Hydrological and Biological Studies of the Trinity River Delta, Texas

The preparation of this document was accomplished under contract DACW63-76-C-0179 with the U.S. Army Corps of Engineers, Fort Worth District, P.O. Box 17300, Fort Worth, Texas 76103.

Texas Department of Water Resources

LP-70

September 1978

HYDROLOGICAL AND BIOLOGICAL STUDIES OF THE TRINITY RIVER DELTA, TEXAS

by

Engineering and Environmental Systems Section
Texas Department of Water Resources

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PREFACE

The Texas Department of Water Resources (TDWR) is charged by the Legislature of the State of Texas to study the effects of freshwater inflows upon the bays and estuaries of Texas and to address the freshwater inflow needs for maintaining the biological productivity therein. To accomplish this legislative mandate, the Department has conducted studies to describe and evaluate the hydrologic, chemical and biological relationships in the estuarine environments of the Texas Gulf Coast. As part of this planning effort, the Department and the United States Army Corps of Engineers (USCE), Fort Worth District, undertook a joint investigation to develop statistical and mathematical procedures to relate the physical, chemical and biological characteristics of the Trinity River Delta ecosystems to its hydrologic-hydraulic characteristics. Partial funding was provided by the Federal Government as part of appropriations for the Corps of Engineers' investigation of the Trinity River Basin.

DESCRIPTION OF THE REPORT

The methodology and data base formulations utilized in this study are summarized in Chapter I of this report.

Chapter II describes a methodology for hydrodynamic analyses of river deltas. This mathematical model was applied to the Trinity River Delta to provide predictive capability for routing river and tidal flows. The application of the model to several high and low flow events in the delta is discussed.

Chapter III describes the development of a water quality simulation model for river deltas. This mathematical model simulates the movement of nonconservative biotic and abiotic constituents of flow. The application of this model to the Trinity River Delta is also described.

The presence of toxic compounds in the water entering the Trinity River Delta is evaluated in Chapter IV. Possible sources for the presence of a number of heavy metals and pesticides are identified.

Chapter V contains a discussion of the fisheries in Galveston Bay. The relationships are evaluated between freshwater inflows into the Trinity River Delta and historical commercial harvest in Galveston Bay of a variety of finfish and shellfish species. The effects of salinity concentrations upon the metabolism of several estuarine finfish species are presented.

Chapter VI discusses the significance of the Trinity River Delta in providing nutrients for the aquatic food chain in Galveston Bay. A criteria is specified for the minimum depth and period of delta inundation required to release nutrients from the marsh into the bay waters. A number of flood events were simulated and the resulting inundation and nutrient exchange evaluation.

ACKNOWLEDGEMENTS

This study represents the combined efforts of a number of individuals and organizations. Staff members of the Engineering and Environmental Systems Section of the Texas Department of Water Resources who contributed to this study include Messrs. Alan Goldstein (Chapter IV), Gary Powell (Chapter V), Gordon Thorn, Quentin Martin, Roger Wolff, Nick Carter, Glenn Merschbrock and Ms. Zelphia Severn.

The firm of Espey, Huston & Associates, Inc. (EH&A) was responsible for the major portions of Chapter II, III and VI. Messrs. Larry Hauck, D. B. Adams, Charles Belaire and George Ward were the primary contributors for EH&A.

The University of Texas, Center for Research in Water Resources, also made substantial contributions to the study. Dr. Neal Armstrong and his associates contributed to Chapter IV.

Appreciation is also extended to the U. S. Corps of Engineers, Fort Worth District, for their guidance in this study. Special thanks are extended to Mr. Robert Lyman with the Fort Worth District.

A B S T R A C T

HYDROLOGICAL AND BIOLOGICAL STUDIES OF THE TRINITY RIVER DELTA, TEXAS

The Trinity River Delta in southeast Texas is an important source of nutrients and habitat for the aquatic organisms in Galveston Bay. This report describes the significant physical, chemical and biological relationships in the Trinity River Delta. A mathematical model for simulating the behavior of river and tidal flows through the delta is presented. The accurate replications of observed water surface elevations are simulated using the model for both high and low historical riverine flow conditions. In addition, a mathematical model is developed for evaluating the movement of nutrient materials in the waters flowing through a river delta. This model's application to the Trinity River Delta is also described.

Toxic materials, which suppress the growth of aquatic organisms, are indicated as being present in the waters of the Trinity River Delta. Possible sources for the observed pesticides and heavy metals are delineated.

The importance of the fisheries in Galveston Bay to the commercial fisheries industry is described. Relationships between freshwater inflows and commercial fisheries harvests are discussed for a variety of aquatic species. The impacts of water temperature and salinity changes upon the metabolic activities of several finfish species is also described.

Utilizing nutrient exchange information and hydrodynamic modeling capabilities, a series of simulations are executed to determine the volume and peak discharge rates of freshwater floods on the Trinity River needed to inundate various percentages of the delta area, thereby releasing significant quantities of nutrient material into Galveston Bay.

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CHAPTER I

PURPOSE AND SUMMARY

PURPOSE

The estuarine waters along the Texas Gulf Coast serve myriad purposes including commercial and sport fisheries, oil and gas production, maintenance and propagation of marine life, navigation, commercial shell dredging and recreation. These and other activities, often conflicting in purpose contribute in major ways to the State's economy. The Texas Department of Water Resources views that the goal of the State of Texas with respect to these bays and estuaries is to develop management programs that will assure multi-purpose use of their resources for the economic, recreational, aesthetic and social benefit of the entire State and Nation. A paramount concern to the State is the effect of upstream water resources development on freshwater inflows to the bays and estuaries. The objective of the Department of Water Resources bay and estuary studies is to determine the quantity, quality and timing of freshwater inflows necessary for maintaining the estuarine environments at levels of productivity determined to be desirable and feasible through the development of estuarine management programs.

In the determination of freshwater inflow needs of the estuaries, it is necessary to assess the physical, chemical and biological interactions taking place in the marsh and delta regions which interface between the estuarine and riverine systems. Through the processes of river and tidal inundation and dewatering, these wetlands supply a major portion of the nutrient materials required for biological activities in an estuarine system. Without evaluating the interactions within the marsh and delta systems it is impossible to adequately determine the effects and impacts of freshwater inflows upon an estuary.

The purpose of this study is to describe the development and application of analytical techniques for representing the major physical, chemical and biological interactions taking place in the Trinity River Delta. This deltaic region is associated with Galveston Bay -- the largest and most biologically productive bay system on the Texas Gulf Coast.

SUMMARY

Application of the Inundation Hydrodynamic Model

A mathematical representation of the physical processes governing the behavior of tidal and freshwater flow in the Trinity River Delta was developed. Utilizing field measurements of cross-sectional area, bank and bed elevations and distance relationships, this hydrodynamic model was applied to reconstruct the observed water depths and flows within the Trinity River Delta during two periods each of low and high flow conditions.

Calibration of the hydrodynamic model was undertaken using information obtained during an intensive 36-hour data collection program in December of 1976. The coefficients in the hydrodynamic model were adjusted utilizing these data and were not changed in subsequent simulations of recorded flow events to provide for a verification of the model.

The simulated water surface elevations for the April 14-21, 1976 low flow case corresponded quite well to the observed conditions over the period with generally consistent tidal phasing and amplitude between the simulated and previously observed conditions. The magnitude of the water stage at certain locations, however, was not in agreement with observed data. From the indicated stage variations it seems likely that the basic elevation data for several of the recording tide gauges are approximately 0.3 feet too high. This is most likely due to local land subsidence resulting from the excessive ground water pumpage in the Houston area.

A second low flow condition simulation was undertaken to replicate the observed conditions over the period November 16 through November 23, 1976. Again, simulated water surface elevations were generally in favorable agreement with the observed data. The gauge elevation datum error also appeared in this simulation.

Flood events causing inundation of essentially the entire marsh area occurred during two periods: June 1 through June 16, 1976 and December 12 through December 27, 1976. Utilizing the hydrodynamic model, satisfactory simulation of river stage and tidal amplitude and frequency were obtained for the observed conditions during the June, 1976 flood event. The simulation of the second flood event over the December, 1976 period replicated in general the conditions observed. However, at one gauge point, the Sulfur Barge Canal gauge, the simulated and measured water elevations exhibited poor agreement. It is felt that this error was the result of unmeasured runoff due to a heavy rainfall of approximately five inches in the deltaic region during this time period. Further analysis is required in this case to verify this hypothesis.

The results of these simulations indicate that the model accurately replicates water surface elevation fluctuations. Lack of more extensive flow data prevents an unqualified judgment of the hydrodynamic model's ability to predict absolute levels of flow through the system; however, the model does exhibit the ability to replicate proper flow direction and periodicity.

Development and Application of a Water Quality Routing Model to the Trinity River Delta

The movement of the chemical and biological constituents of flow through a deltaic region is dependent upon a complex interaction of tidal and freshwater influences including advection, dispersion, sedimentation and biological and chemical reactions. Of particular interest is the movement of the nutrient and algal constituents in the delta. To better understand the movements of these constituents, a mathematical mass transport model of the predominant influences on these constituents was developed for the Trinity Delta. The constituents included in this model were organic nitrogen, ammonia, nitrite, nitrate, phosphorus, carbon and two species of algae. First-order decay processes were assumed for all nonconservative constituents. The mass transport model was coupled with the hydrodynamic model previously described to provide a routing of the indicated nutrients and algae through the Trinity deltaic system.

Based upon the seven major habitat areas that were studied and developed nutrient exchange rates, it was possible to determine the composite nutrient exchange rate for the entire delta system. Based on this exchange rate, the mass transport model was utilized to simulate concentrations of nutrients and algae in the delta. The results of the simulation indicated that the model satisfactorily replicated the data in a qualitative sense but was inaccurate quantitatively. Additional data will be required to properly calibrate the model.

Toxicity Studies

Toxic compounds which suppress the growth of aquatic organisms have been observed in the water discharged from the Trinity River into the Galveston-Trinity estuary. The average or maximum concentrations of copper, iron, mercury and zinc, and of some pesticides, particularly DDT in the lower Trinity River, equal or exceed the maximum allowable concentrations specified by the Environmental Protection Agency for wastewater effluent. The source of the heavy metals and pesticides is not known precisely; however, certain agricultural uses, vector spraying and other non-point uses are probable sources for the pesticides. The significance of these high pesticides and heavy metal concentrations, in terms of productivity loss in Galveston Bay or the Trinity River Delta, has not been determined.

Fisheries in Galveston Bay

The deltaic marsh areas adjacent to Galveston Bay serve as a nursery for the juvenile members of many aquatic species. Therefore, these marsh areas are primary contributors to the fish and shellfish populations that are commercially harvested in the Bay.

Statistical analyses indicate that a portion of the year-to-year variation in the commercial harvest of several important fish and shellfish species can be related to freshwater inflows at the Trinity River Delta. Oysters have had their highest historical commercial catches when relatively low inflows were observed during the September through October period of the previous year. Freshwater inflows also appeared to influence the harvest of brown and pink shrimp, but only 30 percent of the annual variation could be explained by freshwater inflow variations at the delta. Seatrout and redfish commercial harvests were found to have a highly variable response to three-year average antecedent freshwater inflows at the delta.

The effect of salinity upon the metabolic activities of several estuarine finfish species was described. It has been determined that spotted seatrout can function over the salinity range of 10 to 45 parts per thousand (ppt), with an optimal salinity concentration for metabolic activities at 20 ppt.

Marsh Inundation Analysis and Freshwater Needs

The Trinity River Delta provides nutrients to the Galveston Bay aquatic ecosystem when sufficient inundation of these marsh areas occur. Based upon the habitat, nutrient exchange rates, and nutrient balance studies previously described, it was determined that the Trinity River Delta would have to be inundated by at least one-half foot over a minimum period of two days to achieve release to the overlying waters of the major portion of the marsh nutrients.

The hydrodynamic model, under average tidal conditions, was utilized to determine the peak-discharge flood event necessary to achieve a one-half foot inundation of the Trinity Delta. It was determined that total inundation would be expected to occur during a peak discharge of 35.0 thousand cubic feet per second (ft^3/sec), which corresponds to a total flood volume of 1.22 million acre-feet. It was also determined that a peak discharge of 25.0 thousand ft^3/sec, with a total volume of 0.61 million acre-feet spread over 31 days would inundate nearly 85 percent of the marsh area.

Biological studies indicate that a winter and a spring inundation of the magnitudes noted above would provide the necessary nutrients for generating the food supply for the growth of juvenile aquatic organisms of commercially important species.

CHAPTER II

DEVELOPMENT, APPLICATION, AND VERIFICATION OF A HYDRODYNAMIC MODEL OF THE TRINITY RIVER DELTA

SITE DESCRIPTION

The lower reach of the Trinity River (Trinity Estuary and Delta) is a flat, low-lying marshy area containing interconnected lakes and channels. A map of this area is shown in Figure II-1. There is one major freshwater source to the delta area, the Trinity River which flows into Trinity Bay. The deltaic marsh area may be considered as three separate units; an east marsh, a south marsh, and the Wallisville Reservoir marsh. The east marsh is located along the east bank of the Trinity River. Both river stage and tidal elevation are the major factors in controlling water levels in this marsh. South of both the Trinity River and Old River Lake is the south marsh in which water levels are determined almost entirely by the tides. Located in the west area of this southern marsh is the duck pond area which has been leveed from the remainder of the marsh. Several channels entering this area contain gates which are used to regulate flow into or out of this area. The Wallisville Reservoir marsh is located west of the Trinity River and north of Old River Lake. Tidal influence in this marsh is propagated through two breaches in a levee running along the south bank of Old River Lake. The larger opening, the east breach is referred to as Long Island Bayou, and the smaller opening, the west breach, is called Cotton Bayou. Water exchange between the Trinity River and Wallisville Reservoir marsh occurs at the north end of the marsh through the Cutoff and the southeast end of the marsh through Old River Cutoff. During elevated river stages, the north marsh area may be breached at several points, in particular at Picketts Bayou.

FORMULATION OF HYDRODYNAMIC MODEL

As a prerequisite to the evaluation of nutrient transport through deltaic river marshes, it is necessary to have the capability to adequately describe the complex interaction between tidal inundation and the routing of freshwater flow from the river through the marsh systems. To provide the capability of a more detailed analysis of deltaic marsh systems, the TDWR instituted a program of field measurements and mathematical model development in the key marsh systems of the Texas coast. Hauck, et. al. (1976) described the development and application of a hydrodynamic model for the Lavaca and Guadalupe Deltas. This

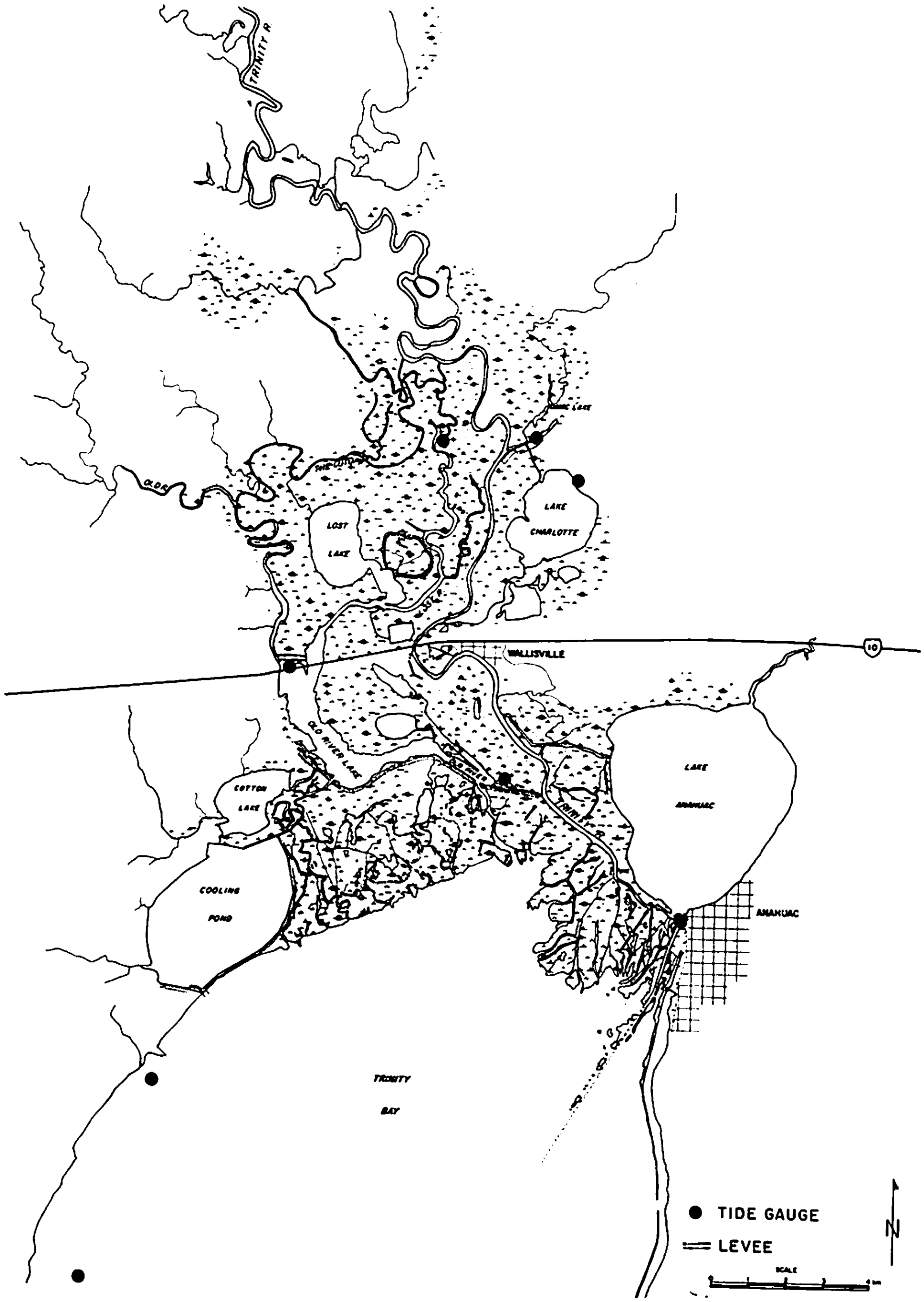

Figure II-1
Trinity Delta System
Source: Hauck, 1977

model addressed both low flow conditions and the condition of large-volume, highly transient floods.

In this study, Contractor Espey, Huston and Associates, Inc. (EH&A) applied the mathematical model to the deltaic system of the Trinity River. Of particular concern in the modeling effort was the inundation of the deltaic marsh areas during high tides and/or moderately high streamflow conditions. The deltaic system that was modeled consists of areas of low relief with narrow, interconnected channels, some of which flow only at higher water levels. The system is fed from upstream by inflow from a river, and is terminated downstream by an open-water bay area. From the bay 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, usually the first streamflow gauging station, to beyond the delta mouth to the first point in the bay 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 component of the channels. This characteristic prevails even when inundation of the flood plain occurs, because the inundated areas function principally as stroage 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 disjunction of channels is appropriate.

The principal factors governing the flow in this type of deltaic system, which was 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 flood plains;
(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 are introduced as boundary conditions. For this study, the direct effect of wind stress upon currents within the delta was neglected. However, meteorological effects 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 Trinity Delta system are discussed in Hauck (1977).

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

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) + gA\frac{\partial H}{\partial x} + \frac{gn^2 Q|Q|}{2.22\,AR^{4/3}} = 0 \qquad \text{(II-1)}$$

$$\frac{\partial H}{\partial t} + \frac{1}{B}\frac{\partial Q}{\partial x} - \frac{Qf}{As} = 0 \qquad \text{(II-2)}$$

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

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

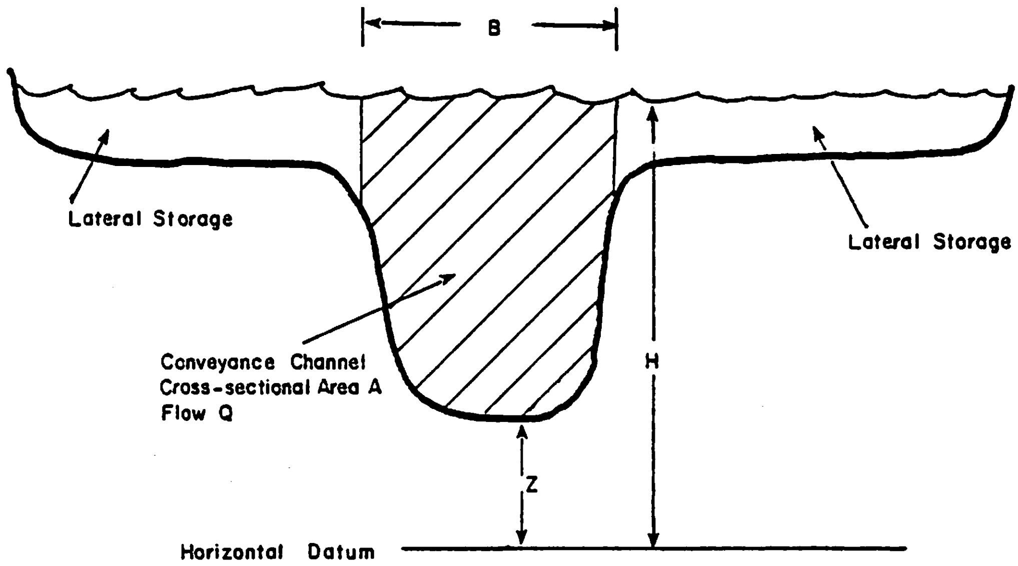

Figure II-2. Definition of Variables in Cross Section
(Source: Hauck, 1977)

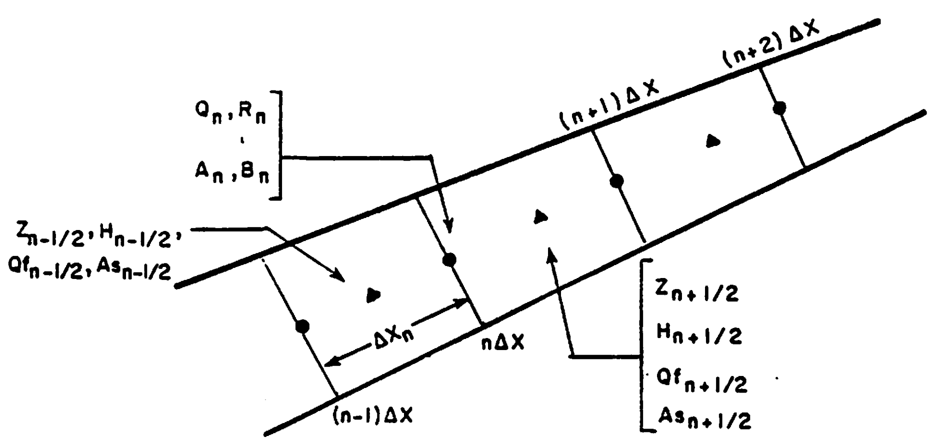

Figure II-3. Variable Definition in Finite-Difference Segmentation for Hydrodynamic Model (Source: Hauck, 1977)

The basic equations (II-1) and (II-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 II-3. Simultaneous solution of the finite difference form of equations (II-1) and (II-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 flood plains, thus accounting for the additional water storage volume in the flood plain. 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, either As_1 or As_2 is 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 Trinity Delta, the upper conditions were specified by flow with Q = 0 or Q = 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 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 or engulfing 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 numerical 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.) In the southwest corner of the Trinity Delta, gates are located in channels in the Duck Pond area.

Also, in the Trinity Delta, at sufficiently high water levels, flow may occur between two water bodies which are separated by dry land at lower water levels. These transient channels are modeled in an identical manner to the closed salt-water barriers. Flow does not occur through transient channels until the water level on one or both sides of the transient channel exceed some specified 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 by Hauck (1977).

APPLICATION OF HYDRODYNAMIC MODEL

The segmentation of the lower Trinity River for computer modeling purposes is presented in Figures II-4 and II-5. All major channels and open water area are included as one-dimensional conveyance channels, and a flood plain (or marsh) is associated with each channel. Together the conveyance channel and flood plain constitute a section.

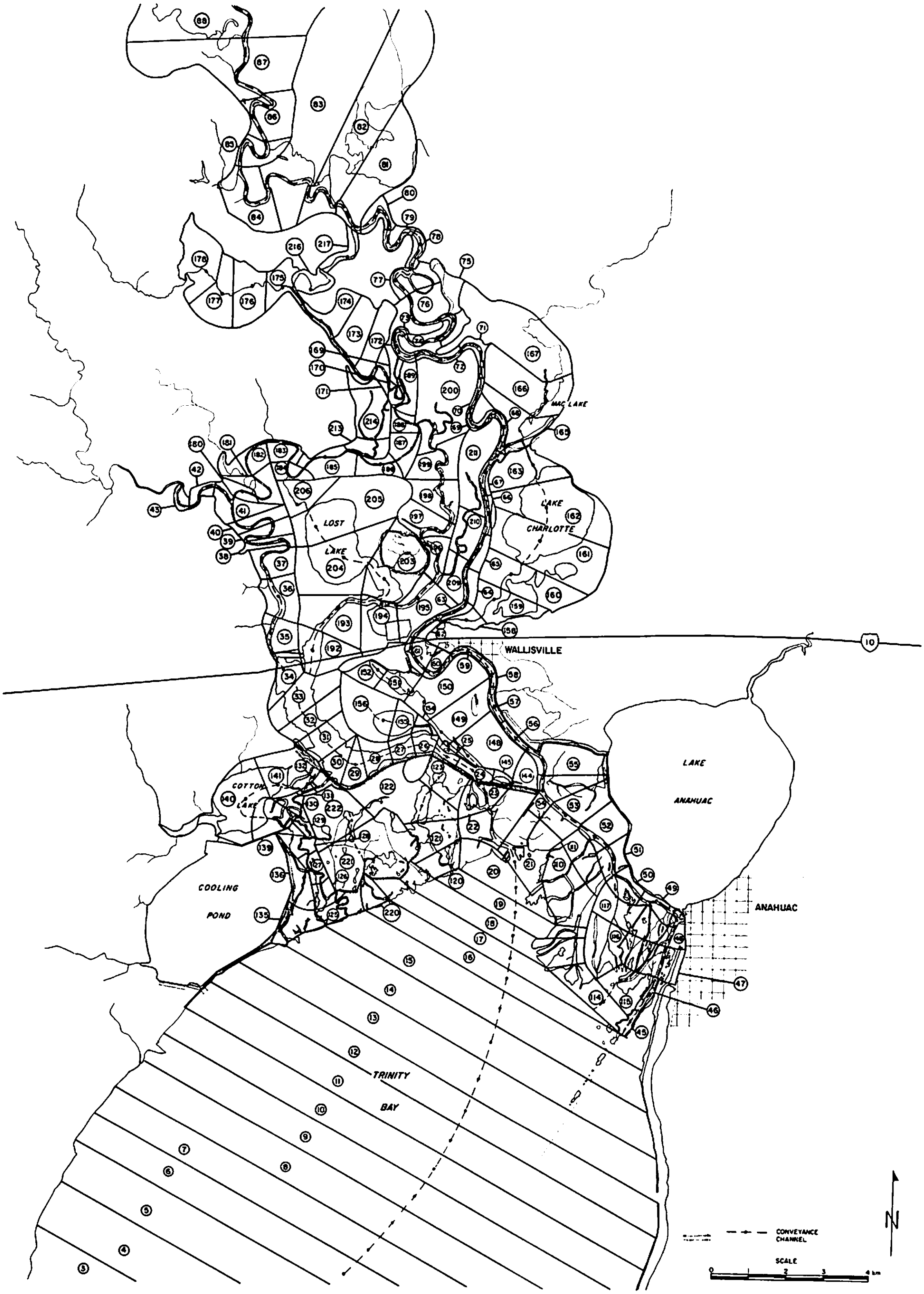

Figure II-4. Trinity Delta System with Lower Portion of Segmentation (Source: Hauck, 1977)

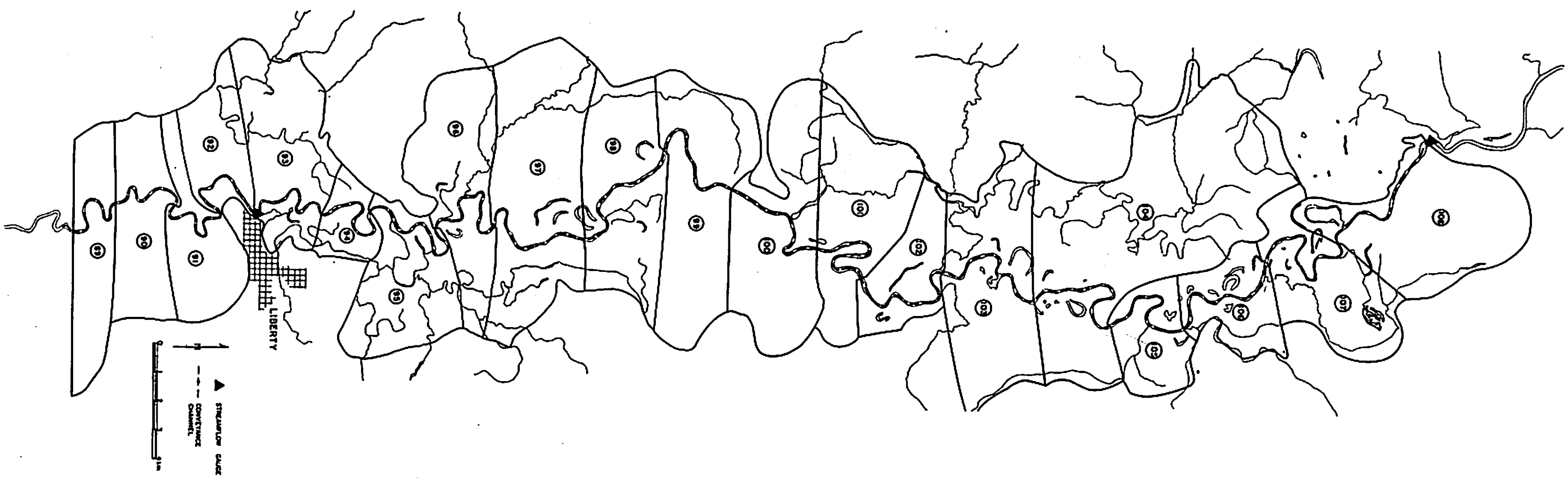

Figure II-5. Trinity River With Upper Portion of Segmentation
(Source: Hauck, 1977)

Several tide and flow gauging stations are located in the area included in the model segmentation. On the Trinity River there are USGS gauging stations at Romayor and at Liberty as shown on the map of the upper portion of the segmentation (Figure II-5). Located in the marsh and bay area (Figure II-1) are the tide gauges at Morgans Point (Barbours Cut), at Point Barrow, on Anahuac Channel at Anahuac, on the Old River Cutoff Channel, on the Lost River near Wallisville, on Lake Charlotte, on the Sulfur Barge Channel and at the confluence of the Old and Lost Rivers (Old River at Mont Belview).

Physiographic input is required for each section to describe channel shape and size of flood plain. 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 Trinity Delta these data were obtained from surveys conducted by USCE for the proposed Wallisville Reservoir supplemented with data gathered by TDWR. The data consisted of depth profiles across conveyance channels at selected locations and level transects across the flood plain at selected lines. In addition, a contour map of a majority of the marsh with one-foot contours was obtained from USCE. The development of the necessary model input from this physiographic data constitutes the most tedious and time-demanding input requirement.

To facilitate the incorporation of accurate information into the model, the upstream end of each section was chosen, whenever possible, to correspond to the position of either a USCE or TDWR survey cross-section. From the survey results and drawings, the channel width and cross-sectional area were 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 flood plain results, were determined from either the appropriate USGS quadrangle map or from the USCE contour map of the Wallisville Reservoir area. The channel length and total surface area subject to inundation of each section was measured from the appropriate USGS 7.5-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, tidal and wind conditions, one value of n for each section was selected. The values of n in the final segmentation ranged from 0.015 to 0.030. 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 0.030 for the sections of the upper reach of the Trinity River, which are normally shallower and narrower than the lower, tidally influenced portions of the Trinity River.

Additional input requirements are streamflows and diversions from the system. The upstream boundary of the segmentation (section 108) corresponds to the location of the USGS streamflow gauge at Romayor. Therefore a time history of flow at the upstream boundary was obtainable from the gauged flows. However, due to significant freshwater inflows and diversions below the Romayor gauge and damage to the gauge during a flood, the Trinity River flow data at Romayor were supplemented with data from the gauge at Goodrich (located 23 river miles above the segmentation) and the gauge at Liberty (located at section 92). For some simulations, the additional inflow between the Romayor and Liberty gauges was estimated and added as an input hydrograph to section 95. In addition, significant water is seasonally diverted for irrigation purposes from the Trinity River below the Liberty gauge. For modeling purposes, a single diversion was assumed at section 86. The withdrawal for each period simulated was calculated by averaging the monthly water use records for the lower Trinity for the two most recent years for which data were available (1974 and 1975) and assuming this was the withdrawal rate for the same month in 1976, which is the year of all simulations presented in this report.

The remaining input data and lower boundary condition is the tidal record for the simulation period from either the Morgans Point Tide Gauge (section 2) or the Point Barrow Tide Gauge (section 8). It was not possible to obtain a continuous tide record for all periods to be simulated from either one of these two gauges, so the tide record from the gauge which was recording during the period to be simulated was input as the driving tide. The tide values are supplied as hourly input and the model performs a linear interpolation between the hourly values to determine tide values for any intermediate time.

MODEL VERIFICATION

Verification Data

The periods chosen for simulation were selected based on tides and freshwater inflow and on the availability of data to verify the velocities and water depths predicted by the model. The availability of adequate verification data restricted the period of study to October 1975 through February 1977. The majority of verification data consists of water elevations (river stage or tide record) from continuous recording gauges operated by the USGS, USCE and TDWR. From October 1975 through September 1976, water elevation records were available from the gauge at the confluence of the Old and Lost Rivers (section 34) and from the gauge on the Trinity River at Liberty (section 92). Beginning October 1976 through February 1977 tide records were available from the gauges on Anahuac Channel at Anahuac (section 48), on the Old River Cutoff Channel (section 24), on Lake Charlotte (section 165), on the Sulphur Barge Channel (section 162) and on the Lost River near Wallisville (section 200). Unfortunately, the tide records from the Lake Charlotte and Lost River gauges were often unuseable as verification data. The Lake Charlotte gauge does not record water elevations below 1.1 ft. (MSL) and the Lost River gauge was not operating reliably during a majority of the period. Daily stage readings for the stream gauge at Liberty were also available for this time period. In addition, for January 1977 tide data are available from the Old River gauge near Mont Belview (same location as Old and Lost River gauge, section 34).

In addition, from 30 November through 2 December, 1976, an intensive hydrologic and biologic study was conducted jointly by USGS, TDWR and EH&A personnel. For various portions of this three-day period, instantaneous velocity and flow measurements were taken at time intervals of from one to six hours at the following locations: Old River Cutoff (section 144), Trinity River above Jack's Pass (section (53), Long Island Bayou above mouth (section 22), Long Island Bayou at levee breach (section 23), Anahuac Channel (section 47), Cove Bayou (section 120), Cross Bayou (section 125, Lake Pass (section 158), Cotton Bayou (section 132), Lost River near Interstate Highway 10 (section 192), Old River near Interstate Highway 10 (section 33), Mac Lake (section 165) and the Cutoff (section 169.

Low Flow Simulations

To initially test the segmentation of the physical system, the hydrodynamic model was used to simulate two low flow equilibrium periods. "Low flow equilibrium" or "steady state" refers to the condition when the streamflow over the desired period was nearly constant. Such a condition eliminates the streamflow variability in the system, and permits an assessment of how adequately the model replicates tidal variations through the system. Because of the large size of the system being simulated, it takes a "start-up time" of 24 to 36 hours for the simulated system to recover from the inaccuracies of the assumed initial conditions and to show proper response to the boundary conditions and mathematical equations. For this reason the first 24 hours of each simulation is not presented.

The first low flow equilibrium period selected was from 14 April through 21 April 1976. During this time period, the flow in the Trinity River at Romayor was approximately 1,600 ft^3/sec with an additional 40 ft^3/sec of inflow determined as entering below this gauging location, and diversions totaling 500 ft^3/sec were calculated to occur below Liberty. The tide at Morgans Point during this time was initially semidiurnal changing to diurnal (see Figure II-6). There was a strong southeast wind during most of this period, particularly on 15 through 18 April, while a light northerly wind prevailed on 21 April. The wind influence on the bay results in the water elevation set-up on 15 through 18 April.

The results of the simulation were compared with the measured water elevation records at the Liberty gauge and the Old and Lost Rivers gauge as shown in Figure II-7 and II-8, respectively. The measured and simulated river stages at Liberty compare favorably, though only minor tidal influence is observed at this location. The major discrepancies occur on the first and last days of the simulation. On the first day, the error is due to the "start-up time" of the model, that is, the river flow is still adjusting from the assumed initial conditions. As the boundary inflow from the Romayor gauge (section 108) reaches the Liberty gauge location (section 92), an increase to approximately the proper water elevation is observed. The last day of simulation, 21 April, is the beginning of passage of a large flood. The increase in stage was not adequately accounted for in this steady-state case. The simulated and recorded tides for the gauge at the Old and Lost Rivers also compare favorably. The phase error is small, approximately one hour. Tidal amplitudes also are adequately simulated. For a majority of the simulation period the error between simulated and recorded tides in less than 0.2 ft, with a maximum discrepancy of 0.5 ft. occurring on 18 April.

The second low-flow equilibrium case selected was the period from 16 November through 23 November 1976. During this period the Trinity River gauge at Romayor was not recording, but based on the flows at Goodrich gauge located 23 river miles above the segmentation, a river flow of 1,200 ft^3/sec was determined as the input at the upper boundary of the segmentation (section 108). Diversions for this period were calculated to be only 60 ft^3/sec. Some additional runoff was required due to a 1- to 2-inch rain which occurred over the lower Trinity watershed on 19 and 20 November. Because of tidal influences at the Liberty gauge for river flows below 10,000 ft^3/sec, the water stage records at Liberty could not be used as a completely reliable source to estimate flows for this low water period. But in lieu of any other information and based on the 1-ft. river stage rise from 20 through 22 November, a hydrograph with a peak discharge of 1,000 ft^3/sec was input at segment 95. This additional inflow is not of significant magnitude to appreciably alter most of the tide records in the deltaic system, so this simulation is still considered a low-flow equilibrium case. The driving tide as recorded at Point Barrow during this period was initially semidiurnal changing to diurnal (see Figure II-9) and winds were light and from the north.

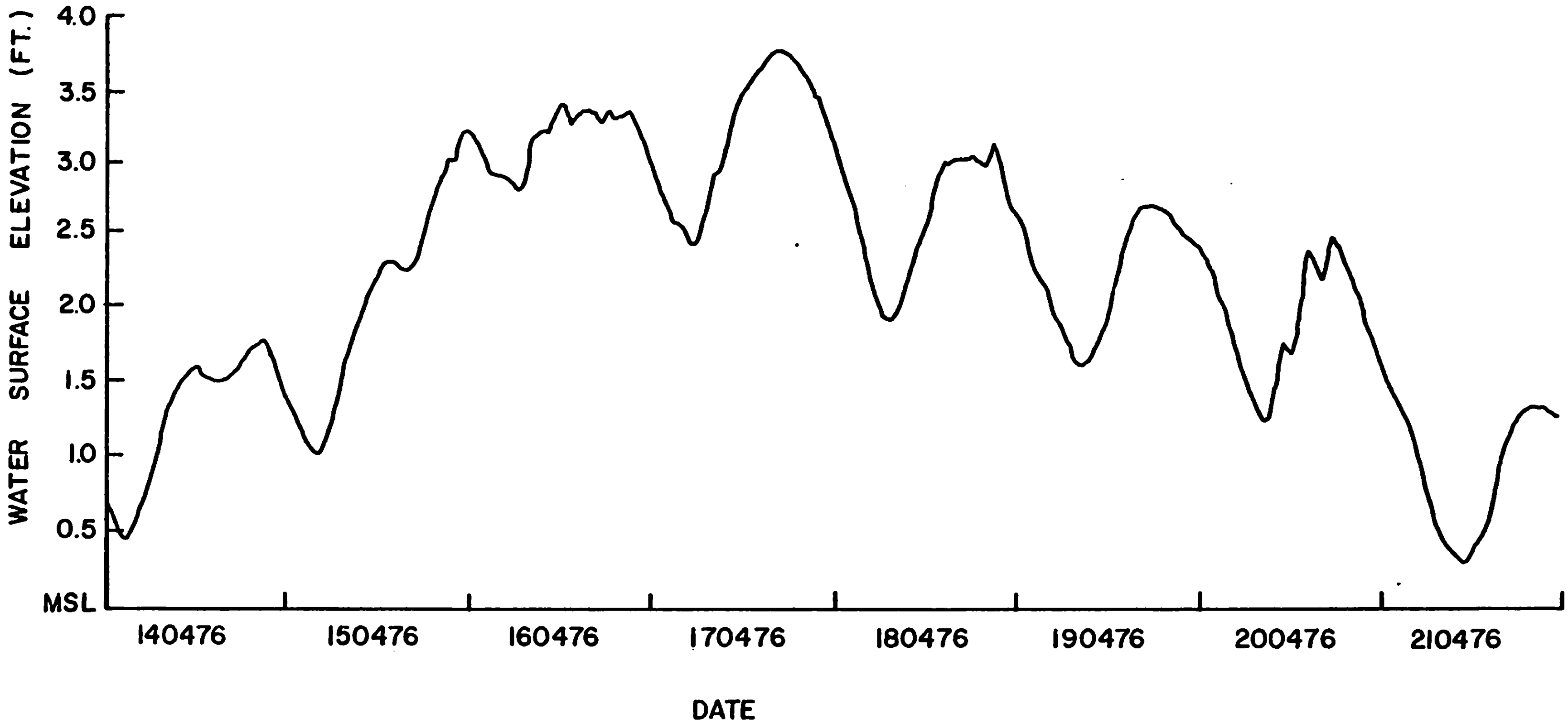

Figure II-6. Driving Tide Record at Section 2, Morgans Point Gauge
(Source: Hauck, 1977)

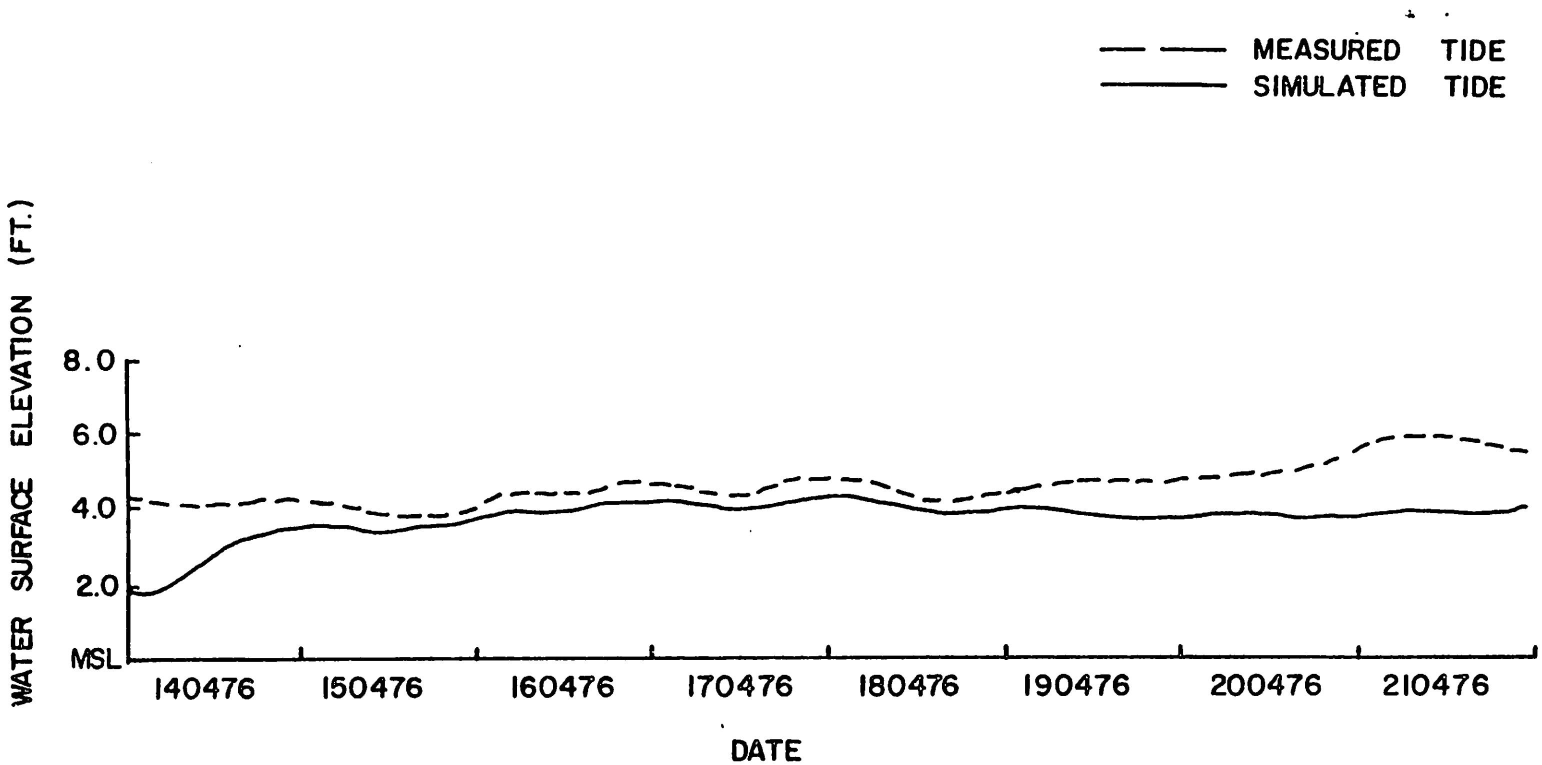

Figure II-7. Water Stage Record at Section 92, Trinity River at Liberty Gauge (Source: Hauck, 1977)

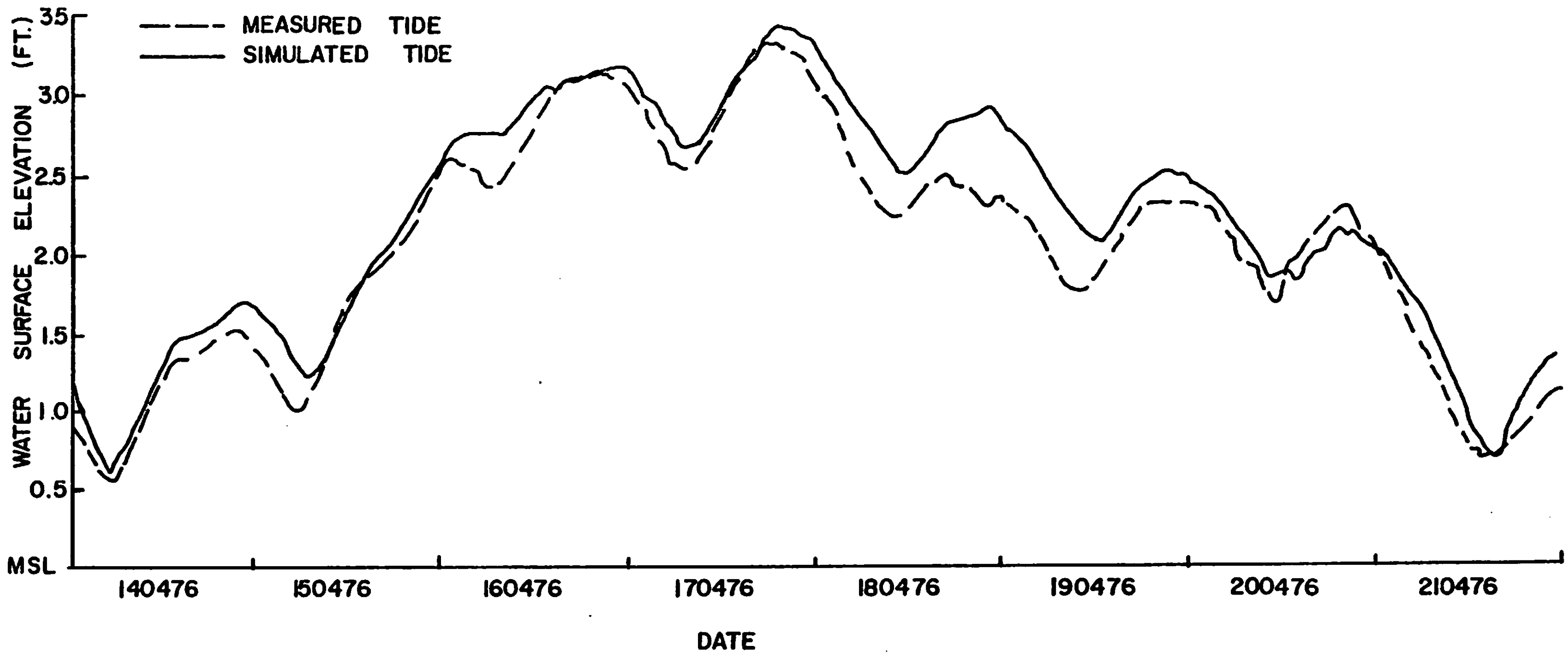

Figure II-8. Tidal Elevation Record at Section 34, Old and Lost River Gauge (Source: Hauck, 1977)

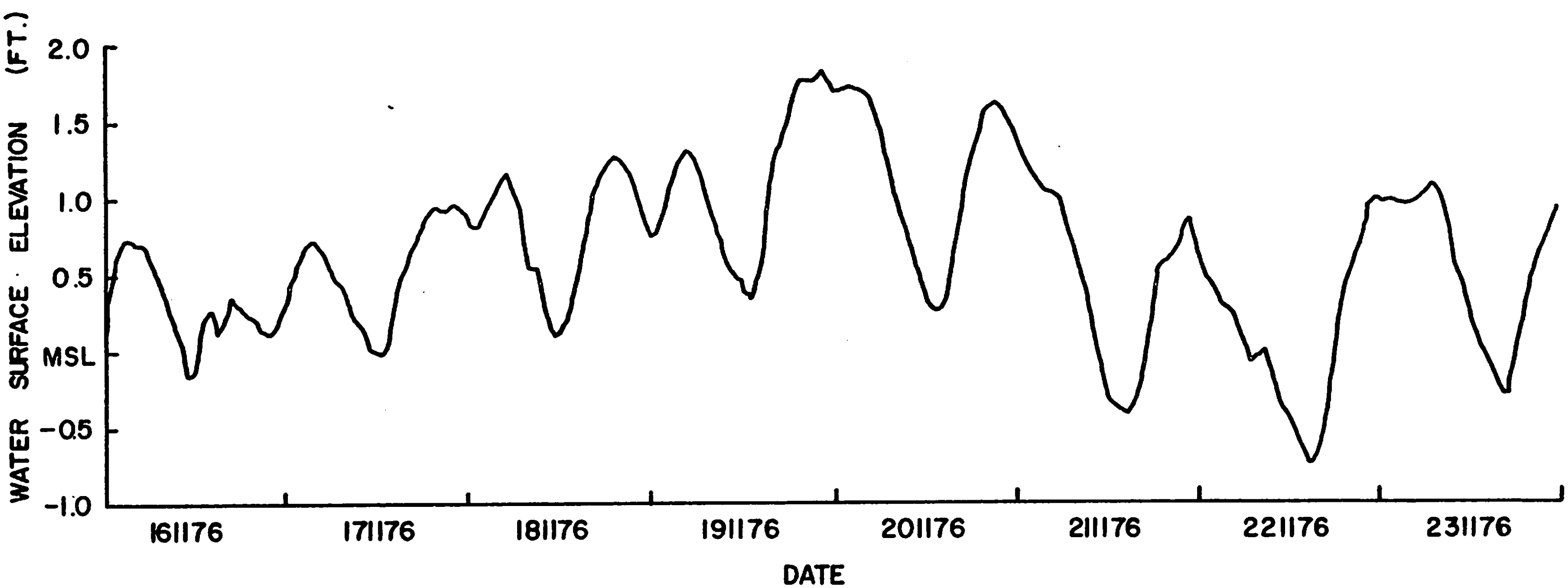

Figure II-9. Driving Tide Record at Section 8, Point Barrow Gauge
(Source: Hauck, 1977)

The results of the simulations were compared with the tidal records for the Old River Cutoff Channel gauge, the Anahuac Channel gauge and the Sulphur Barge Channel gauge as shown in Figures II-10 through II-12. The Lake Charlette gauge did not properly record the tides of this period which were almost entirely below the elevation this gauge can record, and the Lost River gauge was not functioning properly during this time interval. So neither gauge was employed for verification data.

The simulated and recorded tides for the Old River Cutoff and Anahuac Channel gauge locations, Figures II-10 and II-11, respectively, compare favorably as far as tidal amplitude and phase. However, a datum error of approximately 0.3 ft. is apparent at both locations. The measured tide is consistently lower than the simulated tide at both gauges. A comparison of the model driving tide from the Point Barrow gauge with these two gauges also indicates that the driving tide is higher than the measured tides at the Old River Cutoff and the Anahuac Channel gauge. It seems unlikely during this period of light winds that mean water elevations would decrease in the upstream direction, as this implies. It is more likely that there is a datum error, resulting from subsidence of gauges or from a survey error when setting gauge datums.

The simulated and recorded tides at the Sulphur Barge Channel gauge compare satisfactorily (see Figure II-12). The simulated tide lags the measured tide by approximately two hours. For the first four days tidal amplitudes are well simulated, though for the last four days significant errors are apparent. The simulated tidal troughs are deeper than the measured troughs and this error may be due to ungauged local runoff dampening the tidal amplitude and raising the water elevation in the Sulphur Barge Canal.

Flood Simulations

During the study period, two floods occurred and caused an appreciable rise in water elevation in the delta region. Though these floods inundated essentially the entire marsh area, the conditions of one-dimensional flow as implicitly assumed in the computer code were apparently not violated in the physical system. As for the low-flow equilibrium cases, the first day of the simulation was omitted because of the required "start-up time". Because of the long duration of both of these floods, three to four weeks, only that portion of the flood which resulted in significant influences on the delta was simulated.

The first of these floods was simulated as the period 1 June through 16 June 1976. This simulation case represents a nearly ideal flood case from a meteorological view point. Heavy rains of as much as five inches occurred over much of the Trinity watershed on 31 May and 1 June, and no other significant rains occurred

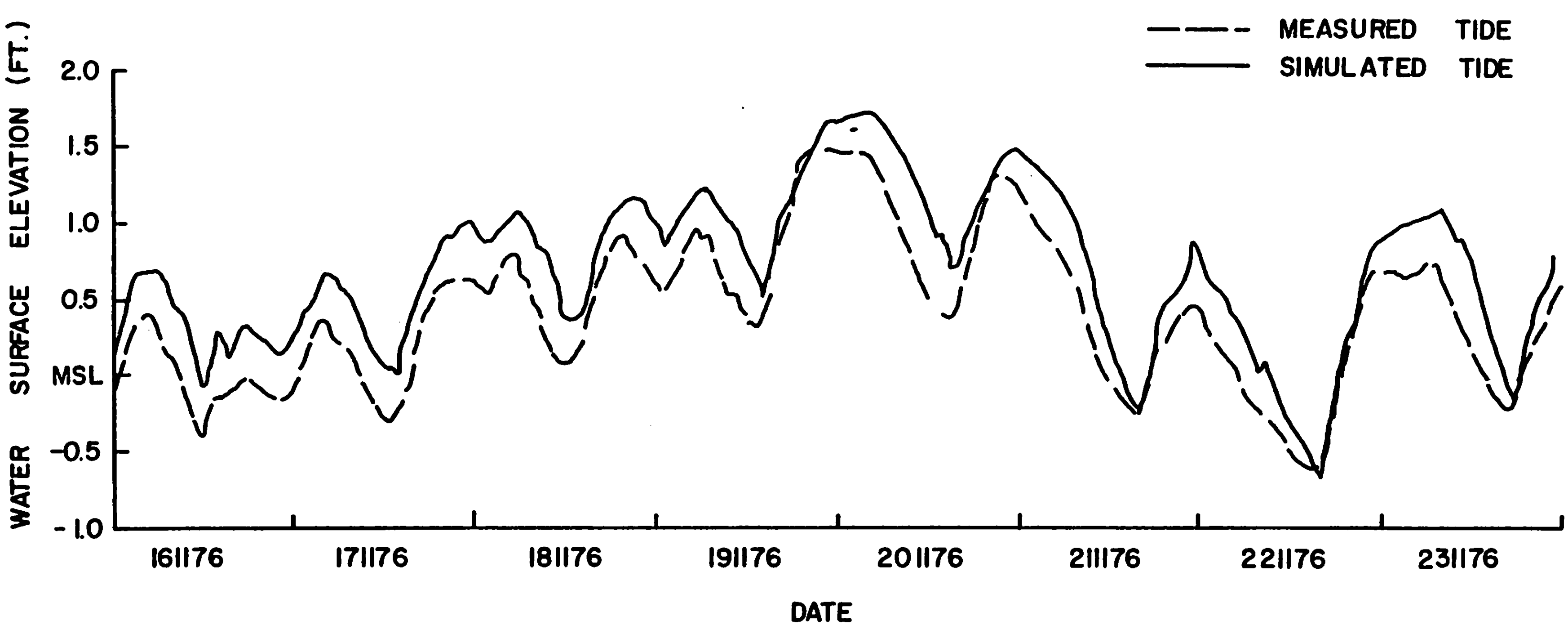

Figure II-10. Tidal Elevation Record at Section 24, Old River Cutoff Channel Gauge (Source: Hauck, 1977)

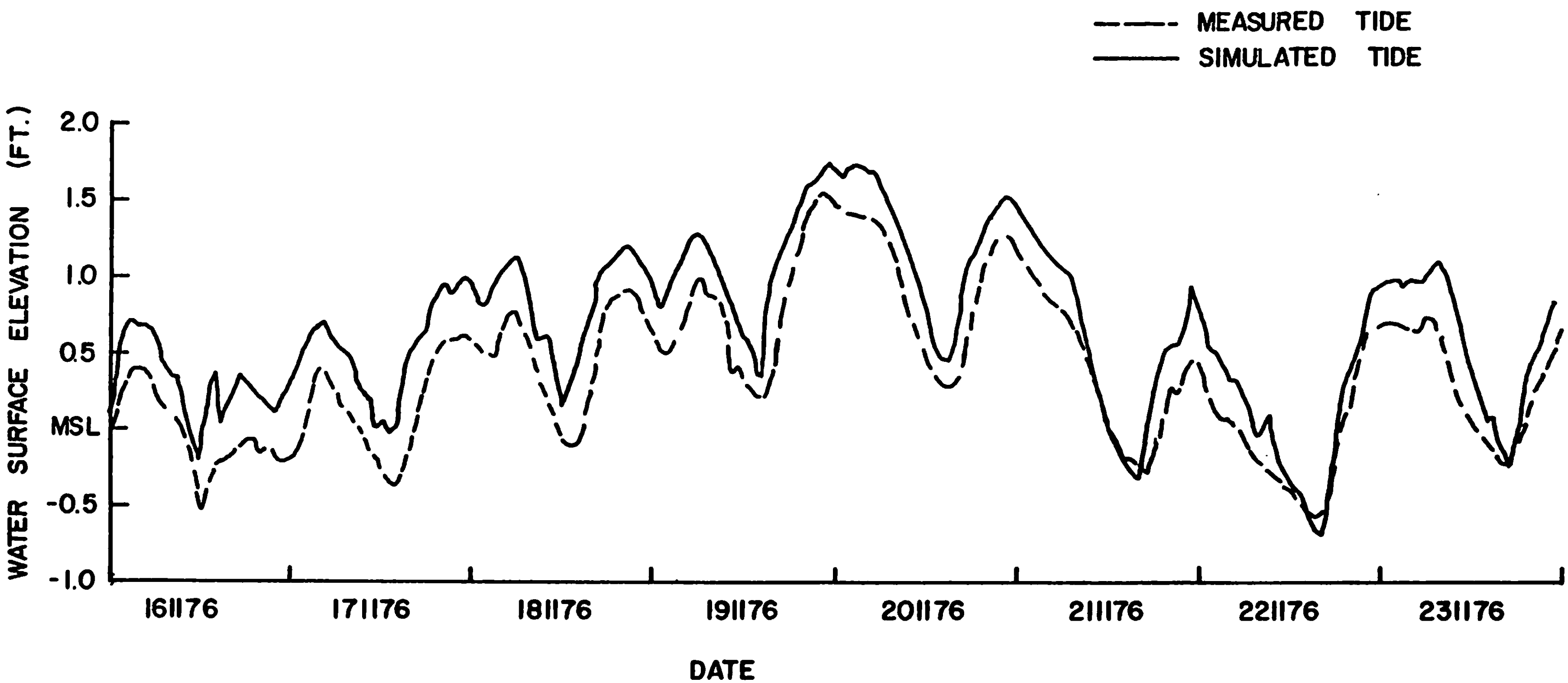

Figure II-11. Tidal Elevation Record at Section 48, Anahuac Channel Gauge (Source: Hauck, 1977)

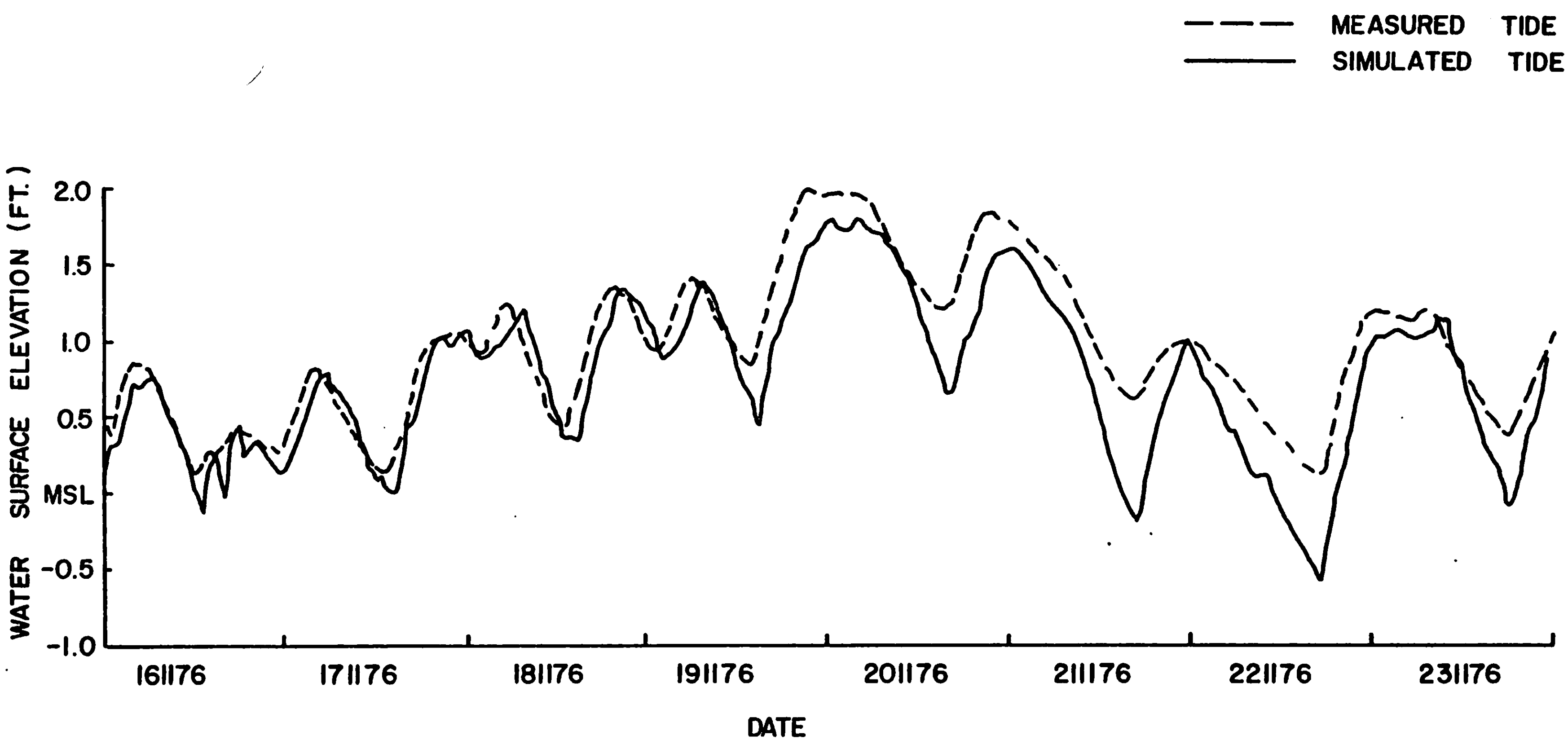

Figure II-12. Tidal Elevation Record at Section 165, Sulphur Barge Channel Gauge (Source: Hauck, 1977) during the remainder of the simulation period. So errors due to rainfall on the lower watershed during the flood per se are minimal. For the entire period winds were of moderate speed, from the northeast on the first nine days and shifting to the southeast for the last seven days. The driving tide at Morgans Point during this time was initially diurnal changing briefly to semidiurnal and then returning to diurnal (see Figure II-13). Because special calculations were performed by the USGS, flows in the Trinity at Romayor plus estimates of the additional inflow occurring between the Romayor and Liberty gauges were available. A maximum daily-average flow of 33,200 ft^3/sec was measured at the Romayor gauge on 3 June. A listing of the daily flows used as input to the model are presented in Table II-1. Withdrawal at section 86 for irrigation purposes was calculated to be 1,000 ft^3/sec.

The comparison of simulated and measured water elevations for the Liberty gauge and the Old and Lost River gauge are shown in Figures II-14 and II-15. The flood passage as recorded at the Liberty gauge is satisfactorily simulated. The simulated water elevation does show significant error over the last four days, 13 through 16 June; however, for the remainder of the period, recorded and simulated elevations are within two feet. The simulated and measured water elevations at the Old and Lost River gauge also compare favorably. The simulation does indicate rising water elevations before they were measured, particularly 3 through 5 June. The peak water elevation and its duration are simulated quite accurately as is the gradual subsidence of the flood.

The simulated flood plain levels in the delta at four day intervals on 1, 5, 9, 13 and 17 June are presented in Figures II-16 through II-20, respectively. This sequence of figures indicates the water level above bank elevation at hour 0000 CST for each day mentioned and depicts the rise and subsequent fall of water levels with the passage of the flood. On 1 June (Figure II-16) moderate levels of inundation are indicated because of the relatively high tides of this period. By 5 June (Figure II-17) flood waters are causing increased water levels in the upper delta and along the Trinity River, and by 9 June (Figure II-18) the maximum water levels are occurring throughout the delta area. The 13 June and 17 June figures indicate water levels as the flood waters recede.

The second flood was simulated as the period 12 December through 27 December 1976. Due to heavy rainfall of approximately 5.0 inchs on the deltaic region during this period and because the streamflow gauge at Romayor was inoperative, it was difficult to estimate flow on the Trinity River. The gauged flow from the Goodrich gauge was used as the head-water flow condition at section 108 and a maximum daily-average flow of 26,800 ft^3/sec was recorded on 16 December. Based on the daily staff readings at Liberty, it was apparent that considerable inflow occurred between the

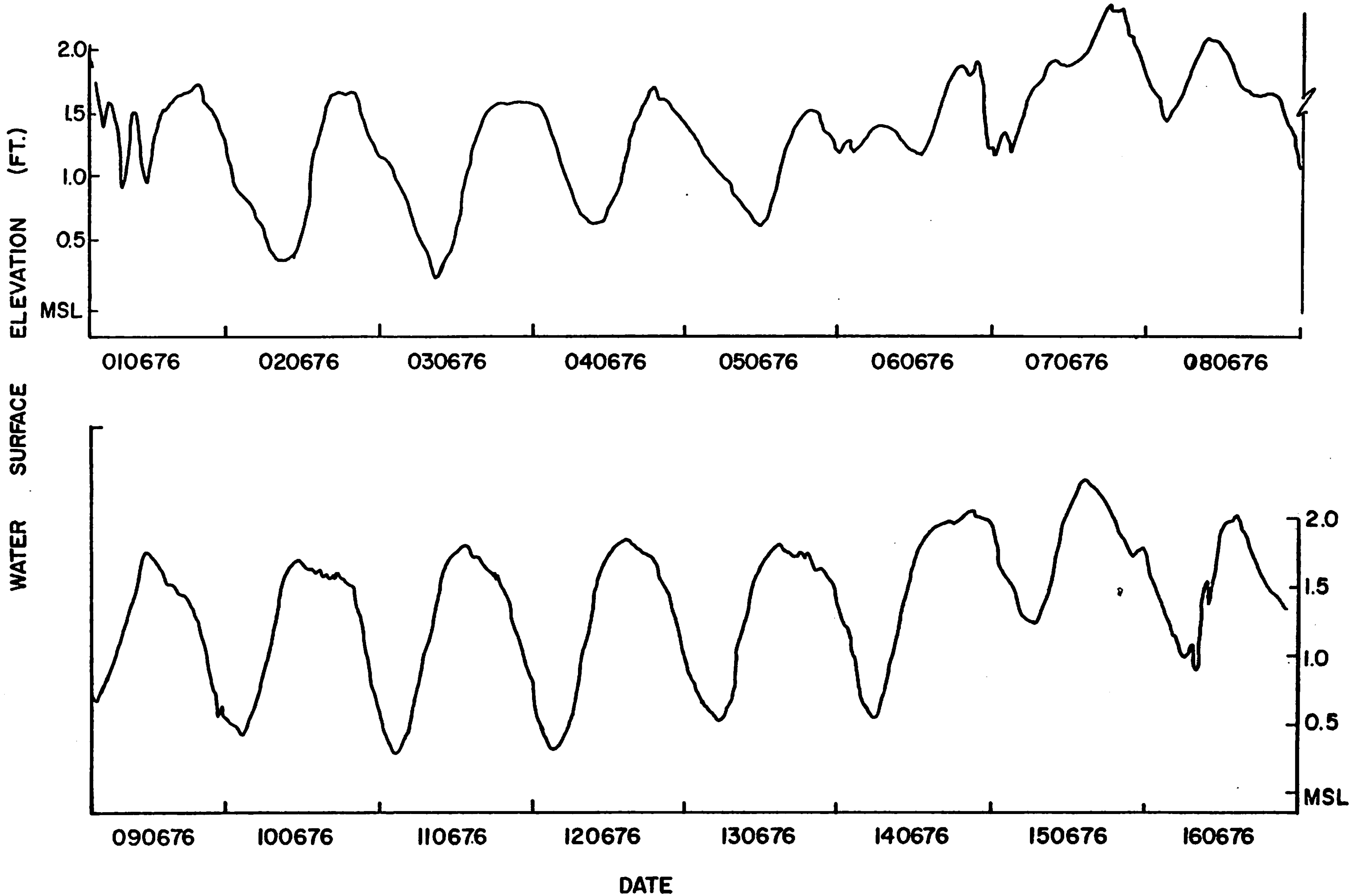

Figure II-13. Driving Tide Record at Section 2, Morgans Points Gauge (Source: Hauck, 1977)

TABLE II-1

FLOW RECORDS FOR TRINITY RIVER

1-16 June 1976[1]
(Source: Hauck, 1977)

Date	TRINITY HEADWATER Segment 108 ft^3/sec	ADDITIONAL INFLOW Segment 95 ft^3/sec
1 June	16,900	1289
2 June	31,500	1384
3 June	33,200	1050
4 June	32,800	1035
5 June	31,800	983
6 June	29,100	947
7 June	27,600	968
8 June	24,900	760
9 June	23,100	660
10 June	21,100	454
11 June	17,800	240
12 June	13,800	137
13 June	9,010	95
14 June	5,830	79
15 June	3,780	83
16 June	3,730	154

[1] All flows from USGS special computations.

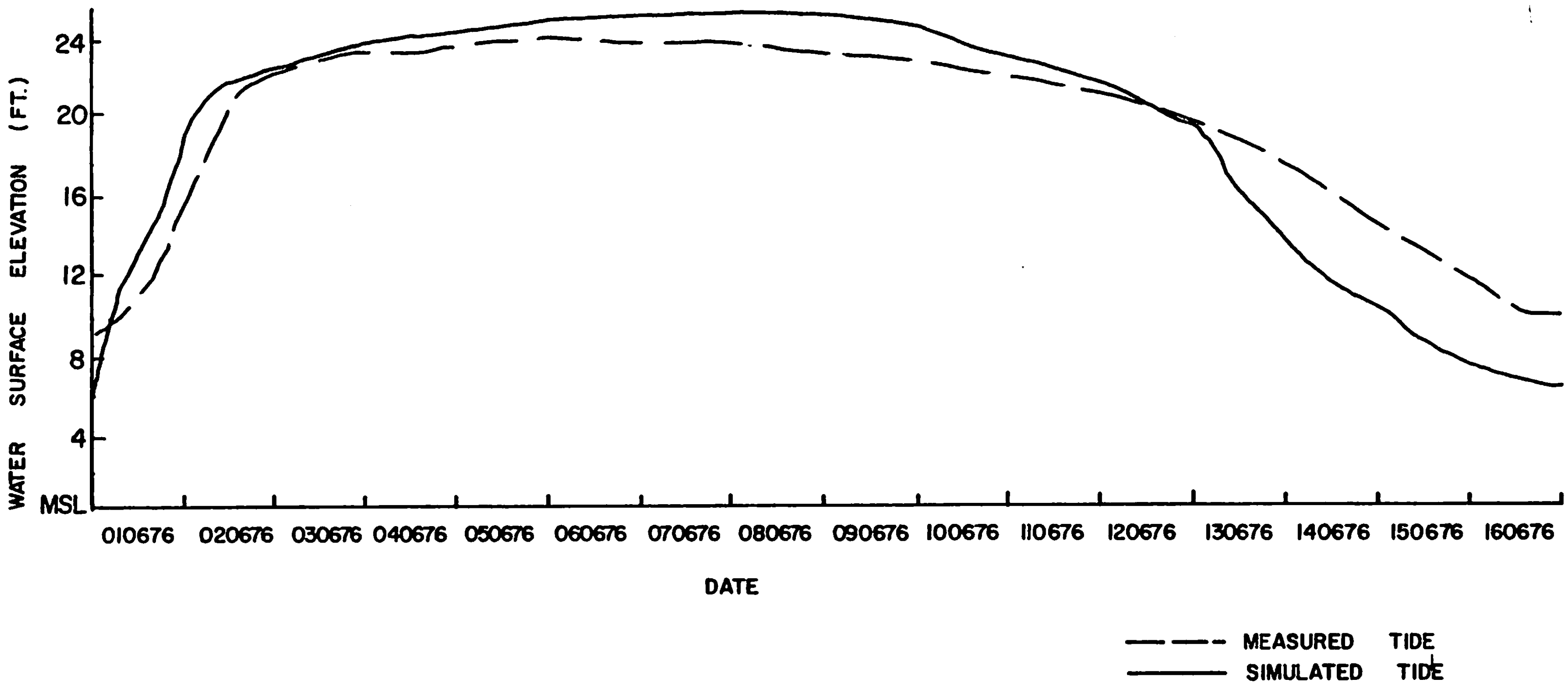

Figure II-14. Water Stage Record at Section 92, Trinity River at Liberty Gauge (Source: Hauck, 1977)

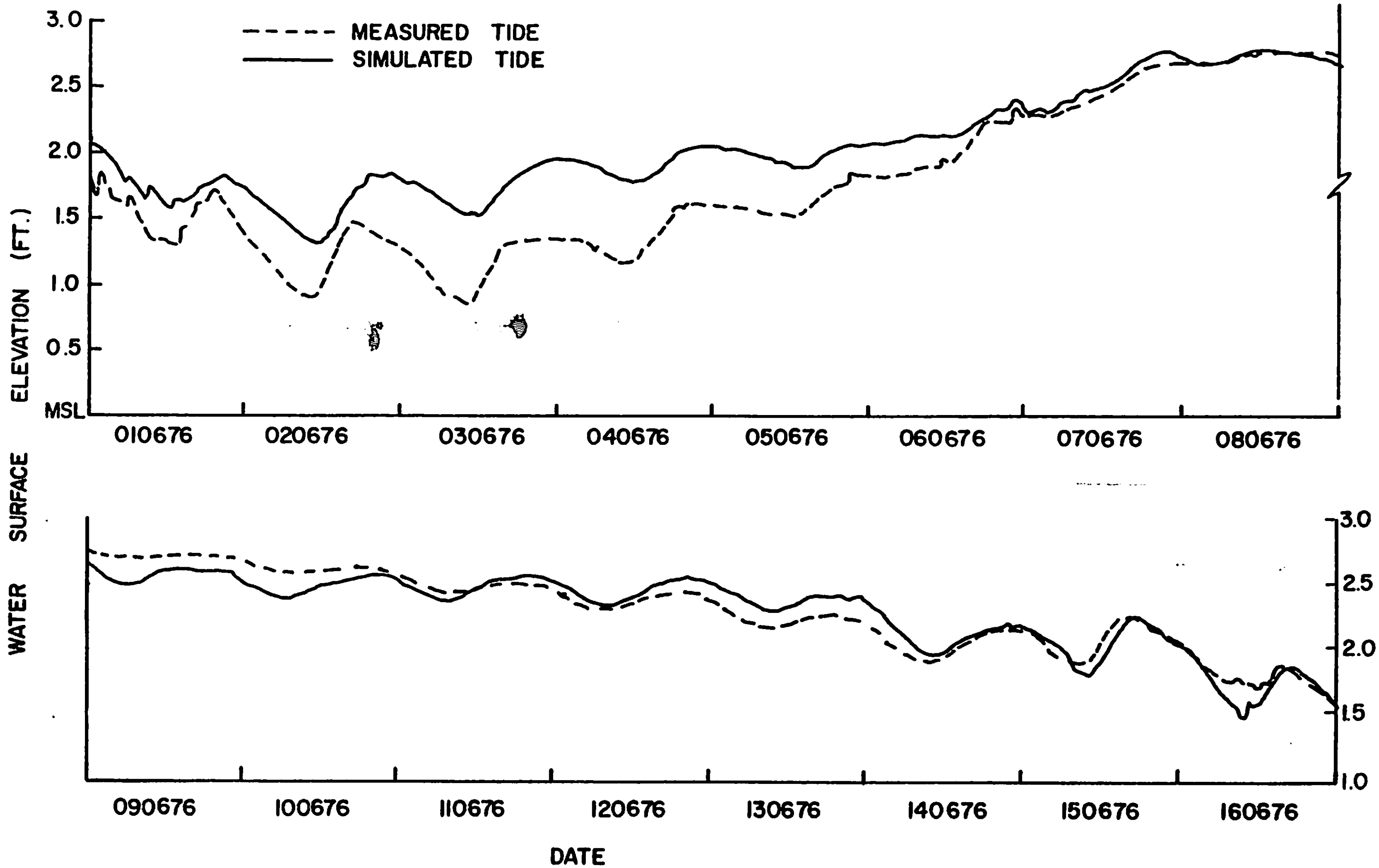

Figure II-15. Tidal Elevation Record at Section 34, Old and Lost River Gauge (Source: Hauck, 1977)

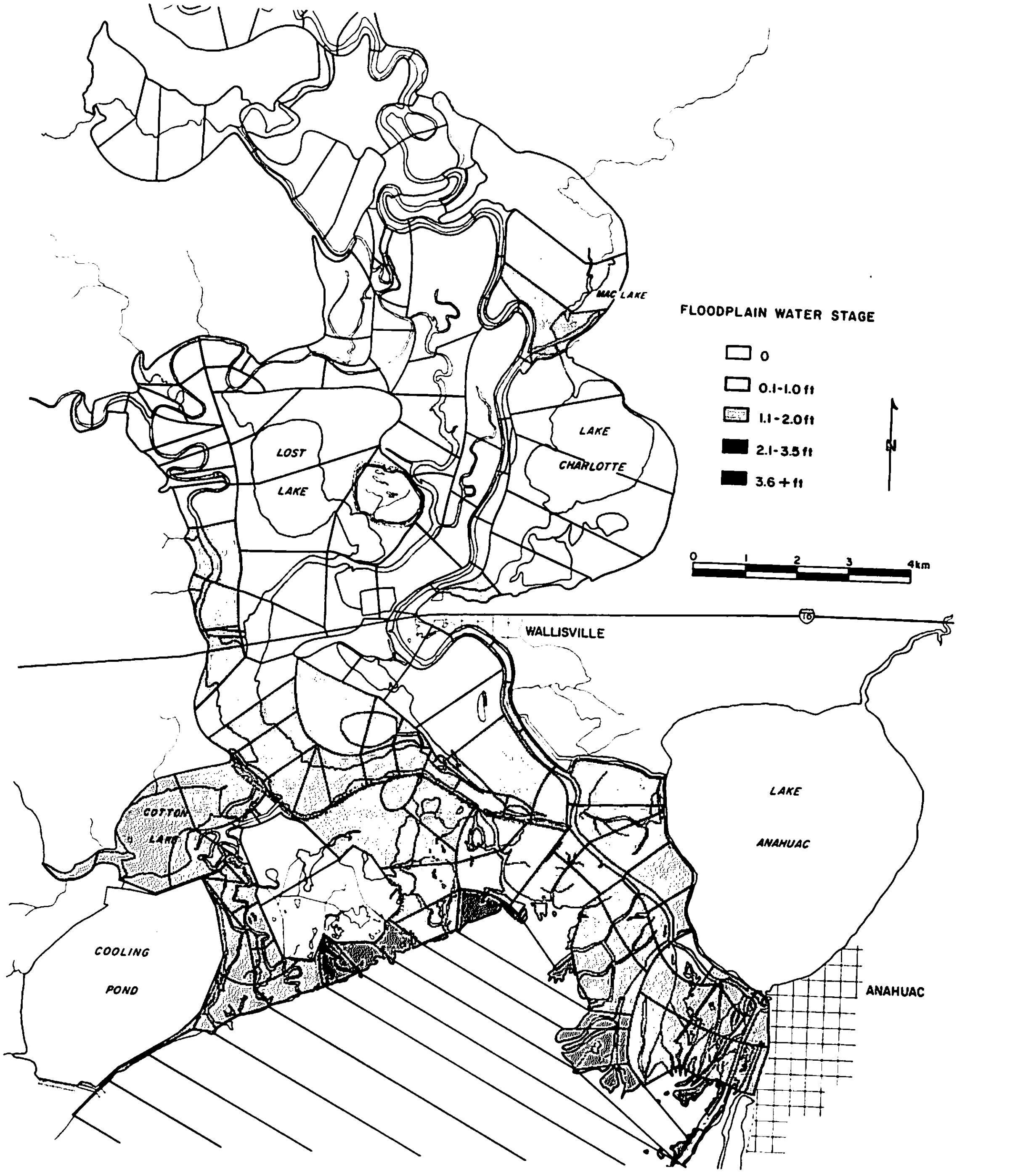

Figure II-16

Floodplain Inundation at 0000 CST
June 1

Source: Hauck, 1977

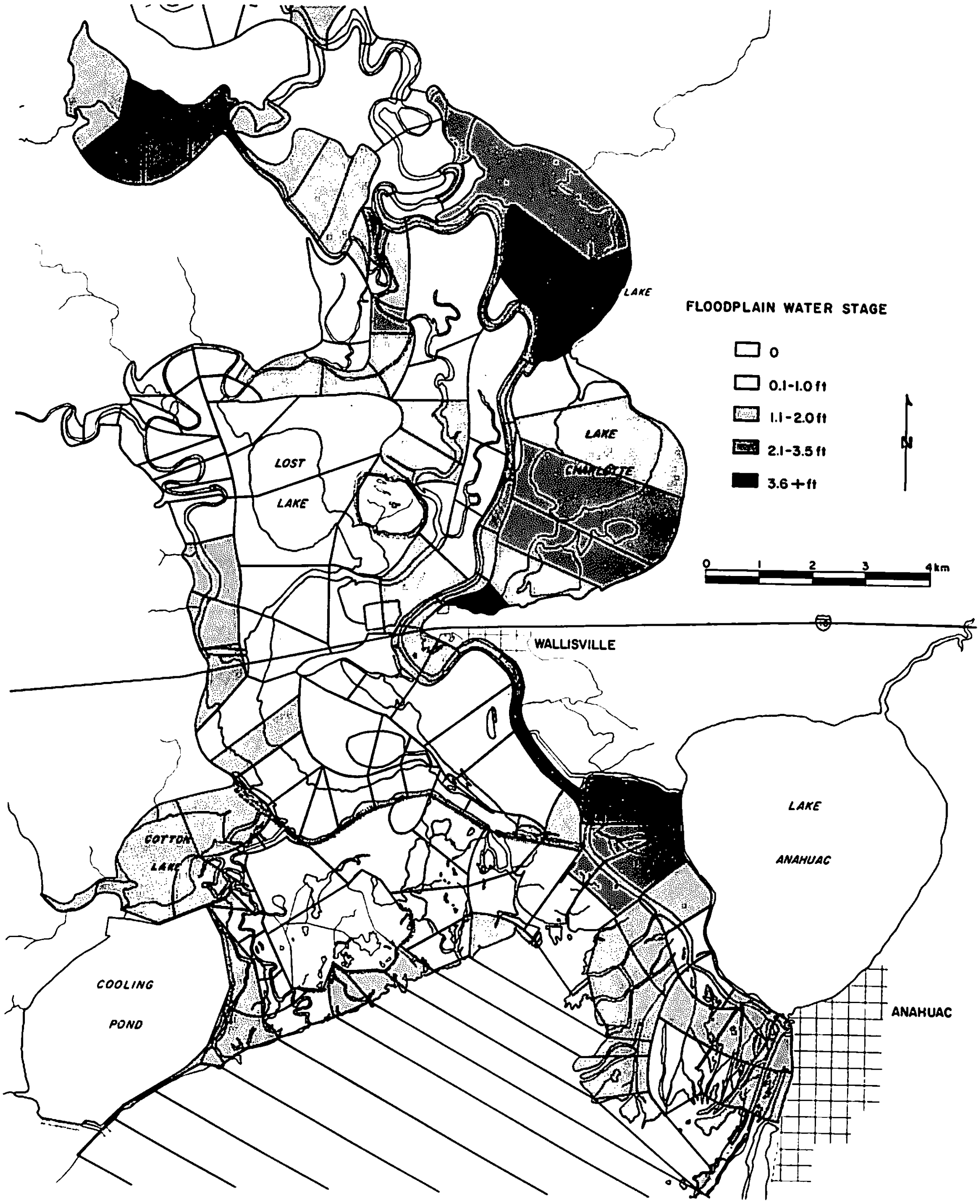

Figure II-17

Floodplain Inundation at 0000 CST

June 5

Source: Hauck, 1977

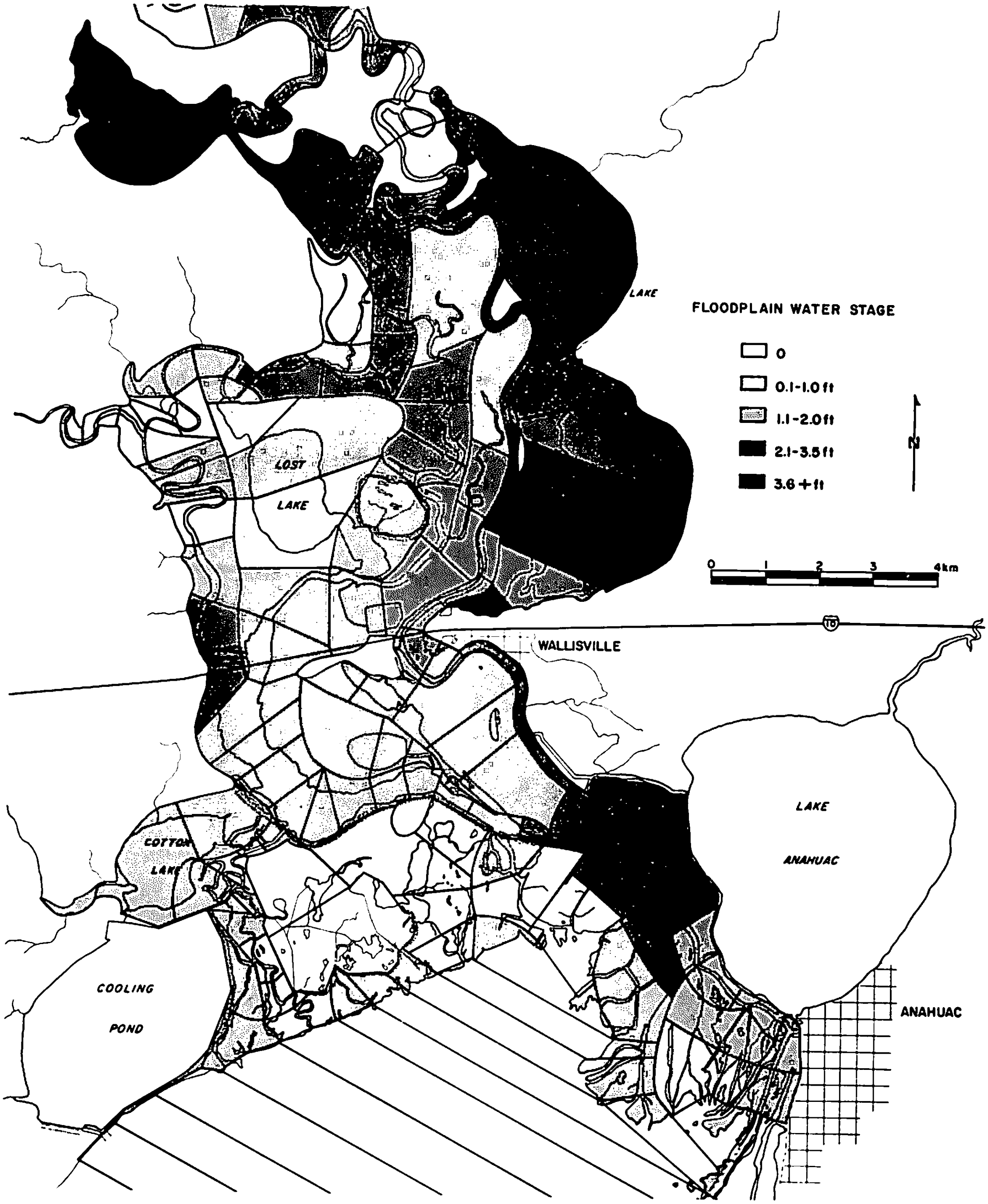

Figure II-18
Floodplain Inundation at 0000 CST
June 9
Source: Hauck, 1977

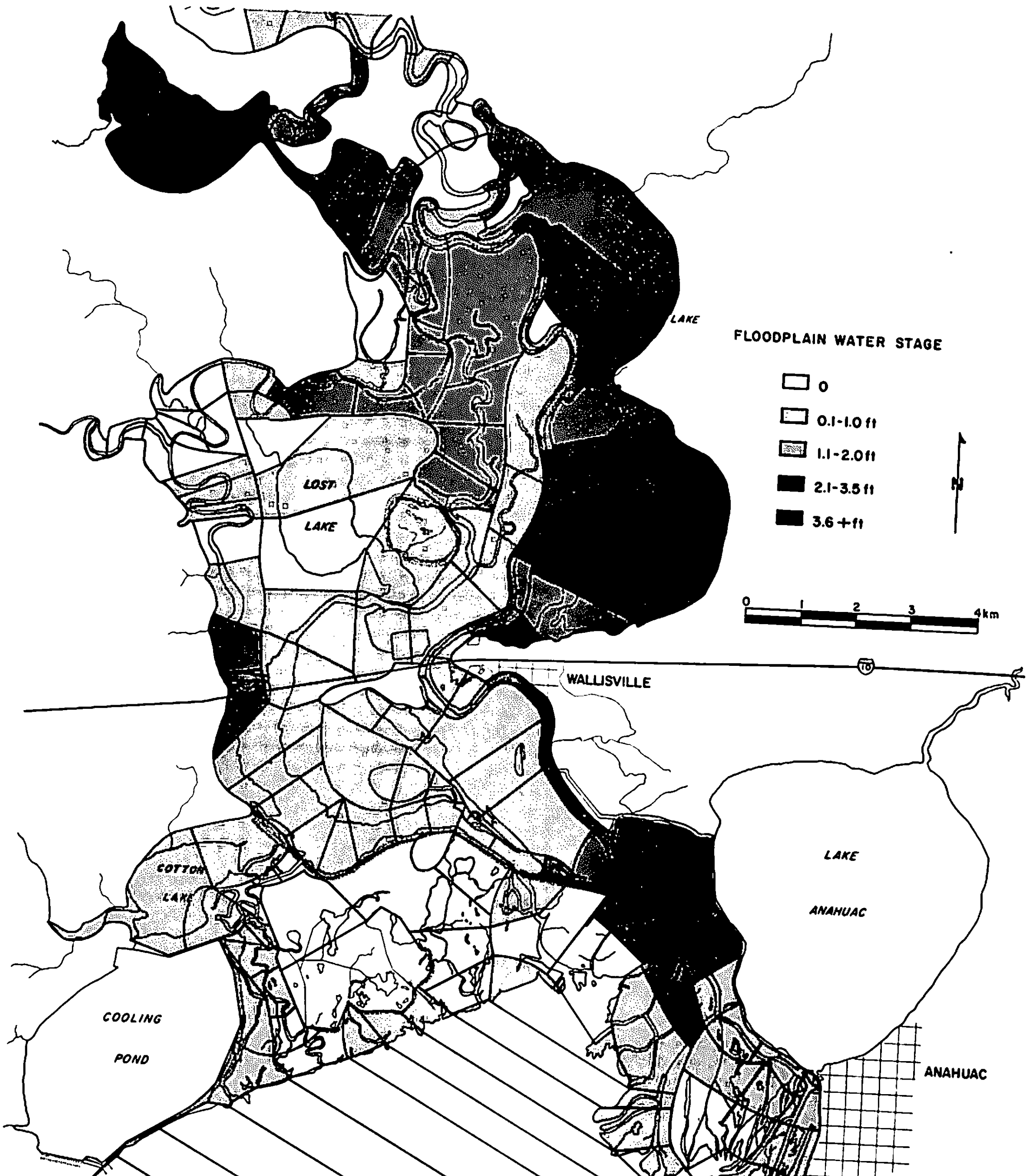

Figure II-19
Floodplain Inundation at 0000 CST
June 13
Source: Hauck, 1977

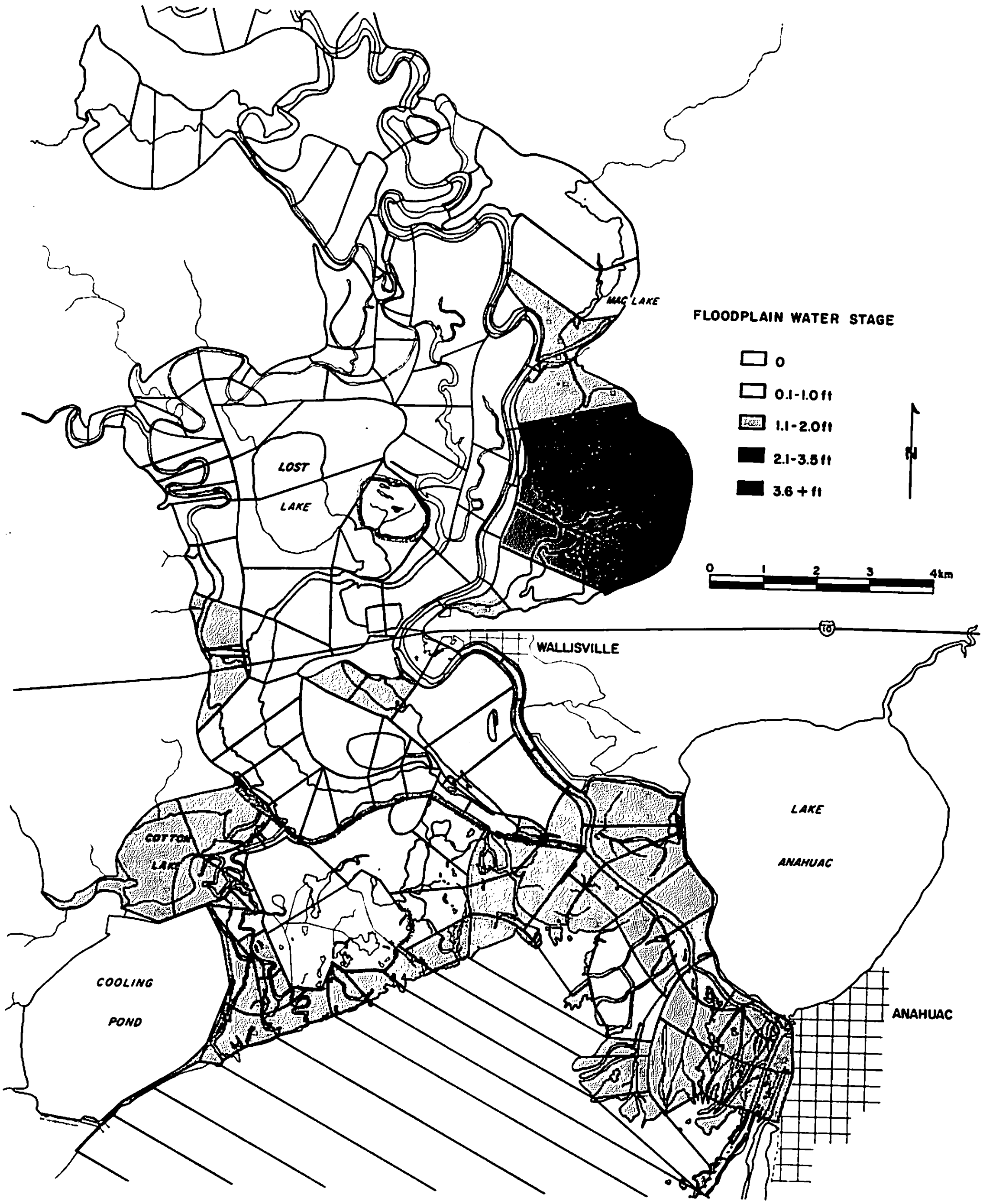

Figure II-20

Floodplain Inundation at 0000 CST
June 17

Source: Hauck, 1977

Goodrich and Liberty gauges due to the heavy rains on the lower watershed. An additional hydrograph was used as input at Segment 95, and the hydrograph shape was constructed to supplement the Goodrich flows in a manner that would produce the proper water stage at Liberty. The daily inflows from both inflow locations are presented in Table II-2. Withdrawals averaged only 60 ft^3/sec for this period. The driving tide at Point Barrow began as semidiurnal became diurnal and returned to semidiurnal (see Figure II-21). During this period, winds were generally from the north or east and of moderate speed, with the exception of a strong north wind on 20 December which resulted in the water set-down apparent in the driving tide at the same time.

Simulated and measured water elevations are compared at the gauges at the Old River Cutoff Channel, the Anahuac Channel, Lake Charlotte, the Sulphur Barge Channel as shown in Figures II-22 through II-25, respectively. The Lost River gauge was not recording properly during this period.

In general, the simulated and measured tides compare favorably at both the Old River Cutoff Channel and Anahuac Channel gauges. The approximately 0.3-ft. datum error at both gauges, previously mentioned with respect to the 16-23 November case, is still apparent in this simulation. The most significant discrepancies occurred during the lower tidal amplitude on 21 and 26 December. Overall tidal amplitude and phase are adequately simulated at both locations, though the simulation during the wind setdown condition is poor.

The flood passage as recorded at the Lake Charlotte gauge (see Figure II-24) is accurately simulated. Water elevation and phasing of the flood is quite good. The short rise in water elevation measured at this gauge on 12 December is most likely due to local runoff from a 1.5-in. rain that occurred on that day. At the Sulphur Barge Canal gauge, the simulated and measured water elevations exhibit poor agreement (see Figure II-25). The phasing of the flood is adequte, but the water elevation is as much as 3.0 feet in error. This error can not be adequately explained. Input conditions were set to produce proper water elevations at the Liberty gauge, and elevations at the Lake Charlotte gauge just off the river were accurately simulated. However, just a couple of miles upstream from the Lake Charlotte area, the simulations at the Sulphur Barge show significant error. Whether this is due to significant unaccounted runoff in this area (Spinks Creek empties into the marsh in this area) or whether the error is purely a simulation error can not be determined from this single flood case. Further investigation of other flood cases, as data becomes available is required.

The simulated flood water levels in the delta are presented at four-day intervals on 12, 16, 20, 24 and 28 December, Figures II-26 through II-30, respectively. As for the first flood, this sequence of figures depicts water levels above bank elevation at

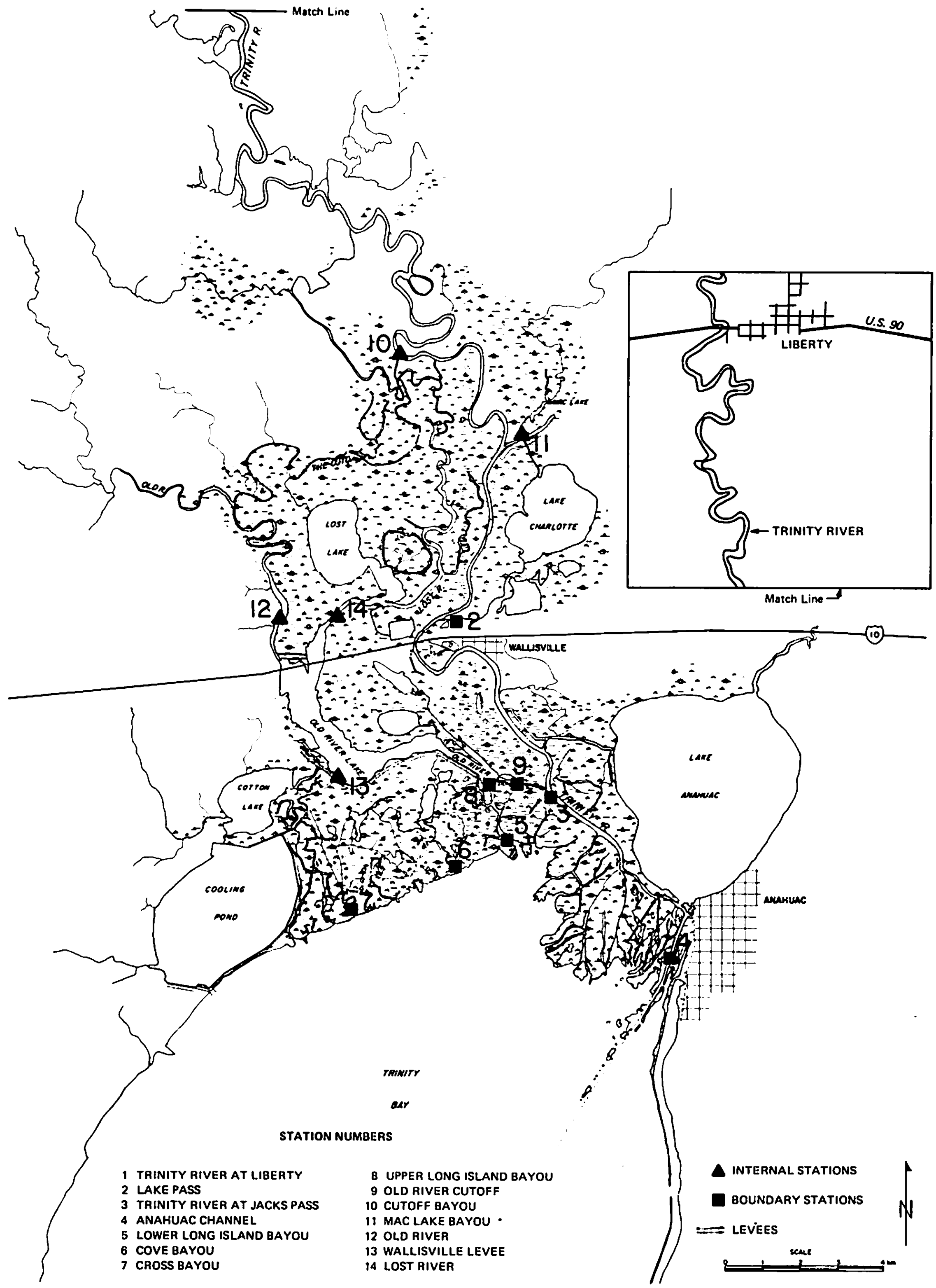

Figure III-4
Location Map of the Fourteen Stations
in the Trinity River Delta Study Under
Three Flow Regimes.

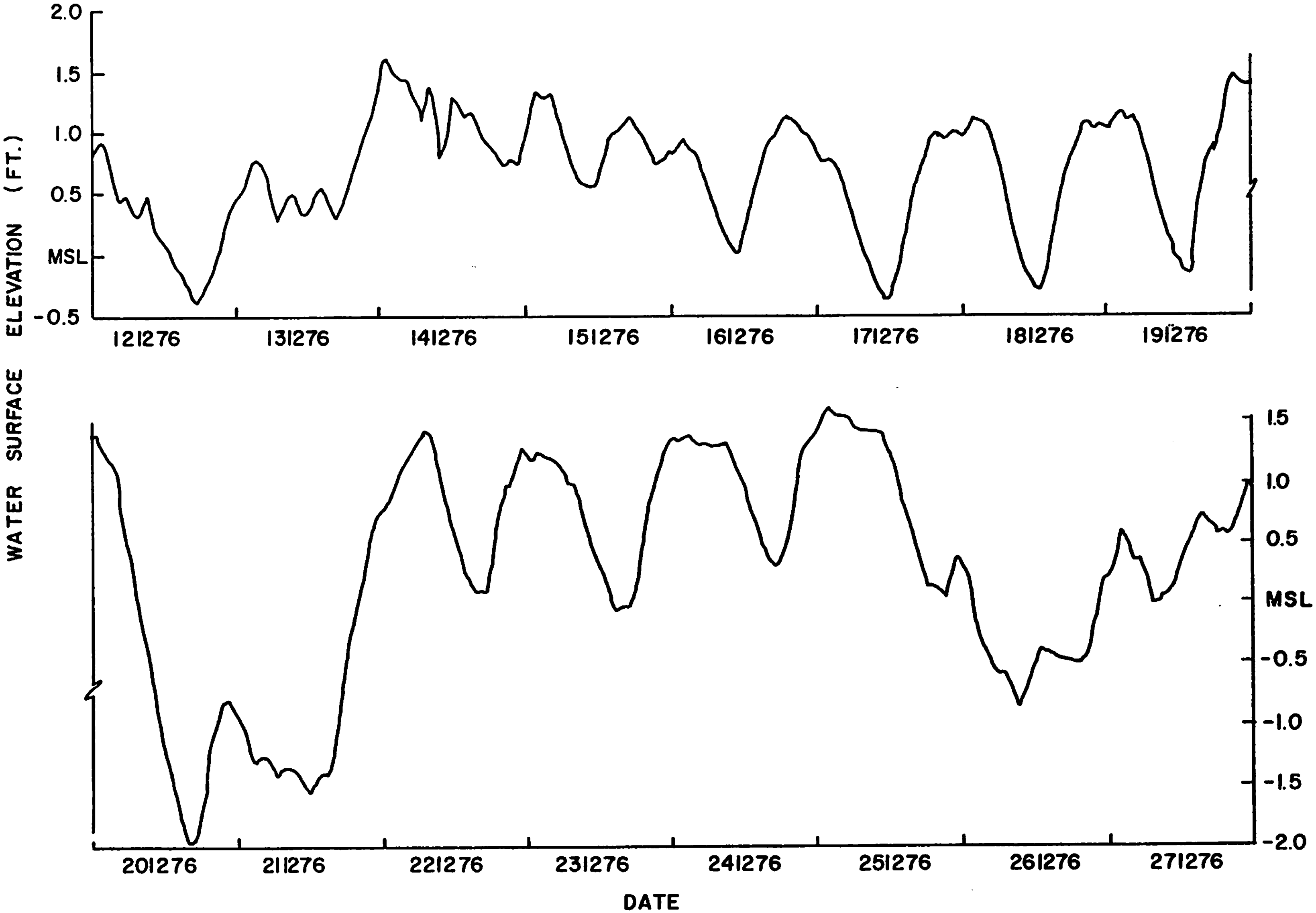

Figure II-21. Tidal Elevation Record at Section 8, Point Barrow Gauge (Source: Hauck, 1977)

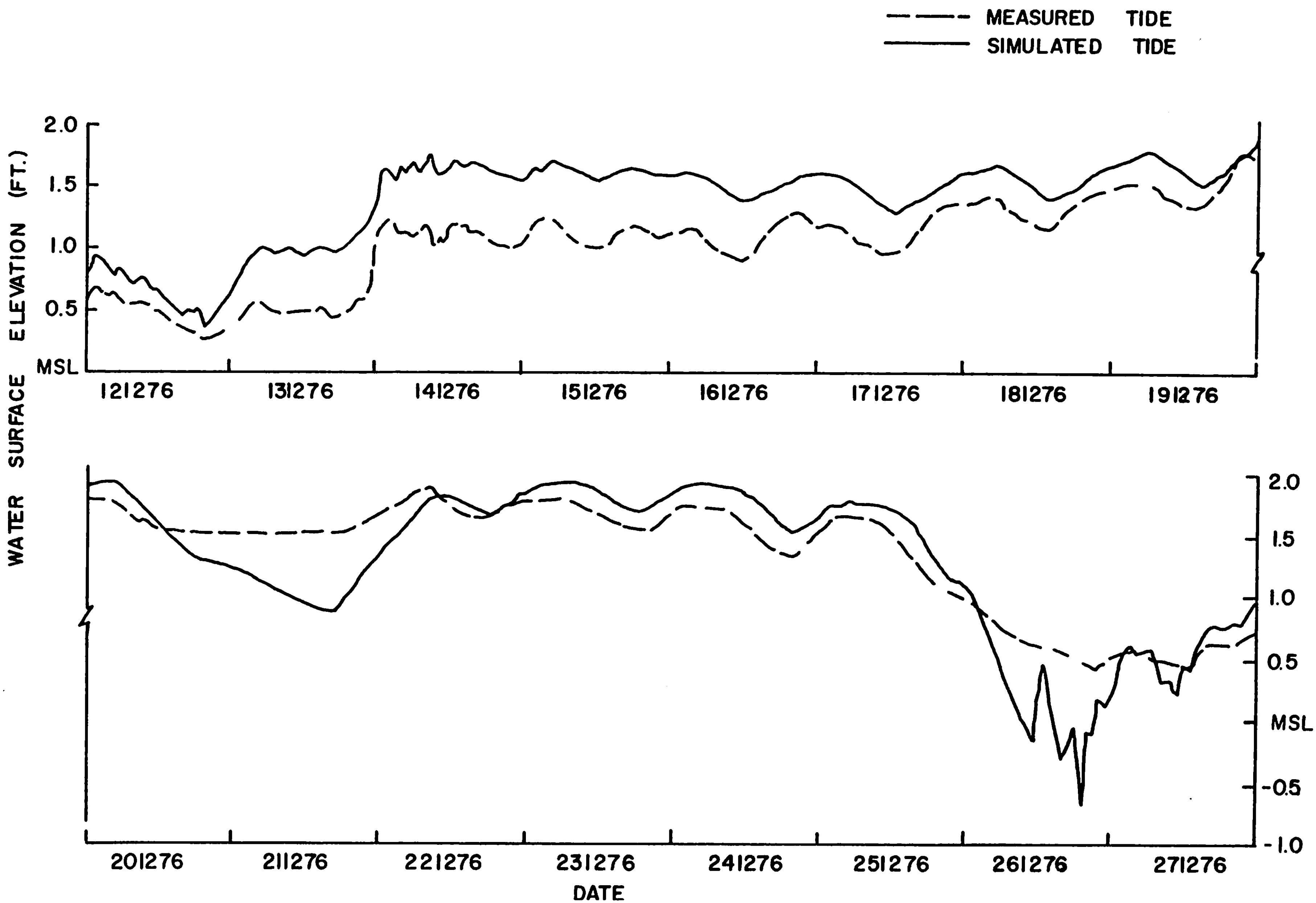

Figure II-22. Tidal Elevation Record at Section 24, Old River Cutoff Channel Gauge (Source: Hauck, 1977)

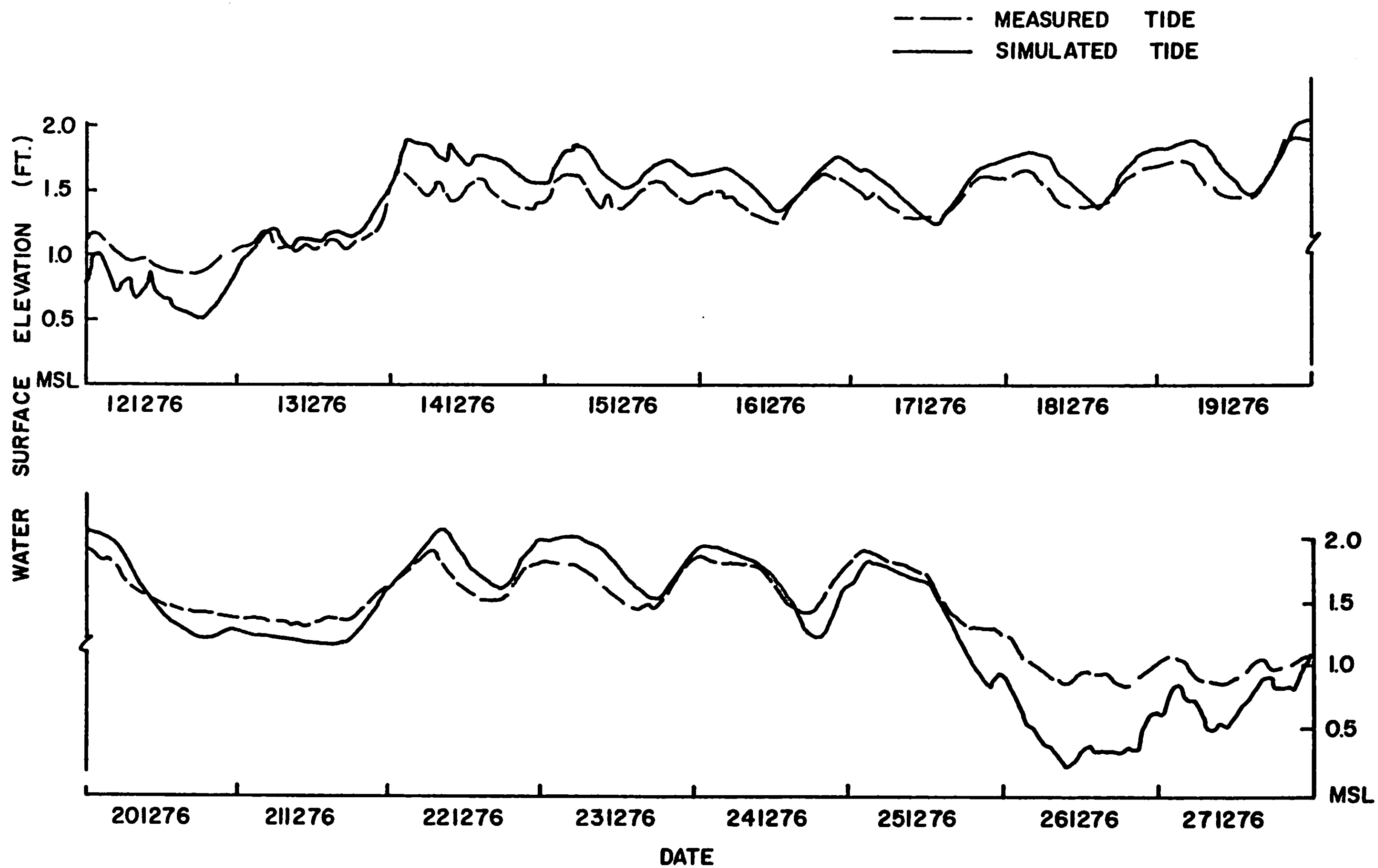

Figure II-23. Tidal Elevation Record at Section 48, Anahuac Channel Gauge (Source: Hauck, 1977)

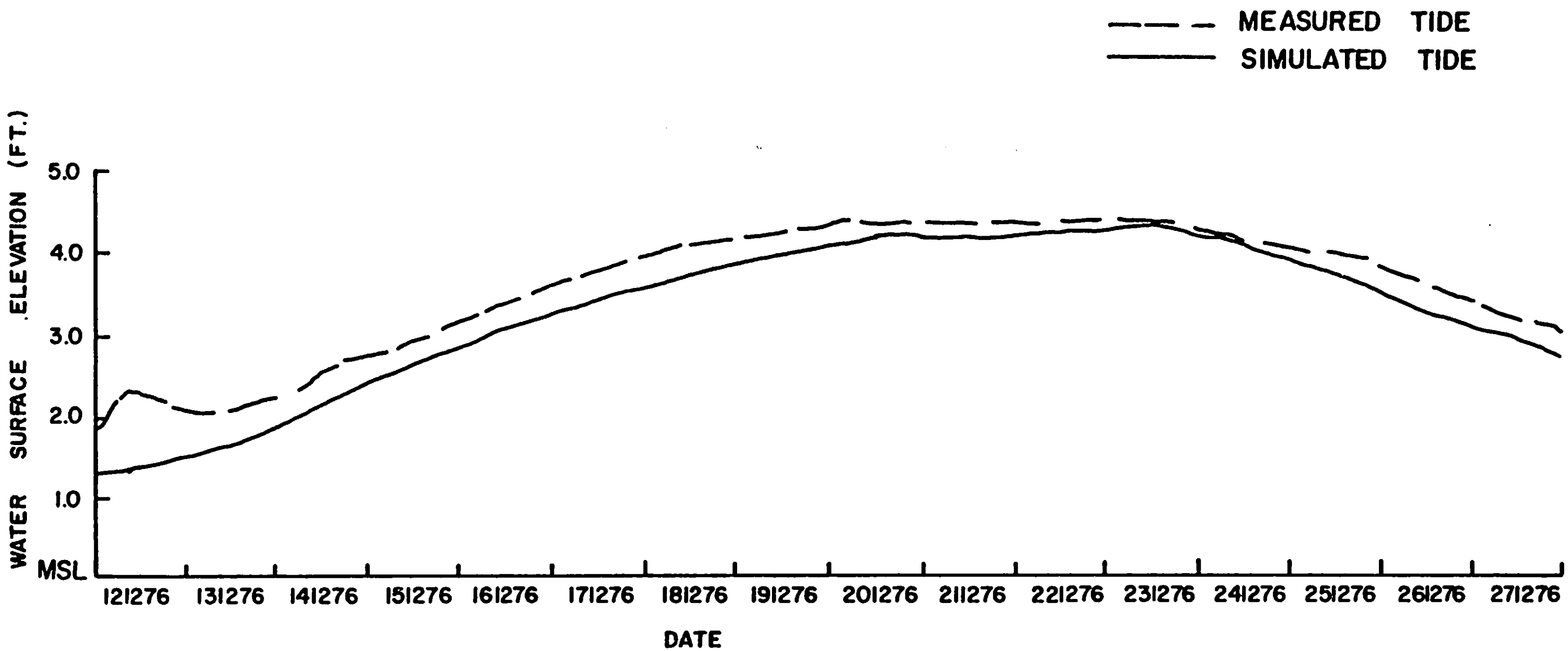

Figure II-24. Tidal Elevation Record at Section 162, Lake Charlotte Gauge (Source: Hauck, 1977)

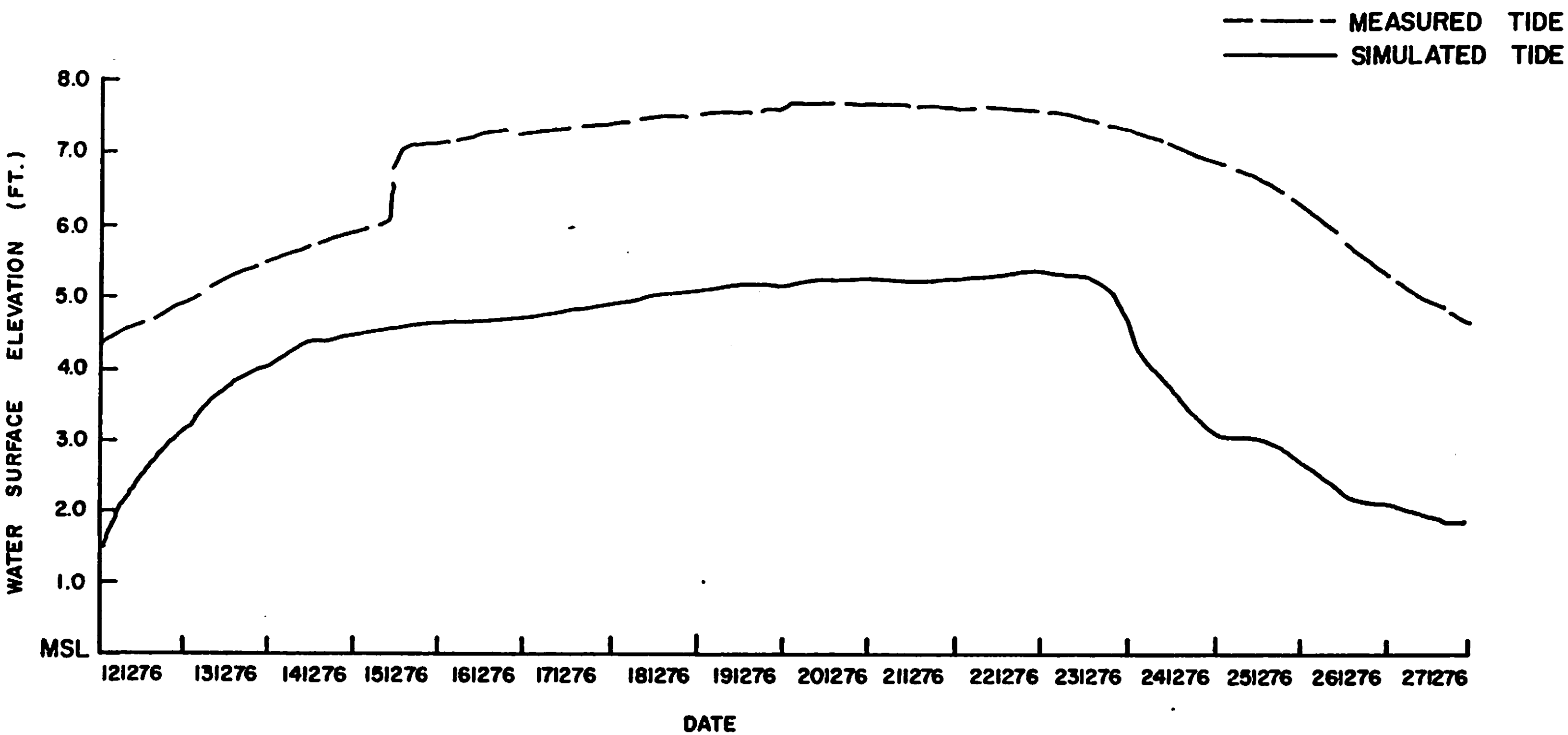

Figure II-25. Tidal Elevation Record at Section 165, Sulphur Barge Canal Gauge (Source: Hauck, 1977)

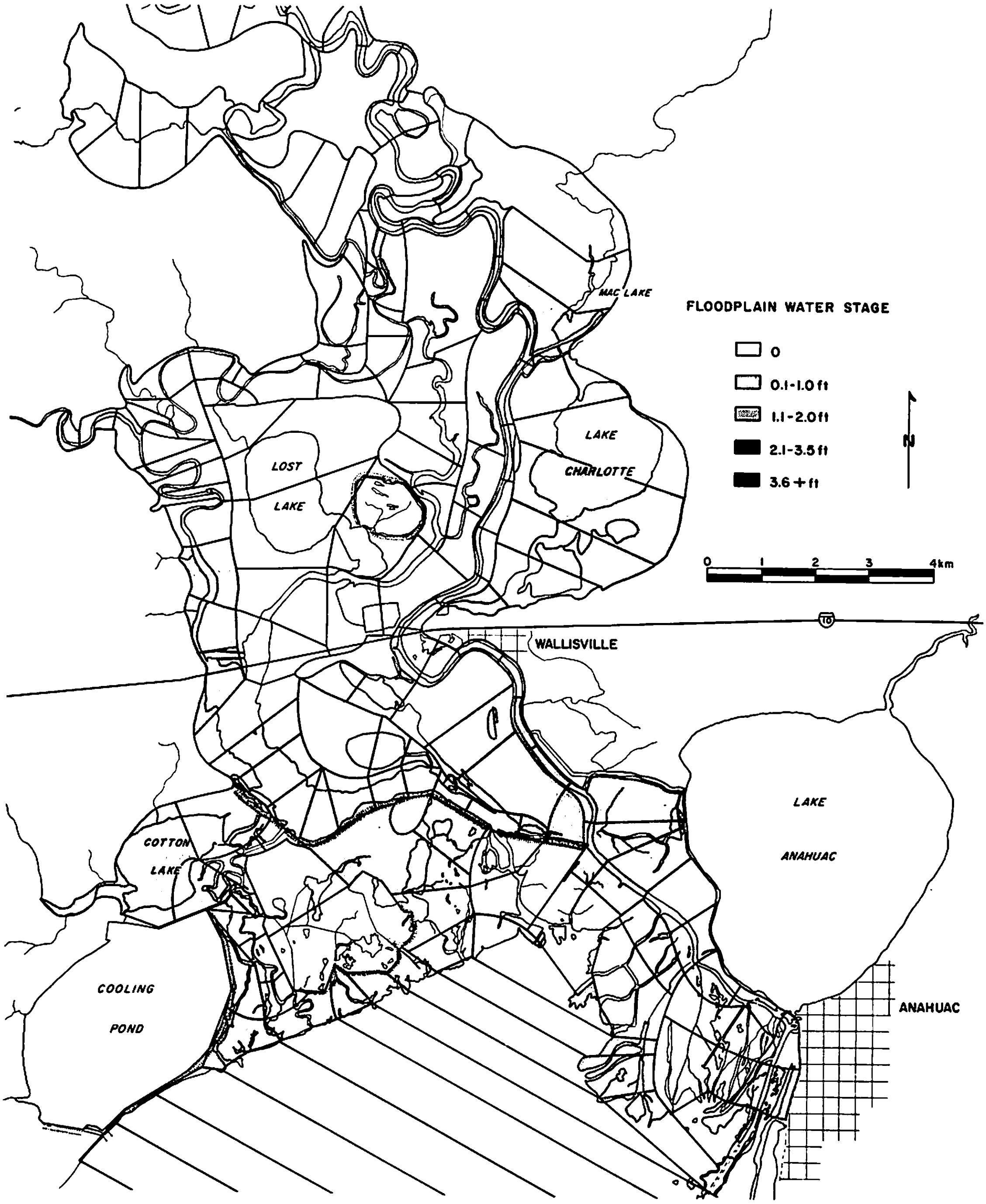

Figure II-26

Floodplain Inundation at 0000 CST December 12

Source: Hauck, 1977

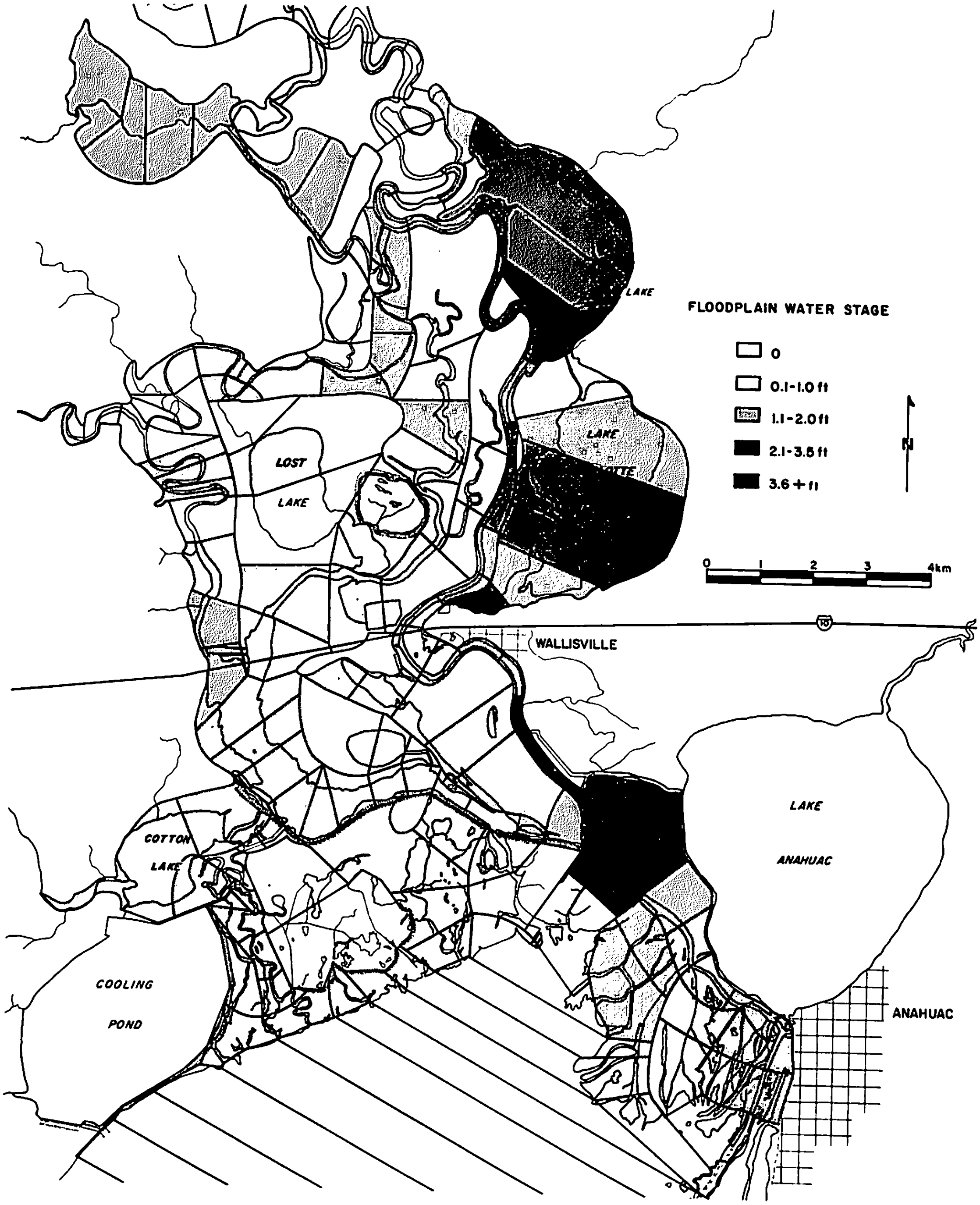

Figure II-27

Floodplain Inundation at 0000 CST

December 16

Source: Hauck, 1977

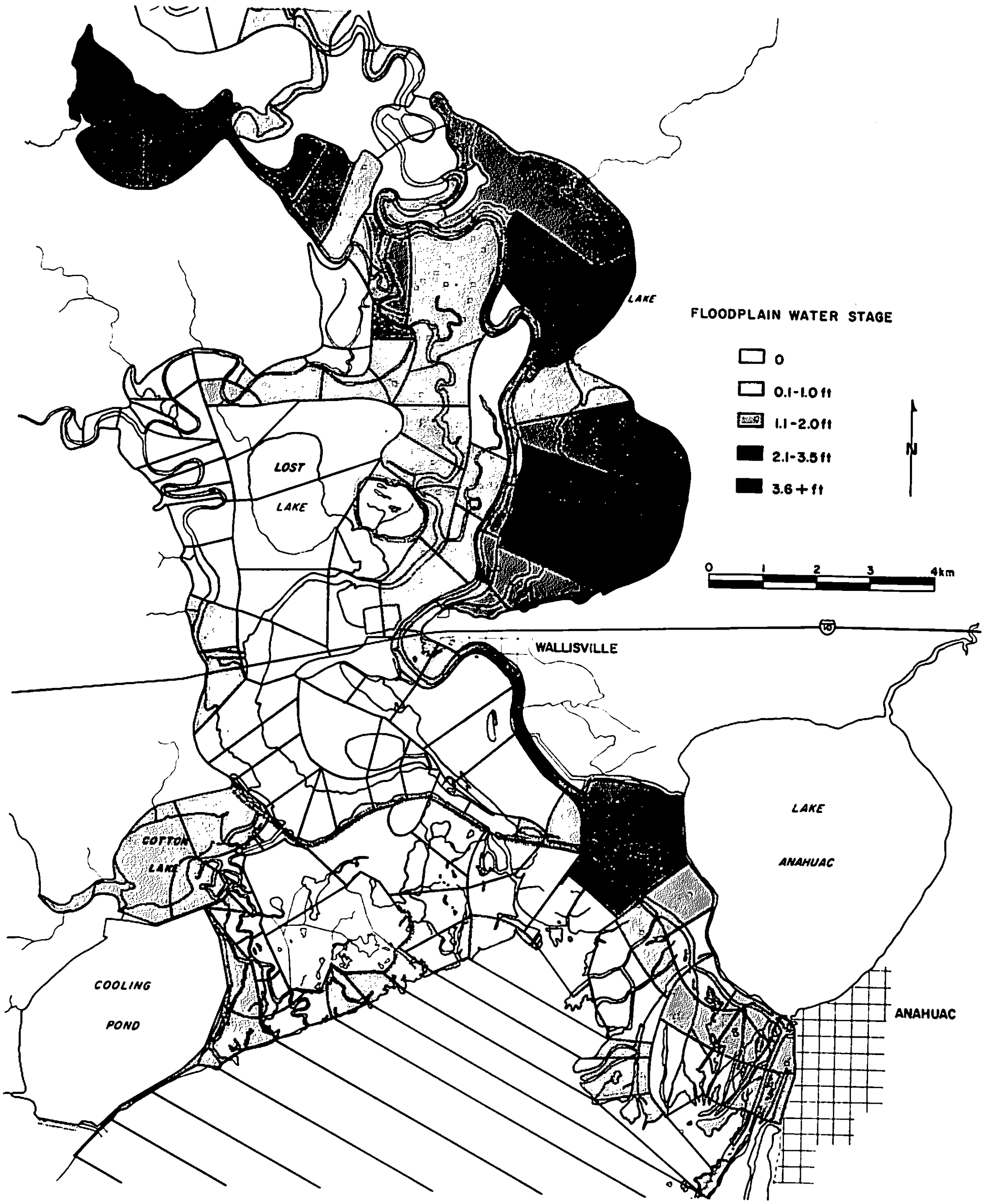

Figure II-28

Floodplain Inundation at 0000 CST

December 20

Source: Hauck, 1977

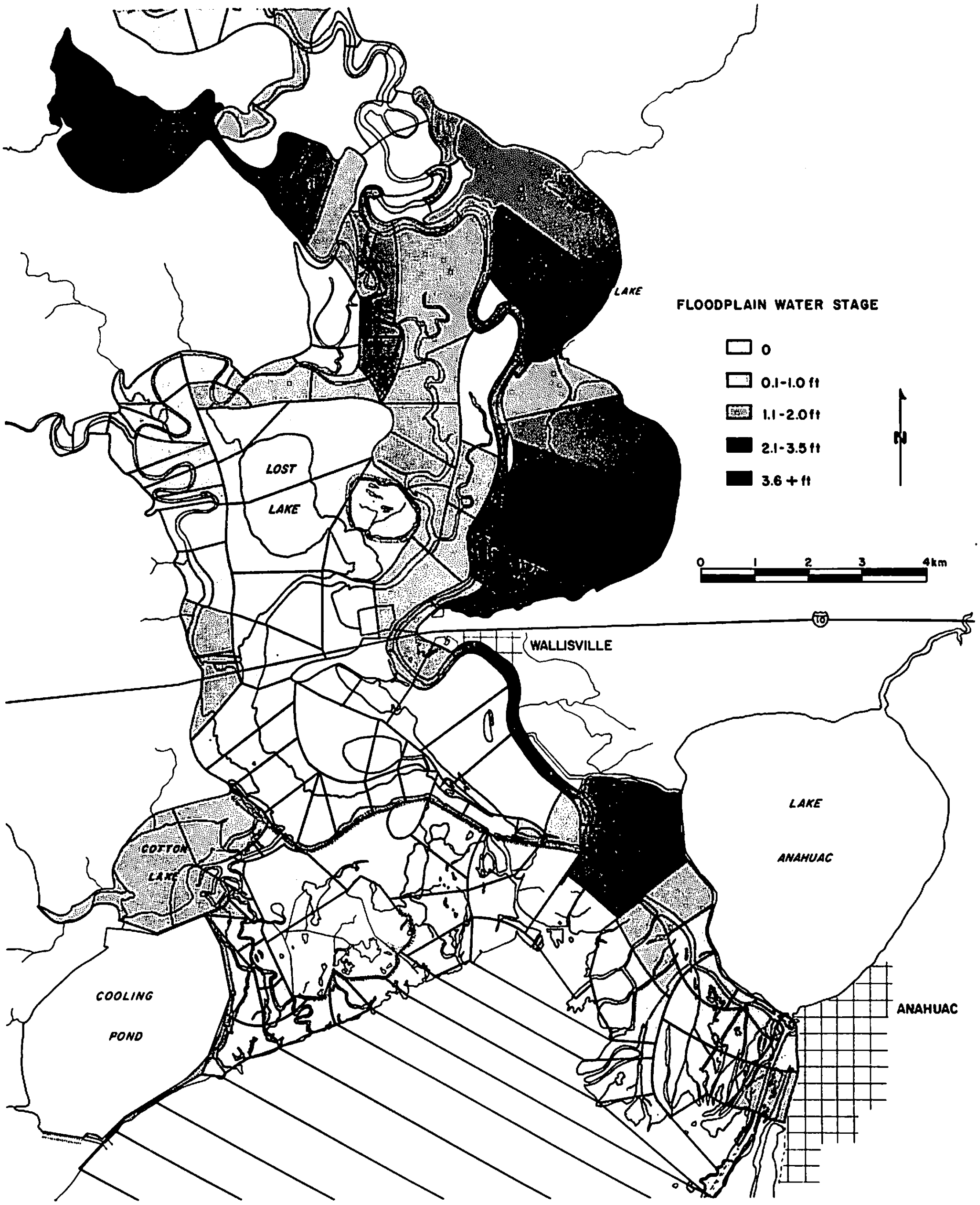

Figure II-29

Floodplain Inundation at 0000 CST
December 24

Source: Hauck, 1977

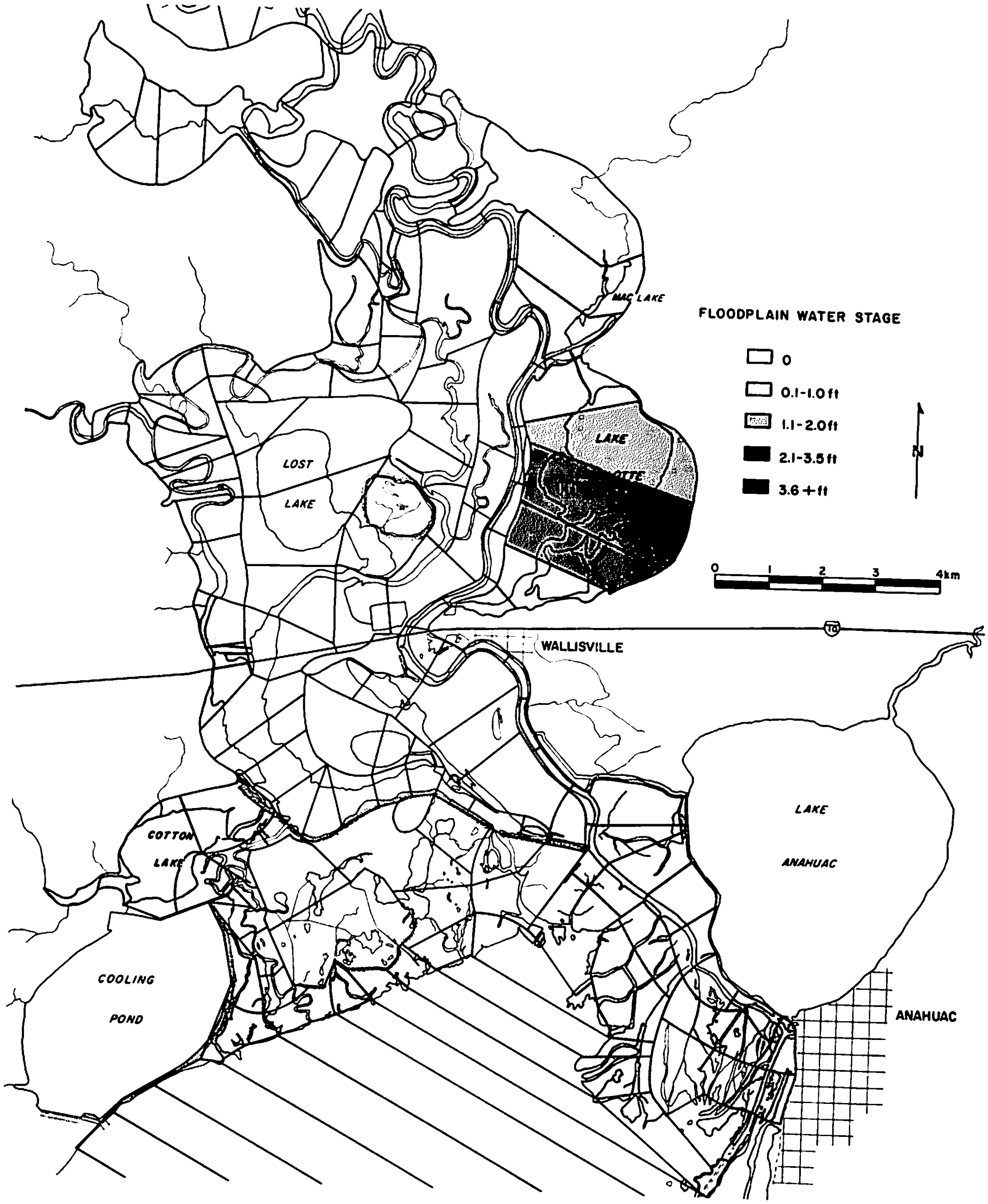

Figure II-30

Floodplain Inundation at 0000 CST December 28

Source: Hauck, 1977

hour 0000 CST for each day mentioned for the deltaic portion of the computer segmentation. Prior to flood passage, some tidal inundation of the deltaic marsh areas is indicated on 12 December (Figure II-26). The next two figures in the sequence, for 16 December and 20 December, indicate the increased rise in water elevations with the passage of the flood crest. Maximum levels of inundation occur on approximately 24 December (Figure II-29). A rapid receding of flood waters occurs as indicated on Figure II-30 for 28 December. Because of a combination of wind set-down on the bay water elevations on 26 and 27 December and the gradual receding of the flood stage, the delta flood levels lower quite rapidly.

Intensive Study Simulation

An intensive diurnal biological and hydrodynamic study was conducted by the USGS, TDWR and EH&A from 30 November through 3 December, 1976. During this period two diurnal field programs were conducted, one from approximately 1100 CST 30 November to 1000 CST 1 December and the other from 1100 CST 2 December to 1000 CST 3 December. In order to take advantage of the flow verification data obtained during this study, a simulation was conducted for the period 26 November through 3 December 1976. Streamflow was nearly constant at approximately 2,400 ft^3/sec with diversions calculated to be 60 ft^3/sec. The driving tide at Morgans Point was diurnal during the entire period (see Figure II-31). The wind during this time was light except for 28 and 29 November when moderately strong north winds persisted. A large wind set-down is apparent in the driving tide on these same two days.

The simulated and measured tides for the gauges on the Old River Cutoff Channel, on Anahuac Channel and on the Sulphur Barge Channel are presented in Figures II-32 through II-34, respectively. Due to the low tides, the Lake Charlotte gauge was not recording during this period and the Lost River gauge was not recording properly, so neither of these records are available. The measured and simulated tides at the Old River Cutoff Channel and at Anahuac Channel compare favorably. The tidal amplitude is reproduced accurately and the tide phasing is within a couple of hours. As in a previous simulation, the 0.3-ft. datum error between measured and simulated tides is evident at both gauges. Besides the datum error, the major simulation inaccuracy occurs during the low tides resulting from the wind setdown. Taking into account the 0.3-ft. datum difference, the simulated tide is approximately one foot too low during setdown conditions.

The simulated and measured tidal amplitude and phase also compare favorably at the Sulphur Barge Channel gauge location (see Figure II-34). As at the two previous gauge locations, the low tide period is poorly simulated. In addition, the simulated tide is approximately 0.3-ft. higher than the measured tide for most of the period. This error was not apparent in the previous

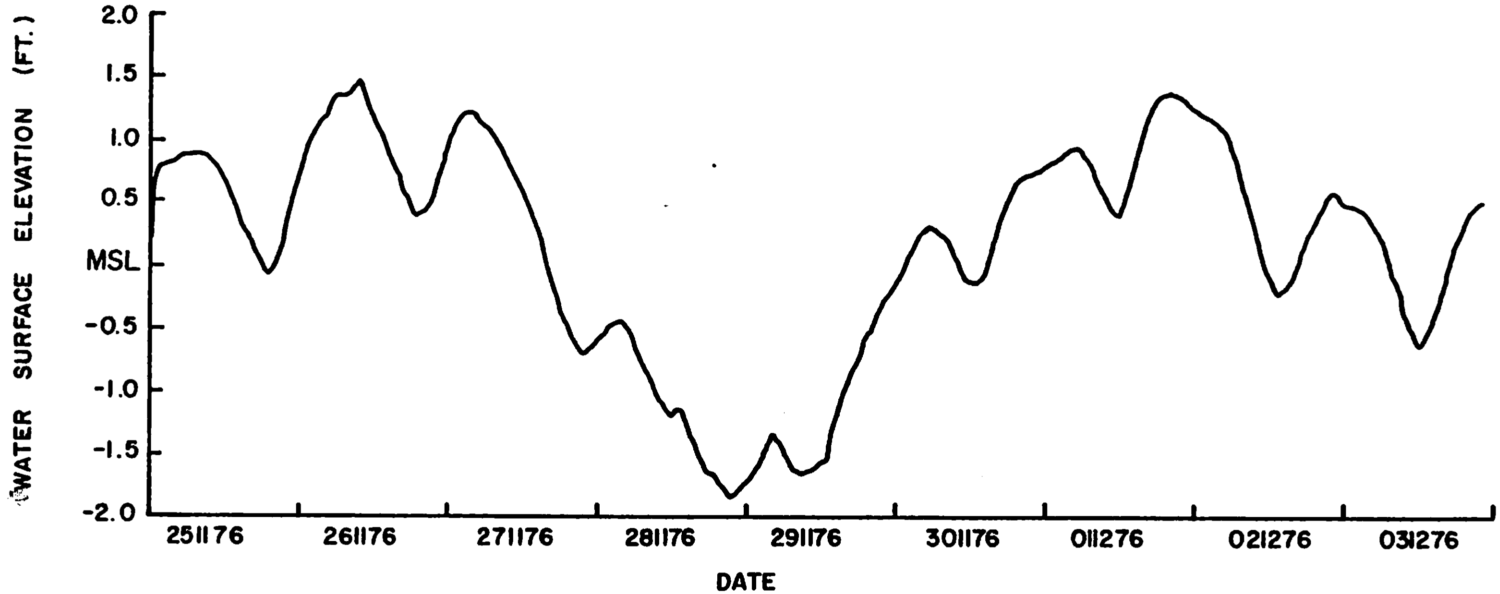

Figure II-31. Driving Tide Record at Section 2, Morgans Point Gauge (Source: Hauck, 1977)

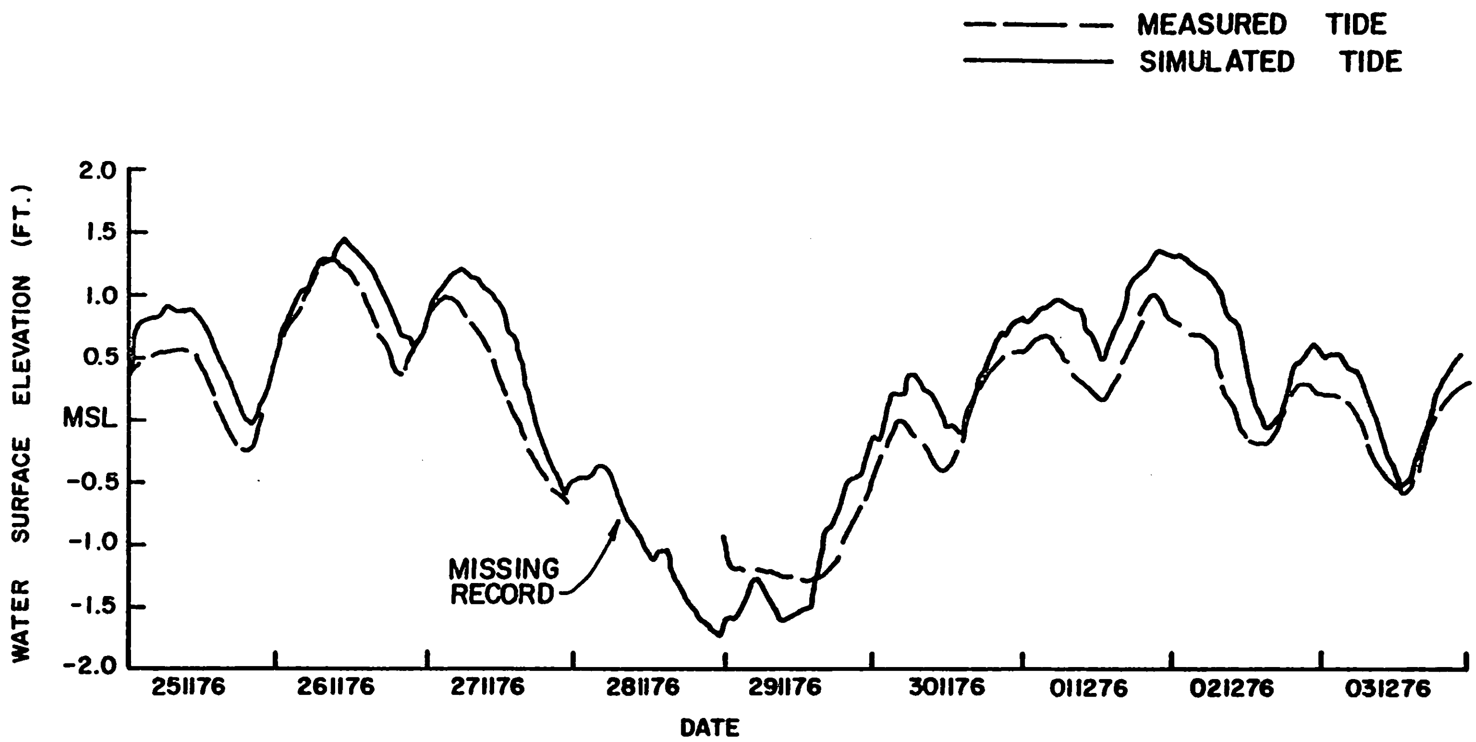

Figure II-32. Tidal Elevation Record at Section 24, Old River Cutoff Channel Gauge (Source: Hauck, 1977)

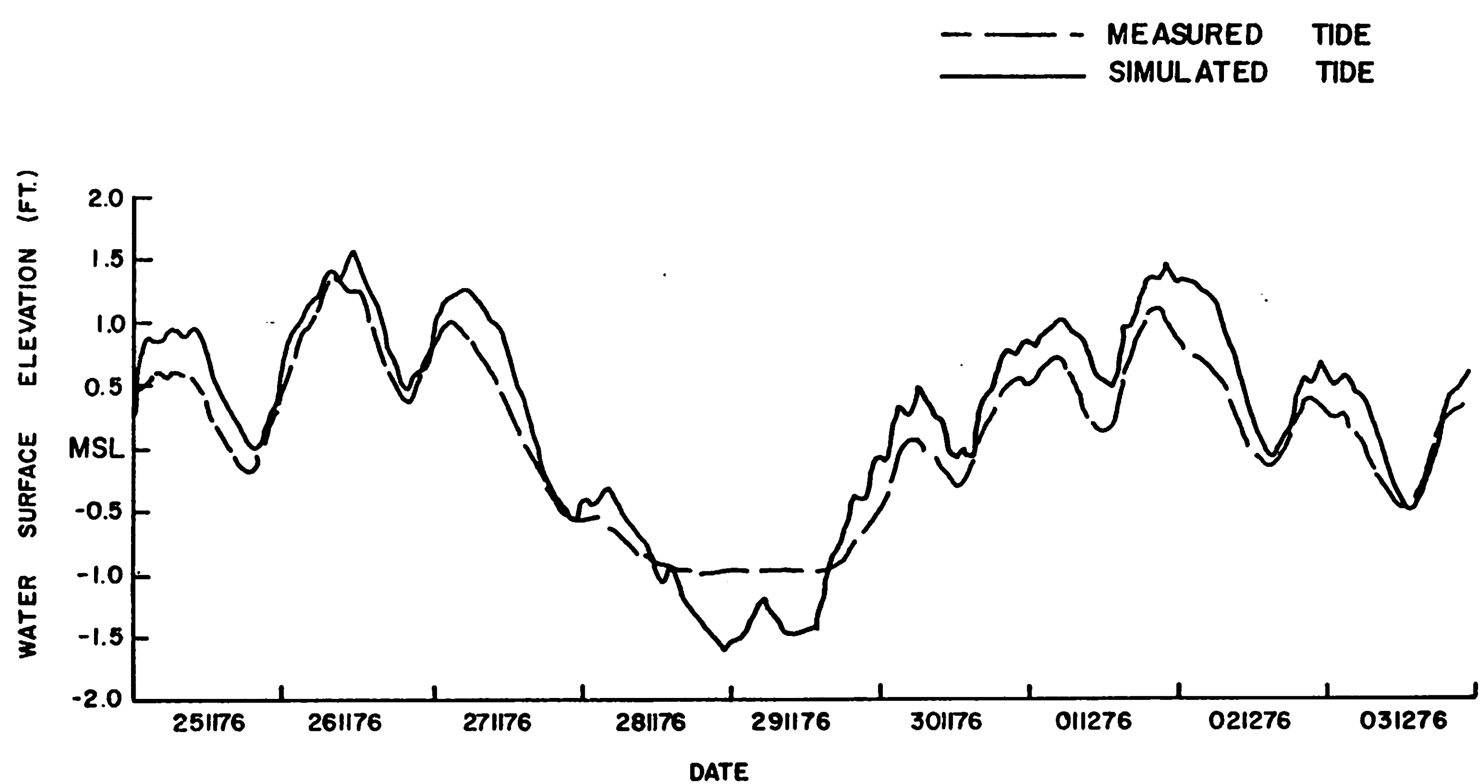

Figure II-33. Tidal Elevation Record at Section 48, Anahuac Channel Gauge (Source: Hauck, 1977)

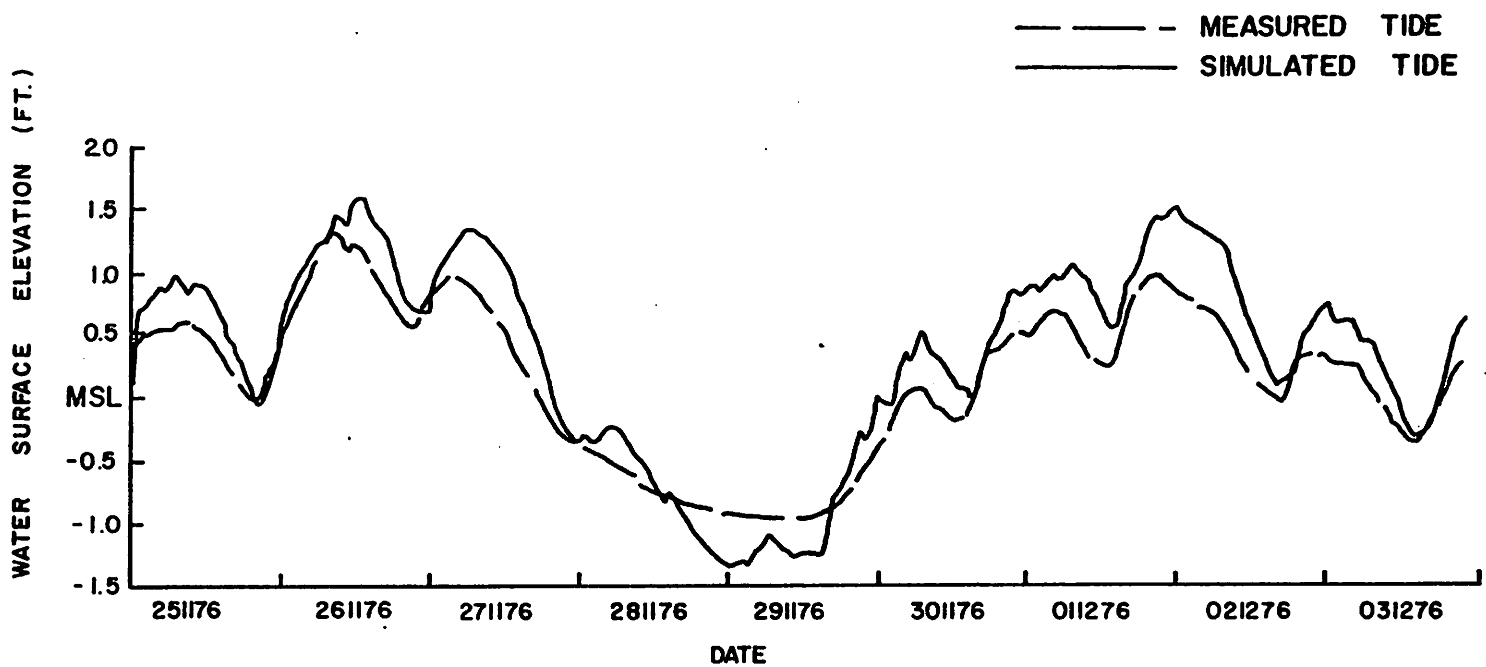

Figure II-34. Tidal Elevation Record at Section 165, Sulphur Barge Channel Gauge (Source: Hauck, 1977) simulations and can not be easily explained. Water elevation in the Sulphur Barge Channel is controlled by a combination of tides and river stage. Since the streamflow gauge at Romayor was inoperative at this time, input flows for the Trinity River were estimated from the measured flow at the Goodrich gauge and measurements at the Liberty gauge on 30 November and 1 December during the intensive inflow study. An over estimate of river flow would result in a mean water elevation that is too high, which could be an explanation of the 0.3-ft. error.

As noted previously, flow measurements from several sampling sites provide a source of additional verification data. In fact, flow measurement is a more preferable form of verification data than water-level records, since the objective of the modeling work is the simulation of transport in the system. However, the individual measurements of velocity required to obtain flows are subject to complex turbulent fluctuations and in areas where relatively fresh river flows mix with highly saline tidally influenced waters, bi-directional flows can occur, i.e., the lower density freshwater on the surface flows in one direction while heavier saline water at lower depths flows in the opposite direction. This should be kept in mind when comparing point-measured flows to the smoothed flows of the model.

A comparison of measured and simulated flows is presented in Figure II-35. For the first diurnal study, 30 November and 1 December, the sampling sites were located at the Old River Cutoff (section 144), Trinity River above Jack's Pass (section 53), Anahuac Channel (section 47), Lake Pass (section 158), Mac Lake (section 165) and the Cutoff (section 169). At this time, the system was recovering from the wind setdown conditions of 28 and 29 November. The reliability of the simulation varies from location to location. The Old River Cutoff simulation is good; flows and direction correlate with measured values at all times. At the Trinity River above Jack's Pass and the Anahuac Channel the flow magnitudes correlate well; however, the simulation indicates a reversal in flow direction for a brief period which was not observed in the physical system. At Lake Pass and Mac Lake there are at times significant errors in flow magnitude and in direction, but over all the simulation satisfactorily reproduces the measured values. The poorest simulation was the Cutoff where measured and simulated flow direction are the same, but simulated flows are approximately an order of magnitude too large. With the exception of the Cutoff, the simulation of flows for this period is satisfactory.

For the second diurnal study conducted on 1 and 2 December, a greater number of locations were measured. Included in the study were sites on the Cutoff (section 169), the Old River (section 33), the Lost River (section 192), Cotton Bayou (section 132), Trinity River above Jack's Pass (section 53), Lower Long

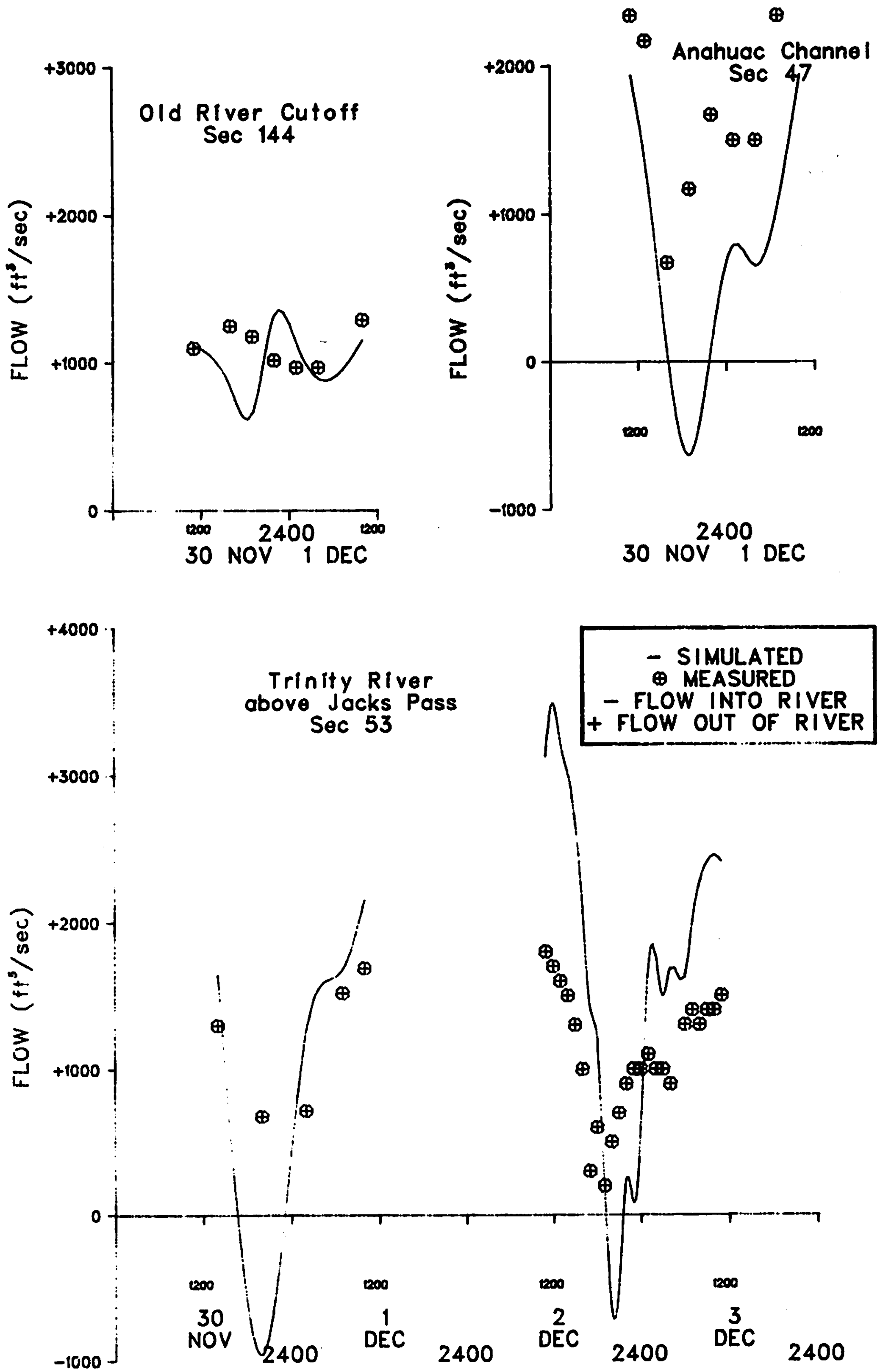

Figure II-35. Comparison of Measured and Simulated Flows.

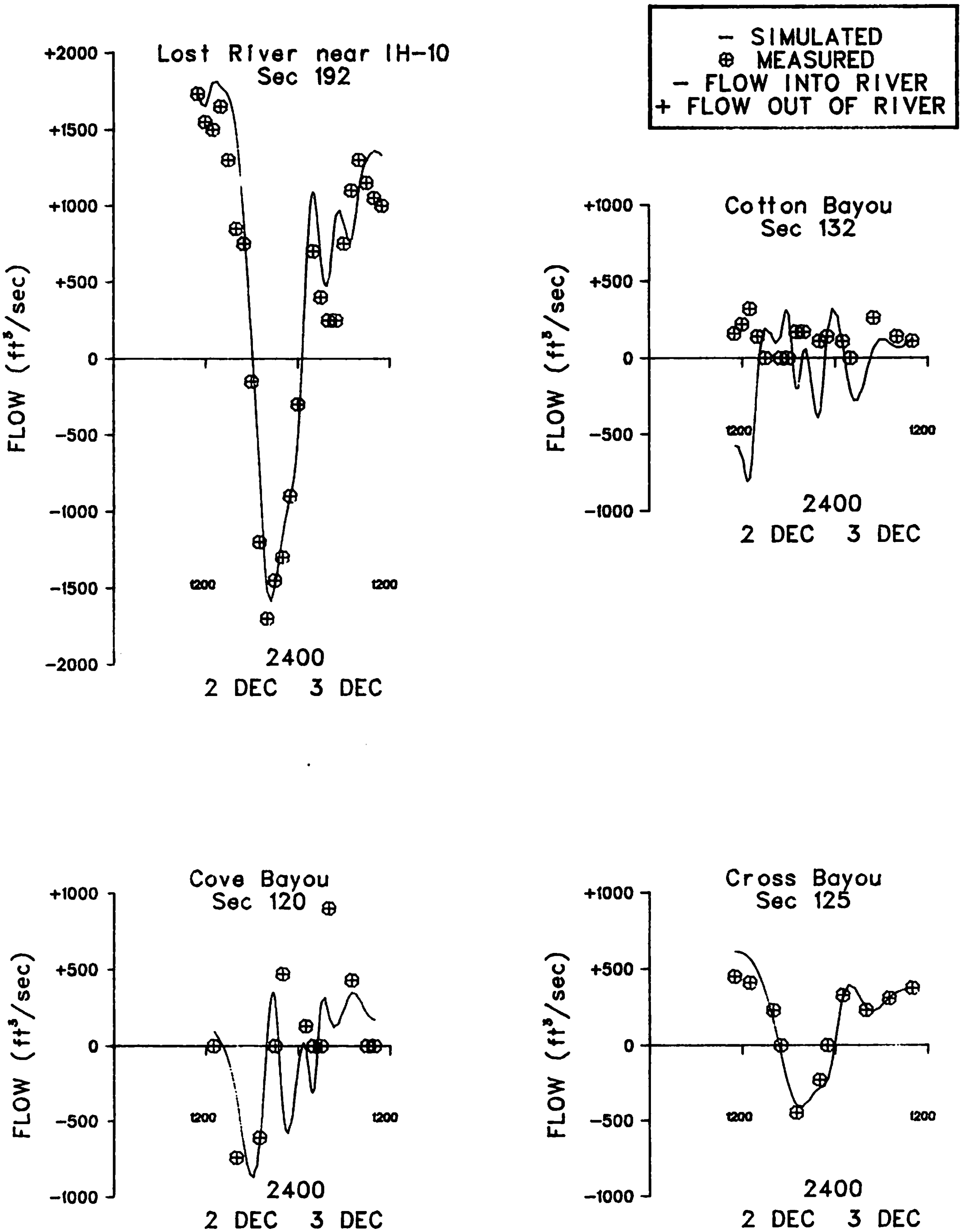

Figure II-35. (contd.) Comparison of Measured and Simulated Flows.

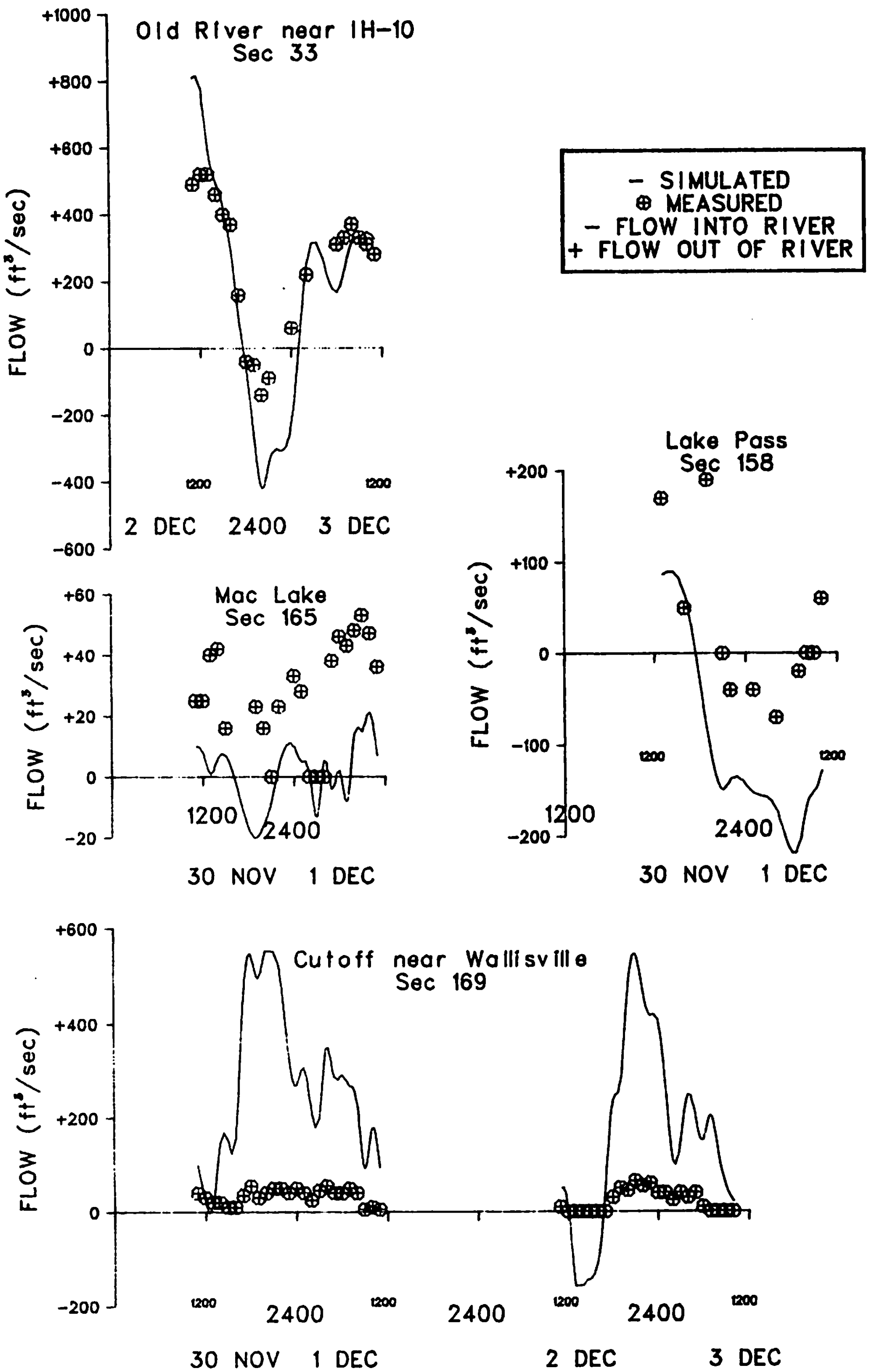

Figure II-35. (contd.) Comparison of Measured and Simulated Flows.

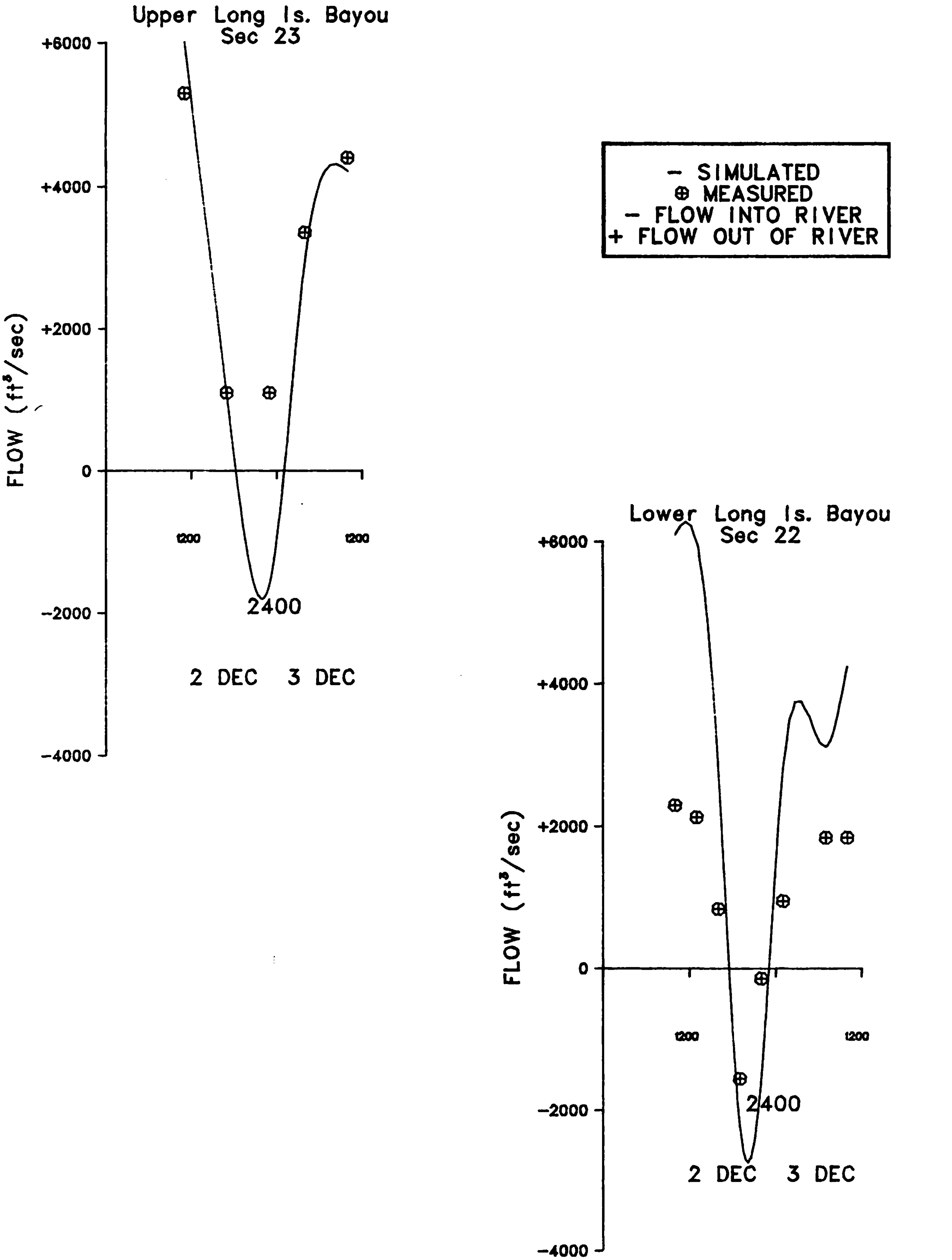

Figure II-35. (contd.) Comparison of Measured and Simulated Flows.

Island Bayou (section 22), Upper Long Island Bayou (section 23), Cross Bayou (section 125) and Cove Bayou (section 120). Again the Cutoff location is the site of the poorest simulation. At this location the flow direction is in general correctly simulated, but simulated flows are approximately an order of magnitude too large. At Cross Bayou, Cove Bayou and Cotton Bayou simulated flows are of approximately the proper magnitude, though errors in flow direction do occur. At the remaining locations on the Lost River, the Old River, Trinity River above Jack's Pass, the Upper Long Island Bayou and the Lower Long Island Bayou the simulated and measured flows compare favorably. There do exist some discrepancies in flow and direction, but most of this error is the result of errors of 1 and 2 hours in the tide phasing. However, a significant error does occur at the Trinity River above Jack's Pass where a reversal in flow for two hours that is indicated by the simulation did not occur in the physical system. Over all this diurnal period was simulated favorably; the Lost River and Old River site measurements show especially good comparison with the simulation results.

This particular case provides a good test of the simulating capabilities of the model, since the extremely low tides resulting from wind setdown provided somewhat abnormal antecedent conditions from which the system may still be recovering during the diurnal studies. Considering the dynamic influence of tides and winds on this area and the fact that even slight tidal phase errors can result in considerable error when comparing nearly instantaneous simulated and measured flows, the magnitudes and direction of flow compare favorably at most sampling sites. Large discrepancies do occasionally occur, especially at the Cutoff, but the model is capable of simulating flow direction and magnitude at most locations in the delta in a satisfactory manner.

A major objective of this study was to apply a one-dimensional hydrodynamic model to the flow regime within the Trinity River Delta and test the efficiency of the model by simulating periods for which tidal elevation and flow verification data were available for the system. This objective has been realized to the extent that the test applications indicate the model is capable of replicating observed water surface elevations within acceptable limits to predict flow regimes necessary for inundation of the marsh areas. Amplitude and phase of the tidal record were replicated accurately at several tide gauge locations in the system. A slight (0.3 ft.) displacement of the observed and simulated tidal records was in constant evidence at the Anahuac Channel and the Old River Cutoff gauges. A study of relative water levels in the system, independent of model results, strongly suggests the discrepancy is in the data and not an error in the model.

Limitations of available flow data prevent an unqualified judgment on the model's ability to predict absolute levels of flow throughout the system. However, the model did exhibit the ability to replicate proper flow direction and periodicity. The major discrepancy in the model simulations occurred during the periods of strong north winds, which results in wind setdown in bay and deltaic waters and periods of low flow such as the onset of flow reversal at slack tide. This could be due to the occurrence of bi-directional flow or simply because the flows are below the threshold of the model's capabilities since the model was designed to predict the occurrence and extent of marsh inundation during periods of high tides and/or moderately high streamflow conditions.

CHAPTER III

DEVELOPMENT AND APPLICATION OF A MASS TRANSFER MODEL OF THE TRINITY RIVER DELTA

FORMULATION OF MASS TRANSFER MODEL

As a means of evaluating the nutrient flux in a deltaic system, the one-dimensional hydrodynamic model described in Chapter II was linked to a mass transfer model. The mass transfer model allows for the simulation of the following water constituents: organic nitrogen, ammonia, nitrite, nitrate, phosphorus, carbon, two species of algae, and a miscellaneous constituent which may be determined by the user. This miscellaneous constituent may either be conservative or subject to first-order decay. The concentration of any one of these constituents is usually a complex interaction of tidal and freshwater advective influences, dispersive fluxes, sediment interactions, biological reactions, and macrophyte and algal nutrient exchanges. Many of the above interactions are in turn a function of water levels, temperature, season of the year, and light intensity. In its entirety, the interactions in the deltaic system are much too complex to be modeled exactly. However, one of the objectives of this study was to examine whether the nutrient concentrations in the delta and the transport of these nutrients can be approximated with a numerical model to a degree satisfactory for water management purposes.

The principal factors governing nutrient concentrations in this type of deltaic system, which are incorporated in the model, include the following:

(1) flow, tidal and streamflow conditions resulting in large-scale mass movement of material;
(2) dispersion, molecular diffusion and larger scale turbulent and eddy dispersion result in the movement of constituents;
(3) marsh exchange, the complex chemical and biological reactions effecting a net release or absorption of nutrients with the sediments and macrophytes in the marsh or channel;
(4) biological reactions, e.g. bacterial decomposition and oxidation resulting in the nitrification of the nitrogen cycle;
(5) algal exchanges, nutrient uptake and release occurring as a function of algal metabolism.

The detailed development of the basic equations and numerical solution technique used in the mass transfer model is discussed in Hauck (1977). The basic equation solved by the model in the section-mean mass continuity equation

$$\frac{1}{A}\frac{\partial}{\partial t}(AC) + \frac{1}{A}\frac{\partial}{\partial x}(AUC) = \frac{1}{A}\frac{\partial}{\partial x}\left(AE_L\frac{\partial C}{\partial x}\right) \pm S \qquad \text{(III-1)}$$

where

C = constituent concentration
E_L = longitudinal dispersion coefficient
S = source/sink terms, i.e. sediment transfer biological reactions, plant uptake, influent sources and withdrawal sinks

Other variable definitions are the same as described in Chapter II. Equation (III-1) contains one unknown C, as a function of x and t. The equation is solved in its full nonlinear form.

As with the hydrodynamic model, the basic equation (III-1) is 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 estuary/river is segmented into discrete sections exactly as utilized in the hydrodynamic model. The concentration is defined at the centerpoint of each channel and a second concentration is specified for the flood plain area associated with each section.

The water surface elevations needed to determine the cross-sectional area and the flows are obtained from the hydrodyanmic model. Since the Trinity Delta is an advection-dominated system, the longitudinal dispersion coefficient E is assumed to be invarient in space. The source/sink term S may take several forms; a withdrawal or inflow Qf may occur, the constituent may be a non-conservative material undergoing some form of biological transformation, some other constituent may be biologically transformed into the constituent or the constituent may be interacting with the sediments, macrophytes or algae in its surroundings. Any combination (or none) of the above source/sink terms may apply to the mass balance of a constituent at a computational nodal point. The constituents contained in the mass transfer model are a first-order constituent, organic nitrogen, ammonia, nitrite, nitrate, phosphorus, carbon, and two algal species.

The first-order constituent is a user-specified constituent. This constituent may undergo first-order decay or be considered conservative by setting the decay rate to zero. As such this constituent may represent any material which can be easily separated from the nutrient cycles. Thus this constituent may be salinity (or total dissolved solids), coliforms, a toxin, a heavy metal or almost any molecular constituent in the water.

The next several constituents are considered together as the nitrogen cycle (see Figure III-1). The nitrogen constituents considered are organic nitrogen, ammonia, nitrites and nitrates. The nitrogen cycle as formulated in the model assumes aerobic conditions at all times. Beginning with organic nitrogen (amines, proteins, nitriles), saprophytic bacteria decompose organic nitrogen into ammonia. This biological reaction is approximated with a first-order reaction with decay rate K_1. The ammonia may be utilized by the plants in the system (algae and macrophytes) to produce plant protein. Algal uptake of ammonia is defined by the term U_1, which will be explained shortly when algae simulation is described, and macrophyte uptake of ammonia is included in the exchange rate term E_2. In addition ammonia is oxidized by autotrophic nitrifying bacteria. The Nitrosomonas group converts ammonia to nitrite, which is approximated in the model by a first-order reaction with decay rate K_2. Occasionally chemical or biological uptake or release of nitrite may occur between the water column and the sediments and this occurrence is accounted for in term E_3. Continuing the cycle, nitrite is oxidized to nitrate by the Nitrobacter bacterial group, and this bacterial reaction is approximated by a first-order reaction with decay rate K_3. Nitrate is a plant nutrient which may be utilized to produce plant protein. Algal uptake of nitrate is defined by term U_2 and sediment-macrophyte exchanges are incorporated in term E_4. The cycle is completed by a return of the organic nitrogen from sediments, algae and macrophytes to the water column through chemical and biological reactions which are incorporated in term E_1. The recycling of algal nitrogen is assumed to be accounted for through the exchange term, since most algal die-off results from settling out to the sediments.

Obviously this nitrogen cycle is a simplified representation of the nitrogen cycle in a deltaic system, particularly, with regard to definition of the various chemical and biological reactions that are occurring in the system. The various E terms combine many sediment reactions, equilibrium exchanges and plant reactions under one exchange rate term with the units of mass/area/time. The studies of Armstrong and Gordon (1977) as described in a later section of this report, have specifically coincide with the development of this nutrient model for the purpose of defining values of E as a function of time of year and dominant plant species in areas of the Trinity Delta. The use of first-order rates to approximate the bacterial decomposition and oxidation of various forms of nitrogen is a method utilized by Thomann, O'Connor, and Di Toro (1976) on the Delware and Potomac estuaries, among others.

It should be noted that algae and organic nitrogen are considered separately, though algae constitutes a portion of the organic nitrogen in deltaic waters. In deltaic areas where large fluxes of organic nitrogen result from exchanges between the water and marsh areas, the organic nitrogen represented by algae is normally a fairly insignificant portion of the total organic nitrogen. While the algae is used to define uptake of nutrients,

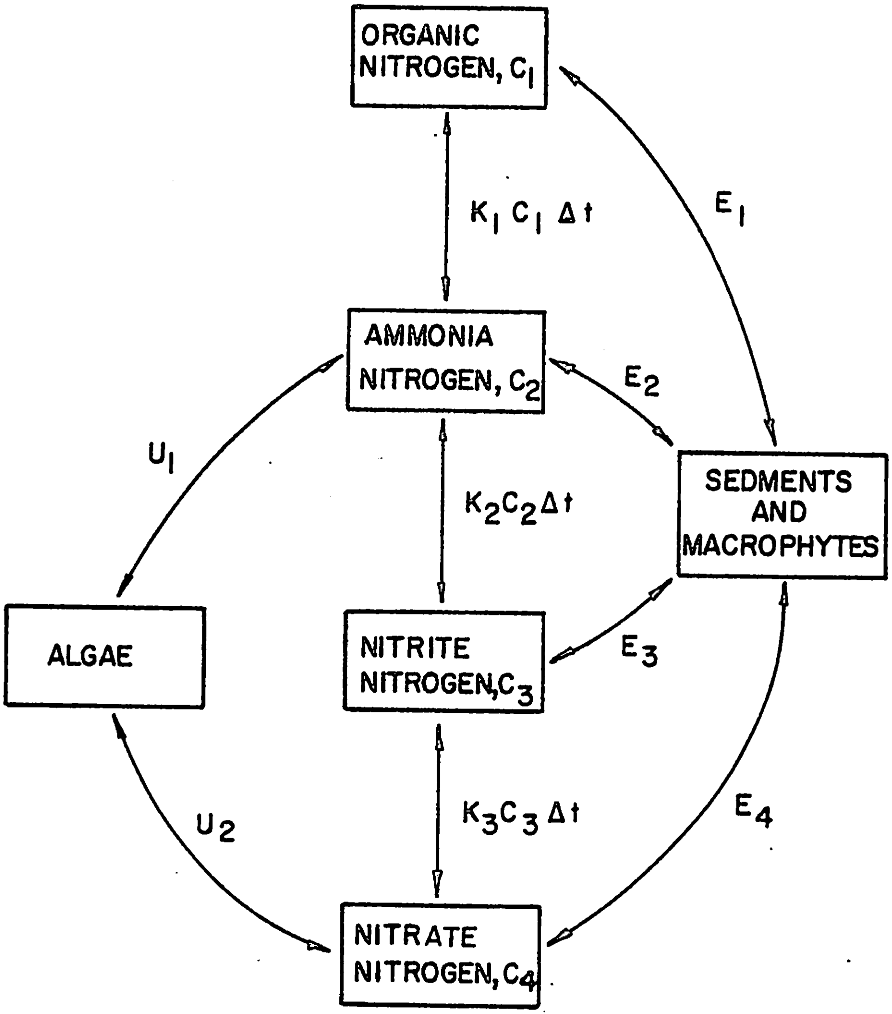

Figure III-1 NITROGEN CYCLE AS FORMULATED FOR MASS TRANSFER MODEL (Source: Hauck, 1977) any recycling of the algae due to settling to the sediments is assumed to be incorporated in the exchange rate terms. Also organic nitrogen from higher trophic levels such as zooplankton is ignored. The modeling of higher trophic levels represents an increased degree of sophistication not attempted in this study. The inclusion of higher trophic levels would require the addition of several poorly defined coefficients and constants which would lead to unreliable simulations. The effort required to refine these relationships is not justified since that portion of the total biomass in deltas attributable to the higher tropic levels is not significant.

With the above constraints and simplications, the nitrogen cycle in this model includes the following source/sink terms for each constituent of the nitrogen cycle

$$S_1 = -K_1\ C_1\ \Delta t \pm E_1 \qquad \text{(organic nitrogen)}$$

$$S_2 = K_1\ C_1\ \Delta t - K_2\ C_2\ \Delta t - U_1 \pm E_2 \qquad \text{(ammonia)}$$

$$S_3 = K_2\ C_2\ \Delta t - K_3\ C_3\ \Delta t \pm E_3 \qquad \text{(nitrite)} \qquad \text{(III-2)}$$

$$S_4 = K_3\ C_3\ \Delta t - U_2 \pm E_4 \qquad \text{(nitrate)}$$

where all variables are as denoted in Figure III-1.

Phosphorus is a second nutrient considered in the model. The usual forms of phosphorus in aqueous solutions include orthophosphates, polyphosphates and organic phosphates. For modeling purposes, all the forms of phosphorus are considered together as total phosphorus. As such, the phosphorus constituent may be considered conservative, though sediment/macrophyte exchange rates and algal uptake are included in addition to the dispersive and advective flux terms. The phosphorus source/sink term has the following form

$$S_5 = -U + E_5 \qquad \text{(III-3)}$$

where U_3 is phosphorus uptake due to algal growth and E_5 is the sediment/macrophyte exchange rate for total phosphorus. The uptake of phosphorus by algae will be discussed later. Recycling of phosphorus from algae is assumed to occur mostly from decomposition of cells that have settled to the bottom and is therefore included in E_5.

The last nutrient considered in the model is carbon. Because of the dependency of inorganic carbon concentrations on pH and reaeration of carbon dioxide from the atmosphere (both these terms being hard to quantify in a deltaic system) only total carbon is considered in the model. The various components of the carbon cycle include carbon dioxide, bicarbonate ions, carbonate ions and organic carbon. To account for carbon in the model, yet to avoid the complicated interactions of the carbon cycle, carbon is modeled as a conservative constituent, with only the sediment/macrophyte exchange rate considered in the source/sink term

$$S_6 = E_6 \qquad \text{(III-4)}$$

where E_6 is the sediment/macrophyte exchange rate for carbon and S_6 is the source/sink term for carbon.

The last constituents of the mass transfer model are two species of algae. Each algal species is considered independently, with its own set of defining variables. The following processes are incorporated in the algae simulation: photosynthesis, respiration and die-off (combination of grazing, settling and parasitization). In order to determine algal growth or phytosynthesis, Monod (Michaelis-Menton) kinetics are used. This form of kinetic equation was first used by Michaelis and Menton to explain enzymatic reactions, and was later used by Monod to describe growth of biological organisms. The basic form of the Monod equation is, for algal species i,

$$\frac{dMi}{dt} = M_i \mu_i \qquad \text{(III-5)}$$

where

$$M_i = \frac{\mu_{i,m} C}{K_{i,m} + C} \qquad \text{(III-6)}$$

μ_i = growth rate species i

M_i = existing mass (concentration) species i

$\mu_{i,m}$ = maximum growth rate (1/time) of species i

C = concentration of substrate (nutrient)

$K_{i,m}$ = half-saturation constant, which is the concentration at which the growth rate equals $(\mu_{i,m})/2$

When used to determine the algal growth rate due to photosynthesis as related to the presence of light, ammonia, nitrate and phosphorus, equation (III-6) becomes the following

$$\mu_i = \min \{\mu_{i,m} \left(\frac{C_2 + C_4}{K_{i,n} + C_2 + C_4}, \frac{C_5}{K_{i,p} + C_5}, \frac{\ln (K_{i,\ell} + I_o) / (K_{i,\ell} + I_o e^{-\varepsilon D})}{(\varepsilon D)} \right\} \qquad \text{(III-7)}$$

where

$K_{i,n}$ = half-saturation constant for nitrogen

$K_{i,p}$ = half-saturation constant for phosphorus

$K_{i,\ell}$ = half-saturation constant for light

C_2 = concentration of ammonia

C_4 = concentration of nitrate

C_5 = concentration of phosphorus

I_o = light intensity at water surface

ε = light extinction coefficient

D = water depth

In this approach, which was used by Lehman, et al. (1975) an algal growth rate is determined for each growth limiting factor and the minimum value determined is used to define the algal growth rate. For this model, the algal growth limiting factors considered are nitrogen (ammonia and nitrate), phosphorus and light.

The light influence on algal growth makes use of the Beer-Lambert equation

$$I = I_o e^{(-\varepsilon D)} \qquad \text{(III-8)}$$

where I is the light intensity at depth D. By intergrating over the depth of the water column and combining the basic forms of equations (III-6) and (III-3), the last term in equation (III-7) is formulated. This manner of determining light influences on growth was utilized by Jorgensen (1976). Influences on ε due to self-shading from algae as a function of time as included by some researchers has been considered to be an unjustified refinement for deltaic systems where ε must normally be crudely estimated.

The other factors influencing net growth of algae are respiration and die-off. Both conditions are estimated with a first-order decay term as follows

$$R_i = -r_i M_i \Delta t \qquad \text{(III-9)}$$

$$D_i = -d_i M_i \Delta t \qquad \text{(III-10)}$$

where

r_i = respiration rate of species i (Δ/time)

d_i = die-off rate of species i (1/time)

R_i = change in mass due to respiration for species i

D_i = chance in mass due to die-off for species i

Recall that die-off is an inclusive term for all forms of algae removal, including grazing and settling.

The net change in algal biomass becomes a function of photosynthesis, respiration and die-off as defined in the following equation which is the source/sink term for algae

$$\frac{dM_i}{dt} = \frac{M_i^{k+1} - M_i^k}{\Delta t} = (\mu_i - r_i - d_i)\, M_i^k \qquad \text{(III-11)}$$

where M_i^k is the algal concentration of species i at time level k and all nonbiological terms such as advection and dispersion fluxes are being ignored for convenience. The uptake of nutrients by algae from the water is expressed as

$$U_1 = \sum_{i=1,2} \left(\mu_i M_i \frac{C2}{C_2 + C_4} f_{i,n}\right) \Delta t$$

$$U_2 = \sum_{i=1,2} \left(\mu_i M_i \frac{C4}{(C_2 + C_4)} f_{i,n}\right) \Delta t \qquad \text{(III-12)}$$

$$U_3 = \sum_{i=1,2} \left(\mu_i M_i f_{i,p}\right) \Delta t$$

where the algal uptake of ammonia U_1 and nitrate U_2 is proportioned to the relative concentration of each constituent, U_3 is the phosphorus uptake term, $f_{i,n}$ is the fractional portion of nitrogen in algal species i, and $f_{i,p}$ is the fractional portion of phosphorus in algal species i.

This discussion of the individual constituents has enumerated and briefly explained the various biological and chemical reactions considered in the modeling of each constituent in the mass transfer model. These reactions are all entered into the mass continuity equation (III-1) as source/sink terms.

The various biological reactions incorporated into the model are assumed to be dependent on the water temperature in accordance with the Arrhenius relationship

$$R_T = R_{20}\, \theta^{(T-20)} \qquad \text{(III-13)}$$

where

R_t = reaction rate of temperature T

R_{20} = reaction rate at temperature 20°C

θ = constant, for this model, $\theta = 1.020$

In this model, the algal respiration and growth rates and the bacterial decomposition and oxidation rates are all temperature dependent. Also, when temperature conditions exist that are outside the normal functioning region of the algae, either too high or too low, the model is formulated to terminate algal growth and to reduce the respiration rate. Such water temperature occurrences are normally rare in Texas deltas, and as such are of only minor concern in most model applications.

Boundary conditions are incorporated into the model in two ways: one accounts for concentration definition at the tidally influenced boundary and the other specifies concentrations at all inflow points to the segmentation. For example, an inflow point is the Trinity River flow at the upstream boundary of the segmentation. For each boundary in the segmentation a set of concentrations, one for each model constituent, is input into the model. At the tidally influenced boundary, the bay concentrations at section one are set to these values and this concentration is not altered by advection or dispersion into this section. So the lower boundary of the model has specified concentrations that are not altered by model operation. At inflow boundaries the concentrations input to the model are the concentrations used in the inflow source/sink term. Through proper input specification, boundary values may be made to vary with time.

Initial conditions throughout the segmentation may be specified in two ways. First, values for each model constituent may be input and all concentrations in the system with the exception of the tidal boundary, section 1, are set to these values. For more refinement, it the necessary data is available or if reasonable estimates can be made, concentrations may be defined for each section. This is done by an interpolation scheme wherein the user specifies concentrations at various sections in the segmentation, the first and last numbered sections must be two of these points, and the model does a linear interpolation between the sections where values are specified to determine the initial concentrations at intermediate sections. The second manner of initiating concentrations can greatly reduce the time required for the model to stabilize from the initial conditions. Initial condition specification is arranged so that it does not change the boundary conditions at the tidal boundary.

The model is formulated to allow some versatility in the specification of exchange-rate coefficients in the segmentation. As many as ten sets of exchange rate coefficients may be input to the model; a set consisting of values for E_1 through E_6. Each section utilizes two separate sets of exchange rate coefficients, one for the conveyance channel and the other for the flood plain. As examples, sets of exchange rate coefficients may be determined for channel bottoms (sediments), <u>Spartina patens</u> marsh and cypress swamp. Thus the changing vegetative patterns throughout the deltaic segmentation can be accounted for with different exchange rate coefficients.

As previously mentioned, the water elevations and flows determined from the hydrodynamic model are necessary information to solve the mass continuity equation. Therefore, while the hydrodynamic model may exist independently of the mass transfer model, the mass transfer model must be run simultaneously with the hydrodynamic model. This is accomplished by linking the models so that the mass transfer model is a set of subroutines called from the hydrodyanmic model. With this linkage, if only a hydrodynamic simulation is desired, the mass transfer model is not called, while if a nutrient simulation is required, both the hydrodynamic and mass transfer models are employed.

APPLICATION OF MASS TRANSFER MODEL

Model Segmentation

Since the mass transfer model utilizes the identical segmentation of the Trinity Delta as the hydrodynamic model, no modification of the segmentation is required for the mass transfer model application. The hydrodynamic input was kept identical to that used for the intensive hydrodynamic study simulation. The one adjustment necessary was to terminate the upstream boundary at the Trinity River at Liberty streamflow gauge (section 92) rather than at the Romayor streamflow gauges (section 108). Since the period (25 November through 30 December 1976) was a relatively low flow period and no inundation of the flood plain between the Liberty and Romayor gauges was occurring, this alteration has essentially no effect on the hydrodynamic results. However, this modification does allow the upstream terminus of the segmentation to correspond to a sampling location during the study and this allows for more accurate boundary condition specification.

In order to determine values for the various coefficients and constants used in the rate process relationships and the constituent concentrations necessary for input at the boundaries of the system, extensive information on the habitat, nutrient loadings, and nutrient exchange rates in the Trinity River Delta is needed. The following is a discussion of the development of this information.

Habitat Description

The Trinity Delta is located on the northeastern extremity of the Trinity-Galveston Bay complex within Chambers County. The adjacent Trinity Bay estuary is geomorphologically a river mouth that was gradually inundated by rising sea level in post glacial times.

In the literature the total area of fresh and brackish water marshes attributed to the Trinity Delta is uncertain. Conner and

Truesdale (1972) reported 28,000 acres of water, intertidal marsh, high marsh, and cypress swamps while Adams (1977) reported the total marsh area as 49,900 acres. No attempt will be made here to reconcile this almost two-fold difference, however, TDWR personnel have planimetered and estimated the total marsh area from USGS 7.5 minute guad sheets to be about 35,000 acres of intertidal marsh, mud flats, cypress swamps, high marsh, and ponds and water courses.

Flora

Comprehensive investigations of flora speciation in the delta area appear to have been limited to two major studies, (1) the Lake Wallisville Environmental Impact Statement by the U.S. Army Corps of Engineers (Trahan, 1977) which contains vegetation transects and (2) Adams (1977) of Espey, Huston & Associates, contracted by the TDWR to produce vegetation habitat descriptions and maps of the Trinity Delta area in support of the TDWR's bay and estuary research program.

The Wallisville EIS study had the delta divided into seven major habitat areas. These were: (1) brackish marsh south of Old River Lake, (2) brackish marsh north of Old River Lake, (3) freshwater marsh, (4) prairie and disturbed sites, (5) mixed woodlands, (6) bottomland hardwoods, and (7) cypress swamps. Adams (1977) divided the marsh into four major zones. These were: (1) the lower marsh, (2) the middle marsh, (3) the upper marsh, and (4) cypress swamps.

Areal extent of the lower marsh corresponds to the brackish marsh south of Old River Lake as designated in the Wallisville EIS. The middle marsh encompasses the area from north of the Wallisville dam to roughly the I.H. 10 roadbed. This corresponds with the Wallisville EIS brackish marsh north of Old River Lake. The area north of I.H. 10 is designated as either upper marsh or cypress swamp by Adams. The Wallisville EIS is more specific and divides the area into the latter five designations.

The brackish marsh vegetation south of Old River Lake is predominantly *Spartina patens* (marsh cordgrass) with local dominant patches of *Phragmites communis* (reid) and Alternathera philoxeroides (alligator weed) interspersed with some *Eleocharis* (spikerush), *Scirpus* (bulrush), and *Sagittaria* (arrowhead). The brackish marsh that lies between Old River Lake and I.H. 10 is dominated by *Echinochloa muricata* (barnyard grass) and *Paspalum lividum* (longtom) along with locally dense areas of *Sagittaria*, *Phragmites*, and *Alternathera*.

The "freshwater" marsh north of I.H. 10 is predominantly bald cypress swamp (*Taxodium distichum*) in the Lake Charlotte-Mac Lake area east of the Trinity River. West of the Trinity River predominant vegetation types include *Phragmites* and *Aster subulatus* (saltwater aster). Areas of locally dominant vegetation such as _Juncus effusus_ (soft rush), _Eleocharis_, and _Alternathera_ were also reported.

Fauna

In view of the proximity of the Anahuac National Wildlife Refuge to the southeast of the Trinity Delta and the similarity of the predominant vegetative species to the lower brackish marshes in the Trinity Delta, it can be assumed that the major terrestrial species present in the refuge would be similar to those found in the delta. The U.S. Fish and Wildlife Service (1978) notes mosquitos and fire ants as the most common organisms present. Mammals include raccoons, armadillo, striped skunk, bobcat, river otter, coyotes, and coyote-wolf hybrids. Common reptiles include the american alligator and the water mocassin. At least 250 species of birds are known to utilize the area.

Aquatic Organisms

Conner and Truesdale (1972) found 106 species of macrocrustaceans and fishes in the lower Trinity River and adjacent deltaic marshes. In general the entire brackish water section was found to be sustaining populations of rapidly growing postlarval and/or juvenile brown shrimp (_Penaeus aztecus_), white shrimp (_P. setiferus_), and blue crabs (_Callinectes sapidus_). The tendency was for the shrimp to concentrate in the shallow, soft bottomed, semi-enclosed habitats like marsh lakes and blind bayous. Of the fishes, three species appear to be the most numerous. These are the Atlantic croaker (_Micropogon unjulutus_), the bay anchovy (_Anchoa mitchilli_), and the Gulf menhaden (_Brevoortia patronus_). The lakes and small bayous seemed to be most important for croakers, menhaden, and sand seatrout (_Cynoscion arenarius_). Lost River yielded the best catches of anchovies and hogchokers (_Trinectes maculutus_). The spot (_Leiostomus xanthuris_) was most abundant in Cross Bayou.

Nutrient Exchange Rate Studies

Feasibility studies and development of methodology to determine nutrient exchange rates in typical deltaic marsh habitats were begun in 1974 by Armstrong et al. under contract with the TDWR. The initial report, Armstrong et al. (1975), focused on studies 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 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. Results of this study indicated that following a prolonged period of drying (at least 45 days), upon reinundation a large pulse of nutrients are released from the sediment within the first several hours. The rate of release then drops rapidly to a lower normal level. An inundation event covering the marsh to a depth of 0.5 feet for a two day period is sufficient to provide a large pulse of nutrients to the estuarine system from the delta. 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 CPN exchange rates of predominant vegetational habitats in each of the major deltaic marshes along the Texas coast.

In the investigation in the Trinity River deltaic marshes, (Armstrong and Gordon, 1977a), exchange for particulate and soluble organic carbon, organic and inorganic nitrogen, and phosphorus through the Trinity 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 concentrations; 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.

Additional nutrient exchange studies are being performed in marshes on the north shore of East Galveston Bay by Harcombe (1977) and his students at Rice University and on marshes in Mississippi by de la Cruz (1977) and his co-workers. Both groups are using the mass exchange technique similar to that used by Armstrong et al. (1975). Results from these studies are not yet available.

Plexiglass core reactor samples were obtained from the shore of Mac Lake and at sites along Cross and Long Island Bayous. The Mac Lake cores were felt to be representative of the peripheral area of the lake likely to be inundated by floodwater or flushed by heavy rainfall and thus likely to exchange nutrients with Mac Lake waters.

Core samples taken from the shores along Cross and Long Island Bayous represented plant types subject to tidal influence in the lower part of the delta and line the water conveyance channels from Lost River to Trinity Bay. Nutrients derived from these areas would be flushed rapidly into the estuary.

Each twelve-inch diameter plexiglass reactor contained a one to two-foot "plug" of sediment surrounding specimens of typical macrophytic vegetation that appeared to be areally predominant around the site at which the core was collected.

A total of eight reactors were collected at these locations. The dominant vegetation that was represented in each reactor is listed in Table III-1.

In addition to the plexiglass cores, a linear model marsh containing sediment and vegetation "slices" were collected from an area in the delta near the Houston Lighting and Power cooling pond. A gradient of typical lower delta vegetation and associated sediment representing species present in normally inundated areas at the waterline, to those marsh species inundated less frequently that lie further up in the marsh. The linear marsh model (see Armstrong and Gordon, 1977c) was a rectangular plywood box 20 feet (6.1 meters) long; two feet (0.61 meters) wide; and four feet (1.2 meters) high. The model had a slanted floor with a 1:20 slope. A removable plate at the lower end permitted placement of the marsh sections. Water level control was obtained by utilizing a pump, a timer, and various siphon arrangements. The gradient of plant species present in the model marsh sections is depicted in Figure III-2. Distichlis spicata is the species predominant at the lower end of the marsh and subject to more frequent inundation. Locations of sites where plexiglass core and linear marsh specimens were collected is depicted in Figure III-3.

The plexiglass core reactors and the linear marsh model were allowed to stabilize and acclimate to climatic conditions of temperature, salinity, and depth of inundation typical of the winter, spring, and summer seasons. After the acclimation period for each season, samples were collected over a two week period and analyzed for the uptake or release of carbon, nitrogen, and phosphorus species.

Nutrient exchange rates determined by the reactor and linear marsh studies are as follows.

Reactors

The reactors obtained in the Mac Lake and Lower River Trinity Delta areas contained a variety of macrophyte species. Usually one species dominated the reactor with no more than one other species being present in any significant amount. The number of each reactor and the location in the Trinity River Delta where the

TABLE III-1

MACROPHYTE SPECIES IN TRINITY RIVER DELTA SYSTEM REACTORS
(Source: Armstrong, et al, 1977)

Reactor No.	Location	Dominant Species
1	Cross Bayou West	Sagittaria lancifolia L., Bacopa monnieri (L.), Wettst.
2	Long Is. Bayou	Scirpus americanus Pers. var. longispicatus Britt., Bacopa monnieri (L.) Wettst.
3	Long Is. Bayou	Scirpus americanus Pers. var. longispicatus Britt.
4	Long Is. Bayou	Scirpus americanus Pers. var. longispicatus Britt., Polygonum punctatum Ell.
5	Cross Bayou East	Spartina patens (Ait.) Muhl.
6	Cross Bayou West	Rhynchospora macrostachya Torr., Ludwigia repens Forst.
7	Mac Lake	Rhynchospora macrostachya Torr., Ludwigia alterniflora L.
8	Mac Lake	Lythrum lanceolatum Ell.

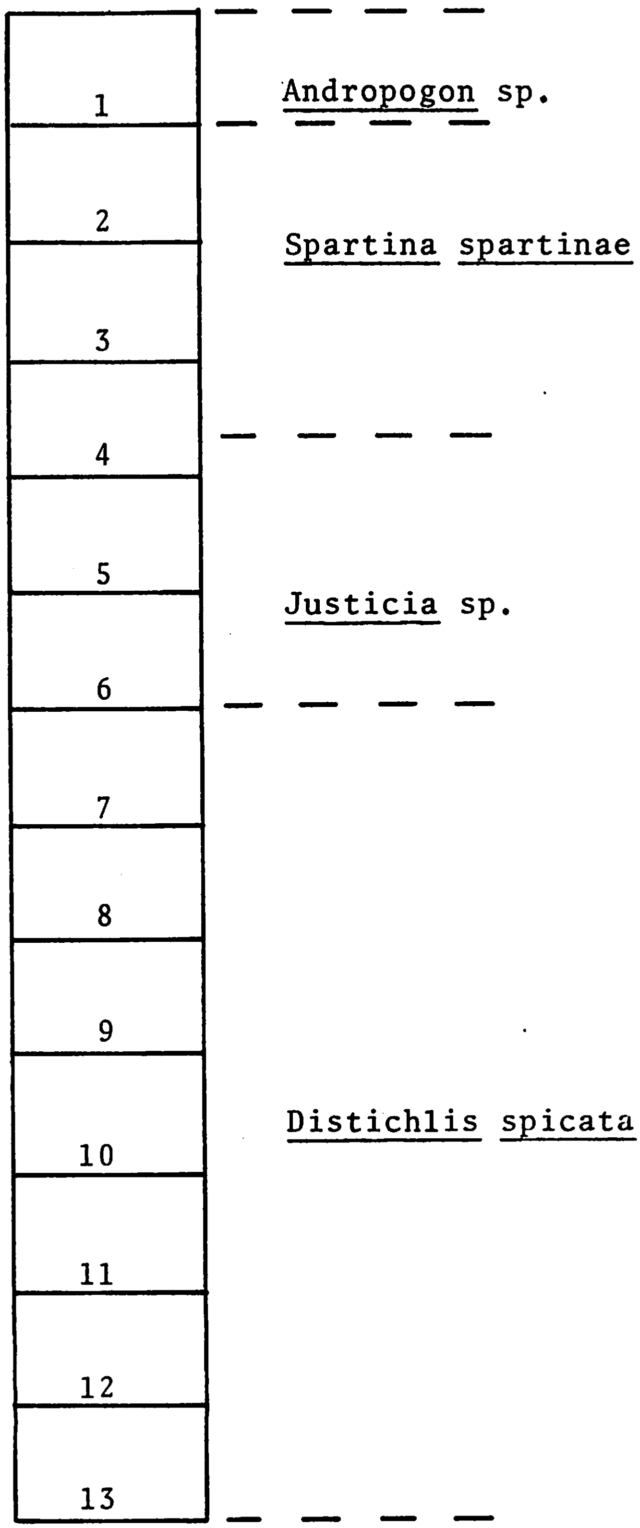

Figure III-2 Distribution Of Plants in Linear Marsh From Lower Trinity River Delta. (Source: Armstrong, et al, 1977)

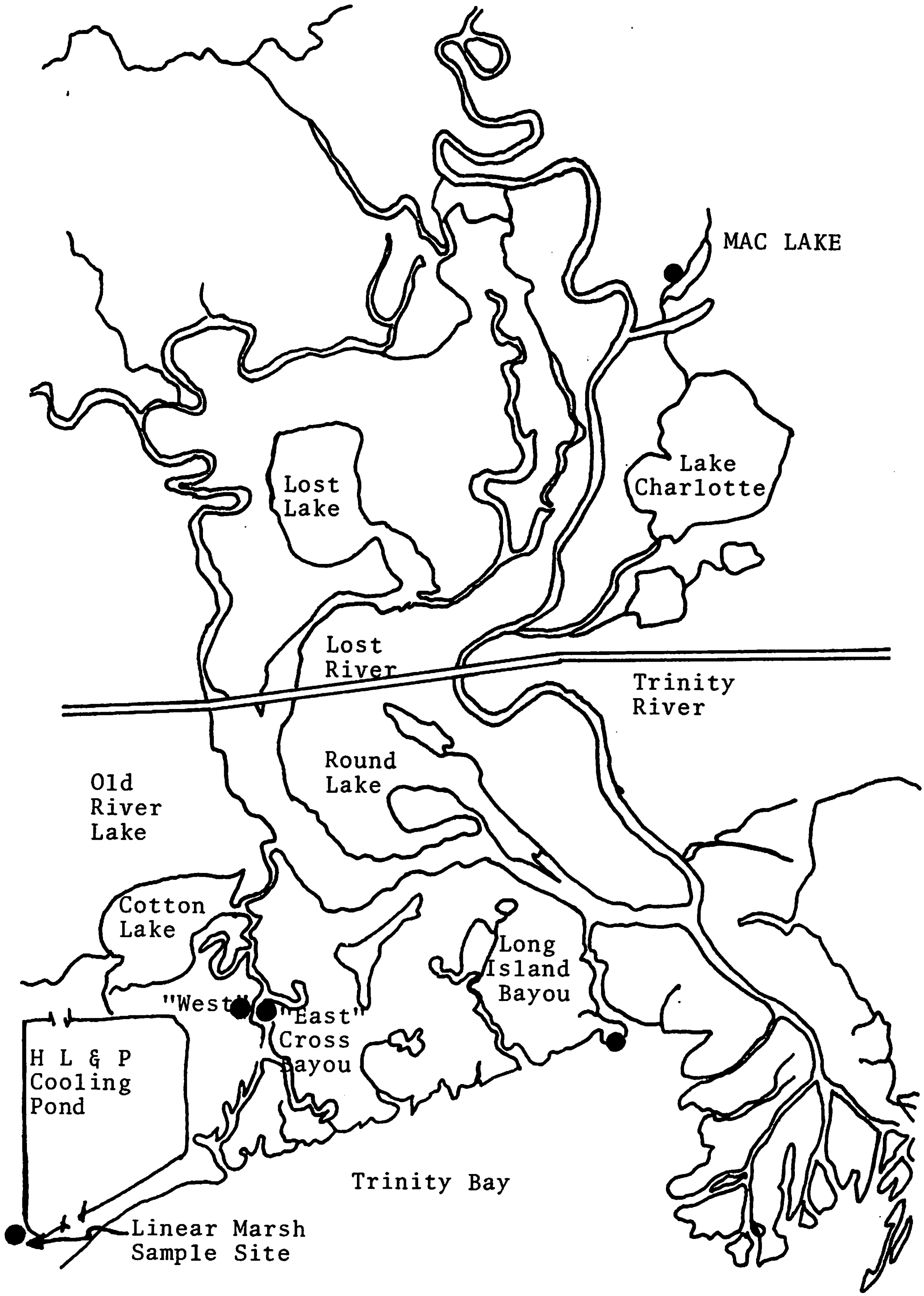

Figure III-3 Location of Sampling Stations in the Lower Trinity River Delta (Source: Armstrong, et al, 1977) reactor was obtained are listed in Table III-1 along with the major and minor macrophyte species. The dominant plants in the Mac Lake reactors were *Rhynchospora macrostachyta* and *Lythrum lanceolatum*. These are predominantly brackish water species as would be expected in the upper delta area. In the Cross Bayou West reactors, *Sagittaria lancifolia*, *Rhynchospora macrostachya*, and *Spartina patens* were dominant while in Long Island Bayou *Scirpus americanus* was dominant.

The exchange rates for the reactors are grouped according to the dominant macrophyte and are given for each of the measurement periods in the following tables.

The results for *Lythrum lanceolatum* (Reactor 8) are shown in Table III-2. The results for this reactor show that exchange rates for organic carbon forms are all negative, that is, in a release mode; the magnitude of the values are quite small indicating, in essence, little exchange of carbon from this reactor. There is essentially no exchange of nitrogen and phosphorus.

Exchange rates for *Rhynchospora macrostachyta* in Mac Lake (Reactor 7) are shown in Table III-3. Again, the magnitude of the exchange rates are quite small and, for the organic carbon fractions, in a release mode. For nitrogen and phosphorus, there appears to be a slight uptake, but rates of this small a magnitude are insignificant. The exchange rates for this same plant in Reactor 6 from Cross Bayou West are shown in Table III-4. These results show a high release of total suspended solids, a smaller release of particulate organic material but an uptake of soluable organic carbon as TOC. The nutrients oxygen and phosphorus show a consistent uptake. There appears to be no seasonal trend of these rates except for total suspended solids which shows a decreasing release rate.

The only reactor containing *Spartina patens* in the Trinity River Delta was Cross Bayou East, and the results for this plant are given in Table III-5. The results show high releases of particulate organic carbon in the winter and spring sampling periods but an uptake of this material during the summer. The organic and inorganic fractions of nitrogen and phosphorus show an almost consistent uptake pattern during all sampling periods.

Scirpus americanus was the dominant macrophyte in the three reactors from Long Island Bayou, and the arithmetic average of exchange rates for these three reactors are shown in Table III-6. As with the *Spartina* reactor, there is a high release of particulate organic carbon during the winter and spring measurement periods and a consistent uptake of organic and inorganic forms of nitrogen and phosphorus. The only evident seasonal trend is for particulate material and there appears to be a decrease in the loss of this material with time.

TABLE III-2

NUTRIENT EXCHANGE DATA
FOR LYTHRUM LANCEOLATUM
IN TRINITY BAY (MAC LAKE)
Kg/ha/day
(Source: Armstrong, et al, 1977)

ANALYSIS	Spring	Summer	Avg.
SALINITY	2.	4.	3.
TSS	-.138	-.529	-0.334
VSS	-.015	-.049	-0.032
BOD(5)	-.002	-.000	-0.001
TOC	-.018	-.001	-0.009
INORG CRBN	.004	.060	0.032
UF TKN	.001	0	0.000
F TKN	.000	-.000	0.000
F NH3	.001	.000	0.000
F NO2	.000	0	0.000
N NO3	.000	.002	0.001
UF TOT P	.001	-.002	0.000
F TOT P	.001	-.002	0.000
F ORTHO P	.001	-.000	0.000
PART T P	-.001	.000	0.000
PART TKN	.000	.000	0.000
ORG N	.000	-.000	0.000

F = FILTERED
UF = UNFILTERED

TABLE III-3

NUTRIENT EXCHANGE DATA
FOR RHYNCHOSPORA MACROSTACHYA
IN TRINITY BAY (MAC LAKE)
Kg/ha/day
(Source: Armstrong, et al, 1977)

ANALYSIS	Spring	Summer	Avg.
SALINITY	3.	4.	4.
TSS	-.156	-.316	-0.236
VSS	-.043	.027	-0.008
BOD(5)	-.002	0	-0.001
TOC	-.007	0	-0.004
INORG CRBN	-.050	.022	-0.014
UF TKN	.001	0	0.000
F TKN	.001	-.000	0.000
F NH3	.001	.000	0.000
F NO2	.000	0	0.000
N NO3	.003	.002	0.002
UF TOT P	.001	.001	0.001
F TOT P	.001	.001	0.001
F ORTHO P	.002	.001	0.002
PART T P	.002	.000	0.001
PART TKN	.000	.000	0.000
ORG N	.001	-.000	0.000

F = FILTERED
UF = UNFILTERED

TABLE III-4

NUTRIENT EXCHANGE DATA
FOR RHYNCHOSPORA MACROSTACHYA
IN TRINITY BAY (LOWER DELTA)
Kg/ha/day
(Source: Armstrong, et al, 1977)

ANALYSIS	Winter	Spring	Summer	Avg.
SALINITY	-177.	157.	157.	46.
TSS	15.582	-12.041	-.787	-9.470
VSS	.472	-4.801	-.393	-1.574
BOD(5)	.078	-.090	-.045	-0.019
TOC	.866	.039	1.180	0.695
INORG CRBN	.039	-.472	.551	0.039
UF TKN	.016	.032	0	0.016
F TKN	.008	.011	-.014	0.002
F NH3	.039	.067	.010	0.039
F NO2	0	.003	0	0.001
N NO3	.171	.255	.255	0.185
UF TOT P	.039	.071	.021	0.044
F TOT P	.028	.063	.041	0.044
F ORTHO P	.011	.062	.030	0.034
PART T P	.132	.098	.013	0.081
PART TKN	.008	.032	.014	0.018
ORG N	.008	.011	-.016	0.001

F = FILTERED
UF = UNFILTERED

TABLE III-5

NUTRIENT EXCHANGE DATA
FOR SPARTINA PATENS
IN TRINITY BAY (LOWER DELTA)
Kg/ha/day
(Source: Armstrong, et al, 1977)

ANALYSIS	Winter	Spring	Summer	Avg.
SALINITY	-406.	-406.	312.	-167.
TSS	-21.970	-20.722	-13.232	-18.641
VSS	-4.494	-8.301	1.997	-3.599
BOD(5)	0.122	-0.213	-.197	-0.096
TOC	0.125	-4.619	1.186	-1.103
INORG CRBN	-2.996	-1.997	1.061	-1.311
UF TKN	0.025	0.034	0	0.059
F TKN	0	0.034	-0.022	0.004
F NH3	0.066	0.101	0.022	0.063
F NO2	0	0.005	0	0.002
N NO3	0.330	0.396	0.204	0.310
UF TOT P	-0.052	0.105	0.120	0.058
F TOT P	0.029	0.110	0.124	0.088
F ORTHO P	0.014	0.125	0.153	0.097
PART T P	0.275	0.156	0.020	0.150
PART TKN	0.012	0.017	0.022	0.017
ORG N	0	0.034	-0.025	0.003

F = FILTERED
UF = UNFILTERED

TABLE III-6

NUTRIENT EXCHANGE DATA
FOR SCIRPUS AMERICANUS
IN TRINITY BAY (LOWER DELTA)
Kg/ha/day
(Source: Armstrong, et al, 1977)

ANALYSIS	Winter	Spring	Summer	Avg.
SALINITY	-329.	172.	268.	37.
TSS	-10.887	-8.555	-16.255	-11.899
VSS	-2.145	-2.704	0.521	-1.443
BOD(5)	0.110	-.160	-0.076	-0.042
TOC	1.208	-.261	0.969	0.639
INORG CRBN	-.653	-1.451	0.581	-0.508
UF TKN	0.017	0.026	0	0.014
F TKN	0.006	0.048	-0.016	0.013
F NH3	0.043	0.069	0.012	0.041
F NO2	0	0.004	0	0.001
N NO3	0.156	0.275	0.142	0.191
UF TOT P	0.031	0.092	0.066	0.063
F TOT P	0.023	0.095	0.067	0.062
F ORTHO P	0.012	0.103	0.076	0.064
PART T P	0.124	0.109	0.014	0.082
PART TKN	0.011	-.010	0.016	0.006
ORG N	0.006	0.048	-0.017	0.012

F = FILTERED
UF = UNFILTERED

The last exchange rates are for Sagittaria lancifolia, which was found only in Reactor 1 from Cross Bayou West. These exchange rates are contained in Table III-7 and show patterns of particulate organic material release consistent with the rates for those plants just discussed. The magnitudes of the release rates are somewhat smaller than for Spartina and Scirpus but larger than the other plants. Again, no consistent temporal trends are evident except for particulate organics for which there is a conversion from a release mode to an uptake model as the summer is reached.

The nitrogen, phosphorus, and carbon contents of the sediments in the reactors are given in Table III-8 and clearly show close correlations between percent dry solids and carbon, nitrogen, and phosphorus concentrations. The Long Island Bayou reactor sediments contain lower levels of nutrients reflecting the erosion of fine particles at the beach. Also evident is the high phosphorus content relative to the nitrogen concentrations, thus indicating a nitrogen limitation for growth of the rooted macrophytes.

A summary of the nutrient exchange rates for the macrophytes found in Mac Lake and the lower delta area are given in Table III-9. The negative rates for TSS and VSS for all reactors show that solids are exported consistently and at higher rates than other nutrients. Exchange rates for BOD_5 and TOC are smaller than those for TSS or VSS and vary between being positive and negative (stored in or released from the reactor, respectively).

The exchange rates for nitrogen and phosphorus are all positive indicating storage in the reactors. Surprisingly, the exchange rates for organic and inorganic forms of nitrogen and phosphorus are zero in the Mac Lake reactors. Nitrate nitrogen and ortho phosphorus were utilized at the highest rates in the lower delta reactors. A distinct difference between the results from Mac Lake and the lower delta area is evident; the exchange rates for the Mac Lake reactors are substantially less than those for the lower delta. These low rates may be due to the small amount of algae growth on the walls of these reactors during the three test periods. In other reactors, a heavy algae growth was found on the reactor walls and often on the sediments; such growths markedly influenced the exchange rates and had to be accounted for when expressing exchange rates and mass exchanged per unit area per unit time. Armstrong and Gordon (1977) called this a "wall effect" and included the reactor wall surface in the area exchanging nutrients. The wall area was always equal to and usually double that of the sediment surface area alone.

Other than the large difference in exchange rates between the Mac Lake and lower delta systems, there appears to be little difference between exchange rates for the four major plant types. Although some marsh macrophytes like Spartina do release phosphorus to the surrounding water, it is not possible from this study to separate the contribution of phosphorus or other nutrients by these

TABLE III-7

NUTRIENT EXCHANGE DATA
FOR SAGITTARIA LANCIFOLIA
IN TRINITY BAY (LOWER DELTA)
Kg/ha/day
(Source: Armstrong, et al, 1977)

ANALYSIS	Winter	Spring	Summer	Avg.
SALINITY	-174.	195.	261.	94.
TSS	-4.429	-7.208	-5.123	-5.587
VSS	-3.734	-2.084	0.261	-1.852
BOD(5)	.261	-.123	0	0.046
TOC	1.259	-2.128	0.130	-0.246
INORG CRBN	-.261	0.434	1.563	0.579
UF TKN	0.017	0.072	0	0.030
F TKN	0.026	0.048	-.016	0.019
F NH3	0.043	0.074	0.011	0.043
F NO2	0	0.004	0	0.001
N NO3	0.175	0.275	0.141	0.197
UF TOT P	0.030	0.069	0.031	0.043
F TOT P	0.020	0.082	0.049	0.050
F ORTHO P	0.007	0.101	0.051	0.053
PART T P	0.133	0.205	0.014	0.117
PART TKN	-0.009	0.024	0.016	0.010
ORG N	0.026	0.048	-0.017	0.019

F = FILTERED
UF = UNFILTERED

TABLE III-8

NITROGEN AND PHOSPHORUS CONTENT OF TRINITY RIVER REACTOR SEDIMENTS*
(Units are mg/gm except as noted)
(Source: Armstrong, et al, 1977)

Reactor	TKN	OrgN	NH3-N	NO2-N	NO3-N	Total P	TOC	Percent Dry Solids (%)	Organic Matter (%)
1	0.18	0.14	0.04	0.06	0.28	0.45	5.43	41	10
2	0.08	0.06	0.02	0.01	0.05	0.20	0.62	89	3
3	0.08	0.06	0.02	0.00	0.02	0.31	1.24	71	2
4	0.11	0.07	0.04	0.02	0.09	0.32	1.01	73	1
5	0.18	0.14	0.04	0.04	0.20	0.33	4.16	30	13
6	0.18	0.14	0.04	0.03	0.14	0.41	6.78	34	11
7	0.20	0.15	0.05	0.03	0.17	0.51	5.32	47	12
8	0.22	0.14	0.08	0.02	0.13	0.83	7.05	42	14

* Average of samples at 0-2, 4-6, and 9-10 cm depth

TABLE III-9

SUMMARY OF NUTRIENT EXCHANGE RATES FOR PLANT TYPES FROM THE LOWER TRINITY RIVER DELTA MARSHES CORRECTED FOR WALL EFFECTS
(Units are kg/ha/day)
(Source: Armstrong, et al, 1977)

	Mac Lake		Lower Delta			
Analysis	Lythrum lanceolatum	Rhynchospora macrostachya	Rhynchospora macrostachya	Spartina patens	Scirpus americanus	Sagittaria lancifolia
Salinity	1.0	2.	19.	-68.	15.	38.
TSS*	-0.136	-0.096	-3.854	- 7.587	-4.843	-2.274
VSS	-0.013	-0.003	-0.641	- 1.465	-0.587	-0.754
BOD_5*	0.000	0.000	-0.008	- 0.096	-0.017	-.019
TOC	-0.004	-0.002	0.283	- 0.449	0.260	-0.100
TKN*	0.000	0.000	0.007	0.024	0.006	0.012
TKN	0.000	0.000	0.001	0.002	0.005	0.008
Part. TKN	0.000	0.000	0.007	0.007	0.002	0.004
Drg-N	0.000	0.000	0.000	0.001	0.005	0.008
NH_3-N	0.000	0.000	0.016	0.026	0.017	0.018
NO_2-N	0.000	0.000	0.000	0.001	0.000	0.000
NO_3-N	0.000	0.000	0.075	0.126	0.078	0.080
Tot. P*	0.000	0.000	0.018	0.024	0.026	0.018
Tot. P	0.000	0.000	0.018	0.036	0.025	0.020
Part. TP	0.000	0.000	0.033	0.061	0.033	0.048
Ortho P	0.000	0.000	0.014	0.039	0.026	0.022

* Results for unfiltered samples

macrophytes from the uptake and release of nutrients by attached algae. Indeed, the uniformity of the results and the "wall effect" seen earlier suggest that the attached algae dominate the exchange of nutrients.

Linear Marsh

The major plants found were Distichlis spicata near the water's edge, Justicia sp. just above the Distichlis. Spartina spartinae followed the Justicia, and finally Andropogon sp. was found at an elevation of approximately 0.6 meters above water level.

The exchange rates measured in the linear marsh during four sampling periods between March and June, 1977 are given in Table III-10. The magnitude of the exchange rates are very comparable to those found in the reactors. The pattern of particulate organic material release in the winter and spring followed by uptake in the summer is found here also. However, the major difference between the linear marsh results and those for the reactors is that the inorganic and organic forms of nitrogen and phosphorus are released for the most part rather than taken up as was the case in the reactors. Further, there is an increasing release of dissolved organic material measured as TOC.

The nutrient contents of sediments in the linear marsh are shown in Table III-11. The correlation between dry solids and carbon, nitrogen, and phosphorus content is obscurred by the addition of sand to the marsh to fill in gaps when the marsh was established, but the nutrient content is similar to that of the reactor sediments. From the ratio of nitrogen to phosphorus concentrations, it appears that nitrogen is limiting to the growth of the macrophytes.

In the linear marsh system, water stage and tide range were controlled to simulate the normal and flood conditions of the spring and the low flow conditions of the summer. The results presented previously in Table III-10 show that the exchange rates of particulate material are higher in the linear marsh than in the reactors. Apparently the stronger mixing action in the linear marsh produces this result. The effect of flooding is mixed; that is, some exchange rates increase while others decrease or become export rather than import. Armstrong and Hinson (1977) argue that upon flooding by freshwaters or wind tides, marshes export substantial amounts of nutrients during the dewatering phase that follows inundation. The attached algae and other plan biomass produced during an inundation dries following dewatering and easily sloughs off upon reinundation to be transported out of the marsh. The sampling periods selected reflect different parts of this cycle: inundation, sloughing and export, attached algae growth and import, drying and then reinundation.

TABLE III-10

EXCHANGE RATES OF CARBON, NITROGEN AND PHOSPHORUS IN THE LINEAR MARSH FROM THE TRINITY RIVER DELTA

Kg/ha/day

(Source: Armstrong, et al, 1977)

Nutrient	Stage			
	Normal	Flood	Low	Low
Total Susp. Solids	-65.49	-52.19	15.228	-37.79
Volatile Susp. Solids	- 3.941	- 9.11	3.384	11.28
BOD_5	0.742	- 1.18	1.523	0.82
Total Organic Carbon	- 0.464	2.07	-2.82	- 4.23
Total Kjeld - N (Un F)	- 0.046	- 0.041	-0.028	- 0.085
Total Kjeld - N	- 0.046	0.083	-0.028	- 0.028
Ammonia - N	- 0.0023	- 0.059	-0.0085*	- 0.006
Nitrite - N	--*	--*	--*	*- 0.014
Nitrate - N	--*	0.094	0.0113	*- 0.024
Total P (Un F)	- 0.0417	0.0041	0.071	- 0.096
Total P	- 0.035	- 0.046		- 0.003
Ortho P	- 0.0058*	- 0.021	0.032	*0

* Some or all data below detectable limits

TABLE III-11

NITROGEN AND PHOSPHORUS CONTENTS OF TRINITY RIVER LINEAR MARSH SEDIMENTS*
(mg/gm)
(Source: Armstrong, et al, 1977)

Analysis	Mud	Grass	High Grass
TKN	0.21	0.17	0.11
Org N	0.12	0.11	0.01
NH_3-N	0.04	0.06	0.10
NO_2-N	0.01	0.03	0.01
NO_3-N	0.08	0.12	0.05
Total P	0.63	0.53	0.81
TOC	1.72	2.86	4.53
Percent Dry Solids (%)	75.	77.	79.
Organic Matter (%)	4.	3.	5.

* Average of samples at 0-2, 4-6, and 9-11 cm depth

Armstrong and Hinson (1977) compared exchange rates for carbon, nitrogen, and phosphorus from the literature to rates measured during their studies in Texas marshes. That comparison has been further updated in Table III-12. Exchange rates in the Trinity and Colorado River Deltas are smaller than most of the measurements for the other delta and probably reflect the small amount of mixing in each reactor. It is expected that transient exchange rates during inundation would be substantially higher for short periods of time. The exchange rates measured in the plexiglass reactors probably represent most closely those conditions when tidal range is small, flooding is nil, and essentially equilibrium conditions exist. To accurately determine a long-term exchange rate for these marsh systems, a time history of tidal ranges and floods in the marsh would have to be known, appropriate exchange rates applied to these temporal events, and the total exchanged mass of nutrients computed and divided by the time period. These averaged exchange rates would likely be in the range of those rates measured in the linear marsh.

Nutrient Balance Studies

The concentrations of nutrients in 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 watersheds drain thousands of acres. Since, with few exceptions, ocean water is relatively nutrient poor, the vast majority of the nutrients to support a productive 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 out over many square miles and offer relatively shallow habitat that supports good 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 serves to provide a type of physical environment that promotes the growth and well-being of the juveniles of many marine species, especially commercially shrimp and crabs, as well as many fishes.

To determine the nutrient contribution of the Trinity River to the Trinity-Galveston Bay System over a range of freshwater inflow conditions, water samples and flow measurements were collected at fourteen locations (Figure III-4). These water 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

TABLE III-12

SUMMARY OF NUTRIENT EXCHANGE RATES
(Units are Kg/ha/day)
(Source: Armstrong, et al, 1977)

	DOC	POC	VSS	Nitrogen Total	Nitrogen Organic	P	Tide Range	Inundation Regularity
Saltwater Marsh								
Pomeroy et al (1967)						-0.1	large	high
Reimold (1972)						-6.3	large	high
Settlemyer and Gardner (1975)			-18.4			-0.18	medium	high
Woodwell et al (1977)	- 0.23	+1.6					medium	high
Odum and de la Cruz (1967)			-2to28				large	high
Brackish Marsh								
Stevenson et al (1976)				-0.029		-0.025	medium	medium
Armstrong and Hinson (1977)								
Lavaca Bay								
Flood Drainage	-12.6			-1.3	-1.2	-0.1	small	low
Small Net Exchange	- 0.94		- 1.5	-0.21	-0.21	<-0.01	small	low
Normal w/Drying	-27.3		-83.6	-1.2	-1.1	-0.16	small	low
Dawson and Armstrong (1975)								
Normal Tidal Exchange	- 2.3			-0.39		-0.08	small	low
Following Drying	- 5.9			-2.1		-0.19	small	low
Armstrong and Brown (1975)								
Sediment Only				-0.74		-0.1	none	none
Armstrong and Gordon (1977a)								
Nueces Bay (Reactors)	- 1.62		- 3.08	-0.08		-0.03	small	high
San Antonio Bay (Reactors)	- 2.42		- 3.54	-0.02		-0.08	small	high
Copano Bay (Linear Marsh)	- 3.75		- 0.86	-0.06		0.00		
Armstrong and Gordon (1977b)								
Colorado River Delta (Reactors)	- 0.46		- 0.18	0.0	0.0	0.0	none	none
This Study								
Trinity River Delta (Reactors)	0.0		- 0.86	0.01	0.0	0.02	none	none
Trinity River Delta (Linear Marsh)	- 1.36		0.40	-0.05		-0.02		

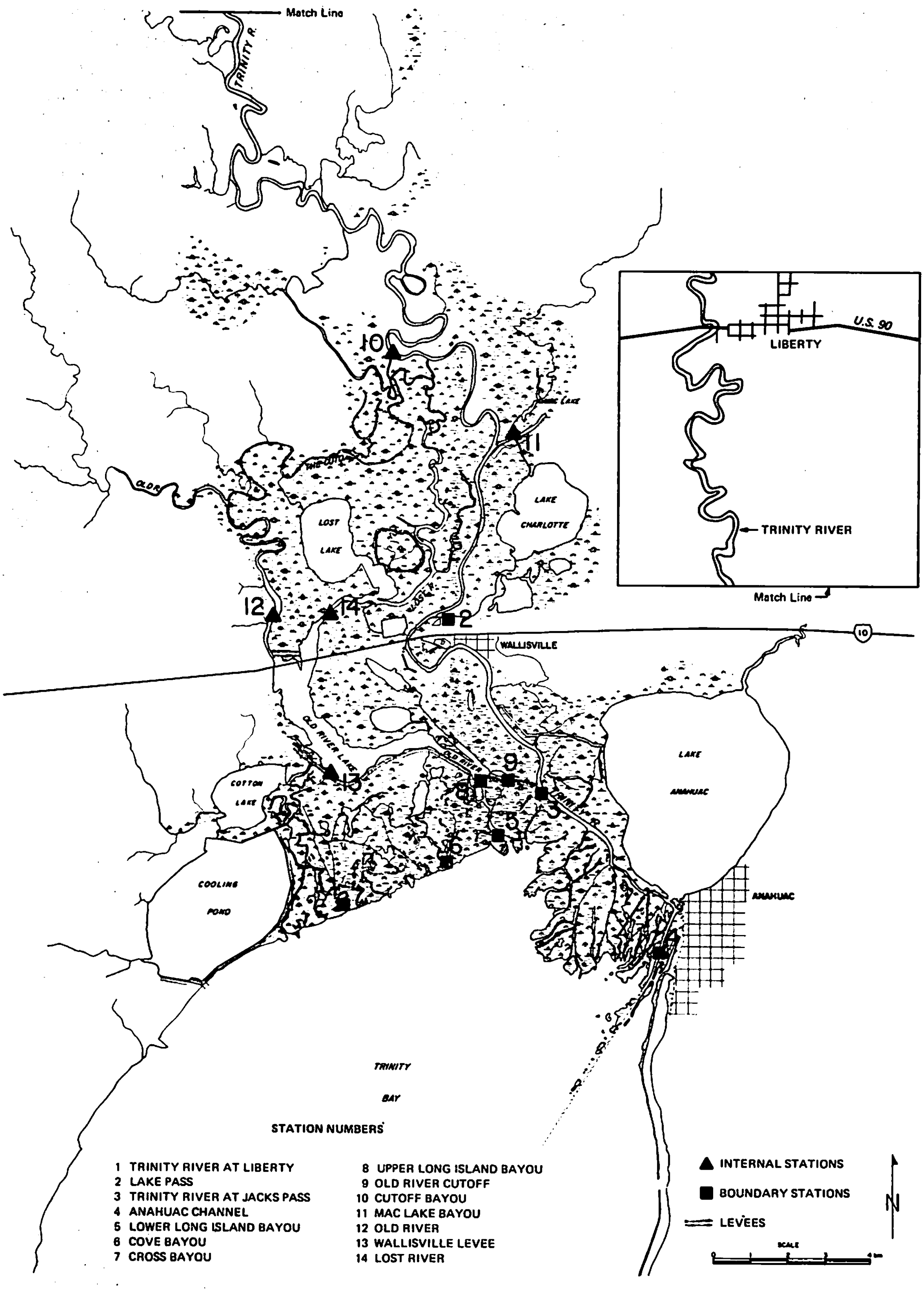

Figure III-4
Location Map of the Fourteen Stations in the Trinity River Delta Study Under Three Flow Regimes.

water quality parameters (temperature, pH, conductivity, and dissolved oxygen) were measured in situ at each site. The measurements and samples were taken at three hour intervals over a 25-hour period. Measurements of the 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 except at times when surface and bottom conductivity were vastly different. In these cases surface and bottom samples were then taken.

The water samples and flow measurements were taken during three, twenty-four hour periods. The dates of these studies were November 30 - December 3, 1976; July 20-21, 1977; and August 10-11, 1977. Due to a shortage of manpower the initial study was divided into two successive 24 hour efforts with half of the stations covered during the first period and the remaining stations monitored during the second. It was assumed that steady conditions existed in the delta over the four-day period so that no significant differences between the two 18-hour studies would have likely been manifested during the period. Enough manpower was available during the July and August studies to allow coverage of the entire delta during a single 24-hour study period.

Sampling locations in the delta were manned by personnel from Espey, Huston & Associates, Inc. of Austin, Texas; the U.S. Geological Survey out of Houston, Texas and TDWR.

Data Reduction

Data reduction was accomplished cooperatively by EH&A and the TDWR, Environmental Studies Unit. Current velocity measurements and channel cross-sections were used to calculate the magnitudes and directions of discharge (in cubic meters/second) for each 3-hour interval at each station. The velocities measured at the beginning and end of each 3-hour interval were averaged, multiplied by the appropriate channel cross-section, and multiplied by the number of seconds in the interval to yield total discharge for that period:

current velocity (m/sec) x cross-section (m^2)

x interval duration (sec)

= interval discharge (m^3)

Except for Station 1, these interval discharges were designated "-" for flows into the delta system. For flows out of the delta and into either the river or the bay, discharges were designated "+". When slack tides occurred (current velocity zero) velocity values measured before and after this event, together with the time interval between the current measurements and the event were used to calculate transport.

Since nutrient and seston concentration data were originally expressed as mg/1, which is equivalent to g/m^3, average nutrient concentration for each interval multiplied by the interval discharge (m^3) yields the interval nutrient transport in grams:

$$\text{average nutrient concentration } (g/m^3) \times \text{interval discharge } (m^3) = \text{interval nutrient transport } (g)$$

Average interval nutrient and seston concentrations were estimated as for average current velocities by averaging the values measured at the beginning and end of each interval. The interval transport or discharge values were summed over the two tidal directions to obtain gross transport (adjusted to kg/day) of each parameter into and out of each hydrologic unit. Net transport of each parameter was taken as the difference between transport in the two possible direction.

Results and Discussion

Trinity River discharges measured during the three field studies near Liberty, Texas (Station 1) were large and stable compared to those at other stations. Station 1 discharges during November-December were about 2430 ft^3/sec and were appreciably lower during July and August (about 1750 and 1370 ft^3/sec, respectively). Due to tidal effects, discharges at the remaining stations varied considerably over the sample periods. This is particularly noticeable for the data collected at Stations 3 and 4, also located on the main channel of the Trinity River. The discharges observed at these stations do not relate to those at Station 1 in any simple manner because of the diversion of water into the delta marshes as a function of river flow and tidal influence (Boon, 1975).

In Table III-13 the total flow and average nitrogen, phosphorus, and carbon concentrations observed during the two possible flow directions are presented for each station. This, and other treatments of the data to follow, are based on the results obtained from unfiltered aliquots for those parameters which were measured in both aliquots (e.g., total kjeldahl nitrogen, total phosphate-phosphorus, total carbon, total inorganic carbon, and total organic carbon). This was done primarily because results on several filtered samples showed higher concentrations for some parameters than did the unfiltered results. It is assumed that unfiltered samples are less likely to be contaminated than are the filtered samples.

Considerable variation in average nitrogen and phosphorus concentrations is often evident between stations and dates. Although nutrients and carbon concentration differences in inflowing and outflowing water are the rule, consistent patterns are not

TABLE III-13

TOTAL FLOW VOLUMES AND AVERAGE CONCENTRATIONS (MG/L) OF CARBON, PHOSPHOROUS AND NITROGEN AT NINE STATIONS IN THE TRINITY RIVER DELTA UNDER THREE FLOW REGIMES

(Source: Belaire, et al, 1977)

11/30/76 12/01/76

PARAMETERS	TRINITY-LIBERTY T IN (-)	TRINITY-LIBERTY T OUT (+)	LAKE PASS IN (-)	LAKE PASS OUT (+)	TRINITY-JACKS PASS IN (-)	TRINITY-JACKS PASS OUT (+)
NH4-N	.000	.011	.019	.040	.000	.011
TKN-N	.000	.237	.500	.833	.000	.380
NO3-N	.000	.174	.117	.015	.000	.110
NO2-N	.000	.015	.010	.010	.000	.010
ORTHO PO4-P	.000	.033	.060	.038	.000	.062
TOTAL PO4-P	.000	.174	.197	.265	.000	.189
TOTAL CARBON	.000	29.625	37.250	38.000	.000	37.800
TOTAL INORGANIC CARBON	.000	16.750	15.500	12.000	.000	17.600
TOTAL ORGANIC CARBON	.000	12.875	21.750	26.000	.000	20.200
TOTAL FLOW VOLUME (CU-M)	0.	5225550.	-43177.	50696.	0.	2246002.

11/30/76 12/01/76

PARAMETERS	ANAHUAC CHANNEL IN (-)	ANAHUAC CHANNEL OUT (+)	LOWER LONG ISL A IN (-)	LOWER LONG ISL A OUT (+)	COVE BAYOU IN (-)	COVE BAYOU OUT (+)
NH4-N	.000	.050	.000	.015	.072	.071
TKN-N	.000	.637	.000	.344	.550	.625
NO3-N	.000	.121	.000	.182	.055	.051
NO2-N	.000	.017	.000	.010	.015	.019
ORTHO PO4-P	.000	.052	.000	.039	.133	.094
TOTAL PO4-P	.000	.320	.000	.195	.335	.341
TOTAL CARBON	.000	31.500	.000	29.250	18.000	23.750
TOTAL INORGANIC CARBON	.000	8.625	.000	17.437	18.500	19.750
TOTAL ORGANIC CARBON	.000	22.875	.000	11.687	.000	4.000
TOTAL FLOW VOLUME (CU-M)	0.	4016004.	0.	3338418.	-395880.	472713.

TABLE III-13 (Cont'd)

11/30/76 12/01/76

PARAMETERS	CROSS BAYOU		UPPER LONG ISL		OLD RIVER CUTOFF A	
	IN (-)	OUT (+)	IN (-)	OUT (+)	IN (-)	OUT (+)
NH4-N	.072	.065	.000	.015	.013	.000
TKN-N	.500	.550	.000	.280	.350	.000
NO3-N	.040	.054	.000	.094	.211	.000
NO2-N	.015	.011	.000	.010	.010	.000
ORTHO PO4-P	.117	.065	.000	.040	.055	.000
TOTAL PO4-P	.340	.301	.000	.141	.211	.000
TOTAL CARBON	21.000	22.750	.000	36.000	35.312	.000
TOTAL INORGANIC CARBON	16.000	16.000	.000	17.600	15.875	.000
TOTAL ORGANIC CARBON	5.000	6.750	.000	18.400	19.437	.000
TOTAL FLOW VOLUME (CU-M)	-178395.	611500.	0.	6142608.	-2775133.	0.

TABLE III-13 (Cont'd)

07/20/77 07/21/77

PARAMETERS	TRINITY LIBERTY IN (-)	OUT (+)	LAKE PASS IN (-)	OUT (+)	TRINITY-JACKS PASS IN (-)	OUT (+)
NH4-N	.000	.010	.044	.067	.000	.056
TKN-N	.000	.267	.300	.267	.000	.311
NO3-N	.000	.010	.010	.020	.000	.017
NO2-N	.000	.010	.010	.010	.000	.010
ORTHO PO4-P	.000	.080	.050	.053	.000	.059
TOTAL PO4-P	.000	.190	.198	.190	.000	.160
TOTAL CARBON	.000	32.333	33.200	32.333	.000	33.333
TOTAL INORGANIC CARBON	.000	23.444	26.000	26.333	.000	26.222
TOTAL ORGANIC CARBON	.000	7.667	7.200	6.000	.000	6.778
TOTAL FLOW VOLUME (CU-M)	0.	4478496.	-44706.	49778.	0.	2662803.

07/20/77 07/21/77

PARAMETERS	ANAHUAC CHANNEL IN (-)	OUT (+)	LOWER LONG ISL IN (-)	OUT (+)	COVE BAYOU IN (-)	OUT (+)
NH4-N	.000	.019	.010	.010	.010	.012
TKN-N	.000	.289	.300	.300	.375	.350
NO3-N	.000	.013	.010	.010	.010	.010
NO2-N	.000	.010	.010	.010	.010	.010
ORTHO PO4-P	.000	.051	.067	.060	.075	.075
TOTAL PO4-P	.000	.172	.167	.174	.220	.216
TOTAL CARBON	.000	32.444	33.667	33.200	33.750	33.750
TOTAL INORGANIC CARBON	.000	25.778	26.000	26.000	25.000	25.000
TOTAL ORGANIC CARBON	.000	7.000	7.667	7.200	9.250	8.500
TOTAL FLOW VOLUME (CU-M)	0.	2695509.	-703826.	2527144.	-510971.	678223.

TABLE III-13 (Cont'd)

07/20/77 07/21/77

PARAMETERS	CROSS BAYOU IN (-)	CROSS BAYOU OUT (+)	UPPER LONG ISL IN (-)	UPPER LONG ISL OUT (+)	OLD RIVER CUTOFF IN (-)	OLD RIVER CUTOFF OUT (+)
NH4-N	.010	.014	.010	.010	.067	.070
TKN-N	.367	.400	.300	.280	.337	.300
NO3-N	.017	.012	.010	.010	.019	.030
NO2-N	.010	.010	.010	.010	.010	.010
ORTHO PO4-P	.110	.108	.060	.060	.060	.060
TOTAL PO4-P	.260	.262	.177	.182	.182	.190
TOTAL CARBON	34.333	35.200	36.667	34.400	32.500	31.000
TOTAL INORGANIC CARBON	25.667	25.600	25.667	26.000	26.250	26.000
TOTAL ORGANIC CARBON	8.667	10.000	9.000	8.400	6.250	5.000
TOTAL FLOW VOLUME (CU-M)	-133353.	404622.	-689705.	4260744.	-950995.	39226.

TABLE III-13 (Cont'd)

08/10/77 08/11/77

PARAMETERS	TRINITY LIBERTY IN (-)	TRINITY LIBERTY OUT (+)	LAKE PASS IN (-)	LAKE PASS OUT (+)	TRINITY-JACKS PASS IN (-)	TRINITY-JACKS PASS OUT (+)
NH4-N	.000	.010	.087	.035	.080	.069
TKN-N	.000	.322	.267	.400	.500	.371
NO3-N	.000	.010	.020	.012	.020	.020
NO2-N	.000	.010	.010	.010	.010	.010
ORTHO PO4-P	.000	.128	.103	.100	.080	.083
TOTAL PO4-P	.000	.227	.170	.265	.180	.193
TOTAL CARBON	.000	29.889	31.667	33.750	32.000	31.857
TOTAL INORGANIC CARBON	.000	22.667	24.667	24.000	33.000	23.857
TOTAL ORGANIC CARBON	.000	7.222	7.000	9.750	9.000	8.000
TOTAL FLOW VOLUME (CU-M)	0.	3364586.	-49370.	66957.	-551586.	3150907.

08/10/77 08/11/77

PARAMETERS	ANAHUAC CHANNEL IN (-)	ANAHUAC CHANNEL OUT (+)	LOWER LONG ISL IN (-)	LOWER LONG ISL OUT (+)	COVE BAYOU IN (-)	COVE BAYOU OUT (+)
NH4-N	.070	.052	.015	.018	.040	.010
TKN-N	.300	.333	.300	.240	.600	.417
NO3-N	.020	.013	.010	.010	.010	.010
NO2-N	.010	.010	.010	.010	.010	.010
ORTHO PO4-P	.110	.110	.090	.088	.130	.140
TOTAL PO4-P	.130	.143	.230	.218	.220	.240
TOTAL CARBON	31.000	31.667	35.000	34.200	31.000	32.167
TOTAL INORGANIC CARBON	25.000	23.667	25.000	24.800	21.000	22.833
TOTAL ORGANIC CARBON	6.000	7.667	10.000	9.400	10.000	9.500
TOTAL FLOW VOLUME (CU-M)	-829532.	2764632.	-1766658.	2283725.	-378140.	473762.

TABLE III-13 (Cont'd)

08/10/77 08/11/77

PARAMETERS	CROSS BAYOU		UPPER LONG ISL		OLD RIVER CUTOFF	
	IN (-)	OUT (+)	IN (-)	OUT (+)	IN (-)	OUT (+)
NH4-N	.020	.014	.105	.028	.096	.000
TKN-N	.600	.375	.400	.380	.444	.000
NO3-N	.010	.010	.010	.010	.023	.000
NO2-N	.010	.010	.010	.010	.010	.000
ORTHO PO4-P	.130	.130	.085	.088	.092	.000
TOTAL PO4-P	.305	.300	.200	.220	.141	.000
TOTAL CARBON	34.000	33.600	36.000	34.000	30.889	.000
TOTAL INORGANIC CARBON	23.500	23.800	23.500	24.000	23.889	.000
TOTAL ORGANIC CARBON	10.500	9.800	12.500	10.000	7.000	.000
TOTAL FLOW VOLUME (CU-M)	-288443.	509187.	-2362738.	4436186.	-1038661.	0.

evident. Although consistent changes in nutrient and carbon concentrations associated with tidal changes have been reported (Boon, 1975; Erkenbrecher and Stevenson, 1975; Gardner, 1975) this behavior was not observed at the stations monitored during the three field studies. In Figures III-5 thru III-9 nutrient parameters and TOC are plotted against time from the first tide reversal observed. Vertical lines within the graphs represent the times of subsequent reversals. Although some parameters (kjeldahl nitrogen, Cove Bayou, Figures III-6 and III-7) do appear to change in response to tide reversals, higher, concentrations do not appear to be closely tied to a particular flow direction.

When all the stations and dates in which tidal cycles were observed are considered, only a slight, and probably nonsignificant bias in favor of higher average concentrations in water exiting the delta is found.

The water flow data in Table III-13 show that there is a consistent net discharge of marsh water into Trinity Bay.

Table III-14 presents total nutrient, carbon, and seston transport in both directions, and total net transport for each station by study date. The dissolved fraction of each parameter is included in this table for comparison purposes. It can be seen that apparent contamination occurred in some instances. The net transport values for each station are repeated by study date, for ease of comparison, in Table III-15.

Net discharges of water to Trinity Bay are obtained by taking the algebraic sum of the total discharges from Stations 4, 5, 6, and 7 (Table III-13). All these stations except 6 (Cove Bayou) are discharge channels for Trinity River and Old River waters. Station 6 drains a litoral marsh area that is isolated from the remainder of Trinity Delta except during periods of unusually high water. This station, and Station 2 (Lake Pass), which drains the relatively isolated Lake Charlotte, provide examples of flow and nutrient transport for individual marsh units. The other stations considered here pass water from a relatively large number of undefined sources. Discharges to Trinity Bay for each investigation may be summarized as shown in Table III-16.

Trinity River discharges (Station 1, Liberty) amounted to 66.4, 90.3, and 121.5 percent of the total discharges to Trinity Bay during November-December, July, and August, respectively.

Nitrogen, phosphorus, and carbon (including seston) transport to Trinity Bay is similarly obtained as shown in Table III-17.

These tables show that the Trinity Delta was a net contributor of all parameters to Trinity Bay during the three field studies. This is the expected situation in a delta marsh where flows tend to be driven by freshwater runoff. The lack of consistent differences

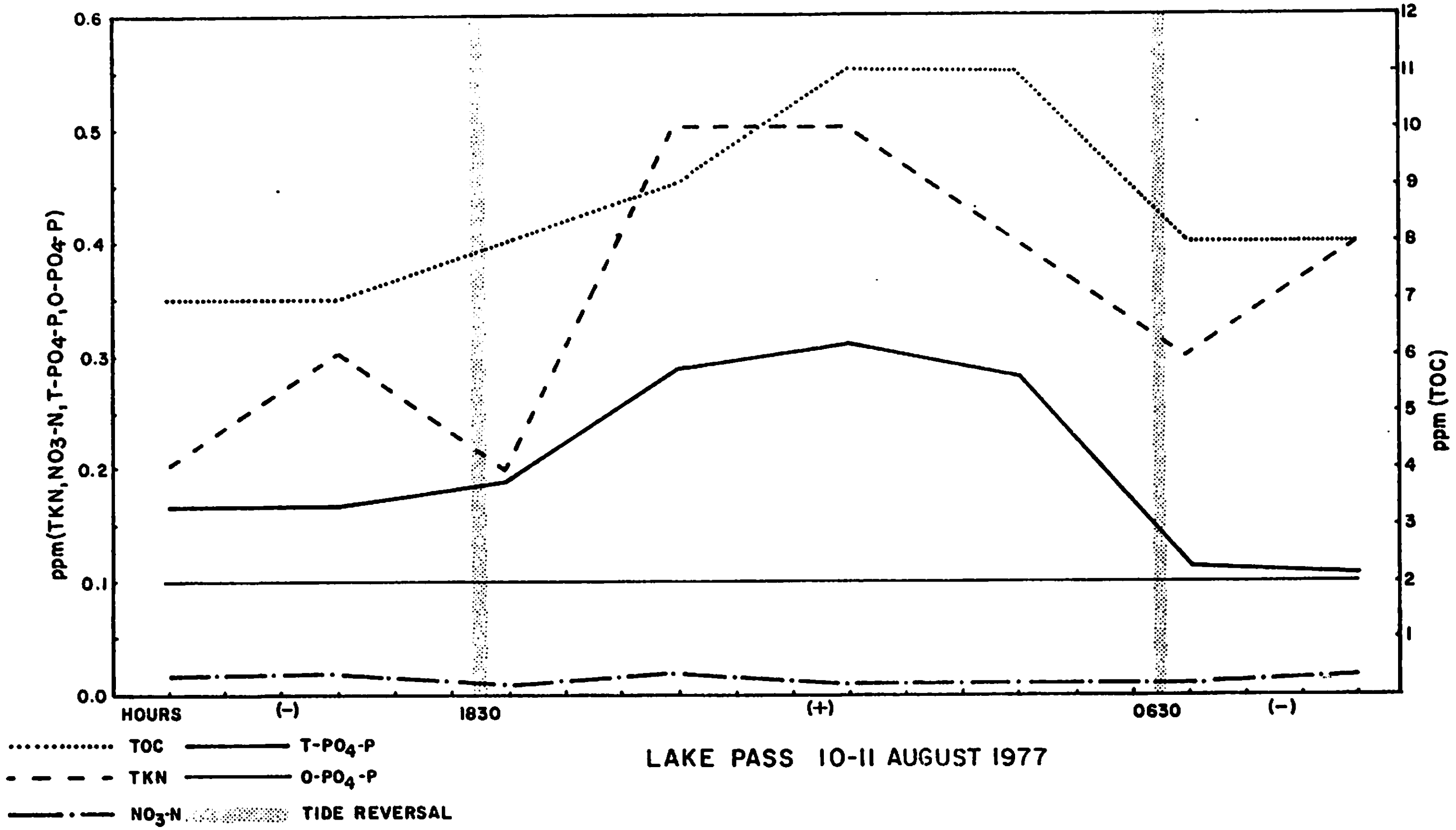

Figure III-5 Total Kjeldahl Nitrogen, Nitrate, Orthophosphorous, Total Phosphorous, and Total Organic Carbon Concentrations (mg/ℓ) Versus Flow Direction at Lake Pass, 10-11 August 1977. (Source: Belaire, et al, 1977)

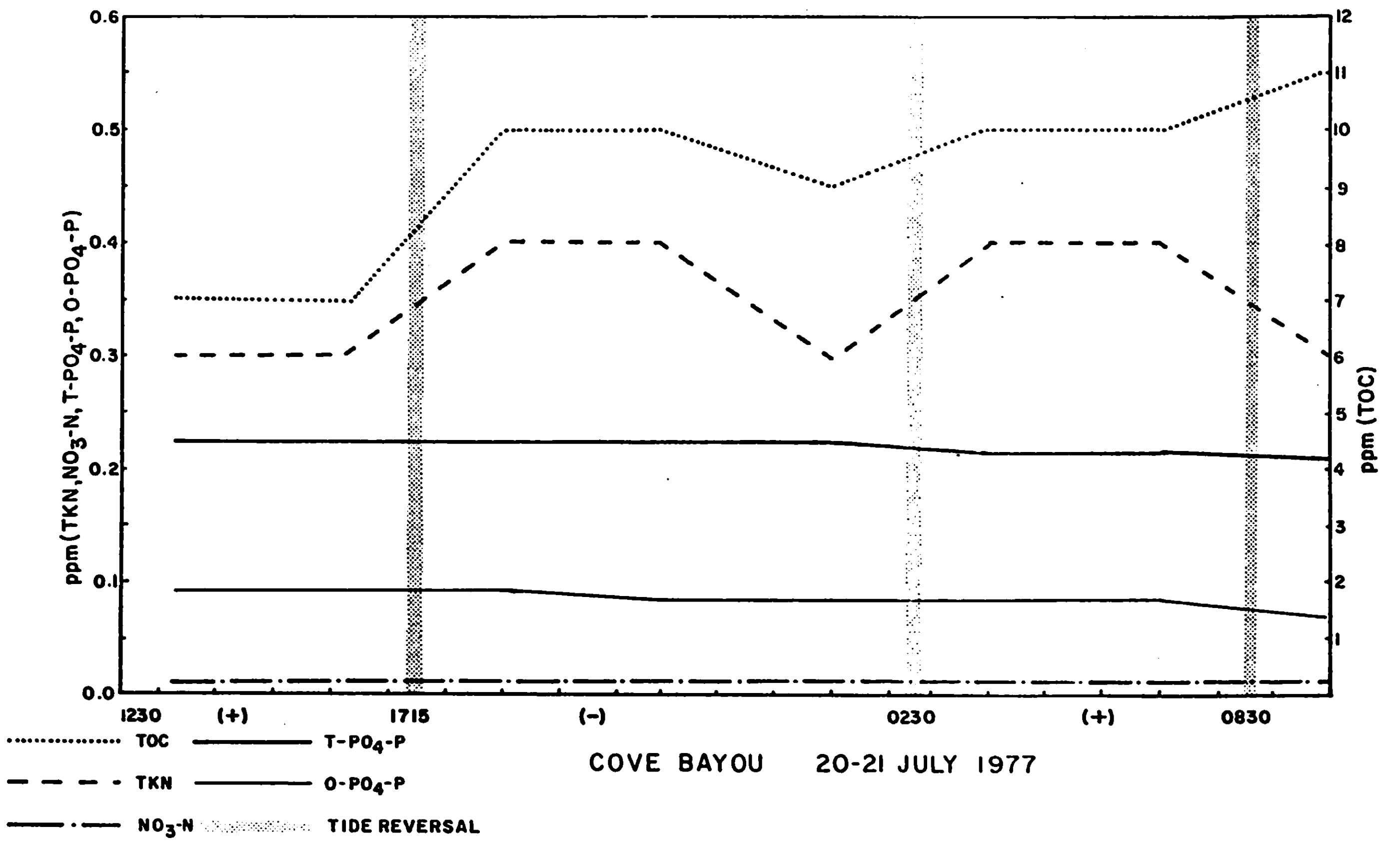

Figure III-6 Total Kjeldahl Nitrogen, Nitrate, Orthophosphoruous, Total Phosphorous, and Total Organic Carbon Concentrations (mg/ℓ) Versus Flow Direction at Cove Bayou, 20-21 July 1977. (Source: Belaire, et al, 1977)

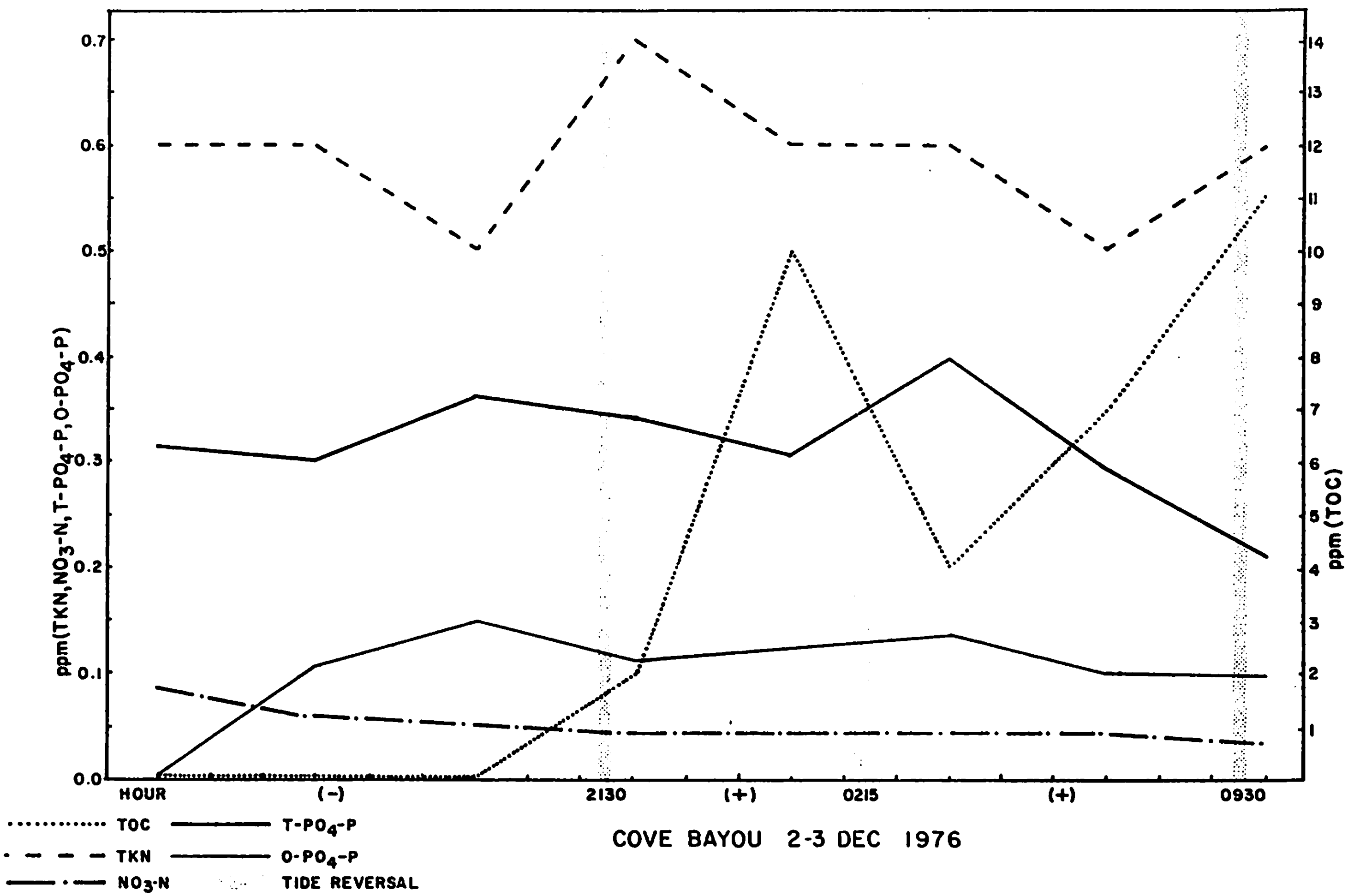

Figure III-7 Total Kjeldahl Nitrogen, Nitrate, Orthophosphorous, Total Phosphorous, and Total Organic Carbon Concentrations (mg/ℓ) Versus Flow Direction at Cove Bayou, 2-3 December 1976. (Source: Belaire, et al, 1977)

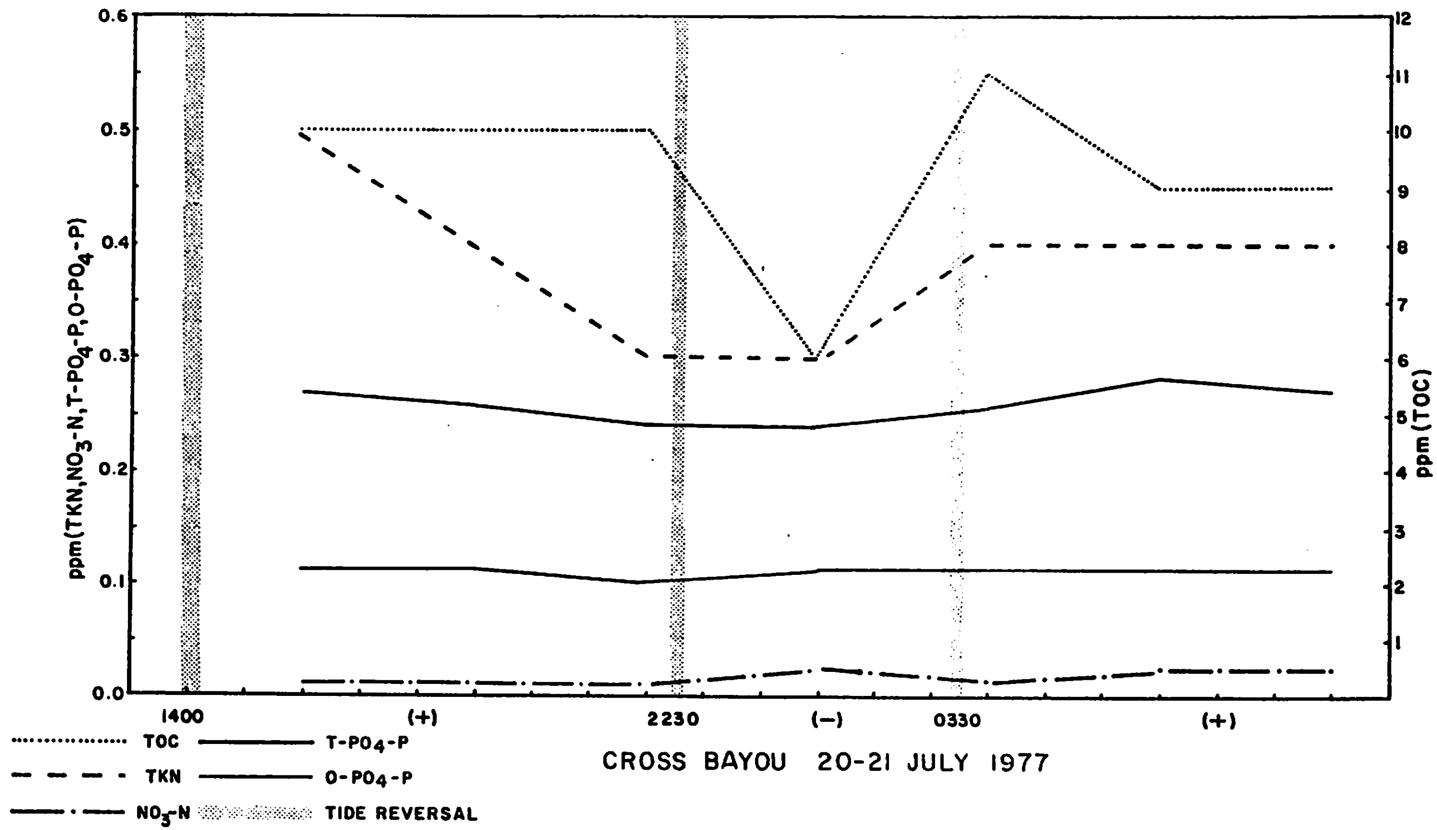

Figure III-8 Total Kjeldahl Nitrogen, Nitrate, Orthophosphorous, Total Phosphorous, and Total Organic Carbon Concentrations (mg/ℓ) Versus Flow Direction at Cross Bayou, 20-21 July 1977. (Source: Belaire, et al, 1977)

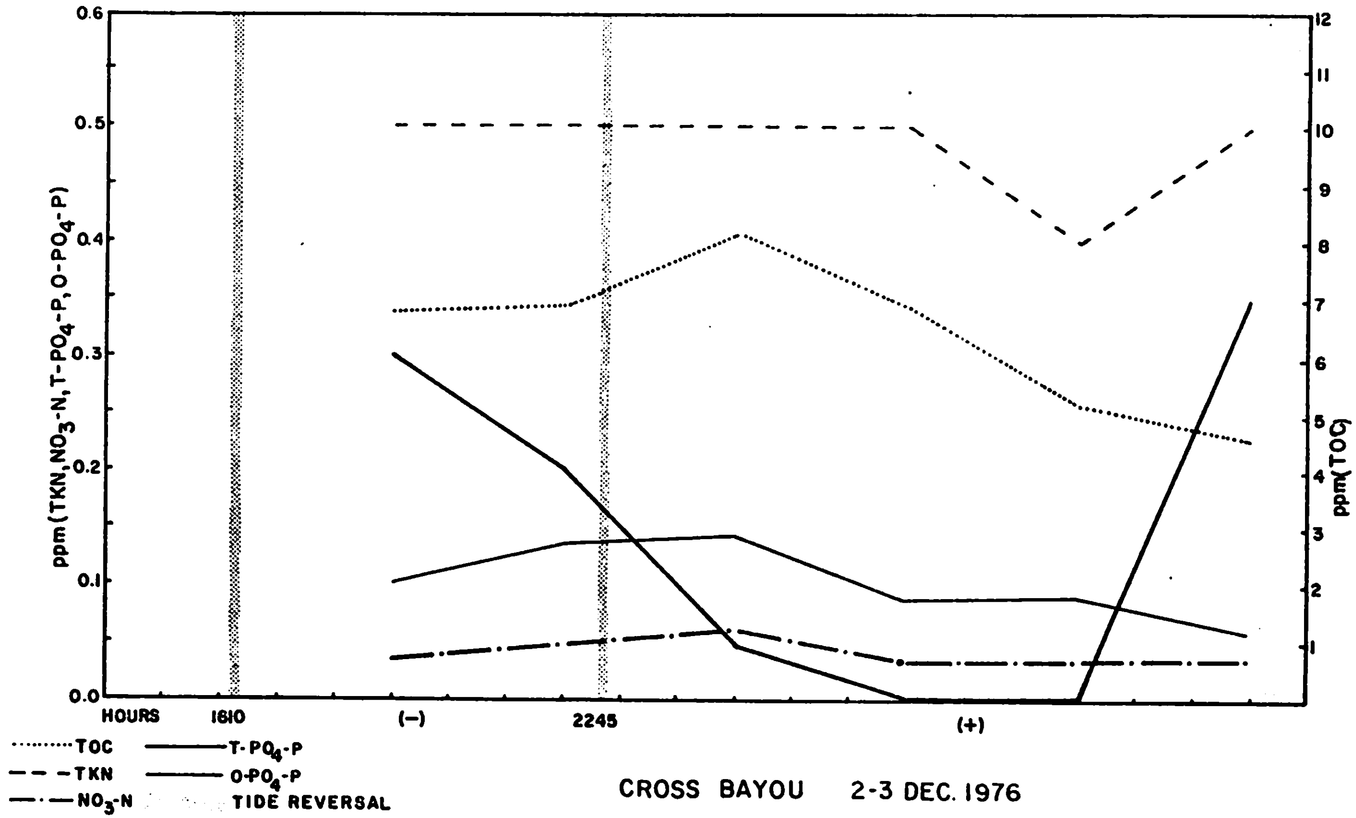

Figure III-9 Total Kjeldahl Nitrogen, Nitrate, Orthophosphorous, Total Phosphorous, and Total Organic Carbon Concentrations (mg/ℓ) Versus Flow Direction at Cross Bayou, 2-3 December 1976. (Source: Belaire, et al, 1977)

TABLE III-14

NET TRANSPORT IN KG/DAY (AND % DISSOLVED) OF CARBON, PHOSPHOROUS, NITROGEN AND SESTON AT NINE STATIONS IN THE TRINITY RIVER DELTA UNDER THREE FLOW REGIMES

(Source: Belaire, et al, 1977)

11/30/76 12/01/76
TRINITY-LIBERTY T

PARAMETER	IN (-)		OUT (+)		NET	
NH4-N	.000		59.825		59.825	
TKN-N	.000	(0.)	1233.900	(149.)	1233.900	(149.)
NO3-N	.000		914.739		914.739	
NO2-N	.000		78.383		78.383	
ORTHO PO4-P	.000		176.782		176.782	
TOTAL PO4-P	.000	(0.)	902.979	(94.)	902.979	(94.)
TOTAL CARBON	.000	(0.)	156330.641	(102.)	156330.641	(102.)
TOTAL INORGANIC CARBON	.000	(0.)	87798.257	(99.)	87798.257	(99.)
TOTAL ORGANIC CARBON	.000	(0.)	68532.387	(106.)	68532.387	(106.)
SESTON	.000		.000		.000	

11/30/76 12/01/76
LAKE PASS

PARAMETER	IN (-)		OUT (+)		NET	
NH4-N	-.730		2.087		1.357	
TKN-N	-20.994	(62.)	39.553	(58.)	18.558	(54.)
NO3-N	-5.037		1.184		-3.853	
NO2-N	-.432		.507		.075	
ORTHO PO4-P	-2.588		2.232		-.356	
TOTAL PO4-P	-8.565	(92.)	12.471	(176.)	3.906	(90.)
TOTAL CARBON	-1631.487	(68.)	1972.909	(170.)	341.422	(399.)
TOTAL INORGANIC CARBON	-654.914	(93.)	651.167	(140.)	-3.747	(436.)
TOTAL ORGANIC CARBON	-692.573	(101.)	1321.741	(72.)	628.169	(133.)
SESTON	-197.851		31.738		-166.114	

TABLE III-14 (Cont'd)

11/30/76 12/01/76
TRINITY-JACKS PASS

PARAMETER	IN (-)	OUT (+)	NET
NH4-N	.000	24.992	24.992
TKN-N	.000 (0.)	865.598 (78.)	865.598 (78.)
NO3-N	.000	247.766	247.766
NO2-N	.000	22.460	22.460
ORTHO PO4-P	.000	139.292	139.292
TOTAL PO4-P	.000 (0.)	424.931 (52.)	424.931 (52.)
TOTAL CARBON	.000 (0.)	86569.225 (72.)	86569.225 (72.)
TOTAL INORGANIC CARBON	.000 (0.)	40267.471 (116.)	40267.471 (116.)
TOTAL ORGANIC CARBON	.000 (0.)	46301.754 (34.)	46301.754 (34.)
SESTON	.000	2073.857	2073.857

11/30/76 12/01/76
ANAHUAC CHANNEL

PARAMETER	IN (-)	OUT (+)	NET
NH4-N	.000	173.106	173.106
TKN-N	.000 (0.)	2003.533 (90.)	2003.533 (90.)
NO3-N	.000	477.132	477.132
NO2-N	.000	62.251	62.251
ORTHO PO4-P	.000	208.302	208.302
TOTAL PO4-P	.000 (0.)	1243.304 (46.)	1243.304 (46.)
TOTAL CARBON	.000 (0.)	125706.028 (77.)	125706.028 (77.)
TOTAL INORGANIC CARBON	.000 (0.)	36562.235 (132.)	36562.235 (132.)
TOTAL ORGANIC CARBON	.000 (0.)	89143.792 (54.)	89143.792 (54.)
SESTON	.000	1623.640	1623.640

TABLE III-14 (Cont'd)

12/02/76 12/03/76
LOWER LONG ISL A

PARAMETER	IN (-)	OUT (+)	NET
NH4-N	.000	50.025	50.025
TKN-N	.000 (0.)	1135.873 (75.)	1135.873 (75.)
NO3-N	.000	546.595	546.596
NO2-N	.000	33.384	33.384
ORTHO PO4-P	.000	136.611	136.611
TOTAL PO4-P	.000 (0.)	651.863 (89.)	651.863 (89.)
TOTAL CARBON	.000 (0.)	98047.872 (116.)	98047.872 (116.)
TOTAL INORGANIC CARBON	.000 (0.)	58783.992 (100.)	58783.992 (100.)
TOTAL ORGANIC CARBON	.000 (0.)	38782.922 (142.)	38782.922 (142.)
SESTON	.000	6507.010	6507.010

12/02/76 12/03/76
COVE BAYOU

PARAMETER	IN (-)	OUT (+)	NET
NH4-N	-28.613	34.073	5.460
TKN-N	-219.495 (72.)	273.242 (70.)	53.747 (59.)
NO3-N	-23.358	18.909	-4.450
NO2-N	-5.833	9.454	3.622
ORTHO PO4-P	-45.920	55.963	10.043
TOTAL PO4-P	-132.126 (67.)	163.563 (55.)	31.436 (6.)
TOTAL CARBON	-7238.541 (198.)	11662.009 (136.)	4423.468 (36.)
TOTAL INORGANIC CARBON	-7397.739 (97.)	16971.822 (101.)	9573.083 (104.)
TOTAL ORGANIC CARBON	.000 (0.)	5474.186 (242.)	5474.186 (109.)
SESTON	-452.234	687.809	235.575

TABLE III-14 (Cont'd)

12/02/76 12/03/76
CROSS BAYOU

PARAMETER	IN (-)		OUT (+)		NET	
NH4-N	-12.791		37.975		25.184	
TKN-N	-89.197	(60.)	301.583	(90.)	212.385	(102.)
NO3-N	-6.851		25.912		19.061	
NO2-N	-2.676		7.895		5.219	
ORTHO PO4-P	-19.966		46.394		26.429	
TOTAL PO4-P	-60.085	(57.)	179.154	(95.)	119.069	(114.)
TOTAL CARBON	-3746.290	(162.)	11662.680	(171.)	7916.390	(175.)
TOTAL INORGANIC CARBON	-2797.423	(117.)	9860.211	(110.)	7062.788	(108.)
TOTAL ORGANIC CARBON	-948.867	(294.)	1958.761	(461.)	1009.894	(617.)
SESTON	-143.102		478.061		334.959	

12/02/76 12/03/76
UPPER LONG ISL

PARAMETER	IN (-)		OUT (+)		NET	
NH4-N	.000		103.685		103.685	
TKN-N	.000	(0.)	1658.249	(111.)	1658.249	(111.)
NO3-N	.000		613.445		613.445	
NO2-N	.000		61.426		61.426	
ORTHO PO4-P	.000		253.389		253.389	
TOTAL PO4-P	.000	(0.)	841.779	(68.)	841.779	(68.)
TOTAL CARBON	.000	(0.)	221133.883	(97.)	221133.883	(97.)
TOTAL INORGANIC CARBON	.000	(0.)	109165.102	(92.)	109165.102	(92.)
TOTAL ORGANIC CARBON	.000	(0.)	111968.780	(101.)	111968.780	(101.)
SESTON	.000		13946.014		13946.014	

TABLE III-14 (Cont'd)

11/30/76 12/01/76
OLD RIVER CUTOFF A

PARAMETER	IN (-)		OUT (+)		NET	
NH4-N	-37.527		.000		-37.527	
TKN-N	-1005.013	(75.)	.000	(0.)	-1005.013	(75.)
NO3-N	-597.014		.000		-597.014	
NO2-N	-27.761		.000		-27.751	
ORTHO PO4-P	-155.284		.000		-155.284	
TOTAL PO4-P	-595.066	(41.)	.000	(0.)	-595.066	(41.)
TOTAL CARBON	-97676.597	(85.)	.000	(0.)	-97676.597	(85.)
TOTAL INORGANIC CARBON	-44246.529	(117.)	.000	(0.)	-44246.529	(117.)
TOTAL ORGANIC CARBON	-53430.067	(58.)	.000	(0.)	-53430.067	(58.)
SESTON	-2849.061		.000		-2849.061	

TABLE III-14 (Cont'd)

PARAMETER	07/20/77 07/21/77 TRINITY LIBERTY IN (-)	OUT (+)	NET
NH4-N	.000	44.785	44.785
TKN-N	.000 (0.)	1199.873 (78.)	1199.873 (78.)
NO3-N	.000	44.785	44.785
NO2-N	.000	44.785	44.785
ORTHO PO4-P	.000	361.312	361.312
TOTAL PO4-P	.000 (0.)	850.914 (59.)	850.914 (59.)
TOTAL CARBON	.000 (0.)	144640.826 (102.)	144640.826 (102.)
TOTAL INORGANIC CARBON	.000 (0.)	104901.341 (107.)	104901.341 (107.)
TOTAL ORGANIC CARBON	.000 (0.)	34205.022 (120.)	34205.022 (120.)
SESTON	.000	.000	.000

PARAMETER	07/20/77 07/21/77 LAKE PASS IN (-)	OUT (+)	NET
NH4-N	-1.963	3.557	1.593
TKN-N	-13.412 (79.)	14.798 (108.)	1.387 (389.)
NO3-N	-.447	.957	.510
NO2-N	-.447	.498	.051
ORTHO PO4-P	-2.235	2.934	.699
TOTAL PO4-P	-8.825 (74.)	9.458 (69.)	.633 (77.)
TOTAL CARBON	-1484.676 (98.)	1602.303 (106.)	117.627 (210.)
TOTAL INORGANIC CARBON	-1162.355 (105.)	1309.675 (106.)	147.321 (118.)
TOTAL ORGANIC CARBON	-322.321 (75.)	292.628 (108.)	-29.694 (71.)
SESTON	-555.027	616.177	61.151

TABLE III-14 (Cont'd)

07/20/77 07/21/77
TRINITY-JACKS PASS

PARAMETER	IN (-)		OUT (+)		NET	
NH4-N	.000		172.636		172.636	
TKN-N	.000	(0.)	818.751	(101.)	818.751	(101.)
NO3-N	.000		47.841		47.841	
NO2-N	.000		26.628		26.628	
ORTHO PO4-P	.000		161.575		161.575	
TOTAL PO4-P	.000	(0.)	426.049	(64.)	426.049	(64.)
TOTAL CARBON	.000	(0.)	89299.561	(91.)	89299.561	(91.)
TOTAL INORGANIC CARBON	.000	(0.)	69821.523	(97.)	69821.523	(97.)
TOTAL ORGANIC CARBON	.000	(0.)	18868.390	(68.)	18868.390	(68.)
SESTON	.000		17401.045		17401.045	

07/20/77 07/21/77
ANAHUAC CHANNEL

PARAMETER	IN (-)		OUT (+)		NET	
NH4-N	.000		66.832		66.832	
TKN-N	.000	(0.)	785.706	(83.)	785.706	(83.)
NO3-N	.000		40.206		40.206	
NO2-N	.000		26.955		26.955	
ORTHO PO4-P	.000		137.267		137.267	
TOTAL PO4-P	.000	(0.)	474.893	(63.)	474.893	(63.)
TOTAL CARBON	.000	(0.)	86788.854	(93.)	86788.854	(93.)
TOTAL INORGANIC CARBON	.000	(0.)	69704.656	(99.)	69704.656	(99.)
TOTAL ORGANIC CARBON	.000	(0.)	17933.866	(64.)	17933.866	(64.)
SESTON	.000		18282.740		18282.740	

TABLE III-14 (Cont'd)

07/20/77 07/21/77
LOWER LONG ISL

PARAMETER	IN (-)	OUT (+)	NET
NH4-N	-7.038	25.271	18.233
TKN-N	-211.148 (67.)	758.143 (72.)	546.995 (74.)
NO3-N	-7.038	25.271	18.233
NO2-N	-7.038	25.271	18.233
ORTHO PO4-P	-46.305	151.629	105.324
TOTAL PO4-P	-117.692 (68.)	451.241 (64.)	333.549 (62.)
TOTAL CARBON	-23818.824 (94.)	84906.991 (96.)	61088.167 (97.)
TOTAL INORGANIC CARBON	-18299.466 (102.)	65705.733 (101.)	47406.268 (101.)
TOTAL ORGANIC CARBON	-5519.358 (68.)	19201.257 (79.)	13681.899 (83.)
SESTON	-11581.805	45234.380	33652.575

07/20/77 07/21/77
COVE BAYOU

PARAMETER	IN (-)	OUT (+)	NET
NH4-N	-5.110	8.803	3.693
TKN-N	-182.841 (73.)	235.811 (88.)	52.970 (140.)
NO3-N	-5.110	6.782	1.673
NO2-N	-5.110	6.782	1.673
ORTHO PO4-P	-36.918	51.023	14.105
TOTAL PO4-P	-112.010 (50.)	146.244 (51.)	34.234 (54.)
TOTAL CARBON	-17255.286 (99.)	22835.183 (101.)	5579.897 (107.)
TOTAL INORGANIC CARBON	-12774.267 (101.)	16955.573 (102.)	4181.306 (106.)
TOTAL ORGANIC CARBON	-4831.225 (86.)	5717.889 (100.)	886.664 (176.)
SESTON	-5323.504	8575.604	3252.101

TABLE III-14 (Cont'd)

07/20/77 07/21/77
CROSS BAYOU

PARAMETER	IN (-)		OUT (+)		NET	
NH4-N	-1.334		6.156		4.823	
TKN-N	-48.550	(92.)	170.369	(72.)	121.820	(63.)
NO3-N	-2.194		5.660		3.465	
NO2-N	-1.334		4.046		2.713	
ORTHO PO4-P	-14.669		44.359		29.690	
TOTAL PO4-P	-34.568	(62.)	108.625	(60.)	74.057	(59.)
TOTAL CARBON	-4561.766	(187.)	14303.967	(102.)	9742.202	(99.)
TOTAL INORGANIC CARBON	-3429.028	(102.)	10443.070	(105.)	7014.042	(106.)
TOTAL ORGANIC CARBON	-1132.738	(122.)	3952.271	(91.)	2819.533	(79.)
SESTON	-1658.843		6633.262		4974.419	

07/20/77 07/21/77
UPPER LONG ISL

PARAMETER	IN (-)		OUT (+)		NET	
NH4-N	-6.897		42.607		35.710	
TKN-N	-206.912	(79.)	1189.599	(92.)	982.688	(95.)
NO3-N	-6.897		46.252		39.355	
NO2-N	-6.897		42.607		35.710	
ORTHO PO4-P	-41.382		255.645		214.262	
TOTAL PO4-P	-119.544	(95.)	770.968	(91.)	651.425	(90.)
TOTAL CARBON	-25235.413	(90.)	146233.783	(95.)	120998.371	(96.)
TOTAL INORGANIC CARBON	-17341.461	(110.)	110779.340	(102.)	93437.879	(100.)
TOTAL ORGANIC CARBON	-5900.153	(62.)	35454.444	(73.)	29554.291	(75.)
SESTON	-16070.247		84031.501		67961.254	

TABLE III-14 (Cont'd)

PARAMETER	07/20/77 07/21/77 OLD RIVER CUTOFF IN (-)		OUT (+)		NET	
NH4-N	-59.641		2.746		-56.895	
TKN-N	-345.425	(87.)	11.768	(67.)	-333.657	(88.)
NO3-N	-15.920		1.177		-14.744	
NO2-N	-9.510		.392		-9.118	
ORTHO PO4-P	-57.060		2.354		-54.706	
TOTAL PO4-P	-170.774	(63.)	7.453	(58.)	-163.322	(63.)
TOTAL CARBON	-31087.328	(107.)	1216.007	(110.)	-29871.321	(106.)
TOTAL INORGANIC CARBON	-25244.231	(93.)	1019.877	(108.)	-24224.355	(92.)
TOTAL ORGANIC CARBON	-5843.096	(123.)	196.130	(126.)	-5646.966	(123.)
SESTON	-12004.926		.000		-12004.926	

TABLE III-14 (Cont'd)

08/10/77 08/11/77
CROSS BAYOU

PARAMETER	IN (-)		OUT (+)		NET	
NH4-N	-3.018		6.935		3.916	
TKN-N	-143.573	(61.)	167.017	(136.)	23.443	(591.)
NO3-N	-2.884		5.092		2.207	
NO2-N	-2.884		5.092		2.207	
ORTHO PO4-P	-37.498		66.194		28.697	
TOTAL PO4-P	-81.099	(58.)	151.342	(56.)	70.243	(53.)
TOTAL CARBON	-9867.951	(100.)	17183.304	(102.)	7315.353	(105.)
TOTAL INORGANIC CARBON	-6915.943	(87.)	12217.995	(82.)	5302.052	(76.)
TOTAL ORGANIC CARBON	-2952.007	(129.)	4965.309	(150.)	2013.301	(181.)
SESTON	-4821.839		5341.844		520.005	

08/10/77 08/11/77
UPPER LONG ISL

PARAMETER	IN (-)		OUT (+)		NET	
NH4-N	-46.656		107.638		60.982	
TKN-N	-991.781	(57.)	1766.212	(63.)	774.432	(71.)
NO3-N	-23.627		44.362		20.734	
NO2-N	-23.627		44.362		20.734	
ORTHO PO4-P	-211.627		389.357		177.730	
TOTAL PO4-P	-488.189	(53.)	997.989	(50.)	509.800	(48.)
TOTAL CARBON	-83732.326	(90.)	152461.564	(96.)	68729.238	(104.)
TOTAL INORGANIC CARBON	-54444.916	(104.)	106436.822	(101.)	51991.907	(98.)
TOTAL ORGANIC CARBON	-29287.411	(65.)	46024.742	(85.)	16737.331	(122.)
SESTON	-38738.615		95682.415		56943.800	

TABLE III-14 (Cont'd)

08/10/77 08/11/77
OLD RIVER CUTOFF

PARAMETER	IN (-)		OUT (+)		NET	
NH4-N	-96.506		.000		-96.506	
TKN-N	-456.146	(71.)	.000	(0.)	-456.146	(71.)
NO3-N	-24.476		.000		-24.476	
NO2-N	-10.387		.000		-10.387	
ORTHO PO4-P	-96.005		.000		-96.005	
TOTAL PO4-P	-148.269	(79.)	.000	(0.)	-148.269	(79.)
TOTAL CARBON	-31977.915	(94.)	.000	(0.)	-31977.915	(94.)
TOTAL INORGANIC CARBON	-24895.985	(103.)	.000	(0.)	-24895.985	(103.)
TOTAL ORGANIC CARBON	-7081.930	(61.)	.000	(0.)	-7081.930	(61.)
SESTON	-12500.968		.000		-12500.968	

TABLE III-14 (Cont'd)

08/10/77 08/11/77
LOWER LONG ISL

PARAMETER	IN (-)		OUT (+)		NET	
NH4-N	-1.070		34.579		33.508	
TKN-N	-486.039	(100.)	594.771	(108.)	108.732	(141.)
NO3-N	-17.667		22.837		5.171	
NO2-N	-17.667		22.837		5.171	
ORTHO PO4-P	-158.999		203.703		44.704	
TOTAL PO4-P	-474.143	(44.)	524.368	(50.)	50.225	(114.)
TOTAL CARBON	-60193.648	(91.)	77936.185	(90.)	17742.536	(90.)
TOTAL INORGANIC CARBON	-41975.677	(102.)	57016.314	(94.)	15040.638	(72.)
TOTAL ORGANIC CARBON	-18217.972	(65.)	20919.870	(81.)	2701.898	(190.)
SESTON	-29317.350		48665.953		19348.603	

08/10/77 08/11/77
COVE BAYOU

PARAMETER	IN (-)		OUT (+)		NET	
NH4-N	-8.923		4.738		-4.185	
TKN-N	-185.532	(44.)	196.243	(71.)	10.711	(534.)
NO3-N	-3.781		4.738		.956	
NO2-N	-3.781		4.738		.956	
ORTHO PO4-P	-49.158		66.327		17.169	
TOTAL PO4-P	-83.191	(86.)	109.412	(84.)	26.221	(75.)
TOTAL CARBON	-11660.938	(104.)	15383.103	(98.)	3722.165	(77.)
TOTAL INORGANIC CARBON	-8125.141	(106.)	10797.048	(98.)	2671.907	(75.)
TOTAL ORGANIC CARBON	-2954.365	(97.)	5007.466	(92.)	2053.101	(86.)
SESTON	-2331.622		4046.233		1714.611	

TABLE III-14 (Cont'd)

08/10/77 08/11/77
TRINITY-JACKS PASS

PARAMETER	IN (-)	OUT (+)	NET
NH4-N	-44.127	231.077	186.950
TKN-N	-252.846 (87.)	1149.080 (74.)	896.234 (70.)
NO3-N	-11.032	59.984	48.952
NO2-N	-5.516	31.509	25.993
ORTHO PO4-P	-44.127	263.569	219.442
TOTAL PO4-P	-99.285 (67.)	597.966 (61.)	498.680 (59.)
TOTAL CARBON	-17421.277 (95.)	100938.708 (94.)	83517.432 (94.)
TOTAL INORGANIC CARBON	-16137.115 (85.)	74890.301 (103.)	58753.186 (108.)
TOTAL ORGANIC CARBON	-4505.335 (61.)	26048.408 (68.)	21543.073 (69.)
SESTON	-14358.468	77667.212	63308.744

08/10/77 08/11/77
ANAHUAC CHANNEL

PARAMETER	IN (-)	OUT (+)	NET
NH4-N	-56.426	174.365	117.939
TKN-N	-267.433 (77.)	937.734 (70.)	670.301 (67.)
NO3-N	-14.733	41.537	26.803
NO2-N	-8.295	27.646	19.351
ORTHO PO4-P	-91.249	304.110	212.861
TOTAL PO4-P	-127.061 (75.)	399.137 (84.)	272.075 (88.)
TOTAL CARBON	-25715.505 (93.)	89260.858 (94.)	63545.354 (94.)
TOTAL INORGANIC CARBON	-20738.311 (96.)	65610.264 (98.)	44871.953 (99.)
TOTAL ORGANIC CARBON	-4977.195 (80.)	22811.759 (76.)	17834.565 (75.)
SESTON	-10410.018	28809.598	18399.580

TABLE III-14 (Cont'd)

08/10/77 08/11/77
TRINITY LIBERTY

PARAMETER	IN (-)		OUT (+)		NET	
NH4-N	.000		33.646		33.646	
TKN-N	.000	(0.)	1117.360	(62.)	1117.360	(62.)
NO3-N	.000		33.646		33.646	
NO2-N	.000		33.646		33.646	
ORTHO PO4-P	.000		431.004		431.004	
TOTAL PO4-P	.000	(0.)	761.977	(72.)	761.977	(72.)
TOTAL CARBON	.000	(0.)	100471.992	(86.)	100471.992	(86.)
TOTAL INORGANIC CARBON	.000	(0.)	76005.383	(96.)	76005.383	(96.)
TOTAL ORGANIC CARBON	.000	(0.)	24466.610	(57.)	24466.610	(57.)
SESTON	.000		.000		.000	

08/10/77 08/11/77
LAKE PASS

PARAMETER	IN (-)		OUT (+)		NET	
NH4-N	-4.378		1.911		-2.467	
TKN-N	-13.725	(100.)	29.390	(74.)	15.665	(51.)
NO3-N	-.925		.821		-.104	
NO2-N	-.494		.670		.176	
ORTHO PO4-P	-5.025		6.696		1.671	
TOTAL PO4-P	-7.760	(98.)	18.895	(43.)	11.135	(4.)
TOTAL CARBON	-1563.638	(123.)	2295.092	(92.)	731.455	(27.)
TOTAL INORGANIC CARBON	-1206.449	(99.)	1606.967	(100.)	400.518	(103.)
TOTAL ORGANIC CARBON	-357.189	(283.)	688.125	(74.)	330.936	(66.)
SESTON	-1213.631		2086.544		872.913	

TABLE III-15

NET NUTRIENT TRANSPORT CALCULATED (KG/DAY)
AT NINE STATIONS IN THE TRINITY RIVER
DELTA UNDER THREE FLOW REGIMES
(Source: Belaire, et al, 1977)
11/30/76 12/01/76

PARAMETER	TRINITY-LIBERTY T	LAKE PASS	TRINITY-JACKS PASS	ANAHUAC CHANNEL	LOWER LONG ISL A
NH4-N	59.825	1.357	24.992	173.106	50.025
TKN-N	1233.900	18.558	865.598	2003.533	1135.873
NO3-N	914.739	-3.853	247.766	477.132	546.595
NO2-N	78.383	.076	22.460	82.251	33.384
ORTHO PO4-P	176.782	-.356	139.292	208.302	136.611
TOTAL PO4-P	902.979	3.906	424.931	1243.304	651.863
TOTAL CARBON	156330.641	341.422	86569.225	125786.028	98047.872
TOTAL INORGANIC CARBON	87798.257	-3.747	40267.471	36562.235	58783.992
TOTAL ORGANIC CARBON	68532.387	345.169	46301.754	89143.792	38782.922
SESTON	.080	-166.114	2073.857	1623.640	6507.010

PARAMETER	COVE BAYOU	CROSS BAYOU	UPPER LONG ISL	OLD RIVER CUTOFF A
NH4-N	5.460	25.184	103.685	-37.527
TKN-N	53.747	212.385	1658.249	-1005.013
NO3-N	-4.450	19.061	613.445	-597.014
NO2-N	3.622	5.219	61.426	-27.751
ORTHO PO4-P	10.043	26.429	253.389	-155.284
TOTAL PO4-P	31.436	119.069	841.779	-595.066
TOTAL CARBON	4423.468	7916.390	221133.883	-97676.597
TOTAL INORGANIC CARBON	1673.083	7062.788	109165.102	-44246.529
TOTAL ORGANIC CARBON	2591.186	1009.894	111968.780	-53430.067
SESTON	235.375	334.959	13946.014	-2849.061

TABLE III-15 (Cont'd)

07/20/77 07/21/77

PARAMETER	TRINITY LIBERTY	LAKE PASS	TRINITY-JACKS PASS	ANAHUAC CHANNEL	LOWER LONG ISL
NH4-N	44.785	1.593	172.636	66.832	18.233
TKN-N	1199.873	1.387	818.751	785.706	546.995
NO3-N	44.785	.510	47.841	40.206	18.233
NO2-N	44.785	.051	26.628	26.955	18.233
ORTHO PO4-P	361.312	.699	161.575	137.267	105.324
TOTAL PO4-P	850.914	.633	426.049	474.893	333.549
TOTAL CARBON	144640.826	117.627	89299.561	86788.854	61088.167
TOTAL INORGANIC CARBON	104901.341	147.321	69821.523	69704.656	47406.268
TOTAL ORGANIC CARBON	34205.022	-29.694	18868.390	17933.866	13681.899
SESTON	.000	61.151	17401.045	18282.740	33652.575

PARAMETER	COVE BAYOU	CROSS BAYOU	UPPER LONG ISL	OLD RIVER CUTOFF
NH4-N	3.693	4.823	35.710	-56.895
TKN-N	52.970	121.820	982.688	-333.657
NO3-N	1.673	3.466	39.355	-14.744
NO2-N	1.673	2.713	35.710	-9.118
ORTHO PO4-P	14.105	29.690	214.262	-54.706
TOTAL PO4-P	34.234	74.057	651.425	-163.322
TOTAL CARBON	5579.897	9742.202	120998.371	-29871.321
TOTAL INORGANIC CARBON	4181.306	7014.042	93437.879	-24224.355
TOTAL ORGANIC CARBON	886.664	2819.533	29554.291	-5646.966
SESTON	3252.181	4974.419	67961.254	-12004.926

TABLE III-15 (Cont'd)

08/10/77 08/11/77

PARAMETER	TRINITY LIBERTY	LAKE PASS	TRINITY-JACKS PASS	ANAHUAC CHANNEL	LOWER LONG ISL
NH4-N	33.646	-2.467	186.950	117.939	33.508
TKN-N	1117.360	15.666	896.234	670.301	108.732
NO3-N	33.646	-.104	48.952	26.803	5.171
NO2-N	33.646	.176	25.993	19.351	5.171
ORTHO PO4-P	431.004	1.671	219.442	212.861	44.704
TOTAL PO4-P	761.977	11.136	498.680	272.075	50.225
TOTAL CARBON	100471.992	731.456	83517.432	63545.354	17742.536
TOTAL INORGANIC CARBON	76005.383	400.518	58753.186	44871.953	15040.638
TOTAL ORGANIC CARBON	24466.610	330.936	21543.073	17834.565	2701.898
SESTON	.000	872.913	63308.744	18399.580	19348.603

PARAMETER	COVE BAYOU	CROSS BAYOU	UPPER LONG ISL	OLD RIVER CUTOFF
NH4-N	-4.185	3.916	60.982	-96.506
TKN-N	10.711	23.443	774.432	-456.146
NO3-N	.956	2.207	20.734	-24.476
NO2-N	.956	2.207	20.734	-10.387
ORTHO PO4-P	17.169	28.697	177.730	-96.005
TOTAL PO4-P	26.221	70.243	509.800	-148.269
TOTAL CARBON	3722.165	7315.353	68729.238	-31977.915
TOTAL INORGANIC CARBON	2671.907	5302.052	51991.907	-24895.985
TOTAL ORGANIC CARBON	2053.101	2013.301	16737.331	-7081.930
SESTON	1714.611	520.006	56943.800	-12590.968

TABLE III-16

NET DISCHARGE (m^3/day) OF WATER TO TRINITY BAY
UNDER THREE FLOW REGIMES
(Source: Belaire, et al, 1977)

Station	30 November - 1 December 1976	20-21 July 1977	10-11 August 1977
4 (Anahuac Channel)	4,016,000	2,695,500	1,935,100
5 (Lower Long Island Bayou)	3,338,400	1,823,400	517,100
6 (Cove Bayou)	76,800	167,300	95,600
7 (Cross Bayou)	433,100	271,300	220,700
Total	7,864,300	4,957,500	2,768,500

TABLE III-17

NET TRANSPORT (Kg/day) OF NITROGEN, PHOSPHORUS, CARBON AND SESTON TO TRINITY BAY UNDER THREE FLOW REGIMES
(Source: Belaire, et al, 1977)
November-December 1976

Station	NH_4-N	TKN	NO_3-N	NO_2-N	O-PO_4-N	T-PO_4-P	TOC	Seston
4	173.1	2,003.5	477.1	62.2	208.3	1,243.3	89,143.8	1,623.6
5	50.0	1,135.9	546.6	33.4	136.6	651.9	38,782.9	6,507.0
6	5.5	53.7	-4.4	3.6	10.0	31.4	2,591.2	235.6
7	25.2	212.4	19.1	5.2	26.4	119.0	1,009.9	335.0
Total	253.8	3,405.5	1,038.4	104.4	381.3	2,045.6	131,527.8	8,701.2
% of Total measured at Station 1	23.6%	36.2%	88.1%	75.1%	46.4%	44.1%	52.1%	

July 1977

Station	NH_4-N	TKN	NO_3-N	NO_2-N	O-PO_4-N	T-PO_4-P	TOC	Seston
4	66.8	785.7	40.2	27	137.3	474.9	17,933.9	18,282.7
5	18.2	547.0	18.2	18.2	105.3	333.5	13,681.9	33,652.6
6	3.7	53.0	1.7	1.7	14.1	34.2	886.7	3,252.1
7	4.8	121.8	3.5	3.5	29.7	74.0	2,819.5	4,974.4
Total	93.5	1,507.5	63.6		286.4	916.6	35,322.0	60,161.8
% of Total measured at Station 1	47.9%	79.6%	70.4%	63.6%	126.2%	92.8%	96.8%	

TABLE III (Cont'd)
17
August 1977

Station	NH_4-N	TKN	NO_3-N	NO_2-N	O-PO_4-P	T-PO_4-N	TOC	Seston
4	117.9	670.3	26.8	19.4	212.9	272.1	17,834.6	18,399.6
5	33.5	108.7	5.2	5.2	44.7	50.2	2,701.9	19,348.6
6	-4.2	10.7	1.0	1.0	17.2	26.2	2,053.1	1,714.6
7	3.9	23.4	2.2	2.2	28.7	70.2	2,013.3	520.5
Total	151.1	813.1	35.2	27.8	303.5	418.7	24,602.9	39,982.8
% of Total measured at Station 1	22.2%	137.4%	95.4%	120.9%	142.0%	182.0%	99.4%	

in the concentrations of these parameters between tide direction means that transformational processes within the marsh are, to the extent detectable in these studies, completely overshadowed by hydrological events.

Rather than transformation in tidal waters, a consideration of the changes in the dissolved and suspended material in waters originating as terrestrial runoff is more appropriate in a delta marsh situation. The Trinity River samples taken near Liberty, Texas (Station 1) provide some baseline freshwater data.

When nutrient and carbon concentrations are compared between Station 1 and the lower delta stations for the November-December study (Table III-13) consistent changes are evident. Both ortho- and total phosphorus were more concentrated in the marsh and bay water samples than in the Trinity River. Of the nitrogen parameters, ammonia, and total kjeldahl nitrogen were more abundant at the delta, while nitrate and nitrite nitrogen tended to be more abundant in the Trinity River at Liberty. TOC concentrations were greater at the internal marsh stations than at Station 1, but were lower at those marsh stations directly communicating with Trinity Bay (Stations 5, 6, and 7).

During the July and August studies (Table III-13), the situation was somewhat different. In this summer period ortho- and total phosphorus were more abundant in the Trinity River (at Liberty) than at the marsh stations, while all nitrogen species were more abundant (or in the case of NO_2, no difference) in the delta. Total organic carbon concentration tended to be greatest in the delta during August, but the results in July were ambiguous, with some marsh stations showing higher, and some showing lower, carbon concentrations than at Station 1.

The discharge results for the November-December study, Table III-13, show a considerable excess of discharge to Trinity Bay (Stations 4, 5, 6, and 7) over that at Station 1. This excess is probably explained by runoff received below Liberty and by local precipitation. Although biological processes within the delta may have affected the parameters studied, no information is available on nutrient and carbon concentrations in the Lower Trinity Basin. During July, discharges at Liberty and those into Trinity Bay were roughly equal. In August (Table III-13), considerably less water was discharged into Trinity Bay than was observed at Station 1. Withdrawals below Liberty for agricultural and municipal uses, plus evaporation in delta areas may account for these discrepancies. In any case, water quality differences in local runoff water are unlikely to have caused the consistent differences in nutrient parameters observed during this period. Thus, although the Trinity Delta is a net contributor of all nutrients and carbon to Trinity Bay because of the dominant flow direction, the summer studies show that this contribution is enriched in nitrogen compounds (particularly NH_4-N) and depleted in phosphorus compared to the water of the Trinity River before it enters the delta. Carbon (TOC) tended to have increased concentrations in the delta relative to that in the Trinity River.

MODEL VERIFICATION

The mass transfer model was applied in conjunction with the hydrodynamic model for the period 25 November through 3 December 1976. Water quality data for model verification were gathered in an intensive diurnal biological and hydrodynamic study during this period at various locations throughout the Trinity Delta.

Input Data

The purpose of this model application was to test the ability of the mass transfer model to simulate nutrient transfer in the deltaic system when compared with existing water sample data. Some modification of the constituents modeled from their strict definition given earlier was required to allow exact correlation between modeled constituents and the constituents as measured during the study. Many of the nutrients measured were from filtered samples, so all nutrient constituents modeled represent filtered values. The following constituents were simulated: total kjeldahl nitrogen (TKN) for organic nitrogen, ammonia ion (NH_4) for ammonia (these are equivalent), nitrite (NO_2) for nitrite, nitrate (NO_3), for nitrate, ortho- phosphates (ortho-PO_4) for total phosphates, and total organic carbon (TOC) for total carbon. In addition, salinity concentrations were simulated as a conservative constituent. Algae was not simulated since no algae or phytoplankton data were measured during this study.

The boundary values used at the tidal boundary (Section 1) and the upstream Trinity River boundary (Section 92) are presented in Table III-18. The Trinity River at Liberty was a sampling site and samples were taken at this location at three hour intervals between 1300 November 30 and 1000 December 1. The range of values measured at this site and the average value which was used as the boundary condition are presented in the table. Most of the constituent values at the lower boundary were determined from samples taken at two locations in Trinity Bay on December 8, 1976 by the TDWR for the state-wide monitoring program. Since the bay sampling program did not coincide with the intensive study, some discretion was made before using measured values. In particular TKN and NO_2 were not included in the bay measurements, and measured values during the study at the strongly tidally influenced sites at Cross and Cove Bayous indicated higher bay NH_4 concentrations than indicated from the bay samples. Therefore values encountered at Cross and Cove Bayou during the flood tide were used as the boundary values for TKN, NH_4 and NO_2.

TABLE III-18

BOUNDARY CONDITIONS
(Source: Hauck, 1977)

Constituent	Bay Boundary (Section 1) Range	Bay Boundary (Section 1) Boundary Value Used	Trinity River at Liberty Boundary (Section 92) Range	Trinity River at Liberty Boundary (Section 92) Boundary Value Used
Salinity (PPT)	12.8-15.5	15.0	0.2-0.2	0.2
TKN-N (mg/ℓ)	---	0.4[1]	0.7-0.2	0.4
NH_4-N (mg/ℓ)	.01-.02	.06[2]	.01-.02	.01
NO_2-N (mg/ℓ)	---	.015[1]	.015-.015	.015
NO_3-N (mg/ℓ)	.01-.12	.06	.165-.185	.17
Ortho PO_4-P (mg/ℓ)	.35-.95	.7	.010-.055	.040
TOC (mg/ℓ)	10.-11.	10.0	9.0-18.0	15.0

[1]No data available, proper value estimated.
[2]Available data did not coincide at all with values in tidally influenced portions of the delta, so a value of proper magnitude was substituted.

From the habitat study described earlier it would be possible to separate the sections of the model segmentation into several categories according to prominent vegetative species and to specify a set of exchange rates for each of these categories. However, on the basis of the available data this refinement was unwarranted. Instead, two sets of exchange rate coefficients were used; one for the channel and the other for the flood plain. All the exchange rate values for the channel were set to zero and the flood plain rates were based on weighted average of values from the nutrient exchange rate studies of Armstrong and Gordon for four marsh species under winter conditions (Table III-19).

Further miscellaneous input requirements include water temperature, dispersion coefficients and the various first-order decay rates in the nitrogen cycle. From the field data, an average water temperature of 9.0 degrees C. for the entire period was used, though temperatures from 7.5 to 11.5 degrees C. were recorded during the study. The longitudinal channel dispersion coefficient E_L was selected to be 500 ft^2/sec. This value may be too high for the upper river portion of the segmentation and at the same time too low for the open bay; however, it is a fairly representative value for the entire system under the conditions experienced during the simulation period. The dispersion coefficient between the channel and flood plain E_F was set at 0.0 ft^2/sec, which eliminates the dispersive flux term in the flood plain. The flood plain channel relationship is advection dominated, and rather than attempt to estimate E_F for such a circumstance, it was simply set to zero. The various first-order decay coefficients are for a temperature of 20 degrees C. The organic nitrogen to ammonia rate K_1 is 0.02 per day, the ammonia to nitrite rate K_2 is 0.1 per day, the nitrite to nitrate rate K_3 is 0.3 per day. These decay rates are within the range of the values determined in other estuaries (see e.g. Thomann, O'Connor and Di Toro; 1976).

Model Simulation

A constant river flow of approximately 2400 ft^3/sec existed at the Liberty gauge during the simulated period, 25 November through 3 December 1976. Diurnal bay tides also existed during this time with a large wind setdown on November 28 and 29. After allowing two days for the hydrodynamic model to stabilize from assumed initial conditions (one day is normally sufficient), the mass transfer model simulation was interfaced with the hydrodynamic simulation beginning at 0000 CST 27 November. The combined hydrodynamic water quality simulation was then continued through 3 December. This allows approximately 3 days for the water quality simulation to stabilize from initial conditions before 30 November when the water sampling field program began.

Water quality measurements were made at the following locations: Anahuac Channel (Section 47), Trinity River above Jack's

TABLE III-19

EXCHANGE RATE COEFFICIENTS
(Source: Hauck, 1977)
Exchange Rate (Kg/ha/day)[1,3]

Constituent	Sagittaria lancifolia	Scripus americanus	Spartina patens	Rhynchospora macrostachya	Weighted Average For Model[2]
filtered TKN,E_1	.026	.006	.000	.008	.01
filtered NH_3,E_2	.043	.043	.066	.039	.05
filtered NO_2,E_3	.000	.000	.000	.000	.0
filtered NO_3,E_4	.175	.156	.330	.171	.25
filtered ortho-PO_4,E_3	.007	.012	.014	.011	.01
TOC,E_6	1.259	1.208	.125	.866	.5

[1]All data from Armstrong and Gordon (1977) for winter conditions.
[2]To determine these averages, the Spartina patens marsh values were given three times the weight of the other three less prominent species.
[3]All values represent an uptake from the water column.

Pass (Section 53), Old River Cutoff (Section 144), Lake Pass (Section 158), Mac Lake (Section 165), the Cutoff near Wallisville (Section 169), Lower Long Island Bayou (Section 22), Upper Long Island Bayou (Section 23), Old River near I.H. 10 (Section 34), Cove Bayou (Section 120), Cross Bayou (Section 125), Cotton Bayou (Section 132) and Lost River I.H. 10 (Section 192). At all these sampling locations, simulated and measured values are compared for salinity, TKN, NH_4, NO_2, NO_3, orthophosphate and TOC (see Table III-20). In general, the values compare favorably. At almost all locations TKN, NO_2 and TOC values show good agreement. The NH_4 simulated concentrations are in general too high except at the highly tidal influenced sites at Cove and Cross Bayous where the values are too low. Also the simulated NO_3 concentrations are almost without exception too high, as are orthophosphate concentrations in the lower delta region below Interstate Highway 10. In a majority of cases, better or more accurate boundary value specification would improve the simulation results. In particular, the bay boundary values were based on limited data with a wide range of values for NO_3 and orthophosphates (see Table III-18). This made it difficult to estimate the true boundary concentration for these two constituents, and the simple mathematical average used to determine the values used in the simulation could be greatly in error. The NH_4 bay boundary was estimated from the field sampling results at Cove and Cross Bayou, and as such its value is subject to some error. Salinity values agree at the majority of sites, though simulated salinities are too high in Long Island Bayou and Anahuac Channel and too low in Cove and Cross Bayous.

The simulation is not a stringent test of the capabilities of the mass transfer model, but the results do indicate the ability of the model to begin with a set of initial conditions and boundary values and to reasonably reproduce measured values after a simulation interval of several days. Additional verification data are necessary before a thorough evaluation of the model's simulation capabilities can be accomplished. Anomalously high freshwater inflow in the Trinity Delta during the spring of 1977 necessitated postponement of further field surveys and prevented the accumulation of additional data in time to be used for model verification. Therefore the veracity of this model has not been tested to the point where it can be used as a planning tool with significant confidence and will not be used in the inundation analysis included later in this report.

TABLE III-20

COMPARISON OF WATER QUALITY CONSTITUENTS ON 30 NOV - 3 DEC, 1976
(Source: Hauck, 1977)

ANAHUAC CHANNEL (Section 47)

TIME		SAL (PPT)		TKN-N (mg/ℓ)		NH_4-N (mg/ℓ)		NO_2-N (mg/ℓ)		NO_3-N (mg/ℓ)		Ortho PO_4-P (mg/ℓ)		TOC (mg/ℓ)	
		M	S	M	S	M	S	M	S	M	S	M	S	M	S
Nov 30	1045	0.0	0.3	.70	.38	.075	.026	.010	.011	.12	.17	.045	.043	16.0	15.0
	1300	0.0	0.2	.50	.38	.070	.024	.010	.010	.14	.17	.045	.038	13.0	15.0
	1600	0.0	0.2	.50	.38	.070	.024	.020	.010	.14	.17	.055	.037	11.0	15.0
	1900	0.0	0.2	.50	.38	.070	.024	.035	.010	.14	.17	.065	.039	12.0	15.0
	2200	0.0	1.3	.40	.38	.045	.030	.020	.011	.13	.15	.060	.065	14.0	15.0
Dec 1	0100	0.0	1.3	.30	.38	.015	.030	.015	.011	.085	.15	.045	.065	8.0	15.0
	0400	0.0	0.6	.40	.38	.035	.028	.015	.011	.11	.16	.040	.049	8.0	15.0
	0700	0.0	0.5	.40	.38	.020	.028	.010	.011	.11	.16	.060	.048	14.0	15.0
	1000	0.0	0.2	.50	.38	.025	.026	.010	.010	.12	.17	.050	.037	14.0	15.0

M = measured values S = simulated values

TRINITY RIVER ABOVE JACK'S PASS (Section 53)

TIME		SAL (PPT)		TKN-N (mg/ℓ)		NH_4-N (mg/ℓ)		NO_2-N (mg/ℓ)		NO_3-N (mg/ℓ)		Ortho PO_4-P (mg/ℓ)		TOC (mg/ℓ)	
		M	S	M	S	M	S	M	S	M	S	M	S	M	S
Nov 30	1330	0.3	0.2	.30	.38	.010	.028	.010	.011	.10	.16	.055	.040	9.0	15.0
	2000	0.3	0.2	.30	.38	.015	.024	.010	.010	.09	.16	.065	.041	7.0	15.0
Dec 1	0100	0.3	0.2	.30	.38	.010	.024	.010	.010	.12	.16	.070	.040	9.0	15.0
	0730	0.3	0.2	.30	.38	.010	.023	.010	.010	.12	.16	.055	.039	7.0	15.0
	1030	0.3	0.2	.30	.38	.010	.021	.010	.010	.12	.16	.065	.039	0.0	15.0

M = measured values S = simulated values

TABLE III (Cont'd)
20

OLD RIVER CUTOFF (Section 144)

TIME		SAL (PPT) M	SAL (PPT) S	TKN-N (mg/ℓ) M	TKN-N (mg/ℓ) S	NH_4-N (mg/ℓ) M	NH_4-N (mg/ℓ) S	NO_2-N (mg/ℓ) M	NO_2-N (mg/ℓ) S	NO_3-N (mg/ℓ) M	NO_3-N (mg/ℓ) S	Ortho PO_4-P (mg/ℓ) M	Ortho PO_4-P (mg/ℓ) S	TOC (mg/ℓ) M	TOC (mg/ℓ) S
Nov 30	1100	0.3	0.3	.25	.38	.013	.025	.010	.011	.09	.16	.055	.043	15.0	15.1
	1540	0.3	0.3	.25	.38	.017	.024	.010	.011	.10	.16	.060	.042	6.5	15.1
	1900	0.3	0.4	.30	.38	.013	.025	.010	.011	.10	.16	.057	.044	8.5	15.1
	2200	0.3	0.4	.30	.38	.015	.026	.010	.011	.12	.16	.052	.045	9.0	15.1
Dec 1	0100	0.3	0.5	.30	.38	.013	.027	.010	.011	.12	.16	.055	.047	10.0	15.1
	0400	0.3	0.5	.30	.38	.010	.027	.010	.011	.12	.16	.055	.047	20.5	15.1
	0700	0.3	0.6	.20	.38	.013	.028	.010	.011	.12	.16	.055	.049	13.5	15.1
	1000	0.3	0.4	.30	.38	.010	.026	.010	.011	.11	.16	.055	.044	10.0	15.0

M = measured values S = simulated values

LAKE PASS (Section 158)

TIME		SAL (PPT) M	SAL (PPT) S	TKN-N (mg/ℓ) M	TKN-N (mg/ℓ) S	NH_4-N (mg/ℓ) M	NH_4-N (mg/ℓ) S	NO_2-N (mg/ℓ) M	NO_2-N (mg/ℓ) S	NO_3-N (mg/ℓ) M	NO_3-N (mg/ℓ) S	Ortho PO_4-P (mg/ℓ) M	Ortho PO_4-P (mg/ℓ) S	TOC (mg/ℓ) M	TOC (mg/ℓ) S
Nov 30	1300	0.2	0.2	.40	.38	.035	.016	.010	.009	.020	.076	.050	.038	15.0	14.9
	1600	0.2	0.2	.50	.38	.050	.016	.010	.009	.010	.060	.045	.038	14.0	14.9
	1900	0.2	0.2	.40	.38	.035	.018	.010	.009	.015	.093	.020	.038	8.0	14.9
	2200	0.2	0.2	.40	.39	.035	.021	.010	.011	.12	.17	.055	.040	7.0	15.0
Dec 1	0100	0.2	0.2	.30	.38	.015	.020	.010	.010	.12	.15	.060	.039	15.0	15.0
	0400	0.2	0.2	.30	.38	.010	.021	.010	.010	.11	.15	.060	.039	10.0	15.0
	0700	0.2	0.2	.20	.38	.015	.021	.010	.010	.12	.15	.065	.039	14.0	15.0
	1000	0.2	0.2	.50	.38	.030	.021	.010	.011	.12	.15	.055	.040	20.0	15.0

M = measured values S = simulated values

TABLE III (Cont'd)
20

MAC LAKE (Section 165)

TIME		SAL (PPT) M	SAL (PPT) S	TKN-N (mg/ℓ) M	TKN-N (mg/ℓ) S	NH_4-N (mg/ℓ) M	NH_4-N (mg/ℓ) S	NO_2-N (mg/ℓ) M	NO_2-N (mg/ℓ) S	NO_3-N (mg/ℓ) M	NO_3-N (mg/ℓ) S	Ortho PO_4-P (mg/ℓ) M	Ortho PO_4-P (mg/ℓ) S	TOC (mg/ℓ) M	TOC (mg/ℓ) S
Nov 30	1200	0.2	0.2	0.70	0.39	.020	.020	.015	.011	.030	.18	.075	.040	15.0	15.0
	1500	0.2	0.2	0.70	0.39	.040	.020	.015	.011	.010	.18	.070	.040	18.0	15.0
	1800	0.2	0.2	0.60	0.39	.020	.020	.020	.011	.010	.18	.085	.040	9.0	15.0
	2100	0.2	0.2	0.60	0.39	.040	.020	.020	.011	.010	.18	.040	.040	14.0	15.0
	2400	0.2	0.2	0.50	0.39	.020	.020	.020	.011	.010	.18	.065	.040	16.0	15.0
Dec 1	0300	0.2	0.2	0.50	0.39	.025	.021	.020	.011	.010	.18	.050	.040	17.0	15.0
	0600	0.2	0.2	0.70	0.39	.020	.021	.020	.011	.010	.18	.050	.040	15.0	15.0
	0900	0.2	0.2	0.50	0.39	.020	.021	.010	.011	.010	.18	.055	.040	16.0	15.0

M = measured values S = simulated values

THE CUTOFF NEAR WALLISVILLE (Section 169)

TIME		SAL (PPT) M	SAL (PPT) S	TKN-N (mg/ℓ) M	TKN-N (mg/ℓ) S	NH_4-N (mg/ℓ) M	NH_4-N (mg/ℓ) S	NO_2-N (mg/ℓ) M	NO_2-N (mg/ℓ) S	NO_3-N (mg/ℓ) M	NO_3-N (mg/ℓ) S	Ortho PO_4-P (mg/ℓ) M	Ortho PO_4-P (mg/ℓ) S	TOC (mg/ℓ) M	TOC (mg/ℓ) S
Nov 30	1100	0.2	0.2	.30	.39	.010	.018	.010	.012	.13	.17	.020	.040	0.0	15.0
	1400	0.2	0.2	.20	.39	.010	.019	.015	.012	.12	.17	.030	.040	1.0	15.0
	1700	0.2	0.2	.50	.39	.010	.018	.015	.012	.13	.17	.030	.040	6.0	15.0
	2000	0.2	0.2	.20	.39	.010	.018	.015	.012	.12	.17	.040	.040	11.0	15.0
	2300	0.2	0.2	.30	.39	.010	.018	.015	.012	.16	.17	.020	.040	7.0	15.0
Dec 1	0200	0.2	0.2	.40	.39	.010	.018	.015	.012	.13	.17	.025	.040	5.0	15.0
	0500	0.2	0.2	.30	.39	.010	.018	.015	.012	.16	.17	.035	.040	8.0	15.0
	0800	0.2	0.2	.30	.39	.010	.018	.015	.012	.17	.17	.035	.040	8.0	15.0
	1100	0.2	0.2	.30	.39	.010	.019	.015	.012	.16	.17	.020	.040	13.0	15.0

TABLE III (Cont'd)
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LONG ISLAND BAYOU, 1/2 MILE ABOVE MOUTH (Section 22)

TIME		SAL (PPT) M	SAL (PPT) S	TKN-N (mg/ℓ) M	TKN-N (mg/ℓ) S	NH_4-N (mg/ℓ) M	NH_4-N (mg/ℓ) S	NO_2-N (mg/ℓ) M	NO_2-N (mg/ℓ) S	NO_3-N (mg/ℓ) M	NO_3-N (mg/ℓ) S	Ortho PO_4-P (mg/ℓ) M	Ortho PO_4-P (mg/ℓ) S	TOC (mg/ℓ) M	TOC (mg/ℓ) S
Dec 2	1000	0.6	1.9	.25	.37	.012	.034	.010	.012	.095	.12	.053	.076	14.0	15.0
	1300	0.5	1.6	.25	.37	.012	.034	.010	.012	.055	.13	.042	.070	15.0	15.1
	1600	0.5	1.3	.25	.37	.010	.034	.010	.012	.065	.13	.035	.065	17.0	15.1
	1900	0.5	1.4	.25	.37	.015	.034	.010	.012	.060	.13	.022	.065	16.0	15.1
	2200	0.5	1.7	.25	.37	.025	.036	.010	.012	.055	.13	.038	.073	18.0	15.1
Dec 3	0100	0.5	1.8	.25	.37	.015	.036	.010	.012	.060	.13	.038	.076	19.0	15.0
	0700	0.4	1.6	.25	.37	.020	.035	.010	.012	.110	.13	.053	.071	16.0	15.0
	1000	0.4	1.3	.30	.37	.010	.034	.010	.012	.100	.14	.033	.065	20.0	15.0

M = measured values S = simulated values

UPPER LONG ISLAND BAYOU AT BREACH IN LEVEE (Section 23)

TIME		SAL (PPT) M	SAL (PPT) S	TKN-N (mg/ℓ) M	TKN-N (mg/ℓ) S	NH_4-N (mg/ℓ) M	NH_4-N (mg/ℓ) S	NO_2-N (mg/ℓ) M	NO_2-N (mg/ℓ) S	NO_3-N (mg/ℓ) M	NO_3-N (mg/ℓ) S	Ortho PO_4-P (mg/ℓ) M	Ortho PO_4-P (mg/ℓ) S	TOC (mg/ℓ) M	TOC (mg/ℓ) S
Dec 2	1100	0.6	1.3	.30	.37	.010	.032	.010	.011	.070	.13	.040	.063	17.0	15.1
	1630	0.3	1.1	.30	.37	.010	.034	.010	.012	.090	.13	.035	.060	19.0	15.1
	2200	0.4	1.5	.30	.37	.015	.035	.010	.012	.070	.13	.035	.069	20.0	15.1
Dec 3	0400	0.3	1.0	.30	.37	.030	.032	.010	.011	.130	.15	.050	.059	19.0	15.0
	1000	0.3	0.9	.30	.37	.010	.033	.010	.011	.110	.14	.040	.055	17.0	15.1

M = measured values S = simulated values

TABLE III (Cont'd)
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OLD RIVER NEAR IH-10 (Section 34)

TIME		SAL (PPT) M	SAL (PPT) S	TKN-N (mg/ℓ) M	TKN-N (mg/ℓ) S	NH_4-N (mg/ℓ) M	NH_4-N (mg/ℓ) S	NO_2-N (mg/ℓ) M	NO_2-N (mg/ℓ) S	NO_3-N (mg/ℓ) M	NO_3-N (mg/ℓ) S	Ortho PO_4-P (mg/ℓ) M	Ortho PO_4-P (mg/ℓ) S	TOC (mg/ℓ) M	TOC (mg/ℓ) S
Dec 2	1200	0.2	0.6	.50	.37	.035	.031	.010	.012	.040	.090	.020	.047	23.0	15.3
	1530	0.2	0.5	.40	.37	.040	.031	.010	.012	.060	.087	.060	.044	21.0	15.4
	1820	0.2	0.4	.50	.37	.040	.033	.010	.012	.060	.095	.060	.043	26.0	15.4
	2100	0.2	0.4	.60	.37	.045	.035	.010	.012	.060	.109	.060	.043	20.0	15.3
Dec 3	0625	0.2	0.6	.60	.37	.045	.037	.010	.012	.060	.120	.035	.047	23.0	15.3
	0900	0.2	0.5	.40	.36	.035	.038	.010	.012	.070	.121	.010	.047	25.0	15.3

M = measured values S = simulated values

COVE BAYOU (Section 120)

TIME		SAL (PPT) M	SAL (PPT) S	TKN-N (mg/ℓ) M	TKN-N (mg/ℓ) S	NH_4-N (mg/ℓ) M	NH_4-N (mg/ℓ) S	NO_2-N (mg/ℓ) M	NO_2-N (mg/ℓ) S	NO_3-N (mg/ℓ) M	NO_3-N (mg/ℓ) S	Ortho PO_4-P (mg/ℓ) M	Ortho PO_4-P (mg/ℓ) S	TOC (mg/ℓ) M	TOC (mg/ℓ) S
Dec 2	1300	4.0	2.1	.40	.37	.070	.035	.015	.013	.085	.070	.010	.081	19.0	15.2
	1600	5.0	2.0	.40	.37	.070	.036	.020	.012	.060	.096	.115	.080	19.0	15.1
	1900	8.0	2.0	.40	.37	.075	.036	.010	.012	.050	.116	.150	.081	17.0	15.0
	2200	9.8	2.4	.60	.37	.070	.038	.020	.012	.040	.119	.115	.089	14.0	15.0
Dec 3	0100	7.8	2.4	.50	.37	.070	.038	.020	.012	.040	.115	.120	.091	18.0	15.0
	0400	6.6	2.4	.40	.36	.075	.039	.020	.013	.040	.109	.130	.091	16.0	15.0
	0700	5.3	2.4	.30	.36	.070	.039	.020	.013	.040	.112	.105	.092	14.0	15.0
	1000	4.2	2.1	.40	.36	.070	.038	.025	.013	.035	.094	.100	.082	15.0	15.1

M = measured values S = simulated values

TABLE III (Cont'd)
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CROSS BAYOU (Section 125)

TIME		SAL (PPT) M	SAL (PPT) S	TKN-N (mg/ℓ) M	TKN-N (mg/ℓ) S	NH_4-N (mg/ℓ) M	NH_4-N (mg/ℓ) S	NO_2-N (mg/ℓ) M	NO_2-N (mg/ℓ) S	NO_3-N (mg/ℓ) M	NO_3-N (mg/ℓ) S	Ortho PO_4-P (mg/ℓ) M	Ortho PO_4-P (mg/ℓ) S	TOC (mg/ℓ) M	TOC (mg/ℓ) S
Dec 2	1130	3.2	5.4	.50	.37	.070	.044	.010	.014	.060	.085	.040	.176	18.0	15.2
	1300	3.2	5.3	.50	.37	.065	.043	.010	.014	.050	.078	.040	.171	17.0	14.1
	1600	3.1	5.3	.50	.37	.060	.042	.010	.014	.050	.072	.040	.171	16.0	14.1
	1900	8.1	6.1	.30	.37	.070	.046	.015	.015	.035	.079	.100	.194	17.0	13.9
	2200	12.2	8.0	.30	.36	.075	.054	.015	.016	.045	.096	.135	.256	13.0	13.4
Dec 3	0100	9.7	7.7	.40	.36	.065	.053	.015	.016	.055	.093	.140	.247	14.0	13.5
	0400	8.9	7.4	.40	.36	.065	.052	.015	.016	.035	.090	.080	.237	15.0	13.5
	0700	6.4	6.9	.40	.36	.060	.050	.015	.015	.035	.086	.085	.221	12.0	13.7
	1000	3.6	5.1	.50	.36	.055	.044	.010	.014	.083	.060	.060	.169	16.0	14.1

M = measured value S = simulated value

COTTON BAYOU AT WEST BREACH IN LEVEE (Section 132)

TIME		SAL (PPT) M	SAL (PPT) S	TKN-N (mg/ℓ) M	TKN-N (mg/ℓ) S	NH_4-N (mg/ℓ) M	NH_4-N (mg/ℓ) S	NO_2-N (mg/ℓ) M	NO_2-N (mg/ℓ) S	NO_3-N (mg/ℓ) M	NO_3-N (mg/ℓ) S	Ortho PO_4-P (mg/ℓ) M	Ortho PO_4-P (mg/ℓ) S	TOC (mg/ℓ) M	TOC (mg/ℓ) S
Dec 2	1110	---	3.6	.30	.37	.055	.039	.010	.013	.050	.090	.070	.124	5.0	14.6
	1430	---	3.5	.50	.37	.055	.037	.010	.013	.040	.081	.070	.122	9.0	14.6
	1700	---	1.9	.40	.37	.050	.037	.010	.012	.050	.11	.055	.081	2.0	14.9
	2000	---	1.8	.40	.37	.035	.037	.010	.012	.050	.11	.050	.078	8.0	14.9
	2300	---	2.3	.40	.37	.030	.037	.010	.013	.050	.10	.040	.092	14.0	14.8
Dec 3	0220	---	1.8	.40	.36	.035	.037	.010	.012	.060	.12	.045	.078	14.0	14.9
	0500	---	1.7	.40	.36	.035	.037	.010	.012	.050	.12	.040	.078	9.0	15.0
	0800	---	1.2	.30	.36	.035	.037	.010	.012	.050	.12	.045	.064	16.0	15.1
	1000	---	1.3	.50	.36	.040	.038	.010	.012	.050	.12	.025	.066	10.0	15.0

M = measured values S = simulated values

TABLE III (Cont'd)
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THE CUTOFF NEAR WALLISVILLE (Section 169)

TIME		SAL (PPT) M	SAL (PPT) S	TKN-N (mg/ℓ) M	TKN-N (mg/ℓ) S	NH_4-N (mg/ℓ) M	NH_4-N (mg/ℓ) S	NO_2-N (mg/ℓ) M	NO_2-N (mg/ℓ) S	NO_3-N (mg/ℓ) M	NO_3-N (mg/ℓ) S	Ortho PO_4-P (mg/ℓ) M	Ortho PO_4-P (mg/ℓ) S	TOC (mg/ℓ) M	TOC (mg/ℓ) S
Dec 2	1100	0.2	0.2	.20	.39	.025	.020	.015	.012	.15	.17	.030	.040	5.0	15.0
	1400	0.2	0.2	.20	.38	.010	.024	.015	.012	.15	.17	.040	.040	4.0	15.0
	1700	0.2	0.2	.30	.38	.010	.026	.015	.012	.14	.16	.045	.040	1.0	15.0
	2000	0.2	0.2	.20	.39	.010	.019	.015	.012	.15	.17	.040	.040	0.0	15.0
	2300	0.2	0.2	.30	.39	.010	.018	.015	.012	.15	.17	.060	.040	6.0	15.0
Dec 3	0200	0.2	0.2	.30	.39	.010	.018	.015	.012	.15	.17	.045	.040	1.0	15.0
	0500	0.2	0.2	.30	.39	.010	.018	.015	.012	.15	.17	.045	.040	0.0	15.0
	0800	0.2	0.2	.30	.39	.010	.019	.010	.012	.13	.17	.050	.040	5.0	15.0

M = measured values S = simulated values

LOST RIVER NEAR IH-10 (Section 192)

TIME		SAL (PPT) M	SAL (PPT) S	TKN-N (mg/ℓ) M	TKN-N (mg/ℓ) S	NH_4-N (mg/ℓ) M	NH_4-N (mg/ℓ) S	NO_2-N (mg/ℓ) M	NO_2-N (mg/ℓ) S	NO_3-N (mg/ℓ) M	NO_3-N (mg/ℓ) S	Ortho PO_4-P (mg/ℓ) M	Ortho PO_4-P (mg/ℓ) S	TOC (mg/ℓ) M	TOC (mg/ℓ) S
Dec 2	1235	0.3	0.4	.40	.37	.015	.037	.010	.012	.060	.14	.060	.045	16.0	15.2
	1515	0.3	0.3	.40	.37	.020	.037	.010	.012	.080	.14	.030	.042	19.0	15.1
	1800	0.3	0.3	.40	.37	.020	.037	.010	.012	.070	.14	.045	.041	21.0	15.1
	2130	0.3	0.5	.50	.37	.015	.036	.010	.012	.070	.13	.030	.045	18.0	15.2
	2400	0.3	0.6	.30	.37	.015	.037	.010	.012	.070	.12				
Dec 3	0325	0.3	0.5	.50	.37	.015	.037	.010	.012	.070	.13	.030	.046	18.0	15.2
	0600	0.3	0.5	.50	.37	.015	.037	.010	.012	.080	.13	.030	.045	13.0	15.2
	0915	0.3	0.4	.20	.37	.020	.037	.010	.012	.070	.14	.035	.043	18.0	15.1

M = measured values S = simulated values

TABLE IV-1

FREQUENCY OF EXCEEDING ENVIRONMENTAL PROTECTION AGENCY RECEIVING WATER MAXIMUM ACCEPTABLE CONCENTRATIONS FOR HEAVY METALS IN GALVESTON BAY*
(Source: Armstrong, et al, 1977)

Segment	Station	Zinc	Lead	Mercury	Cadmium	Copper	Arsenic	Nickel
1006	9	0	0	60	43	75	0	40
1007	11	50	20	0	50	75	0	40
2421	18	20	20	60				
	22	37	14	37				
	23	0	20	60				
	28	0	20	80				
	31	0	20	80				
	33	0	20	75	0	80	0	50
	41	0	20	100				
2422	26	25	14	25				
	38	0	40	80				
	39	0	20	60				
	42	0	20	100				
2423	29	37	14	25				
2424	14	37	14	25				
2437	17	37	14	57				
2501	1	29	29	71				

*All values are percentage of total samples that exceed criteria; data taken from Armstrong and Eskew, 1977.

TABLE IV-2

TRANSPORT OF TOXIC MATERIALS IN TRINITY RIVER DURING 1972*

(Source: Armstrong, et al, 1977)

USGS Station or Other	Miles Upstream (mi)	Arsenic (10^4 gms/yr)	Cadmium (10^4 gms/yr)	Chromium (10^4 gms/yr)	Copper (10^4 gms/yr)	Lead (10^4 gms/yr)	Mercury (10^4 gms/yr)	Nickel (10^4 gms/yr)	Zinc (10^4 gms/yr)
Ft. Worth	550								
Dallas	500								
547.1	491.8	825	124	578	2,516	206	87	1,897	14,850
625	451.4	1,942	65	0	1,942	129	252	3,560	18,770
653.5	265.2	3,704	0	1,235	3,087	0	99	5,309	17,286
L. Living-ston	125								
665	94.3	1,204	120	0	14,448	0	4,214	0	46,956
Comparison To Natural Concs.		Equal	?	Greater	Equal to L. Livgstn; Greater Below	Lower	Greater To Much Greater	Equal	Greater To Much Greater

* From Armstrong and Eskew, 1977

Blue-green algal bioassays conducted by Van Baalen (1973) and Brogden (1973), while investigating the possible presence of growth supressing substances in the Trinity River discharge, demonstrated the presence of an unknown growth suppressor that was adsorbed onto particles, since it could be removed from the water by filtration. The supressor was also rendered non-toxic by autoclaving and it could be removed in an ion exchange column.

The present studies to determine the presence and concentrations of toxic materials in Trinity River water discharged into Trinity Bay were conducted by the Department of Environmental Health Engineering, The University of Texas at Austin, Dr. Neal E. Armstrong, Chief Investigator. Effort was focused on two major activities. The first involved a review of the literature and records collected by various governmental agencies and individuals. This study focused on the Trinity River below Lake Livingston so that point and non-point source contributions could be more accurately identified and evaluated. The sources utilized were: industrial and municipal discharges; oil field discharges; agricultural runoff containing herbicides, pesticides, and crop seed preservation toxins; vector control and forest spraying; and air pollution washout.

The second activity involved the use of a hydroponic growth suppressor bioassay study using delta macrophytes common on the Texas coast. This activity was modeled after the studies of Lee, Sturgis, and Landen (1976) for heavy metal uptake. Experiments were designed to detect decreases in growth rate and yield caused by the presence of toxic materials. Water sources for the study were Trinity River water obtained in March 1977 at the point where Interstate Highway 10 passes over the river. Ground water available at The University of Texas, Center for Research in Water Resources at Austin, Texas served as a control. Both water sources were spiked with nutrients so that nutrient concentrations of each matched those of the solution used by Lee, Sturgis, and Landen (1976). Such a solution provided enough nutrients for maximum growth rate. Wet weights and stem length were measured for each plant at the start and finish of the experimental period. Dry weight and ash weight were also measured at the end.

BASIN DESCRIPTION

Only the lower portion of the Trinity River Basin was considered during this toxicity analysis. This portion is shown in Figure IV-1 and extends from the Lake Livingston Dam to Trinity Bay. The drainage area in this portion of the river basin is very narrow, includes three cities, Livingston, Liberty, and

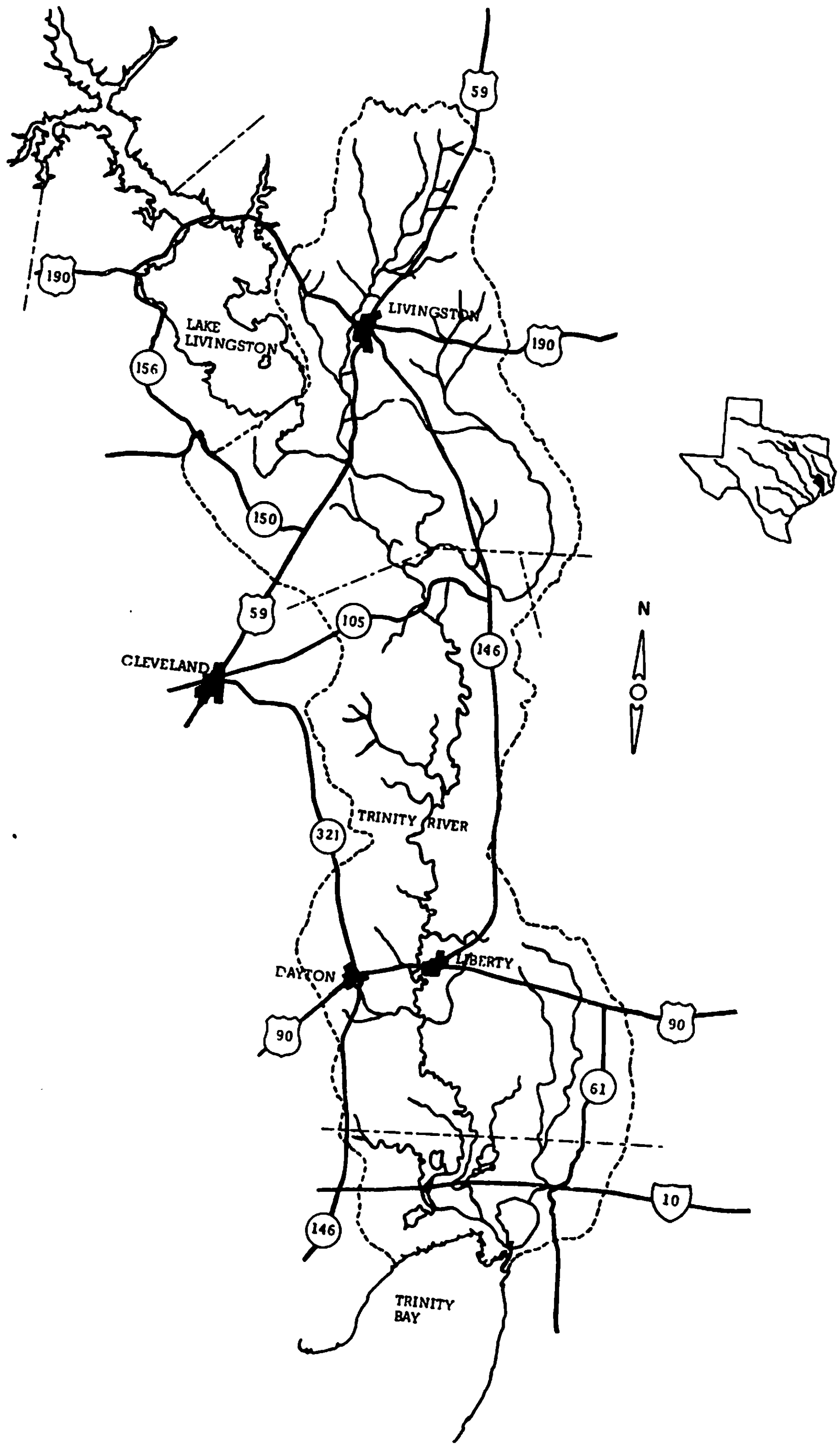

Figure IV-1. POLITICAL AND GEOGRAPHICAL ORIENTATION, LOWER TRINITY RIVER BASIN (Source: Armstrong, et al, 1977)

Dayton, and a few small towns. The major activities in the basin are farming with some industrial development in the lower portion of the basin.

SOURCES

Point Sources

At the present there are 27 National Pollution Discharge Elimination System (NPDES) permits issued in the Lower Trinity Basin below Lake Livingston (see Table IV-3). Five of these 27 permits are issued to two cities which discharge at only one location each. Of the actual 24 point sources, four do not discharge into any surface water, and one domestic sewage treatment plant is not yet in operation. Fifteen of the remaining nineteen point sources are from public or private domestic sewage treatment plants. The total maximum discharge permitted from these plants is 4.55 million gallons per day (MGD). These PRDES permits do not allow any toxicants to be discharged into any surface waters. Self reporting data from each of these sites and return flow data as monitored by the Texas Water Quality Board for ten of the sites state that no toxicants are entering the surface waters of the basin.

The remining four NPDES permits are for discharges from these industrial plants: Texas Gulf, Inc., a sulfur mining plant, holds two discharge permits: WCO #00952-2 is for 4.5 MGD which contains Cl^-, sulfur and thiosulfates and WCO #00952-1 is for 0.44 MGD and contains Fe, Al, Si, Mg, Na, NCO_3, and Cl^{--}. Records available show no permit violations from this plant. National Pipe and Tube Co. (WCO # 0217-01) is an electric seam welding plant. This permit allows a maximum discharge of 1.73 MGD and 32.0 mg/1 concentration of oil and grease or 160 pounds per day of oil and grease. Self reporting and state monitored return flow data show this plant to be well within its permit limitations with an oil and grease concentration of 6.6 mg/1. The thir industrial permit holder is Arjay, Inc. (WCO #01969-01). This permit allows a maximum discharge of 0.01 MGD and a maximum concentration of 1.0 mg/1 phenols or 0.04 lbs/day and 15 mg/1 oil and grease or 0.73 lbs/day with no free or floating oil or solids permitted in the effluent. There will normally be no discharge from this plant since the effluent is used to irrigate a 62-acre plot of alfalfa. However, return flow data gathered by the TWQB showed an effluent containing 202.0 mg/1 oil and grease and 0.439 mg/1 of phenols. The effluent also contains surface active agents, amines, fatty acids, glycols, ethylene, propylene oxides and alkyls. These chemicals are all toxic at certain concentrations. Rough calculations using 6416 ft^3/sec, which is the average flow rate of the Trinity

TABLE IV-3

PERMITTED DISCHARGES IN THE LOWER TRINITY RIVER BASIN
(Source: Armstrong, et al, 1977)

Waste Control Order Number	Discharger	Maximum Flow (MGD)	Potential Toxicants In Effluent Identified in WCO Permit
INDUSTRIAL			
00952-01	Texas Gulf, Inc.	0.004	Fe, Al
-02	"	4.5	Thiosulfate
-03	"	N.D.	
01638-01	F. L. Lee Washateria	N.D.	
01969-01	Arjay, Inc.	0.01	Phenols, Oil & Grease
02017-01	National Pipe & Tube Co.	1.73	Oil & Grease
39016	Liberty Waste Disposal Co.	N.D.	
DOMESTIC SEWAGE			
10108-01	Liberty STP	2.00	
-03	"	0.66	
-04	'	0.04	
10208-01	Livingston STP	0.75	
10495	City of Houston	0.002	
10564-01	Dayton STP	0.2	
-02	"	0.353	
11030-01	Mont Belview	0.0075	
11109-01	R. R. Harrington MHP	0.006	
11139-01	Moscow Water Supply Corp.	0.04	
11223-01	Southland Park STP	0.003	
11277-01	Hardin STP	0.15	
11288-01	Manpower Ed. & Trng. Inc.	0.023	
11377-01	Tarkington Inc. Sch. Dist.	0.03	
11380-01	Shepherd STP	0.20	
11449-01	Dutton & Gray MHP	0.006	
11520-01	MGL, Inc. STP	0.07	
11643-01	Texas Highway Comfort Sta.	N.D.	
11697-01	Lakeside Village Water Corp.	0.045	(Not presently on line)
11720-01	Eddie V. Gray STP	0.01	

River would have been inconsequential, as would the oil and grease concentration.

An additional possible point source of pollution for the Lower Trinity River Basin are the areas of concentrated septic tank usage. As can be seen from Figure IV-2, there are 42 sites spread through the basin. Since septic tanks are used for domestic sewage only, it is felt that these sites would likely not contribute to any toxicity found in the lower basin.

The remaining possible point sources of pollution that can be identified in the Lower Trinity River Basin are oil fields. Figure IV-3 shows the approximate location of the fields within the basin. The sizes of these fields are probably much smaller than the figure indicates. Permits for oil field discharges are regulated by the Texas Railroad Commission in Texas, and their records show that there is no discharge of oil field wastes to the surface waters in the Lower Trinity River Basin. This is true of gas wells also. All wastes are required to be re-injected into oil wells in the area. In the event that these wastes did reach the surface water, various toxicants would be present.

Non-Point Sources

Non-point sources of toxic materials in this area would arise primarily from the use of pesticides and herbicides in agricultural areas and pesticides for vector control. The magnitude of these sources would be dependent on land uses within the lower basin area and soil types as an indication of potentially erodable areas, and this information is given below.

A summary of land use in the Lower Trinity River is given in Table IV-4. The land area within the Lower Trinity River Basin is 819.8 thousand acres or 36.4 percent of the total land area in the four counties represented. Of this area within the lower basin, 13.9 percent is used for irrigated and non-irrigated cropland, 15.7 percent for grassland, 63.4 percent as forest, 4.0 percent as other uses such as farmsteads, 2.9 percent in urban areas and 0.1 percent in small water bodies. This distribution of land use in the lower basin is shown in Figure IV-4. In many areas, the land use patterns follow closely the soil types present in the Lower Trinity River Basin. The distribution of soil types and their descriptions are shown in Figure IV-5 and Table IV-5, respectively.

The crops raised in the basin are sorghum, soybeans, rice hay (other than sorghum), rye and pasture. The use of herbicides or pesticides to protect crops is highly individualized from farm to farm and varies from year to year. Further,

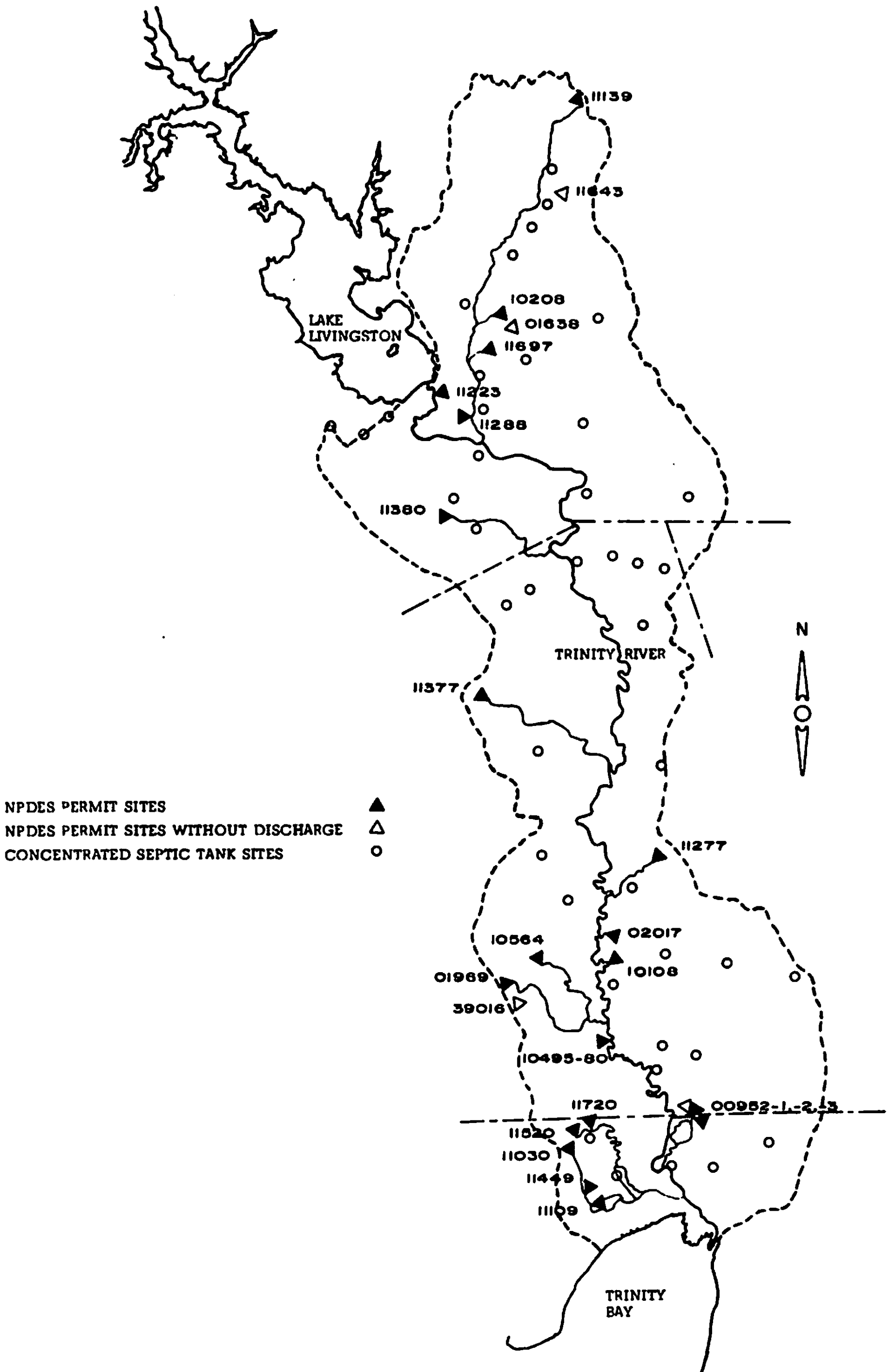

Figure IV-2. POINT DISCHARGE LOCATIONS, LOWER TRINITY RIVER BASIN (Source: Armstrong, et al, 1977)

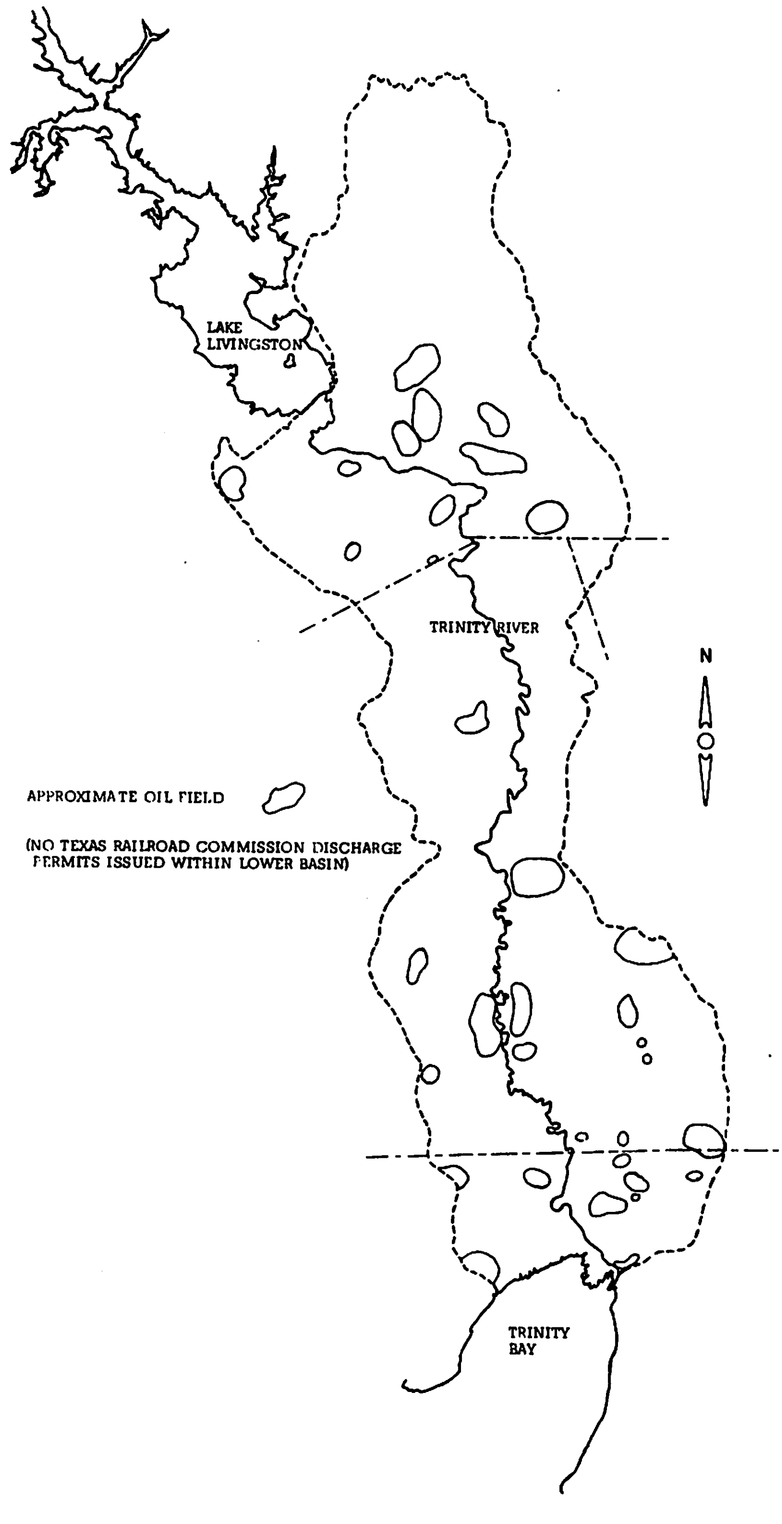

Figure IV-3. OIL FIELD LOCATIONS, LOWER TRINITY RIVER BASIN (Source: Armstrong, et al, 1977)

TABLE IV-4

LAND USE INVENTORY IN THE
LOWER TRINITY RIVER BASIN (ACRES)
(Source: Armstrong, et al, 1977)

AREA/USE	CHAMBERS	LIBERTY	POLK	SAN JACINTO	TOTAL
Total County	394,304	756,480	703,744	399,360	2,253,888
Within Lower Basin					
Acres	53,671	425,350	256,444	84,371	819,836
Percent of Total Co.	13.6	56.2	36.4	21.1	(36.4%)
Inventoried Land Uses					
Crop Land: Total	16,102	92,548	2,000	3,000	113,650
Irrigated	15,744	82,047	--	--	(13.9%)
Non-Irrigated	358	10,501	2,000	3,000	
Grass Land: Total	21,144	55,299	40,000	12,000	128,443
Pasture	1,966	55,299	40,000	12,000	(15.7%)
River Bottom	19,178	--	--	--	
Forest: Total	13,696	232,551	208,000	65,940	520,187 (63,4%)
Other Land: Total	1,529	28,687	800	1,371	32,387
Farms	874	2,125	400	800	(4.0%)
Not in Farm	655	26,562	400	571	
Non-Inventoried Land Use					
Urban	1,200	16,166	5,000	1,600	23,966 (2.9%)
Water Bodies 40 Acres	--	99	644	460	1,203 (0.1%)

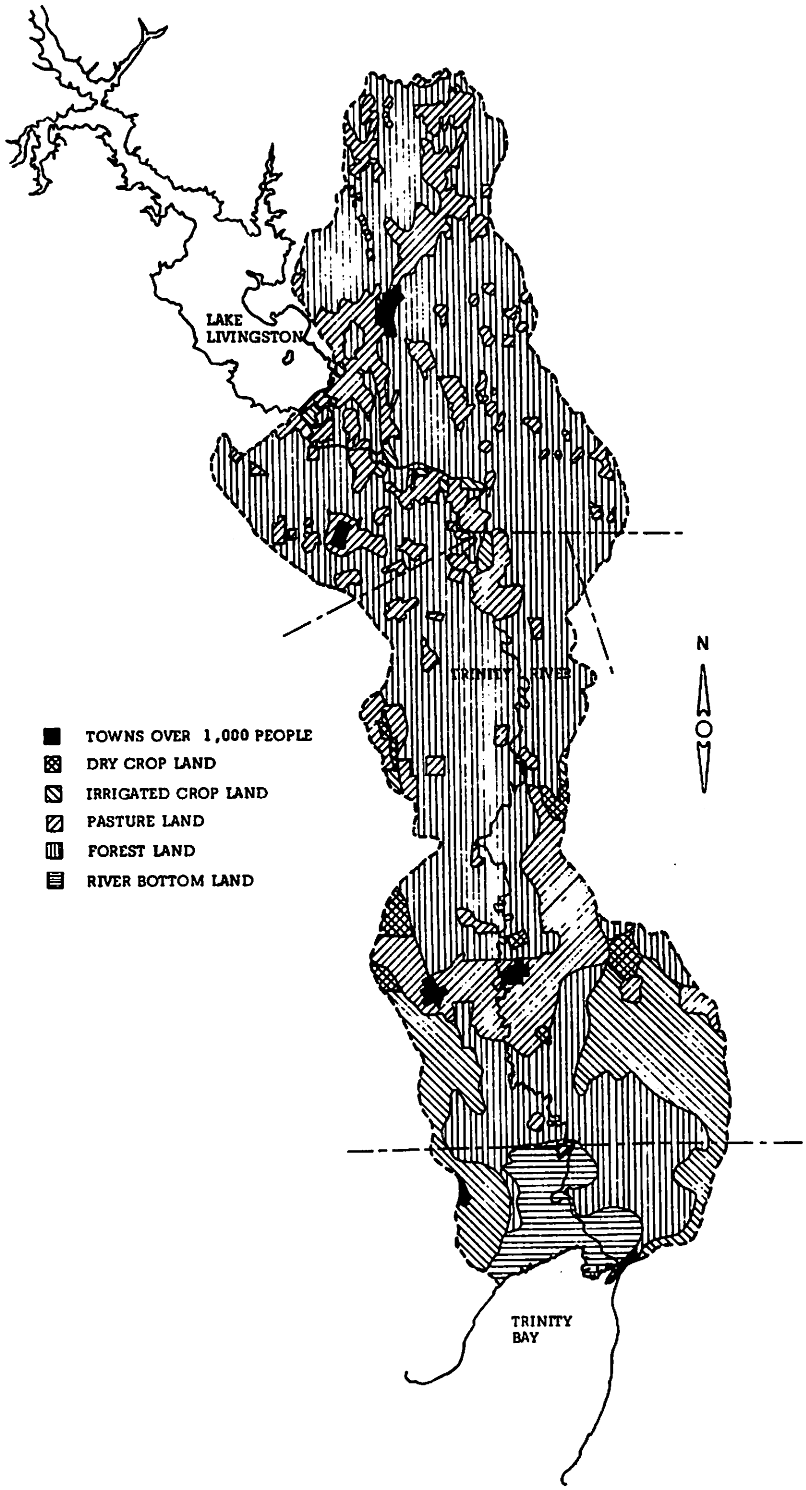

Figure IV-4. LAND USE,
LOWER TRINITY RIVER BASIN
(Source: Armstrong, et al, 1977)

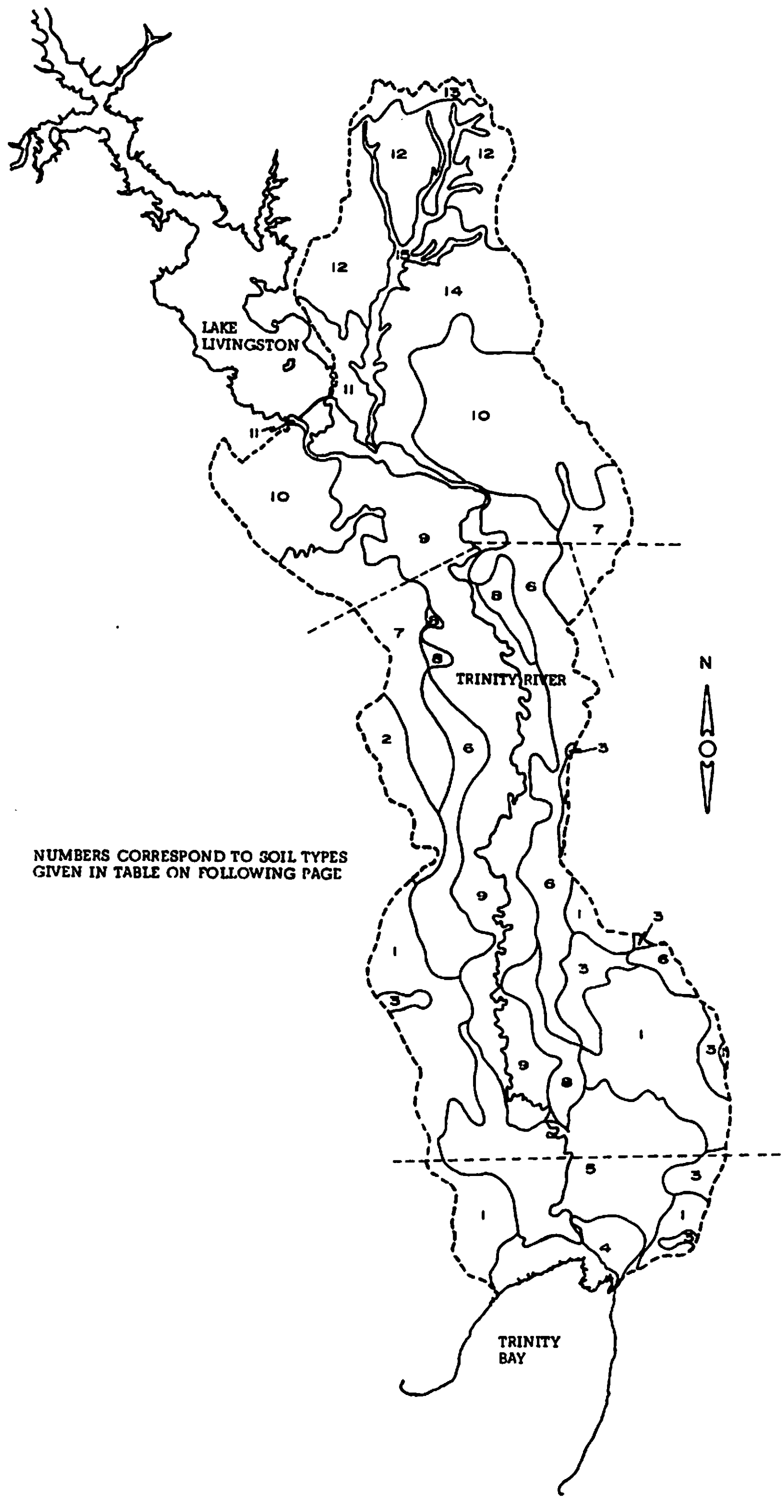

Figure IV-5. SOIL TYPES,
LOWER TRINITY RIVER BASIN
(Source: Armstrong, et al, 1977)

TABLE IV-5

SOIL TYPES IN THE LOWER TRINITY RIVER BASIN
(Source: Armstrong, et al, 1977)

1. Beaumont - Morey - Lake Charles Association: acid and neutral, clayey and loamy soils.

2. Hockley - Segno Association: acid, moderately well to well drained, loamy soils.

3. Ananuac-Morey - Frost Association: acid, poorly and somewhat poorly drained, loamy soil.

4. Harris - Kaufman Association: neutral and alkaline, saline and non-saline and frequently flooded clayey soils.

5. Vaiden - Acadia - Calhoun Association: acid, poorly and somewhat poorly drained, clayey and loamy soils.

6. Vaiden - Crowley - Acadia Association: acid, somewhat poorly drained, clayey and loamy soils.

7. Segno - Splendora - Waller Association: acid, moderately well, somewhat poorly and poorly drained, loamy soils.

8. Kenney - McKamie - Acadia Association: acid, sandy and loamy soils.

9. Kaufman Association: acid, frequently flooded, clayey, poorly drained, level to gently sloping soils.

10. Segno Association: deep, loamy, moderately well drained, nearly level to sloping soils of uplands.

11. Garner-Susquehanna Association: deep, clayey, and loamy, somewhat poorly drained, nearly level to gently sloping soils of terraces and uplands.

12. Susquehanna - Segno Association: deep, loamy, somewhat poorly drained and moderately well drained, nearly level to sloping soils.

13. Corrigan - Rayburn Association: deep and moderately deep, loamy, moderately well drained, nearly level to sloping soils.

TABLE IV-5 SOIL TYPES IN THE LOWER TRINITY RIVER BASIN (Continued)

14. Fuquay - Troup - Sacul Association: deep, sandy and loamy, well drained to poorly drained, gently sloping to level or depressional soils.

15. Urbo - Mantacie Association: deep, loamy, somewhat poorly drained, nearly level soils.

it is almost impossible to determine the amounts of pesticides used in any locale, and thus it would be extremely difficult to estimate the pesticide load originating from cropland or grassland. Herbicides used for soybeans are commonly Laso and Lorox. On feedgrass, 2, 4-D is used for weed control while "7" insecticide is used. Other herbicides used are 2, 4, 5-T and MCP (for rice) according to Bowmer (1977).

Some spraying is done by the U.S. Forest Service for insect and hardwood control. Benzine tetrachloride is used for insects, while 2, 4, 5-T and 2, 4-D for hardwoods. The amount sprayed is kept to a minimum (Kec, 1977). No spraying is done by the Texas Forest Service.

Some spraying for vector control is done in Chambers County by the county (Yates, 1977). Dibrome is sprayed from airplanes at the rate of 0.5 ounces per acre. The only marsh spraying is adjacent to and west of Anahuac. Some spraying is also done in rice field areas. In addition to spraying by plane, ground trucks are used in counties to spray roadside ponds and drainage ditches to kill mosquito larvae. Vector spraying is heaviest in the months of March through November.

RIVER CONCENTRATIONS

Sampling Stations

The U.S. Geological Survey (USGS), Texas Department of Water Resources, and Texas Department of Health (TDH) all have sampling stations in the Lower Trinity River area. These stations are shown in Figure IV-6 and described in Table IV-6. The USGS sampling stations are gaging stations for surface water quantity and quality measurements. The TDWR stations are for periodic water quality monitoring, and the TDH stations are primarily for bacteriological analyses. Samples collected by these agencies, however, are analyzed for toxic materials, primarily heavy metals and pesticides, and their results constitute substantially all the data found to date.

Sample Handling and Analysis

To interpret data for heavy metals and pesticides in the Trinity River or any water body, it is imperative that information on sample collection, preservation, transport from field to lab, storage in the lab, and analysis be known. A summary of the procedures used by each of these agencies follows.

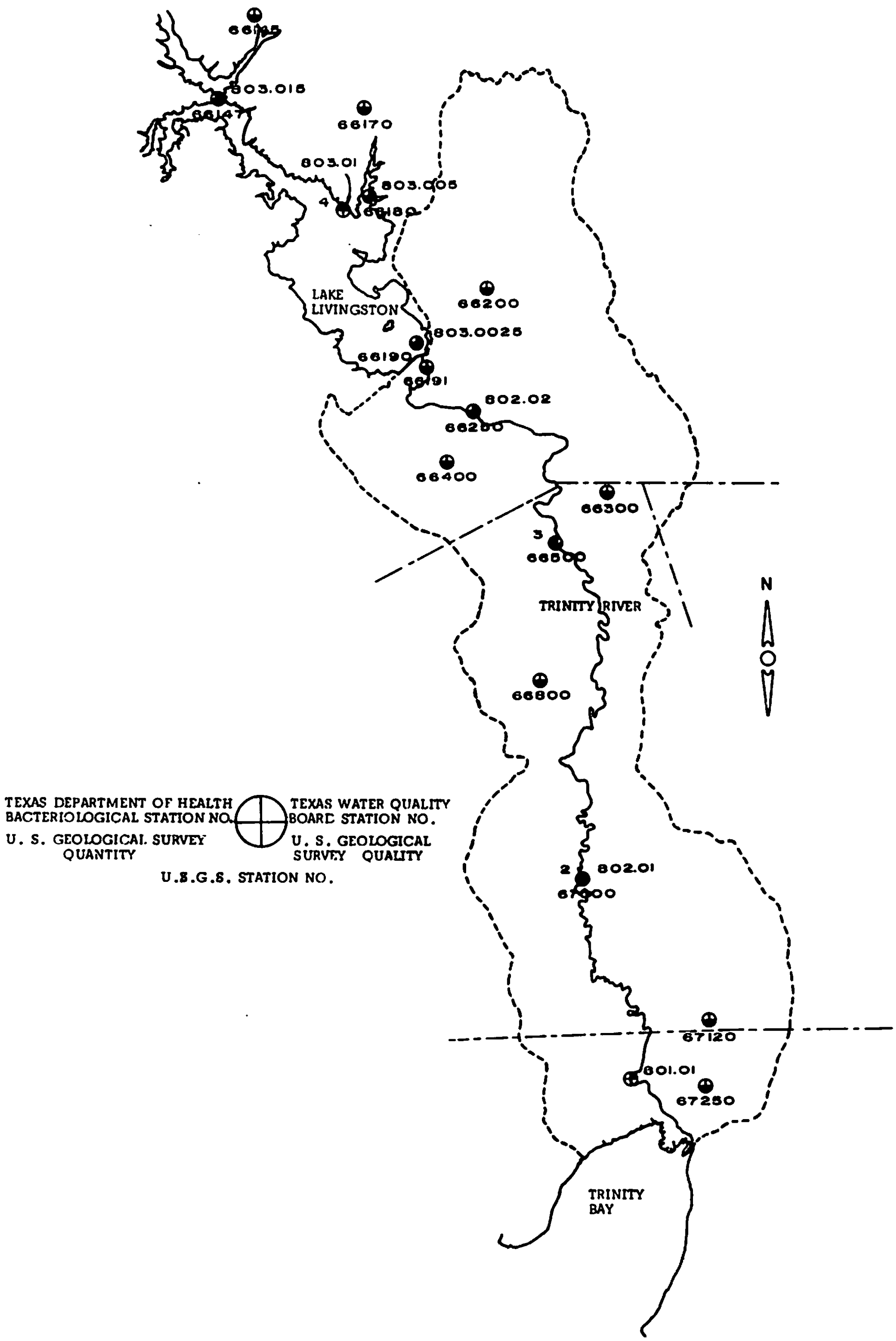

Figure IV-6. GAUGING AND SAMPLING STATIONS, LOWER TRINITY RIVER BASIN (Source: Armstrong, et al, 1977)

TABLE IV-6

SAMPLING STATIONS FOR WATER QUALITY IN THE LOWER TRINITY RIVER
(Source: Armstrong, et al, 1977)

River Mile	Location	U.S. Geological Survey Sta #	Texas Water Quality Board Sta #	Texas State Dept. Health Sta #
0.0	Anahuac Canal Mouth			
3.7	Wellisville Dam Site			
4.1	Hog Bayou (Lake Anahuac)			
7.7	IH 10 Bridge		0801.01	
21.3	Devers Canal Pump			
27.2	CIWA Canal Pump			
27.3	Dayton Canal Pump			
40.4	US 90 Bridge	08067000	0802.01	2
69.4	FM 162 Bridge			
88.3	SH 105 Bridge	08066500		3
92.0	Big Creek Mouth			
95.4	Menard Creek Mouth			
109.7	US 59 Bridge	08066250	0802.02	
110.0	Long King Creek Mouth	08066191		
120.7	Livingston Dam			

The USGS sampling and analysis is always performed in-house. Formerly, all samples were analyzed at the USGS laboratory in Austin, Texas; however, now all samples are sent to their Colorado laboratory for analysis. Heavy metal water samples are taken in polyethylene, teflon, or other plastic containers or in a glass container which is thoroughly cleaned. Samples for pesticides and herbicides are taken in one-quart Boston round glass bottles which are sealed with a teflon-lined screwcap and washed in dilute hydrochloric acid followed by distilled water and then dried. Samples are taken in the river in such a way as to integrate the sample over the water depth. The heavy metal sample is filtered and acidified with nitric acid to a pH of 3.0 or less for all metals but barium, lithium, and selenium which are not acifified. The pesticide sample is not preserved or cooled but is transported as quickly as possible in a DUO-PAK container to the laboratory. The heavy metal sample is kept in a tighly capped bottle until analysis, and the analysis is done by a Perkin Elmer Model 303 atomic absorption spectrophotometer. Arsenic is extracted for analysis by use of silver diethyldithiocarbamate, boron dianthrimide or carmine for boron, selenium by diaminobenzinde, and mercury by the coal vapor method. All other metals are extracted using a direct or chelation extraction method. Insecticide samples are stored at room temperature and analyzed usually within eight to ten days for chlorinated compounds while herbicide samples are acidified to a pH of 2 or less with concentrated sulphuric acid and refrigerated at 4 degrees C. until analysis. The insecticides and pesticides are extracted using nanograde hexane and then concentrated through evaporation. The organochlorine insecticide analysis and herbicide analyses are performed using an electron capture gas chromatograph. Varian-Aerograph Model 200, Micro-Tek Model 160, and Varian-Aerograph Model 600-D with tritium and Nichel-63 detectors are used. Organophosphorus insecticides are analyzed using a flame photometric dector. No information on analytical error or recovery was available (Marigold and Schulze, 1969; Brown, Skougstad, and Fishman, 1970; Goerlity and Brown, 1972; Schulze, Marigold and Andrews, 1973; and USGS, 1976).

The TDWR sampling is done by the Department or by contract. Until 1975 the TDH laboratory in Austin did most of the analyses of these samples for heavy metals, herbicides, and pesticides. Since that time, these analyses have been performed by the Sabine River Authority (SRA) laboratory in Orange, Texas or the EPA's laboratory in Houston, Texas. Apparnetly the SRA analyzed most of the samples taken in the Lower Trinity River. Samples for heavy metal analysis are collected and transported in new one-quart plastic cubitainers. Pesticide and herbicide samples are collected in a glass jar with teflon liners which have been washed in chromic acid and pesticide solvent. Sampling is done by the TDWR to meet EPA standard methods procedures. The heavy metal samples are preserved with 5 ml of concentrated nitric acid. While no preservative is added to the herbicide and pesticide samples, the samples are kept on ice. Samples delivered to the SRA laboratory are usually analyzed within one week. Heavy metal samples are analyzed on an Instrumentation Laboratory Model 253-02 atomic absorption spectrophotometer. Direct and chelation-extraction methods are used for most metals analyzed, but the graphite furnace flameless method is used for arsenic and selenium and the coal-vapor method for mercury. Water samples for insecticide and herbicide analyses are extracted within one week, are frozen, and sediment samples are stored for about one month at 4 degrees C. The organochlorine insecticide analysis and herbicide analyses are done on a Hewlett-Packard Model 5830 flame photometric gas chromatograph. No statistical analyses on analytical error or pesticide recovery are performed by this laboratory (Pickard, 1977).

The TDH laboratory in Austin stores water samples for heavy metal analysis at room temperature and analyzes these samples within two days. Insecticide and herbicide samples are stored at 4 degrees C. and analyzed within one month. Heavy metals were analyzed on a Jarell Ash Model AC2-20 atomic absorption spectrophotometer before 1973 and since that time an Instrumentation Laboratory Model 353 has been used. Arsenic is extracted using silver diethyl dithiocarbonate, selenium using the 2, 3-diaminonapthaline fluorometric method, aluminum using 8-hydoxyquinoline extraction, and mercury by the coal-vapor method. Pesticides are extracted using nonograde hexane or ethylmethylene depending on the pesticide. Organochlorine insecticides are analyzed using one of the following electron capture gas chomatographs, FM Model 810, Micro-Tek Model MT-220, and Tracor Model 560 with Nichel-63 detectors. The organophosphorus insecticides are analyzed using a Micro-Tek Model MT-220 flame photometric gas chromatograph. Information on the precision and accuracy of these analyses, recovery for heavy metals and pesticides, are given in Table IV-7, IV-8, and IV-9 (Elbert, 1977; Duboise, 1977; and Boyer, 1977).

The EPA laboratory in Houston, Texas obtains their samples for heavy metals in new one-quart plastic cubitainers and their samples for pesticides and herbicides in one-quart glass jars with teflon-lined lids. Grab samples are tkaen for both heavy metals and pesticides and herbicides, and the heavy metal samples are preserved with 5 mls of concentrated nitric acid and placed on ice. The pesticide and herbicide samples are not preserved, but are kept on ice. The heavy metal sample metals are stored according to EPA procedures and analyzed on a Perkin-Elmer Model 403 atomic absorption spectrophotometer. The direct or chelation-extration methods are used for the appropriate metal

TABLE IV-7

SUMMARY OF RECOVERY DATA FOR METALS IN WATER SAMPLES, JANUARY 1975 - DECEMBER 1976, BY THE TEXAS STATE DEPARTMENT OF HEALTH LABORATORY
(Source: Armstrong, et al, 1977)

Metal	Spike Concentration (ug/l)	Mean Percent Recovery	Standard Deviation	Warning Limits (1 std. dev.)	Control Limits (2 std. dev.)
Arsenic	25	84.5	20.9	63.6-105.4	42.7-126.3
Barium	1000	97.5	9.2	88.3-106.7	79.1-115.9
Cadmium	100	100.4	3.8	96.6-104.2	92.8-108.0
Copper	100	99.0	6.7	92.3-105.7	85.6-112.4
Chromium	100	97.0	9.6	87.4-106.6	77.8-116.2
Iron	300	95.4	10.8	84.6-106.2	73.8-117.0
Lead	100	99.2	9.3	89.9-108.5	80.6-117.8
Manganese	100	93.2	14.0	79.2-107.2	65.2-121.2
Mercury	2	101.2	8.8	92.4-110.0	83.6-118.8
Nickel	100	100.4	6.1	94.3-106.5	88.2-112.6
Selenium	5;15	99.7	4.6	95.1-104.3	90.5-108.9
Silver	100	91.1	14.7	76.4-105.8	61.7-120.5
Zinc	100	102.8	9.3	93.5-112.1	84.2-121.4

TABLE IV-8

PRECISION AND ACCURACY DATA
FOR METALS IN WATER SAMPLES BY THE
TEXAS STATE DEPARTMENT OF HEALTH
(ug/1)
(Source: Armstrong, et al, 1977)

Metal	Low		Medium		High		Low Recovery		High Recovery	
	mean	s.d.	mean	s.d.	mean	s.d.	added	% rec.	added	% rec.
Cd	0.008	0.001	0.052	0.002	0.74	0.007	0.02	104	0.30	102
Cu	0.16	0.004	0.80	0.007	0.69	0.017	0.10	100	0.30	98
Cr	0.030	0.008	0.26	0.009	0.86	0.009	0.05	95	0.30	109
Fe	0.13	0.008	0.21	0.016	0.60	0.026	0.10	117	0.30	108
Pb	0.063	0.008	0.32	0.011	0.74	0.023	0.05	97	0.30	100
Mn	0.028	0.002	0.35	0.003	0.86	0.01	0.05	100	0.30	97
Hg	0.89	0.027	1.61	0.10	4.16	0.18	0.5	101	2.0	102
Ni	0.097	0.007	0.33	0.010	0.86	0.017	0.103	96	0.309	101
Se	0.0039	0.0004	0.0193	0.0012	0.039	0.0008	0.005	98	0.010	98
Zn	0.15	0.010	0.31	0.018	0.68	0.014	0.10	100	0.30	97

TABLE IV-9

QUALITY CONTROL FOR
PESTICIDES IN WATER SAMPLES
BY THE TEXAS STATE DEPARTMENT OF HEALTH
(Source: Armstrong, et al, 1977)

	Spiking Concentration (μg/ℓ)	% Recovered (Mean)	Standard Deviation (%)	Warning Limits = Mean ± 2 (%)
Insecticides				
Lindane	0.158	93.9	5.34	83.2-105
Aldrin	0.162	80.0	12.3	55.4-105
Hept. Epox.	0.194	91.1	5.56	80.0-102
DDE	0.202	95.4	8.14	79.1-112
DDD	0.404	88.0	5.02	78.0-98.0
DDT	0.420	111	12.4	86.2-136
Herbicides				
2,4D	10	80.9	7.8	65.3-96.5
Silvex	2.0	107	10.6	85.5-128
2,4,5T	2.0	89.5	10.4	68.7-110

analyses and the Coleman mercury analyzer using the coal vapor technique is used for mercury. Insecticide samples are stored at 4 degrees C., extracted with 15 percent hexanemethylene chloride three times, and then the extracts are concentrated to 5 mls and analyzed. Organochlorine insecticide analyses and herbicide analyses are done in a Micro-Tek MT-220 electron capture gas chromatograph with a Nichel-63 detector. Organophosphorus insecticide analyses are done on a Micro-Tek Model MT-220 flame photometric gas chromatograph. No statistical analysis of analytical procedures were readily available (Langley, 1977).

The limits of detection of the heavy metals and pesticides for these four laboratories are given in Table IV-10. It is apparent that substantial variation occurs among these laboratories, and that these variations must be taken into account when interpreting data analyzed by these laboratories.

Heavy Metal Concentrations

The results of monitoring by the USGS at Romayor, Texas are shown in Table IV-11. These results are for the dissolved forms of these heavy metals. The number of samples taken over the seven year monitoring period is rather small and does not provide the best data base for assessing the presence of toxic materials. Also listed in Table IV-11 are the recommended maximum conccentrations of heavy metals as proposed by the National Academy of Sciences and National Academy of Engineering in 1972 (NAS/NAE, 1972). It is apparent that the average concentration of copper, iron, mercury, and zinc equal or exceed the maximum recommended concentrations. The maximum measured concentrations usually exceed the maximum recommended concentrations. It should be noted, however, that some of the average and maximum concentrations measured are less than the limits of detection as presented in Table IV-10 and thus should be interpreted with caution.

The amounts of total (dissolved plus particulate) forms of these heavy metals are given in Table IV-12 and were compiled from USGS data at Romayor, Texas from October 1973 through November 1976. Comparing these figures to the dissolved concentration given in Table IV-11 shows that the particulate fraction of these heavy metals is substantially higher than the dissolved fraction as one would expect. Of particular interest are the very high concentrations of copper, iron, lead, mercury, and zinc. These concentrations are substantially higher than the NAS/NAE maximum recommended concentrations.

TABLE IV-10

LIMITS OF DETECTION FOR VARIOUS TOXICANTS
AS REPORTED BY LABORATORIES ANALYZING TRINITY RIVER WATER SAMPLES
(Source: Armstrong, et al, 1977)

Group	Toxicant	Units	Laboratory Performing Analysis			
			EPA	SRA	TDHR	USGS
Misc.	Oil & grease	mg/kg	< 10.0	< 30.0	< 10.0	-
	Phenols	µg/l				
	PCB	µg/l	< 1.0		< 2.0	< 1.0
	PCN					-
	MBAS	mg/l				< .01
Heavy Metals	Aluminum	µg/l	<100.0	<100	<100	< 10.0
	Arsenic	µg/l	< 1.0	< 20	< 10	< 1.0
	Barium	µg/l	<100.0	<500	<500	100
	Boron	µg/l			<100	< 10.0
	Cadmium	µg/l	< 10.0	< 20	< 10	10.0
	Chromium	µg/l	< 20.0	< 20	< 50	< 10.0
	Hexavalent Chrome	µg/l	< 2.0	< 50	< 20	1.0
	Cobalt	µg/l	< 30.0	< 20	-	1.0
	Copper	µg/l	< 10.0	< 20	50	1.0
	Iron	µg/l	< 20.0	< 20	<100.0	< 10.0
	Lead	µg/l	< 50.0	< 20	< 50.0	< 1.0
	Lithium	µg/l			< 10.0	< 10.0
	Manganese	µg/l	< 1.0	< 20	< 50.0	< 10.0
	Mercury	µg/l	< .2	< .3	< .2	< .10
	Nickel	µg/l	< 30.0	< 20	<100.0	< 1.0
	Selenium	µg/l	< 1.0	< 10.0	< 2.0	< 1.0
	Selenium				-	-
	Silver	µg/l	< 10.0	< 20.0	< 20.0	1.0
	Strontium	µg/l		< 5	<100	< 10.0
	Zinc	µg/l	< 10.0	< 10	<100	< 10.0
Chlorinated Hydrocarbon Pesticides	Aldrin	µg/l	< .02		< .04	< .01
	Chlordane	µg/l	< .2		-	< .10
	DDD	µg/l	< .02		< .30	< .01
	DDE	µg/l	< .02		< .09	< .01
	DDT	µg/l	< .02		< .24	< .01
	Dieldrin	µg/l	< .02		< .14	< .01
	Endrin	µg/l	< .02		< .20	< .01
	Heptachlor	µg/l	< .02		< .04	< .01
	Heptachlor Epoxide	µg/l	< .02		< .06	< .01
	Lindane	µg/l	< .02		< .03	< .01
	Methoxychlor	µg/l	< .2		< 1.1	< .01
	Toxaphene	µg/l	< .2		< 5.0	< 1.0
Organo-Phosphorous Pesticides	Diazanon	µg/l	< .02		0.4	< .01
	Ethion					< .10
	Malation	µg/l	< .1		< 1.4	< .01
	Methyl Parathion	µg/l			.5	< .01
	Methyl Tritnion					< .10
	Parathion	µg/l	.1		< .5	< .01
	Trithion					< .10
Hormonal Herbocides	2, 4 - D	µg/l			< 50.0	< .02
	Silvex	µg/l			< 10.0	< .01
	2, 4, 5 - T	µg/l			< 10.0	< .01

TABLE IV-11

DISSOLVED TOXICANT CONCENTRATIONS IN THE TRINITY RIVER AT ROMAYOR, TEXAS (U.S.G.S. DATA FROM STATION 08066400) FROM OCTOBER 1969 THROUGH NOVEMBER 1976

(Source: Armstrong, et al, 1977)

GROUP	TOXICANT	No. SAMPLES	UNITS	CONCENTRATIONS MIN	CONCENTRATIONS AVG	CONCENTRATIONS MAX	NAS/NAE CRITERIA Max. Recommended Conc. Fresh Water	NAS/NAE CRITERIA Max. Recommended Conc. Marine Water
MISC.	Oil & Grease	-	mg/kg	-	-	-	1,000.	
	Phenols	13	µ/l	.0	1.23	9.00	100.	530.
	PCB	15	µ/l	.0	.0	.0	.002	.0094
	PC Naphthalenes	3	µ/l	.00	.00	.00		
	MBAS (LAS)	15	mg/l	.00	.00	.06	200.	
HEAVY METALS	Aluminum	25	µ/l	0.	33.20	300.	100.	200.
	Arsenic	26	µ/l	0.	2.19	10.		10.
	Barium	1	µ/l	100.	100.	100.		500.
	Boron	12	µ/l	0.	75.83	360.		5000.
	Cadmium	26	µ/l	0.	0.08	1.	0.4	.2
	Chromium	26	µ/l	0.	0.58	10.	50.	50.
	Hexavalent Chromium	1	µ/l	0.	0.	0.		10. (oyster)
	Cobalt	26	µ/l	0.	.04	1.		
	Copper	26	µ/l	0.	6.92	100.	6.	10.
	Iron	26	µ/l	0.	74.50	490.		50.
	Lead	26	µ/l	0.	1.08	15.	30.	10.
	Lithium	25	µ/l	0.	4.20	20.		
	Manganese	26	µ/l	0.	15.69	120.		20
	Mercury	22	µ/l	.0	0.35	2.3	.2	< .10
	Nickel	25	µ/l	0.	1.36	8.	30.	2.
	Selenium	11	µ/l	0.	0.18	1.		5.
	Selfnium	1	µ/l	0.	0.	0.		
	Silver	1	µ/l	0.	0.	0.		
	Strontium	25	µ/l	110.	302.00	380.		
	Zinc	26	µ/l	0.	30.08	160.	30.	20.
CHLORINATED HYDROCARBON PESTICIDES	Aldrin	28	µ/l	.00	.00	.00	.01	.007
	Chlordane	26	µ/l	.0	.0	.0	.04	.18
	DDD	28	µ/l	.00	.00	.12		.025
	DDE	28	µ/l	.00	.00	.05	.002	-
	DDT	28	µ/l	.00	.00	.22		.001
	Dieldrin	28	µ/l	.00	.00	.01	.005	.009
	Endrin	28	µ/l	.00	.00	.00	.002	.003 .0005
	Heptachlor	28	µ/l	.00	.00	.00	.01	.008
	Heptachlor Epoxide	28	µ/l	.00	.00	.00		
	Lindane	28	µ/l	.00	.00	.01	.02	.05
	Methylchlor	-	µ/l	-	-	-	.005	.0044
	Toxaphene	8	µ/l	.0	.0	.0	.01	.078
ORGANO-PHOSPHOROUS PESTICIDES	Diazanon	24	µ/l	.00	.01	.02	.009	-
	Ethion	4	µ/l	.00	.00	.00	.02	
	Malathion	24	µ/l	.00	.00	.00	.008	.27
	Methyl Parathion	24	µ/l	.00	.00	.00	-	.02
	Methyl Trithion	4	µ/l	.00	.00	.00		
	Parathion	24	µ/l	.00	.00	.00	.0004	-
	Trithion	4	µ/l	.00	.00	.00		
HORMONAL HERBICIDES	2,4 - D (BEE)	27	µ/l	.00	.03	.09	4.0	7.4
	Silvex (PGBE)	27	µ/l	.00	.00	.01	2.0	7.1
	2,4,5 - T	27	µ/l	.00	.01	<.06		6.0

TABLE IV-12

TOTAL HEAVY METAL CONCENTRATIONS
IN THE TRINITY RIVER AT ROMAYOR, TEXAS
(U.S.G.S. DATA FROM STATION 08066500)
FROM OCTOBER 1973 THROUGH NOVEMBER 1976
(Source: Armstrong, et al, 1977)

Heavy Metal	No. Samples	Units	Concentrations			σ
			Min.	Average	Max.	
Aluminum	1	μg/l	380	380	380	0
Arsenic	13	μg/l	0	4.15	9	2.73
Barium	-	μg/l	-	-	-	-
Boron	-	μg/l	-	-	-	-
Cadmium	13	μg/l	0	< 5.38	10	5.19
Chromium	13	μg/l	0	< 8.38	24	8.10
Hexavalent Chrome	-	μg/l	-	-	-	-
Cobalt	13	μg/l	0	< 26.92	50	25.94
Copper	13	μg/l	1	< 29.23	280	75.73
Iron	13	μg/l	410	1070	2300	710.73
Lead	13	μg/l	0	< 56.69	< 100	49.05
Lithium	1	μg/l	10	10	10	0
Manganese	13	μg/l	60	90	170	34.64
Mercury	12	μg/l	0	< 0.17	.5	0.16
Nickel	1	μg/l	0	0	0	0
Selenium	11	μg/l	0	0.36	1	0.50
Selenium	-	μg/l	-	-	-	-
Silver	-	μg/l	-	-	-	-
Strontium	1	μg/l	200	200	200	0
Zinc	13	μg/l	0	127.69	470	140.78

The results of sampling by the former Texas Water Quality Board are given in Table IV-13 for the period from March 1969 through March 1977. On the whole, the concentrations measured are within an order of magnitude of the USGS Survey data given in Table IV-11, but it should be pointed out that the TWQB data are based on one sample only.

Pesticide Concentrations

The concentrations of chlorinated hydrocarbon and organophosphorus pesticides are given in Tables IV-11 and IV-13 for USGS and TWQB results, respectively. The USGS results show very small concentrations of pesticides as would be expected in filtered samples; however, some of the maximum concentrations measured for DDT and its derivatives do exceed the NAS/NAE maximum recommended concentrations. The TWQB results are from unfiltered samples and show higher average concentrations than the USGS data. Concentrations of dieldrin, endrin, and methoxchlor of the chlorinated hydrocarbons are much higher than the maximum recommended concentrations, and malathyon and parathyon of the organophosphorus pesticides are all higher than the maximum recommended concentrations. This is also the case of the hormonal pesticides 2, 4-D Silvex, and 2, 4, 5-T.

A 23 month study was undertaken in July 1970 by the Texas Department of Agriculture to evaluate the extent of pesticide pollution in Texas streams (Tidswell and McCasland, 1972). Eight major Texas river systems and three smaller streams were monitored every other month for chlorinated hydrocarbon compounds found in bottom silt deposits. It was felt that pesticide pollution problems for the state could best be defined by silt collection and subsequent pesticide analysis because of the ease of sample collection. This in turn would be useful in defining the qualitative pesticide problems that might exist within the water column and the food chain. Chlorinated hydrocarbon compounds were chosen for analysis because of their persistence in nature.

The study found that 54 percent of the 433 total samples taken contained measurable quantities of one or more chlorinated hydrocarbon compounds. DDT, or one of its metabolities DDD or DDE, was found in almost 50 percent of the samples taken with heaviest concentrations occurring in the agricultural drainage areas and below urban areas.

As part of this study, a special investigation was conducted in the Dallas-Ft. Worth metropolitan area to evaluate the urban pesticide impact. The study demonstrated that point source discharges from urban areas can be major contributors of pesticide contamination to the nearby rivers. It was also

TABLE IV-13

DISSOLVED TOXICANT CONCENTRATIONS IN THE TRINITY RIVER AT ROMAYOR, TEXAS (U.S.G.S. DATA FROM STATION 08066500) FROM OCTOBER 1969 THROUGH NOVEMBER 1976
(Source: Armstrong, et al, 1977)

GROUP	TOXICANT	NO. SAMPLES	UNITS	CONCENTRATIONS MIN.	AUG.	MAX.	NAS/NAE MAXIMUM RECOMMENDED CONC. FRESH WATER	CRITERIA MAXIMUM RECOMMENDED CONC. MARINE WATER
MISC.	Oil & Grease	4	μg/kg	0.001	0.209	0.364	1.0	
	Phenols	-	μg/l	-	-	-	100	530
	PCB	3	μg/l	0.000	0.7	2.0	0.002	0.0094
	PCN	-	μg/l	-	-	-	-	-
	MBAS	-	μg/l	-	-	-	200	-
HEAVY METALS	ALUMINUM	1 unfilt.	μg/l	4.28	4.28	4.28	0.1	0.2
	ARSENIC	1	μg/kg	0.00	0.00	0.00		10
	BARIUM	1 unfilt.	μg/l	100	100	100		500
	BORON	-	μg/l	-	-	-		5000
	CADMIUM	1 unfilt.	μg/l	10.0	10.0	10.0	0.4	0.2
	CHROMIUM	1 unfilt.	μg/l	20.0	20.0	20.0	50	50
	HEXAVALENT Cr	-	μg/l	-	-	-	50	10(oyster)
	COBALT	-	μg/l	-	-	-		
	COPPER	1 unfilt.	μg/l	10.0	10.0	10.0	6	10
	IRON	-	μg/l	-	-	-		50
	LEAD	1 unfilt.	μg/l	50.0	50.0	50.0	30	10
	LITHIUM	-	μg/l	-	-	-		
	MANGANESE	1 unfilt.	μg/l	60.0	60.0	60.0		20
	MERCURY	1 unfilt.	μg/l	0.2	0.2	0.2	0.2	0.10
	NICKEL	1 unfilt.	μg/l	20.0	20.0	20.0	30	2
	SELENIUM	-	μg/l	-	-	-		5
	SILVER	1 unfilt.	μg/l	10.0	10.0	10.0		1
	STRONTIUM	-	μg/l	-	-	-		
	ZINC	1 unfilt.	μg/l	10.0	10.0	10.0	30	20
CHLORINATED HYDROCARBON PESTICIDES	ALDRIN	2	μg/l	0.00	0.00	0.00	0.01	0.007
	CHLORDANE	-	μg/l	-	-	-	0.04	0.18
	DDD	2	μg/l	0.00	0.00	0.00	0.002	0.025
	DDE	2	μg/l	0.00	0.00	0.00	0.002	-
	DDT	-	μg/l	-	-	-	0.002	0.001
	DIELDRIN	3	μg/l	0.00	0.33	1.00	0.005	0.009
	ENDRIN	3	μg/l	0.00	0.33	1.00	0.002	0.0005
	HEPTACHLOR	3	μg/l	0.00	0.01	0.40	0.01	0.008
	HEPT EPOXIDE	3	μg/l	0.00	0.02	0.06		0.008
	LINDANE	3	μg/l	0.00	0.01	0.03	0.02	0.05
	METHOXYCHLOR	3	μg/l	0.00	0.37	1.10	0.005	0.0044
	TOXAPHENE	2	μg/l	0.00	0.00	0.00	0.01	0.078
ORGANO-PHOSPHOROUS PESTICIDES	DIAZANON	-	μg/l	-	-	-	0.009	-
	ETHION	-	μg/l	-	-	-	0.02	
	MALATHION	1	μg/l	1.40	1.40	1.40	0.008	0.27
	METHYL PARATHION	-	μg/l	-	-	-	-	0.02
	METHYL TRITHION	-	μg/l	-	-	-		
	PARATION	1	μg/l	0.50	0.50	0.50	0.0004	-
	TRITHION	-	μg/l	-	-	-		
HORMONAL	2,4-D	1	μg/l	50.00	50.00	50.00	4.0	7.4
	SILVEX	1	μg/l	10.0	10.0	10.0	2.0	7.1
	2,4,5-T	1	μg/l	10.0	10.0	10.0		6.0

shown that concentrations of chlordane, toxaphene and PCB residues were considerably greater in the Trinity River below Dallas-Ft. Worth than any other river system in the state. Chemical concentrations in silt deposits did diminish downstream downstream from this urban area. Samples taken at Crockett, Texas (above Lake Livingston) showed slight contamination while those at Liberty, Texas (below Lake Livinston) were void of the toxicants. Since most silt would settle within the quiescent lake, it might be concluded that there is no problem source for chlordane, toxaphene or PCB's in the Lower Trinity River Basin. The water column could continue to register small concentrations since a chemical equilibrium does exist between the pesticide-laden silt and water above it. The study concluded that each river basin was unique and that the pesticide load carried by the silt was a function of land use, soil erodibility and the ability of rainfall runoff to carry the silts to the stream. The metropolitan areas contribute significant quantities of pesticide contamination to streams which likely comes from point source discharges. Conversely, agricultural lands account for a relatively constant pesticide burden on the streams which is a function of the factors noted above.

In January 1972 the Trinity River Authority (TRA) began a comprehesive water quality management plan for the Trinity River Basin in order to fulfill the requirements of Section 3, PL 84-660 then in effect. The Federal Water Pollution Control Act Amendments of 1974 (PL 92-500) stipulated slightly different requirements for basin planning in Section 303 (e) and so the TRA shifted its efforts to satisfy the requirements of both acts. The resulting report (TRA, 1974) is a multi-volume work which falls into two major categories: (1) Basin Plan Reports which include Basic Information, Trinity River Basin, Texas; Water Diversions and Wastewater Treatment Facilities; Water Quality Management Plan for the Trinity River Basin (CFR 171 Basin Plan) and the Management Plan; and (2) Technical Reports which include Biological Aspects of Water Quality Management Planning in the Trinity River Basin, Texas; A Network for Continuous Monitoring of Water Quality in the Trinity River Basin, Texas; Automated Data Storage and Retrieval Management Systems; Evaluation of Supplemental Aeration for the Trinity River System; Degradation Rates of Advanced Treated Effluents Anticipated in tbe Trinity River Basin, Texas; Oxygen Uptake or Organic Bottom Sludges from the Trinity River, Texas - Methods and Preliminary Results; Lake Livinstone Area-Wide Wastewater Treatment Plan; Synthesis of Future Flow Conditions for Selected Streams in the Trinity River Basin, Texas; Water Quality Modeling and Other Analyses in the Trinity River, Texas; and Hydrodynamics of the Lake Livingston, Texas Headwater. The report was used extensively as a starting point in evaluating possible toxic substance sources in the basin below Lake Livingston. Unfortunately, no quantitative or even qualitative water quality data dealing with toxic substances were contained in the report. The report's main emphasis centered on the metropolitan Dallas-Ft. Worth area rather than the lower basin area. The lower area is directly involved with marsh productivity since the quality of Trinity River water as it flows into Trinity Bay is function of the water quality from Lake Livingston and the Lower Trinity River Basin. Because of this fact, the TRA report could only be used to catalogue possible sources of pollution.

HYDROPONIC STUDIES

The results of the hydroponic studies are given in Table IV-14 in terms of yield per stem. The nature of this bioassay is such that a decrease in growth rate and/or yield would be expected if the growth of the plants is suppressed by the presence of taxic materials. The yield per stem of *Distichlis* grown in spiked groundwater averaged 0.66 grams while those grown in spiked Trinity River averaged 0.58 grams for a difference of 0.08 grams or 12 percent of the former stems. This difference, however, is not statistically significant. Such is the case for *Spartina* also for which a decrease of 22 percent in yield per stem is noted comparing groundwater grown *Spartina* to those grown in Trinity River water. Finally, for *Scirpus* an increase of 7 percent in per stem yield is seen but the results for *Scirpus* are so erratic that the difference between the groundwater grown and Trinity River grown plants is completely obscurred.

The results of this study are inconclusive primarily because of the variability of the results. While the reductions in yield for *Distichlis* and *Spartina* are evident, they are not significant because of the high standard deviations compared to the means (average coefficient of cariation = 29 percent).

DISCUSSION

Data gathered by state and federal agencies in the lower Trinity River from 1969 to 1976 were used to assess the presence and amounts of toxic materials. Though this data base is weak in terms of sampling frequency, types of samples, and variable analytical accuracy, it seems very possible that a sublethal and perhaps even lethal toxic material exists in the lower Trinity River.

Based on comparisons of heavy metal and pesticide concentrations in the water with concentrations considered hazardous by the National Academy of Sciences the average levels of copper,

TABLE IV-14

YIELD PER STEM OF MACROPHYTES EXPOSED TO SPIKED TRINITY RIVER AND GROUNDWATER IN A HYDROPONIC SYSTEM
(Source: Armstrong, et al, 1977)

Plant	Water Source	Container No.	Yield Per Stem (gm)	$\overline{x}$ (gm)	(gm)	N	σ joint	t
Distichlis	Ground	1	1.91*					
		2	0.78					
		3	0.52					
		4	0.61					
		5	0.74	0.66	0.12	4		
	Trinty	16	0.67					
		17	0.66				0.075	1.07 NS***
		18	0.50					
		19	0.45					
		20	0.60	0.58	0.10	5		
Spartina	Ground	6	1.03					
		7	2.00					
		8	1.72					
		9	-					
		10	0.80	1.39	0.56	4		
	Trinity	21	0.83**					
		22	1.34					
		23	- *				0.318	0.94 NS
		24	1.10					
		25	- *	1.09	0.26	3		
Scirpus	Ground	11	3.52					
		12	9.78					
		13	-					
		14	1.58					
		15	5.26			4		
	Trinity	26	-					
		27	5.58					
		28	-				1.76	0.20 NS
		29	-					
		30	5.2	5.39	0.27	2		

* All tagged stems died; data deleted from anaylsis

** Some tagged stems died

*** NS = not significant

lead, mercury, zinc, and DDT and its metabolities are above these levels in the lower Trinity River. Neleigh (1974) found the Trinity River to be a major source of toxic materials for Galveston Bay, and Armstrong and Eskew (1977) showed that the Bay Concentrations of the above heavy metals often exceeded EPA criteria for marine waters. The results of this study simply confirm the River as a source of these materials.

With regard to the sources of these materials, it was not possible in this study to delineate specific sources of heavy metals and pesticides and their locations. Either the data base for effluents did not include such data or the activities generating the waste were intermittent and/or transportable from location to location so as to defy estimating amounts and discharge points. However, domestic and industrial point spirces in the lower Trinity River basin must continue to be considered as possible sources of heavy metals or pesticides and should be monitored for such materials. Non-point sources such as agriculture, especially irrigation agriculture, are possible sources of heavy metals or pesticides while vector control spraying by airplane and truck are possible sources of pesticides. If the importance of these non-point sources is to be determined, a concerted effort will have to be made to monitor these sources for at least one or two years to ascertain the types of heavy metal and/or pesticides used, application rates, transport from the application areas via erosion and leaching, and disposal methods for old or unused heavy metal compounds and/or pesticides.

CHAPTER V

FISHERIES

The Trinity-Galveston estuary is the largest estuary on the Texas coast and has gained recognition as one of the State's most economically and ecologically important ecosystems. This may be particularly true for the renewable fishery resources which are greatly influenced by both economic and ecologic factors.

A comparative measure of the estuary's fisheries importance can be obtained by computing the percent contribution of commercially harvested fish and shellfish from the estuary to the composite of all commercial Texas bay landings, and to the total commercial Texas landings which include the offshore harvests taken in the Texas Gulf (Table V-1). The percentages were computed from the recent 1972 through 1976 Texas Landings, Annual Summary reports (Farley, 1973 through 1977). The analysis indicates that commercial fisheries harvest taken within the estuarine system have accounted for an average 37.7 percent of Texas bay landings and an average 9.5 percent of total Texas landings. Specifically, the Trinity-Galveston estuary's commercial fisheries harvest has averaged 9.24 million lbs/yr (590,000 lbs/yr fish, 8.65 million lbs/yr shellfish) during the 1972 through 1976 period of record. However, if about 80 percent of the Texas Gulf harvest (offshore landings component) is directly dependent upon this estuarine system and the "nursery" habitats it provides (Curington, et. al., 1966), then the contribution of the Trinity-Galveston estuary can be computed to average approximately 69.4 percent (67.5 million lbs/yr) of the total Texas landings (97.3 million lbs/yr).

About 82.2 percent (79.9 million lbs/yr) of the total Texas landings are composed of penaeid shrimp and 87.4 percent (69.9 million lbs/yr) of this recent five-year average shrimp harvest occurs offshore in the Texas Gulf. The Trinity-Galveston estuary contributed an average 81.8 percent (2.2 million lbs/yr) to the total Texas commercial oyster harvest during the 1972 through 1976 interval.

Recreational or sport fishing catches also represent a substantial harvest component. Heffernan, et al. (1976) report that sport fishing accounted for about 85.9 percent (2.8 million lbs) of the total fish harvest (3.3 million lbs) taken in the Trinity-Galveston estuary during a 12-month interval from September 1, 1974 to August 31, 1975. Commercial fish harvest accounted for only 14.1 percent (500,000 lbs) during the same survey period, therefore the sport fishing component was found to be over six

Table V-1. Percent Contribution of Trinity-Galveston Estuary Commercial Fisheries Harvest to Texas Bay Landings and Total Texas Landings (1972-1976).

Trinity-Galveston Estuary Harvests	Contribution to Texas Bay Landings (%)	Contribution to Total Texas Landings (%)
All Fish	11.0	7.9
Red Drum	3.4	3.2
Spotted Seatrout	13.8	11.5
All Shellfish	45.4	9.6
White Shrimp	47.7	18.9
Brown & Pink Shrimp	41.8	2.1
Oysters	81.8	81.8
Crabs	29.4	29.2
Total Harvest	37.7	9.5

times greater than the commercial fishing component in the category of fish harvest. Information is not presently available to accurately estimate the recreational or sport fishing component in the category of shellfish harvest.

FRESHWATER INFLOWS AND FISHERIES HARVEST RELATIONSHIPS

The fluctuating contributions of freshwater inflows, and associated nutritive and sedimentary constituents, from the Trinity River and Delta system have been of continuing interest because of their physical, chemical, and biological effect on the estuary, particularly Trinity Bay. In a case study of the estuary, Lankford, et al. (1969) state that under the extreme low flow drought conditions of 1956, the gaged Trinity River flow (Romayor site) of 900,000 acre-feet was sufficient to flush the estimated Trinity Bay volume (654,200 acre-feet) 1.4 times per year (annual displacement rate). This does not, however, consider the flushing needs or displacement rate of the larger volume of estuarine waters remaining in the estuary's other associated bays. These authors also conclude that the effect of river inflows on Trinity Bay is confounded because daily tidal currents can exchange nearly three times the combined runoff volumes of the Trinity and San Jacinto Rivers.

Baldauf, et al. (1970) found an inverse correlation between Trinity River inflows and the density of crustaceans, while Parker and Blanton (1970) employed 1958 through 1968 commercial fisheries statistics to hypothesize a reduction in seafood landings when average winter salinities exceeded summer salinities as a result of high spring/summer freshwater inflows to the estuary.

Copeland, et al. (1972) estimated that the upper Trinity Bay habitats were up to 72 percent dependent upon river-borne organic matter to support an observed high secondary productivity. More specifically, Parker, et al. (1972) conclude that a minimum 1.3 million acre-feet per year of Trinity River freshwater inflows may provide sufficient nutrients to sustain a low level of phytoplankton and marsh plant production in the Trinity Delta and Bay area. However, Soloman and Smith (1973) suggest that although Trinity Bay is highly dependent upon the Trinity River inflows for maintenance of the salinity gradient, the bay is not as dependent upon river-borne nutrients because its large observed benthic biomass provides a major source of energy.

In another attempt to correlate commercial fisheries statistics with freshwater inflows, Armstrong and Hinson (1973) report their analysis of the 1959 through 1964 records indicates that Galveston Bay system displacement rates exceeding twice per year apparently cause a decrease (i.e., negative correlation) in total commercial harvests. Recognizing this type of correlation as rather gross, Armstrong and Hinson (1973) further suggest that the estuarine system would produce the largest commercial catch at displacement rates ≤2.0/year, estimating the maximum fisheries production to be near 0.5/year.

By using a longer period of record it may be possible to illustrate additional apparent relationships between the harvest of commercially important species and the dynamic flow regime of the Trinity River. Table V-2 displays the monthly gaged river flows at Romayor, which if corrected for the ungaged sub-basin runoff and flow diversions occurring below the gaging station, leads to an approximation of the monthly and annual freshwater inflows to the estuary at the Trinity Delta. This recent 18-year record (1959 through 1976) has a mean average gaged flow of 5.017 million acre-feet/year (standard error = ± 612,000 acre-feet/year), a mean average ungaged sub-basin runoff of 716,000 acre-feet/year (± 96,000), a mean average flow diversion of 235,000 acre-feet/year (± 6,000), and a resultant mean average flow at the Trinity Delta of 5.497 million acre-feet/year (± 689,000).

To avoid data uncertainties in earlier years, only current fisheries statistics from the 1962 through 1976 record of commercial Texas landings (Farley, 1963 through 1977) were compiled for analysis (Table V-3). During this period the Trinity-Galveston estuary ranked first in "shellfish" landings and fourth in "finfish" landings by comparison with the harvest weights from the seven other major Texas estuarine systems. The "finfish" category used herein is specified for the following species: croaker (*Micropogon undulatus* Linnaeus), black drum (*Pogonias cromis* Linnaeus), red drum or redfish (*Sciaenops ocellata* Linnaeus), flounders (*Paralichthys* spp.; mostly *P. lethostigma* Jordan and Gilbert), sea catfish (*Arius felis* Linnaeus), spotted seatrout (*Cynoscion nebulosus* Cuvier), and sheepshead (*Archosargus probatocephalus* Walbaum). Similarly, the "shellfish" category refers here to commercial harvests of blue crab (*Callinectes sapidus* Rathbun), oyster (*Crassostrea virginica* Gmelin), brown and pink shrimp (*Penaeus aztecus* Ives and *Penaeus duorarum* Burkenroad; mostly *P. aztecus*), and white shrimp (*Penaeus setiferus* Linnaeus).

Although oyster harvesting areas in the Trinity-Galveston estuary have been substantially limited by the Texas Department of Health (Shellfish Sanitation Program under authority of Section 76.202, Parks and Wildlife Code) because of pollutant levels, the remaining general areas approved for harvesting have accounted for about 80 percent of the Texas oyster harvests and include the mid to lower reaches of Trinity Bay, mid to lower Galveston Bay east of the Houston Ship Channel, the western portion of East Bay, and the western portion of West Bay. In recent years, the oyster harvests have been mostly from the Redfish Bar reef complex in mid Galveston Bay.

Table V-2. Freshwater Inflows at Trinity Delta (Thousands of Acre-Feet).

Year	Month	Gaged Flow at Romayor	Ungaged Sub-basin Runoff	Flow Diversions	Flow At Trinity Delta
1959					
	Jan.	58	65	1	122
	Feb.	375	371	0	746
	Mar.	154	0	2	152
	Apr.	817	110	17	910
	May	948	84	35	997
	June	368	8	43	333
	July	407	222	36	593
	Aug.	105	95	37	163
	Sept.	41	0	13	28
	Oct.	576	53	2	627
	Nov.	240	15	4	251
	Dec.	644	56	1	699
	TOTAL	4,733	1,079	191	5,621
1960					
	Jan.	1,260	20	1	1,279
	Feb.	703	122	2	823
	Mar.	463	6	2	467
	Apr.	147	32	25	154
	May	248	0	49	199
	June	241	88	45	284
	July	123	17	41	99
	Aug.	98	236	30	304
	Sept.	63	0	16	47
	Oct.	159	109	1	267
	Nov.	500	39	1	538
	Dec.	1,408	183	2	1,589
	TOTAL	5,413	852	215	6,050
1961					
	Jan.	1,841	149	6	1,984
	Feb.	1,208	163	1	1,370
	Mar.	682	17	2	697
	Apr.	456	21	22	455
	May	120	0	52	68
	June	407	221	33	595
	July	379	51	46	384
	Aug.	67	30	49	48
	Sept.	332	441	15	758
	Oct.	83	0	4	79
	Nov.	127	146	1	272
	Dec.	548	20	4	564
	TOTAL	6,250	1,259	235	7,274

Table V-2 (Continued)

Year	Month	Gaged Flow at Romayor	Ungaged Sub-basin Runoff	Flow Diversions	Flow at Trinity Delta
1962					
	Jan.	346	10	1	355
	Feb.	243	0	1	242
	Mar.	229	1	6	224
	Apr.	227	7	34	200
	May	499	11	49	461
	June	160	74	47	187
	July	159	13	55	117
	Aug.	231	24	51	204
	Sept.	388	2	18	372
	Oct.	502	1	4	499
	Nov.	138	19	4	153
	Dec.	486	99	1	584
	TOTAL	3,608	261	271	3,598
1963					
	Jan.	193	91	1	283
	Feb.	180	56	1	235
	Mar.	111	0	3	108
	Apr.	167	0	42	125
	May	473	0	51	422
	June	158	9	48	119
	July	58	0	48	10
	Aug.	33	0	40	-7
	Sept.	31	19	22	28
	Oct.	23	0	9	14
	Nov.	32	5	1	36
	Dec.	63	12	0	75
	TOTAL	1,522	192	266	1,448
1964					
	Jan.	72	49	0	121
	Feb.	84	98	3	179
	Mar.	232	89	1	320
	Apr.	233	10	25	218
	May	175	6	49	132
	June	119	0	51	68
	July	33	22	51	4
	Aug.	37	10	19	28
	Sept.	67	28	14	81
	Oct.	342	0	2	340
	Nov.	303	0	1	302
	Dec.	502	95	3	594
	TOTAL	2,199	407	219	2,387

Table V-2 (Continued)

Year	Month	Gaged Flow at Romayor	Ungaged Sub-basin Runoff	Flow Diversions	Flow at Trinity Delta
1965					
	Jan.	286	0	0	286
	Feb.	806	8	0	814
	Mar.	490	42	4	528
	Apr.	391	1	40	352
	May	1,168	5	41	1,132
	June	854	20	47	827
	July	75	3	50	28
	Aug.	41	6	25	22
	Sept.	51	23	21	53
	Oct.	53	14	7	60
	Nov.	105	24	2	127
	Dec.	354	138	1	491
	TOTAL	4,674	284	238	4,720
1966					
	Jan.	211	130	0	341
	Feb.	459	196	0	655
	Mar.	156	13	5	164
	Apr.	591	245	16	820
	May	3,197	186	24	3,359
	June	695	1	52	644
	July	369	10	51	328
	Aug.	158	194	26	326
	Sept.	129	14	24	119
	Oct.	108	31	3	136
	Nov.	45	77	0	122
	Dec.	55	3	3	55
	TOTAL	6,173	1,100	204	7,069
1967					
	Jan.	59	5	0	64
	Feb.	55	18	0	73
	Mar.	62	3	17	48
	Apr.	198	90	41	247
	May	146	104	43	207
	June	269	6	52	223
	July	114	10	40	84
	Aug.	32	1	37	-4
	Sept.	141	0	30	111
	Oct.	169	2	4	167
	Nov.	501	0	1	500
	Dec.	320	3	0	323
	TOTAL	2,066	242	265	2,043

Table V-2 (Continued)

Year	Month	Gaged Flow at Romayor	Ungaged Sub-basin Runoff	Flow Diversions	Flow at Trinity Delta
1968					
	Jan.	676	89	0	765
	Feb.	540	13	0	553
	Mar.	869	33	8	894
	Apr.	1,696	116	28	1,784
	May	1,627	161	43	1,745
	June	1,316	178	45	1,449
	July	445	11	45	411
	Aug.	128	2	50	80
	Sept.	76	20	18	78
	Oct.	80	12	6	86
	Nov.	97	39	1	135
	Dec.	357	20	0	377
	TOTAL	7,907	694	244	8,357
1969					
	Jan.	188	5	0	193
	Feb.	467	136	0	603
	Mar.	1,313	58	3	1,368
	Apr.	1,632	150	26	1,756
	May	2,227	201	35	2,393
	June	836	22	54	804
	July	126	48	49	125
	Aug.	89	25	45	69
	Sept.	83	21	26	78
	Oct.	87	5	10	82
	Nov.	129	3	0	132
	Dec.	221	85	4	302
	TOTAL	7,398	759	252	7,905
1970					
	Jan.	300	10	0	310
	Feb.	231	26	0	257
	Mar.	1,291	133	9	1,415
	Apr.	513	32	33	512
	May	209	184	42	351
	June	153	58	49	162
	July	113	13	54	72
	Aug.	66	13	43	36
	Sept.	59	87	31	115
	Oct.	46	275	4	317
	Nov.	27	37	1	63
	Dec.	22	11	0	33
	TOTAL	3,030	879	266	3,643

Table V-2 (Continued)

Year	Month	Gaged Flow At Romayor	Ungaged Sub-basin Runoff	Flow Diversions	Flow at Trinity Delta
1971					
	Jan.	21	0	0	21
	Feb.	25	8	1	32
	Mar.	56	13	15	54
	Apr.	70	48	39	79
	May	80	15	39	56
	June	67	10	39	38
	July	58	0	45	13
	Aug.	29	60	38	51
	Sept.	28	80	18	90
	Oct.	27	13	14	26
	Nov.	310	2	6	306
	Dec.	1,487	104	5	1,586
	TOTAL	2,258	353	259	2,352
1972					
	Jan.	1,198	109	0	1,307
	Feb.	248	15	0	263
	Mar.	108	27	19	116
	Apr.	101	25	33	93
	May	241	212	32	421
	June	57	46	48	55
	July	75	53	34	94
	Aug.	25	0	20	5
	Sept.	28	97	30	95
	Oct.	20	7	2	25
	Nov.	190	81	2	269
	Dec.	196	19	0	215
	TOTAL	2,487	691	220	2,958
1973					
	Jan.	522	100	0	622
	Feb.	548	75	0	623
	Mar.	1,289	223	6	1,506
	Apr.	1,235	351	13	1,573
	May	1,419	46	35	1,430
	June	1,908	286	44	2,150
	July	445	75	54	466
	Aug.	205	94	36	263
	Sept.	202	161	16	347
	Oct.	1,561	221	7	1,775
	Nov.	886	39	0	925
	Dec.	882	35	0	917
	TOTAL	11,102	1,706	211	12,597

Table V-2 (Continued)

Year	Month	Gaged Flow at Romayor	Ungaged Sub-basin Runoff	Flow Diversions	Flow at Trinity Delta
1974					
	Jan.	1,358	221	0	1,579
	Feb.	368	37	0	405
	Mar.	252	48	11	289
	Apr.	170	105	29	246
	May	500	162	41	621
	June	217	7	58	166
	July	110	6	54	62
	Aug.	91	5	29	67
	Sept.	884	12	20	876
	Oct.	311	20	8	323
	Nov.	1,832	225	1	2,056
	Dec.	1,488	90	0	1,578
	TOTAL	7,581	938	251	8,268
1975					
	Jan.	777	63	0	840
	Feb.	1,675	28	0	1,703
	Mar.	630	24	11	643
	Apr.	946	77	27	996
	May	1,188	149	39	1,298
	June	1,113	114	45	1,182
	July	351	36	42	345
	Aug.	236	97	25	308
	Sept.	68	18	23	63
	Oct.	69	44	7	106
	Nov.	90	64	2	152
	Dec.	79	20	0	99
	TOTAL	7,222	734	221	7,735
1976					
	Jan.	107	3	0	110
	Feb.	103	1	0	104
	Mar.	166	4	8	162
	Apr.	446	19	29	436
	May	1,265	32	36	1,261
	June	926	78	38	966
	July	394	54	34	414
	Aug.	72	7	28	51
	Sept.	142	32	23	151
	Oct.	202	53	5	250
	Nov.	167	42	3	206
	Dec.	687	129	1	815
	TOTAL	4,677	454	205	4,926

Table V-3. Commercial Fisheries Harvests of the Trinity -Galveston Estuary (Thousands of Lbs.)

	"Finfish"	Spotted Seatrout	Redfish	"Shellfish"	White Shrimp	Brown & Pink Shrimp	Oysters	Crabs
1962	59.9	17.0	2.6	5,254.1	3,324.4	868.5	749.9	311.3
1963	159.0	142.9	1.3	6,736.8	3,027.2	600.8	2,131.3	977.5
1964	411.0	176.9	25.7	9,534.1	4,700.7	717.0	2,920.8	1,195.6
1965	413.4	277.0	32.2	10,600.1	3,066.2	1,132.2	4,583.3	1,817.9
1966	350.5	161.7	29.8	7,382.2	1,260.0	681.1	4,083.3	1,357.8
1967	635.1	280.4	45.0	6,227.8	1,038.8	1,148.5	2,992.6	1,047.9
1968	333.4	174.2	21.2	7,203.1	2,154.0	307.8	2,838.7	1,542.6
1969	278.1	55.7	38.1	9,438.0	3,809.6	475.5	3,447.2	1,705.7
1970	264.7	89.2	35.3	12,097.7	4,069.5	1,556.0	3,850.2	2,622.0
1971	155.3	75.9	18.1	11,196.4	2,963.8	2,050.1	4,021.7	2,160.8
1972	295.8	128.4	33.6	9,485.0	2,956.7	1,398.5	3,259.7	1,870.1
1973	498.6	232.8	49.6	9,184.4	4,063.4	951.6	2,129.4	2,040.0
1974	446.2	272.9	34.9	6,634.8	2,392.4	1,422.6	836.8	1,983.1
1975	452.9	221.0	79.5	7,855.9	3,927.2	828.4	1,236.8	1,863.5
1976	445.4	181.5	97.5	10,058.5	3,358.2	1,802.0	3,298.8	1,599.5

An examination of the 1962 through 1976 commercial landings record extremes is afforded by tabulation of the "Best" versus "Worst" oyster harvest years, based on the ranking of annual harvest weights (Table V-4). Freshwater inflows given with the harvest data are one-year antecedent to the specified harvest year for investigation of any observable effect of the inflows on spat setting, survival, and growth of immature oysters which may be harvested the following year. The "Best" years' harvests averaged 4.0 million lbs, while the "Worst" years' harvest averaged 1.4 million lbs. Inspection of springtime, summer, fall, and annual antecedent inflows indicates that the greatest difference occurs with the fall inflows of September through October. "Best" harvest years were associated with an average fall inflow of 258,000 acre-feet, while the "Worst" harvest years averaged a substantially higher 1.03 million acre-feet of freshwater inflow at the Trinity Delta in September through October. It is of interest to note that peak spat setting at Redfish Bar reef complex in the middle of Galveston Bay occurs in June or July with secondary peaks most common in October (Hofstetter, 1977). Although higher inflows may increase spat setting by cleaning substrate areas, reduced survival may occur at prolonged low salinities (<5 ppt).

Figure V-1 graphically displays the results of linear regression and correlation analysis of September through October freshwater inflows on the commercial oyster harvests (lagged one-year). The value of the negative correlation coefficient ($r = -0.784$) is very highly significant ($P \leq 0.1$ percent), suggesting that about 61.5 percent of the year-to-year variation in commercial oyster harvest can be accounted for by fluctuations in the one-year antecedent freshwater inflows of September through October. The highest harvests are all associated with fall inflows below 500.0 thousand acre-feet, while lower harvests appear when the inflows exceed 800.0 thousand acre-feet.

Amemiya (1926) estimated the oyster's upper and lower salinity limits to be 39.0 ppt and 1.5 ppt. Gunter (1953) reported that the oyster can survive in freshwater (0.0 ppt) for several days, increasing to about a month at 2.0 ppt. In addition, Eleuterius (1977) found, with only one exception, that the producing reefs of the Mississippi Sound were subjected to salinity minimums of 2.0 through 4.0 ppt, with average conditions being 10-16 ppt salinity. Similar results were obtained by Hofstetter (1977) in the Trinity-Galveston estuary where peak spat setting periods on the Redfish Bar reef complex averaged 16 ppt salinity and ranged as low as 4 ppt. Further, Hofstetter (1977) states that when Trinity River inflows were low (i.e., averaging about 2.0 million acre-feet/year) approximately 89 percent of the larval spat became seed oyster size, 71 percent sub-market size, and 45 percent market size; however, when inflows were high (i.e., averaging about 7.0 million acre-feet/year) approximately 75 percent of the larval spat developed to seed oyster size, 56 percent to sub-market size, and market sized oysters declined to 36 percent. Nevertheless, the general scientific consensus remains that although

Table V-4. "Best" versus "Worst" Years of Commercial Oyster Harvest (Thousands of Lbs) in Trinity-Galveston Estuary with One-Year Antecedent Freshwater Inflows at Trinity Delta (Thousands of Acre-Feet).

	Harvest	March, April May, June	June, July August	September October	Total Annual Inflow
"Best" Years[1]					
1965	4583.8	738	877	421	2387
1966	4083.3	2839	1298	113	4720
1971	4021.7	2440	102	432	3643
1970	3850.2	6321	270	160	7905
1969	3447.2	5872	998	164	8357
Mean (± S.E.)	3997.2 (± 183.9)	3642 (± 1065)	709 (± 226)	258 (± 69)	5402 (± 1176)
"Worst" Years[2]					
1962	749.9	1815	508	837	7274
1974	836.8	6659	295	2122	12,597
1975	1236.8	1322	1835	1199	8268
1973	2129.4	685	2879	120	2958
1963	2131.3	1072	122	871	3598
Mean (± S.E.)	1416.8 (± 302.6)	2311 (± 1102)	1128 (± 532)	1030 (± 325)	6939 (± 1745)

[1] top 5 ranked harvest years by weight

[2] bottom 5 ranked harvest years by weight

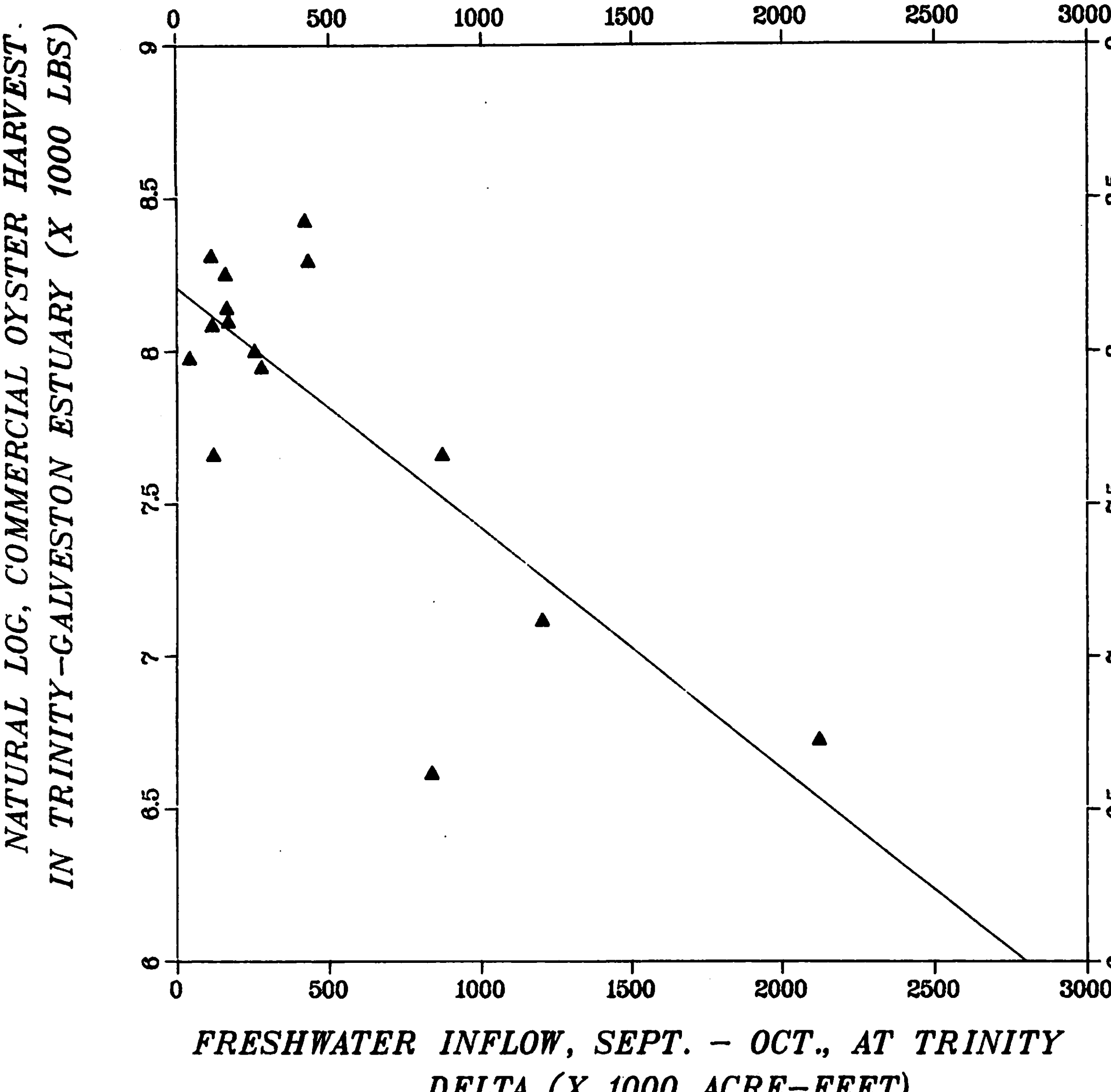

FIGURE V-1

CORRELATION OF COMMERCIAL OYSTER HARVESTS (1962-1976) WITH 1-YEAR ANTECEDENT, SEPTEMBER-OCTOBER FRESHWATER INFLOWS AT TRINITY DELTA (1961-1975).

moderate salinities (15-20 ppt) appear optimal for growing oysters, low salinities (< 10 ppt) during short seasonal intervals of high freshwater inflow (e.g., spring freshets) are necessary to eliminate dangerous oyster parasites and predators, such as the fungus Labyrinthomyxa marina and the oyster drill Thais haemastoma, which may proliferate in higher salinity waters and are capable of decimating an entire reef's oyster population in less than one year.

The extremes of brown and pink shrimp (mostly brown shrimp) commercial harvest in the Trinity-Galveston estuary can also be examined through tabulation of "Best" and "Worst" years (Table V-5); however, associated seasonal freshwater inflows are from the same year as the harvest to reflect the capacity of penaeid shrimp for growth and maturation within an annual interval. The tabular analysis suggests that "Best" brown shrimp harvest years have generally lower inflows in the spring and early summer. In particular, the "Best" harvest years averaged 1.222 million acre-feet in springtime (March, Spril and May), while the "Worst" harvest years averaged a substantially higher inflow of 3.122 million acre-feet during the same seasonal interval.

Linear regression and correlation analysis of the March through May inflows with annual brown and pink shrimp harvests of the Trinity-Galveston estuary are graphically displayed in Figure V-2. The value of the correlation coefficient ($r = -0.54$) is significant ($P \leq 5.0$ percent) and suggests that at least 29 percent of the year-to-year variation in brown and pink shrimp harvests may be accounted for by fluctuations in springtime (March, April and May) freshwater inflow at the Trinity Delta. This is recognized as the seasonal interval immediately prior to peak emigration of brown shrimp from the estuary in May and June (Trent, 1966). The negative correlation of harvest on springtime inflows supports the conclusion of previous laboratory studies (Zein-Eldin and Griffith, 1969) that low salinity, especially in combination with low temperature, is detrimental to postlarval brown shrimp. In particular, Johnson (1974) reports that the survival of brown shrimp in the estuary during 1970 through 1971 was apparently favored by mild 1970 winter temperatures and dry climate in spring and summer of 1971 which produced the "Best" harvest year of the recent 15-year (1962 through 1976) commercial landings record for the Trinity-Galveston estuary.

A "Best" versus "Worst" years analysis of commercial white shrimp harvests (1962 through 1976) is given in Table V-6. The greatest difference is found in the column of freshwater inflows at Trinity Delta during February, March and April. While the "Best" years of commercial harvest averaged 2.7 million acre-feet in the early spring interval, "Worst" years averaged only 1.3 million acre-feet with three of five "Worst" years below 1.0 million acre-feet. Linear regression and correlation analysis was not statistically significant for the 15-year harvest record.

Table V-5. "Best" versus "Worst" Years of Commercial Brown and Pink Shrimp Harvest (Thousands of Lbs) in Trinity-Galveston Estuary with Freshwater Inflows at Trinity Delta (Thousands of Acre-Feet).

	Harvest	January, February, March	March, April, May	May, June, July	July, August, September	Total Annual Inflow
"Best" Years[1]						
1971	2050.1	107	189	107	154	2352
1976	1802.0	376	1859	2641	616	4926
1970	1556.0	1982	2278	585	223	3643
1974	1422.6	2273	1156	849	1005	8268
1972	1398.5	1686	630	570	194	2958
Mean (± S.E.)	1645.8 (± 123.9)	1285 (±438)	1222 (± 348)	950 (± 439)	438 (± 164)	4429 (± 1051)
"Worst" Years[2]						
1968	307.8	2212	4423	3605	569	8357
1969	475.5	2164	5517	3322	272	7905
1963	600.8	626	655	551	31	1448
1966	681.1	1160	4343	4331	773	7069
1964	717.0	620	670	204	113	2387
Mean (± S.E.)	556.4 (± 74.7)	1356 (± 353)	3122 (± 1025)	2403 (± 845)	352 (± 140)	5433 (± 1458)

[1] top 5 ranked harvest years by weight

[2] bottom 5 ranked harvest years by weight

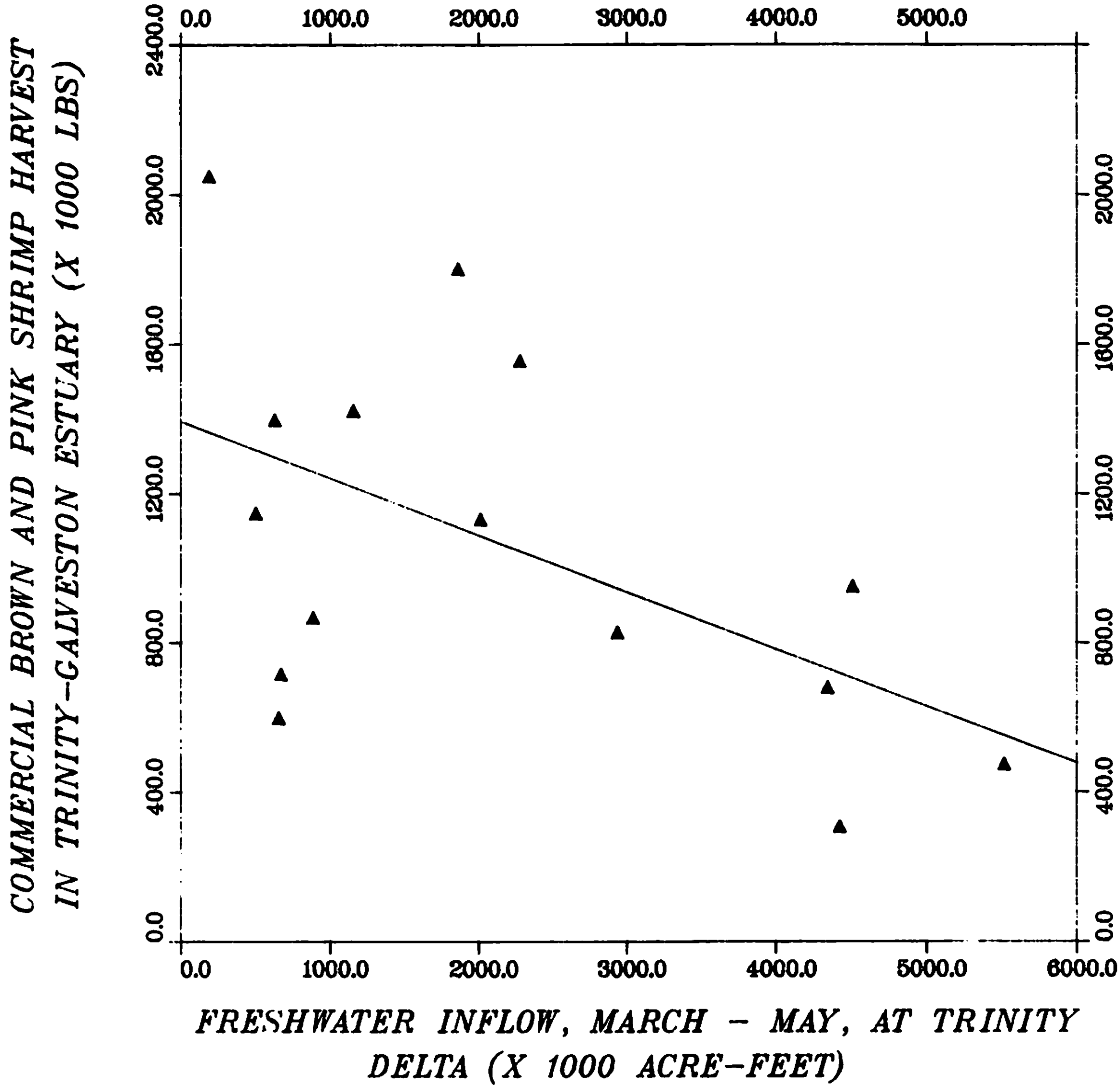

FIGURE V-2

CORRELATION OF BROWN AND PINK SHRIMP HARVESTS WITH MARCH-MAY FRESHWATER INFLOWS AT TRINITY DELTA (1962–1976)

Table V-6. "Best" versus "Worst" Years of Commercial White Shrimp Harvest (Thousands of Lbs) in Trinity-Galveston Estuary With Freshwater Inflows at Trinity Delta (Thousands of Acre-Feet).

"Best" Years[1]	Harvest	January, February March	March, April May, June	June, July August	September October	Total Annual
1964	4700.7	717	738	113	421	2387
1970	4069.5	2184	2440	223	432	3643
1973	4063.4	3702	6659	1076	2122	12597
1975	3927.2	3342	4119	716	169	7735
1969	3809.2	3727	6321	272	160	7905
Mean (± S.E.)	4190.2 (±155.0)	2734 (±577)	4055 (±1130)	480 (±181)	661 (±370)	6853 (±1805)
"Worst" Years[2]						
1967	1038.8	368	725	191	278	2043
1966	1260.0	1639	4987	773	255	7069
1968	2154.0	3231	5872	569	164	8357
1974	2392.4	940	1322	1005	1199	8268
1972	2956.7	472	685	194	120	2958
Mean (± S.E.)	1960.4 (±357.5)	1330 (±525)	2718 (±1121)	546 (±160)	403 (±201)	5739 (±1349)

[1] top 5 ranked harvest years by weight

[2] bottom 5 ranked harvest years by weight

Although Gunter (1956, 1961), Gunter, et al. (1964) and Parker (1970) have commented on the presence of postlarval brown and white shrimp in low to very low (< 5 ppt) salinities, Zein-Eldin (1963), Zein-Eldin and Aldrich (1965), and Zein-Eldin and Griffith (1969) found the general tolerance of these shrimp to a wide range of salinities (2-40 ppt) with the particular exception of low salinity-low temperature (< 15 degrees C) conditions. Venkataramiah, et al. (1977) report that brown shrimp can be raised on a low protein diet (40 percent) in low salinity (8.5 - 17.0 ppt) at a normal temperature (26 degrees C), which seems to be close to optimal. Indeed, the findings indicate that low salinity (25-50 percent seawater) is essential for fast growth in the postlarval from age 16 days and older.

A "Best" versus "Worst" years analysis was also performed for the "finfish" category of commercial Trinity-Galveston estuary harvests (Table V-7), and in particular the commercial harvests of spotted seatrout (Table V-8) and red drum or redfish (Table V-9). Since a weak year-class entering the commercial (adult) population can result in a reduced harvest, the associated freshwater inflow was selected to be the three-year average antecedent inflow at Trinity Delta before harvest occurred in the following year. The "finfish" category appears to have a highly variable response to freshwater inflows, although inflows of fall (September through October) and early winter (November through December) averaged somewhat higher for the "Best" harvest years (Table V-7). Linear regression and correlation analysis was not significant. Tables V-8 and V-9 also show higher inflows in the fall and winter seasonal intervals for the "Best" harvest years of spotted seatrout and redfish, respectively, being more pronounced for the spotted seatrout. In addition, Table V-8 indicates that springtime inflows (March, April, May and June) averaged substantially lower (2.0 million acre-feet) for the associated "Best" spotted seatrout harvest years. However, linear regression and correlation analysis of the 15-year (1962 through 1976) spotted seatrout and red drum harvest records used in this study did not contribute statistically significant results because of the highly variable response to fluctuations in the antecedent freshwater inflows.

Important predator-prey relationships exist in the estuary between links in the food-chain; however, most are complex and difficult to demonstrate beyond simple observation of the presence or absence of prey species in the putative predator's stomach. Further, man may influence natural predator-prey relationships by harvesting the predator, the prey, or both. The latter is the case for spotted seatrout which spend all or most of their life in the estuarine system and feed heavily on penaeid shrimp. A linear regression and correlation analysis (Figure V-3) was performed to investigate the association between year-to-year fluctuations in the relative abundance of spotted seatrout stocks (represented by the 1965 through 1976 commercial harvests) and the three-year antecedent fluctuations in the relative abundance of penaeid shrimp stocks (represented by the 1962 through 1973

Table V-7. "Best" versus "Worst" Years of Commercial "Finfish" Harvest (Thousands of Lbs) in Trinity-Galveston Estuary with 3-Year Average Antecedent Freshwater Inflows at Trinity Delta (Thousands of Acre-Feet).

"Best" Years[1]	Harvest	January, February, March	March, April, May, June	June, July, August	September October	November December	Total Annual
1967	635.1	1136	2855	758	263	564	4725
1973	498.6	1258	1117	175	223	824	2984
1975	452.9	2237	2889	1109	1147	1987	7941
1974	446.2	1515	2524	1045	786	1406	5969
1976	445.4	2737	4033	1670	1163	1909	9533
Mean (± S.E.)	495.6 (± 36.2)	1777 (± 307)	2684 (± 468)	951 (± 244)	716 (± 205)	1338 (± 284)	6230 (± 1156)
"Worst" Years[2]							
1962	59.9	2547	1770	934	602	1304	6315
1971	159.0	2480	1330	741	674	1233	5641
1963	155.3	2119	4878	1069	252	347	6635
1970	264.7	1520	4306	1080	201	590	6102
1969	278.1	1186	3861	1180	232	504	5823
Mean (± S.E.)	183.4 (± 40.1)	1970 (± 268)	3229 (± 708)	1001 (± 76)	392 (± 101)	796 (± 197)	6103 (± 176)

[1] top 5 ranked harvest years by weight

[2] bottom 5 ranked harvest years by weight

Table V-8. "Best" versus "Worst" Years of Commercial Spotted Seatrout Harvest (Thousands of Lbs) in Trinity-Galveston Estuary with 3-year Average Antecedent Freshwater Inflows at Trinity Delta (Thousands of Acre-Feet).

"Best" Years[1]	Harvest	January, February March	March, April May, June	June, July August	September October	November December	Total Annual
1967	280.4	1136	2855	758	263	564	4725
1965	277.0	689	861	243	445	581	2478
1974	272.3	1515	2524	1045	786	1406	5969
1973	232.8	1258	1117	175	223	824	2984
1975	221.0	2237	2889	1109	1147	1987	7941
Mean (± S.E.)	256.8 (± 12.4)	1367 (± 255)	2049 (± 439)	666 (± 196)	573 (± 175)	1072 (± 275)	4819 (± 998)
"Worst" Years[2]							
1962	17.0	2547	1770	934	602	1304	6315
1969	55.7	1186	3861	1180	232	504	5823
1971	75.9	2119	4878	1069	252	347	6635
1970	89.2	1520	4306	1080	201	590	6102
1972	128.4	1418	2996	457	236	807	4633
Mean (± S.E.)	73.2 (± 18.4)	1758 (± 250)	3562 (± 543)	944 (± 128)	305 (± 75)	710 (± 166)	5902 (± 344)

[1] top 5 ranked harvest years by weight

[2] bottom 5 ranked harvest years by weight

Table V-9. "Best" versus "Worst" Years of Commercial Red Drum Harvest (Thousands of Lbs) in Trinity-Galveston Estuary with 3-Year Average Antecedent Freshwater Inflows at Trinity Delta (Thousands of Acre-Feet).

"Best" Years[1]	Harvest	January, February, March	March, April, May, June	June, July, August	September October	November December	Total Annual
1976	97.5	2737	4033	1670	1163	1909	9533
1975	79.5	2237	2889	1109	1147	1987	7941
1973	49.6	1258	1117	175	223	824	2984
1967	45.0	1136	2855	758	263	564	4725
1969	38.1	1186	3861	1180	232	504	5823
Mean (± S.E.)	61.9 (± 11.4)	1711 (± 327)	2951 (± 248)	978 (± 224)	606 (± 327)	1158 (± 327)	6201 (± 1158)

"Worst" Years[2]	Harvest	January, February, March	March, April, May, June	June, July, August	September October	November December	Total Annual
1963	1.3	2480	1330	741	674	1233	5641
1962	2.6	2547	1770	934	602	1304	6315
1971	18.1	2119	4878	1069	252	347	6635
1968	21.2	991	2850	826	215	539	4611
1964	25.7	1833	1220	552	583	561	4107
Mean (± S.E.)	13.8 (± 5.0)	1994 (± 282)	2410 (± 681)	824 (± 87)	465 (± 96)	797 (± 196)	5462 (± 485)

[1] top 5 ranked harvest years by weight

[2] bottom 5 ranked harvest years by weight

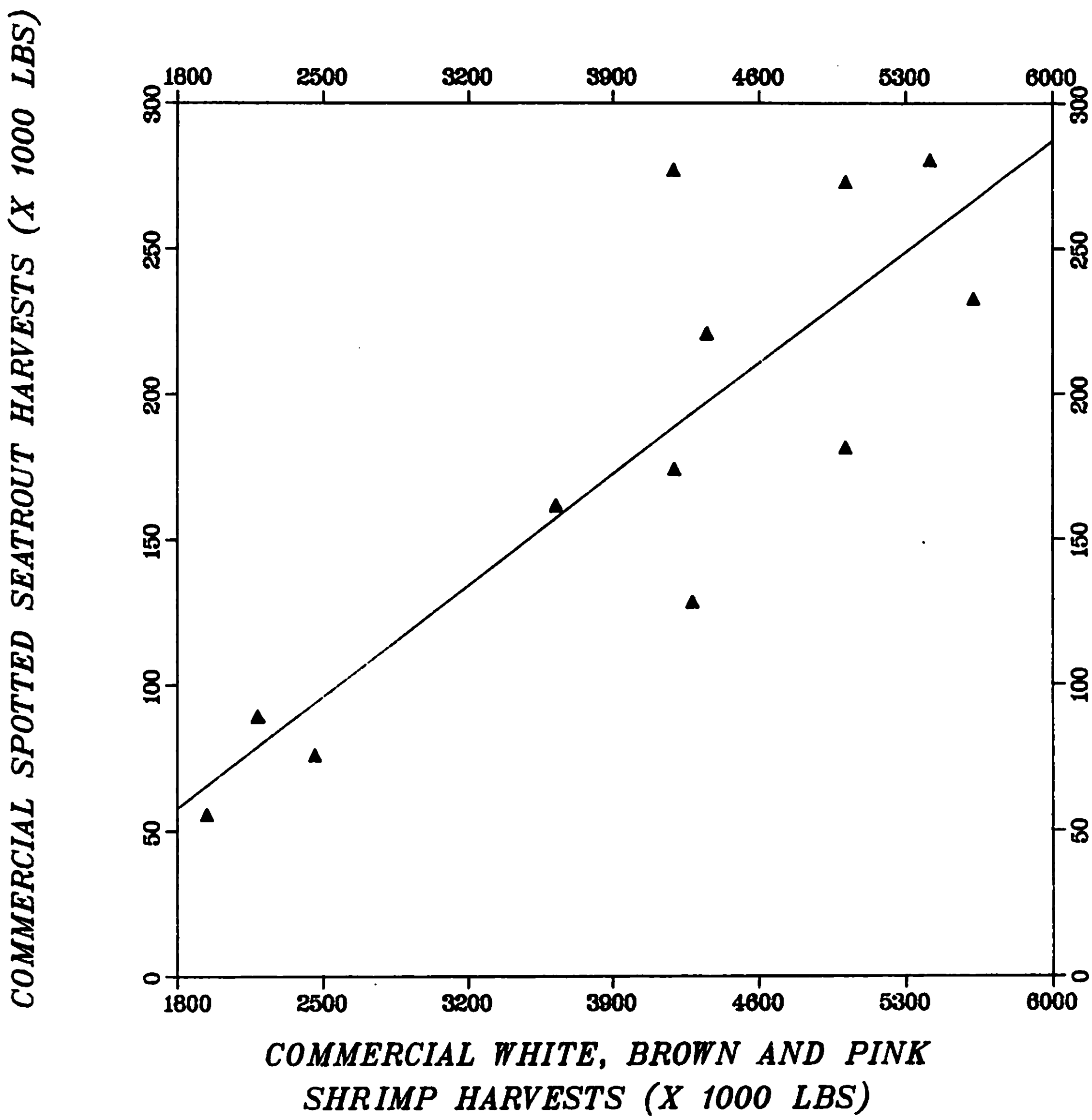

FIGURE V-3

CORRELATION OF COMMERCIAL SEATROUT HARVESTS (1965–1976) WITH 3-YEAR ANTECEDENT COMMERCIAL SHRIMP HARVESTS (1962–1973) IN TRINITY-GALVESTON ESTUARY commercial harvests). Lagging the predator's abundance three years behind the prey's abundance is reasonable because abundant food resources (i.e., white, brown and pink shrimp) for young seatrout provide an opportunity for good growth and survival, and may be reflected some years later (averaging about three years) when the strong age-class enters the adult population and becomes available to commercial fishery harvests. The correlation coefficient ($r = 0.85$) is very highly significant ($P \leq 0.1$ percent) and suggests that about 72 percent of the year-to-year fluctuations in spotted seatrout relative abundance may be associated with variations in the three-year antecedent relative abundance of white, brown and pink shrimp in the Trinity-Galveston estuary.

FINFISH METABOLIC STRESS ANALYSIS

Wohlschlag (1976 and 1977) and Wakeman (1978) have reported on the effects of freshwater inflows, and associated salinity changes, on the metabolic stresses of several Texas estuarine fish species. Using the concept of maximum swimming performance and its equivalency to maximum scope for metabolic activity when environmental conditions are optimal, the studies have provided measurement of natural metabolic expressions of stress with particular emphasis on salinity levels.

Essentially, there are three kinds of metabolic rates to be considered. The first is the standard rate, which is the lowest maintenance rate possible for completely quiescent and fasted fish. The second is the active rate corresponding to the maximum sustained swimming rate. The difference between the active and standard rates is especially important because it defines the maximum scope for metabolic activity. The third metabolic rate of interest is the routine or ecologically operational rate that lies between standard and maximum activity levels. The routine level is often characterized in terms of swimming speed as about 1.0 body length per second during normal foraging behavior. Interestingly, it also represents about the same metabolic level for inactive fish that have recently fed, and thus, is considered roughly equivalent to the metabolic energy level required for digestion and assimilation.

Figures V-4 and V-5 are adapted from Wohlschlag (1976) and illustrate how these three levels are related and how metabolic scope under sublethal stress is reduced by either a reduction in the active metabolic rate, an increase in the standard metabolic requirements, or by both processes simultaneously. Specifically, Figure V-4 displays data on the three metabolic rates of interest for the spotted seatrout as they vary with salinity. In panel A of Figure V-4, the upper line represents average maximum sustained metabolic rates at different salinities. Fish in poor condition at 30 ppt (see arrow) had a markedly depressed active metabolic rate. Note that the optimum among the sustained maximum active

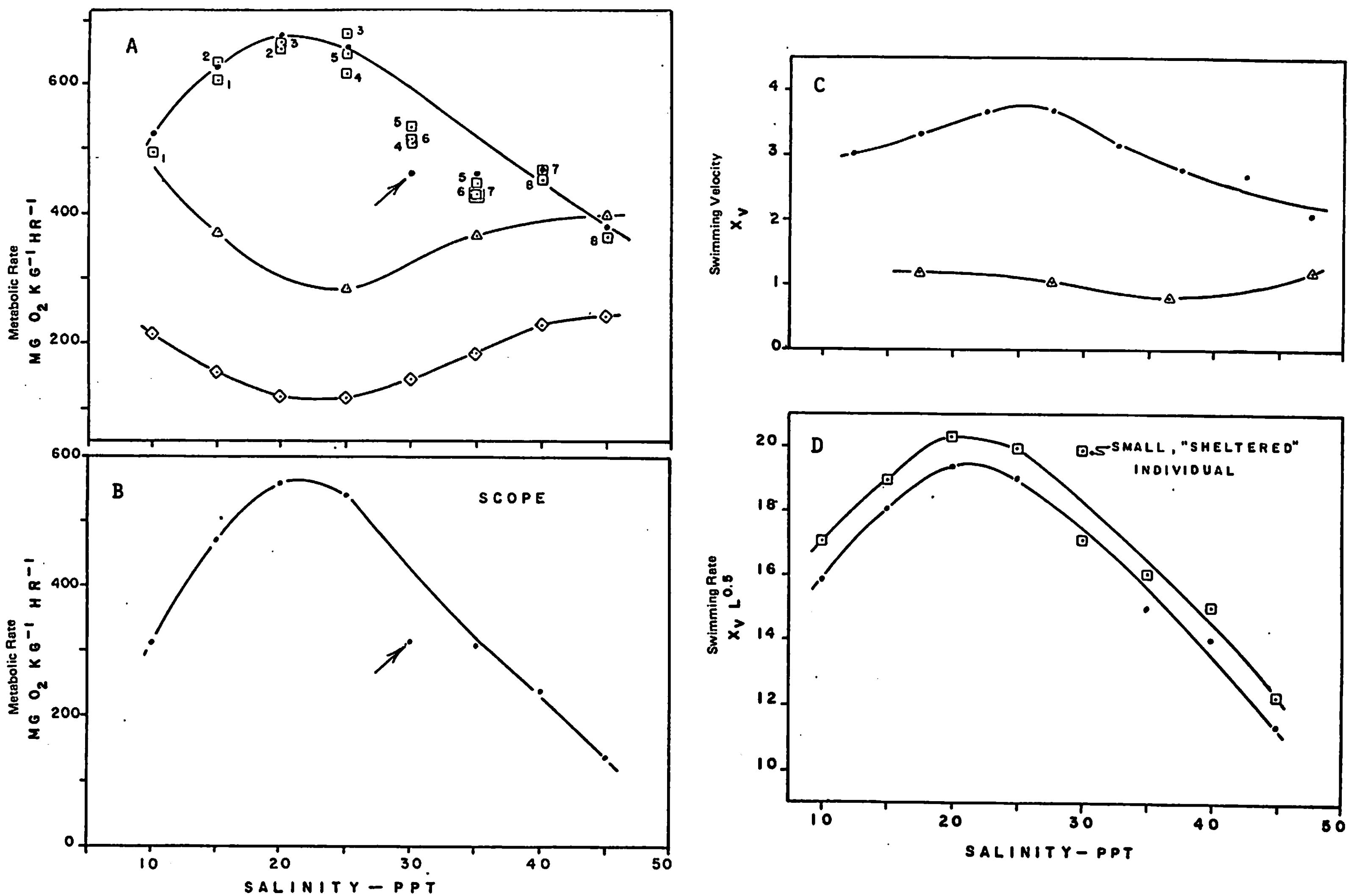

Figure V-4. Effects of Salinity on Spotted Seatrout Metabolic Rates and Swimming Velocities

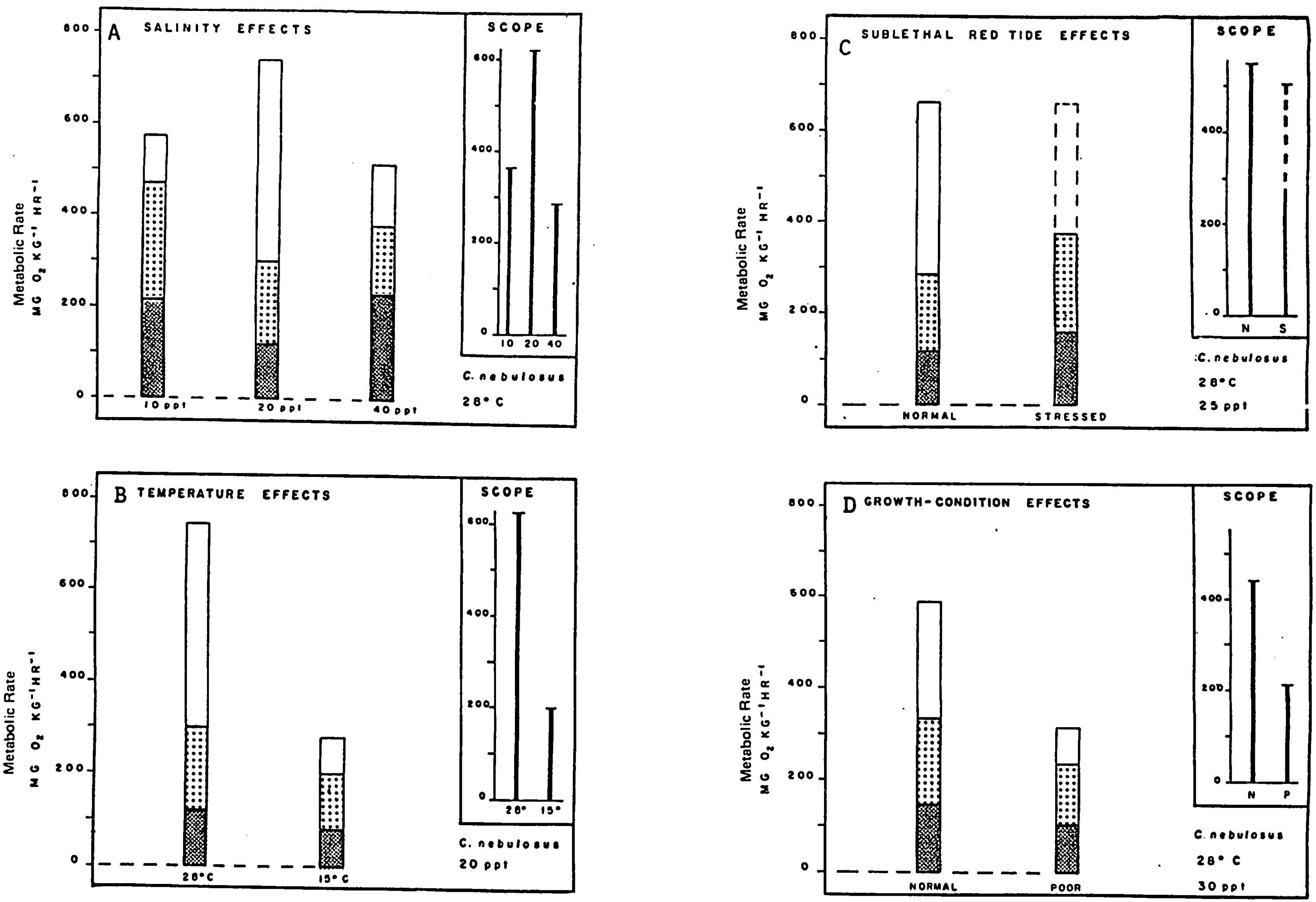

Figure V-5. Effects of Environmental Conditions on Spotted Seatrout Standard, Routine, and Active Metabolic Rates with the Metabolic Scope for Activity metabolic rates is at a salinity of about 20 ppt. The middle line of panel A represents the routine or ecologically operational metabolic rates over the salinity range. It is of interest to note that at about 10 and 45 ppt salinity, the routine and maximum sustained active metabolic rates coincide, indicating these extremes as the general limit of ecological operability for this species. The bottom line of panel A represents the standard or minimum maintenance metabolic level, which appears optimal at about 20-25 ppt.

Panel B of Figure V-4 shows the curve of the metabolic scope for activity which results as the difference between the active and standard metabolic rate curves. An optimal salinity of about 20 ppt is also indicated by the maximum scope curve for the spotted seatrout.

The relation of swimming velocities (X_V = bodylengths per second) to salinity is presented in Panel C of Figure V-4. The top line gives average values for maximum sustained velocities at each salinity and appears optimal at about 20-25 ppt salinity. The bottom line gives average routine velocities which remain near 1.0 bodylength per second over the salinity range.

Since the expression of swimming rates in velocity per square root of bodylength ($X_V / \sqrt{L}$) has a hydrodynamic advantage by better taking into account the relationships between size and swimming performance, panel D of Figure V-4 is designed to show swimming velocities at average maximum sustained rates (line through dots) and at the highest single swimming rate at each salinity (line through squares), with both trend lines indicating an optimum condition at about 20 ppt salinity.

Figure V-5 presents some comparisons of standard, routine, and active metabolic components, as well as metabolic scopes for activity, under various specified environmental conditions for the spotted seatrout. Panel A reveals scope diminution at salinities higher and lower than the apparent 20 ppt optimum, while Panel B reveals scope reduction from summer temperatures of 28 degrees C to winter temperature of 15 degrees C. Panel C shows that scope can be reduced by an increase in the standard metabolism as a result of a mild red tide (Gonyaulax monilata) bloom. In Panel D, the scope appears reduced for spotted seatrout noted to be in poor condition. Cech and Wohlschlag (1975) have also noted a similar growth depression and reduced metabolic scope in another fish, the striped mullet (Mugil cephalus Linnaeus). In both cases, the depression occurred in late summer with the larger individuals being in relatively poorer condition than smaller individuals. It is of interest to note that all panels of Figure V-5 indicate the energy component for routine requirements, above the standard or minimum metabolic rate, is about the same regardless of environmental circumstances.

In a study by Wakeman (1978), the maximum sustained swimming speeds of four estuarine fish species (i.e., spotted seatrout, sheepshead, and black and red drum) were measured at 28 degrees C over a range of salinities (10-40 ppt) normally encountered by these Texas estuarine fishes. Figure V-6 graphically displays the maximum sustained standardized speeds for individuals of the four species averaged at the various salinities. The solid bars represent ± two standard errors and if the bars from any two sets of data do not overlap, the difference between the means is considered to be statistically significant. The performance-salinity curves for sheepshead (Panel A), black drum (Panel B), red drum (Panel C), and spotted seatrout (Panel D) all appear to be maximal near salinity optima in the 20-25 ppt range. Of the four species, spotted seatrout showed the steepest curve with maximum sustained speeds dropping off rapidly as salinity levels were increased or decreased from the optimum. All of the species are of commercial and recreational importance to the Trinity-Galveston estuary, therefore results of these metabolic research studies should be valuable to those concerned with planning and management of the estuarine system and its production of renewable fish resources.

In this chapter, observed and potential effects of freshwater inflow at Trinity Delta on the estuary's renewable fishery resources has been explored. Where seasonal needs are competitive between estuarine-dependent species (e.g., one species prefers low salinities in the spring and another prefers high salinities in the same season) a management decision must be made to give preference or balance the species' needs. The decision could be made on the basis of which organism's production has been more characteristic of the estuary of interest.

Quite obviously, there are distinctive conditions associated with each estuarine system that reflect long-term adaptations to differing salinity, nutrient, and sedimentary balances. Among such distinctive characteristics are bay size, salinity, number and size of contributing marshes, extent of submerged seagrass communities, species diversity, and dominant species production, all of which respond differently to fluctuating inflow conditions. Therefore, timing of freshwater inflows can be extremely important, especially since adequate inflows during critical periods (or seasons) can be of much greater benefit to ecological maintenance than abundant inflows at non-critical periods or a more constant (i.e., non-dynamic) inflow regime. As a result, the environmental needs of an estuarine ecosystem are not static annual needs. Indeed, dynamic equilibrium about the productive range is both realistic and desirable for an estuarine environment; however, extended or semi-permanent inflow conditions which consistently fall below maintenance levels can lead to a degraded estuarine environment, loss of important "necessary" functions for estuarine-dependent fish and shellfish resources, and a reduction in the large potential for safe assimilation of organic and nutritive wastes.

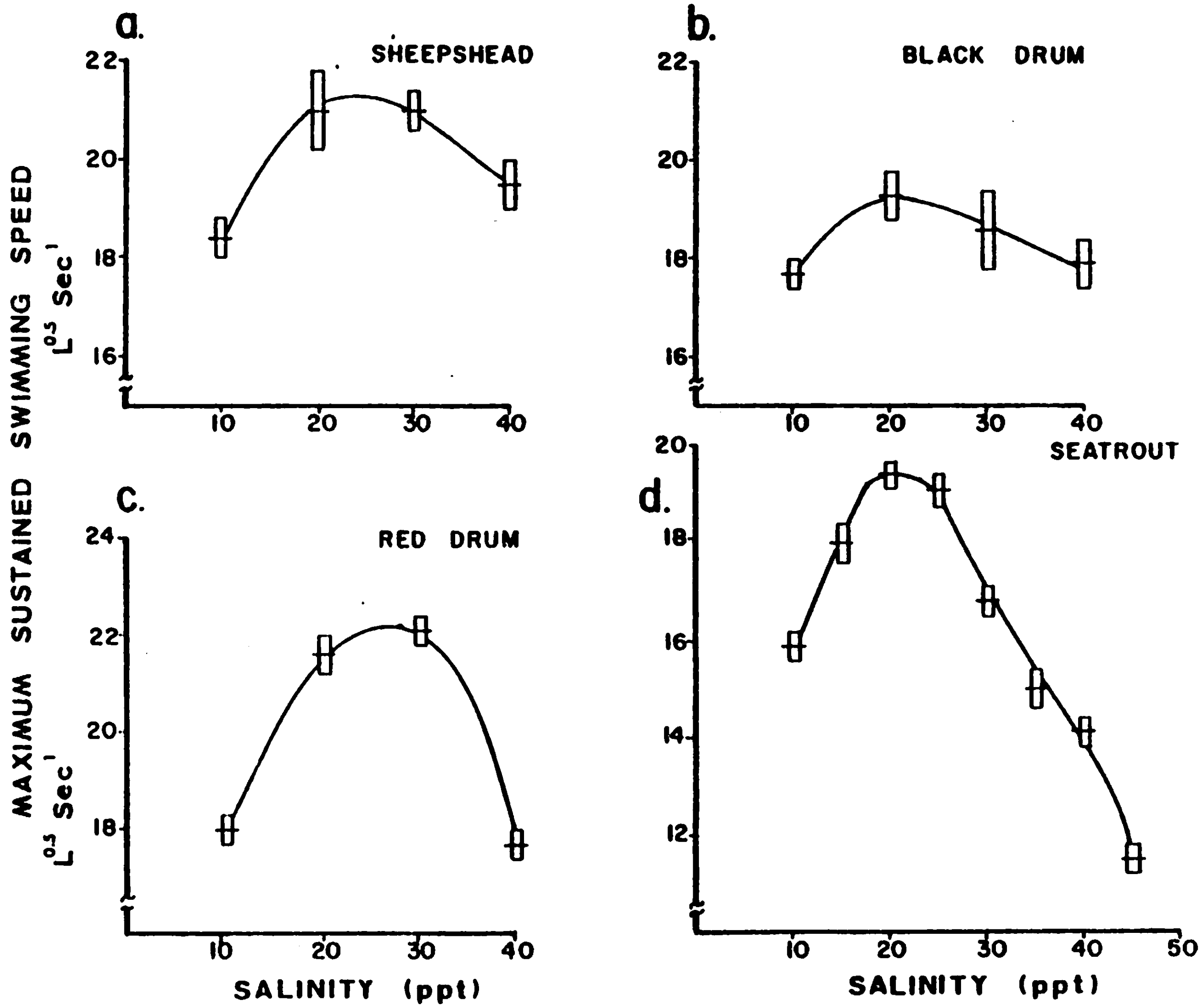

Figure V-6. Effects of Salinity on the Maximum Sustained Swimming Speed of Four Common Texas Coastal Fishes

CHAPTER VI

MARSH INUNDATION ANALYSIS

After the development and verification of mathematical modeling procedures relating the physical, chemical and biological characteristics of the Trinity River Deltaic Marsh ecosystem to the hydrodynamic characteristics of the ecosystem, the hydrodynamic model was used to simulate various flow regimes to predict the quantity of Trinity River flow necessary to periodically inundate the deltaic marsh and to transport organic and inorganic materials from the deltaic marsh to the Trinity-Galveston Bay complex. This was accomplished by routing floods of various magnitudes through the model of the deltaic marsh and determining the extent of inundation by these flow regimes. The next step was to operate the mass transfer model with these same flow regimes to simulate the quantities of nutrients transported to the bay. However, since the mass transfer model was not fully verified, an alternate method was used to estimate the transport of nutrients. This method involved the use of the results of nutrient exchange rate studies to predict the quantity of nutrient exchange that would occur under an inundation of a given areal and temporal extent.

Prior to the operation of the hydrodynamic model for various flood events, it was necessary to determine the amount of inundation, i.e., areal extent of inundation, depth of inundation, and total time inundated, required for adequate nutrient exchange to occur.

This information was developed from the results of the habitat, nutrient exchange rates, and nutrient balance studies presented in Chapter III. Based on these studies, the region considered to be biologically the most important area of the Trinity marsh systems was determined to be that area bounded on the south by the Wallisville levee and continuing northward to the beginning of the cypress swamp area. The eastern boundary is the Trinity River, and extends westward from the river to the beginning of the uplands. Included within this area are all major marsh regions subject to inundation from river flow. This marsh area has high productivity, and inundation of this area should result in the adequate flushing of nutrients into Trinity Bay. This area is the region shaded in Figure VI-1. The nutrient exchange rate studies indicate that upon reinundation after a prolonged drying period of at least 45 days, there is a large initial pulse of nutrients released from the sediments and the sloughing off of dryed attached algae. The rate of release then drops rapidly toward equilibrium. After a period of 24 to 36 hours, the major portion of the nutrients have been released. The studies also indicate an inundation depth of at least four to six inches was necessary for rapid release. Therefore, for the purposes of the

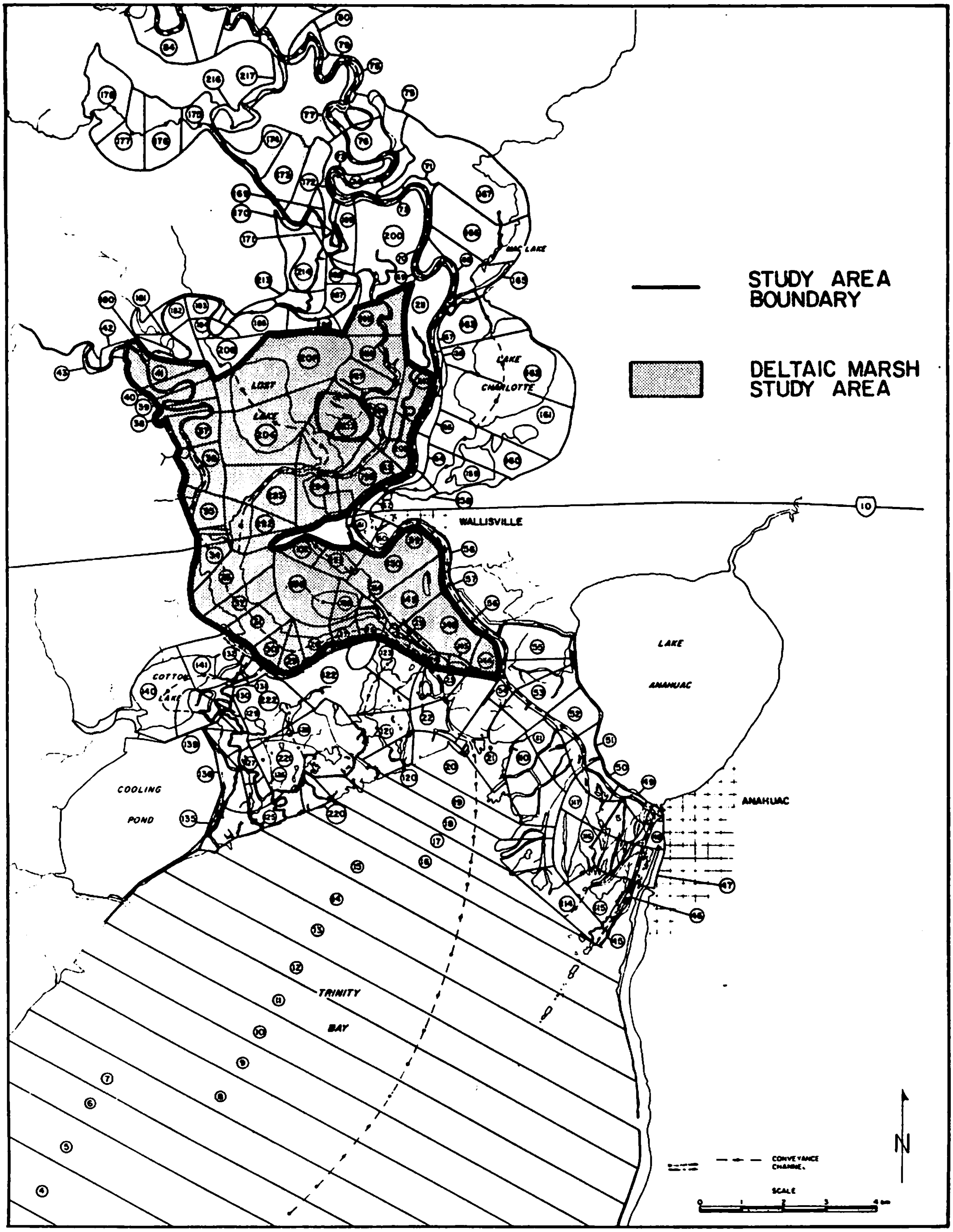

Figure VI-1. Trinity Delta System with Lower Portion of Segmentation (Source: Hauck, et. al., 1978) inundation analysis, the hydrodynamic model was operated to determine the flood event necessary to inundate the marsh area indicated in Figure VI-1 to a minimum depth of 0.5 ft. for a minimum continuous time of two days.

The occurrence and extent of inundation is dependent on the magnitude of the river flow, the tidal conditions at the river mouth, the local meteorological effects such as wind setup and setdown, and runoff from local rainfall. Local meteorological effects such as wind setup were ignored since the model was not designed to handle meteorological conditions explicitly. However, since the delta region is greatly influenced by tide elevations, it is important to determine the proper tide with which to drive the model. High amplitude diurnal tides can result in considerable inundation even at low river inflows, while extremely low tide elevations with small amplitudes which may occur during semi-diurnal tides can result in little marsh inundation even at moderate river inflows. To minimize these effects of tidal amplitude without removing them altogether, it was decided for this study to use an "average" tide, that is, a tide with an amplitude intermediate between the extremes of the semi-diurnal and diurnal tides.

The tide records at Morgans Point for the years 1975 through 1977 were visually scanned for appropriate tides. Specifically, the tides that occurred at the transition from diurnal to semi-diurnal were analyzed. The tidal amplitude and the elevation relative to MSL (mean sea level) of the tide trough were recorded. These data were averaged to arrive at the diurnal tide depicted in Figure VI-2. This tide was used as the tidal input to the model for all simulations.

In order to use realistic but yet generalized flood hydrographs as input to the model, the streamflow records for the Romayor gauge for the period after the Livingston Reservoir had filled were analyzed. During this period five hydrographs that approximated the form of the idealized unit hydrograph occurred. All other hydrographs suffered from multiple peaks, greatly extended peaks, etc. For each of the five hydrographs, the time to peak T_p, the width at 50 percent of the peak discharge T_{50} and, the time of the recession T_r were measured. These three parameters were used to define the canonical (standard) hydrographs used in the simulations, see Figure VI-3. For the five floods, the three parameters were plotted with a sixth data point at (0,0) included and regression lines were fitted to the data to display the relation between these time measures and peak flow Q_p. The time to peak, width at 50 percent of peak discharge and time of recession plots with respective regression lines against Q_p are depicted in Figures VI-4, VI-5 and VI-6, respectively.

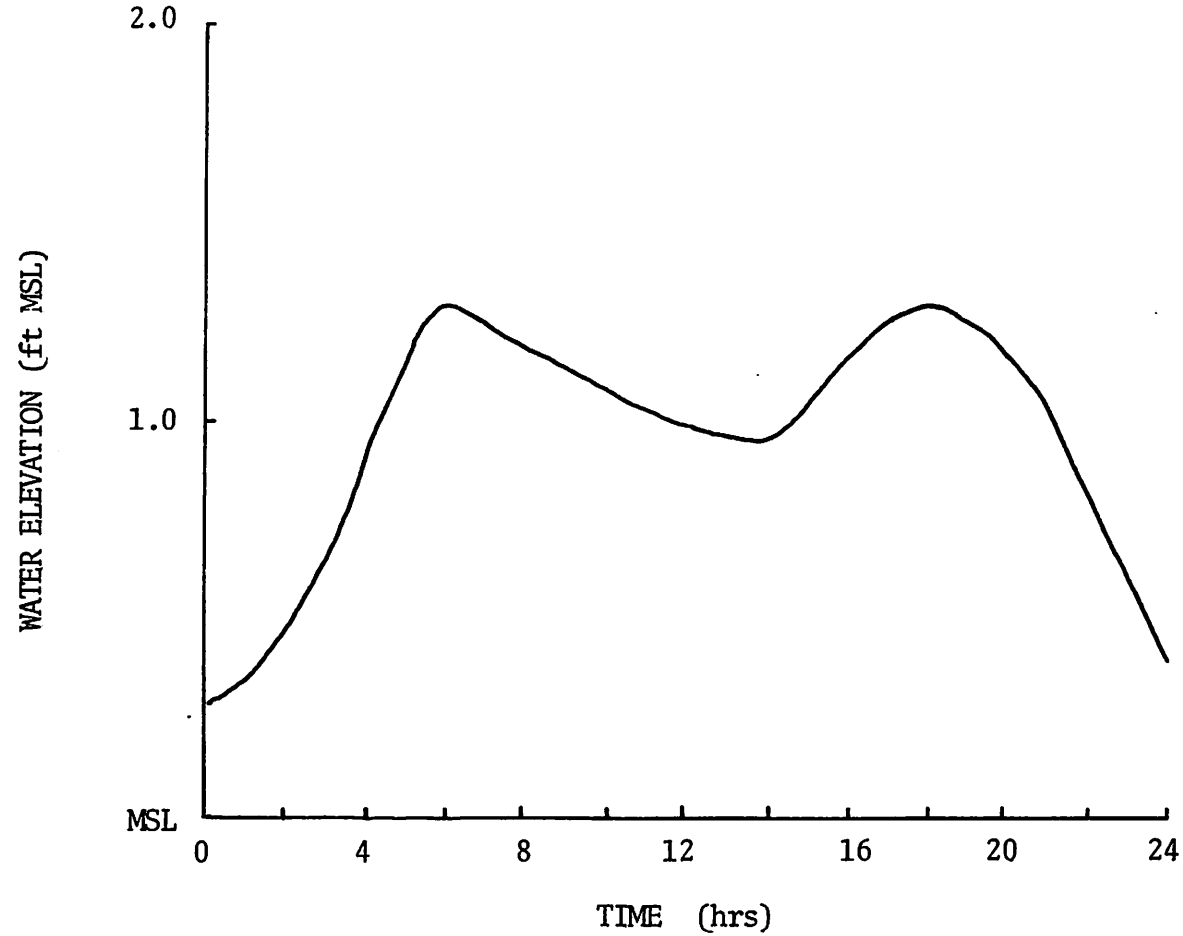

Figure VI-2. Driving Tide at Morgans Point
(Source: Hauck, et. al. 1978)

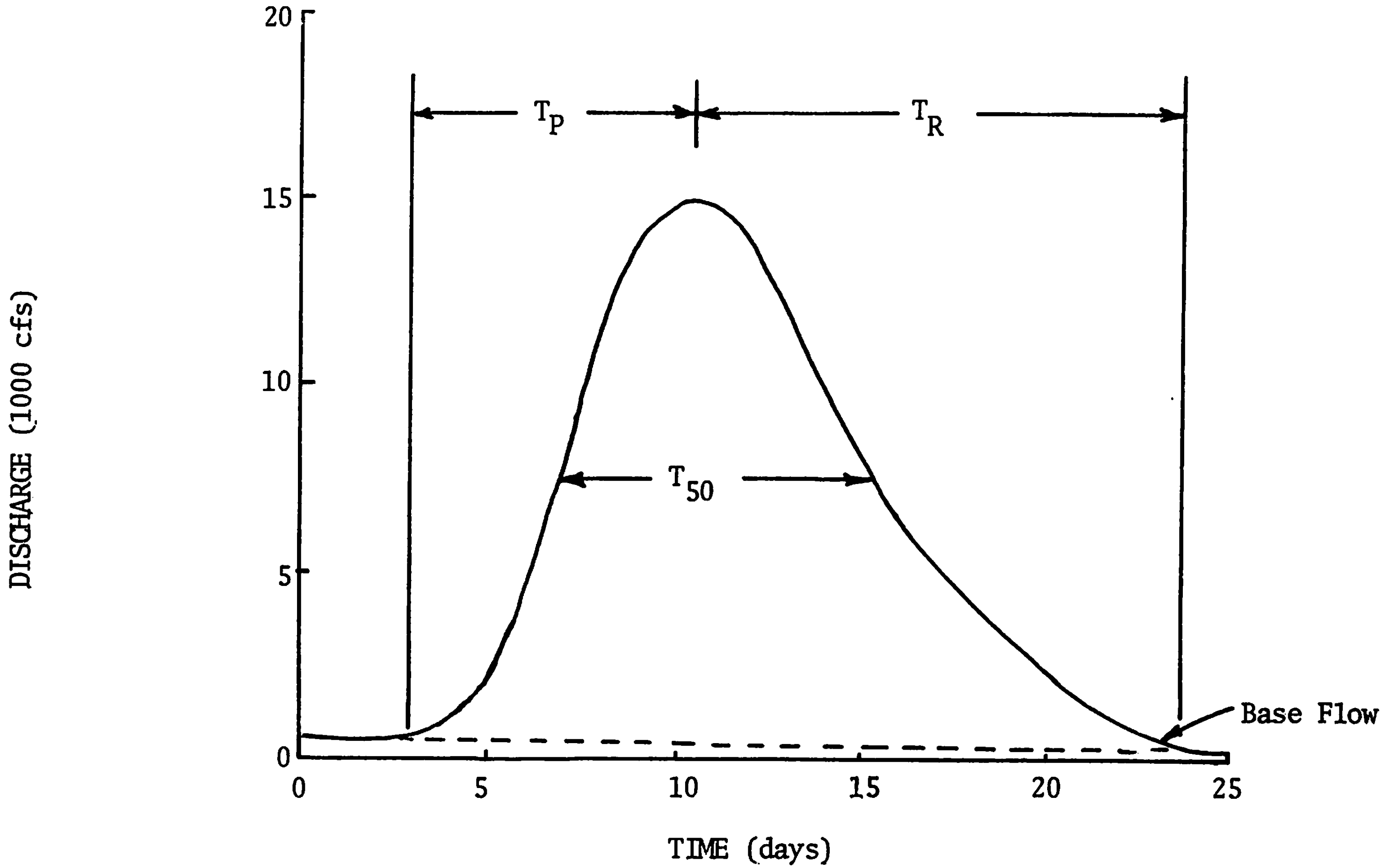

Figure VI-3. Typical Canonical Hydrograph (Source: Hauck, et. al. 1978)

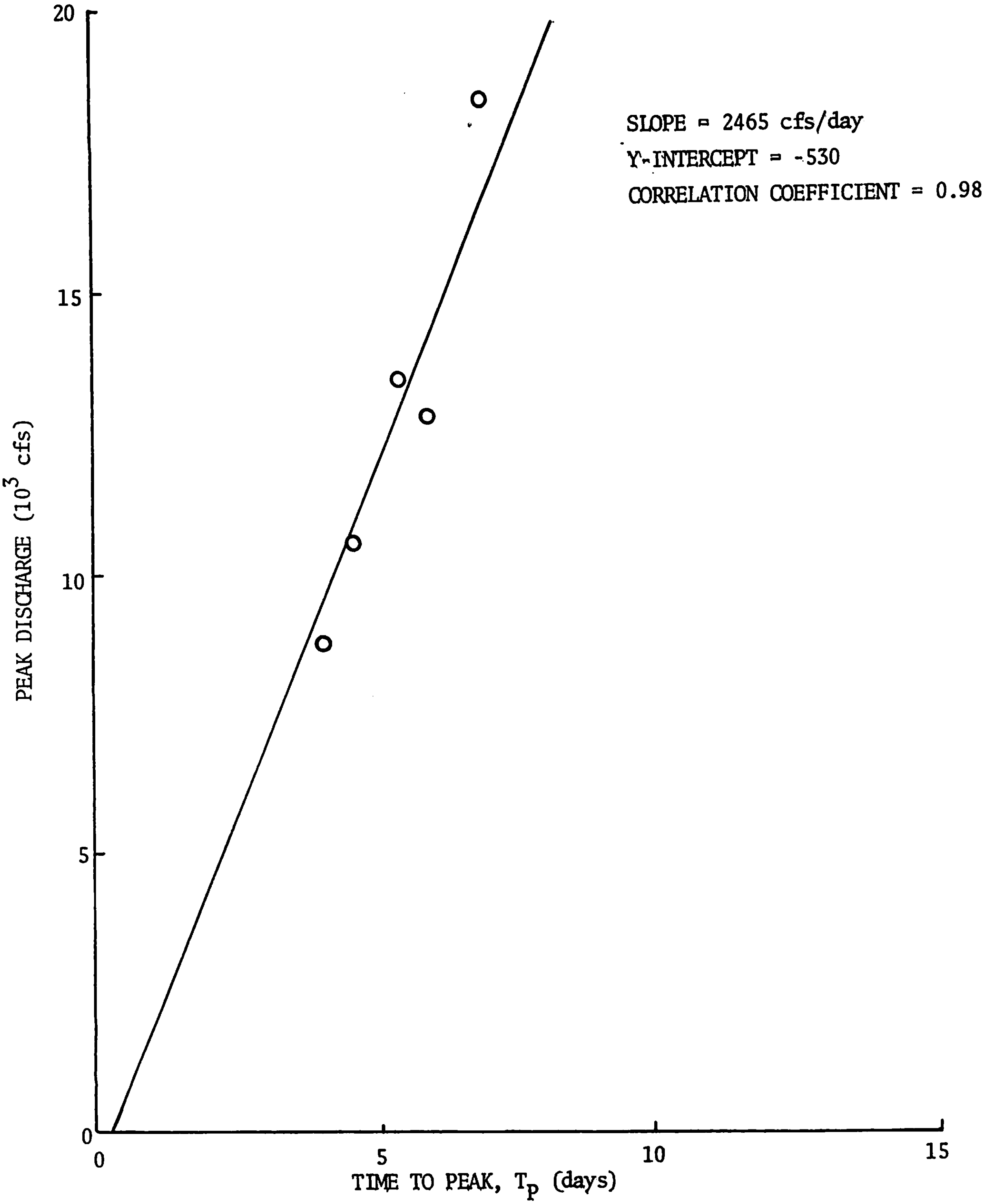

Figure VI-4. Time to Peak for Canonical Hydrograph, Trinity River at Romayor (Source: Hauck, et. al. 1978)

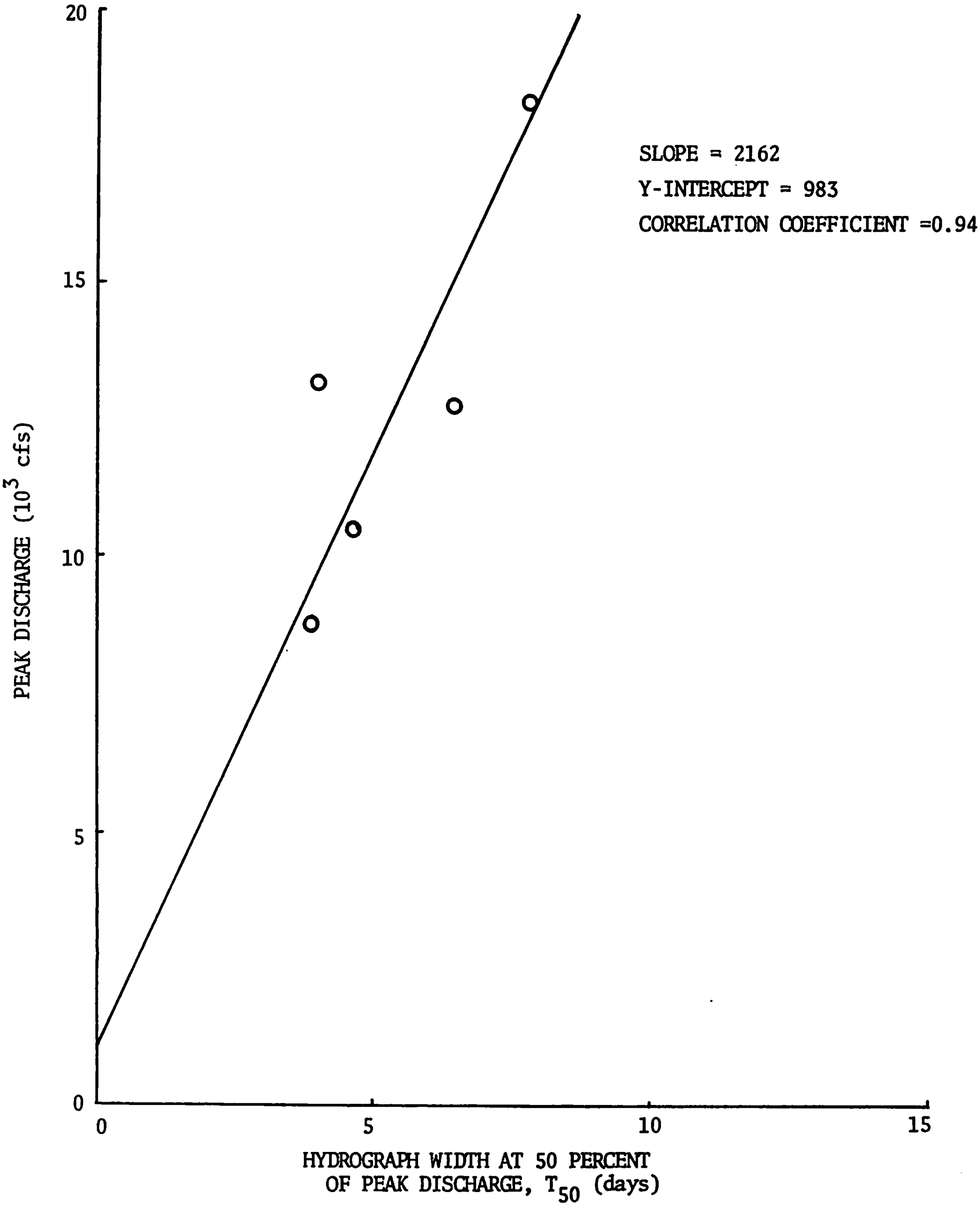

Figure VI-5. Hydrograph Width at 50 Percent of Peak Discharge, Trinity River at Romayor (Source: Hauck, et. al. 1978)

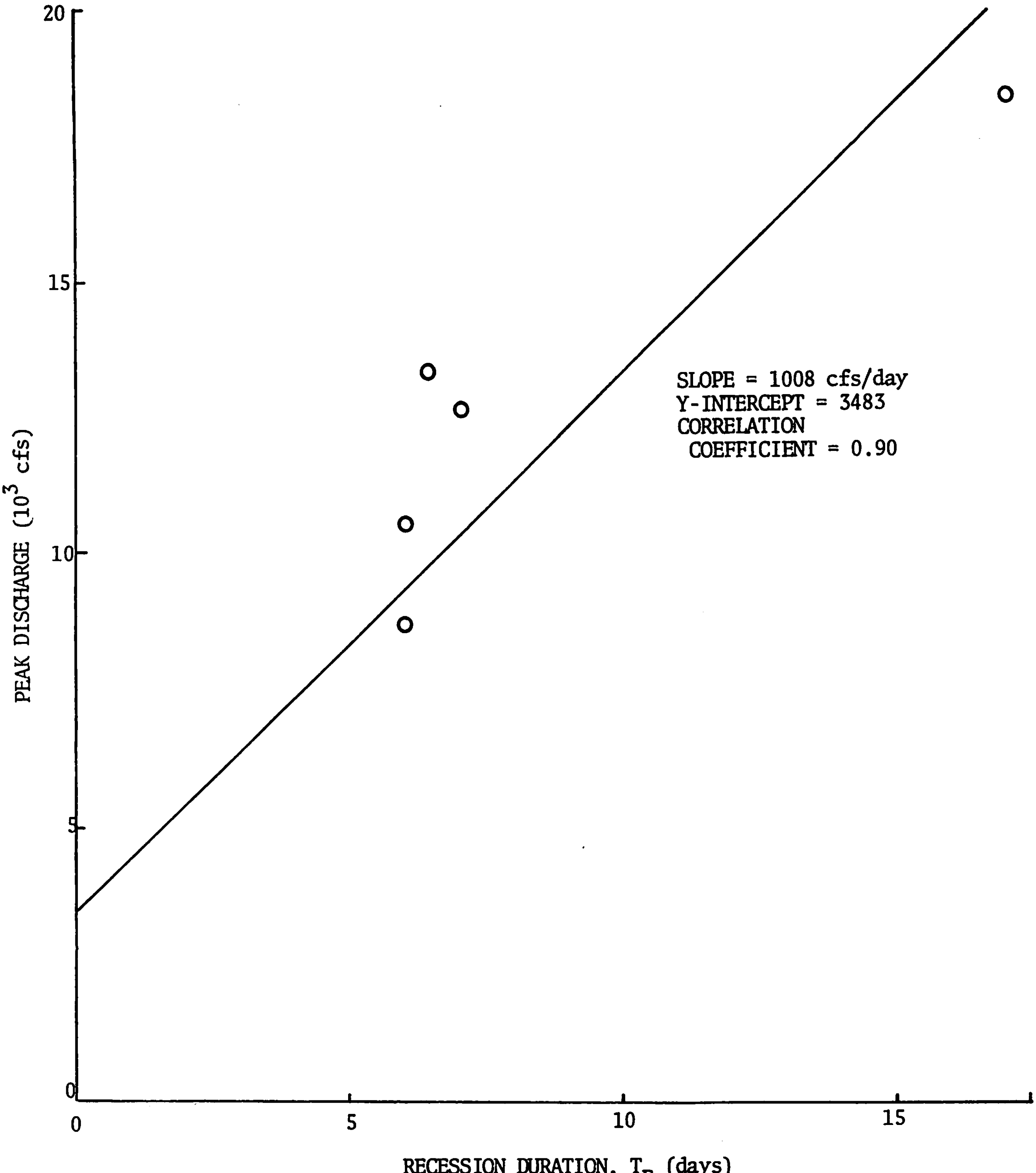

Figure VI-6. Time of Hydrograph Recession, Trinity River at Romayor
(Source: Hauck, et. al. 1978)

Canonical hydrographs were determined for a series of six peak flows ranging from 10,000 ft^3/sec to 35,000 ft^3/sec at increments of 5,000 ft^3/sec and with a base flow of 500 ft^3/sec. The parameters describing these six hydrographs are presented in Table VI-1.

These six hydrographs were used as boundary conditions for the model simulations. For each simulation the amount of the study area marsh inundated at a minimum depth of 0.5 ft. for at least two days was determined. The results are presented in Figures VI-7 and VI-8, which depict percent inundation versus peak discharge and percent inundation versus flood volume, respectively. The simulations indicate a rapidly increasing amount of inundation between the 15,000 cfs peak discharge flood (190.0 thousand acre-feet flood volume) and the 25,000 cfs peak discharge flood (71.0 thousand acre-feet flood volume). At a peak discharge of 25,000 cfs, nearly 85 percent of the marsh area is inundated. From this point, increased flow results in a diminishing return in terms of area inundated. Total inundation of the marsh occurs in a peak discharge of 35,000 cfs, which has a flood volume of 122.0 thousand acre-feet.

From the simulation results it appears that a peak discharge of 25,000 ft^3/sec with a total volume of 61.0 thousand acre-feet spread over 31 days, which inundates nearly 85 percent of the marsh, is the most judicious use of water in terms of the amount of inundation for quantity of water required. Above this value, a larger quantity of water results in only a few percent change in inundated area; indeed, the total volume must be doubled to 122.0 thousand acre-feet to inundate the remaining 15 percent of the marsh.

The mean monthly total inflow for the Trinity River Delta for 1970 through 1976 (the period after Livingston Reservoir had filled) are shown in Table VI-2. These flows include the gauged flows at Romayor and ungauged flows below Romayor, but exclude all diversions below Romayor. Also included in Table VI-2 are the mean flows for each month for the seven-year period. These data show that sufficient historical flow resulting in significant marsh inundation has generally occurred at least once during the winter months of December through February and again during the spring and early summer months of March through June. Biological studies have indicated that a winter inundation is needed to provide the bay system with nutrients to build a food base for the juvenile species which arrive in the spring. Another inundation is required in the spring to continue this food supply and to maintain salinity levels low enough for optimal growth of the juvenile species.

To translate the inundation events into nutrient transfers from the delta to the bay, it is necessary to apply appropriate nutrient exchange rates. The studies by Armstrong, Harris, and Gordon (1977) showed that, with the exception of those reactors taken from the Mac Lake area, nutrient exchange rates for the

Table VI-1. Canonical Hydrographs Used in Simulations (Source: Hauck, et. al., 1978)

Peak Discharge (cfs)	Time to Peak (days)	Width At 50% of Peak Flow (days)	Time of Recession (days)	Flood Volume* (acre-feet)	Average Discharge* (cfs)
10,000	4	4	6	0.91×10^5	4.6×10^3
15,000	6	6	11	1.9×10^5	5.6×10^3
20,000	8	8.5	16	3.9×10^5	8.0×10^3
25,000	10	11	21	6.1×10^5	9.9×10^3
30,000	12	13	26	8.6×10^5	11.4×10^3
35,000	14	15.5	31	12.2×10^5	13.6×10^3

* The 500 cfs base flow is not included in this calculation.

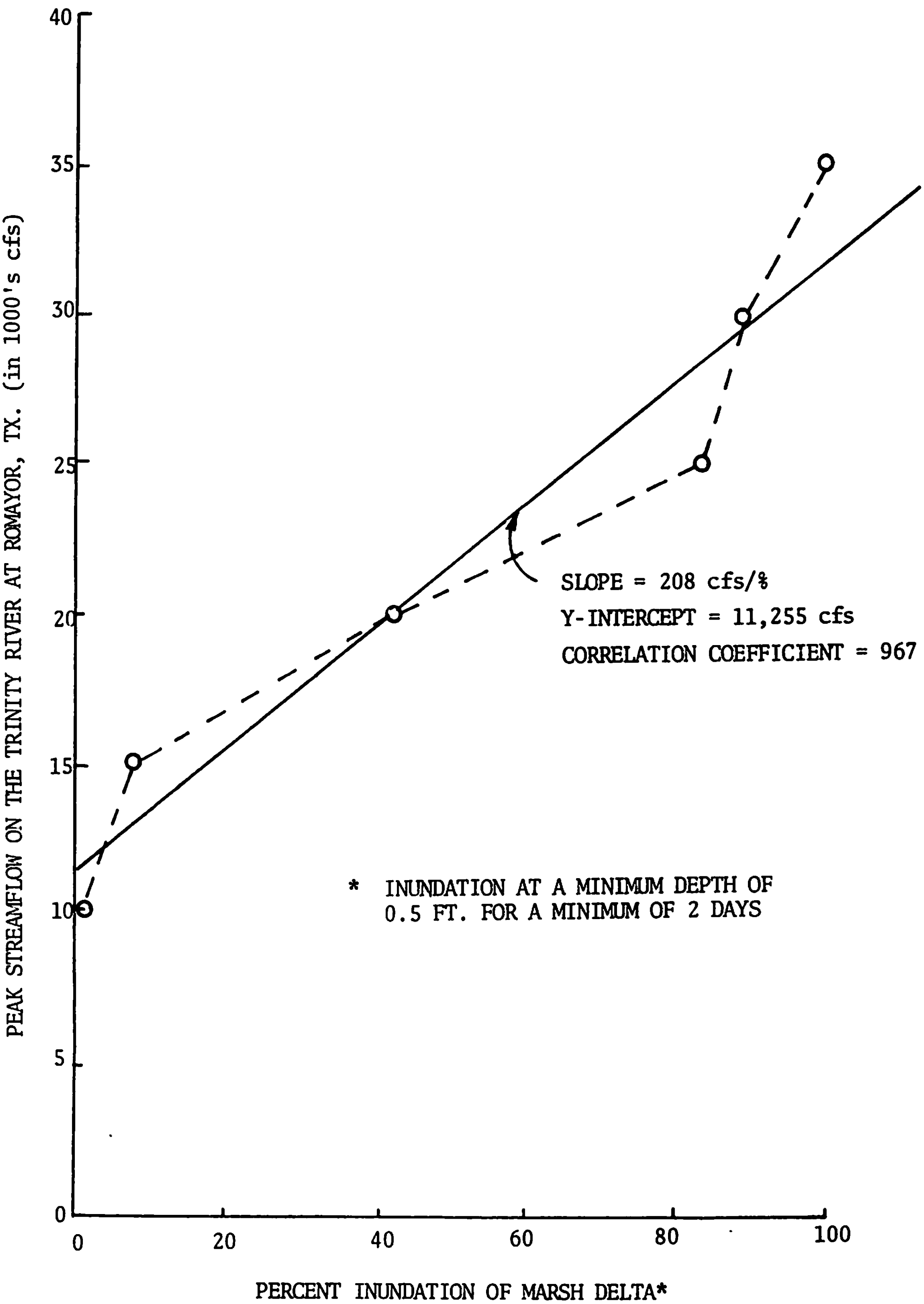

Figure VI-7. Percent Inundation Vs. Peak Discharge
(Source: Hauck, et. al. 1978)

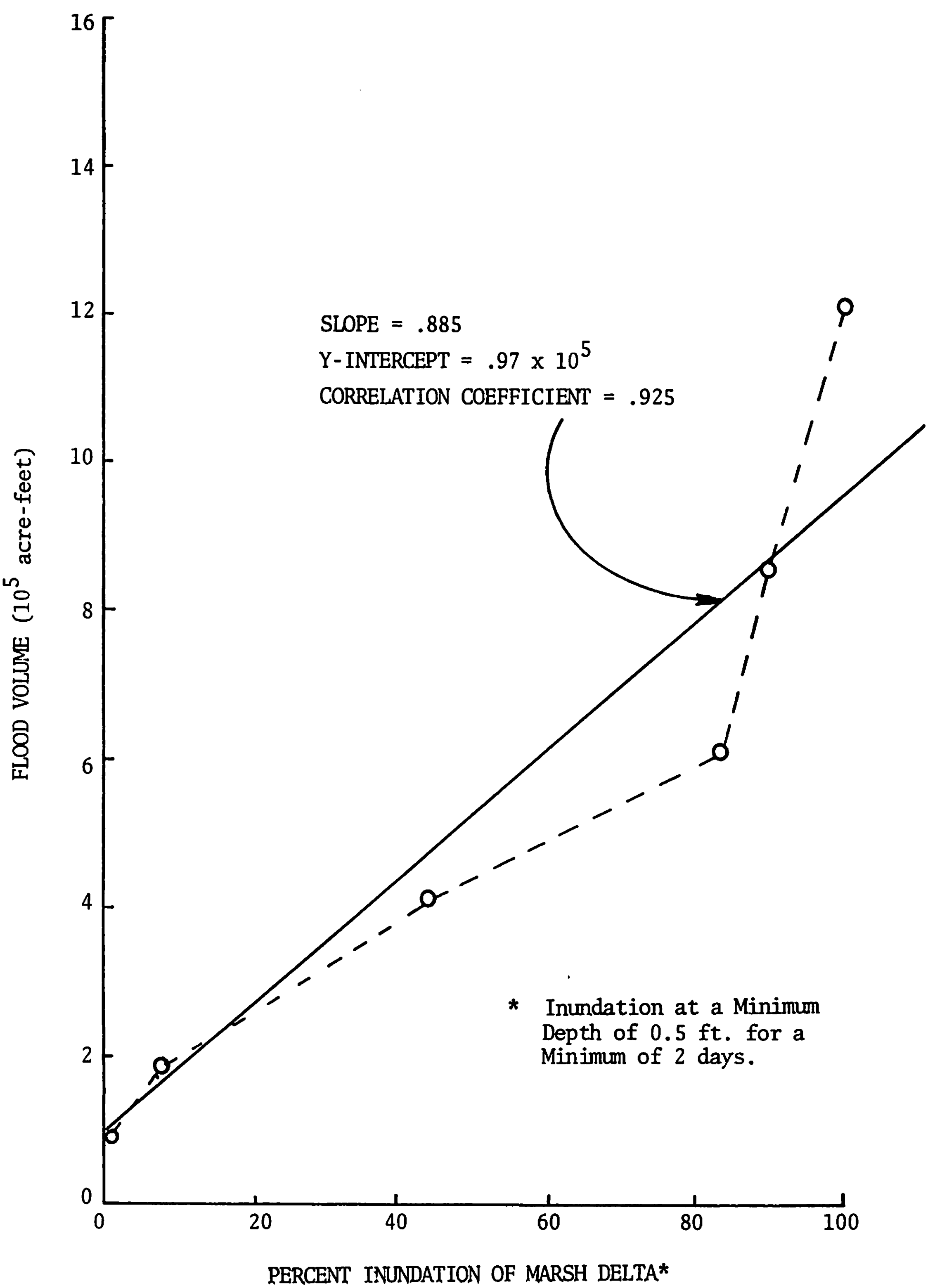

Figure VI-8. Percent Inundation Vs. Flood Volume (Source: Hauck, et. al.1978)

Table VI-2. Mean Monthly Flows at the Trinity Delta (x 10^3 acre-feet) Including Gauged Flow at Romayor, Ungauged Runoff, and Excluding Diversions (Source: Hauck, et. al. 1978)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1970	310	257	1415	512	351	162	72	36	115	317	63	33
1971	21	32	54	79	56	38	13	51	90	26	306	1586
1972	1307	263	116	93	421	55	94	5	95	25	269	215
1973	622	623	1506	1573	1430	2150	466	263	347	1775	925	917
1974	1579	405	289	246	621	166	62	67	876	323	2056	1578
1975	840	1703	643	996	1298	1182	345	308	63	106	152	99
1976	110	104	162	436	1261	966	414	51	151	250	206	815
Mean	684	483	598	562	777	678	209	112	248	403	568	749

major plant types found in the plexiglass reactor from the Trinity delta were similar. In general these exhibited a consistent export of solids (TSS and VSS), some alternate uptake or release of BODs and TOC at rates less than those for the solids, and consistent low rates of uptake of nitrogen and phosphorus.

These exchange rates were smaller than those reported from similar studies in other Texas marshes (Armstrong, et. al., 1975; Armstrong and Gordon 1977a; and Armstrong and Gordon 1977b). It was felt that these rates reflect the small amount of mixing in each reactor. As previously mentioned it is expected that exchange rates during inundation following a prolonged dry period would be substantially higher in a release mode for a short period of time. Unlike the plexiglass cores that reflected long term, steady-state conditions the water stage and tide range in the linear model marsh was manipulated to more accurately simulate the normal and flood conditions of spring and the subsequent low flow conditions of summer. This system was felt to more nearly represent actual conditions that might occur in the Trinity Delta for a community of diverse plant species including the contribution of blue-green algal mats that seem to be playing an important role in the nutrient exchange process. For these reasons the exchange rates applied to the inundation analysis are those derived from the linear marsh studies.

Based on the delta inundation model presented here, it has been shown that at a peak discharge of 25,000 cfs the shaded area depicted in Figure VI-1 becomes inundated. This area of roughly 4,220 hectares is populated by several macrophyte species that include Paspalum lividum, Echinochlon muricata, Spartina patens, Sagittaria graminea, Phragmites communis, Aster subtalus, and Persicania punetata (Adams, 1977). Spartina patens was the only species in the linear model marsh common to those in the above list. Since the plexiglass core reactor studies indicate a similarity in magnitude of exchange rates for different species (with the exception of those from the Mac Lake area), the rates derived from the linear marsh studies are assumed to apply throughout the shaded area of inundation in Figure VI-1. These studies indicate that during March through June organic carbon, organic nitrogen, and organic phosphorus should be released during most inundation events.

Applying the exchange rates in Table III-10, one can determine the potential order of magnitude of nutrient contributions from the marsh to the estuary. For an inundation event of the magnitude depicted in Figure VI-1 during the period March through June the marsh would be releasing from 150,000 to 275,000 kg/day of total suspended solids, 2,000 to 18,000 kg/day of total organic carbon, 120 to 350 kg/day of organic nitrogen, and roughly 100 to 125 kg/day of organic phosphorus.

During the late fall and winter months of 1976, the linear model marsh was allowed to stabilize from the shock of being dug up and transported from the coast to the laboratory in Austin. For this reason no nutrient exchange data were collected for the late fall and winter seasonal; therefore, no direct comparison can be made between nutrient loading potential of this period versus that discussed above. It is reasonable that an inundation event in late January or February would be beneficial to "prime" the marsh and adjacent estuary with the low salinities preferred by many larval marine species. In addition, large amounts of carbonaceous particulate materials that include remains of senescent plant biomass from the previous growing season and "chunks" of sloughed-off blue-green algae would be flushed into the open estuarine waters providing a detrital and nutrient supply source for the incoming young organisms.

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