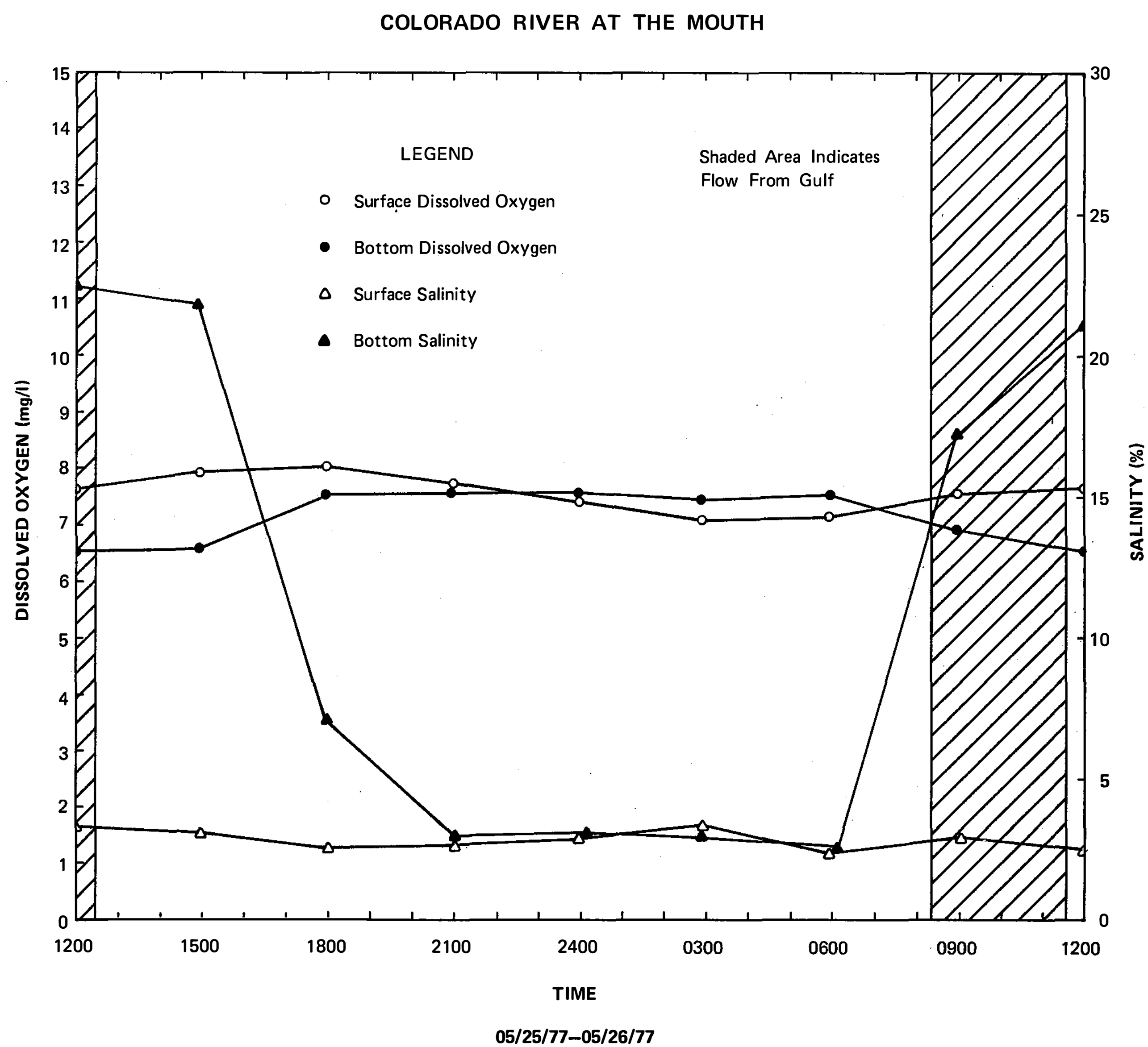


Figure IV.4.—Surface and Bottom Dissolved Oxygen and Salinity at Station D During the May 1977 Inflow/Exchange Study

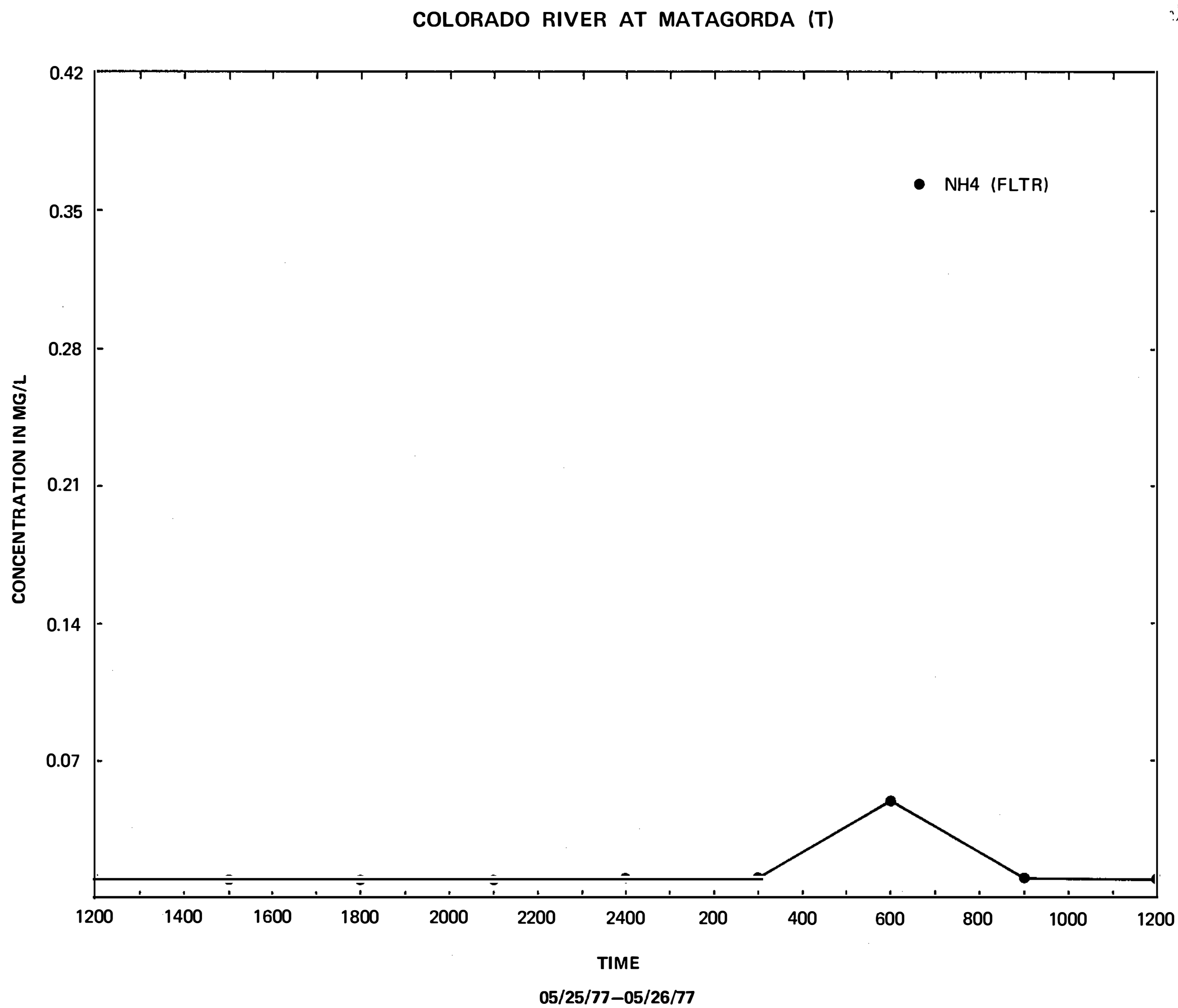


Figure IV.5.—Surface Concentration of Ammonia at Station A During the May 1977 Inflow/Exchange Study

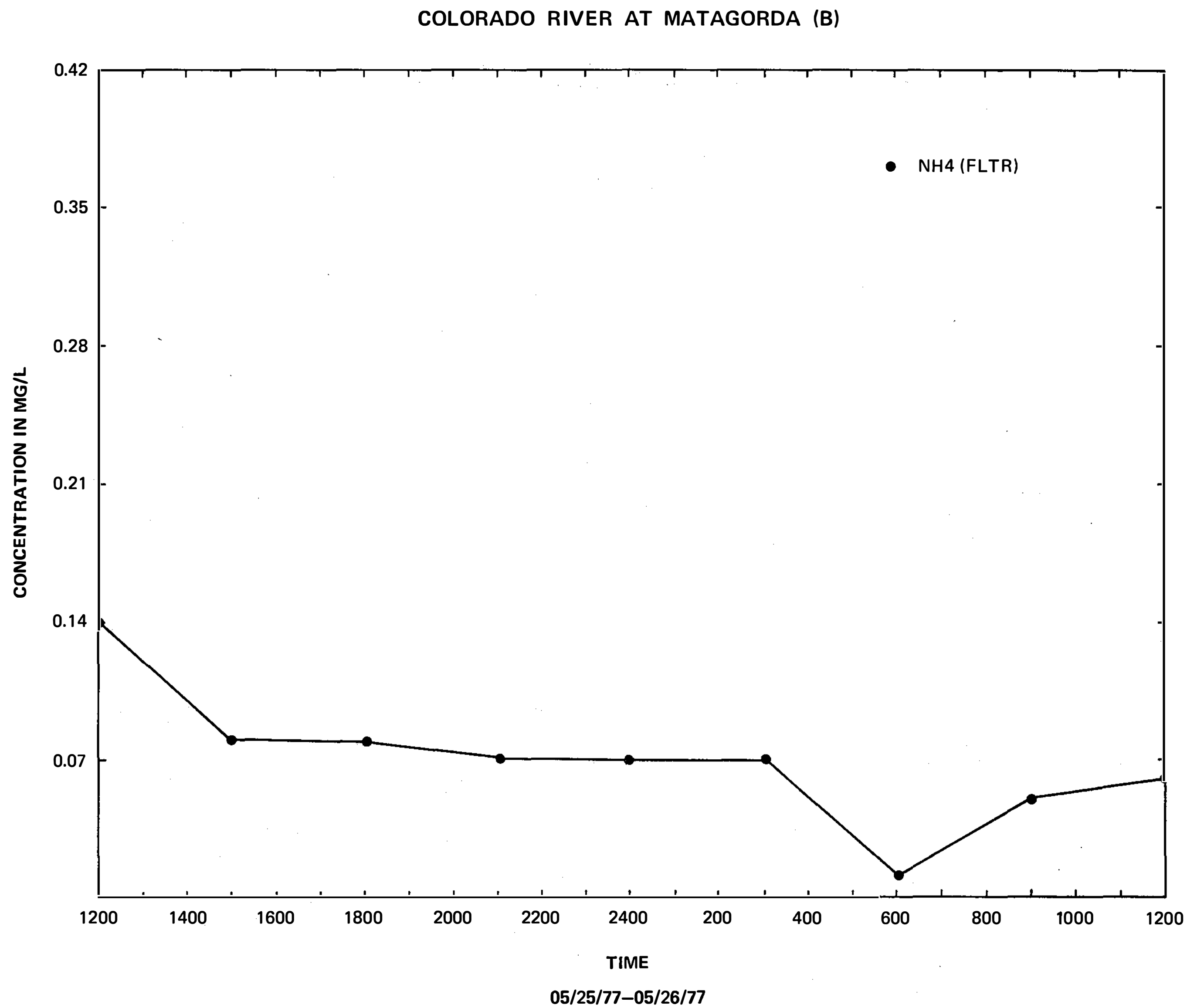


Figure IV.6.—Bottom Concentration of Ammonia at Station A During the May 1977 Inflow/Exchange Study

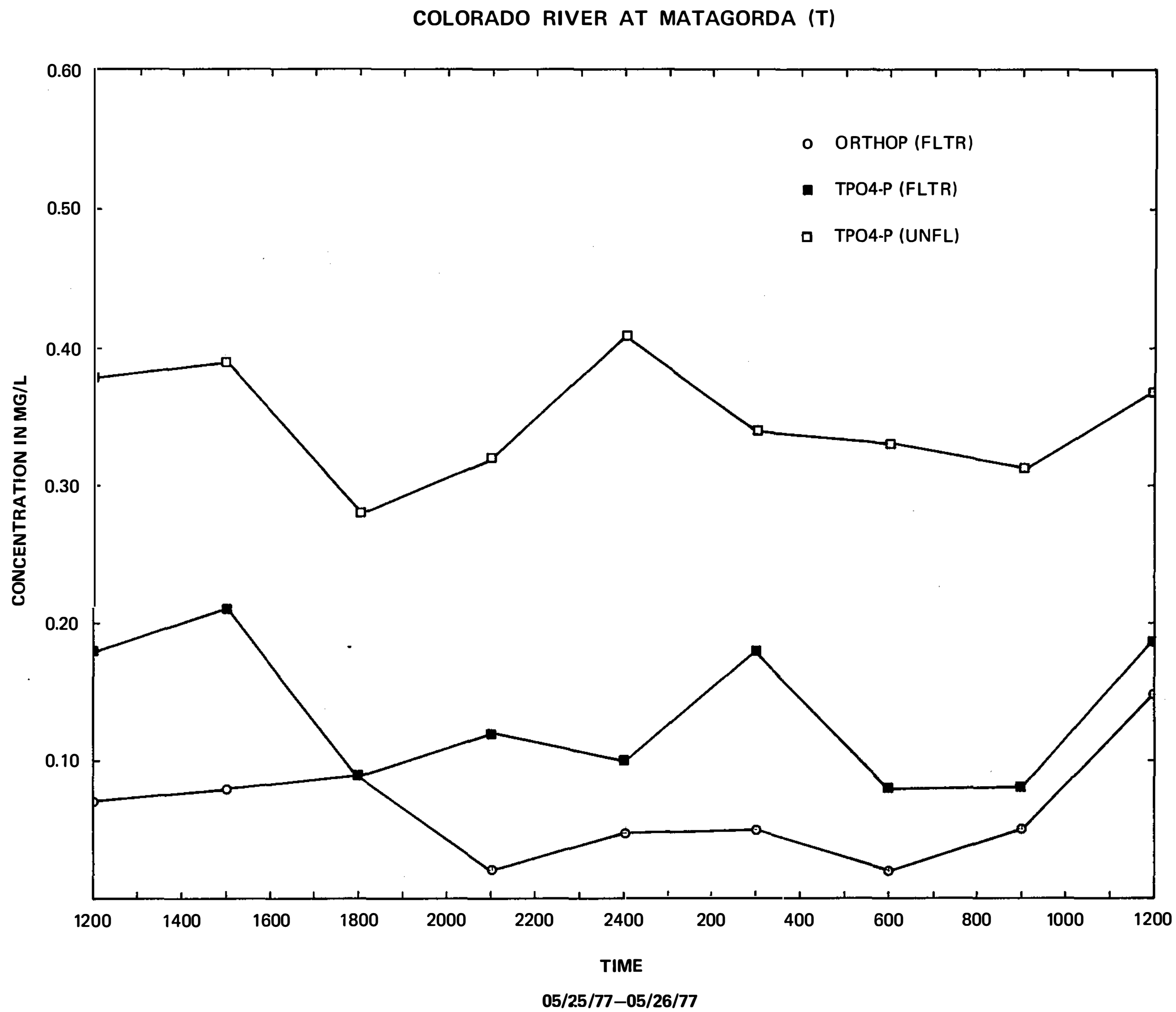


Figure IV.7.—Surface Concentrations of Total and Orthophosphorus at Station A During the May 1977 Inflow/Exchange Study

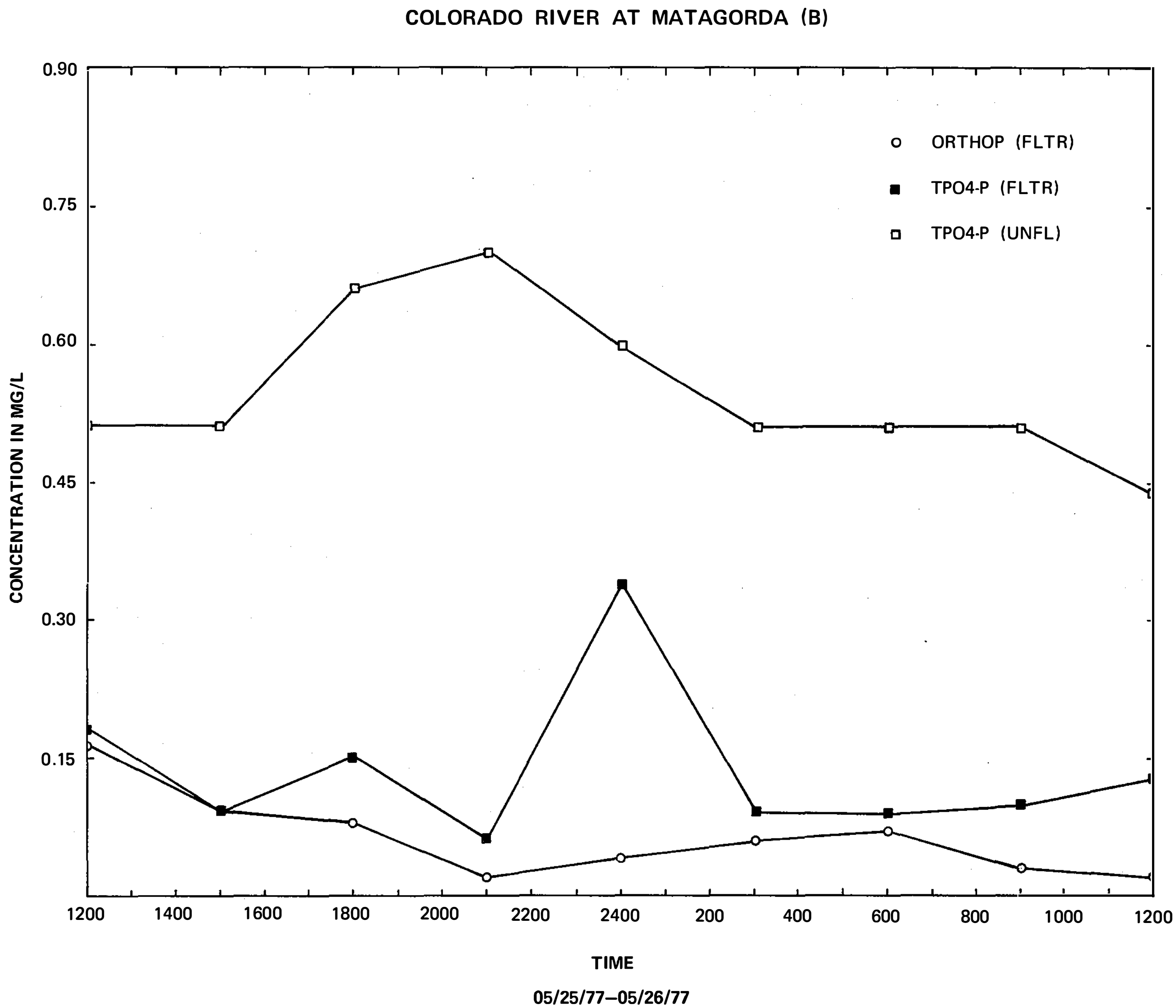


Figure IV.8.—Bottom Concentrations of Total and Orthophosphorus at Station A During the May 1977 Inflow/Exchange Study

TIGER ISLAND CUT (T)

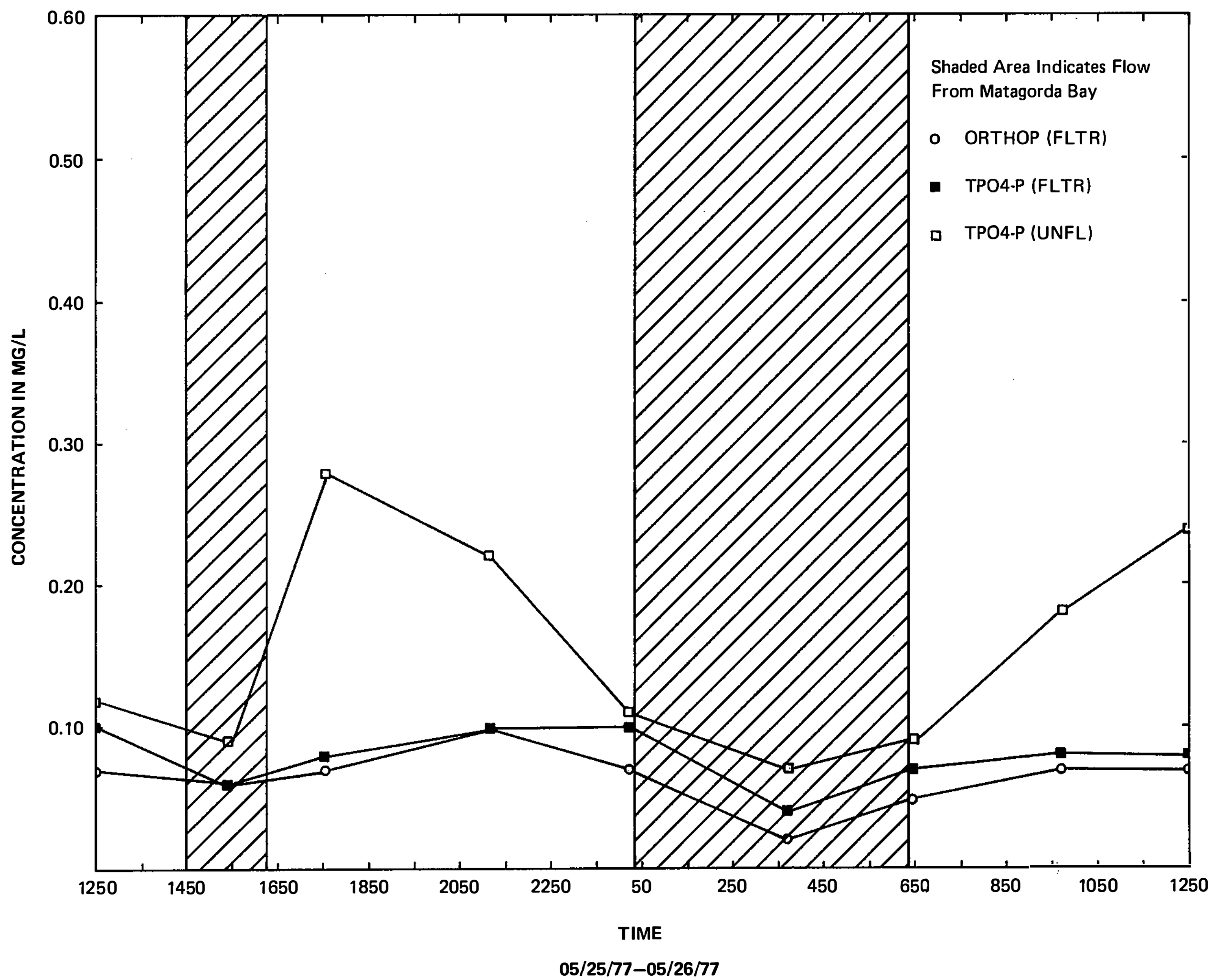


Figure IV.9.—Surface Concentrations of Total and Orthophosphorus at Station C
During the May 1977 Inflow/Exchange Study

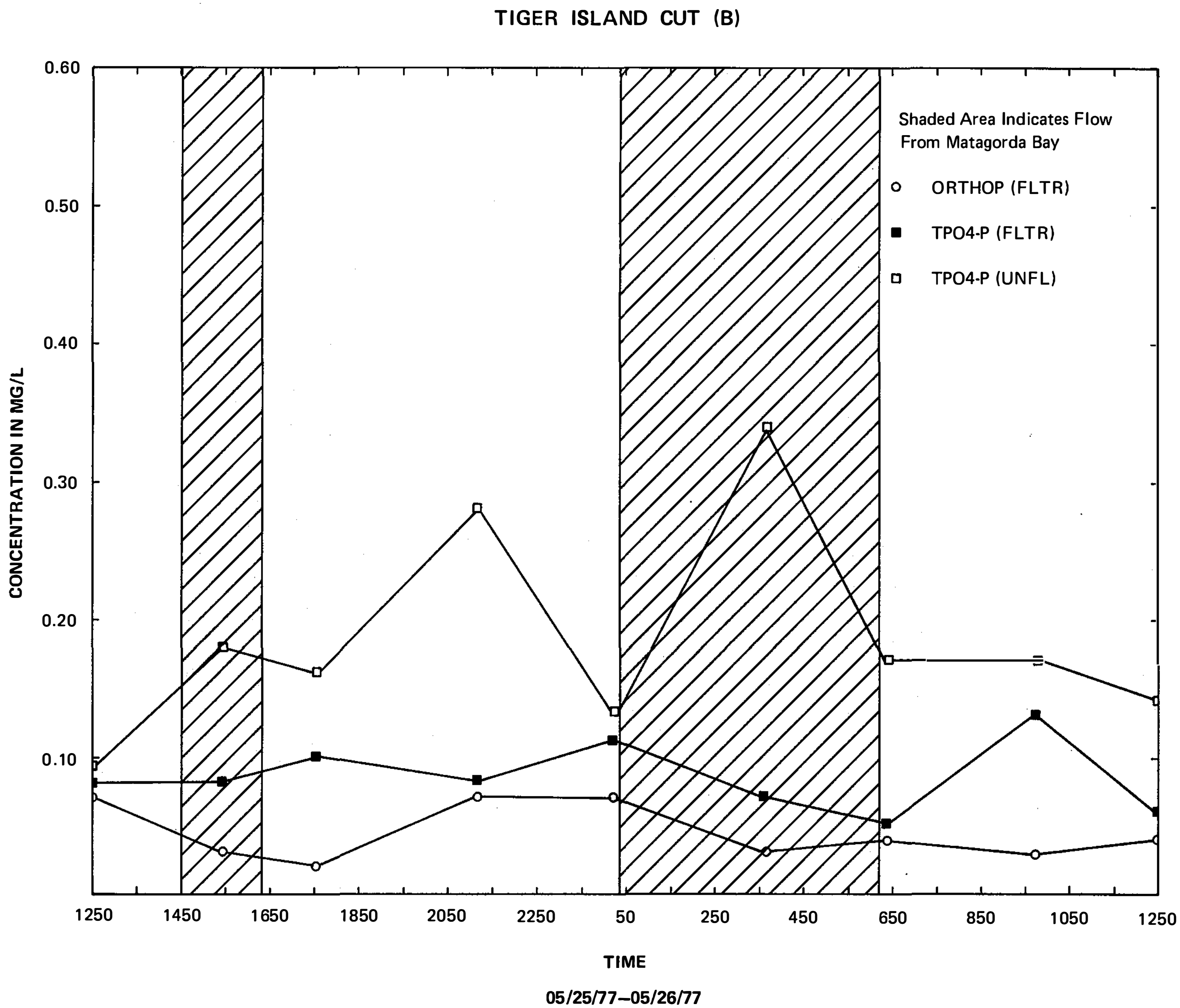


Figure IV.10.—Bottom Concentrations of Total and Orthophosphorus at Station C During the May 1977 Inflow/Exchange Study

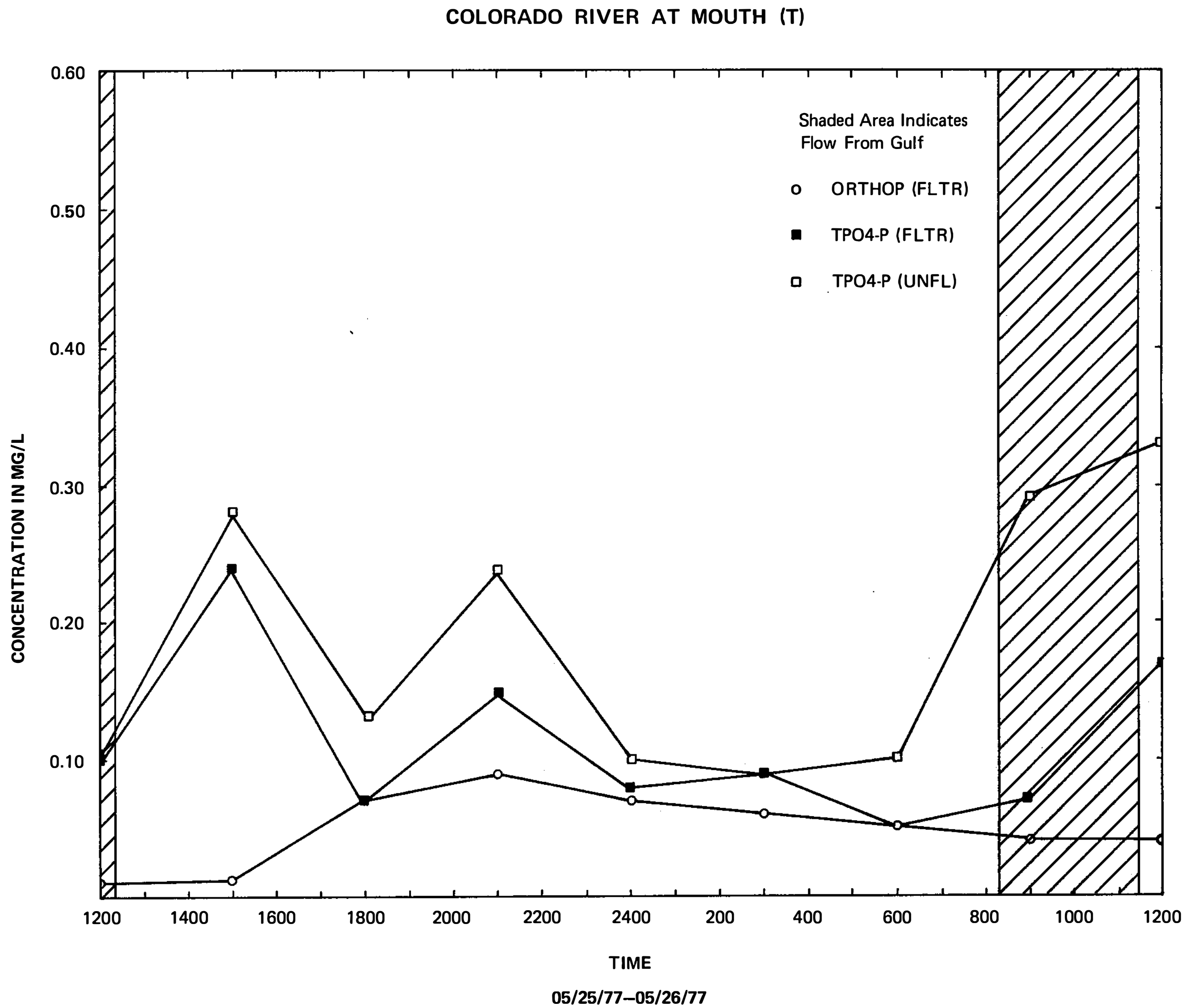


Figure IV.11.—Surface Concentrations of Total and Orthophosphorus at Station D During the May 1977 Inflow/Exchange Study

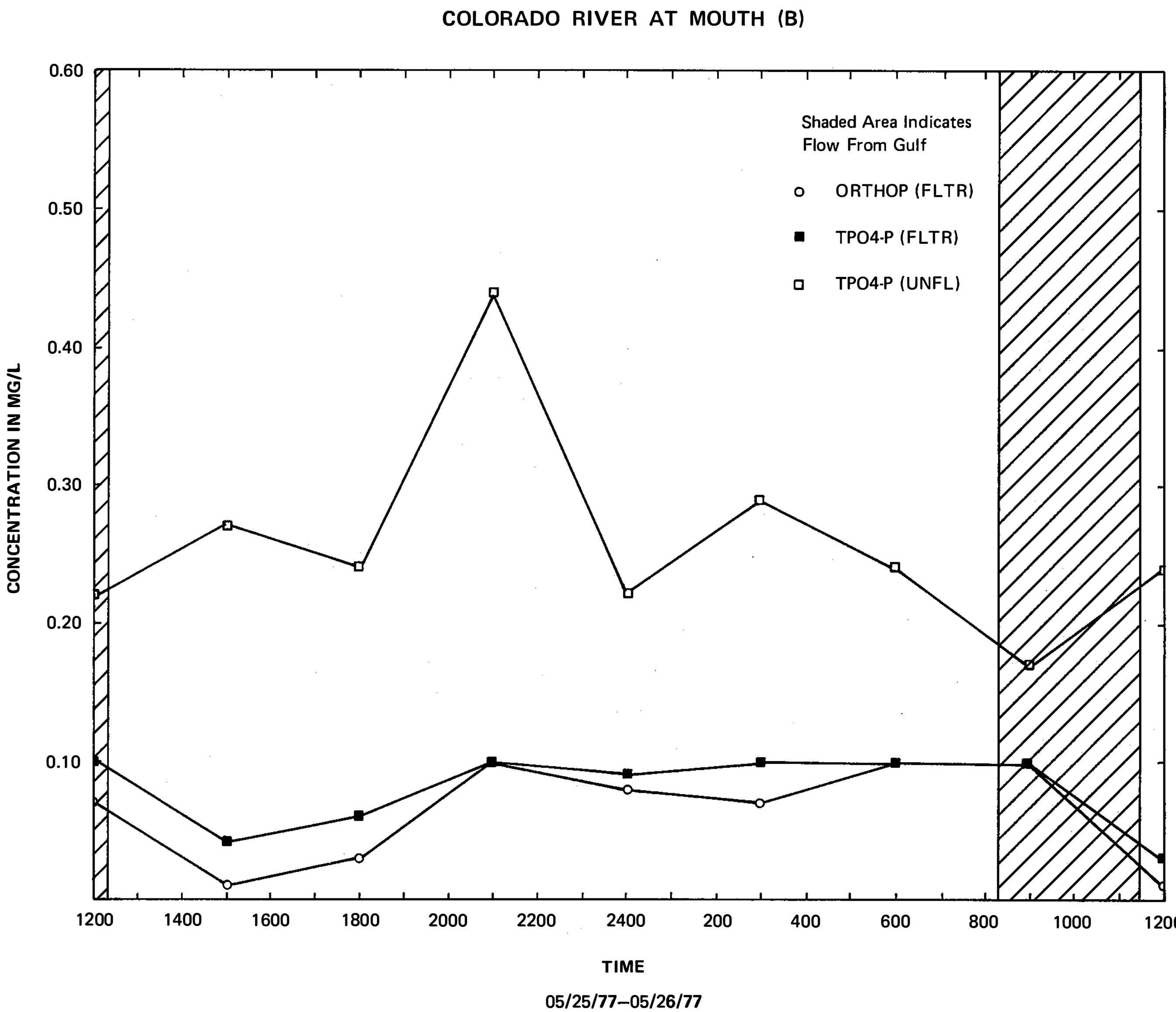


Figure IV.12.—Bottom Concentrations of Total and Orthophosphorus at Station D During the May 1977 Inflow/Exchange Study

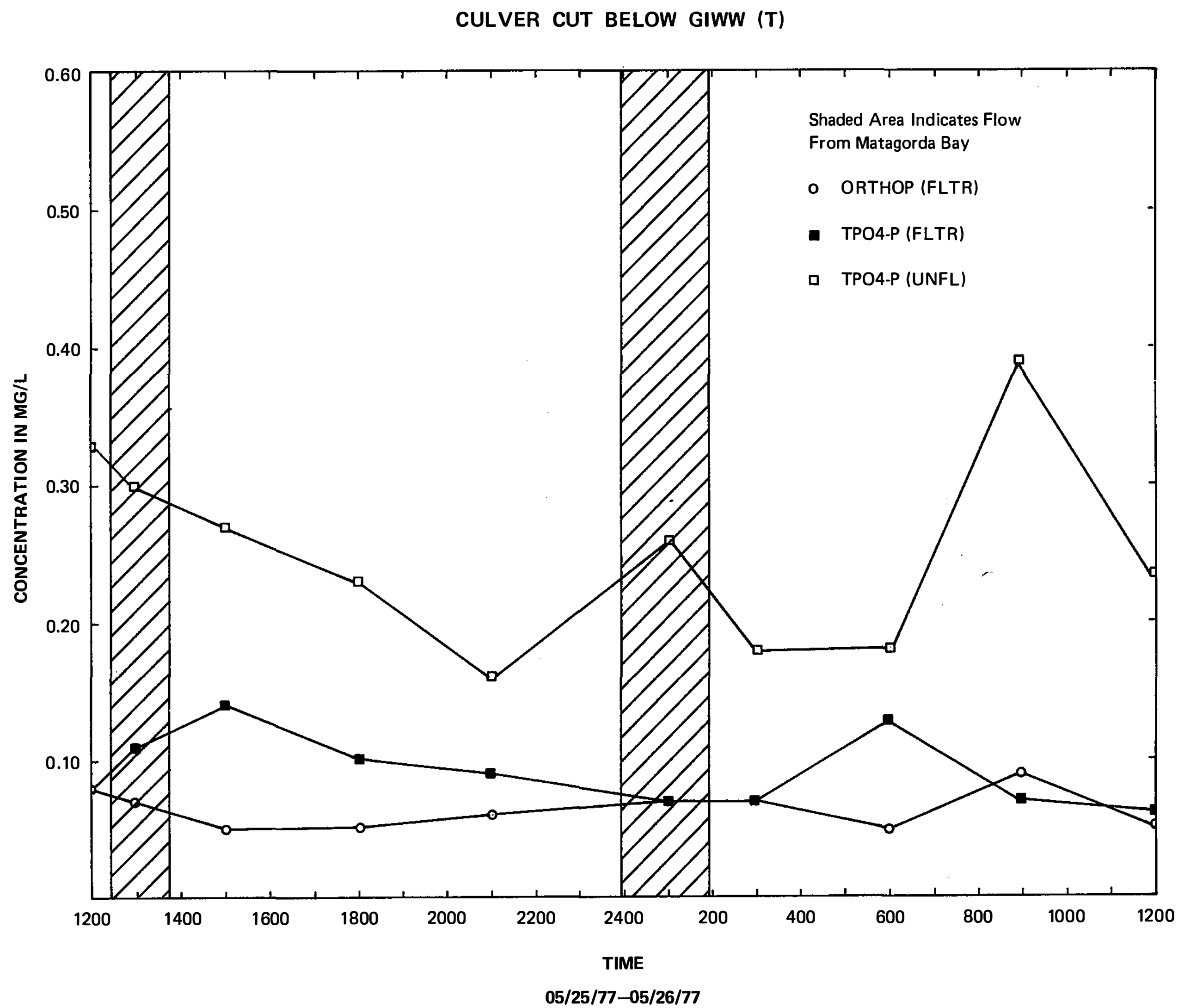


Figure IV.13.—Surface Concentrations of Total and Orthophosphorus at Station F During the May 1977 Inflow/Exchange Study

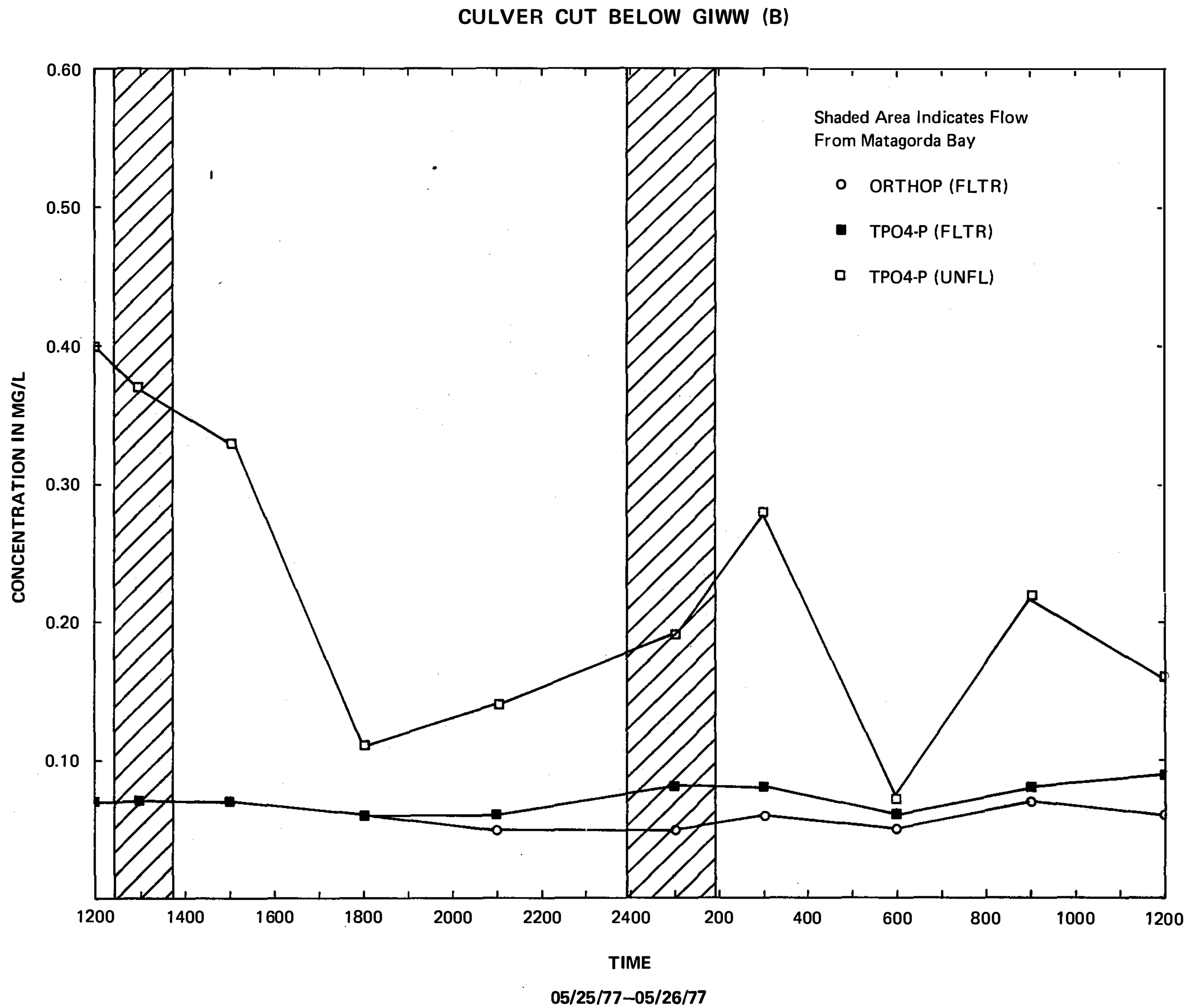


Figure IV.14.—Bottom Concentrations of Total and Orthophosphorus at Station F
During the May 1977 Inflow/Exchange Study

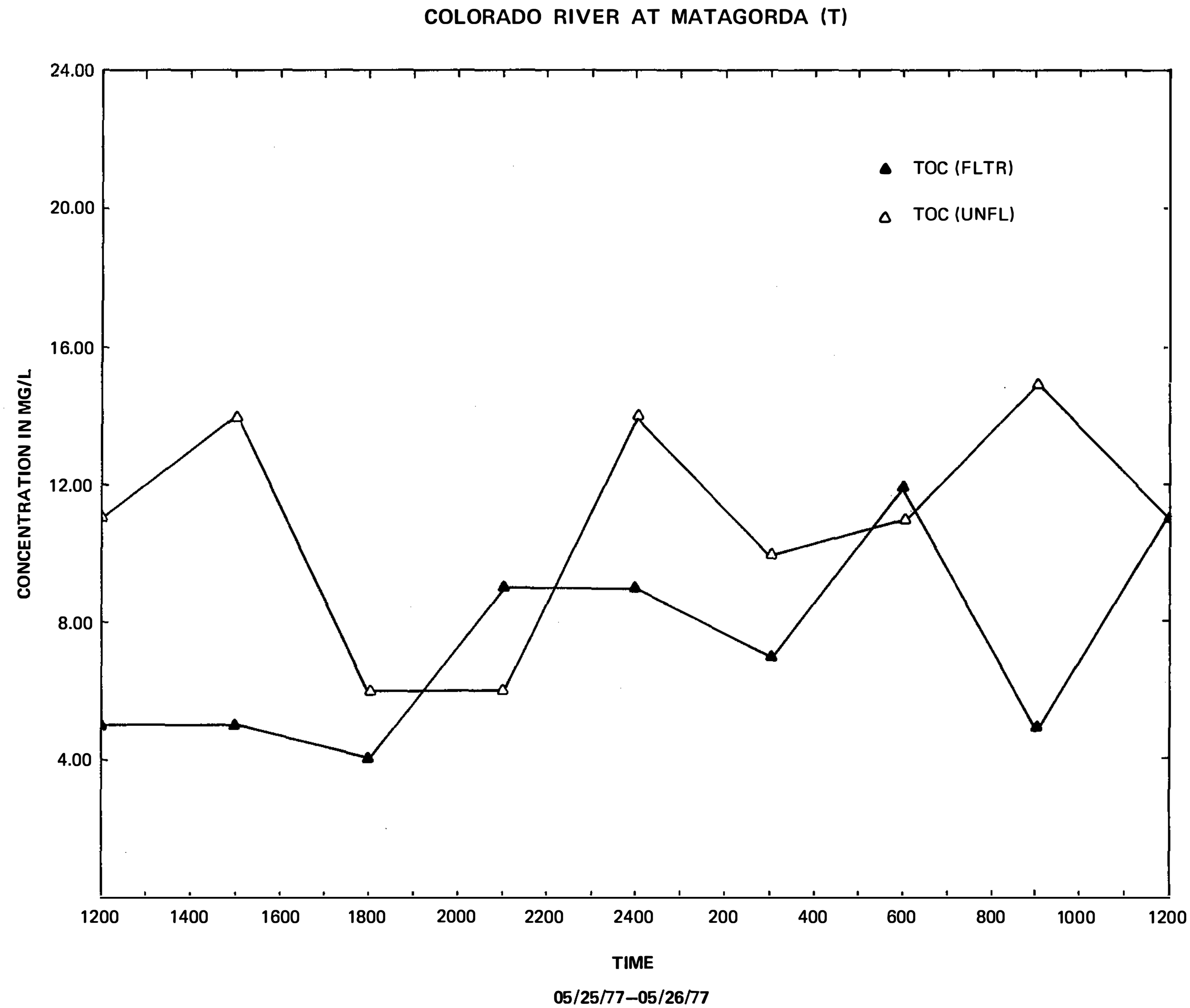


Figure IV.15.—Surface Concentrations of Total Organic Carbon at Station A During the May 1977 Inflow/Exchange Study

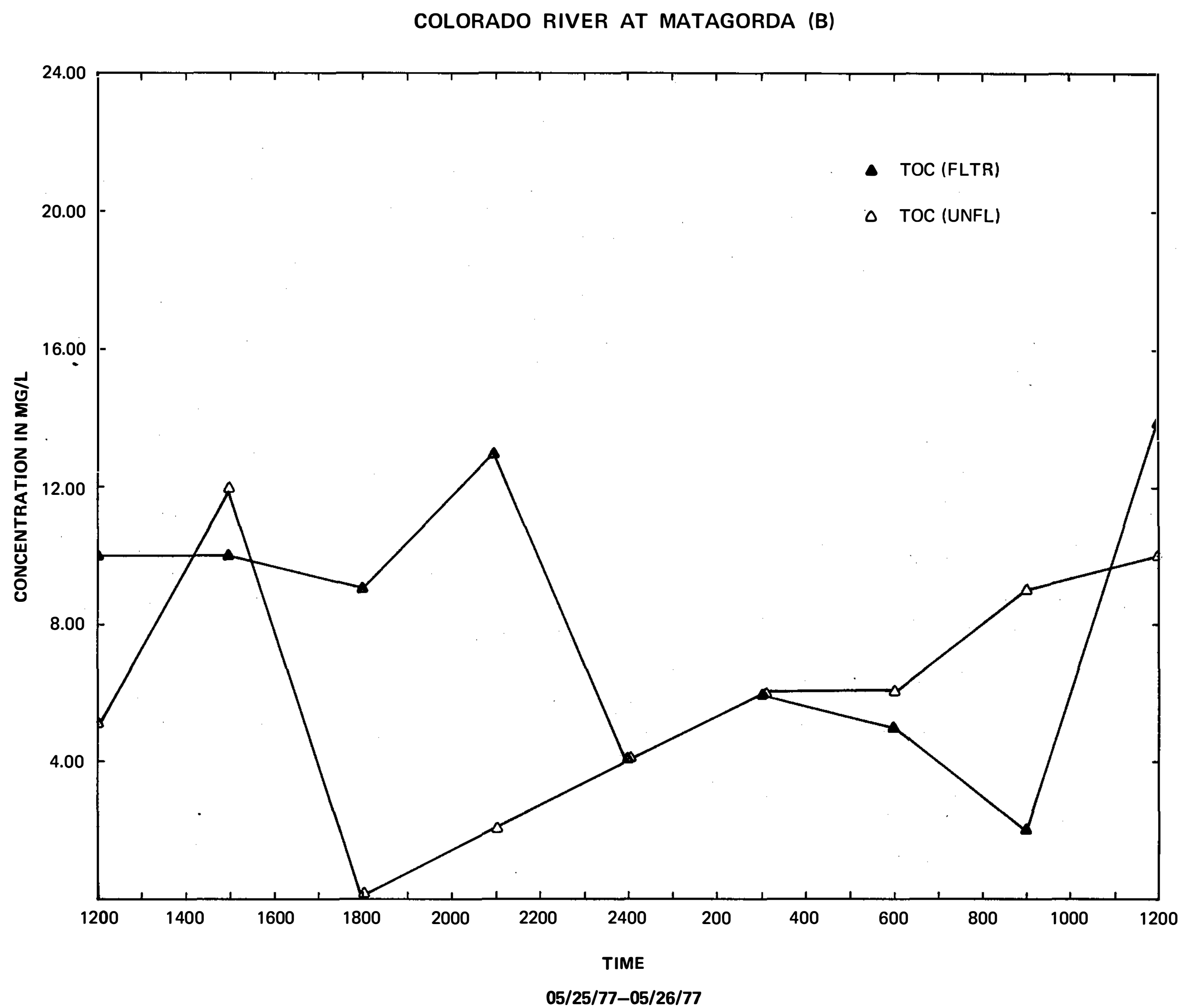


Figure IV.16.—Bottom Concentrations of Total Organic Carbon at Station A During the May 1977 Inflow/Exchange Study

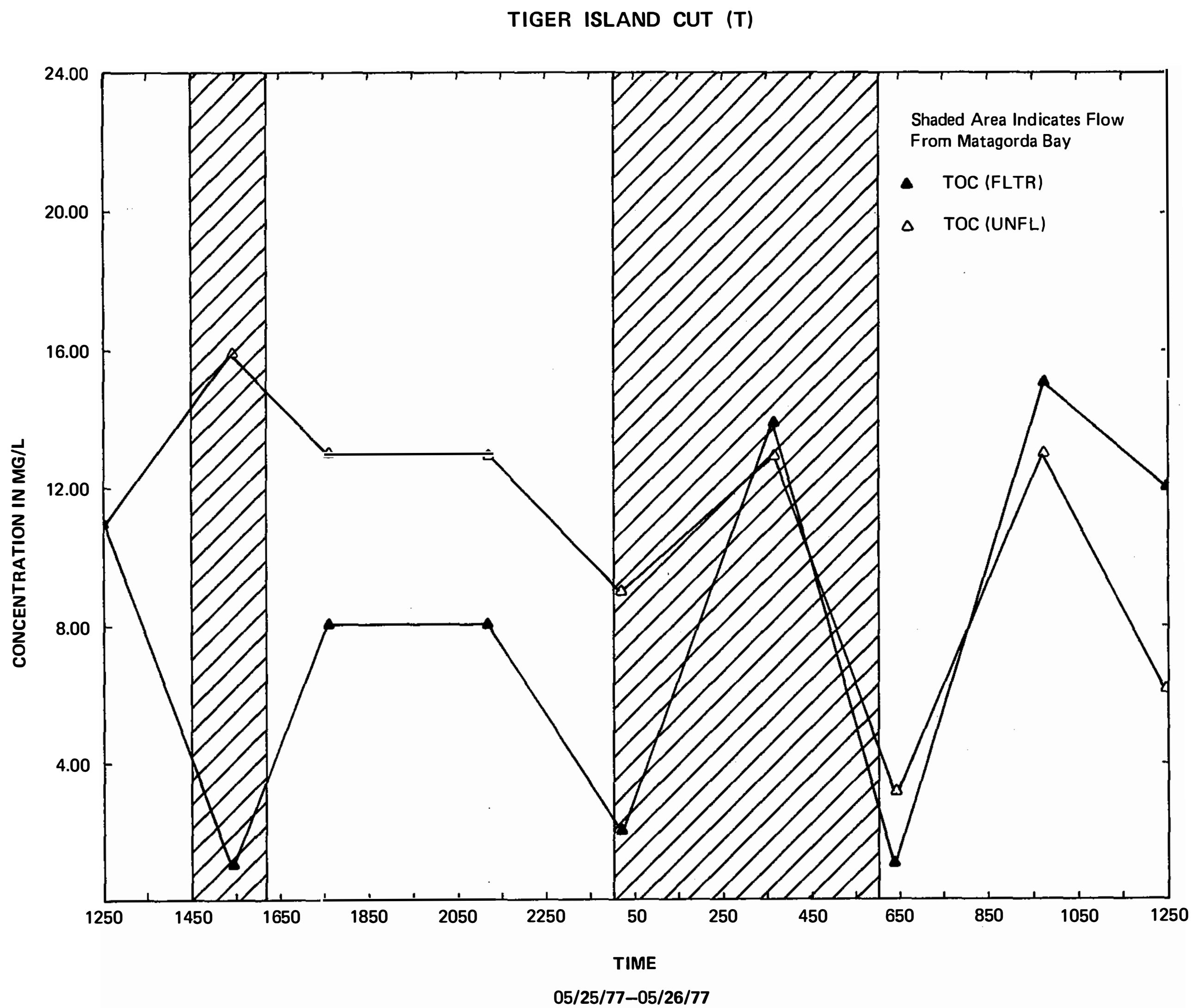


Figure IV.17.—Surface Concentrations of Total Organic Carbon at Station C During the May 1977 Inflow/Exchange Study

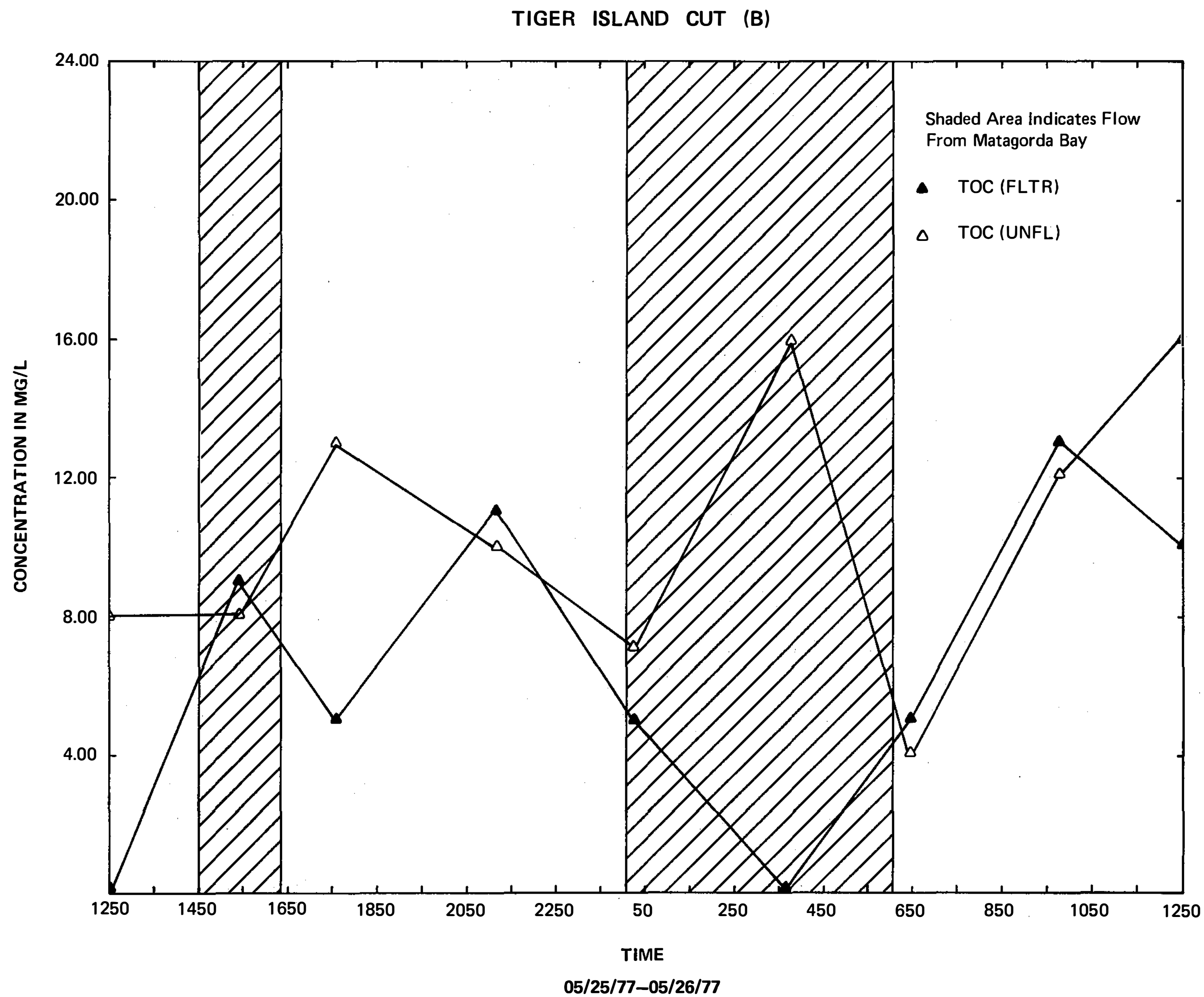


Figure IV.18.—Bottom Concentrations of Total Organic Carbon at Station C During the May 1977 Inflow/Exchange Study

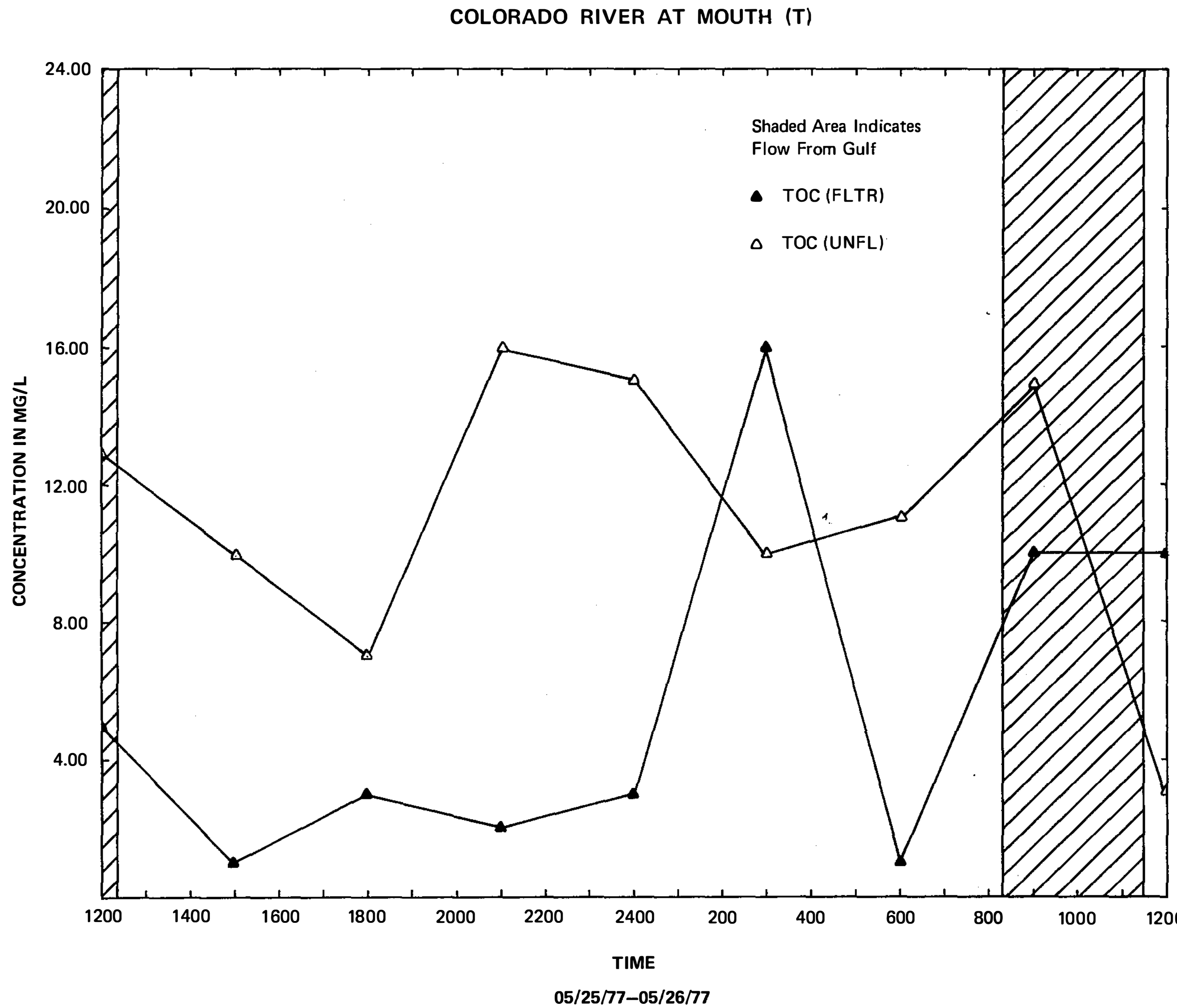


Figure IV.19.—Surface Concentrations of Total Organic Carbon at Station D During the May 1977 Inflow/Exchange Study

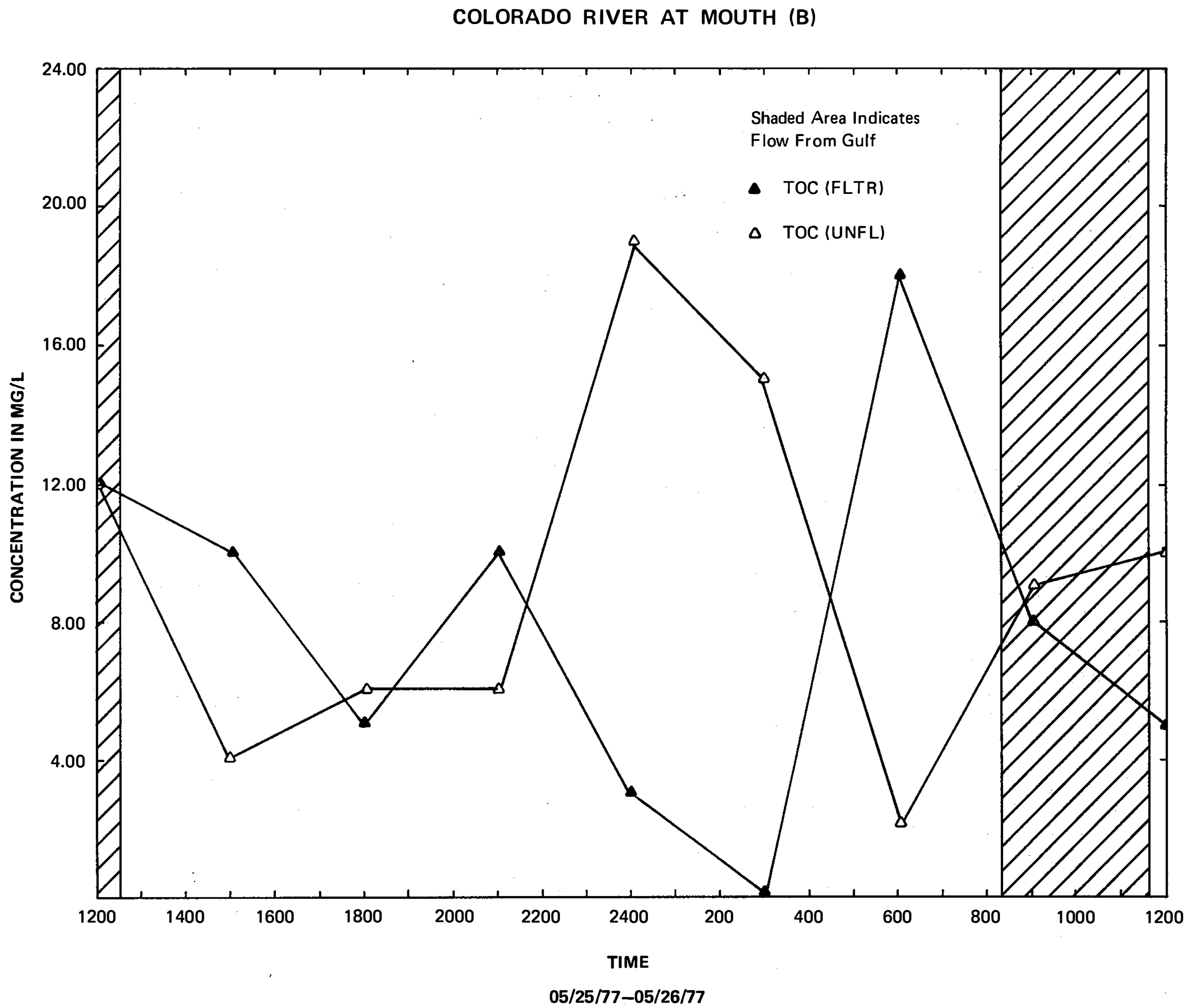


Figure IV.20.—Bottom Concentrations of Total Organic Carbon at Station D During the May 1977 Inflow/Exchange Study

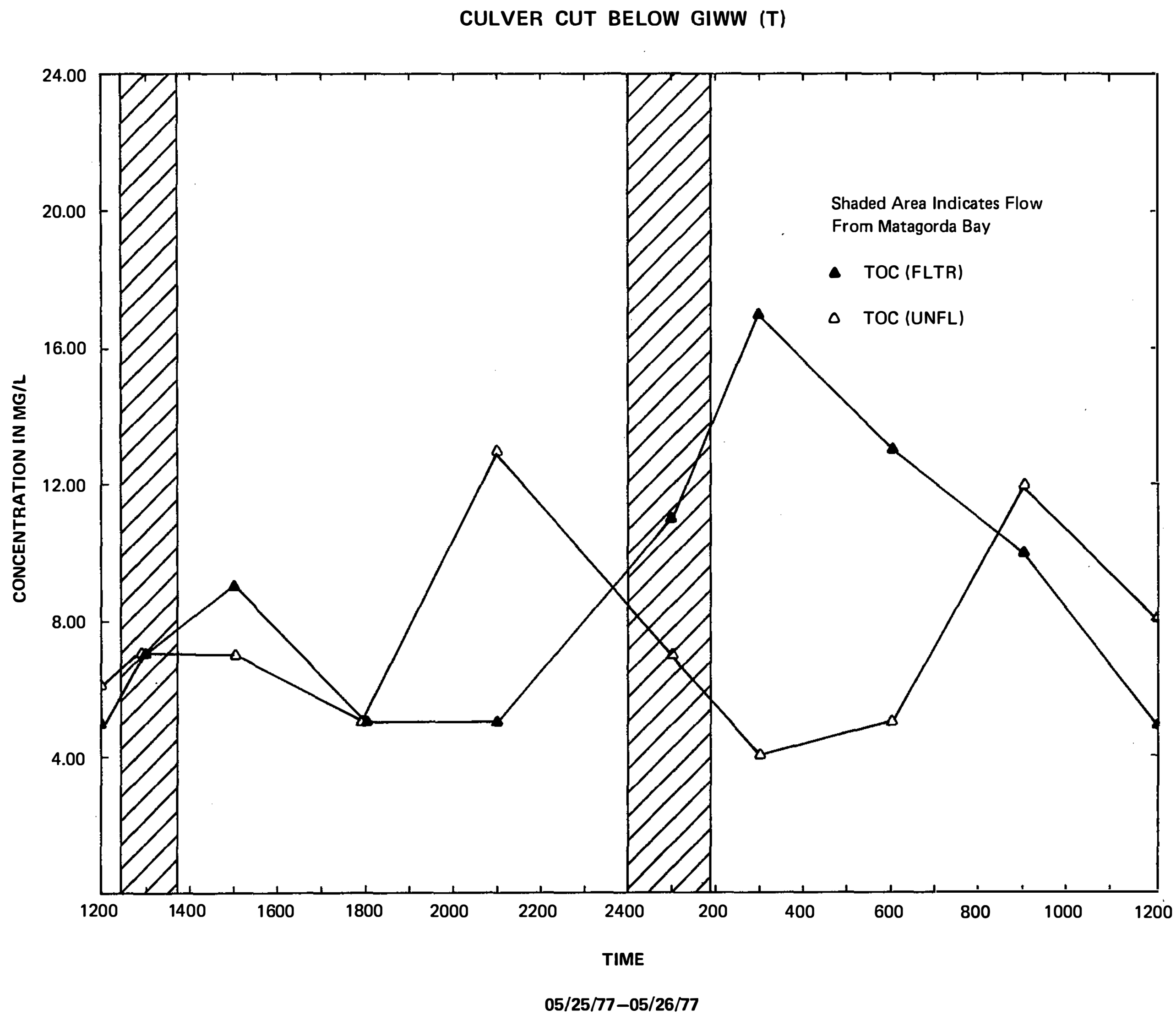


Figure IV.21.—Surface Concentrations of Total Organic Carbon at Station F During the May 1977 Inflow/Exchange Study

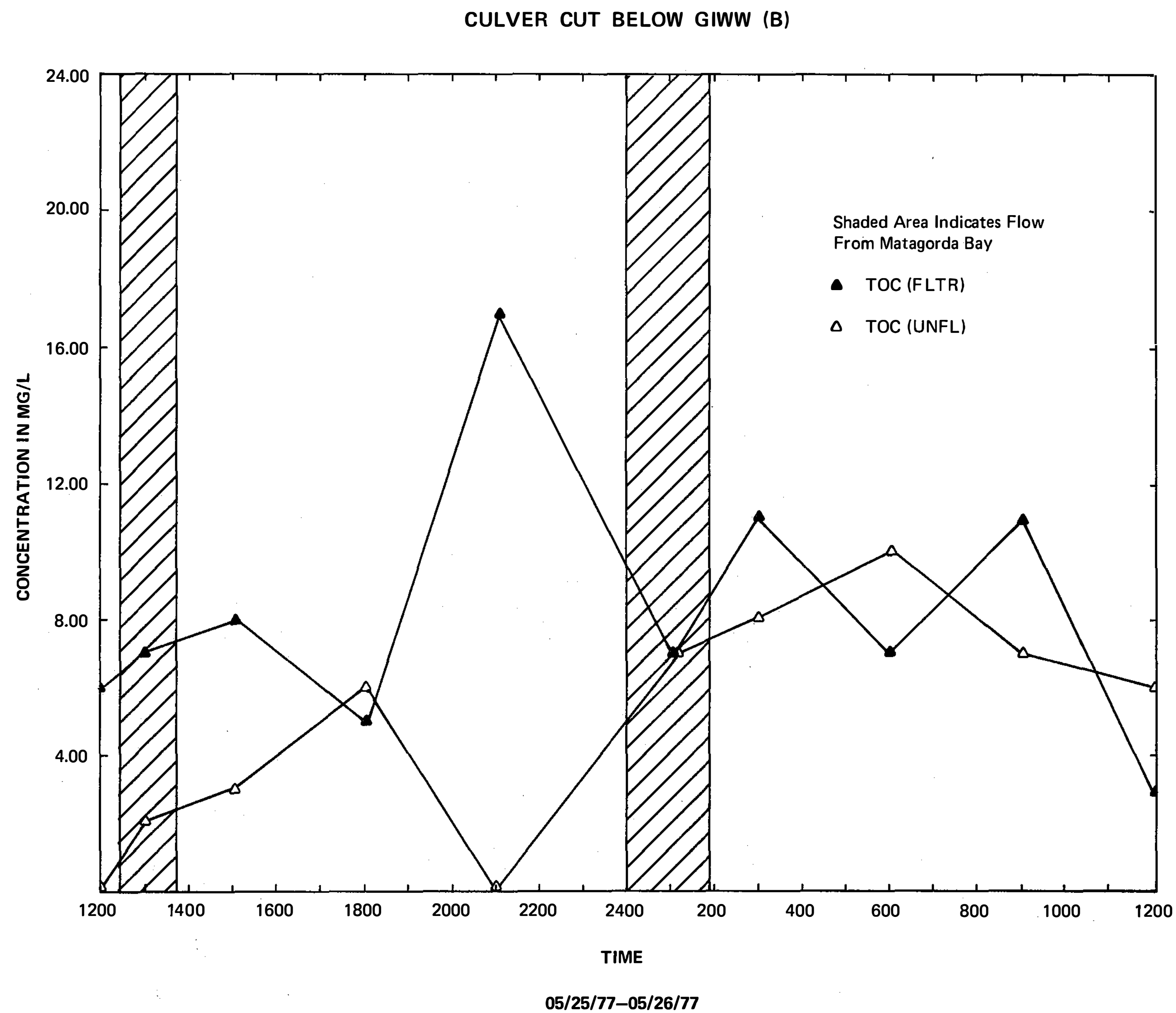


Figure IV.22.—Bottom Concentrations of Total Organic Carbon at Station F During the May 1977 Inflow/Exchange Study

Table IV.1

Transport of Carbon, Nitrogen, and Phosphorus
in the Colorado River at Matagorda
May 25-26, 1977
Kg/day

Parameter	Surface		
	Upstream (-)	Downstream (+)	Net
NH_4-N-U	0	182	182
TKN-N-F	0	2,772	2,772
TKN-N-U	0	3,259	3,259
NO_3-N-U	0	3,908	3,908
NO_2-N-U	0	182	182
Ortho-PO_4-U	0	736	736
Total-PO_4-F	0	1,623	1,623
Total PO_4-U	0	4,261	4,261
Total Carbon-F	0	503,715	503,715
Total Carbon-U	0	516,742	516,742
Total Inorganic Carbon-F	0	413,613	413,613
Total Inorganic Carbon-U	0	382,702	382,702
Total Organic Carbon-F	0	90,102	90,102
Total Organic Carbon-U	0	134,039	134,039

NH_4-N = Ammonia Nitrogen
TKN-N = Total Kjeldahl Nitrogen
NO_3-N = Nitrate Nitrogen
NO_2-N = Nitrite Nitrogen
Ortho-PO_4 = Orthophosphate Phosphorus
Total-PO_4 = Total Phosphate Phosphorus
F = Filtered
U = Unfiltered

Table IV.1 (cont'd)

Parameter	Bottom Upstream (-)	Downstream (+)	Net
NH_4-N-U	0	833	833
TKN-N-F	0	3,355	3,355
TKN-N-U	0	3,634	3,634
NO_3-N-U	0	1,997	1,997
NO_2-N-U	0	336	336
Ortho-PO_4-U	0	756	756
Total-PO_4-F	0	1,652	1,652
Total-PO_4-U	0	6,958	6,958
Total Carbon-F	0	451,434	451,434
Total Carbon-U	0	419,688	419,688
Total Inorganic Carbon-F	0	355,231	355,231
Total Inorganic Carbon-U	0	345,180	345,180
Total Organic Carbon-F	0	96,203	96,203
Total Organic Carbon-U	0	71,752	71,752

NH_4-N = Ammonia Nitrogen
TKN-N = Total Kjeldahl Nitrogen
NO_3-N = Nitrate Nitrogen
NO_2-N = Nitrite Nitrogen
Ortho-PO_4 = Orthophosphate Phosphorus
Total-PO_4 = Total Phosphate Phosphorus
F = Filtered
U = Unfiltered

Table IV.2

Transport of Carbon, Nitrogen, and Phosphorus
in the Colorado River above Tiger Island Cut
May 25-26, 1977
Kg/day

Parameter	Upstream (-)	Surface Downstream (+)	Net
NH_4-N-U	0	234	234
TKN-N-F	0	2,841	2,841
TKN-N-U	0	3,192	3,192
NO_3-N-U	0	3,568	3,568
NO_2 N-U	0	142	142
Ortho-PO_4-U	0	964	964
Total PO_4-F	0	1,212	1,212
Total PO_4-U	0	2,204	2,204
Total Carbon-F	0	569,006	569,006
Total Carbon-U	0	631,507	631,507
Total Inorganic Carbon-F	0	460,913	460,913
Total Inorganic Carbon-U	0	469,936	469,936
Total Organic Carbon-F	0	108,093	108,093
Total Organic Carbon-U	0	161,570	161,570

NH_4-N = Ammonia Nitrogen
TKN-N = Total Kjeldahl Nitrogen
NO_3-N = Nitrate Nitrogen
NO_2-N = Nitrite Nitrogen
Ortho-PO_4 = Orthophosphate Phosphorus
Total-PO_4 = Total Phosphate Phosphorus
F = Filtered
U = Unfiltered

Table IV.2 (cont'd)

Bottom			
Parameter	Upstream (-)	Downstream (+)	Net
NH_4-N-U	0	655	655
TKN-N-F	0	3,115	3,115
TKN-N-U	0	3,634	3,634
NO_3-N-U	0	1,494	1,494
NO_2-N-U	0	222	222
Ortho-PO_4-U	0	1,138	1,138
Total-PO_4-F	0	1,574	1,574
Total-PO_4-U	0	4,168	4,168
Total Carbon-F	0	522,573	522,573
Total Carbon-U	0	607,425	607,425
Total Inorganic Carbon-F	0	424,337	424,337
Total Inorganic Carbon-U	0	440,161	440,161
Total Organic Carbon-F	0	93,282	93,282
Total Organic Carbon-U	0	167,263	167,263

NH_4-N = Ammonia Nitrogen
TKN-N = Total Kjeldahl Nitrogen
NO_3-N = Nitrate Nitrogen
NO_2-N = Nitrite Nitrogen
Ortho-PO_4 = Orthophosphate Phosphorus
Total-PO_4 = Total Phosphate Phosphorus
F = Filtered
U = Unfiltered

Table IV.3

Transport of Carbon, Nitrogen, and Phosphorus
in the Colorado River at the Mouth
May 25-26, 1977
Kg/day

	Surface		
Parameter	Upstream (-)	Downstream (+)	Net
NH_4-N-U	6	315	308
TKN-N-F	63	2,390	2,327
TKN-N-U	92	2,390	2,298
NO_3-N-U	58	1,954	1,895
NO_2-N-U	3	119	116
Ortho-PO_4-U	11	659	647
Total-PO_4-F	23	1,468	1,445
Total-PO_4-U	86	2,000	1,913
Total Carbon-F	12,202	449,231	437,028
Total Carbon-U	15,159	528,547	513,388
Total Inorganic Carbon-F	9,173	400,608	391,435
Total Inorganic Carbon-U	10,460	396,243	385,782
Total Organic Carbon-F	3,029	48,622	45,593
Total Organic Carbon-U	4,698	132,303	127,605

NH_4-N = Ammonia Nitrogen
TKN-N = Total Kjeldahl Nitrogen
NO_3-N = Nitrate Nitrogen
NO_2-N = Nitrite Nitrogen
Ortho-PO_4 = Orthophosphate Phosphorus
Total-PO_4 = Total Phosphate Phosphorus
F = Filtered
U = Unfiltered

Table IV.3 (cont'd)

	Bottom		
Parameter	Upstream (-)	Downstream (+)	Net
NH_4-N-U	6	497	490
TKN-N-F	126	3,214	3,093
TKN-N-U	129	3,350	3,220
NO_3-N-U	11	1,628	1,617
NO_2-N-U	3	119	116
Ortho-PO_4-U	30	687	656
Total-PO_4-F	31	914	882
Total-PO_4-U	55	3,367	3,312
Total Carbon-F	10,191	443,546	433,355
Total Carbon-U	11,057	460,327	449,269
Total Inorganic Carbon-F	7,543	353,244	345,701
Total Inorganic Carbon-U	8,120	343,422	335,301
Total Organic Carbon-F	2,648	90,302	87,653
Total Organic Carbon-U	2,936	96,927	93,990

NH_4-N = Ammonia Nitrogen
TKN-N = Total Kjeldahl Nitrogen
NO_3-N = Nitrate Nitrogen
NO_2-N = Nitrite Nitrogen
Ortho-PO_4 = Orthophosphate Phosphorus
Total-PO_4 = Total Phosphate Phosphorus
F = Filtered
U = Unfiltered

Table IV.4

Transport of Carbon, Nitrogen, and Phosphorus
in Tiger Island Cut
May 25-26, 1977
Kg/gm

Surface			
Parameter	Upstream (-)	Downstream (+)	Net
NH_4-N-U	104	12	+91
TKN-N-F	598	68	+530
TKN-N-U	621	68	+552
NO_3-N-U	590	48	+542
NO_2-N-U	29	3	+26
Ortho-PO_4-U	216	11	+205
Total-PO_4-F	256	15	+240
Total-PO_4-U	540	26	+514
Total Carbon-F	125,531	14,181	+111,350
Total Carbon-U	129,113	15,987	+113,126
Total Inorganic Carbon-F	99,184	10,737	+88,446
Total Inorganic Carbon-U	98,842	11,214	+87,628
Total Organic Carbon-F	26,347	3,443	+22,903
Total Organic Carbon-U	30,270	4,772	+25,498

NH_4-N = Ammonia Nitrogen
TKN-N = Total Kjeldahl Nitrogen
NO_3-N = Nitrate Nitrogen
NO_2-N = Nitrite Nitrogen
Ortho-PO_4 = Orthophosphate Phosphorus
Total-PO_4 = Total Phosphate Phosphorus
F = Filtered
U = Unfiltered

Table IV.4 (cont'd)

	Bottom		
Parameter	Upstream (-)	Downstream (+)	Net
NH_4-N-U	108	14	+93
TKN-N-F	675	68	+606
TKN-N-U	733	79	+654
NO_3-N-U	465	42	+423
NO_2-N-U	29	3	+26
Ortho-PO_4-U	137	10	+126
Total-PO_4-F	273	25	+248
Total-PO_4-U	524	99	+424
Total Carbon-F	112,724	11,841	+100,883
Total Carbon-U	117,531	14,942	+102,589
Total Inorganic Carbon-F	94,256	10,901	+83,355
Total Inorganic Carbon-U	97,534	10,290	+87,244
Total Organic Carbon-F	24,972	940	+24,032
Total Organic Carbon-U	30,485	4,652	+25,833

NH_4-N = Ammonia Nitrogen
TKN-N = Total Kjeldahl Nitrogen
NO_3-N = Nitrate Nitrogen
NO_2-N = Nitrite Nitrogen
Ortho-PO_4=Orthophosphate Phosphorus
Total-PO_4=Total Phosphate Phosphorus
F = Filtered
U = Unfiltered

Table IV.5

Transport of Carbon, Nitrogen, and Phosphorus
in Culver Cut above the GIWW
May 25-26, 1977
Kg/day

Surface			
Parameter	Upstream (-)	Downstream (+)	Net
NH_4-N-U	0	1	0
TKN-N-F	7	24	16
TKN-N-U	9	32	23
NO_3-N-U	5	1	-4
NO_2-N-U	0	0	0
Ortho-PO_4-U	1	2	1
Total-PO_4-F	2	10	7
Total-PO_4-U	7	21	14
Total Carbon-F	1,652	3,183	1,531
Total Carbon-U	1,671	3,239	1,568
Total Inorganic Carbon-F	1,396	2,729	1,332
Total Inorganic Carbon-U	1,383	2,602	1,219
Total Organic Carbon-F	260	454	193
Total Organic Carbon-U	289	637	347

NH_4-N = Ammonia Nitrogen
TKN-N = Total Kjeldahl Nitrogen
NO_3-N = Nitrate Nitrogen
NO_2-N = Nitrite Nitrogen
Ortho-PO_4 = Orthophosphate Phosphorus
Total-PO_4 = Total Phosphate Phosphorus
F = Filtered
U = Unfiltered

Table IV.5 (cont'd)

	Bottom		
Parameter	Upstream (-)	Downstream (+)	Net
NH_4-N-U	0	1	0
TKN-N-F	10	18	8
TKN-N-U	11	21	10
NO_3-N-U	3	7	4
NO_2-N-U	0	0	0
Ortho-PO_4-U	2	3	1
Total-PO_4-F	3	6	2
Total-PO_4-U	8	22	14
Total Carbon-F	1,740	3,375	1,635
Total Carbon-U	1,693	3,384	1,691
Total Inorganic Carbon-F	1,341	2,638	1,296
Total Inorganic Carbon-U	1,258	2,619	1,360
Total Organic Carbon-F	398	736	338
Total Organic Carbon-U	429	765	336

NH_4-N = Ammonia Nitrogen
TKN-N = Total Kjeldahl Nitrogen
NO_3-N = Nitrate Nitrogen
NO_2-N = Nitrite Nitrogen
Ortho-PO_4 = Orthophosphate Phosphorus
Total-PO_4 = Total Phosphate Phosphorus
F = Filtered
U = Unfiltered

Table IV.6

Transport of Carbon, Nitrogen, and Phosphorus
in Culver Cut below the GIWW
May 25-26, 1977
Kg/day

Surface			
Parameter	Upstream (-)	Downstream (+)	Net
NH_4-N-U	3	40	36
TKN-N-F	13	190	176
TKN-N-U	13	281	267
NO_3-N-U	12	153	140
NO_2-N-U	0	9	8
Ortho-PO_4-U	4	57	53
Total-PO_4-F	5	91	85
Total-PO_4-U	17	215	197
Total Carbon-F	2,911	41,016	38,104
Total Carbon-U	2,602	39,759	37,157
Total Inorganic Carbon-F	2,308	32,195	29,887
Total Inorganic Carbon-U	2,156	32,203	30,046
Total Organic Carbon-F	603	8,767	8,164
Total Organic Carbon-U	446	7,556	7,110

NH_4-N = Ammonia Nitrogen
TKN-N = Total Kjeldahl Nitrogen
NO_3-N = Nitrate Nitrogen
NO_2-N = Nitrite Nitrogen
Ortho-PO_4 = Orthophosphate Phosphorus
Total-PO_4 = Total Phosphate Phosphorus
F = Filtered
U = Unfiltered

Table IV.6 (cont'd)

Parameter	Upstream (-)	Downstream (+)	Net
		Bottom	
NH_4-N-U	3	44	41
TKN-N-F	12	189	177
TKN-N-U	12	265	252
NO_3-N-U	8	124	116
NO_2-N-U	0	15	14
Ortho-PO_4-U	3	55	51
Total-PO_4-F	4	64	59
Total-PO_4-U	16	160	143
Total Carbon-F	2,784	41,301	38,516
Total Carbon-U	2,524	38,520	35,996
Total Inorganic Carbon-F	2,338	32,022	29,684
Total Inorganic Carbon-U	2,225	33,123	30,898
Total Organic Carbon-F	446	9,278	8,832
Total Organic Carbon-U	323	5,396	5,073

NH_4-N = Ammonia Nitrogen
TKN-N = Total Kjeldahl Nitrogen
NO_3-N = Nitrate Nitrogen
NO_2-N = Nitrite Nitrogen
Ortho-PO_4 = Orthophosphate Phosphorus
Total-PO_4 = Total Phosphate Phosphorus
F = Filtered
U = Unfiltered

Table IV.7

Net Transport of Carbon, Nitrogen, and Phosphorus in the Colorado River Delta[a/]
May 25-26, 1977
Kg/day

Parameter	Colorado River at Matagorda	Colorado River at Tiger Island Cut	Colorado River at Mouth	Tiger Island Cut	Culver Cut above GIWW	Culver Cut Below GIWW
NH_4-N-U[b/]	507	444	399	92	1	39
TKN-N-F[c/]	3,063	2,978	2,710	568	12	176
TKN-N-U	3,446	3,154	2,759	603	16	259
NO_3-N-U	2,953	2,531	1,756	483	4	128
NO_2-N-U	259	182	116	26	1	11
Ortho-PO_4-U	746	1,051	652	166	1	52
Total-PO_4-F	1,624	1,393	1,164	244	5	72
Total-PO_4-U	5,610	3,186	2,612	469	14	170
Total Carbon-F	477,574	545,790	435,191	96,234	1,583	38,310
Total Carbon-U	468,215	619,466	481,328	109,483	1,629	36,576
Total Inorganic Carbon-F	384,422	442,625	368,568	85,901	1,314	29,785
Total Inorganic Carbon-U	363,941	455,049	360,541	87,436	1,289	30,472
Total Organic Carbon-F	93,152	100,688	66,623	23,468	266	8,498
Total Organic Carbon-U	102,895	164,417	110,797	25,666	341	6,091

a/ Average of top and bottom samples.

b/ U = Unfiltered samples.

c/ F = Filtered samples.

Table IV.8

Nutrient Transport Summary, Colorado River Delta
May 25-26, 1977

Station (Cross-Section)	N[a/] (%)	P[a/] (%)	TOC[a/] (%)	Net Discharge[b/] (%)
Export to Gulf of Mexico (D)	4,633 (75)	2,620 (80)	110,798 (78)	11,319,288 (76)
Export to Matagorda Bay (C)	113 (18)	469 (15)	25,666 (18)	2,651,331 (18)
(F)	400 (7)	171 (5)	6,097 (4)	885,819 (6)
Total Net Export	6,145 (100)	3,253 (100)	142,556 (100)	14,856,438 (100)
Total Net Import (A)	6,660	5,610	102,896	12,395,732
Source/Sink (+) (-)	-514	-2,357	+39,660	+2,460,706

a/ Measured in Kilograms

b/ Measured in Cubic Meters

of all nutrient species to the delta and the delta appeared to be a source of organic carbon and a nitrogen and phosphorus sink.

The July study was conducted in a manner similar to that of the May study, except that based on the May data the contribution from Culver Cut above the GIWW was determined to be negligible, therefore Station E was dropped from the July study.

Flow reversal at Matagorda above the GIWW occurred twice over the 24-hour study period. The average net contribution downstream was 650 cfs. As noted during the May study, the Colorado River at Matagorda exists in a state of permanent vertical salinity stratification (Figure IV.23). At Tiger Island Cut and the mouth of the river stratification was again a function of tide direction. During flood tides vertical stratification breaks down as the influx of the saline Gulf and bay waters dominate the system and the water column becomes uniformly saline. On ebb tides the water column again becomes vertically stratified (Figures IV.24 and IV.25).

Total organic carbon and phosphorus concentrations were extremely low at each location when compared to the concentrations measured during the May study. With few exceptions TOC values were less than 6 ppm while total phosphorus concentrations were at times below detection thresholds for the laboratory analysis procedure. Ammonia concentrations on the other hand are high, particularly in the more saline waters. This is particularly evident at Station A in the river above the GIWW (Figure IV.26, Figure IV.27). At Stations C and D where only mid-depth samples were collected, the ammonia concentrations rise abruptly as the tidal regime forces the more saline waters of the Gulf or Matagorda Bay through the channels (Figures IV.28 and IV.29).

During the July study the river was a net contributor of both nitrogen and organic carbon to the Gulf of Mexico and Matagorda Bay. On the other hand, the river channel may be acting as a phosphorus sink (Tables IV.9 and IV.10). The low phosphorus concentrations cloud the accuracy and preclude a definite conclusion of this last issue.

A total of 1,717 kilograms (3,800 lbs) of nitrogen was exported over the 24-hour study. From calculations based on field observations, roughly half entered the Gulf of Mexico and half entered Matagorda Bay. About 83 percent of the 13,200 kilograms (29,000 lbs) of total organic carbon and 63 percent of the 198 kg (436 lbs) of the total phosphorus exported from the river was contributed to the Gulf, while the remainder was routed into Matagorda Bay. The net export of all nutrients into Matagorda Bay occurred through Tiger Island Cut as net contributions of carbon, nitrogen or phosphorus occurred through Culver Cut during the July study.

The authors must caution the reader, however, that nutrient loadings and distribution are predicated on when a hydrologic period or event occurs as well as the magnitude of flow. Nutrient loadings derived from runoff of later storms in a series of storm events will contribute significantly less to the delta than would be observed as the result an initial storm after a period of very little runoff. In addition, the distribution within the delta will change as the flow distribution patterns change with flow increases (see Chapter III).

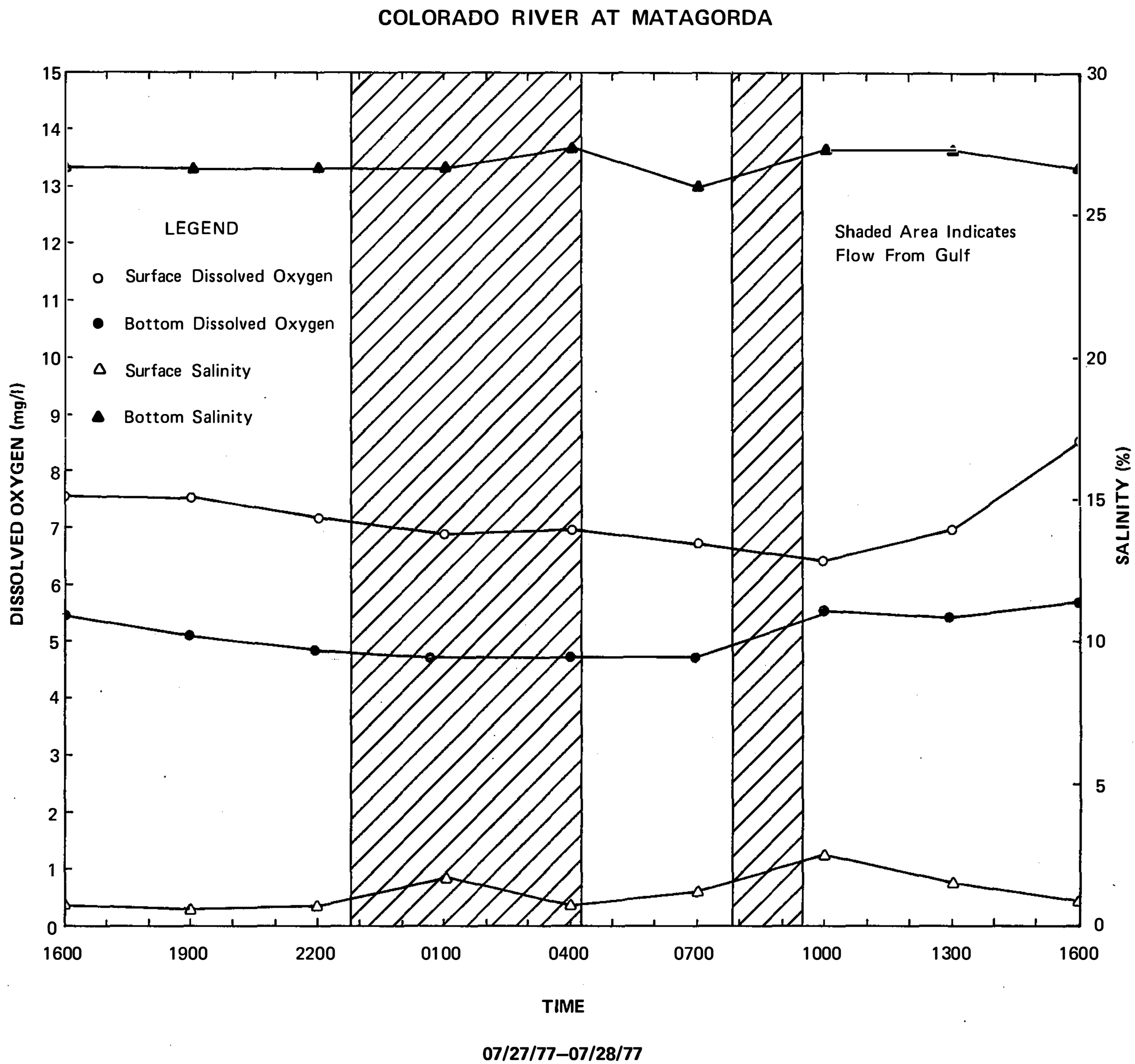


Figure IV.23.—Surface and Bottom Dissolved Oxygen and Salinity at Station A During the July 1977 Inflow/Exchange Study

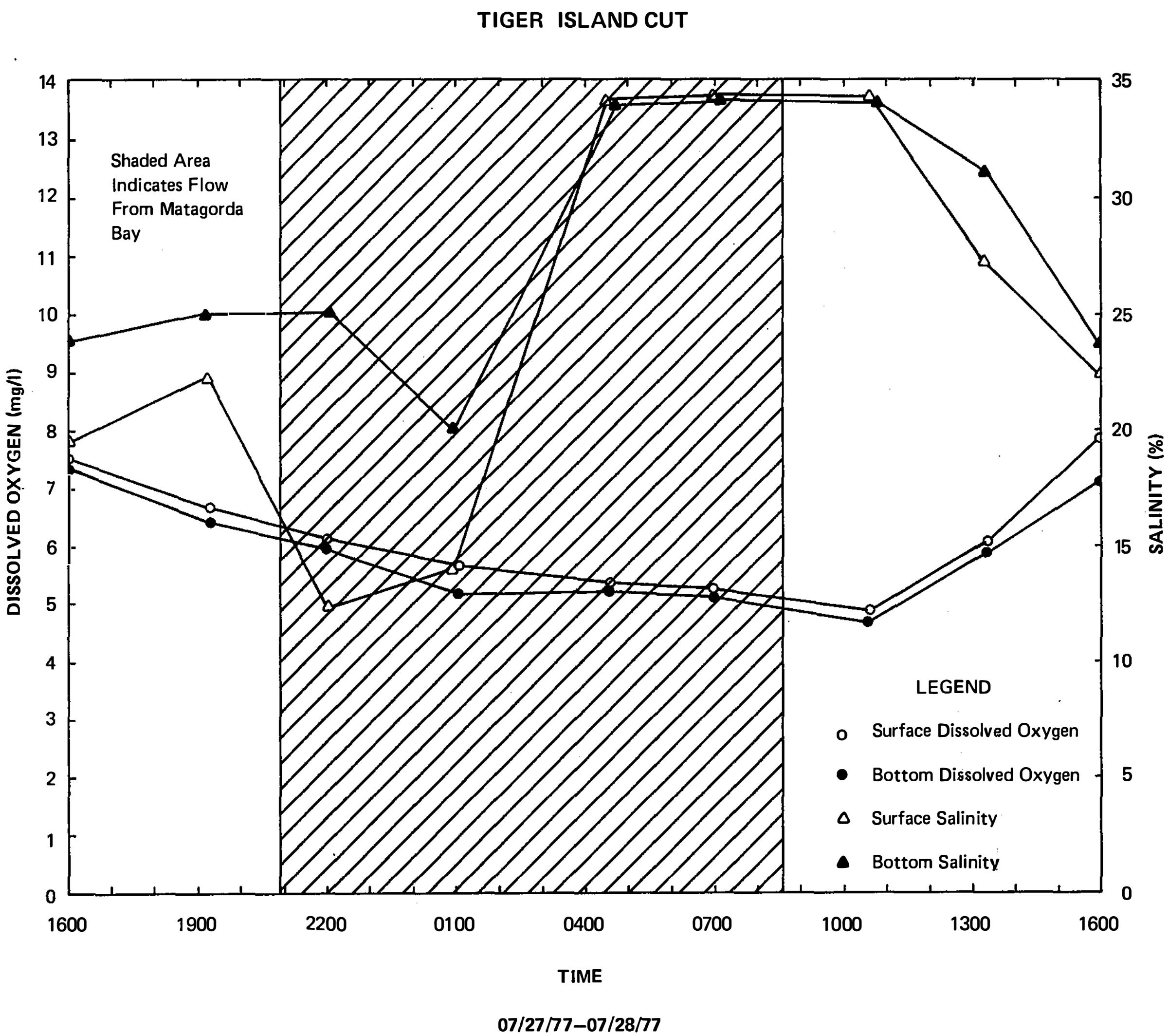


Figure IV.24.–Surface and Bottom Dissolved Oxygen and Salinity at Station C During the July 1977 Inflow/Exchange Study

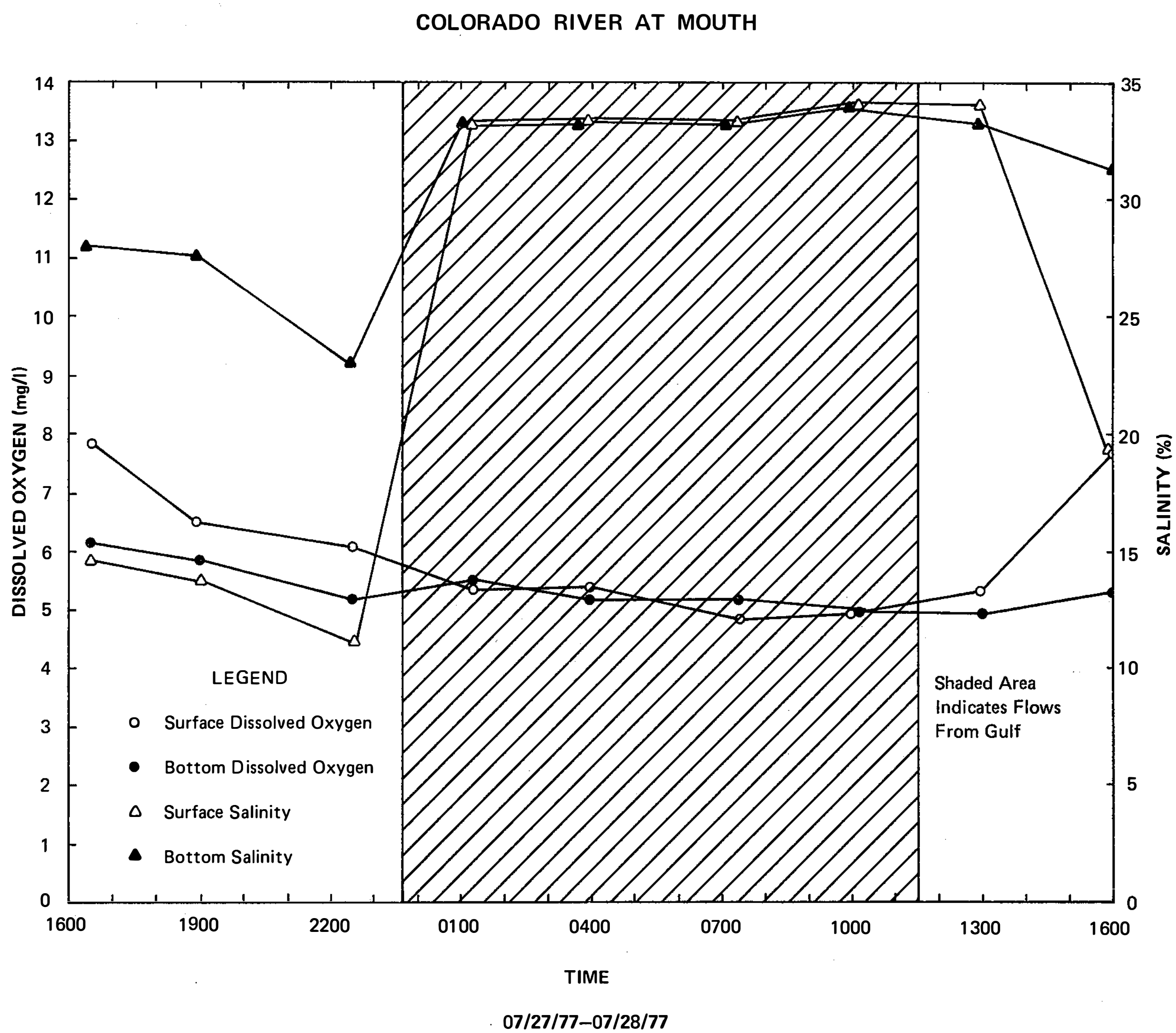


Figure IV.25.—Surface and Bottom Dissolved Oxygen and Salinity at Station D During the July 1977 Inflow/Exchange Study

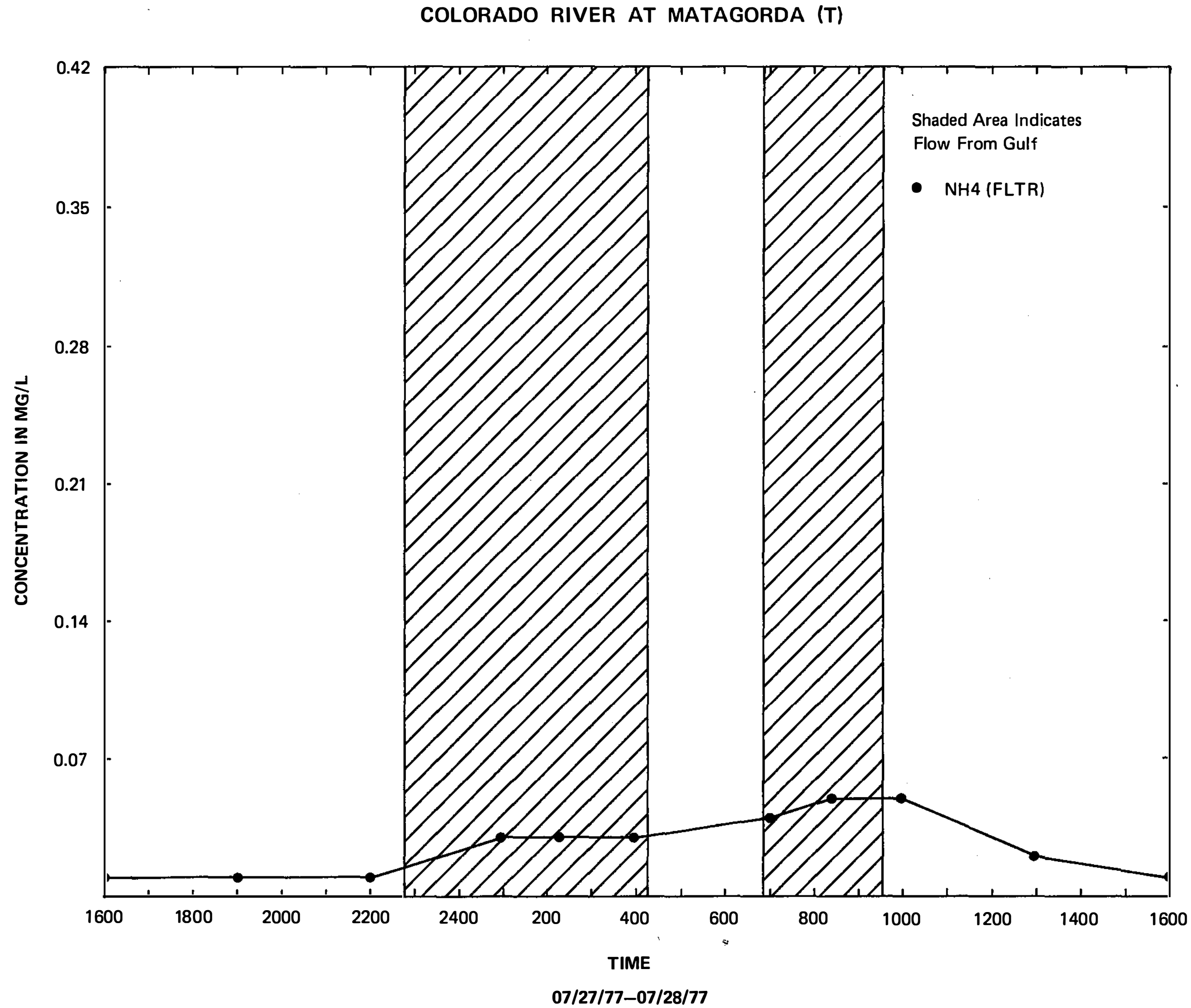


Figure IV.26.—Surface Concentrations of Ammonia at Station A
During the July 1977 Inflow/Exchange Study

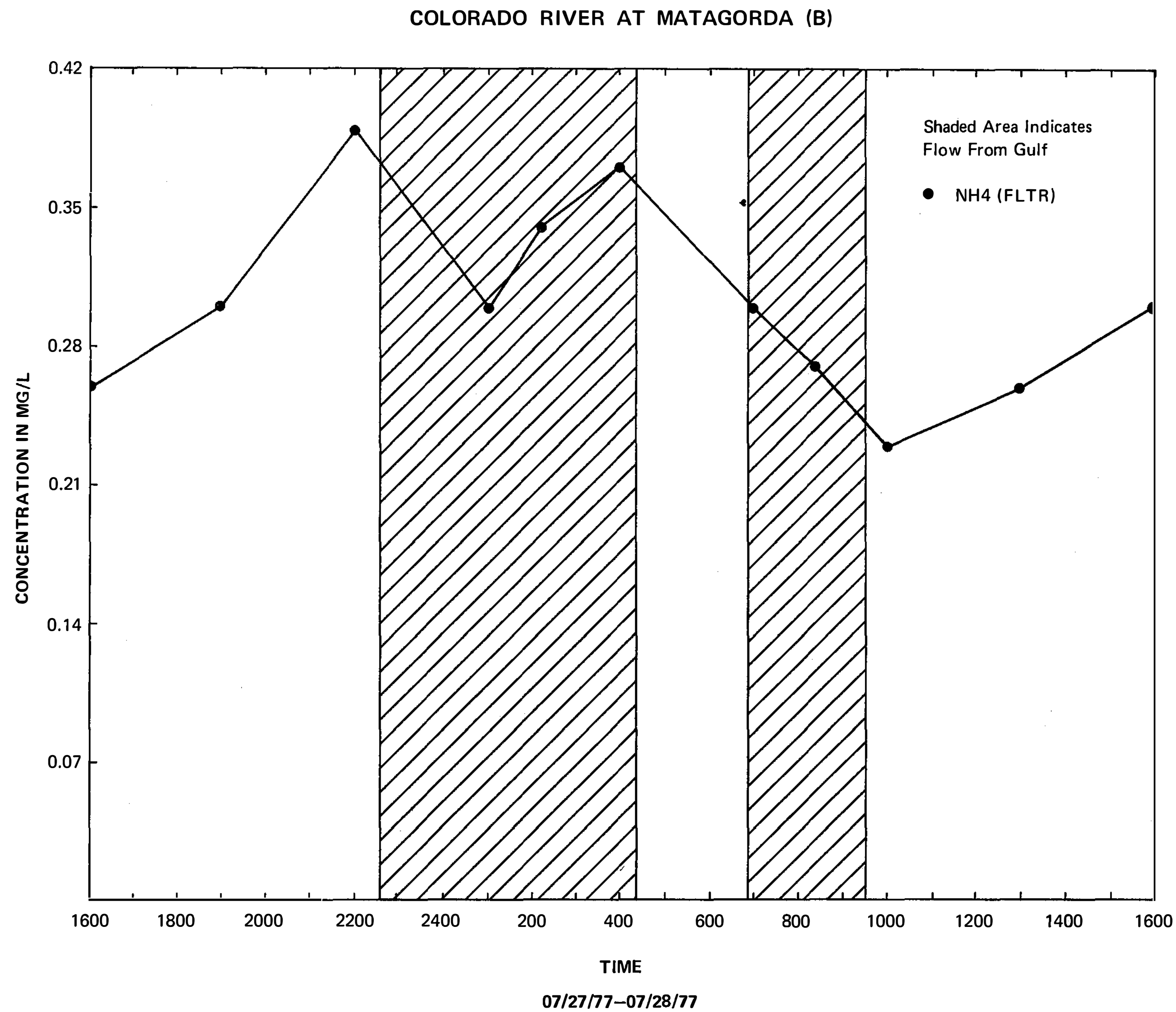


Figure IV.27.—Bottom Concentrations of Ammonia at Station A During the July 1977 Inflow/Exchange Study

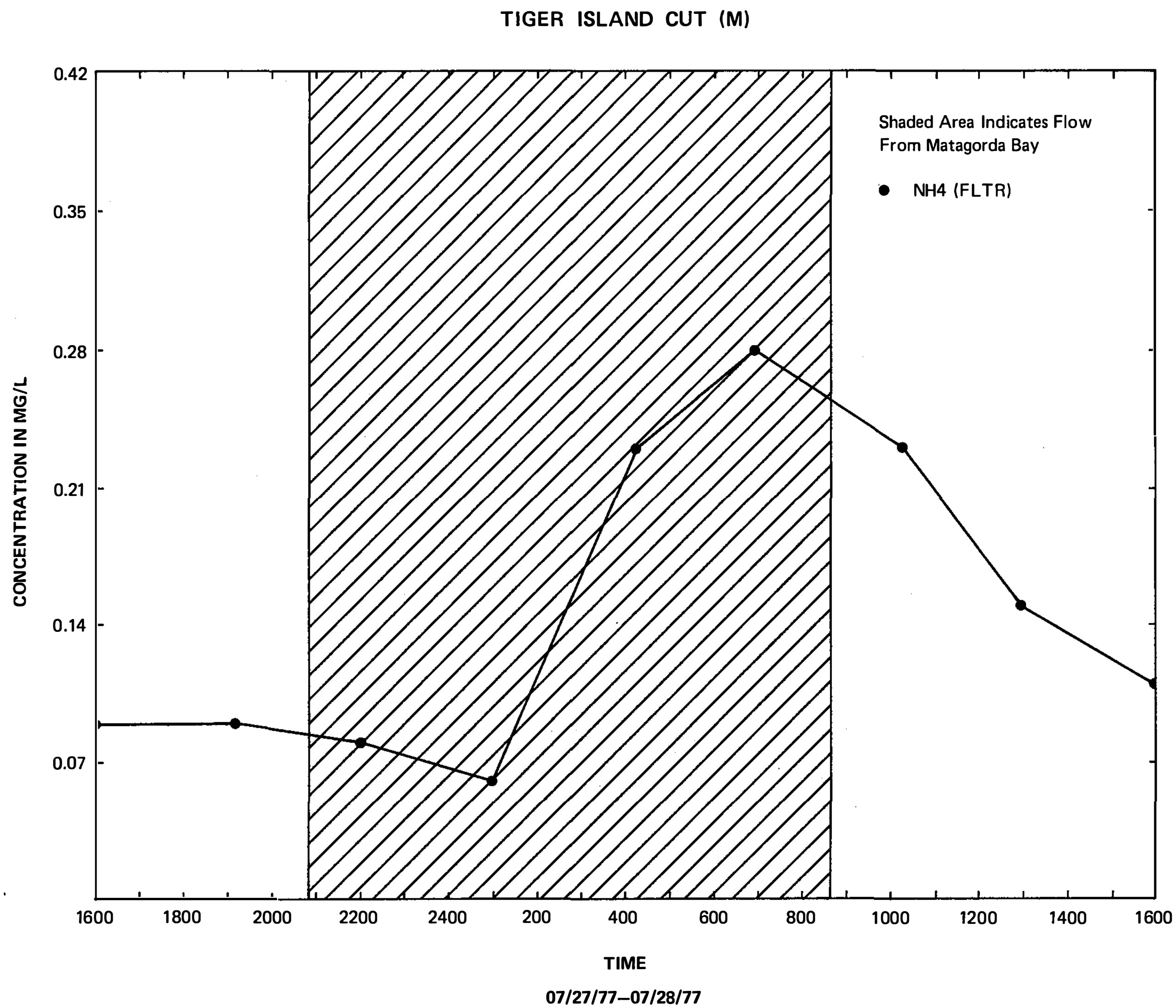


Figure IV.28.–Mid-Depth Concentrations of Ammonia at Station C
During the July 1977 Inflow/Exchange Study

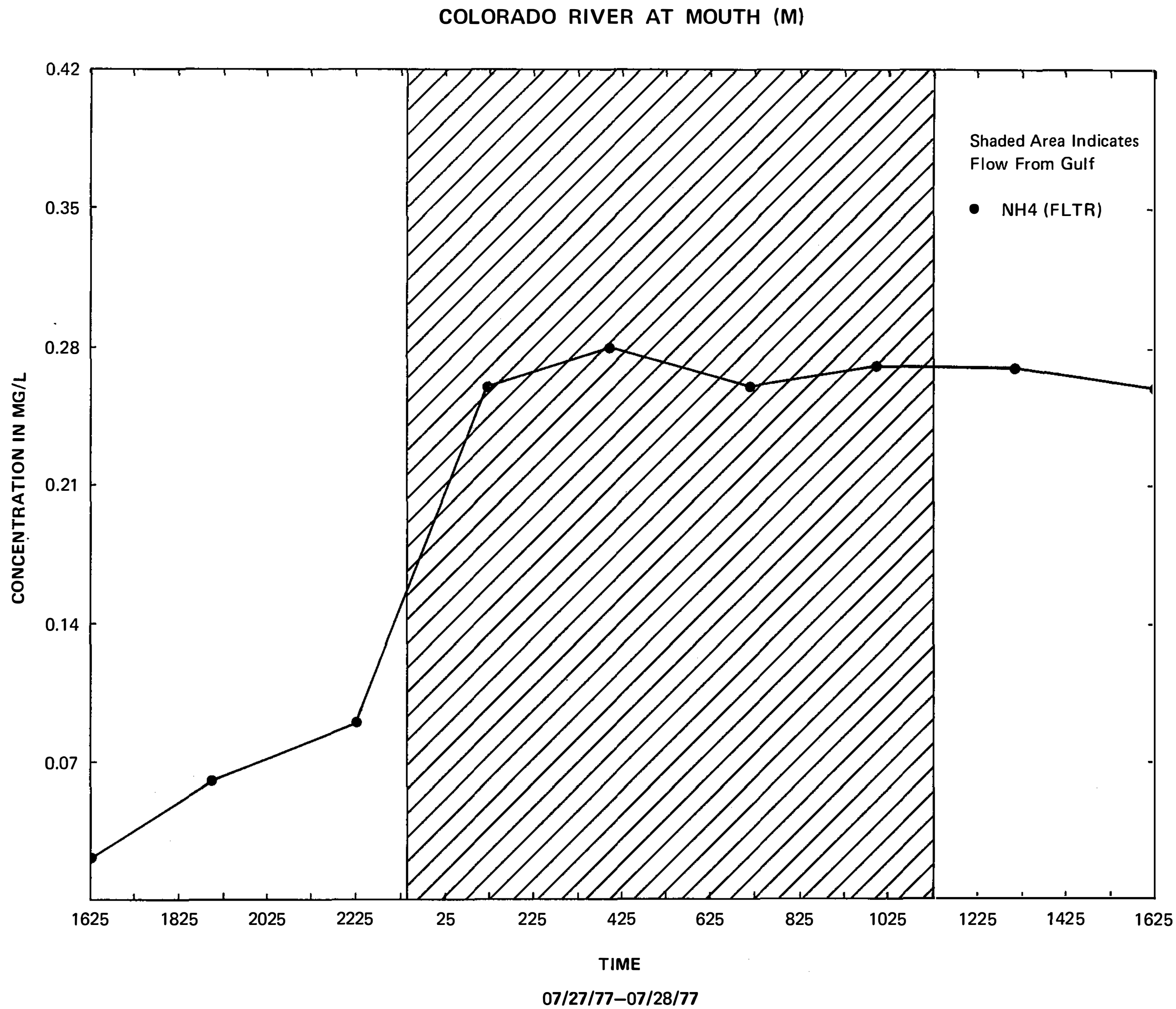


Figure IV.29.—Mid-Depth Concentrations of Ammonia at Station D During the July 1977 Inflow/Exchange Study

Table IV.9

Net Transport of Carbon, Nitrogen, and Phosphorus, Colorado River Delta, in Kilograms Per Day, July 27-28, 1977.[a/]
Kg/day

Parameter	Colorado River at Matagorda	Colorado River above Tiger Island Cut	Colorado River at Mouth	Tiger Island Cut	Culver Cut Below GIWW
NH_4-N-U[b/]	243	-146	-713	167	-19
TKN-N-F[c/]	436	158	66	151	-42
TKN-N-U	427	61	250	332	-43
NO_3-N-U	68	21	69	44	-1
NO_2-N-U	23	6	12	7	-1
Ortho PO_4-U	26	-6	12	7	-3
Total-PO_4-F	113	27	123	23	-5
Total-PO_4-U	228	116	123	73	-1
Total Carbon-F	54,735	28,940	67,719	22,141	-963
Total Carbon-U	61,716	37,241	51,885	21,232	-1,029
Total Inorganic Carbon-F	48,926	21,039	51,173	21,408	-1,039
Total Inorganic Carbon-U	53,985	33,008	40,876	23,447	-601
Total Organic Carbon-F	5,821	7,901	16,546	733	75
Total Organic Carbon-U	7,719	4,232	11,009	2,214	-427

a/ Average of top and bottom samples

b/ U = Unfiltered samples

c/ F = Filtered samples

Table IV.10

Nutrient Transport Summary
Colorado River Delta
July 27-28, 1977

Station (Cross-Section)	N[a/] (%)	P[a/] (%)	TOC[a/] (%)	Net Discharge[b/] (%)
Export to Gulf of Mexico (D)	332 (46)	124 (63)	11,009 (83)	1,239,865 (62)
Export to Matagorda (C)	385 (54)	74 (37)	2,215 (17)	747,497 (38)
Total Net Export	717 (100)	198 (100)	13,224 (100)	1,987,362 (100)
Import from Colorado River (A)	519 (92)	228 (99)	7,719 (95)	1,657,037 (98)
Import through Culver Cut (F)	46 (8)	2 (1)	428 (5)	28,319 (2)
Total Net Import	565 (100)	230 (100)	8,147 (100)	1,685,356 (100)
Source/Sink (+) (-)	+152	-32	+5,077	+302,006

a/ Measured in Kilograms

b/ Measured in Cubic Meters

CHAPTER V

NUTRIENT EXCHANGE STUDIES

Once the amount of inundation, as predicted by the hydrodynamic model, and the areal extent of the habitat are known, the final data needed to determine the potential magnitude of annual nutrient contribution from the deltaic marsh to the estuarine system, is information on the exchange rates among the sediments and biota of the marsh and grassflat system and the water flowing through them.

Feasibility studies and development of methodology to determine nutrient exchange rates in typical deltaic marsh habitats were first reported in Armstrong et al. (1975). This report focused on studies funded by the TDWR which were performed in the Swan Lake area of the Lavaca River Delta, Texas. The field study demonstrated that the net export of carbon, nitrogen, and phosphorus was a function of flooding and tide stage conditions.

Subsequent studies by Dawson and Armstrong (1975) and Armstrong and Brown (1977) focused on the roles of plants and sediments, respectively, in nutrient exchange processes. The former study demonstrated the important role that attached algae play in nutrient uptake and the drastic effects the alternate drying/reinundation processes typical of the Texas coastal marshes have on nutrient exchange rates. The latter study indicated that there was a tendency for CPN concentrations to approach an equilibrium when gradients exist between the sediment and the overlying water column. Salinity did have an effect on exchange rates for ammonia and phosphorus but temperature had little effect except in those systems where increased biological activity influenced uptake and release rates.

Further studies by Armstrong and Gordon (1977a), Armstrong and Gordon (1977b), and Armstrong, Harris, and Gordon (1977) have focused on determining seasonal carbon: phosphorus: nitrogen (CPN) exchange rates of predominant vegetational habitats in each of the major deltaic marshes along the Texas coast.

In the investigation of the Colorado River deltaic marshes, (Armstrong and Gordon, 1977b), exchange rates of particulate and soluble organic carbon, organic and inorganic nitrogen, and phosphorus through the Colorado River delta marshes were determined by: (1) securing portions of the marshes in plexiglass cylinders; (2) establishing these marsh portions in laboratory conditions under controlled light, flow and influent nutrient concentrations simulating natural, seasonal conditions and conditions likely to be encountered under a modified regime such as reduced flow and/or high nutrient concentration; and (3) conducting exchange studies measuring the flow rates, nutrient concentrations in the reactor and linear marsh influent and effluents, and biological parameters for two-week periods during three seasons.

Four reactor samples were obtained in the Colorado River Delta on December 20, 1977, at the sampling sites shown in Figure V.1. The first reactor sample was obtained from Tiger Island Cut and a second was obtained in Culver Cut. A

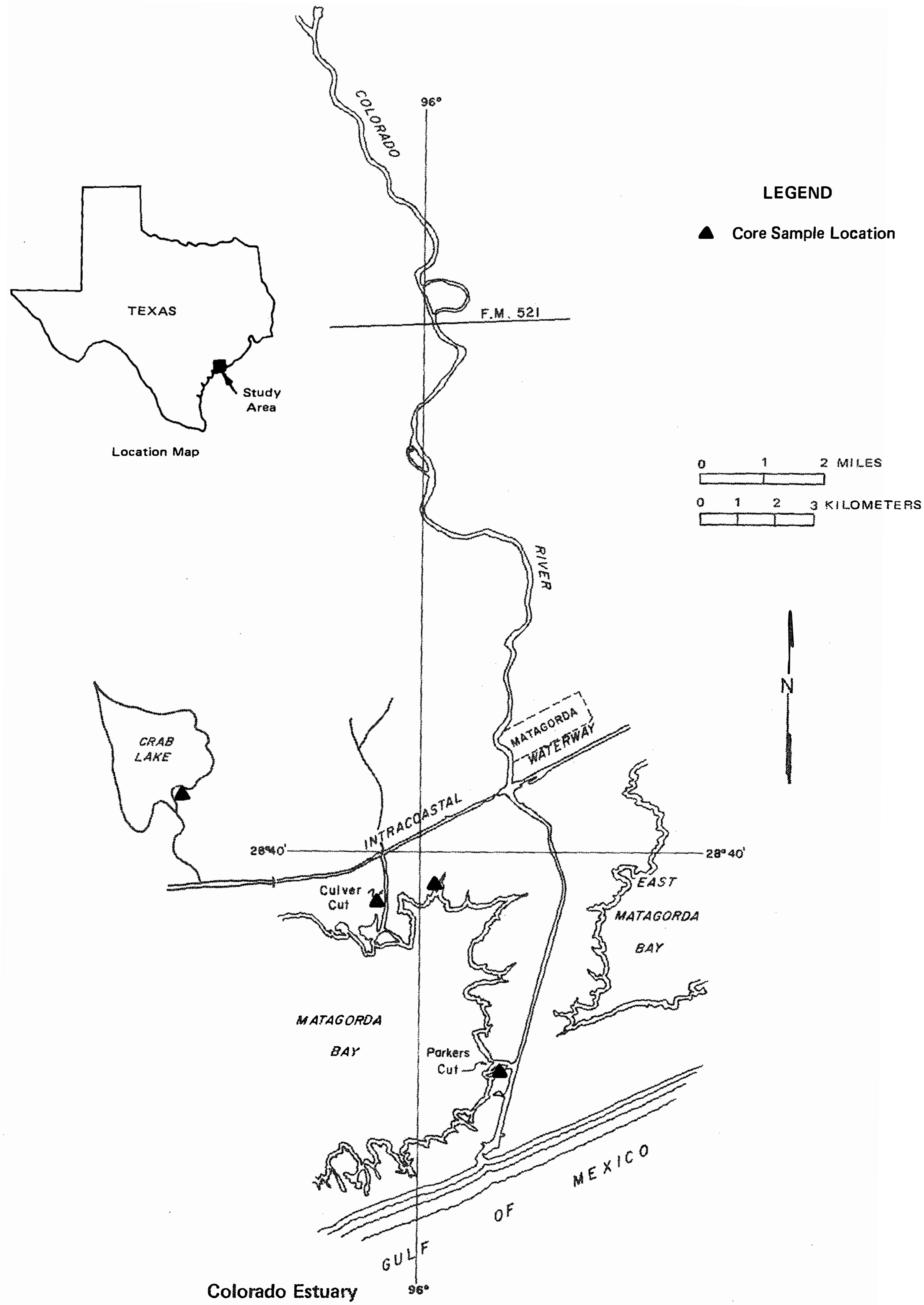


Figure V.1.—Plexiglass Core Reactor Sites in the Colorado River Delta

third reactor was obtained in the northeastern portion of Matagorda Bay between Tiger Island and Culver Cut in an area which would represent a portion of the marsh inundated by tidal water alone as compared to the previous two which would be impacted by tidal exchange as well as freshwater flows. The fourth reactor was obtained in Crab Lake, which is north of the Intracoastal Canal west of Culver Cut, and inundated by tidal exchange and freshwater draining from the low-lying area northwest of this lake. Overflow from the Colorado River also reaches this area during flood periods.

The marsh reactors obtained from the delta area included two macrophyte species. The reactors from Culver Cut, Tiger Island Cut, and Matagorda Bay all included pure stands of Spartina alterniflora L. While the reactor from Crab Lake included Spartina as well as Sporobolus virginicus (L) Kunth, Sporobolus was the dominant macrophyte in the Crab Lake reactor, however.

Three seasonal periods were simulated in the marsh reactor using the temperatures and water quality conditions found in the Colorado River during the seasons. The nutrient exchange rates were then determined by the difference in mass flows into and out of the marsh reactors during these experimental periods and based on the surface area of the sediments and reactor wall, respectively, as described in Armstrong and Gordon (1977a). The nutrient exchange rates by plant types are given in Table V.1 and V.2. To obtain the data given in Table V.1, the exchange rates for the Culver Cut, Tiger Island Cut, and Matagorda Bay reactors, which contained pure stands of Spartina alterniflora, were averaged for each season, and then a final average was calculated. The one reactor from Crab Lake contained a dominant stand of Sporobolus virginicus and the nutrient exchange rates determined in that reactor are given in Table V.2 for Sporobolus virginicus.

The results for Spartina alterniflora show very high rates of export of particulate material. In particular, a rather high rate of 14.1 kg/ha/day of total suspended solids (TSS) was observed as well as a rate of 1.2 kg/ha/day for volotile suspended solids (VSS). From the ratio of biochemical oxygen demand (BOD) to volotile suspended solids (VSS), it is apparent that much of the export of volotile suspended solids (VSS) was non-biodegradeable. The results show substantial export of particulate nitrogen in the organic form, but an import of particulate total phosphorus. The inorganic forms of nitrogen and phosphorus are taken up in the reactor apparently by the algae growing on the sediment, walls of the reactors, and plant surfaces. There appears to be a seasonal trend for some of the chemical parameters. For example, the TSS, VSS, and BOD results all show increasing export rates proceeding from the winter to the summer. This was apparently due to the increased growth of attached algae in the reactors. Other parameters have variable rates during the seasonal periods with no consistent trends evident.

The results for Sporobolus virginicus shown in Table V.2 differed from Spartina alterniflora in several respects. First, while there is a substantial export of TSS, there is an import of VSS and BOD in contrast to the Spartina reactors. BOD, however, is tending more toward export, but its rate is not that different from the Spartina reactor. Second, the export of particulate nitrogen is consistent with the Spartina reactor; the import of particulate phosphorus is not. These differences cannot be significant considering the magnitude of the rates and their variability, but the difference in the VSS rate does appear to be significant. The exchange rates for inorganic forms of nitrogen and phosphorus are consistent with the Spartina reactors and very

Table V.1. Nutrient Exchange Data, *Spartina alterniflora* in Matagorda-Lavaca Bay.[a/]

Analysis[b/]	Winter	Season Spring	Summer	Avg.
Salinity	115	-1401	363	-308.0
TSS	-5.101[e/]	-18.017	-19.311	-14.143
VSS	.381	-1.182	-2.789	-1.197
BOD (5)	.156	-.100	-.154	-0.033
TOC	.077	-2.332	-.308	-0.854
Inorg Crbn	-5.380	-1.558	-3.030	-3.323
UF TKN[c/]	-.038	-.041	-.004	-0.028
F TKN[d/]	-.025	-.013	0	-0.013
F NH_3	.002	.023	.032	0.019
F NO_2	0	-.003	.004	0.000
N NO_3	.196	.279	.151	0.209
UF Tot P	-.011	.033	-.063	-0.014
F Tot P	.007	.062	-.031	0.013
F Ortho P	.003	.082	.015	0.033
Part T P	.189	.233	.038	0.153
Part TKN	-.016	-.009	-.004	-0.010
Org N	-.025	-.013	0	-0.013

a/ Units are kg/ha/day.

b/ Salinity = Concentration of salts
TSS = Total Suspended Solids
VSS = Volatile Suspended Solids
BOD (5) = 5-Day Biochemical Oxygen Demand
TOC = Total Organic Carbon
Inorg Crbn = Inorganic Carbon
TKN = Total Kjeldahl Nitrogen
NH_3 = Ammonia
NO_2 = Nitrite
NO_3 = Nitrate
Tot P = Total Phosphorus
Ortho P = Orthophosphorus
Part T P = Particulate Phosphorus
Part TKN = Particulate Kjeldahl Nitrogen
Org N = Organic Nitrogen

c/ UF = Unfiltered

d/ F = Filtered

e/ Negative values indicate export

Table V.2. Nutrient Exchange Data, *Sporobolus virginicus*, Matagorda-Lavaca Bay.[a]

Analysis[b]	Winter	Season Spring	 Summer	Avg.
Salinity	280	-1604	522	-267
TSS	7.015	-48.358	-47.090	-29.478
VSS	1.791	2.612	1.493	1.965
BOD (5)	.161	-.011	-.139	0.004
TOC	.784	-2.239	-1.791	-1.082
Inorg Crbn	-7.127[e]	-.224	-.485	-2.612
UF TKN[c]	0	0	-.007	-0.002
F TKN[d]	0	.021	0	0.007
F NH_3	.025	.028	.037	0.030
F NO_2	0	-.002	.004	0.001
N NO_3	.272	.375	.166	0.271
UF Tot P	.018	.072	-.062	0.009
F Tot P	.018	.072	-.053	0.012
F Ortho P	.005	.064	.031	0.033
Part T P	.250	.260	.040	0.183
Part TKN	0	0	-.007	-0.002
Org N	0	.021	0	0.007

a/ Units are kg/ha/day.

b/ Salinity = Concentration of Salts
TSS = Total Suspended Solids
VSS = Volatile Suspended Solids
BOD (5) = 5-Day Biochemical Oxygen Demand
TOC = Total Organic Carbon
Inorg Crbn = Inorganic Carbon
TKN = Total Kjeldahl Nitrogen
NH_3 = Ammonia
NO_2 = Nitrite
NO_3 = Nitrate
Tot P = Total Phosphorus
Ortho P = Orthophosphorus
Part T P = Particulate Phosphorus
Part TKN = Particulate Kjeldahl Nitrogen
Org N = Organic Nitrogen

c/ UF = Unfiltered

d/ F = Filtered

e/ Negative values indicate export

similar in magnitude.

The nutrient contents of sediment samples taken from each of the reactors are given in Table V.3. From analysis of these samples it appears that reactors taken from Culver Cut, Tiger Island Cut, and Matagorda Bay exhibit nutrient leaching due to erosion and scouring of organic materials by wave action and currents. The Crab Lake reactor contains higher nutrient concentrations which are apparently due to the low mixing regime at its location and sedimentation of organic material. As noted by Armstrong, Harris, and Gordon (1977), there is a close correlation between the percent dry solids content of the sediment samples and the concentration of carbon, nitrogen, and phosphorus. It should also be noted that phosphorus appears to be in excess in these sediments, that is, macrophytes extracting nutrients from these sediments would appear to be nitrogen limited since the nitrogen concentrations are substantially less than these of phosphorus.

It was noted by Armstrong and Gordon (1977a) that the nutrient exchange rates in the reactors for Nueces and San Antonio Bays were influenced by the growth of attached algae on the walls of the reactors. It was also noted that the exchange rates appear to be directly correlated with the volume of water in the reactors and hence the wall surface exposed, and it was determined that this "wall effect" must be taken into account (through exposed wall algae scrapings, analysis, and mass balance calculations) in the calculation of nutrient exchange rates on an areal basis. Visual inspection of the reactors at the end of the experimental periods showed in every case that a heavy attached algal film covered the reactor walls, sediments, and stems of the macrophytes, and those attached algae were probably dominating the nutrient exchange rates. The attached algae on the reactor walls were taken into account in the calculation of the rates given in Table V.4 for Spartina alterniflora and Sporobolus virginicus. These exchange rates are somewhat smaller than those given in Table V.1 and V.2 as would be expected, but the rates also appear to be more comparable in magnitude. As a result of this correction, it also appears that some of the nutrient exchange rates are very small and essentially zero. The exchange rates measured are very similar to those found by Armstrong and Gordon (1977a) in Nueces Bay and San Antonio Bay for Spartina patens and other macrophytes. They are also similar to those measured in the Trinity River delta area by Armstrong, Harris, and Gordon (1977), and in the Lavaca Bay system by Armstrong, et al. (1975).

In summary, the nutrient exchange rates for the macrophytes Spartina alterniflora and Sporobolus virginicus found in the Colorado River Delta are very similar in magnitude to the exchange rates for other marsh systems in Texas. These rates indicate that particulate and carbonaceous material is generally exported from the systems, while inorganic nitrogen and phosphorus are consistently taken up. It is likely that the mode of export in the Colorado River Delta system is very similar to that of the other Texas marshes; that is, the export is driven by normal tidal action, wind tides, and flood flows through the marsh systems flushing the nutrients out of the marshes into the adjacent waters.

Table V.3. Nitrogen and Phosphorus Contents, Colorado River Delta Reactor Sediments.[a]

Analysis[b]	Culver Cut	Reactor: Tiger Island Cut	Reactor: Matagorda Bay	Crab Lake
TKN	0.12	0.07	0.18	0.26
Org N	0.06	0.04	0.15	0.21
NH_3-N	0.06	0.03	0.03	0.05
NO_2-N	0.01	0.01	0.02	0.03
NO_3-N	0.04	0.05	0.11	0.14
Total P	0.35	0.33	0.30	0.49
TOC	1.59	2.33	2.77	6.48
Percent Dry Solids (%)	63.9	70.2	46.1	40.1

a/ Units are mg/gm except as noted.

b/ TKN = Total Kjeldahl Nitrogen
Org N = Organic Nitrogen
NH_3-N = Ammonia Nitrogen
NO_2-N = Nitrite Nitrogen
NO_3-N = Nitrate Nitrogen
Total P = Total Phosphorus
TOC = Total Organic Carbon

Table V.4. Summary of Nutrient Exchange Rates for Macrophytes, Colorado River Delta System, Corrected for Wall Effects.[a]

Analysis[b]	*Spartina alterniflora*	*Sporobolis virginicus*
Salinity	-150[c]	-130
TSS	-6.77	-14.12
VSS	-0.57	0.94
BOD_5	-0.02	0.00
TOC	-0.41	-0.52
TKN	-0.01	0.00
TKN	-0.01	0.00
Part TKN	0.00	0.00
Org N	-0.01	0.00
NH_3-N	0.01	0.01
NO_2-N	0.00	0.00
NO_3-N	0.10	0.13
Tot. P	-0.01	0.00
Tot. P	0.01	0.01
Part. Tot. P	0.07	0.09
Ortho-P	0.02	0.02

a/ Units are kg/ha/day.

b/ Salinity = Concentration of salts
TSS = Total Suspended Solids
VSS = Volatile Suspended Solids
BOD_5 = 5-Day Biochemical Oxygen Demand
TOC = Total Organic Carbon
TKN = Total Kjeldahl Nitrogen
Part TKN = Particulate Kjeldahl Nitrogen
Org N = Organic Nitrogen
NH_3-N = Ammonia Nitrogen
NO_2-N = Nitrite Nitrogen
NO_3-N = Nitrate Nitrogen
Tot. P = Total Phosphorus
Part. Tot. P = Particulate Total Phosphorus
Ortho-P = Orthophosphorus

c/ Negative values indicate export

CHAPTER VI

DELTAIC FLOW ROUTING

BACKGROUND

The flow routing and exchange patterns within the Colorado Delta are complex and result from the interaction of two land locked bay tides (both of which are affected by wind stresses), the Gulf of Mexico tide, and the various freshwater inflow patterns of the Colorado River. The avenues of difluence and circulation within the system include the GIWW at Matagorda, Culver Cut between the GIWW and Matagorda Bay, and Tiger Island Cut between the Colorado River and Matagorda Bay, as well as the junction of the Colorado River and the Gulf of Mexico. With so many interrelated components, the Colorado Delta represents an extremely complex system with respect to simulation model application.

ASSUMPTIONS AND SIMULATION PROCEDURES

Management of the complex system of variables which describes the flow patterns within the Colorado Delta may be expedited through the utilization of specific scenarios and simplifying assumptions. The simulated results obtained from the application of such assumptions and system simplifications are less precise than those obtainable if each and every case of each and every variable is investigated, however, it appears that overall trends of such an analysis are discernable, and the absolute values generated are of sufficient resolution to result in an adequate analysis.

The first assumption is, the configuration and related cross-sectional areas of the mouth of the Colorado River vary with the riverine freshwater inflows; decreasing in cross-sectional area over periods of time with extended low flow and degenerating to almost complete closure with the increased siltation rate resulting from the interaction of Gulf tides and low freshwater flow velocities. Inspection of historical cross-section data assembled by the U.S. Army Corps of Engineers, supports this assumption. However, the rate of closure due to the sediment deposition or the rate of sediment scour at elevated flows are unknown, adding to the complexity of the system and necessitating additional assumptions concerning the mouth configuration at various flow intensities.

The second assumption concerns the open/close condition of the navigation locks located on the GIWW east and west of the Colorado River at Matagorda. While somewhat arbitrary, the locks are generally closed when river velocities reach approximately 3-4 ft/sec. For the cross-sectional configuration used in this modeling effort, those velocities would occur at a flow of roughly 5,000 ft^3/sec. Therefore, it will be assumed that the navigation locks will be closed for all Colorado River flows greater than or equal to 5,000 ft^3/sec. While the lock configuration at Matagorda would seem to have little impact on conditions at Tiger Island Cut, in fact, as a result of the circulation patterns through

Culver Cut and the GIWW, water surface elevations and net flows at Tiger Island Cut are strongly affected.

Given the assumptions stated above, three scenarios were established for the purpose of specifying cases with which to analyze the deltaic flow patterns under all anticipated Colorado River mouth and navigation lock conditions. The three scenarios are:

Scenario 1. Colorado River flows range from 250 to 1,000 ft^3/sec; the low flow conditions have persisted for some time and the mouth of the Colorado River is silted closed with respect to mean tidal elevations, but becomes periodically inundated on the flood tide (avg. bed elevation = +0.3 ft. MSL and avg. channel width = 100 ft.);

Scenario 2. Colorado River flows range from 1,100 to 4,900 ft^3/sec; the mouth of the river has been maintained partially open by the downstream flow momentum (avg. bed elevation = -0.3 ft. MSL and avg. channel width = 250 ft.); the navigation locks at Matagorda are open.

Scenario 3. Colorado River flows vary from 5,100 to 10,000 ft^3/sec; the river mouth is completely open (avg. bed elevation = -4.5 ft. MSL and avg. channel width = 450 ft.); the navigation locks at Matagorda are closed.

Reliable flow verification data were available for portions of just the first scenario. Data were not available for Scenarios 2 and 3.

The driving tides for each of the above scenarios remained the same and were constructed from observed tide gauge data obtained from tide gages located in Matagorda Bay (gauge 08162515) during the period 13-19 October, 1972 and East Matagorda Bay (gauge 08117985) 13-19 October, 1977. The tides are consistent with the typical tidal elevations observed at these locations for this season. The 1972 tide was selected to coincide with available flow validation data collected during the same period at Tiger Island. The 1977 data for East Matagorda Bay were utilized because observed data for 1972 were unavailable for that location. The model driving tides utilized for the Gulf of Mexico, Matagorda Bay and East Matagorda Bay boundary inputs are presented in Figure VI.1.

MODELING RESULTS

The results of the flow routing within the Colorado Delta will be presented in three parts before summarizing: (1) flow trifurcation at the junction of the Colorado River and GIWW, (2) flow diverted through Tiger Island Cut, and (3) flow through Culver Cut. The authors emphasize, however, the sensitivity analyses performed with this model have demonstrated the strong influence of the Matagorda Bay and East Matagorda Bay tidal alignments on flow patterns throughout the delta (Sullivan and Hauck, 1978). Since the tides of Matagorda Bay and East Matagorda Bay appear to be unrelated, the modeling results must be viewed as indicative of this alignment only, and that the results are not absolute and may vary slightly for differing tidal alignments.

The interaction of the Colorado River and the GIWW at Matagorda for Scenarios 1 and 2, is demonstrated in Figure VI.2. At low river flows, with river mouth constrictions (Scenario 1), the flows in the Colorado River below the GIWW are

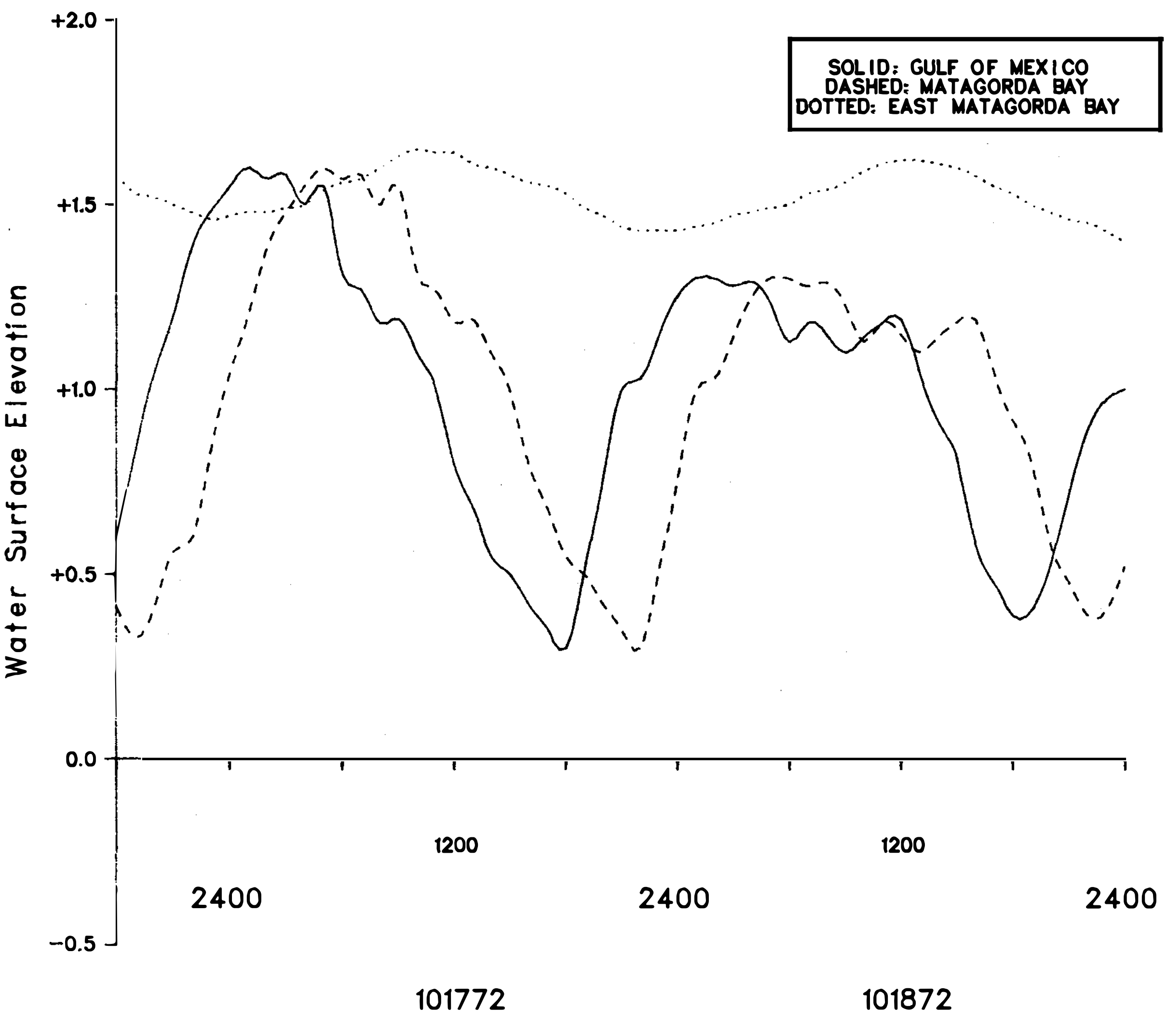


Figure VI. 1. Input Tides of the Gulf of Mexico, Matagorda Bay, and East Matagorda Bay.

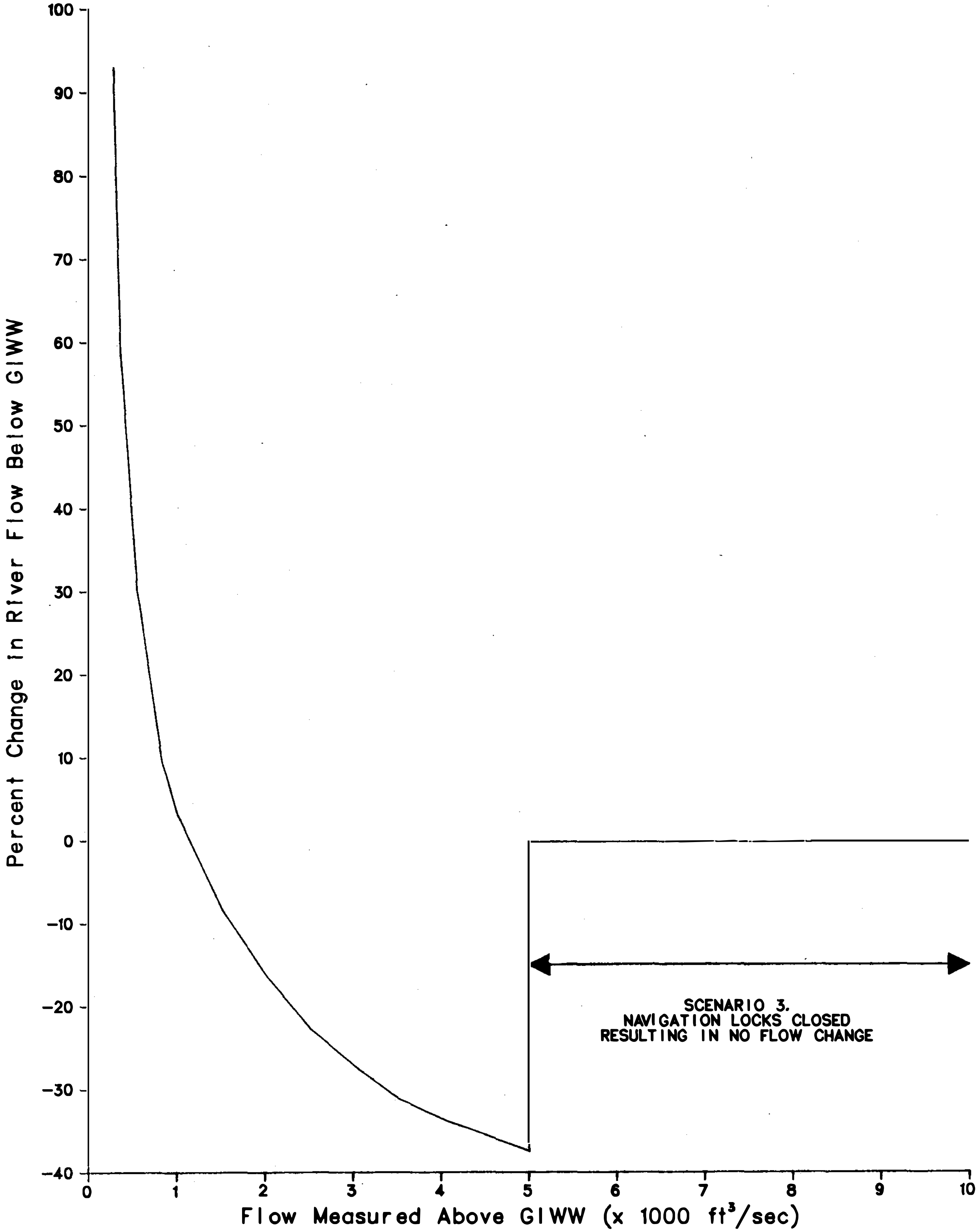


Figure VI. 2. Percent Change in River Flow Below GIWW as a Function of River Flow Above GIWW.

augmented with bay water derived from the GIWW. Inspection of the simulated flows at the GIWW east and west of the Colorado River indicate that from 10 to 100 percent of this increase can be directly attributed to circulation patterns removing water from East Matagorda Bay, depending on the magnitude of riverine flow.1/ Moderate river flows, with their accompanying increased river mouth cross-sectional area (Scenario 2), tend to contribute water to the GIWW at rates up to 40 percent of the river flow; the greater the Colorado River flow, the greater the diversion at the GIWW. Throughout Scenario 3 the exchange between the Colorado River and the GIWW were negligible because the navigation locks were assumed closed.

At Tiger Island Cut the interactions of river mouth geomorphology, recirculation patterns, and navigation lock positioning were not so easily discernable. In attempting to develop a relationship between flow through Tiger Island Cut and flow in the Colorado River above Tiger Island Cut, the three simulation scenarios yielded three distinct curves, when comparing percent of flow traveling through Tiger Island Cut with flow above the cut. For each scenario as flow increased, the percentage diverted through Tiger Island Cut increased. However, with the increased flow, the average percent diversion decreased from Scenario 1 to Scenario 2 and from Scenario 2 to Scenario 3. This appears to be incongruous, but under the assumptions, the river mouth cross-sectional area was fixed for each scenario, when in fact, the cross-sectional area is known to increase gradually with increased flow and accompanying increased downstream momentum. Utilizing an exponential regression, a curve of "best fit" was computed for the simulated data. A correlation coefficient of 0.78 was obtained for the fitted curve indicating a reasonably close fit with the simulated data. A graphic display representing the percentage of river flow diverted through Tiger Island Cut as a function of river flow above the cut accounting for the continuously variable nature of the river mouth is presented in Figure VI.3. Low flows with a constricted river mouth result in as much as 95 percent of the river flow being diverted into Matagorda Bay through Tiger Island Cut. During moderate and high hydrologic events (>6,000 ft^3/sec), the percentage of flow diverted through Tiger Island Cut is reduced to approximately 62 percent.

For all cases simulated utilizing the October 1972 combination, the flow through Culver Cut was approximately 12 to 15 percent of the Colorado River flow and, in all cases, directed into Matagorda Bay. At low to moderate flows (<2,000 ft^3/sec), the simulations indicated that the Colorado River flows below the GIWW were augmented with flow derived from the GIWW. Inspection of the simulated flow indicates that, under the October tidal alignment, nearly all of this additional water was derived from East Matagorda Bay. However, under different tidal conditions, as demonstrated in Chapter III, the opposite may be true, i.e., river flow augmentation may be derived from Matagorda Bay. Low flow simulations indicate that water can circulate from Matagorda Bay through Culver Cut and into the Colorado River and even into East Matagorda Bay.

FLOW VALIDATION

Previous attempts at flow validation of this model utilizing data derived during May and July, 1977 were not successful due to inconsistencies present in the observed data, which indicated the possibility of bi-directional flow

1/ The remainder is derived from flow in the GIWW west of Matagorda

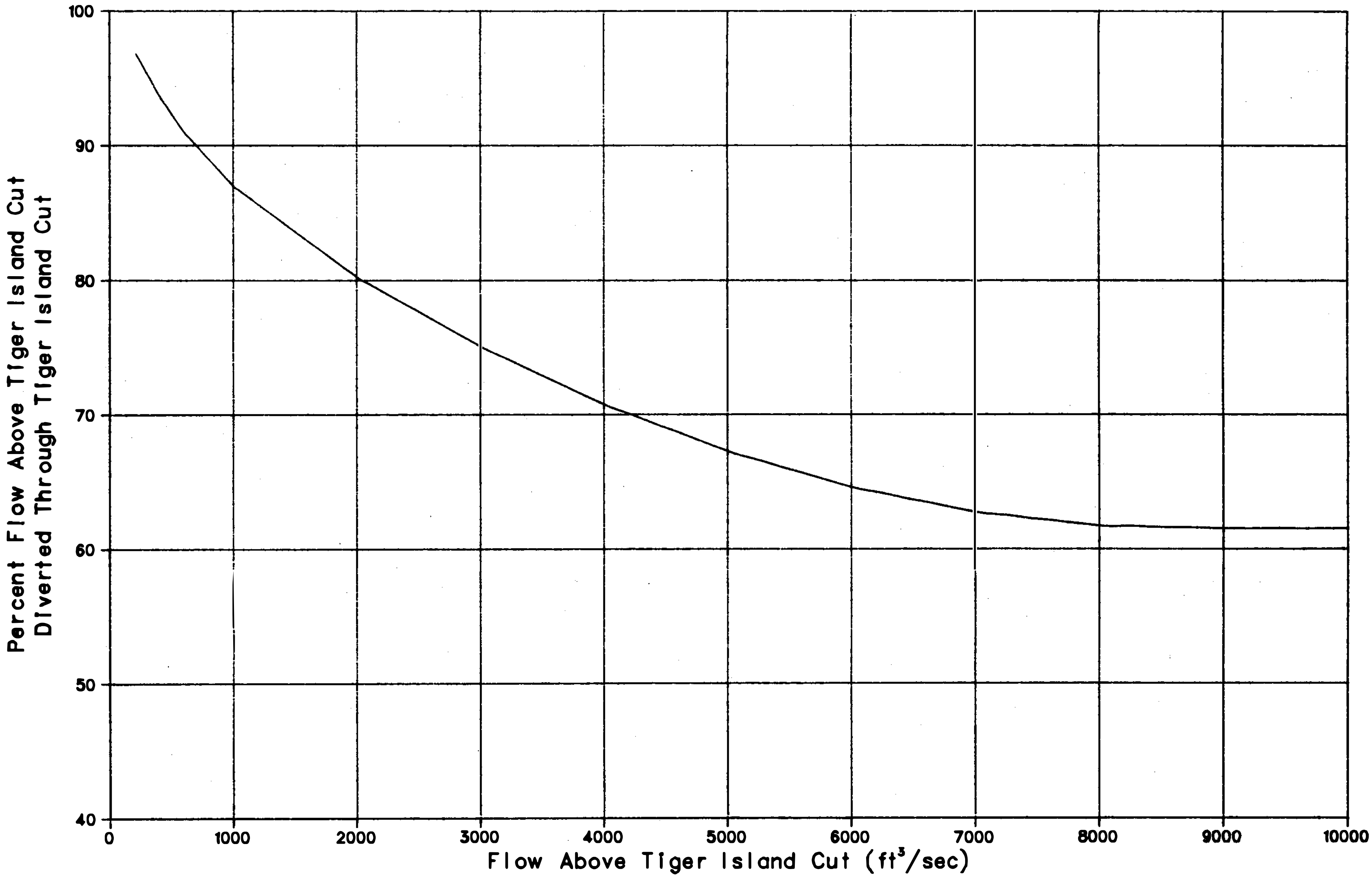


Figure VI. 3. Percent Flow Through Tiger Island Cut as a Function of River Flow.

not recorded in the measurements, see Chapter III. In this attempt at validation, the observed data were obtained during an intensive inflow study conducted October 16-19, 1972 at Tiger Island Cut and Culver Cut through the joint effort of USGS and TWDB (currently TDWR) personnel.

Figure VI.4 shows observed and simulated flows through Tiger Island Cut for the same period. Measured flows of the Colorado River at Bay City averaged 551 ft^3/sec. The conditions of the river mouth for these runs were those of Scenario 1, i.e., average bed elevation of +0.3 ft MSL and an average channel width of 100 ft. These conditions allow some tidal influence on the flood portion of the tidal cycle but result in a closed river mouth through the majority of the tidal cycle.

The phasing of the observed and simulated flows is exceptionally close throughout the simulation period. Net flow through the Tiger Island Cut is also in close agreement with observed at 637.5 ft^3/sec into Matagorda Bay and simulated of 663.9 ft^3/sec into the bay (4 percent error).

The time-absolute simulated flows tend to be exaggerated over the observed data, however, the differences may be partially explained. As formulated, the model assumes exclusively unidirectional flow within each channel segment over the simulation time step. In nature, however, true unidirectional flow within tidally influenced channels is rarely observed and this is especially true of Tiger Island Cut which consists of a network of interconnecting deltaic finger channels and junctions. In addition, the variations in depth of the numerous fingers of the fan-shaped delta produce backwater interactions, resulting in a sloshing effect which is nonunidirectional in nature. Thus it can be anticipated that the observed instantaneous flows will be lower than the simulated flows.

Flow validation at Culver Cut was less successful than at Tiger Island Cut. Observed flows at Culver Cut for the validation period tend to lack periodicity, thus demonstrating little influence of the Matagorda Bay tidal fluctuations. This may be due to the propogation of the tidal action of Matagorda Bay up the GIWW west of Culver Cut through other active exchange points. This would result in nearly the same tidal activity at both ends of the cut. The model, however, was fixed with a system boundary to the west of Culver Cut thus, not allowing this interaction. Culver Cut would then feel a forced tidal action as depicted in Figure VI.5.

The observed net flow over the simulation period was 113 ft^3/sec, into Matagorda Bay. The simulated net flow was 72 ft^3/sec (-50 percent error). The absolute flows simulated were far in excess of flows. This once again results from the absence of true unidirectional flow in the observed data and the model's assumption of unidirectional flow exclusively. On the whole simulated and observed water surface elevations were in such close agreement throughout the delta and since corrected simulation of water surface elevation and flow are somewhat interdependent it is fair to consider the delta model validated with respect to water surface elevation simulations and a reasonable predictor of net flows for the lower reaches of the Colorado River Delta.

FLOW FREQUENCY ANALYSIS

Utilizing the curve presented in Figure VI.3, percent flow diverted through

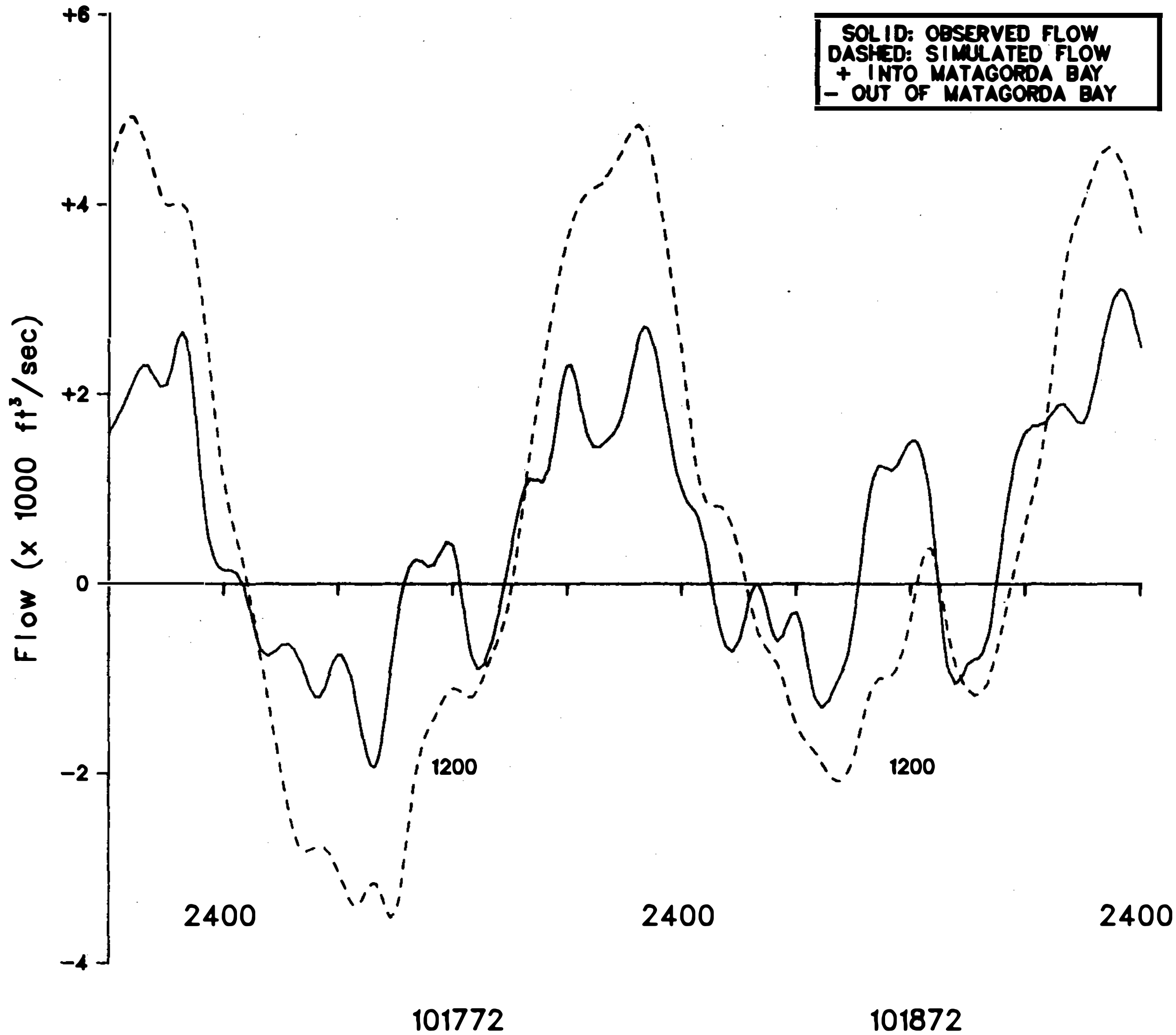


Figure VI. 4. Comparison of Measured and Simulated Flows at Tiger Island Cut.

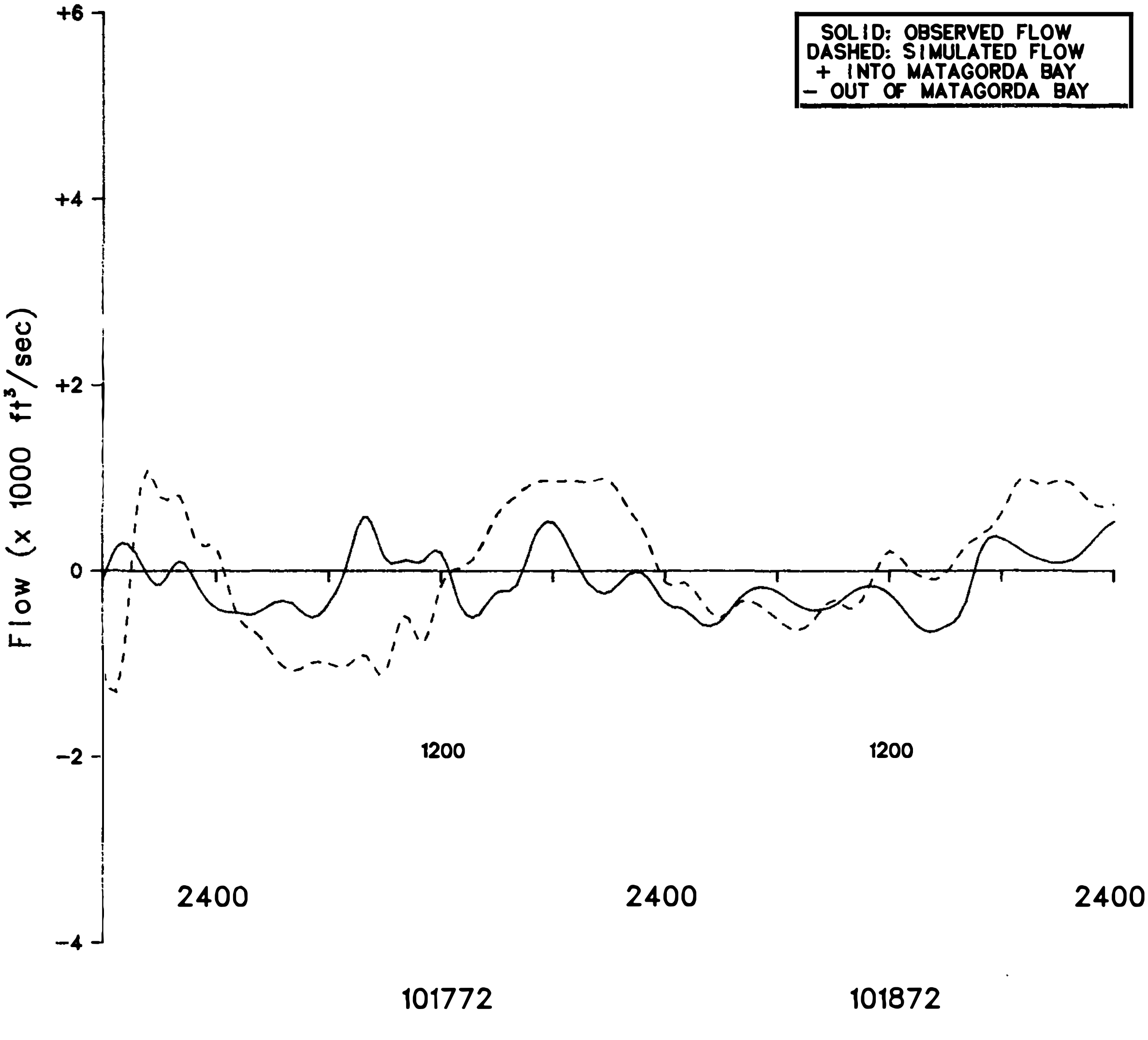


Figure VI. 5. Comparison of Measured and Simulated Flows at Culver Cut.

Tiger Island Cut as a function of river flow above the cut and mouth configuration, monthly and annual flow frequency analyses were performed utilizing monthly flow data constructed for Matagorda, Texas. These flow data include undiverted run-of-the-river flows, spills and undiverted releases from upstream reservoirs. They also include municipal return flows as well as irrigation return flows in the Lower Colorado River Basin and were derived from Bureau of Reclamation (BUREC) monthly flows which were distributed within each month according to historical distribution patterns at the Wharton stream gage over the period 1941 through 1965 (Table VI.1 and Figure VI.6). The range of flows presented is limited to 250 ft^3/sec to 5,000 ft^3/sec because (1) the lower flow extreme of Scenario 1 utilized in the curve generation was 250 ft^3/sec and (2) at flows above 3,000 ft^3/sec the curve is essentially asymptotic at approximately 62 percent.

Excluding the two months of traditionally low flows, July and August, the mean monthly flows demonstrate a range of 750 to 1,200 ft^3/sec through Tiger Island Cut; altered slightly by tidal alignment and the prevalent circulation patterns resulting from it. Mean monthly flows for July and August are approximately 550 and 450 ft^3/sec, respectively; lowering the annual average to about 800 ft^3/sec. The range of one standard deviation is 270 to 2,900 ft^3/sec or nearly a ten-fold variation.

Additional flow frequency analyses were performed at Tiger Island Cut for anticipated or possible future Colorado River flow conditions. Included in the analyses were cases involving various combinations of Clearview, Cummins Creek, La Grange, Stacy and Columbus Bend Reservoirs. The upstream development cases were obtained from previous work performed by the TDWR on the lower Colorado River Basin and presented in Present and Future Surface-Water Availability in the Colorado River Basin, Texas, TDWR (LP-60), June, 1978. The resultant flows upstream of Tiger Island Cut were derived utilizing the distributed BUREC flow records, modified by the presence or absence of these upstream impoundments. The cases and conditions simulated are presented in Table VI.2 and the results are presented in Figure VI.7 through VI.14. Results of a comparative analysis of the future-case flows through Tiger Island Cut are presented in Table VI.3. The percent change of flows are with respect to present water demands, reservoir configuration and reservoir operating procedures, and the current geomorphology of Tiger Island Cut and the Colorado River Mouth, i.e., no physical alterations other than the natural siltation/scour patterns of the Colorado River south of the GIWW.

It appears that case 3 impacts the largest negative impact on Matagorda Bay by reducing the available freshwater to the bay by as much as 83 percent (which, in turn, would result in the presence of higher than currently observed salinities within the bay) through the construction and management alternatives of all five of the proposed impoundments: Clearview, La Grange, Columbus Bend, Cummins Creek, and Stacy. The second largest negative impact results from the implementation of case 4 which differs from case 3 only in the exclusion of Stacy Reservoir. However, the reduction in freshwater flow is only reduced slightly to 81 percent.

If the simulation cases involving the construction of Columbus Bend, La Grange, and Clearview, with and without Stacy but without Cummins Creek Reservoir are examined (cases 7 and 8) the percent freshwater flow reductions are 80 and 77 percent respectively. Stacy Reservoir is thereby accounting for approximately nine percent of the larger loss.

TABLE VI.1 MONTHLY FLOW FREQUENCY DISTRIBUTION THROUGH TIGER ISLAND CUT FOR PRESENT CONDITIONS

RANGE	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
280.0	.960	1.000	.935	.989	.997	.999	1.000	.959	1.000	.950	.965	.943	.974
300.0	.960	1.000	.933	.989	.997	.999	1.000	.947	1.000	.933	.940	.943	.970
320.0	.959	1.000	.928	.989	.992	.999	1.000	.941	1.000	.923	.927	.942	.966
340.0	.957	1.000	.925	.989	.992	.999	1.000	.932	1.000	.915	.916	.941	.963
360.0	.954	1.000	.921	.987	.990	.999	1.000	.924	1.000	.901	.913	.937	.960
380.0	.950	1.000	.917	.985	.987	.999	1.000	.919	1.000	.889	.908	.935	.957
400.0	.945	1.000	.916	.980	.985	.997	1.000	.910	1.000	.877	.900	.929	.953
450.0	.938	1.000	.910	.960	.979	.996	1.000	.894	.999	.843	.877	.906	.941
500.0	.921	.990	.898	.953	.977	.996	.992	.868	.985	.794	.869	.886	.927
550.0	.895	.979	.888	.947	.966	.993	.977	.831	.965	.748	.833	.849	.905
600.0	.862	.963	.883	.925	.957	.992	.951	.782	.948	.705	.801	.826	.882
650.0	.808	.914	.876	.901	.951	.987	.921	.742	.928	.665	.771	.800	.854
700.0	.791	.884	.872	.863	.936	.977	.894	.708	.905	.640	.755	.782	.833
750.0	.770	.875	.863	.847	.926	.963	.867	.676	.888	.622	.731	.765	.815
800.0	.752	.868	.845	.833	.919	.945	.834	.641	.861	.601	.705	.756	.796
850.0	.730	.857	.832	.813	.895	.923	.803	.623	.848	.581	.685	.746	.777
900.0	.711	.836	.808	.785	.884	.897	.755	.612	.836	.568	.665	.741	.757
950.0	.693	.823	.788	.765	.870	.876	.721	.600	.823	.556	.641	.734	.740
1000.0	.670	.810	.773	.751	.850	.853	.694	.581	.801	.548	.615	.730	.722
1200.0	.632	.782	.723	.685	.799	.797	.585	.468	.749	.501	.564	.688	.663
1400.0	.601	.752	.654	.663	.757	.704	.494	.372	.665	.475	.505	.654	.607
1600.0	.590	.721	.608	.629	.719	.623	.422	.315	.577	.455	.475	.627	.562
1800.0	.572	.680	.548	.589	.685	.564	.346	.277	.488	.448	.457	.614	.521
2000.0	.543	.642	.510	.549	.658	.515	.285	.245	.457	.431	.445	.587	.488
2200.0	.507	.601	.486	.517	.632	.480	.231	.217	.421	.412	.439	.570	.458
2400.0	.472	.576	.454	.499	.605	.445	.196	.164	.391	.396	.417	.547	.429
2600.0	.432	.544	.435	.476	.586	.411	.181	.126	.343	.379	.401	.532	.403
2800.0	.409	.511	.395	.457	.546	.400	.165	.106	.324	.350	.393	.506	.379
3000.0	.382	.487	.388	.443	.530	.385	.143	.086	.316	.341	.380	.465	.361
3200.0	.365	.469	.378	.423	.512	.375	.135	.067	.304	.332	.373	.432	.346
3400.0	.356	.458	.370	.413	.494	.363	.121	.055	.277	.324	.369	.399	.332
3600.0	.351	.449	.364	.387	.477	.355	.115	.048	.252	.319	.359	.373	.319
3800.0	.345	.433	.357	.363	.459	.349	.115	.043	.225	.311	.333	.350	.306
4000.0	.335	.429	.355	.353	.440	.344	.110	.037	.197	.305	.307	.329	.294
4500.0	.311	.387	.339	.324	.400	.333	.103	.030	.165	.286	.257	.283	.267
5000.0	.297	.341	.315	.301	.372	.316	.102	.023	.143	.266	.231	.261	.247
5500.0	.277	.302	.294	.272	.348	.288	.094	.015	.125	.234	.196	.235	.223
6000.0	.254	.280	.252	.255	.337	.275	.092	.013	.111	.209	.168	.215	.204
6500.0	.231	.268	.235	.245	.328	.255	.092	.012	.091	.191	.143	.179	.188
7000.0	.208	.255	.203	.228	.315	.244	.084	.009	.077	.177	.125	.143	.172
7500.0	.196	.242	.165	.211	.302	.225	.067	.004	.064	.169	.105	.097	.155
8000.0	.179	.232	.165	.200	.290	.191	.052	.004	.051	.160	.081	.084	.140
8500.0	.160	.227	.154	.187	.275	.177	.044	.004	.045	.154	.072	.072	.130
9000.0	.148	.205	.145	.177	.270	.159	.036	.004	.039	.145	.060	.068	.121
9500.0	.138	.187	.125	.140	.254	.151	.032	.003	.035	.139	.053	.062	.110
10000.0	.121	.171	.114	.132	.237	.143	.028	.003	.028	.129	.047	.054	.100
20000.0	.017	.034	.021	.052	.108	.065	.013	.000	.013	.045	.007	.010	.032
30000.0	.004	.016	.005	.033	.059	.035	.005	.000	.005	.023	.004	.001	.016
40000.0	.001	.007	.000	.016	.040	.016	.001	.000	.004	.013	.001	.000	.008
50000.0	.000	.004	.000	.007	.008	.008	.000	.000	.004	.008	.000	.000	.003

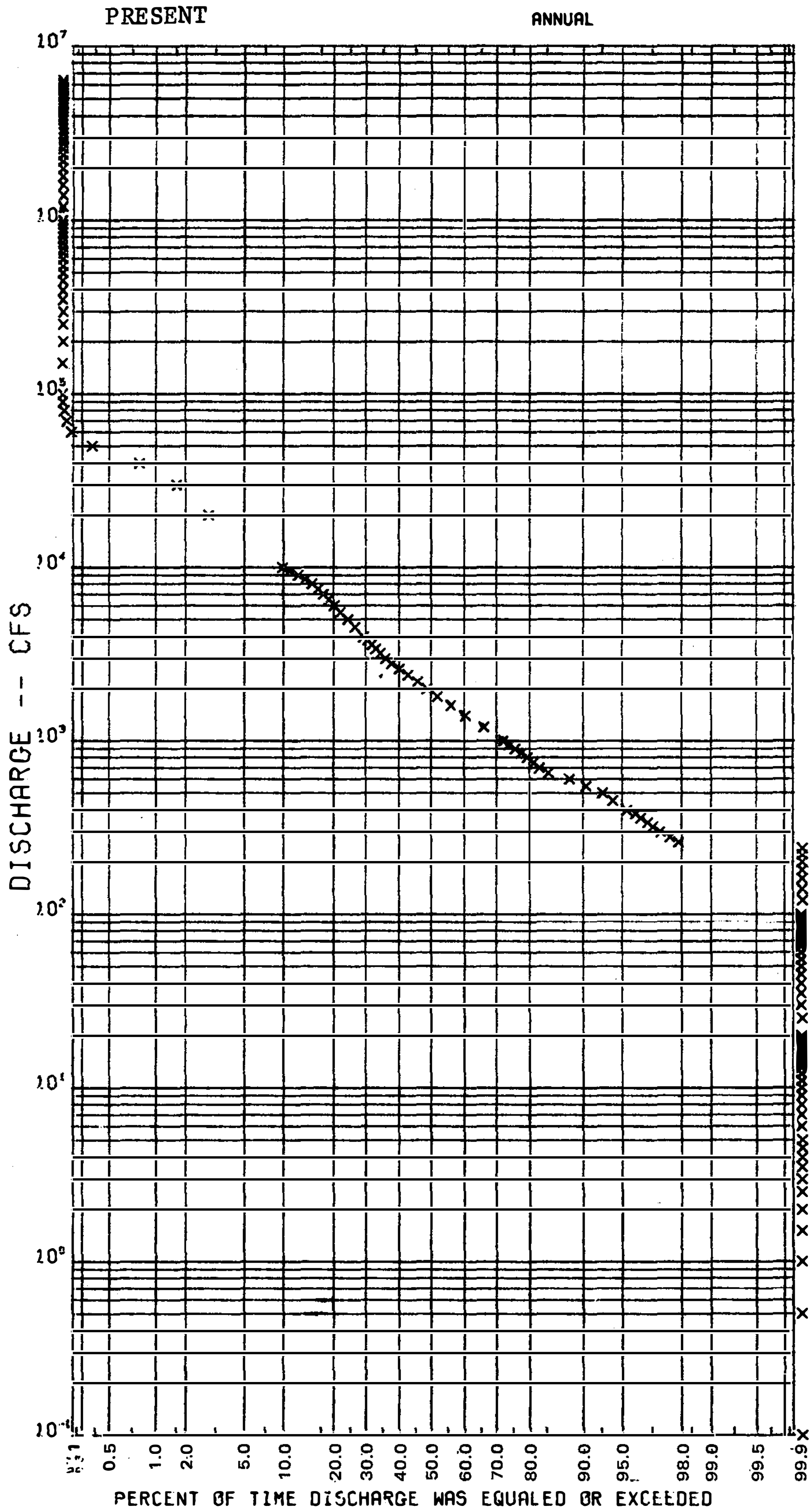


FIGURE VI.6 Flow Frequency at Tiger Island Cut Under Present Conditions

Table VI.2 Description of Alternate River System Configurations for Lower Colorado River Basin

Case	Basin Condition and Reservoir System
1	2030 Data with La Grange and Columbus Bend Reservoirs, with Stacy Reservoir upstream.
2	2030 Data with La Grange and Columbus Bend Reservoirs, without Stacy Reservoir upstream.
3	2030 Data with Clearview, La Grange, Columbus Bend and Cummins Creek Reservoirs, with Stacy Reservoir upstream.
4	2030 Data with Clearview, La Grange, Columbus Bend and Cummins Creek Reservoirs, without Stacy Reservoir upstream.
5	2030 Data with no development downstream from Town Lake, with Stacy Reservoir upstream.
6	2030 Data with no development downstream from Town Lake, without Stacy Reservoir upstream.
7	2030 Data with Columbus Bend, La Grange and Clearview, with Stacy Reservoir upstream.
8	2030 Data with Columbus Bend, La Grange and Clearview, without Stacy Reservoir upstream.

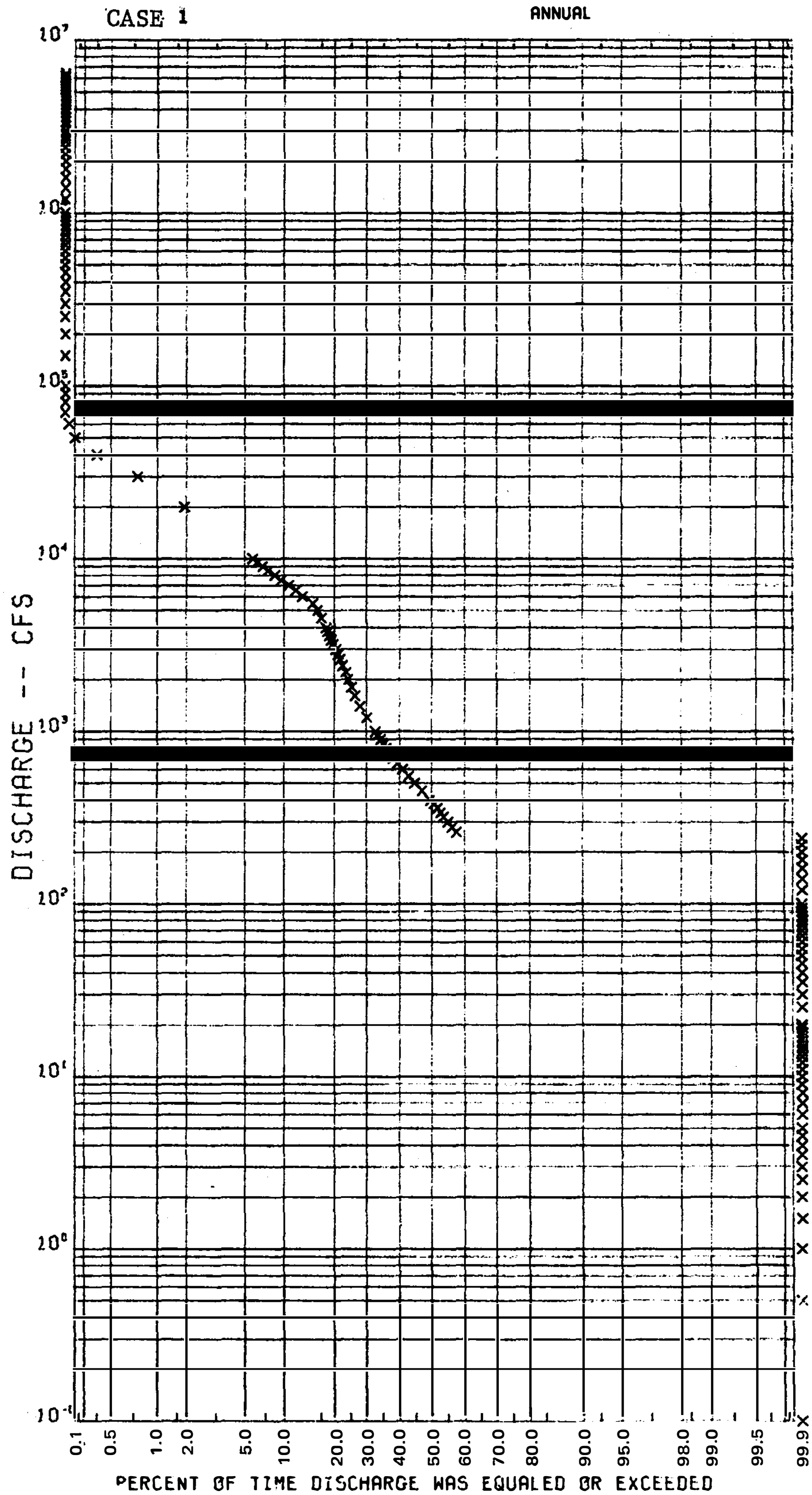


FIGURE VI.7 Flow Frequency at Tiger Island Cut: 2030 Data with La Grange and Columbus Bend Reservoirs, with Stacy Reservoir Upstream

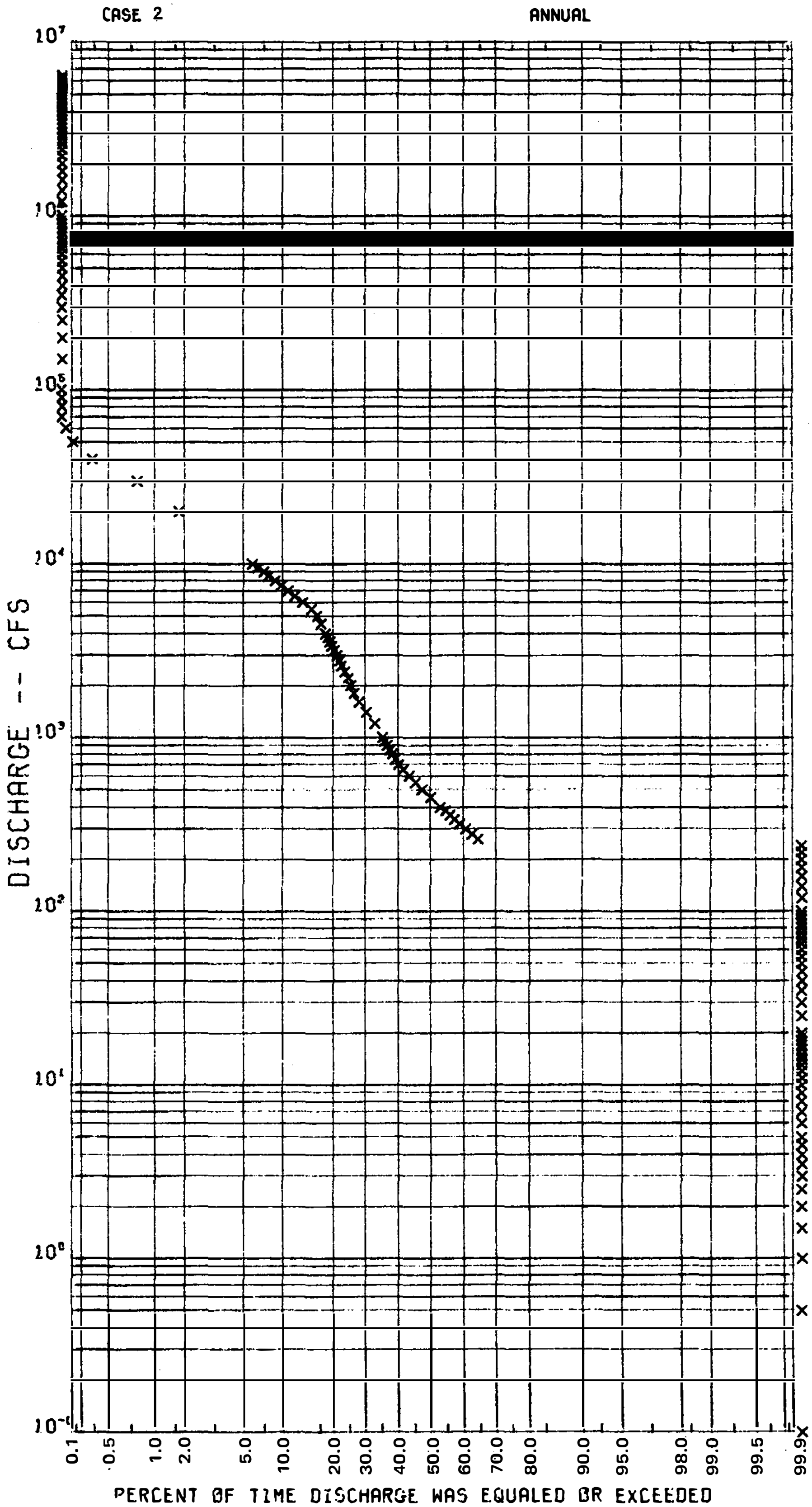


FIGURE VI.8 Flow Frequency at Tiger Island Cut: 2030 Data with La Grange and Columbus Bend Reservoirs, without Stacy Reservoir Upstream

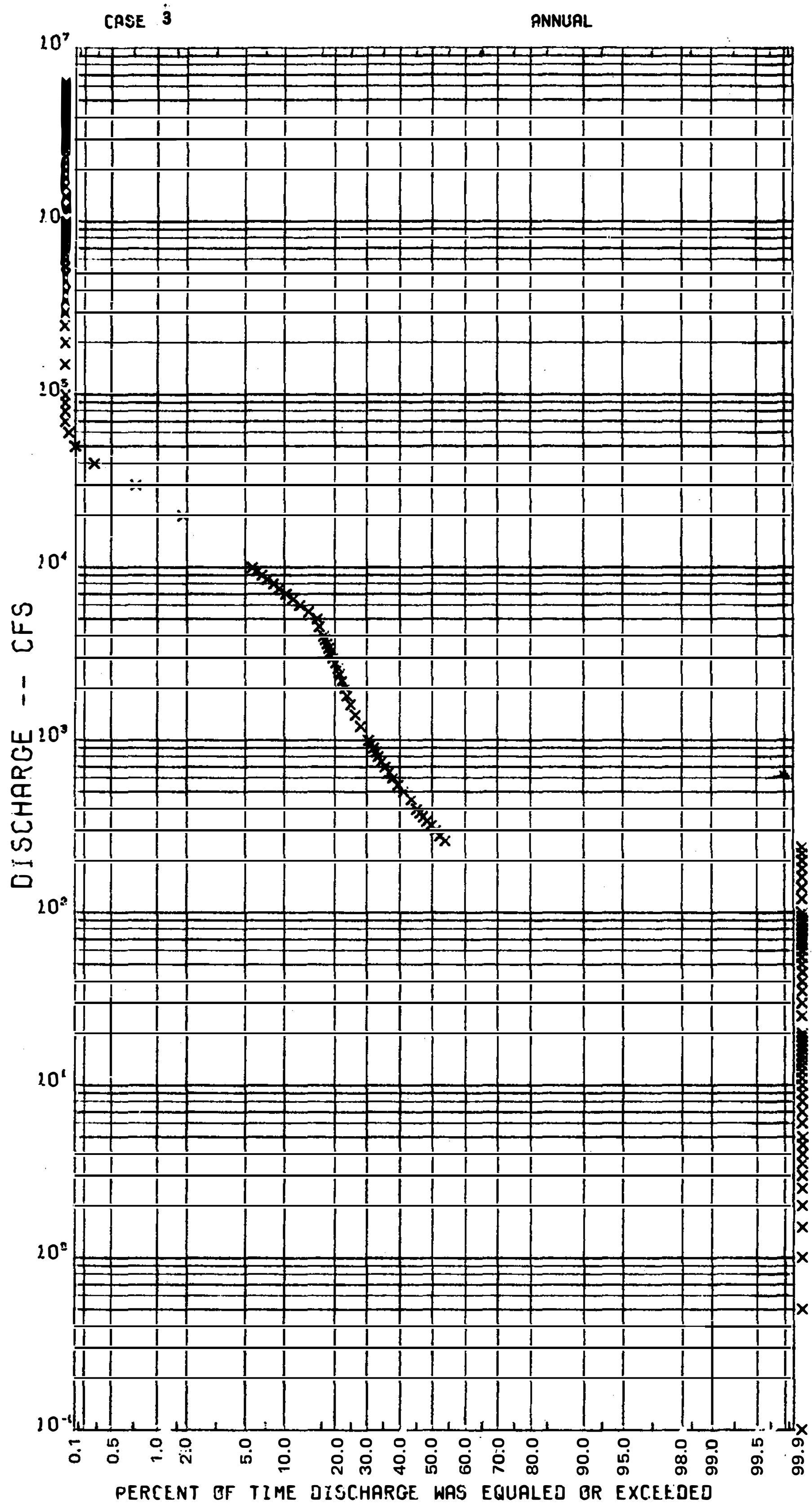


FIGURE VI.9 Flow Frequency at Tiger Island Cut: 2030 Data with Clearview, La Grange, Columbus Bend and Cummins Creek Reservoirs, with Stacy Reservoir Upstream

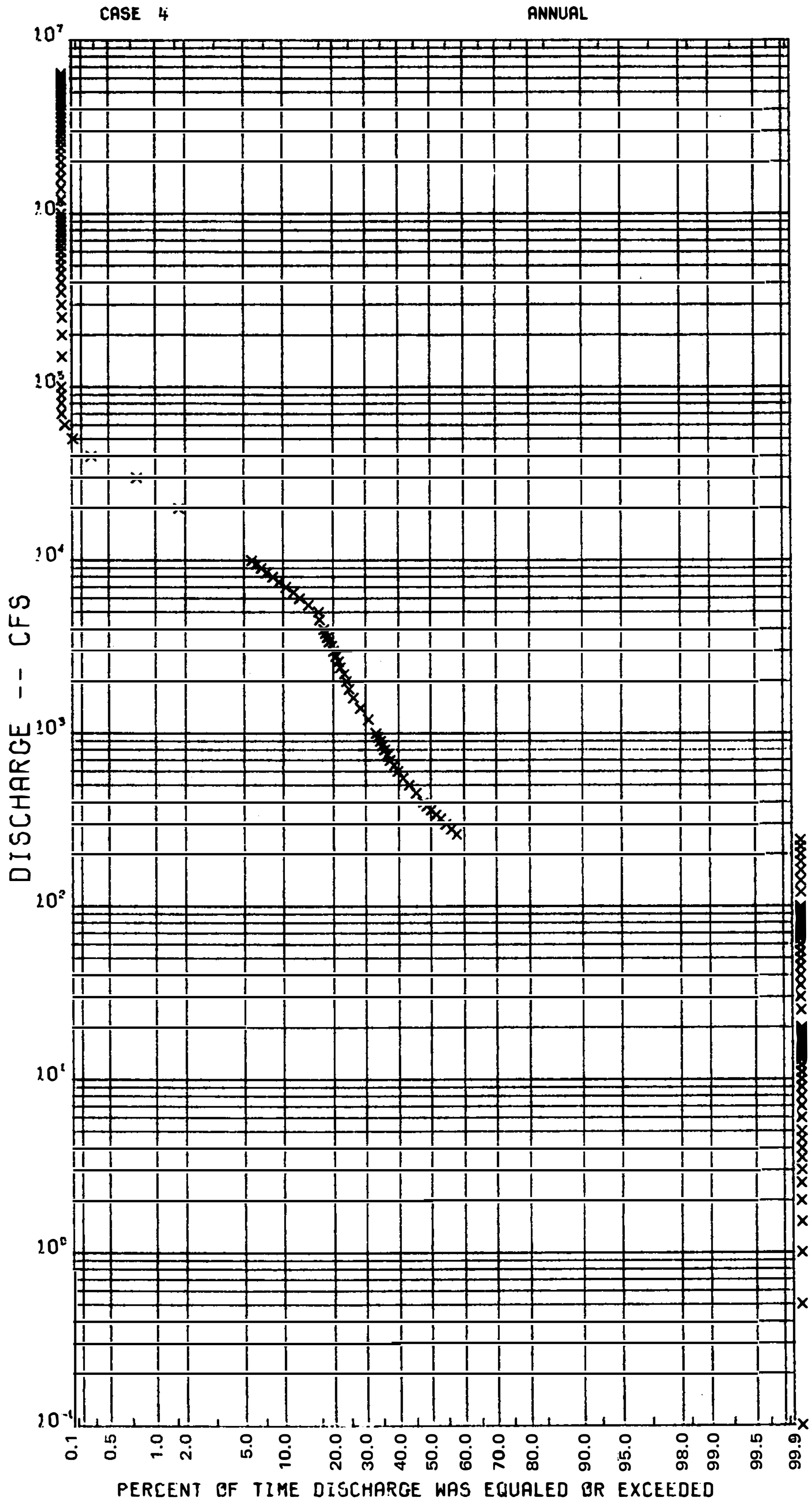


FIGURE VI.10 Flow Frequency at Tiger Island Cut: 2030 Data with Clearview, La Grange, Columbus Bend, and Cummins Creek Reservoirs, without Stacy Reservoir Upstream

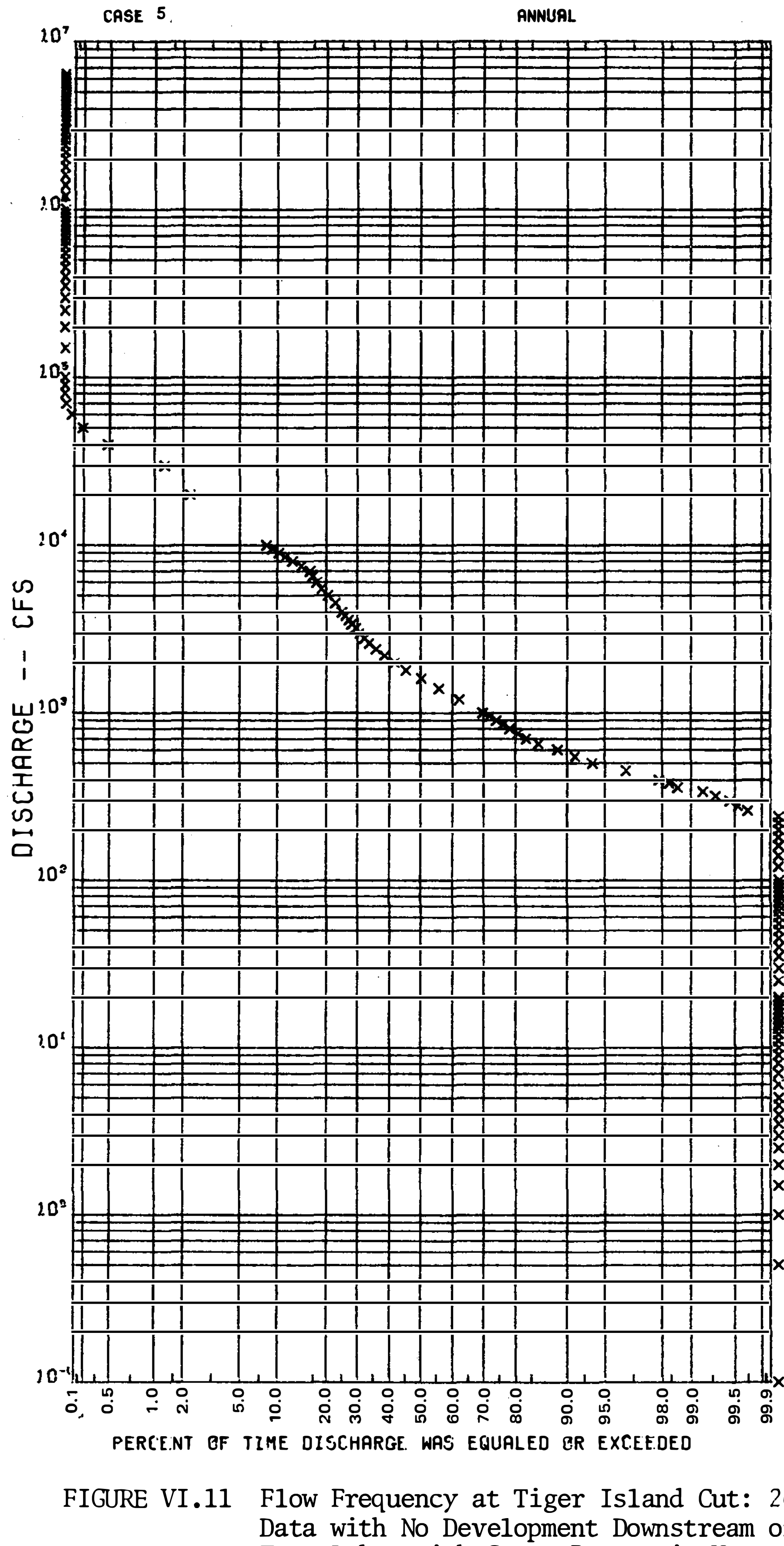


FIGURE VI.11 Flow Frequency at Tiger Island Cut: 2030 Data with No Development Downstream of Town Lake, with Stacy Reservoir Upstream

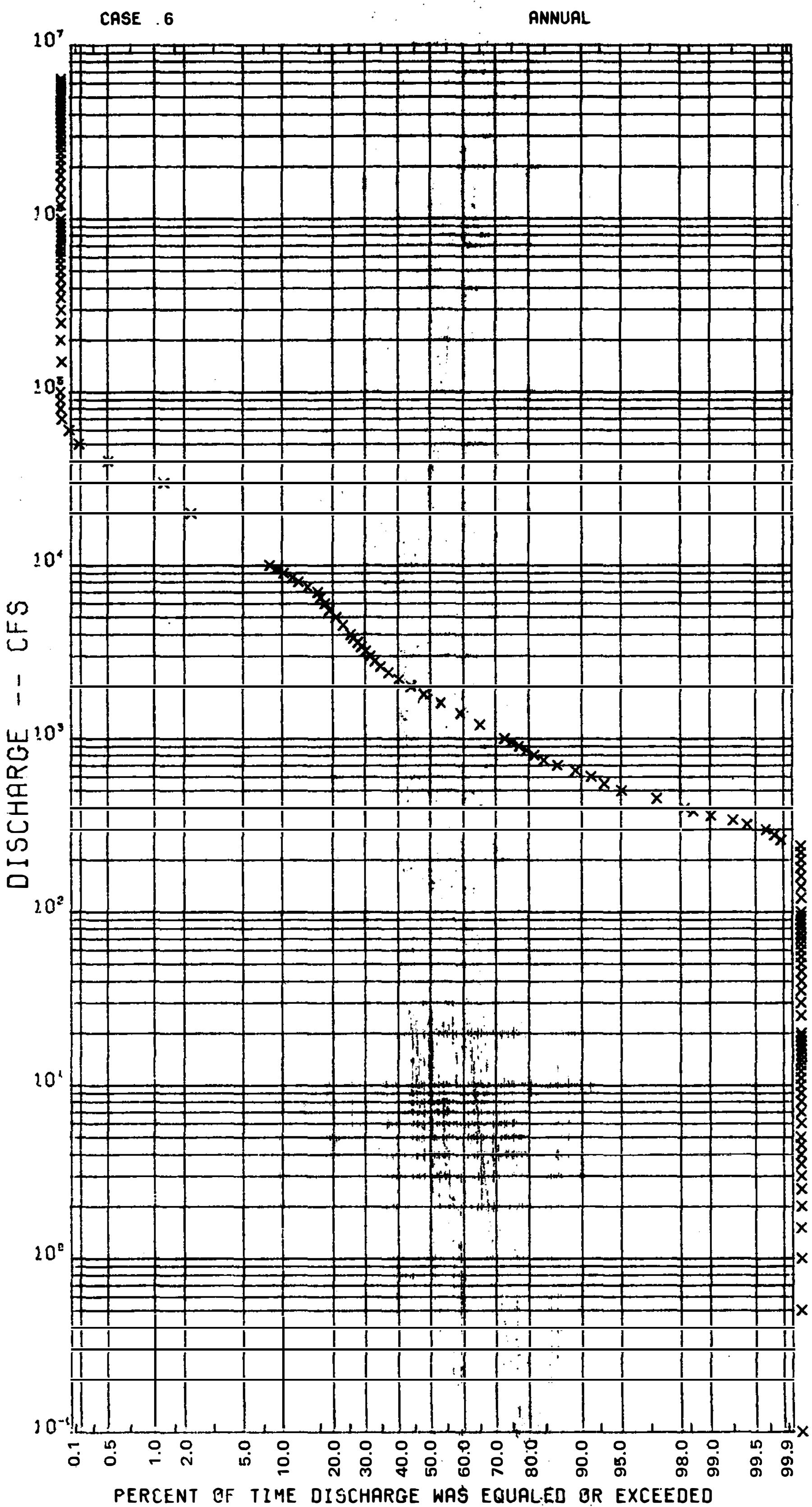


FIGURE VI.12 Flow Frequency at Tiger Island Cut: 2030 Data with No Development Downstream of Town Lake, without Stacy Reser oir Upstream

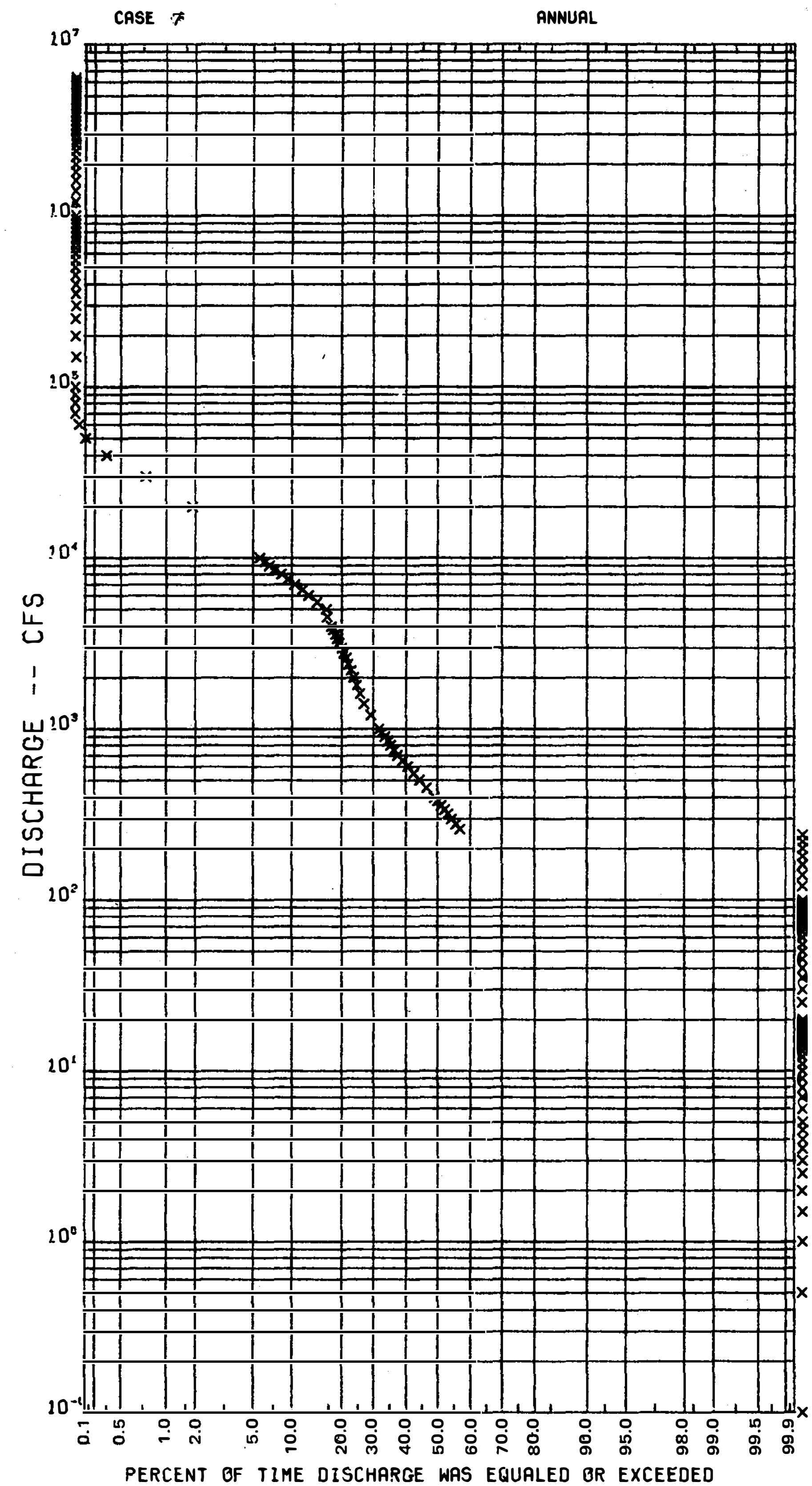


FIGURE VI.13 Flow Frequency at Tiger Island Cut: 2030 Data with Columbus Bend, La Grange, and Clearview Reservoirs, with Stacy Reservoir Upstream

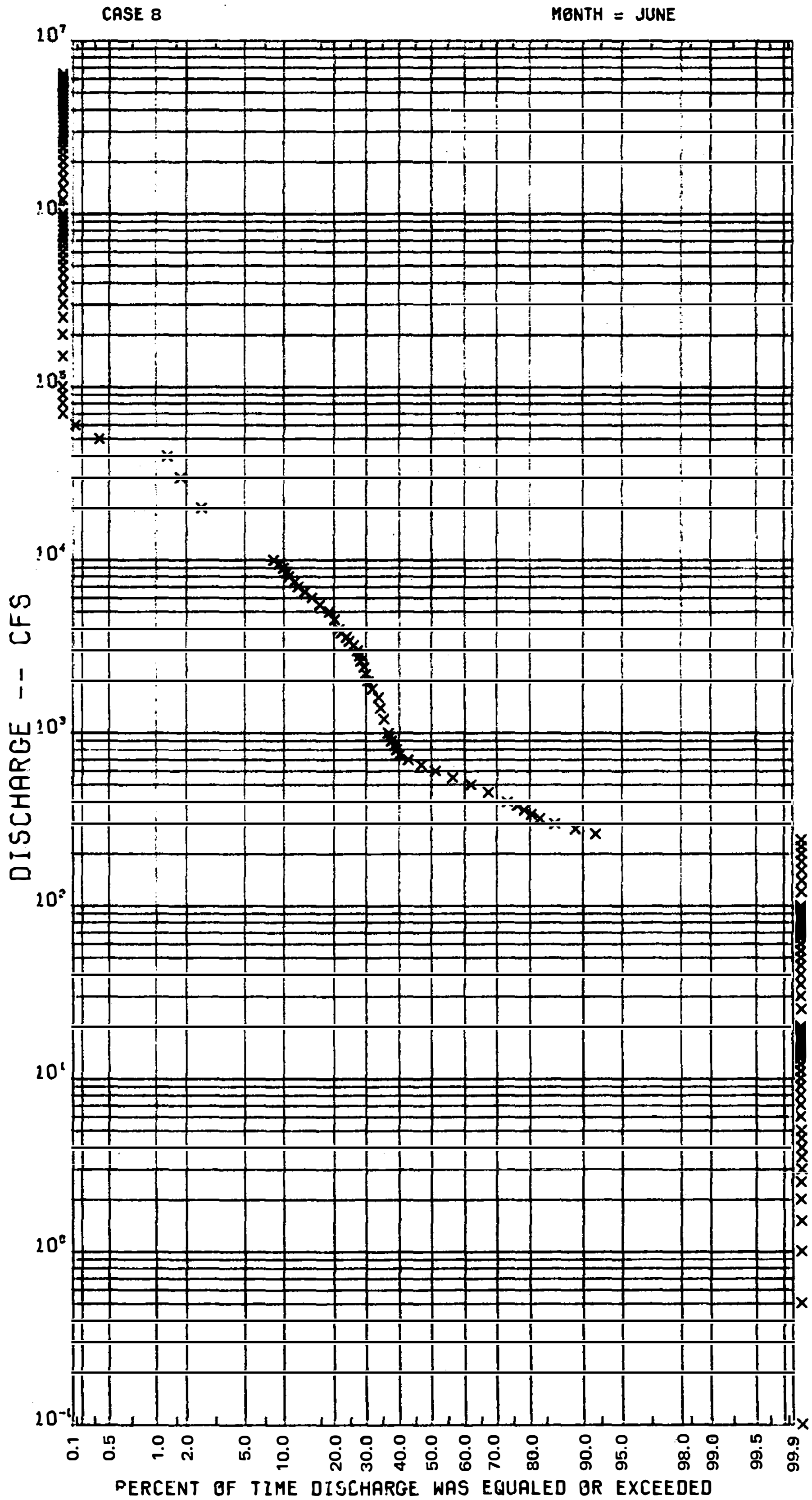


FIGURE VI.14 Flow Frequency at Tiger Island Cut: 2030 Data with Columbus Bend, La Grange, and Clearview Reservoirs, without Stacy Reservoir Upstream

TABLE VI.3

PERCENT REDUCTION OF FLOW THROUGH TIGER ISLAND CUT AS A RESULT OF FUTURE RESERVOIR CONSTRUCTION

Development Case	Annual Average Flow Through Tiger Island Cut, ft^3/sec	Percent Reduction in Flow From Present Conditions
Present	1925	N.A.*
1	390	-80
2	450	-77
3	320	-83
4	360	-81
5	1600	-17
6	1700	-12
7	380	-80
8	450	-77

*N.A. = Dot Applicable

Assuming that La Grange and Columbus Bend Reservoirs are to be built and examining the simulation cases with and without the inclusion of Stacy Reservoir (cases 7 and 8), the reduction of freshwater available to Matagorda Bay again would be 77 and 80 percent respectively.

Examination of cases 5 and 6, year 2030 water demands being met assuming no new development of water resources downstream of Austin with and without Stacy Reservoir, indicates only a slight depression in the amount of freshwater available to Matagorda Bay (12 and 17 percent respectively). Though the freshwater demands for the City of Austin as well as the manufacturing demands for the areas south of Austin are projected to increase substantially by the year 2030, the attendant return flows and the larger volumes of water not subject to control (assuming an equal reservoir management efficiency for 2030 will result in more water lost due to inefficiency because of the increased volumes) will result in only slight reductions in the available freshwater to Matagorda Bay through Tiger Island Cut (12 and 17 percent, respectively).

IMPACTS ON SALINITY

In conjunction with the flow frequency analyses, preliminary investigations were performed to quantify the effects that implementation of the eight alternative future river system configurations (see Table VI.2) may have upon the salinity regimes in the eastern arm of Matagorda Bay. To actuate these analyses, it was necessary to correlate recorded flows of the Colorado River with recorded salinity data gathered in the eastern arm of Matagorda Bay. The salinity data utilized was gathered as part of a cooperative TWDB-USGS program and covered a period beginning in July, 1967 through February, 1977. The fine-site sampling stations used specifically in these analyses are: line 330 station 2; line 333 stations 1, 2 and 3, and line 340 stations 2 and 3 (Figure VI.15). The flows corresponding to these salinities were obtained from historical records of the USGS Bay City flow gage.

The correlation procedure involved averaging the measured salinities of the seven sampling locations for each day and regressing these values on anticedent flow conditions in the Colorado River to obtain an equation that will predict salinities in the eastern arm of Matagorda Bay as a function of anticedent flows measured at Bay City. Several different possible relationships were examined. However, the equation which yielded accounted for the greatest variation in the data was:

$$S_t = 9.78+40.64\, Q_{t-4}^{-0.5} + 1477.63 \left(\sum_{i=1}^{30} Q_{t-i}\right)^{-0.5} \qquad [VI.1]$$

where

S_t = Salinity in parts per thousand (ppt),

Q_{t-4} = Anticedent stream flow four (4) days prior to the salinity measurement,

$\sum_{i=1}^{30} Q_{t-i}$ = Summation of the 30-day anticedent flows prior to the salinity measurement.

The coefficients in the above equation yielded a correlation coefficient (r) of 0.84 with an explained variation (r^2) of 70 percent. Applying the (ANAOV) test of statistical significance indicated the regression was highly significant.

Using the regressed equation [VI.1], a set of "present condition" salinities for the eastern arm of Matagorda Bay were calculated by applying the same "present condition" annual flow distribution are used in the Tiger Island Cut flow frequency analyses. These "present condition" flows may differ from the measured gage flows at Bay City as they include the ungaged flow contribution obtained between Bay City and Matagorda. However, these ungaged flows are small and introduce no appreciable error in simulations. The simulated and observed monthly salinities (and observed salinity ranges) are presented in Figure VI.16. During all months for which salinity data were available simulated salinities fell within the range of observed average salinity values for that month. During the months of April and June simulated values were less than the observed average. However, the absolute values of the simulated salinities areless important than the relative changes in these "present condition" salinities as a result of implementation of one of the proposed future reservoir configuration alternatives. These changes are presented in Table VI.4, along with the simulated values in parentheses.

As in the flow frequency analyses, future alternative cases 5 and 6 result in the least predicted impact on Matagorda Bay in the year 2030 since they indicate no new water resource development downstream of Town Lake. Construction of Stacy Reservoir would reduce the freshwater flows to the bay during May through the retention of some spring runoff.

All of the other possible new reservoir configurations will result in salinity increases in the eastern arm of Matagorda Bay. The variations between the salinity increases are relatively small and the overall impacts are most noticeable during the dry summer months.

Construction of LaGrange, Columbus Bend and Cummins Creek Reservoirs with or without Stacy results in the least salinity increase to the eastern arm of Matagorda Bay, compared to the remaining alternative cases, for the months of January, February and March. Salinities in these two cases would, most likely, increase about six percent (or one part per thousand). The other cases yield higher salinities except for case 8 (Columbus Bend, La Grange and Clearview, without Stacy) which results in about the same six percent increase in salinity.

During the late spring months (April, May and June), the impacts of the additional impounding areas upstream of Matagorda become slightly more pronounced. The cases of no development downstream of Town Lake (cases 4 and 5) result in slightly elevated salinities observed in the eastern arm of Matagorda Bay (seven percent or about one part per thousand). The other development alternatives result in the higher simulated salinity increases, 13 percent in April and June, and 21 percent in May, in each case.

The strongest impacts on salinity concentrations in Matagorda Bay of the development of additional water resources along the Colorado River are felt in the dry summer months of July, August and September. Salinity increases ranging from 21 percent to 57 percent were simulated for these months using equation (VI.1). All six of the development cases (1,2,3,4,7 and 8) result in similar simualted

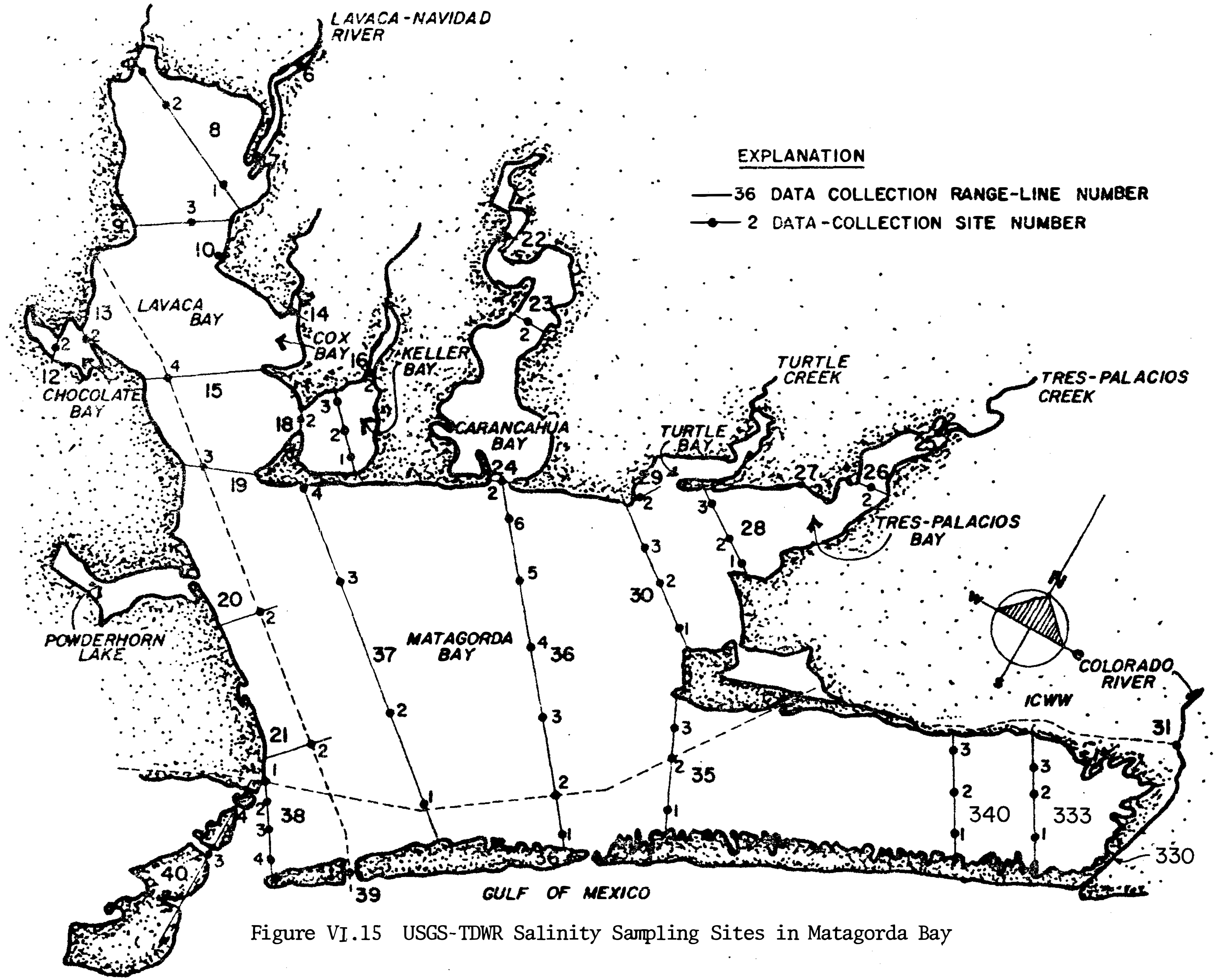


Figure VI.15 USGS-TDWR Salinity Sampling Sites in Matagorda Bay

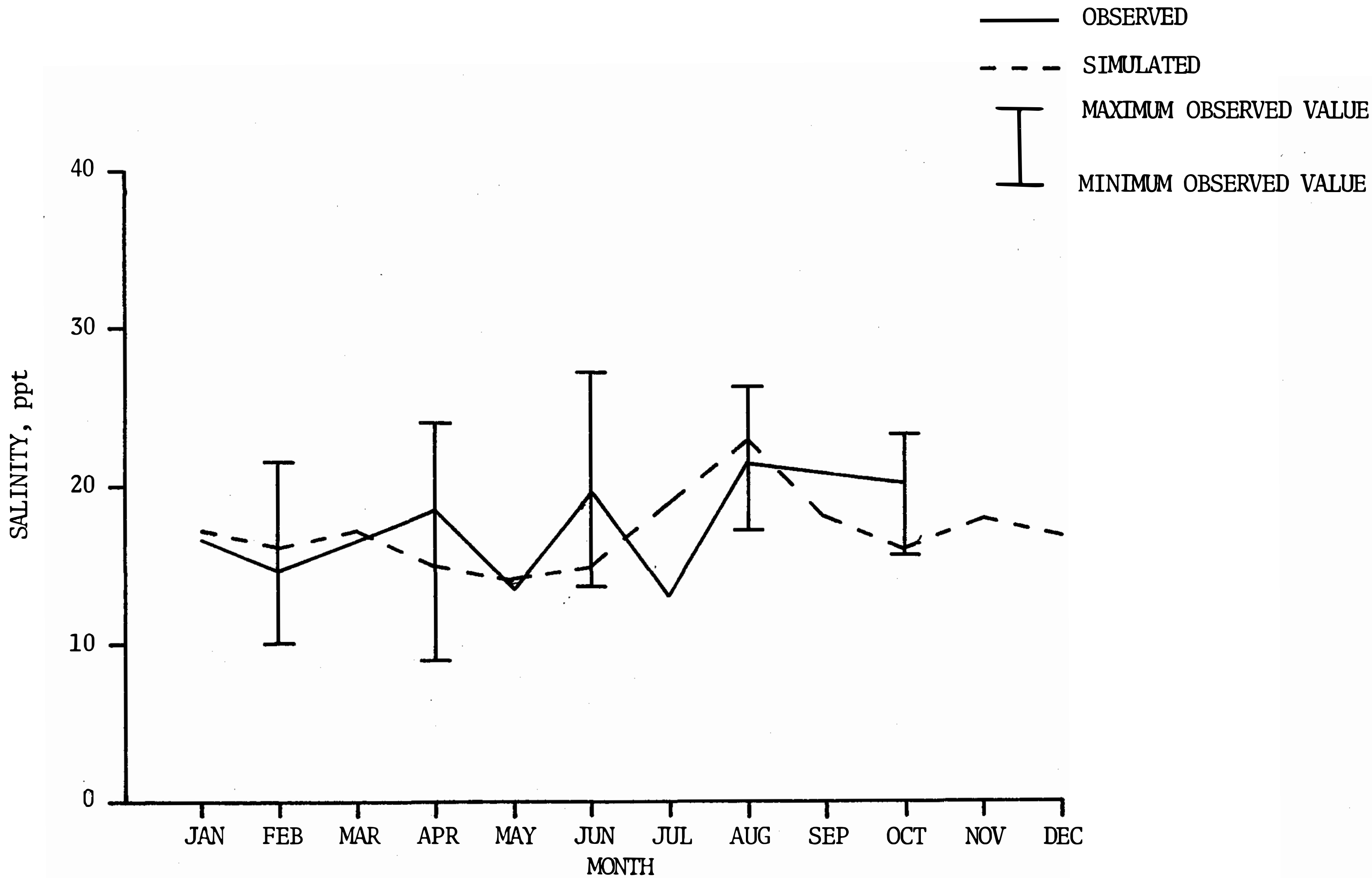


Figure V1.16 Observed and Simulated Salinities in the Eastern Arm of Matagorda Bay.

Table VI.4 Percent Changes in Matagorda Bay as a Result of Implementation of Various Future Reservoir Configuration Alternatives

CASE[a]	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	+6[b] (18)	+6 (17)	+6 (18)	+13 (17)	+21 (17)	+13 (17)	+21 (23)	+48 (34)	+39 (25)	+6 (17)	+11 (20)	+18 (20)
2	+12 (19)	+12.5 (18)	+12 (19)	+13 (17)	+21 (17)	+13 (17)	+26 (24)	+52 (35)	+44 (26)	+6 (17)	+17 (21)	+24 (21)
3	+6 (18)	+6 (17)	+6 (18)	+13 (17)	+21 (17)	+13 (17)	+26 (24)	+52 (35)	+44 (26)	+6 (17)	+11 (20)	+18 (20)
4	+12 (19)	+6 (17)	+12 (19)	+13 (17)	+21 (17)	+13 (17)	+26 (24)	+57 (36)	+44 (26)	+6 (17)	+11 (20)	+24 (21)
5	0 (17)	0 (16)	0 (17)	+7 (16)	+14 (16)	+7 (16)	0 (19)	0 (23)	+6 (19)	0 (16)	0 (18)	+6 (18)
6	0 (17)	0 (16)	0 (17)	+7 (16)	+14 (16)	+7 (16)	0 (19)	0 (23)	+6 (19)	0 (16)	0 (18)	+6 (18)
7	+6 (18)	+6 (17)	+6 (18)	+13 (17)	+21 (17)	+13 (17)	+26 (24)	+48 (34)	+39 (25)	+6 (17)	+11 (20)	+18 (20)
8	+12 (19)	+6 (17)	+12 (19)	+13 (17)	+21 (17)	+13 (17)	+26 (24)	+48 (34)	+39 (25)	+6 (17)	+11 (20)	+18 (20)

a/ Simulated cases detailed in Table VI.2

b/ + indicates increased salinity with respect to "present condition" simulations

( ) indicates simualted salinity in ppt.

increases while the no development cases (5 and 6) result in about a six percent salinity increase in September.

Simulated salinities for the fall months October, November and December, are less impacted than those of the summern months by new reservoir construction demonstrating increases ranging from six percent to 24 percent with the largest salinity increases in December.

DISCUSSION OF RESULTS

Drawing on the simulation results presented in Chapter III and the results demonstrated above, it can be concluded that the tidal alignment between Matagorda Bay and East Matagorda Bay is the dominant force governing the exchange at the junction of the Colorado River and the GIWW. Under meteorological stress conditions resulting in higher water surface elevations in East Matagorda Bay and low flow conditions in the Colorado River, flow is from East Matagorda Bay into the Colorado River with a portion proceeding through the junction and on to Culver Cut where it enters Matagorda Bay. Under an opposite tidal alignment, as deomonstrated in Cahpter III, flow often proceeds northward from Matagorda Bay through Culver Cut and the GIWW into the Colorado River and even into East Matagorda Bay.

Flow conditions at Tiger Island Cut are influenced primarily by the conditions of the Colorado River mouth. After sustained periods of low flow, the mouth may become severely constricted or silted-in, thus forcing more of the river flow through the cut into Matagorda Bay. When proceeding from a period of low flow to a period of higher flow, the resultant increase in the downstream momentum tends to flush the mouth of the river. This results in a smaller percentage of the river flow being diverted through Tiger Island Cut. It must be emphasized, however, that the relationship presented in Figure VI.3 is directly applicable when proceeding from conditions of a constricted river mouth to conditions of lesser constriction. The converse is not necessarily true, as it would require the implementation of sediment transport and sedimentation models to determine the rate of deposition relationships necessary to develop similar curves for the transition from a period of moderate or high flows to a period of sustained low flows.

Flow conditions at Culver Cut are determined by the Colorado River flow-tidal interaction occurring at the junction of the river and the GIWW. Under relatively high flows (>2,000 ft^3/sec), net flow is usually through Culver Cut into Matagorda Bay. At lower flows, direction is dominated by the Matagorda Bay - East Matagorda Bay tidal alignment.

As a result of the flow frequency analyses, it was determined that under all future reservoir alternatives that the freshwater available to Matagorda Bay, through Tiger Island Cut, would be reduced. The reductions in available freshwater ranged from 12 percent, with no new reservoir construction upstream or downstream of Austin before year 2030, to 83 percent with the construction of all five proposed impoundments; Clearview, La Grange, Columbus Bend and Cummins Creek Reservoirs downstream of Austin and Stacy Reservoir Upstream of Austin.

Concurrent with the reductions in freshwater would be an increase in the observed salinities of Matagorda Bay near the Colorado River. The salinity increases would vary widely from season to season with the summer months, July, August and September, being the most impacted. However, the variation in salinity increases between the cases involving reservoir development below Austin was not large, only two parts per thousand during August (the most affected month).

The impacts of these salinity increase on the productivity, as measured by harvest yields, in Matagorda Bay are not easily discernable. To assess the impacts would require more intensive scrutiny of the phase relationships between the seasonal freshwater needs of the eastern arm of Matagorda Bay, the seasonal inflow variation to the bay as a result of upstream water resource development, and the salinity changes resultant from these flows. These analyses are currently being conducted at the TDWR as part of the Agency's Bay and Estuary Studies Program as mandated through enactment of Senate Bill 137 by the 64th Texas Legislature.

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