Technical Report TAMU-CC-CBI-96-01

ENVIRONMENTAL MONITORING OF DREDGING AND PROCESSES IN LOWER LAGUNA MADRE, TEXAS

Final Report, Year 1

by

Cheryl A. Brown, Nicholas C. Kraus

with contributions by

Kenneth H. Dunton, James E. Kaldy,
Troy A. Schleman, and John W. Tunnell, Jr.

Prepared for:

U.S. Army Corps of Engineer District, Galveston
2000 Fort Point Blvd.
Galveston, Texas 77553

March 20, 1997

Texas A&M Research Foundation

Conrad Blucher Institute for Surveying and Science

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Texas A&M Research Foundation

Executive Summary

This study was conducted for the Galveston District of the U.S. Army Corps of Engineers (USACE) to investigate the physical processes and sediment transport in the vicinity of open-bay dredged material placement areas along the Gulf Intracoastal Waterway (GIWW) in the lower Laguna Madre. This report summarizes the first year of an anticipated 2.5-year monitoring effort to provide data to assist in the development of a comprehensive dredged material management plan addressing environmental and economic concerns. In the lower Laguna Madre, there is a 8-km (5-mile) reach of the GIWW which has relatively high shoaling rates and requires maintenance dredging by the USACE approximately every 2 years. The objectives of this study are to assess the flow and sediment transport conditions and to identify possible modifications of the dredging practice to both reduce environmental impacts and to minimize the cost and frequency of dredging. The main issues of concern in the monitoring project are:
1) encroachment of sediment on seagrass beds and reduction of light within the water column, 2) encroachment of sediment into wetlands, 3) transport of dredged material back into the GIWW and loss of material from placement areas, and 4) understanding of cause-and-effect relations between hydrodynamic forcing and sediment transport.

The objectives of the study were achieved through a comprehensive, multi-disciplinary monitoring effort consisting of four components: 1) sustained measurements from fixed stations, 2) synoptic surveys; 3) hydrographic surveys; and 4) quantitative seagrass distribution surveys. The fixed-station monitoring consisted of continuous long-term (1-year) monitoring of physical parameters at a platform deployed in the vicinity of an open-bay placement area.

Major results and conclusions of Year 1 of this study are:

1. Analysis of the dredging records shows that, subsequent to the initial construction of the GIWW, the sedimentation rate of the GIWW in the high shoaling reach has remained fairly uniform, however, extreme meteorological events, such as hurricanes, can substantially increase the shoaling rate in this region. The average shoaling rate in the GIWW for this reach is 250,000 cu yd of material per year, or 2.2 ft per year. Hydrographic surveys, conducted in the vicinity of open-bay placement areas, indicate that approximately 70% of the material placed in the region erodes within 8 months subsequent to dredging, and the bathymetry returns to a configuration similar to that observed prior to dredging. The highest shoaling rates for the GIWW also occur within 8 months subsequent to dredging, indicating that a large percentage of the material is being re-deposited into the GIWW.

2 The high shoaling rate in the study area is a result of wide-area circulation pattern produced by a depression in the bathymetry in the southwestern portion of the lower Laguna Madre The high-shoaling reach is situated where the GIWW crosses this geomorphic feature Long-term current measurements (1 year) show that there is a consistent cross-channel flow in the vicinity of the open-bay placement area, which is present throughout the year during all hydrodynamic conditions (tidal phases and wind conditions). The current in this region typically is within the range of 10-15 cm/sec (0.3-0 5 ft/sec) directed to the northeast or southwest, depending upon the tidal phase and or meteorological conditions.

3 Wind-generated waves and wind-generated currents are the dominant mechanisms for sediment resuspension in the study area Typically, when the wind speed exceeds a threshold level of about 10 m/sec (22 mph), there is an increase in the level of suspended solids and a corresponding increase in light attenuation. During the passage of fronts, the turbidity levels increase within hours of the initiation of the wind forcing, and return to pre-frontal conditions within 24 hours of reduction in the wind forcing

4 The 1-year data set shows that prior to dredging, the suspended solids and subsequent light attenuation were minimal during the calm seasonal meteorological conditions characteristic of September. Subsequent to dredging (that occurred in late September through October, 1994), the suspended solids and light attenuation became more variable and increased approximately three-fold By June, 1995, the sediment concentration and underwater light returned to levels similar to those observed prior to dredging One year after dredging, there was a statistically significant difference in the light attenuation; however, this difference may be explained by variability in the background conditions and inter-annual variation in the meteorological conditions.

5 *Thalassia testudinum*, the most commonly occurring seagrass species in the study area, showed a statistically significant decline in above-ground biomass over the study period, however, this difference is within the range of interannual variation of the species. No other seagrass species exhibited a significant change during the study period.

The recommendations of this study to reduce the environmental impacts, and cost and frequency of dredging are

1. Eliminate open-placement in the vicinity of the high shoaling reach of the GIWW (Stations 45+000 and 70+000). There are several alternatives for the placement of this material, to augment existing emergent islands to the north of the high shoaling reach, to place the material to the south of the high shoaling reach, or to remove the material from the system, by either placing the material in an upland location or offshore.

2 In conjunction with eliminating open-bay placement in the high shoaling reach, overdredge this reach by approximately 0 8 m (2.5 ft) The high shoaling reach will continue to shoal more rapidly than the surrounding portions of the GIWW due to the preferential cross-channel flow in this region. Assuming a uniform typical shoaling rate, overdredging by 0 8 m (2 5 ft) may extend the maintenance cycle by approximately one year reducing the frequency of environmental impacts associated with maintenance dredging

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Preface

The one-year environmental monitoring study of dredging and physical processes in the lower Laguna Madre described herein was conducted for the U.S. Army Corps of Engineers, Galveston District, under the recommendation of the Laguna Madre Interagency Coordination Team Notice of authorization to proceed was received on August 12, 1994, and data-collection commenced on August 31, 1994

This multi-disciplinary study was conducted by staff from the Conrad Blucher Institute for Surveying and Science at Texas A&M University-Corpus Christi (TAMU-CC), University of Texas at Austin Marine Science Institute; and the Center for Coastal Studies (CCS) at TAMU-CC The study was planned and organized by Co-Principal Investigators Dr. Nicholas C Kraus and Cheryl A. Brown of the Blucher Institute. Dr Kenneth H Dunton and Mr. James E Kaldy, UTMSI, conducted the light monitoring component of this study, including data collection, analysis, and reporting Under the direction of Dr John W. Tunnell, Jr , CCS, Mr Troy Schleman, graduate student, performed the field and laboratory work, and wrote the text for the seagrass distribution component of this study Blucher Institute staff designed, installed, and maintained the data-collection equipment, imported and archived the data; conducted hydrographic surveys and associated data reduction, analyzed the data, and reported on the progress and status of the study

The following Blucher Institute staff members assisted significantly in this project Messrs Daniel Prouty, Donald Waechter, Greg Hauger, and John Adams performed the hydrographic surveying component of the study. Radio communications expertise was provided by Mark Earle. Computer and database support was provided by Scott Duff, Gerardo Garza, and Rocky Freund Location maps were generated by Deidre Williams, Karen Bridges, and Daniel Prouty. Instrumentation and datalogger expertise was provided by Daryl Slocum and Mike Grady. The fixed stations were maintained by numerous Blucher Institute personnel, including John Adams, James Rizzo, Mark Earle, Scott Fagan, and Walt Sohl Analysis of the water samples and associated data entry was performed by Maureen Pate, Sara Ussery, and Shekar Koneru.

For the light attenuation component, Kun-Seop Lee and Sharon Herzka provided valuable assistance in the field and kindly reviewed previous versions of the manuscript Joseph Kowalski, Chris Krull, Jim White and Carina Chiscano also provided valuable assistance in PAR datalogger and sensor maintenance, and Susan Schonberg provided exceptional support in data organization and management, and graphics production Dr. Christopher Onuf and Mr Jamie Ingold, National Biological Survey, and Edward Kobilizek of TAMU-CC assisted with the sampling for the seagrass component

The authors would also like to thank Mr Don Hockaday, Director of the Coastal Studies Laboratory, University of Texas-Pan American, for providing support and laboratory space and Mr Jeff Lillycrop of the Waterways Experiment Station for providing recent hydrographic data

1. Introduction[1]

This chapter includes the study background and objectives of the monitoring effort in the lower Laguna Madre, as well as a description of the components of the study An orientation to the study site is presented, including a comparison of historical and recent bathymetry in the region The chapter concludes with a short description of the contents and organization of this report

Background and Problem Statement

Concern has been raised about the environmental consequences of maintenance dredging operations and traditional dredged-material placement techniques in the Laguna Madre, Texas (for example, Onuf 1994) In the lower Laguna Madre (roughly defined as the region of the Laguna Madre from the Land Cut south to Brownsville), there is a 8-km (5-mile) reach of the Gulf Intracoastal Waterway (GIWW) characterized by high shoaling rates, requiring maintenance dredging there approximately every 2 years

During late September and October, 1994, the Galveston District of the U S Army Corps of Engineers (USACE) conducted maintenance dredging of this high shoaling reach of the GIWW Four different types of placement techniques were utilized during these dredging operations submerged confined levees, submerged shallow mounding, confined in-bay, and open-bay placement Through a Memorandum of Agreement between the Galveston District and the Texas A&M Research Foundation, authorized on August 12, 1994, the Conrad Blucher Institute for Surveying and Science at Texas A&M University-Corpus Christi (TAMU-CC) conducted an environmental monitoring study of this maintenance dredging project with emphasis on the traditional open-bay placement locations The objectives of this ongoing multidisciplinary study are to assess water flow and sediment transport conditions and to identify possible modifications of the dredging practice to both reduce environmental impacts and to minimize the cost and frequency of dredging The main issues of concern in the monitoring project were and continue to be

1 Encroachment of sediment on seagrass beds
2 Resuspension of sediment in dredged material placement areas.
3 Reduction of light within the water column
4 Transport of dredged material back into the GIWW and loss of material from placement sites

[1] Written by Cheryl A Brown and Nicholas C Kraus, Conrad Blucher Institute for Surveying and Science, Texas A&M University-Corpus Christi

5 Understanding of cause-and-effect relations between hydrodynamic forcing and sediment movement

Site Description

The Laguna Madre is a shallow, coastal embayment extending approximately 200 km (125 miles) southward from Corpus Christi Bay to Port Isabel, Texas, near the border with Mexico (Figure 1.1) The Laguna Madre system is one of only three permanent hypersaline lagoonal water basins in the world, specifically Laguna Madre of Texas, Laguna Madre de Tamaulipas in Mexico, and the Sivash next to the Sea of Azov in the Crimea (Gunter 1967). The hypersaline conditions of the Laguna Madre are primarily attributed to the limited water exchange with the Gulf of Mexico, negligible fresh water inflow, and high evaporation rate (Breuer 1962) Exchange between the Laguna Madre and the Gulf of Mexico is limited to three permanent openings. Brazos Santiago at the southern terminus of the Laguna, Mansfield Pass, and Aransas Pass at the northern terminus via Corpus Christi Bay

Based on area, the Laguna comprises only 20% of the coastal embayments of Texas, but it contains approximately 80% of its seagrasses Seagrass meadows cover most of the bottom of the Laguna due to shallow depth, and relatively low allochthonous inputs of suspended particles and nutrients (Quammen and Onuf 1993). The high productivity of the Laguna, inferred from finfish catch, has been well correlated with the presence of the extensive seagrass beds (Texas Department of Natural Resources 1979)

The Laguna is subdivided into two basins each with an average depth of about 1 m (3 ft), referred to as the upper and lower Laguna Madre The basins are separated by a 40 km-long wind-tidal flat known as Saltillo Flats. The USACE completed the GIWW along the south Texas coast in 1949, reconnecting the upper and lower basins via the channel cut through Saltillo Flats, known as the Land Cut The GIWW, which is 4 m (12 ft) deep, 38 m (125 ft) wide at the bottom, and 64 m (209 ft) wide at the top (design dimensions), was dredged through the entire length of the Laguna Madre The construction of the GIWW has moderated the hypersaline conditions in the Laguna Madre. In the lower Laguna Madre, prior to the construction of the GIWW, salinities greater than 60 parts per thousand (ppt) were measured However, subsequent to the construction of the GIWW, salinities rarely exceed 40 ppt (Quammen and Onuf 1993)

Because of the shallow water of the Laguna Madre and limited connections with the Gulf of Mexico, the Laguna is classified as micro-tidal with mean tidal range varying from 0 3 m (1 ft) in the vicinity of passes with the Gulf to a few centimeters in the interior portion of the Laguna During strong winds, the wind-driven circulation can dominate that produced by astronomical

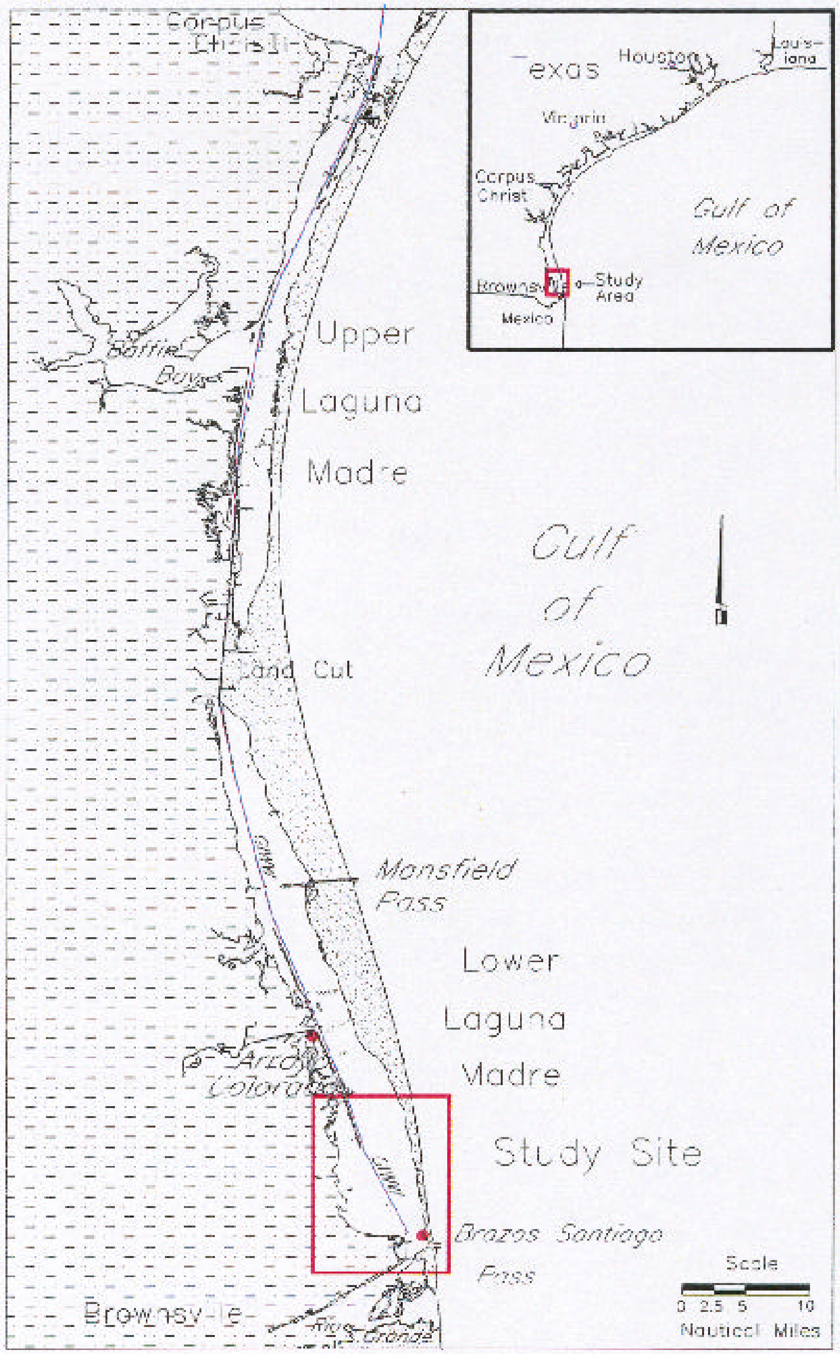

Figure 1.1. Laguna Madre location map.

tidal forcing. Meteorologically, the region is dominated by strong southeast winds for most of the year, interrupted by strong north winds associated with the passage of cold fronts during the winter

Bathymetry

Figure 1.2 shows contours of the bathymetry referenced to Mean Lower Low Water (MLLW) for the southern portion of lower Laguna Madre This figure was generated from recent data provided by USACE, Waterways Experiment Station, obtained from a hydrographic survey conducted of the entire Laguna Madre during April to July, 1995, sponsored by the USACE, Galveston District. In the southern portion of lower Laguna Madre, the depths typically are on the order of 1 m (3 ft), with the exception of the GIWW The western portion of the study area has a slight depression with depths of 1.2 to 1 5 m (4 to 5 ft) In the vicinity of the portion of the GIWW experiencing high shoaling rates (identified in Figure 1.2), the GIWW crosses this depression To the north and south of the region with high shoaling rates, there are areas with shallower water to the west of the GIWW, both emergent and submerged, associated with the placement areas holding dredged material. However, in the high shoaling reach the majority of the dredged material, which has been placed there for approximately 50 years, has been eroded and transported out of the area, leaving little evidence of its placement This geomorphic feature has impacts on the circulation, suspended sediment patterns, and the seagrass distribution in the study area.

Figure 1.3 shows the historic bathymetry in the study area prior to the construction of the GIWW, scanned and modified from U. S. Coast and Geodetic Survey, Chart No. 1288 (1941), based on hydrographic surveys performed in 1867. Comparison of Figures 1 2 and 1 3 show that the bathymetry today is similar to that of 130 years ago, and that the depression in the western portion has maintained its size and is of comparable depth Most probably the depression was produced by the circulation generated by the dominant strong southeast winds characteristic of South Texas The northwest directed currents, driven by the southeast winds, would be deflected by the western mainland boundary, and the shallow depths west of the GIWW to the north of the study area. Persistent flow in this pattern would eventually, scour the region to form the depression

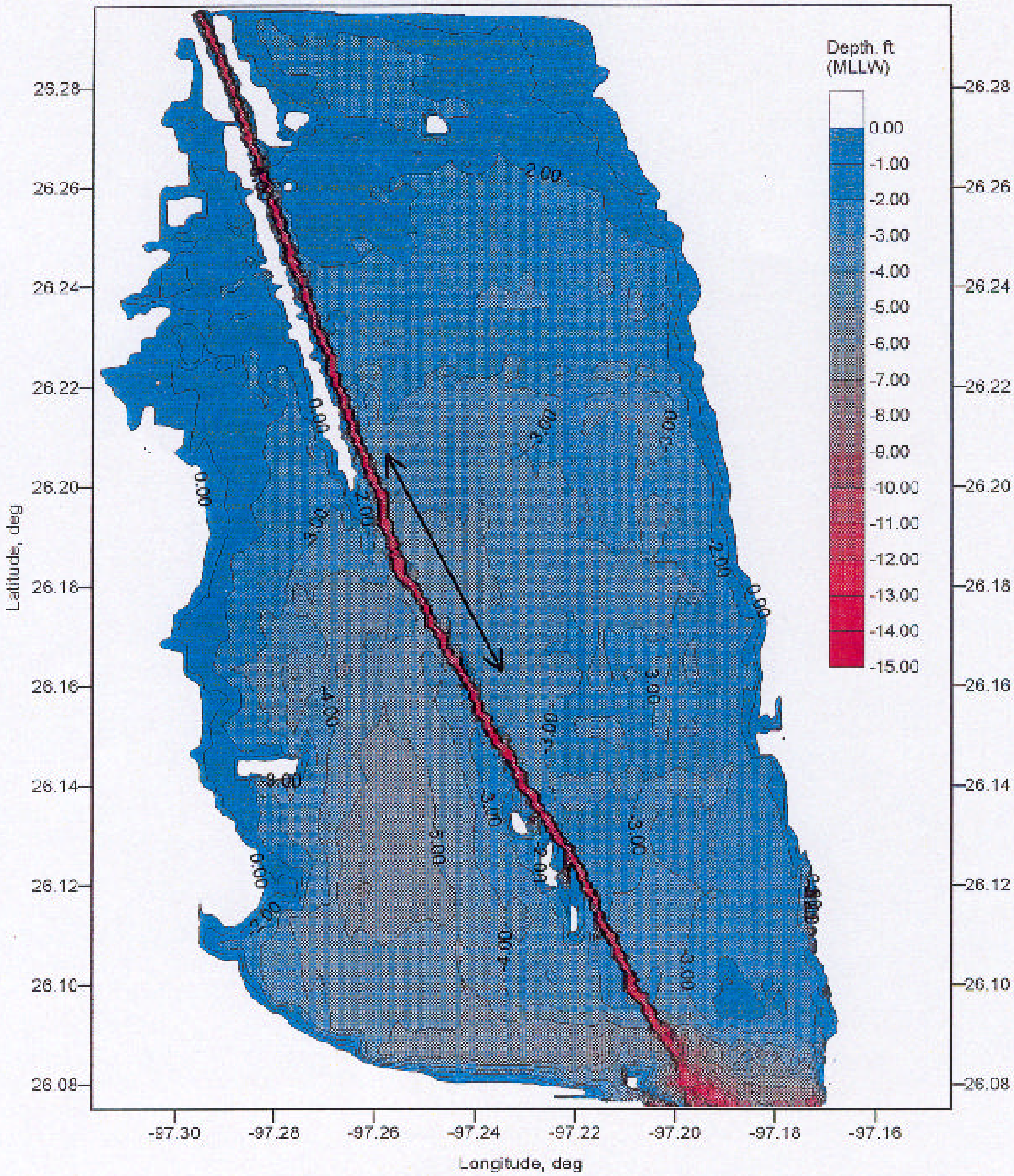

Figure 1.2. Contours of recent bathymetry in study area (data provided by USACE).

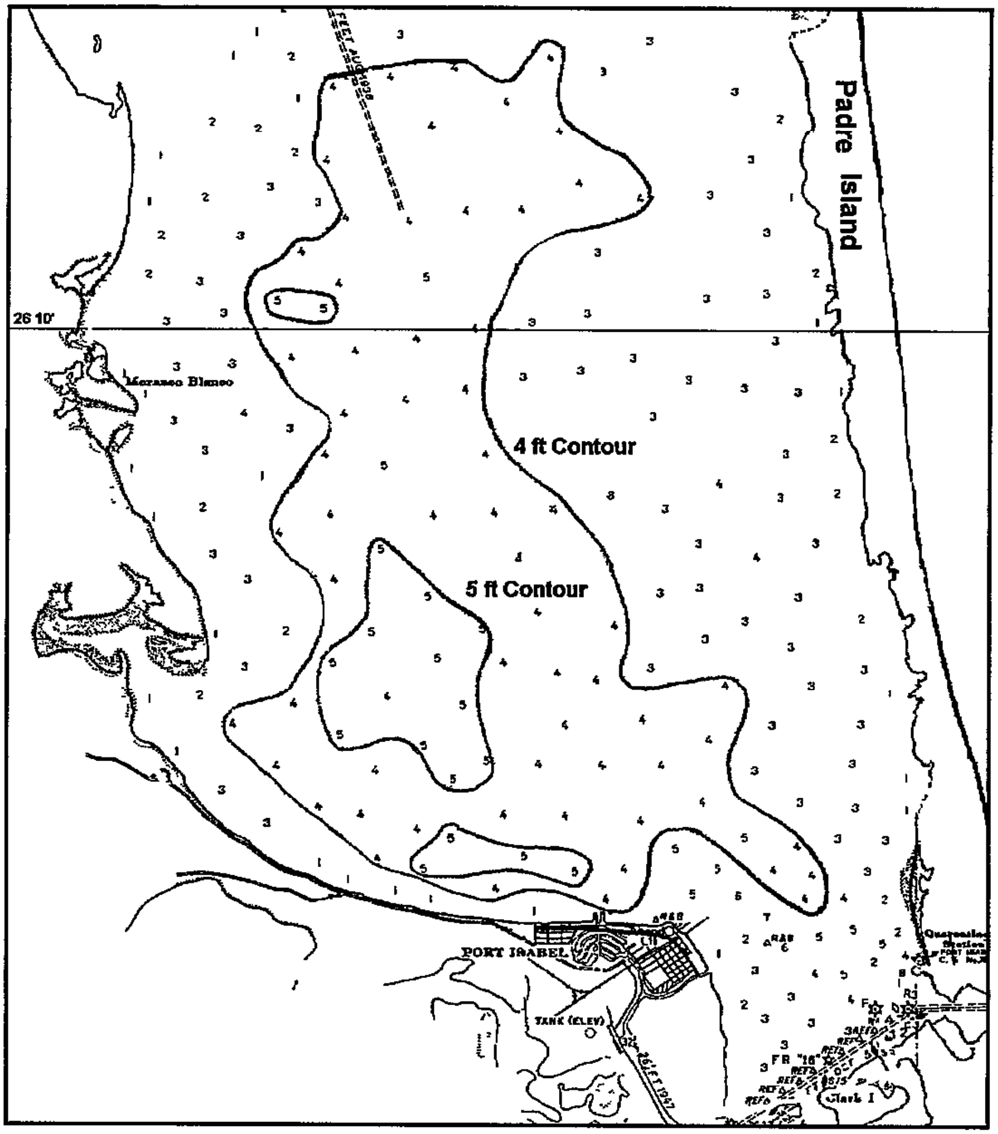

Figure 1 3 Historic bathymetry (referenced to Mean Low Water) in the study area

Structure of Study

The objectives of this monitoring effort were achieved through a multidisciplinary study, including the participation of staff members and students from University of Texas Marine Science Institute (UTMSI), Center for Coastal Studies (CCS) at TAMU-CC, and the Blucher Institute. The monitoring effort consisted of four components: 1) sustained monitoring from fixed stations, 2) synoptic surveys, 3) hydrographic surveys, and 4) seagrass distribution surveys

The fixed-stations monitoring consisted of continuous long-term (1-year) monitoring of physical parameters at a platform emplaced in the vicinity of an open-bay placement area. The synoptic surveys consisted of short-term surveys (1 to 2 days) of physical parameters in the study area performed prior to dredging activities, immediately post-dredging activities, and 6- and 12-month post-dredging activities. The hydrographic surveying component included local-area surveys of the bathymetry of the GIWW and placement areas with the objective of assessing shoaling rates and transport of dredged material. The objectives of the seagrass component were to assess the impact of dredging activities on seagrass beds and to compare the present distribution of seagrasses and biomass with historic data

Organization of the Report

Chapter 1 contains the statement of the study problem, the objectives, an overview of the study area, and a description of the technical approach Chapter 2 describes the data-collection program, including a description of the measurement equipment and procedures. Chapter 3 contains a review of historical dredging activities, recent maintenance dredging activities, and results of hydrographic surveys Chapter 4 summarizes the physical processes of the study area, including winds, tides, and currents and their interactions. Chapter 5 contains the sediment resuspension and turbidity data Chapter 6 summarizes the results of the light attenuation data. The methods and results of the seagrass component of the study are presented in Chapter 7 Chapter 8 discusses the interrelationships between the physical parameters monitored. Chapter 9 completes the main body of the report with conclusions and recommendations Appendices are given that provide specifics of the data generated in this study

2. Field Data Collection[2]

This chapter describes the continuous monitoring component of this study, including instrument deployment information (deployment dates and location), equipment utilized, and calibration and maintenance procedures. The data collected in this study are supplemented with data from neighboring Texas Coastal Ocean Observation Network (TCOON) stations in the region.

Description of Monitoring Platforms

The continuous monitoring component consisted of a fully-instrumented data-collection platform (FIX 1) installed in the vicinity of the open bay placement area, and two additional platforms (FIX 2 and 3) equipped with only automated water samplers. Table 2.1 lists the instruments deployed and parameters measured in the fixed-station monitoring component of this study. The fully-instrumented platform is equipped with acoustical and optical instruments as well as radio communications equipment, which provides near-real time data collection capabilities, including the capability to remotely download data and check the status of the systems.

Table 2.1. Measured parameters and associated equipment.

Instruments	Parameter	Location
Sontek Acoustic-Doppler Velocimeter (ADV)	3 components of current velocity	FIX 1
Hydrolab® Multiparameter unit	Turbidity, salinity, pH, water temperature, and dissolved oxygen	FIX 1
Chelsea Instruments Fluorometer	Chlorophyll-a	FIX 1
LI-COR Photosynthetically-Active Radiation (PAR) sensors	Incident and underwater light irradiance	FIX 1
Isco® Automated water sampler	Concentration of suspended solids and particle-size distribution	FIX 1, FIX 2, FIX 3

Location of Monitoring Platforms

The three fixed platforms, denoted as FIX 1, FIX 2, and FIX 3, were emplaced along a line running approximately transversely to the GIWW at Channel Marker 91 in the lower Laguna Madre, as shown in Figure 2.1. FIX 1 is the main monitoring platform located to the west of Disposal Area 233 (Lat. 26° 10' 45.2"N, Long. 97° 15' 36.2"W). FIX 2 is located inside Disposal Area 233 (Lat. 26° 10' 50.9"N, Long. 97° 15' 18.0"W) and FIX 3 is located to the east of the

[2] Written by Cheryl A. Brown and Nicholas C. Kraus, Conrad Blucher Institute for Surveying and Science, Texas A&M University-Corpus Christi

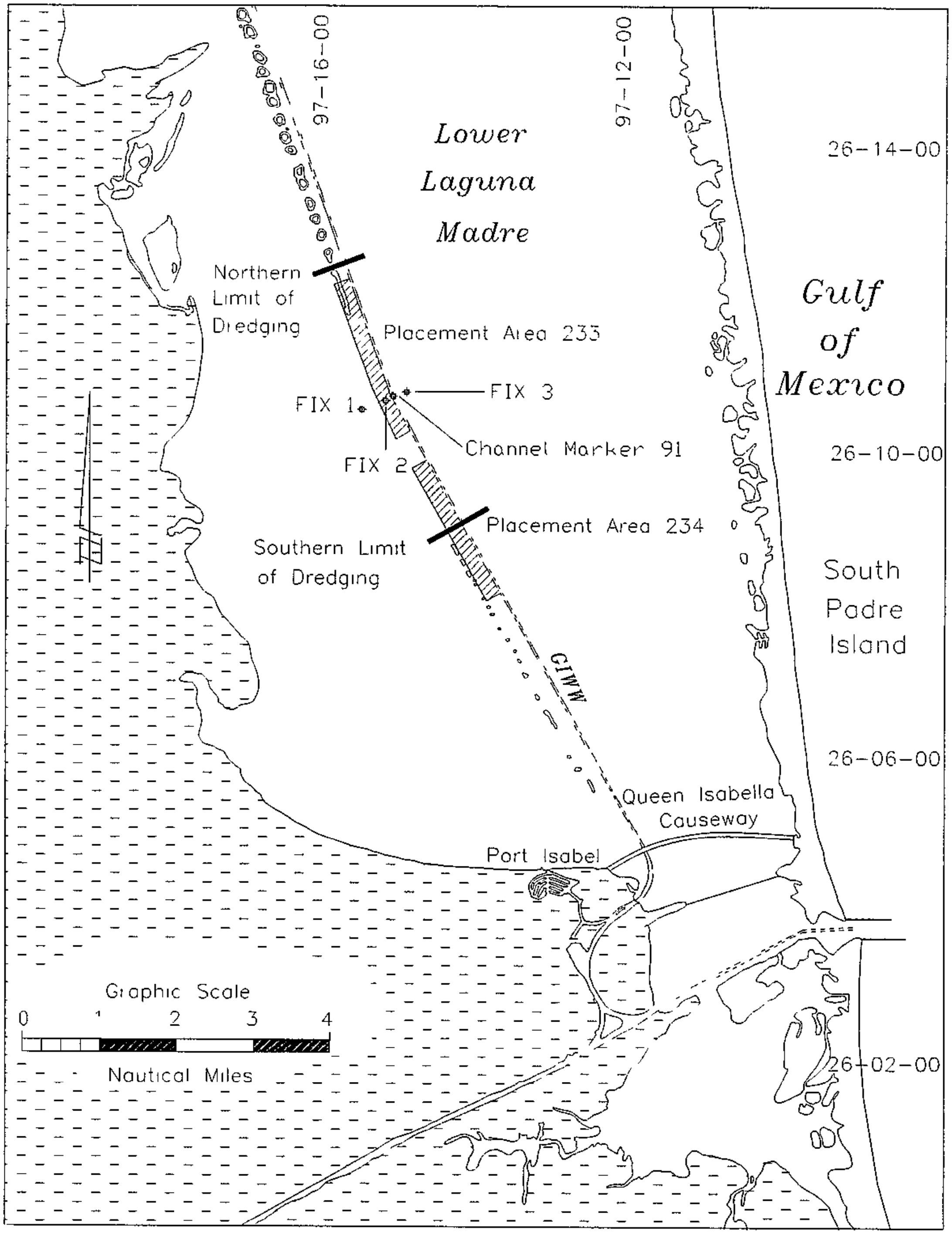

Figure 2 1 Location map of study area in lower Laguna Madre, Texas

GIWW (Lat. 26° 10' 58 1"N, Long 97° 15' 04 3"W) The water depth at all platforms is approximately 1.5 m (5 ft).

Installation of Monitoring Platforms

The platforms were constructed using 6 in by 6 in. by 15 ft treated wooden posts, which were driven approximately 1.2 to 1.5 m (4 to 5 ft) into the bottom using a jet-pump, and for FIX 1, a pile driver was used to drive the legs through an apparent layer of shell located approximately 1 m (3 ft) below the bottom of the lagoon Elevated platforms, with a deck located approximately 1.5 m (5 ft) above the mean water level, were constructed to minimize exposure to salt water and salt spray The platforms and equipment were installed during the period of August 28-31, 1994, and the stations became fully operational when data-collection commenced on August 31, 1994.

Description of Data-Collection System

Figure 2.2 shows the main monitoring platform, referred to as FIX 1, which is equipped with two environmental enclosures to minimize exposure of electronics and equipment to salt water, rain, and spray One environmental enclosure houses the batteries, and the other enclosure contains the data collectors, signal processing units, and radio communications equipment. Power is supplied to the station by two gel cell batteries, which are charged by four solar panels. All sensors with the exception of the PAR sensors are logged with a specially-designed, low-power consumption micro-computer The data collector has on-site storage capacity of approximately 14 days of data at present sampling rates.

The status of the data-collection system was checked remotely and data were transmitted to the Blucher Institute via packet radio-modem connection, schematically depicted in Figure 2.3. Data were downloaded from FIX 1 via a high-speed packet radio connection between the data-collection platform and a radio tower located in Los Fresnos, Texas, which then relayed the files to the Blucher Institute via a modem/phone line connection Presently, the data are downloaded via a high-speed packet radio connection between the data-collection platform and the University of Texas-Pan American Coastal Studies Laboratory located in the Town of South Padre Island, and then the data are transferred to the Blucher Institute via an Internet connection Once at the Institute, the data are decoded and imported into the CBI Environmental database where 6-minute averages of all parameters are stored The data are then imported into the database, where individual parameters are plotted and inspected

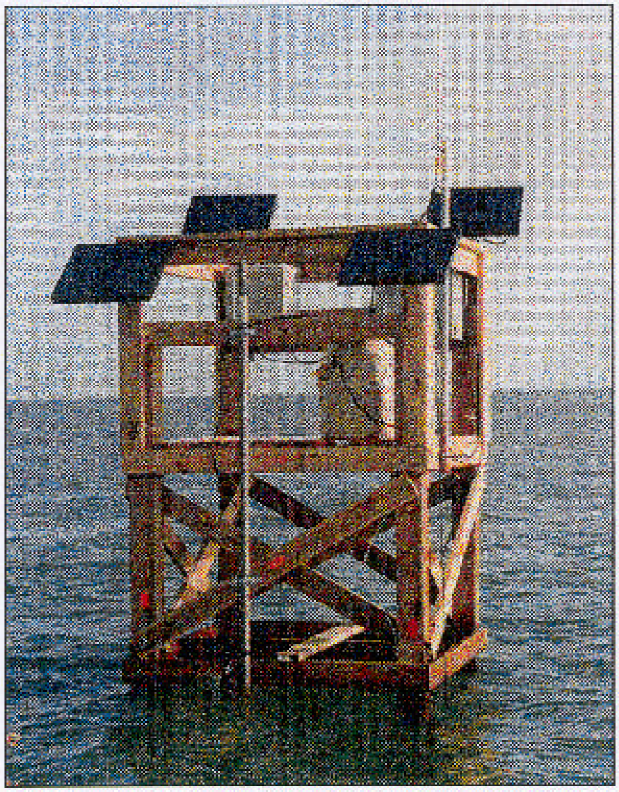

Figure 2.2. Fixed data-collection platform, FIX 1, lower Laguna Madre, Texas.

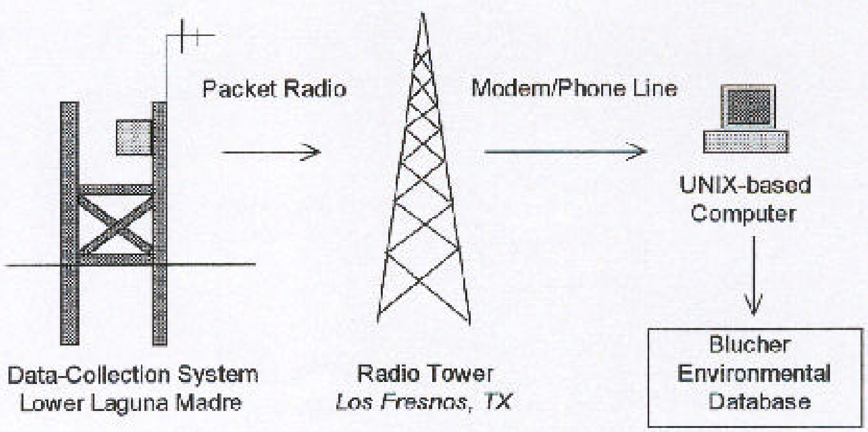

Figure 2.3. Schematic diagram of data-collection and radio communication system.

Equipment

Acoustic-Doppler Velocimeter

Three components of water velocity, north-south (*u*), east-west (*v*), and vertical (*w*), were measured continuously using an acoustic-Doppler velocimeter (ADV) (SonTek, San Diego, California, USA), which is a new type of current meter that is highly accurate (even at weak water velocities) and relatively insensitive to drift due to aging and biofouling. The ADV acoustically measures the three components of flow velocity at a point based on the Doppler-shift principle The ADV has a centrally-located transmitting transducer surrounded by three receiving transducers mounted on arms orientated at 120 deg angles. The transmitting transducer emits periodic short acoustic pulses which are scattered by material in the water column, such as bubbles and suspended material which are assumed to move at the speed of the water flow These acoustic echoes are detected by the receivers By knowledge of the orientation of the acoustic beams and the principle that the frequency of the echo is Doppler shifted according to the relative motion of the scattering material, the orthogonal components of current velocity are computed The ADV has a resolution of 0 1 mm/sec over the range of 0 to 2 5 m/sec and an accuracy of ±0 25% or ± 0 25 cm/sec, whichever is greater (Kraus, *et al* 1994) In this study, the sampling rate of the ADV was 1 Hz (1 sample per second) with 6-min averages of each component of the water velocity, signal-to-noise ratio, and correlation coefficients stored in the on-site datalogger The signal-to-noise ratio and correlation coefficients were used to determine the quality of the velocity data and to identify problems associated with the hardware, such as misaligned receivers or biofouling of the transmitters or receivers The ADV is mounted at mid-depth with the probe orientated in such a manner that positive flow (*u*, *v*, *w*) components are directed towards the north, west, and upwards, respectively

PAR Sensors

Measurements of photosynthetically active radiation (PAR), which is light with wavelengths of 400 to 700 nm, were collected continuously using a LI-193SA spherical (4π) quantum-sensor (underwater) and LI-190SA cosine-corrected (2 π) quantum sensor (surface) providing input to a LI-1000 datalogger (LI-COR Inc., Lincoln, Nebraska, USA) The underwater sensor was mounted on a 3-cm (1 2-inch) diameter PVC pole about 25 cm (0 8 ft) above the seabed to minimize fouling by drift algae and seagrass blades The terrestrial sensor was mounted above the platform Sensor locations were selected to avoid shading by the platform structure (south-east corner) Instantaneous PAR was measured at 1-min intervals and integrated hourly. Light sensors are calibrated or checked for accuracy annually and are accurate to ±5% (traceable to

National Bureau of Standards), stability is ±2% over any 1-year period, and data are recorded with a precision of ± 0 01 µmol photons per m^2 per sec

Water Quality Multiprobe

Water-quality parameters were monitored using a H20® Water Quality Multiprobe (Hydrolab® Corporation, Austin, Texas, USA), equipped with turbidity, water temperature, conductivity, pH, and dissolved oxygen sensors. The Hydrolab is sampled every 2 minutes and data are logged using the Blucher Data Collector The Hydrolab units deployed in the field are calibrated in the laboratory prior to deployment The specific conductance, pH, and turbidity sensors are calibrated using standard solutions The pH and turbidity sensors are calibrated using a slope-calibration method and the conductivity sensor is calibrated using a one-point calibration with a standard solution with a conductivity similar to that observed in the field The turbidity sensor is calibrated using 0 2-µm filtered, deionized water and 90 ntu formazin standard The dissolved oxygen sensor is air-calibrated at atmospheric pressure The temperature sensor was calibrated by the manufacturer during fabrication and is considered stable for 3 years

Fluorometer

Chlorophyll-a levels were continuously monitored using an Aquatracka III fluorometer (Chelsea Instruments, Surrey, UK) The fluorometer optically determines the concentration of chlorophyll-a by exciting a specimen within the sampling volume with a beam of pulsed visible and ultra-violet light, and comparing the intensity of the fluorescence excitation to that of a reference beam generated by the same light source. Chlorophyll-a is measured over a range of 0 to 100 µg/L with an accuracy of ± 0 02 µg/L plus 5% of value However, because the fluorometer optically determines the concentration of chlorophyll-a, it is susceptible to biofouling when deployed in a biologically-productive environment The fluorometer was factory-calibrated by the manufacturer, and the calibration was confirmed by Blucher Institute staff prior to deployment of the instrument The fluorometer was calibrated by exposing it to approximately seven different concentrations of chlorophyll-a dissolved in acetone, in addition to deionized water and pure acetone The fluorometer output was then related to chlorophyll-a concentration using a linear relationship The fluorometer was logged using a Blucher Data Collector and sampled at a rate of one reading every 2 min

Water Samples

Mid-depth water samples were collected twice daily at 6 00 AM and 6 00 PM (local time) using a 3700 Portable Sampler (Isco®, Lincoln, Nebraska, USA). During approximately weekly routine servicing, the samples were removed from the water sampler and transported to the Blucher Institute for analysis The samples were analyzed for total suspended solids and particle-size distribution of the suspended solids. Total suspended solids concentration was determined by filtering a known volume of the sample twice, using two pre-weighed filters, a 1-µm glass fiber filter and a 0.45-µm cellulose filter, which were then dried at 65°C to constant weight. The volume of sample filtered was typically 500 mL, however, if the sample contained a relatively large amount of sediment, determined visually, the volume filtered was reduced to 250 to 300 mL Once the concentration of total suspended solids was determined, the filters were archived in labeled bags. Particle-size of the suspended solids was determined using laser-particle analyzer (Mastersizer/E, Malvern Instruments, Worcestshire, UK), which determines the particle-size distribution based on laser-diffraction principles for particle sizes ranging from 0 1 to 600 µm The accuracy of the particle analyzer is ±2% of the median diameter (traceable to National Bureau of Standards), and the instrument is checked annually to confirm accuracy

Maintenance Schedule

The installation and maintenance of the data-collection platforms proved to be more labor intensive than anticipated During the 1-year period from August, 1994, through September, 1995, there were approximately 100 days of field work A chronology of events, including servicing of the platform, is presented in Appendix A Regular maintenance of the fixed platforms was performed approximately once a week, as weather permitted, with duties including inspection of the data-collection and power systems, field cleaning of the ADV and fluorometer, weekly exchange of the Hydrolab unit with a laboratory-calibrated unit and post-calibration of the instrument returned from the field; replacement of the sample bottles in the automated samplers, and replacement of batteries and desiccant, as needed Upon removal from the automated water sampling unit, sample bottles were labeled and transported to the Blucher Institute for analysis.

UTMSI personnel maintained the PAR sensors and associated datalogger. The datalogger was checked at monthly intervals, and preliminary data inspection was carried out in the field When anomalous data were found, the problem was isolated and corrected using standard trouble-shooting procedures, typically involving replacing a cable or sensor If less than 50% of the total memory remained, the datalogger was removed from the field and replaced with another unit External marine batteries (12 V) powered the datalogger and were exchanged with a newly charged battery on a monthly basis. On each datalogger maintenance trip, the sensor was cleaned, and the protective polyethylene bag over the sensor was replaced Additionally, sensor maintenance trips were scheduled so that the bag over the sensor was replaced every 2 to 3 weeks The bag minimizes direct biofouling of the sensor globe, increasing the time between recalibration Analysis indicates that frequent bag changes (2 to 3 weeks) minimize the impact of biofouling and that a clear polyethylene bag has a negligible effect on light measurements

Other Available Data

This monitoring effort is supplemented by other instrumentation located in the region, including additional PAR sensors, operated by the National Biological Survey (NBS) and UTMSI, and water-level and wind-measurement systems operated by the Blucher Institute as part of the TCOON Water-level and wind data provided by TCOON stations located at Port Isabel, Arroyo Colorado, and South Padre Island are invaluable for analyzing the tidal and meteorological components of variations in physical and water-quality parameters Six-min water level data provided by the TCOON are collected according to National Ocean Service Standards and reported to an accuracy of 0 1 ft Wind speed (average wind speed and gust) and direction data are collected hourly with average wind speed based on a 5 5-min average sampled at 1 Hz and the gust is defined as the highest 5 sec sustained wind speed in the 5.5-min sampling period

The NBS maintains an underwater PAR sensor installed at FIX 2, located inside the dredged-material placement area In addition, UTMSI operates three underwater PAR sensors in the study area as well as a surface sensor installed at UT-Pan American, Coastal Studies Laboratory, located about 13 km south of FIX 1. The data from these additional sensors have proven useful in filling occasional breaks in the data associated with instrument malfunction

From August 1994 to September 1995, the Blucher Institute made real-time measurements of water quality and hydrodynamics, supplemented by twice monthly water sampling, at the mouth of the Arroyo Colorado to estimate the nutrient load entering the lower Laguna Madre, as part of the Rio Grande Coastal Impact Monitoring Program, sponsored by the U S Environmental Protection Agency through the Texas General Land Office (Adams and Kraus 1995) The Arroyo Colorado monitoring program provided measurements of inflows from the Arroyo Colorado (including inflow rates, salinity, dissolved oxygen, pH, and turbidity)

3. Dredging Activities and Shoaling Analysis[3]

This chapter contains a review of historical dredging analysis performed in the study area for comparison with recent dredging activities The maintenance dredging operations monitored during this study are also reviewed, including descriptions of volume dredged and placement techniques utilized. The methods and results of the hydrographic survey component are presented

Historic Dredging Analysis

Atturio, *et al* (1976) computed shoaling rates for the entire length of the Texas GIWW available for the time period subsequent to the initial construction of the GIWW through 1974 from maintenance dredging records In the region monitored in this present study, Atturio, *et al* identified a relatively high shoaling (8-km) 5-mile long reach in lower Laguna Madre with a shoaling rate of approximately 0.6 m (2 ft) per year. Based on satellite imagery, James, *et al* (1977) suggested that this high shoaling reach was in a region with predominant cross-channel flow (Figure 5 2) Militello and Kraus (1994) performed a dredging analysis similar to that of Atturio, *et al* (1976) for the region between Port Isabel and Port Mansfield utilizing maintenance dredging records from 1945 through 1991.

Presented in Figure 3 1 is the volume of material dredged from the GIWW during maintenance operations from 1945 to 1991 for the region between Port Isabel and the Arroyo Colorado, with the number above each bar indicating the number of times each 5,000-ft section was dredged (modified from Militello and Kraus 1994) The reach of the GIWW between USACE Stations 45+000 and 70+000 experiences high shoaling and requires maintenance dredging approximately once every 18 to 24 months to maintain navigable depth Directly to the north and south of the high shoaling reach, the total volume dredged and the dredging frequency decreases, with some sections requiring no maintenance dredging since initial construction of the GIWW The shoaling analysis by Militello and Kraus (1994) indicated that the sedimentation patterns and dredging volumes in the study area have remained fairly consistent through time, however, extreme meteorological events, such as hurricanes, can produce variations in the sedimentation rates.

Figure 3.2 shows the total volume dredged in the high shoaling reach (Stations 45+000 to 70+000) subdivided into 6-year intervals from 1949 through 1991 Under typical conditions,

[3] Written by Cheryl A Brown and Nicholas C Kraus, Conrad Blucher Institute for Surveying and Science, Texas A&M University-Corpus Christi

about 1 5 million cu yd of material are dredged from the high shoaling reach every 6 years, which is equivalent to a sedimentation rate of about 250,000 cu yd per year Assuming a rectangular cross section for the GIWW, the shoaling rate for a specified length of the GIWW is

$$d = \frac{V}{l\ w}$$

where d is the shoaling rate, V is the volume of material dredged per year, l is the length of the reach (25,000 ft), and w is the width of the channel (125 ft) Using this formula, a shoaling rate of 2.2 ft per year was computed for this high shoaling reach, which agrees with the findings of Atturio, *et al* (1976) During the interval of 1967-1972, the volume of material dredged from the high shoaling segment of the GIWW approximately doubled During 1973-1978, the dredging volumes remained elevated (approximately 50% greater than typical conditions) Subsequent to 1979, the dredging volumes decreased down to typical levels (250,000 cu yd per year). The average annual precipitation computed for 6-year intervals at Port Mansfield are presented in Figure 3 2 (data obtained from National Climatic Data Center). The elevated dredging volumes occurring in 1967-1978 are strongly correlated with increases in precipitation in the region ($P < 0.025$, $r^2 = 0.85$)

On September 20th, 1967, Hurricane Beulah made landfall in the vicinity of Brownsville, Texas Hurricane Beulah, a Category 5 hurricane with maximum sustained winds of 140 knots and central pressure of 923 millibars, ranks 32nd on the National Hurricane Center's list of the most intense hurricanes in the United States during this century (1900-1992) The majority of the damage from Beulah was due to flooding of the mainland from the storm surge and massive rains associated with the storm Approximately 630,000 acres of coastal lowlands were inundated by the storm surge and about 1 4 million acres of land were inundated from stream flooding and ponded water associated with the rainfall (USACE, Galveston 1968) During September, 1967, monthly precipitation was 22 79, 19.2, and 14 36 inches in Port Isabel, Port Mansfield, and Harlingen, respectively (data from National Climatic Data Center). In addition, between Corpus Christi and Brazos Santiago Pass the USACE identified 31 breaches in the barrier island (USACE, Galveston 1968), and Berryhill (1969) states that as many as 67 storm passes were opened along Padre Island Large amounts of sediment were probably introduced into the Laguna Madre (which would otherwise have limited input due to low freshwater inflows) from mainland runoff associated with flooding, overwash of the barrier island, inlet formation, and wave action eroding emergent islands and the shoreline. In addition, Hurricanes Celia and Fern, which occurred in 1970 and 1971, respectively, would have probably have introduced a substantial amount of sediment into the study area from mainland runoff.

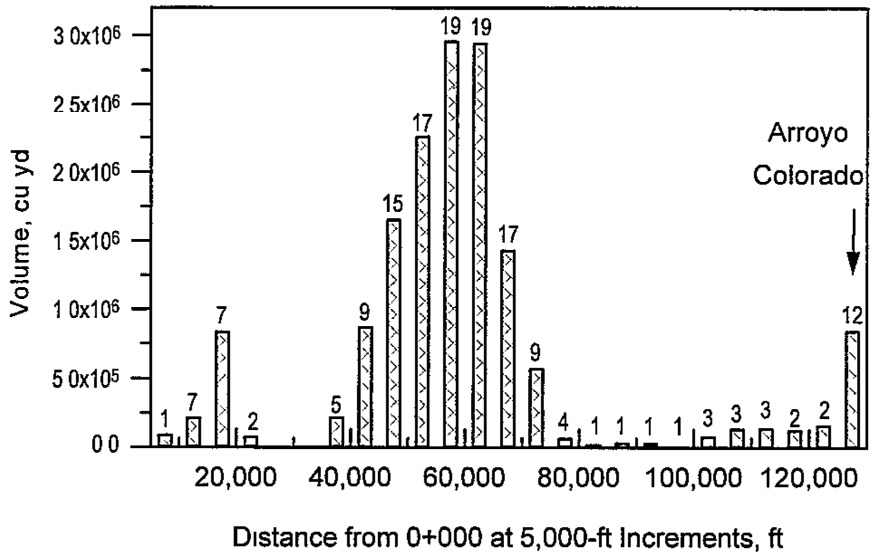

Figure 3 1 Volume of material dredged from the GIWW (1945-1991) (after Militello and Kraus, 1994)

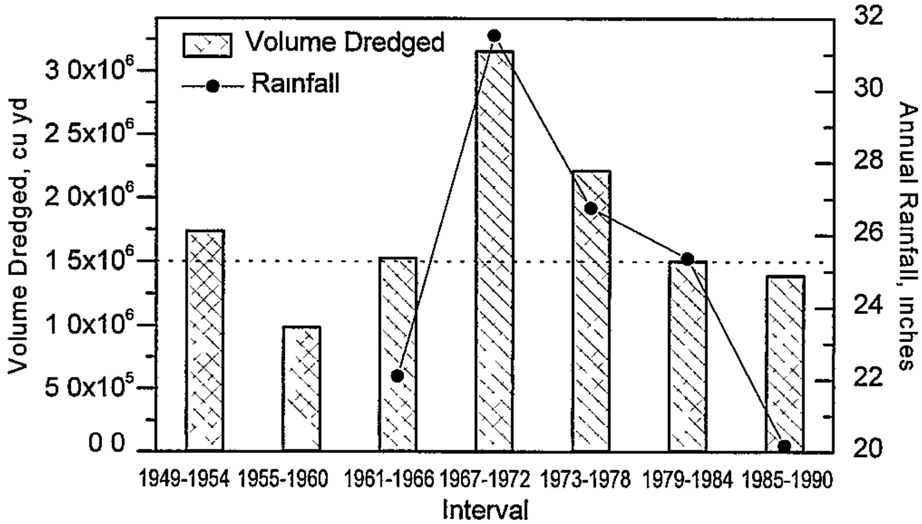

Figure 3 2 Volume dredged in high shoaling reach (45+000 to 70+000) for 6-year intervals

Recent Dredging Activities

In this section, recent maintenance dredging activities are reviewed for use in interpretation of data and analysis of hydrographic surveys The Galveston District conducted maintenance dredging of the Port Isabel to Arroyo Colorado open-bay reach of the GIWW during September 26, to October 29, 1994. The extents of dredging are presented in Figure 2 1 together with the locations of the placement areas The GIWW is maintained by dredging to a nominal depth of 16 ft (14 ft required depth plus 2 ft allowable overdepth) and to a width of 125 ft

Records were obtained from Great Lakes Dredge and Dock, Inc., the contractor of the Galveston District, which performed the dredging in 1994 Table 3 1 presents a chronology of the maintenance dredging of the Port Isabel to Arroyo Colorado for September to October, 1994 The location of the 5000-ft sections, station numbering, and placement areas are presented in Figure 3 3. At the request of the State of Texas, all of Section 1 and part of Section 2 were not dredged during this maintenance cycle to reduce the total volume of material dredged Dredging commenced on September 26, 1994, at the southern limit of Disposal Area 234 at Station 47+960, and progressed northward.

During dredging operations, four different types of placement techniques were utilized submerged confined levees, submerged shallow mounding, confined in-bay disposal, and open-bay disposal The objective of the submerged confined levees is to reduce the spreading of the dredged material to create a region of reduced depth capable of supporting seagrasses. The submerged shallow mounding method is an experimental technique which is part of a Galveston District Section 1135 Program The objective of the Section 1135 Program is to restore fish and wildlife habitats on Corps projects or immediately adjacent areas The shallow mounding technique consists of limiting the discharge to a 200 ft^2 area for the purpose of increasing mounding and reducing depth to promote the growth of seagrasses In the study area, there are two sites using the submerged shallow mounding technique, located at the northern ends of Disposal Areas 233 and 234 After the material placed at these sites consolidated, seagrasses were planted and monitored as a part of another study The confined in-bay disposal consists of building emergent levees to limit movement of the dredged material and to convert aquatic habitat to emergent habitat The confined in-bay disposal is located in the middle of Disposal Area 233

The open-bay placement technique is the traditional method used in the Laguna Madre. During open-bay placement, the material is placed a minimum of 800 ft from the centerline of the channel The emphasis of this study is to monitor the open-bay placement site, which is located at the southern limit of Disposal Area 233 On October 4-6, the discharge location for

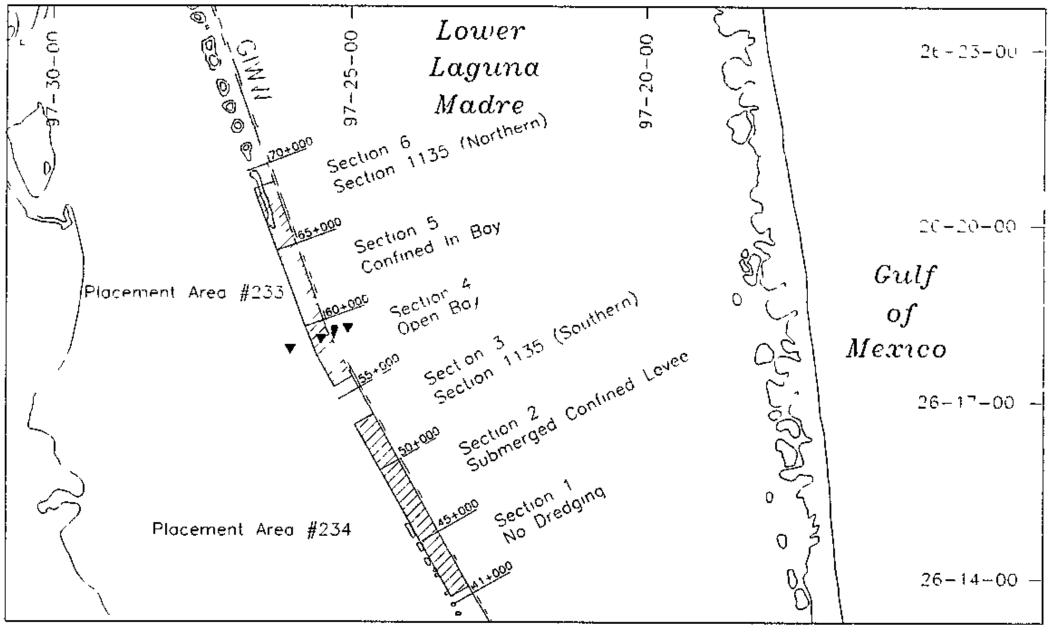

Figure 3 3 Schematic diagram of dredged-material placement areas

Table 3.1. Recent dredging chronology.

Date 1994/1995	Placement Technique	Location Disposal Area/Section
9/26/94 - 9/28/94	Submerged confined levees	Disposal Area 234 - Section 2
9/28/94 - 10/2/94	Submerged shallow mounding (Southern Section 1135 Site)	Disposal Area 234 - Section 3
10/3/94 - 10/8/94	Open bay placement	Disposal Area 233 - Section 4
10/8/94 - 10/15/94	Confined in-bay placement (Emergent Levee)	Disposal Area 233 - Section 5
10/15/94 - 10/20/94 10/22/94 - 10/25/94	Submerged shallow mounding (Northern Section 1135 site)	Disposal Area 233 - Section 6
10/27/94 - 10/29/94	Submerged shallow mounding (Southern Section 1135 site)	Disposal Area 234 - Section 3

the dredge was approximately 1400 ft south of FIX 1 On October 7, the discharge location was approximately 400 ft south and, on October 8 the discharge point was located 600 ft north of FIX 1.

Using the same method as Militello and Kraus (1994), the distribution of volume of material dredged during this maintenance cycle was determined from the dredging records Dredging records specify the amount of material removed from a specified section, defined by starting and ending stations To facilitate comparison with the Militello and Kraus (1994) analysis, material volumes were distributed uniformly over each specified section, and then placed into 5,000-ft interval subsections (see Figure 3.3 for stations) to allow comparisons of volumes over equal distances Comparison of Figures 3.1 and 3 4 shows that the extents of dredging for this maintenance cycle in the southern portion of lower Laguna Madre was confined to the high shoaling reach Figure 3 5 shows the extents of dredging as they relate to the 3 5-ft contour, which illustrates the depression in the western portion of the lower Laguna Madre The region where the GIWW crosses the 3 5-ft contour delimits the extents of dredging.

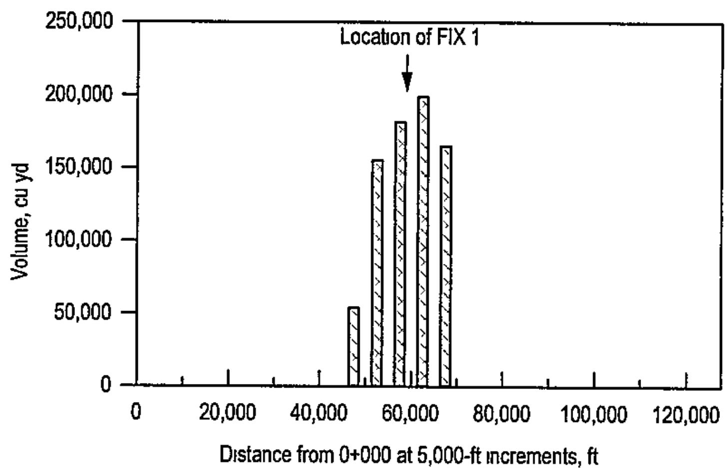

Figure 3 4 Volume of material dredged in 1994 maintenance operations

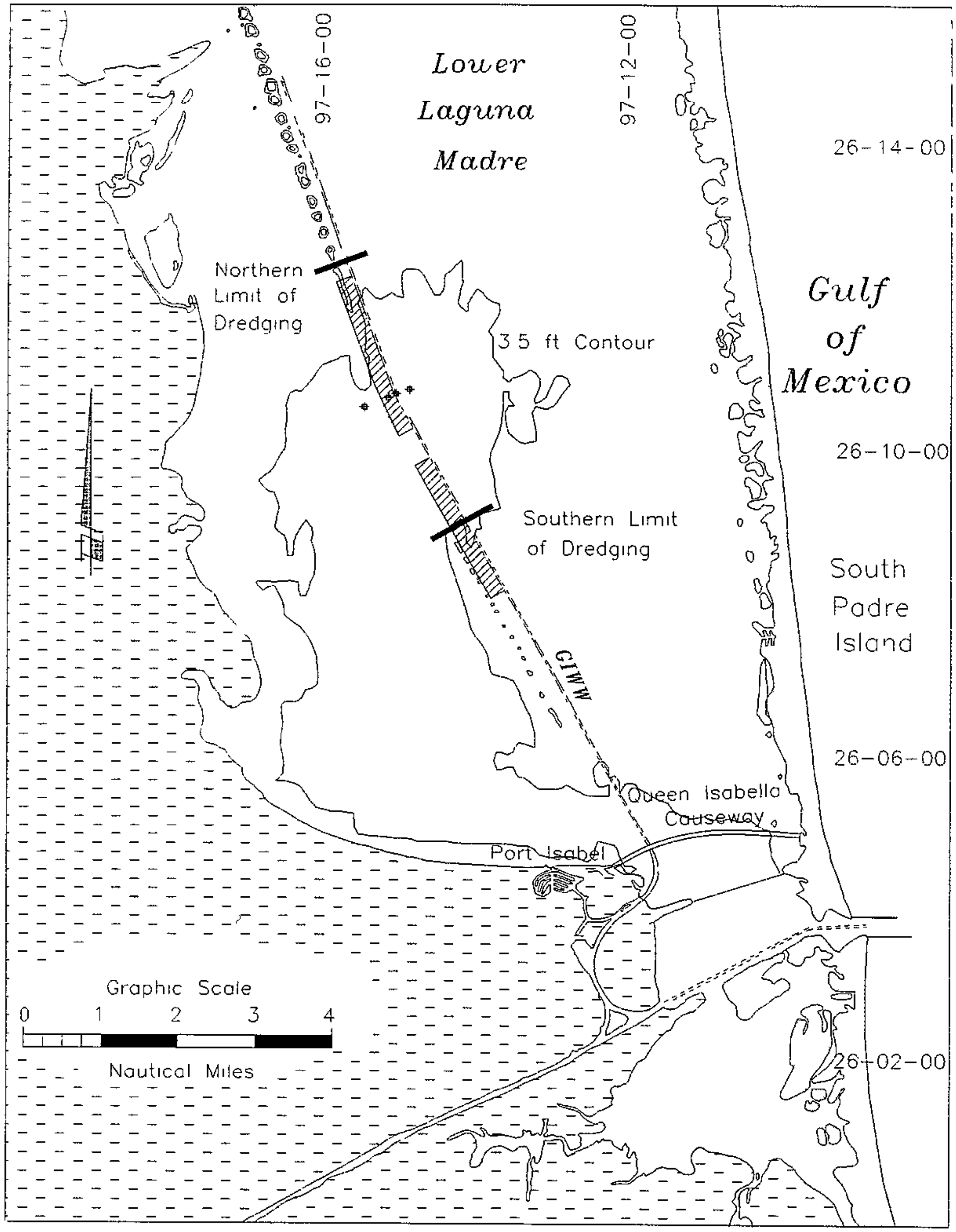

Figure 3 5 Extents of dredging with respect to 3 5-ft depth contour (referenced to MLLW)

Hydrographic Surveys

To determine shoaling rates and the transport of dredged material from placement areas, bathymetric surveys were conducted in the vicinity of the placement areas prior to dredging activities, immediately post-dredging, 8-months post-dredging, and 13-months post-dredging Figure 3.6 shows the design locations of the survey transects Each survey consisted of approximately eighteen 4,000-ft long transects orientated perpendicular to the GIWW spaced at approximately 1,000-ft intervals Due to inclement weather, it was not possible to perform all surveys on planned dates (6 months and 12 months post-dredging), actual dates of the surveys are presented in Table 3 2

Depths were measured using a dual-frequency (24 kHz and 200 kHz) Echotrac MKII echosounder with an accuracy of ± 0 1 ft for a solid sand bottom Positions were determined using a Starlink differential Global Positioning System (GPS) receiver Typically, six to seven satellites were available for positioning, implying that horizontal position was known to within approximate 1-m (3-ft) radius Depth and position data were logged using HYPACK® software running on a 486-based lap-top computer Echo sounder readings were frequently compared to readings taken from a graduated survey staff Typically, the echo sounder and staff readings agreed within 0.2 ft, often coinciding to the nearest 0.1 of a foot Post-processing of the data included transforming the position to distance along transect, and smoothing the depths using an adjacent-averaging (7 points) to eliminate the effect of surface waves Because water-level data in close proximity of the transects were not available, for the purpose of volume calculations depths were adjusted by matching the depths to the east of the GIWW The depths in the graphs approximate mean lower low water.

Table 3.2. Chronology of hydrographic surveys.

Period of Survey	Date of Survey
Pre-Dredging	Sept 2, 1994
Post-Dredging	Nov 16-17, 1994
8-Months Post Dredging	June 27-30, 1995
13-Months Post Dredging	December 12-15, 1995

Figures 3 6 to 3.14 show comparisons of the pre-dredging, post-dredging, 8-months post-dredging, and 13-months post-dredging cross sections During the initial post-dredging survey, staff and echosounder measurements indicated that a 5 to 7 ft layer of high-density, unconsolidated fine-grained material was present in the GIWW on most of the transects Cross sections presented show the top of this high density layer Figure 3.7 shows the bathymetry in

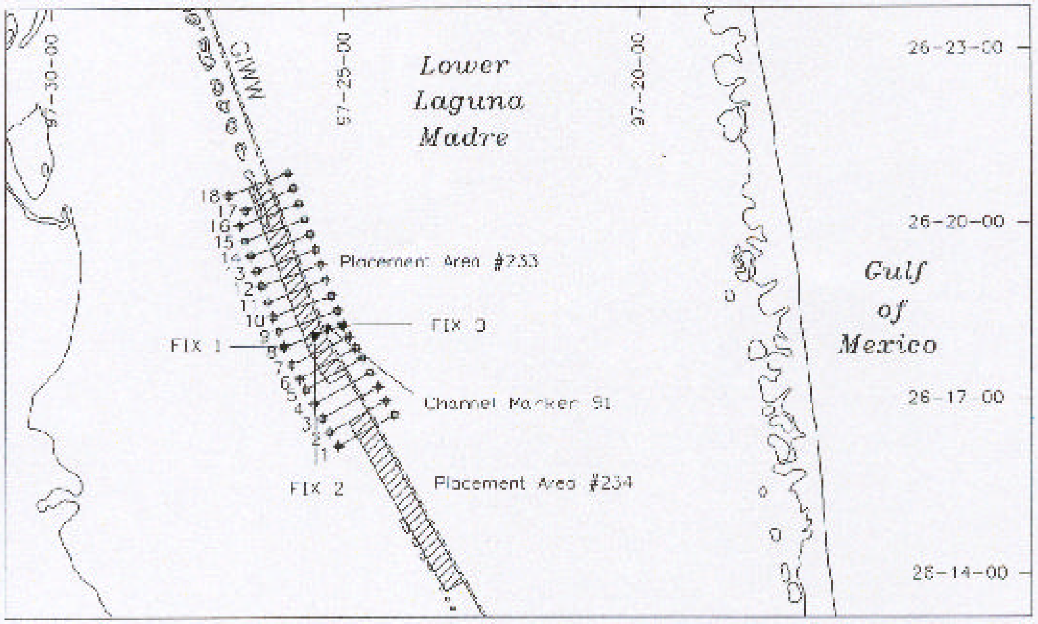

Figure 3.6. Location of hydrographic survey transects.

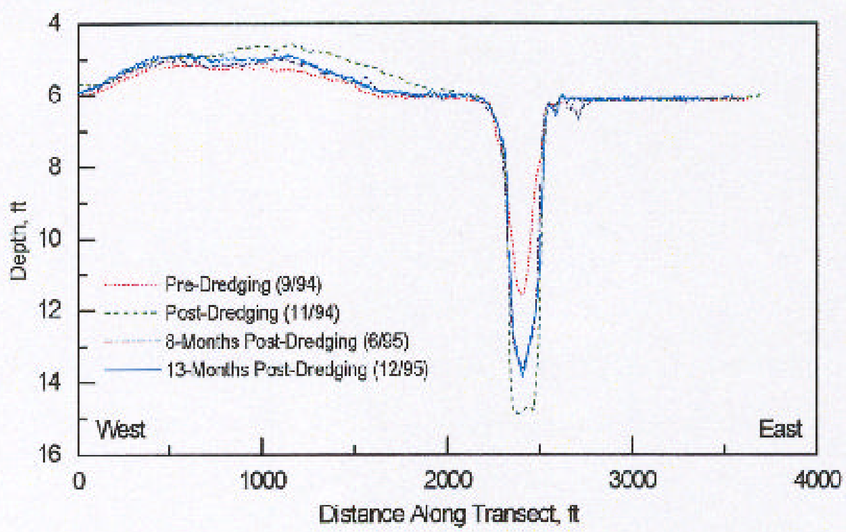

Figure 3.7. Change in bathymetry in vicinity of open bay placement area (Transect 7).

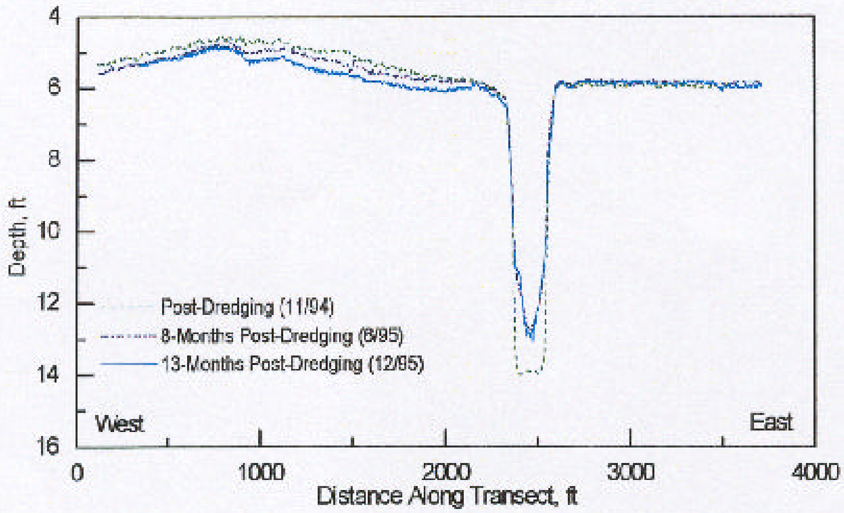

Figure 3.8. Change in bathymetry in open bay placement area, Transect 8.

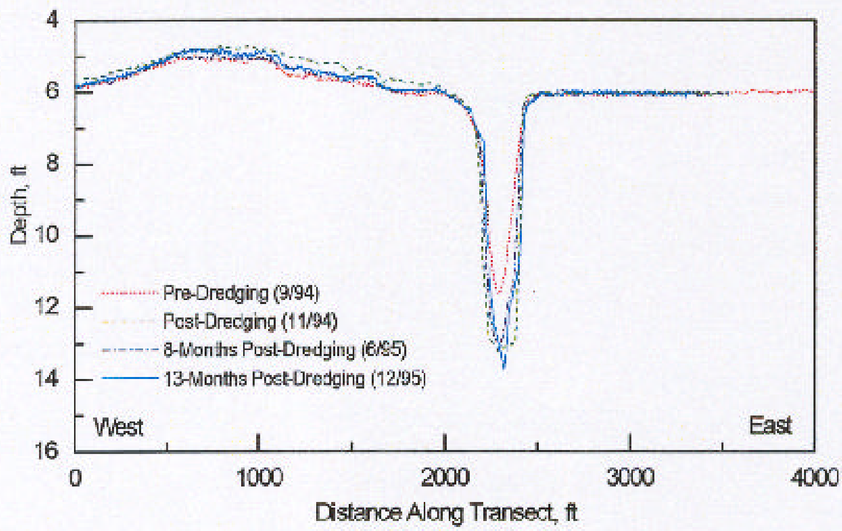

Figure 3.9. Change in bathymetry, Transect 9.

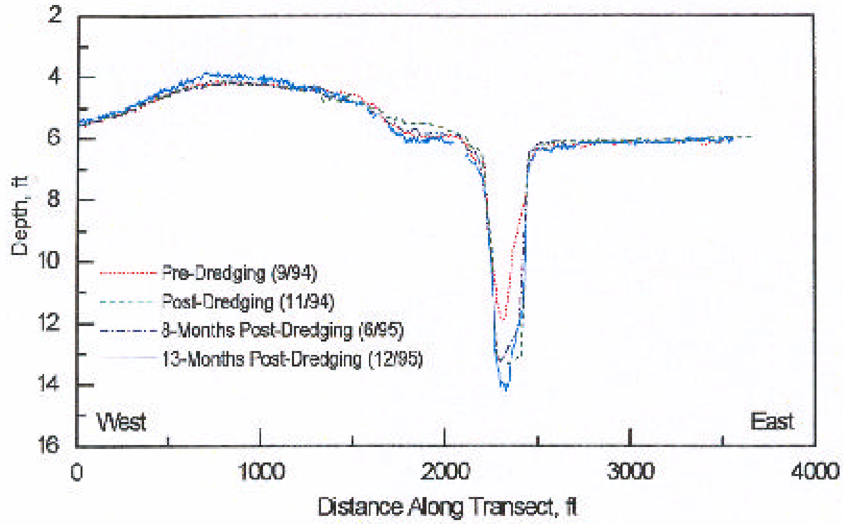

Figure 3.10. Change in bathymetry, Transect 10.

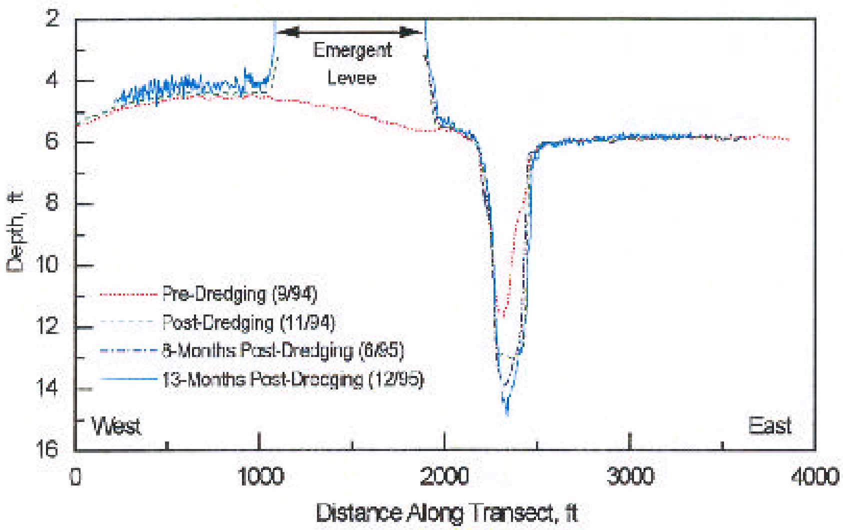

Figure 3.11. Change in bathymetry, Transect 11.

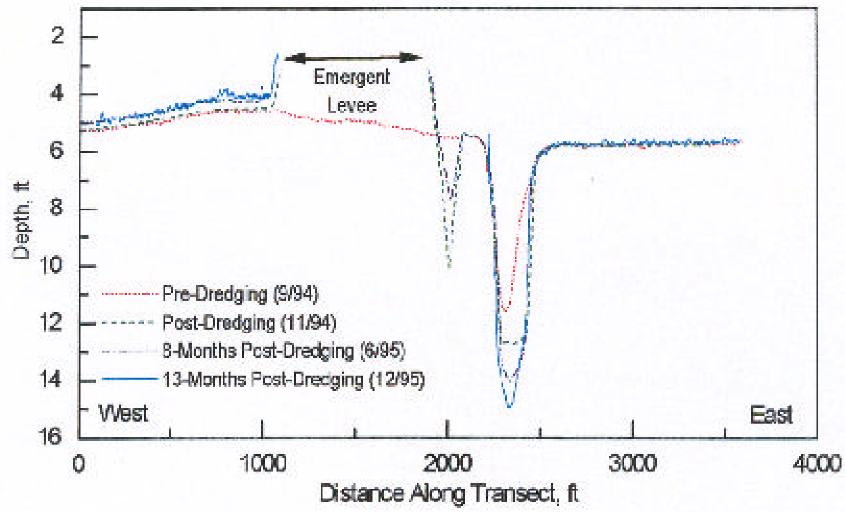

Figure 3.12. Change in bathymetry, Transect'12.

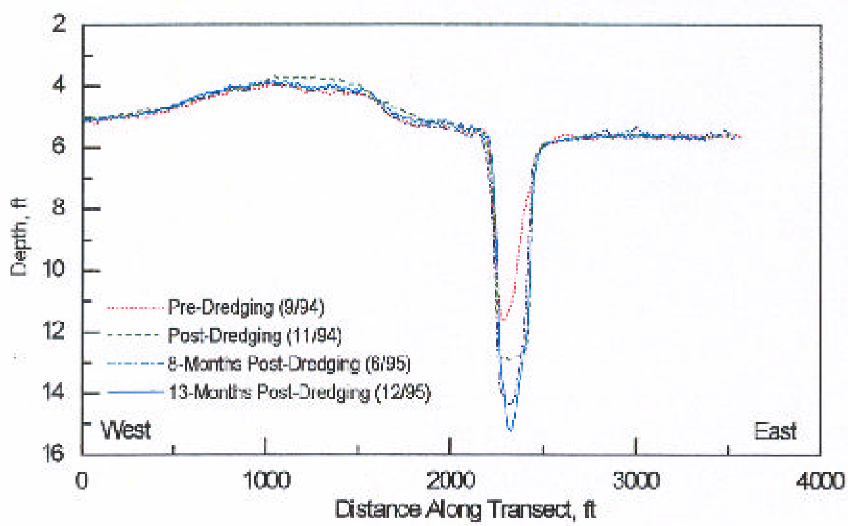

Figure 3.13. Change in bathymetry, Transect 13.

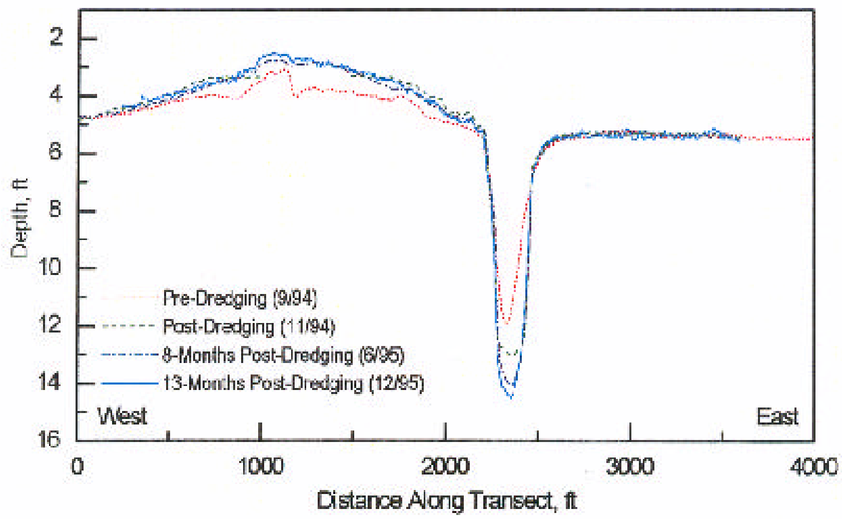

Figure 3.14. Change in bathymetry, Transect 14.

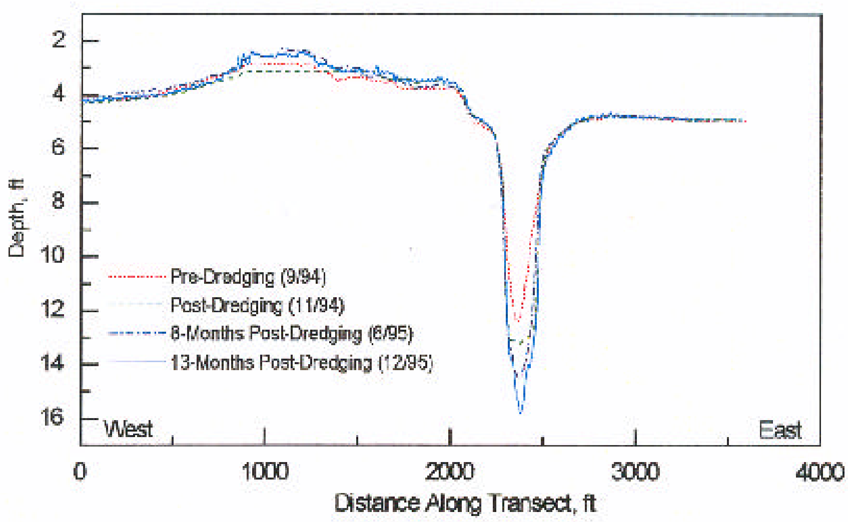

Figure 3.15. Change in bathymetry, Transect 15.

the vicinity of the open bay placement area (Transect 7) Comparison of the pre-dredging and post-dredging survey shows the volume of material deposited in the placement area, approximately 33 cu yd per ft of channel length, and the amount of material removed from the GIWW, approximately 30 cu yd per ft of channel length Comparison of the pre-dredging and post-dredging profiles indicates that the maximum change in elevation associated with the placement of dredged material is approximately 9 inches

Within 8 months subsequent to dredging activities, the GIWW at Transect 7 shoaled approximately 1.2 ft (approximately 13 5 cu yd per ft of channel length), with approximately 70% of the material placed in the open bay placement area eroding and consolidating (approximately 24 cu yd per ft of channel length eroded/consolidated), and the bathymetry returning to a configuration similar to that measured prior to dredging activities To the west of the GIWW, the 13-month post-dredging transect is approximately 3 inches higher in elevation that the pre-dredging transect There is almost no detectable difference between the 8- and 13-month post-dredging surveys at Transect 7, indicating that the transport of the dredged material and subsequent shoaling of the GIWW, occurs within the first 8 months of cessation of maintenance dredging activities.

Figure 3.8 shows a comparison of the immediately post-dredging, 8- and 13-months post-dredging surveys (Transect 8) in the vicinity of FIX 1, FIX 2, and FIX 3 (Unfortunately, the GPS receiver malfunctioned during the pre-dredging survey, and there are no data for this transect) Comparison of the post-dredging and 8-month post-dredging cross sections indicates that approximately 18.5 cu yd of material per ft of channel length eroded and consolidated, and approximately 13 cu yd per ft of channel length of material were deposited in the GIWW, resulting in about 1 ft of shoaling along the centerline of the GIWW Comparison of the 8- and 13-month post-dredging surveys shows that there was no discernible change in material deposited in the GIWW; however, an additional 15 cu yd per ft of material had eroded or consolidated in the placement area

Transect 9 (Figure 3 9) had a minimal amount of dredged material placed in the area; however, the bathymetry configuration returned to that measured prior to dredging activities within 8 months subsequent to dredging activities, and there was little change between the 8- and 13- month surveys Transect 10 (Figure 3 10) had a minimal amount of dredged material placed along it

Transects 11 and 12 (Figures 3.10 and 3.11) are located in the vicinity of the confined in-bay placement area, which included an emergent levee The deposition of material to the west of the emergent levees is probably a result of slumping and erosion of the sides of the levees The deep hole to the east of the levees on Transect 12, the presence of which was confirmed using a graduated rod, may have been created by borrowing material from this location to repair the levees and erosion from the propellers of a vessel which was repairing the levee

Comparison of the post-dredging, 8-month post-dredging, and 13-month post-dredging cross sections in Figures 3 9 to 3.15, indicate that the GIWW increased in depth subsequent to the post-dredging survey There are three possible explanations for this increase in depth 1) malfunction of the survey equipment, 2) presence of layer of unconsolidated sediment recording a false bottom, and 3) scour in this region. It is improbable that malfunction of the survey equipment was the source of this observation, because to the east of the GIWW the bathymetry overlays perfectly and to the west of the GIWW the bathymetry returns to a configuration similar to that measured prior to dredging activities. Depth measurements in the GIWW obtained with a graduated rod during the initial post-dredging survey indicated that there was a 5- to 7-ft thick layer of high-density, unconsolidated fine-grained material The presence of a high density layer, such as this would be expected subsequent to dredging activities, due to the settling of suspended material If the presence of this 5- to 7-ft thick layer was accounted for in the post-dredging survey, then the hydrographic surveys would have indicated that the GIWW shoaled within 8 months subsequent to the cessation of dredging activities, as observed in Transects 7 and 8

Transects 14 and 15 (Figures 3 14 and 3 15) are located in the vicinity of the northern Section 1135 site. The post-dredging survey is incomplete over the placement area due to the shallow depth, and not being able to get the survey boat into the region Comparison of the pre-dredging and 8- and 13-month post-dredging survey shows that a 1-ft layer of dredged material has remained in this placement area, as long as 13 months subsequent to dredging. However, these transects are located at the northern limit of the high shoaling reach (refer to Figure 3 1) and the sediment placed in this region probably experiences reduced erosional forces (i e , waves and currents) than the material placed in the open-bay placement reach (Transects 7 and 8)

On all of the transects (Figures 3.7 to 3.15), there is an accumulation of 1 to 2 ft of sediment to the west of the GIWW, which is associated with the construction and maintenance of the GIWW On the transects, the amount of material build up to the west of the GIWW ranged from 900 ft^2 to 2,800 ft^2 Integration along a 9000-ft section of the GIWW (Transects 5 to 14, which coincide with Stations 56+000 to 65+000), yields that approximately 550,000 cu yd of material placed in this region have remained in the placement areas. This estimate of the amount of material in the placement areas is an under-estimate, because the transects do not extend far enough to the west to encompass the entire volume of the mound For comparison, approximately 6 million cu yd of material have been dredged from the GIWW between Stations 55+000 and 65+000 (see Figure 3.1) during the interval of 1945 to 1991, including 750,000 cu yd of material dredged during the initial construction of the GIWW

4. Wind, Water Level, and Current[4]

This chapter documents wind, water level, and currents in the study area during the first year of this monitoring effort, as well as the inter-relationships between these parameters.

Wind

Wind forcing has numerous implications for physical processes and sediment transport in shallow-water systems, including producing local set-up and set-down of the water level, wind-driven currents, and wind waves, which often result in resuspension of sediment Numerous investigations in shallow-water systems similar to Laguna Madre suggest that wind-generated waves are a dominant mechanism for resuspension of sediment in these environments (e g., Ward, *et al* 1984, Pejrup 1986, Onuf 1994, Schoellhamer 1995)

The study area is characterized by strong winds (6-12 m/sec or 13-27 mph) predominantly from the southeast for approximately six months of the year (April to October), interspersed with short-duration strong north winds associated with the passage of fronts in the winter (October to April) Time-series of wind data from a gauge located at the mouth of the Arroyo Colorado for the period of September, 1994, through August, 1995, are presented in Appendix B In this study, the wind direction is defined as the angle from which the wind is originating, where 0 deg represents wind from the north, and increases in wind direction correspond to a clock-wise rotation Comparison of wind data at Arroyo Colorado and the South Padre Island Coast Guard Station, which is located approximately 9 miles south of the study area, indicates that Arroyo Colorado wind data are representative of the wind conditions at the study site Occasional gaps in the Arroyo Colorado wind record were filled with data from the South Padre Island Coast Guard Station

Figure 4 1 is an annual wind rose generated using data collected for the one-year period from September 1, 1994, to August 31, 1995, at the TCOON station located approximately 13 miles north of the study area at the mouth of the Arroyo Colorado The mean annual wind speed for September, 1994, to September, 1995, is 6 m/sec (13 mph). The annual wind rose indicates that 50% of the year the wind speed was greater than 6 m/sec (33% of the year between 6 to 9 m/sec (13 to 20 mph) and 17% of the year greater than 9 m/sec or 20 mph) For approximately one-half

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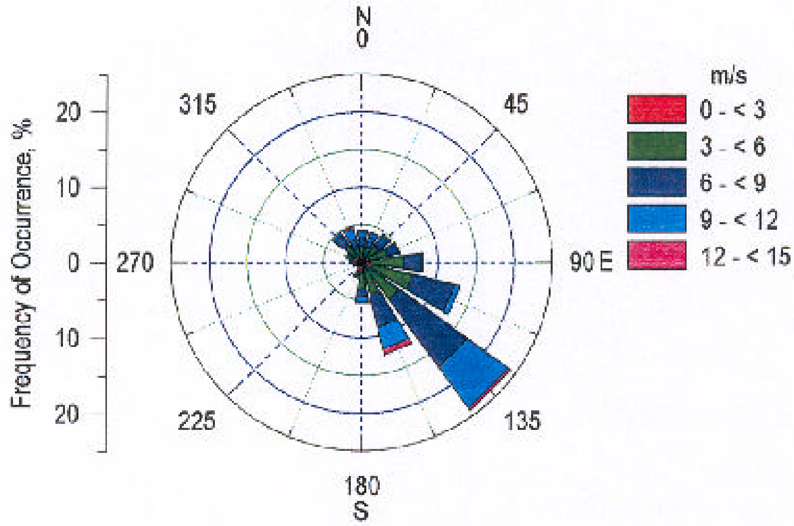

Figure 4.1. Wind rose for September 1, 1994 to August 31, 1995.

of the year, the wind was from southeast quadrant (112.5 to 157.5 deg) and for about 20% of the year the wind was from the north (= 45 deg).

Figures 4.2 and 4.3 are monthly wind roses showing the seasonal variations in the wind conditions. Tabulated in Table 4.1 are the frequency of occurrence, mean, and standard deviation of the wind speed at Arroyo Colorado for September, 1994, through September, 1995. September and August are typically the calmest months of the year, with the wind predominantly out of the east. During these relatively calm months, there is less wave energy because of the minimal fetch associated with the easterly wind direction and reduced wind forcing. During September, 1994, the wind speed was predominantly less than 6 m/sec or 13 mph (80% of the time) with wind speeds rarely exceeding 9 m/sec or 20 mph (~1%), and the monthly mean wind speed was 4 m/sec (9 mph).

The first front of the winter season generally arrives in South Texas in late September or October and these fronts continue to pass through the region until about March. These fronts persist for about 1 to 3 days, and during their passage the average wind speeds may reach approximately 12 to 17 m/sec (27 to 38 mph). These short-duration, strong wind events figure importantly in the mechanism for sediment resuspension and transport. Typically, 15 to 20 north fronts pass through the region each year (Hayes 1965). For the 1994-1995 winter season, the first front passed through the study area on October 8, 1994, with accompanying average wind speeds reaching 13 m/sec (29 mph).

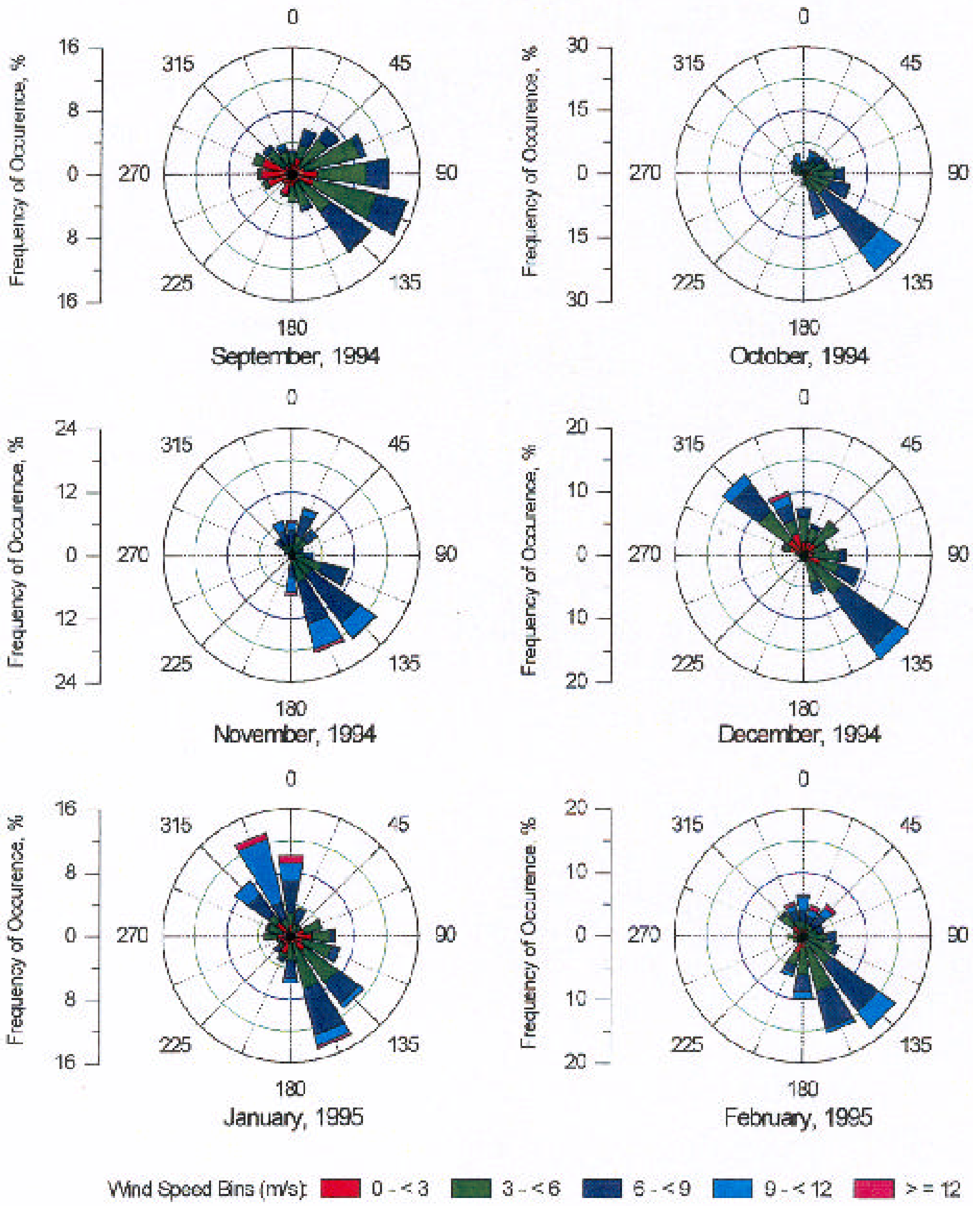

Figure 4.2. Monthly wind roses for September, 1994, through February, 1995, respectively.

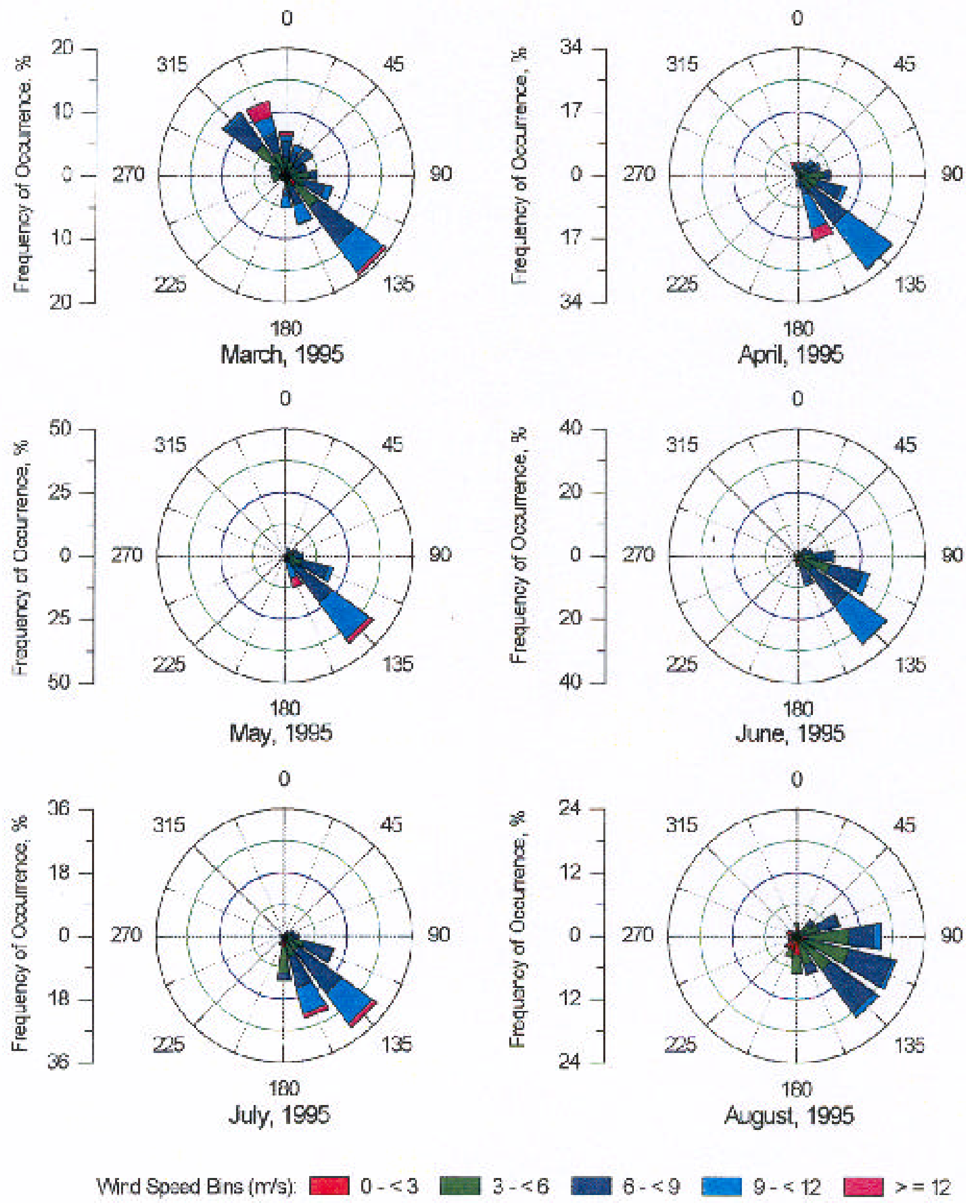

Figure 4.3. Monthly wind roses for March, 1995, through August, 1995, respectively.

Table 4.1. Frequency of occurrence, mean, and standard deviation of wind speed.						
	Frequency of Occurrence, %					
Month	0 - < 3 m/sec	3 - < 6 m/sec	6 - < 9 m/sec	9 - < 12 m/sec	>12 m/sec	Mean ± 1 S.D., m/sec
9/94	34 0	45 5	19 4	1 1	0 0	4 0 ± 2 2
10/94	13 8	36 3	37 5	12 0	0 4	5 9 ± 2 6
11/94	9 4	29 4	42 0	16 7	2 5	6 6 ± 2 7
12/94	27 3	38 4	27 3	6 4	0 6	4 9 ± 2 6*
1/95	23 6	32 9	25 8	15 5	2 2	5 6 ± 3 2*
2/95	18 9	37 9	29 9	10 9	2 4	5 7 ± 3 0
3/95	13 2	31 3	34 8	16 5	4 1	6 5 ± 3 1
4/95	7 0	22 5	34 1	30 7	5 7	7 6 ± 2 9
5/95	3 4	18 2	41 9	30 5	6 0	7 9 ± 2 6
6/95	12 4	27 5	41 1	18 9	0 1	6 4 ± 2 7
7/95	13 2	26 5	38 6	19 0	2 7	6 6 ± 2 9
8/95	26 1	39 7	30 7	3 5	0 0	4 7 ± 2 5
9/95	23 0	46 6	26 2	2 9	1 3	4 8 ± 2 5

Note S D represents standard deviation *These months have missing wind data (~4 days), which may slightly alter calculated the monthly mean wind speed

During October, 1994, the wind was primarily from the southeast, and the wind speed was less than 6 m/sec (13 mph) 50% of the time, between 6 and 9 m/sec (13 and 20 mph) 37% of the time, and 12% of the time the wind speed exceeded 9 m/sec (20 mph) The monthly mean wind speed for October increased by almost 50% from the monthly mean for September, 1994 During November through March, the winds became bi-modal with predominant directions out of the southeast and north or northwest. The monthly mean wind speeds for November through March, were typically about 5 to 6 m/sec (11-13 mph) The last front of the 1994-1995 winter season passed through the study area on April 22, 1995

During April through July, the region had predominantly strong southeast winds, with April and May having the highest monthly mean wind speeds of 7 6 and 7 9 m/sec (about 17 mph), respectively, recorded during the study period. During both June and July, 1995, the monthly mean wind speed was approximately 6 5 m/sec (14.5 mph), and in August and September, 1995, the monthly mean wind speed decreased to 4.7 and 4 8 m/sec (about 10 5 mph), respectively During August, 1995, the wind direction returned to the predominantly easterly direction characteristic of August or September; however, in neither August nor September, 1995, did the wind conditions return to levels as calm as those experienced in September, 1994 The monthly mean wind speed during September, 1995, was 20% higher than that recorded in September, 1994, and a one-way ANOVA performed on wind speed data indicates that there is a statistically significant difference ($p < 0$ 00001) between the wind speeds for September, 1994, and

September, 1995 The first front of the 1995-1996 wınter season occurred on September 22, 1995, with wınd speeds reachıng 17 m/sec (38 mph)

Water Level

Water-level varıations are an ımportant physıcal mechanism for movıng sedıment, because they can generate currents whıch transport suspended sedıment and, ıf of sufficient magnıtude, the current can suspend sedıment In the Laguna Madre, water level variatıons are a combınatıon of the astronomıcal tides, local wind forcıng, and other meteorologıcal effects These water-level varıatıons are superımposed on the long-term water elevatıon The depth ın the lower Laguna Madre is ınfluenced by the relatıve change ın water level, with contributıons by the global change in water level on the earth (eustatic change), local changes ın water level, and risıng or fallıng (subsıdence) of land Lyles, *et al* (1988) analysıs of a long-term (1945-1986) water level record of the NOS tide gauge at Port Isabel ındicated that there had been an average relatıve rıse ın sea level of 3 1 mm/year (0 01 ft/year) ın thıs region (Fıgure 4 4) After 1971, the mean sea level ıs elevated compared to that prior (1945-1970) Prıor to 1971, the long-term average of the mean sea level (1945-1970) ıs 1 29 m (4.24 ft), the peak mean sea level is 1.35 m (4 42 ft), and 54% of the tıme the annual mean sea level ıs less than 1 295 m (4 25 ft) Subsequent to 1970, the average mean sea level (1971-1986) is 1 38 m (4 52 ft), the peak mean sea level ıs 1 42 m (4 66 ft), the minimum mean sea level ıs 1 35 m (4 42 ft), and 42% of the time the mean sea level is hıgher than 1 37 m (4 5 ft) Milıtello and Kraus (1994) estimated that over a 50-year perıod (1945-1994), the water level in the lower Laguna Madre would have risen 15.5 cm (0 5 ft) Thıs long-term change in depth would have ımplıcatıons for lıght attenuatıon and seagrass dıstributıon.

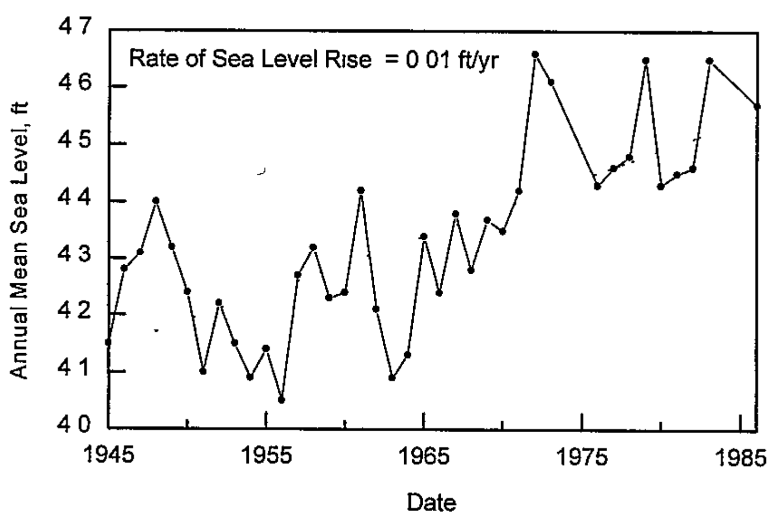

Fıgure 4 4 Annual mean sea level at Port Isabel (1945-1986) from Lyles et al (1988)

In the Laguna Madre, one of the dominant variations in water level is the semi-annual rise and fall of sea level (Smith 1978). Time-series of the low-pass filtered (with a cutoff frequency of 2 months) hourly water levels at South Padre Island and Arroyo Colorado (Figure 4.5) reveals a semi-annual rise and fall of sea level of approximately 0.5 m (1.6 ft) during 1995, with maximum water elevations occurring in April-May and October, and minimum levels occurring in February, and July. It is believed that the semi-annual variations in coastal water elevation in the Gulf of Mexico is driven by thermohaline and dynamic forcing (Marmer 1954, Whitaker 1971, Sturges and Blaha 1976, and Smith 1978). Elevated coastal waters associated with spring run-off produce the peak in May. Seasonal warming and cooling result in maximum expansion and contraction of the shelf waters in September-October and January-February, respectively. The July minimum in water elevation may be associated with the temporary storage of water in an anticyclonic gyre in the western Gulf of Mexico.

In semi-enclosed, shallow water systems, the astronomical tidal signal is attenuated as it propagates through restricted inlets and shallow water, and the meteorological effects are amplified (Smith 1977). The northwestern Gulf of Mexico is characterized by weak astronomical forcing and strong wind forcing (Smith 1977). Due to the low amplitude of the astronomical forcing, limited connections with the Gulf, and shallow depths, the Laguna Madre is classified as micro-tidal with the mean tidal range varying from approximately 0.3 m (1 ft) in the vicinity of connections with the Gulf of Mexico to centimeters in the interior portions of the Laguna. The fixed platforms are located approximately 16 km (10 miles) north of Brazos Santiago Pass and approximately 35 km (22 miles) south of Mansfield Pass. Figure 4.6 shows the spatial variation in mean range in water level variations from the South Padre Island Coast Guard Station (SPICGS) northward to the Land Cut.

The tidal signal is not significantly damped as it propagates through the Brazos Santiago Pass. The mean diurnal tidal range is 43 cm (1.4 ft) outside the jetties at Brazos Santiago Pass and 40 cm (1.3 ft) inside the pass at Port Isabel (NOAA 1983). As the tidal signal propagates approximately 27 km (17 miles) northward into the Laguna Madre, it is attenuated by frictional effects associated with the shallow water to a mean range of approximately 10 cm (0.3 ft) at Arroyo Colorado. In contrast to Brazos Santiago Pass, the tidal signal propagating through Mansfield Pass is substantially attenuated by the long, narrow channel and as a result little tidal signal reaches the Laguna Madre. In the Laguna Madre at Port Mansfield the mean range is approximately 7 cm (0.2 ft).

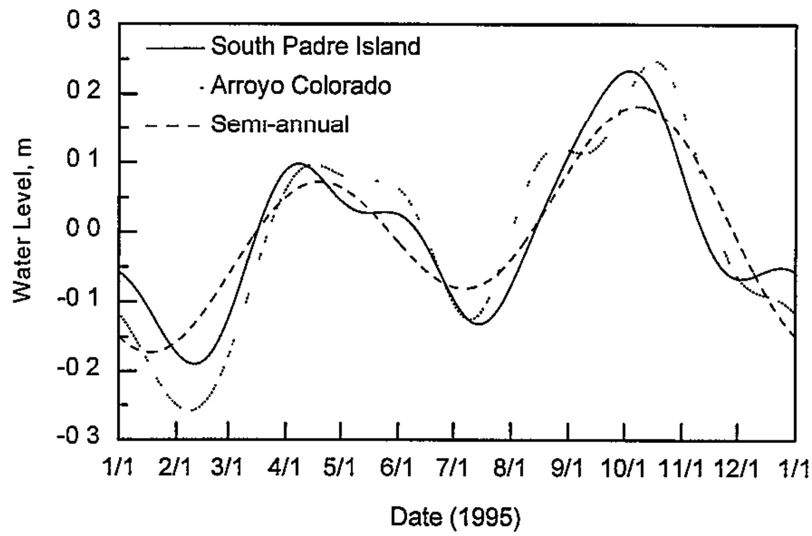

Figure 4 5 Seasonal variations in water level at South Padre Island and Arroyo Colorado

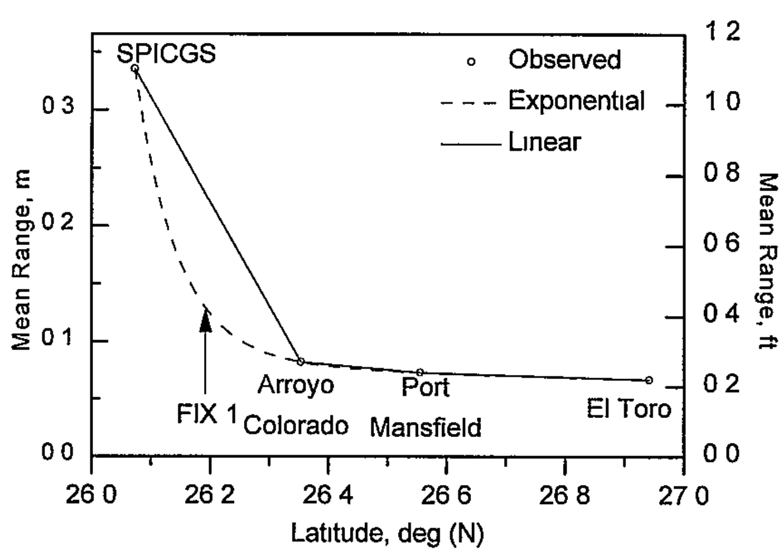

Figure 4 6 Mean range at South Padre Island, Arroyo Colorado, Port Mansfield, and El Toro

In addition to the seasonal and astronomical variations in water elevation, meteorological forcing results in water level variations on the order of 10 to 20 cm occurring at time scales of 1 to 2 weeks Exchange between the adjacent coastal shelf and intracoastal regions driven by the strong meteorological forcing of the region is a dominant mechanism for these low frequency variations (Smith 1978) In addition, local meteorological forcing results in local set-up and set-down of the water Figures 4.7 and 4 8 show the hourly and low-pass filtered (cut off frequency of 0.333 cycle/day) de-meaned water elevation at SPICGS and Arroyo Colorado, illustrating the magnitude of the seasonal and low-frequency variations in water elevation in the study area

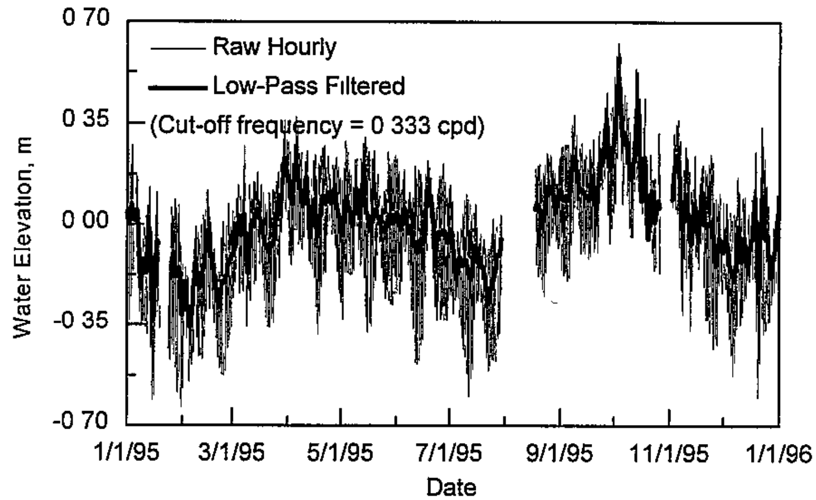

Figure 4 7 Hourly and low-pass filtered water elevation at SPICGS

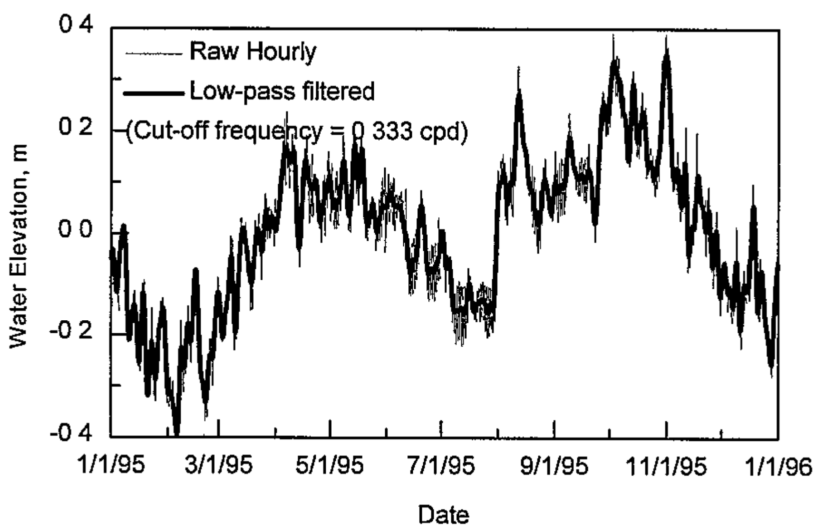

Figure 4 8 Hourly and low-pass filtered water elevation at Arroyo Colorado

Current

Previous Investigations

There are limited measurements of the current in the lower Laguna Madre It is believed that the data set presented in this report is the first long-term (1 year) record of the current in this region James, *et al* (1977) inferred the surface current patterns in the lower Laguna Madre from suspended sediment patterns acquired from satellite imagery. Analysis of the satellite images in conjunction with tide and wind data suggested that in the region of relatively high shoaling rates identified by Atturio, *et al* (1976), there was generally flow across the GIWW under various hydrodynamic conditions However, there were insufficient data to confirm the current patterns hypothesized by James, *et al* Reconnaissance-level hydrodynamic modeling by Militello and Kraus (1994) also indicated that there was cross-channel flow in the identified region of high shoaling.

Principal Direction and Magnitude of Flow

Plots of the north-south (u) and east-west (v) components of current are presented in Appendix B, with positive values indicating flow towards the north and west, respectively Presented in Figures 4 9 and 4 10 are scatter plots of the current at FIX 1 for individual months, where the dashed line denotes the orientation of the GIWW These plots indicate that there is consistent cross-channel flow in the vicinity of FIX 1, oriented in the north-east and south-west directions throughout the year. The magnitude of the current at the study site is typically within the range of 10-15 cm/sec (about 0.5 ft/sec) and is fairly symmetric. The annual (9/1/94-9/1/95) mean magnitude of the current (± standard deviation) at FIX 1 is 6.3 (± 3 9) cm/sec The flow is less than 10 cm/sec (0 33 ft/sec) the majority of the year (~84%) and equally divided between the ranges of 0-5 and 5- 10 cm/se The flow is between 10 to 15 cm/sec (0 33 - 0 5 ft/sec) about 14% of the year and greater than 15 cm/sec (0 5 ft/sec) only about 2% of the year The cross-channel flow is present throughout the year, and during various hydrodynamic conditions, including tidally-dominated (flood and ebb), and wind-dominated conditions This cross-channel flow is probably attributable to the orientation of the bathymetric depression

Figures 4 11 to 4 17 show current roses of the flow at FIX 1 for September and November 1994, and January, February, March, June, and July 1995, respectively. In these current roses, the direction indicates where the current is flowing towards with the arrows indicating the predominant orientation of the flow. Tabulated in Table 4 2 are the frequency of occurrence, mean, and standard deviation of the current at FIX 1 for months with less than 25% missing data. During September 1994, the hydrodynamic conditions were relatively calm

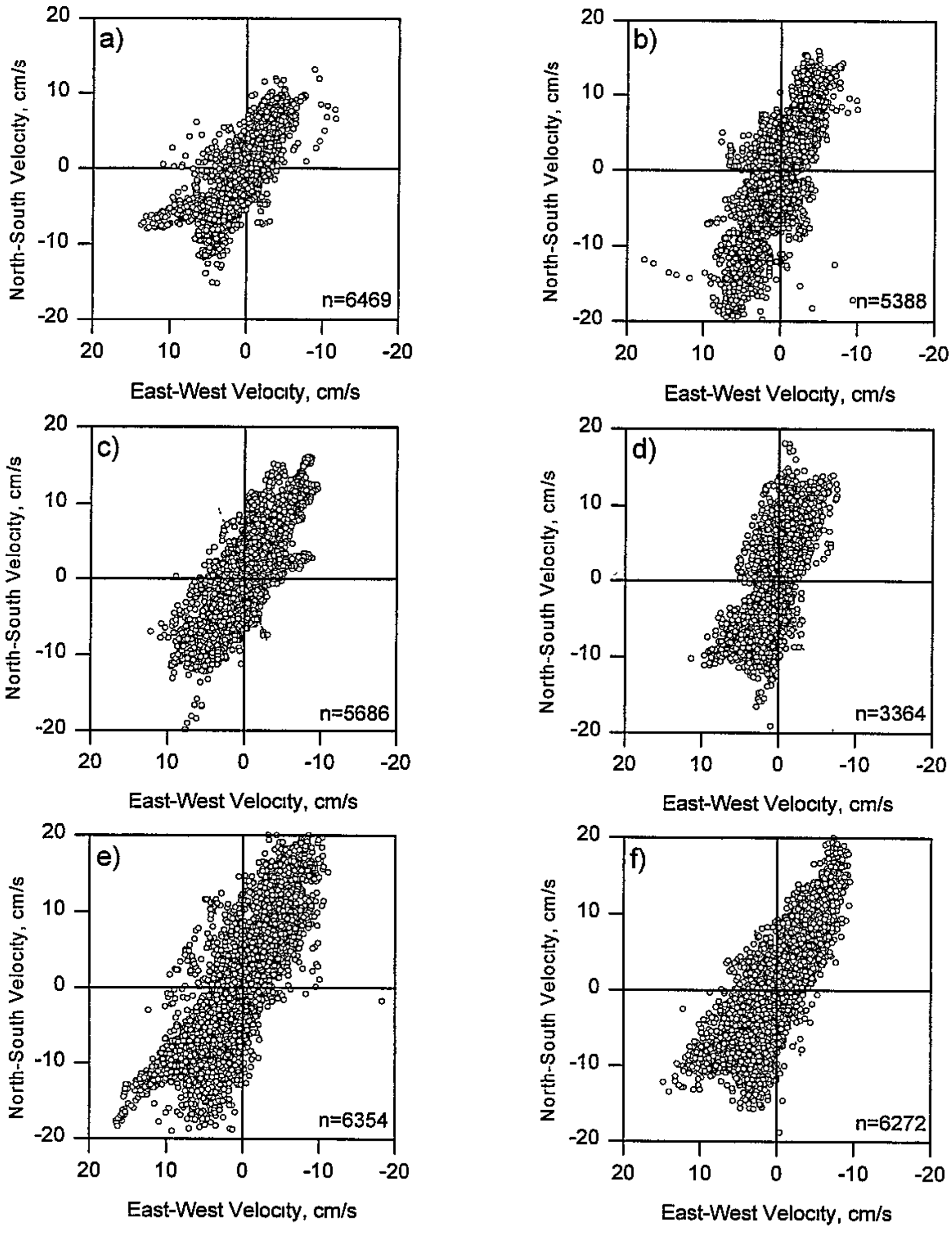

Figure 4 9a-f Scatter plots for September, 1994, to February, 1995, respectively

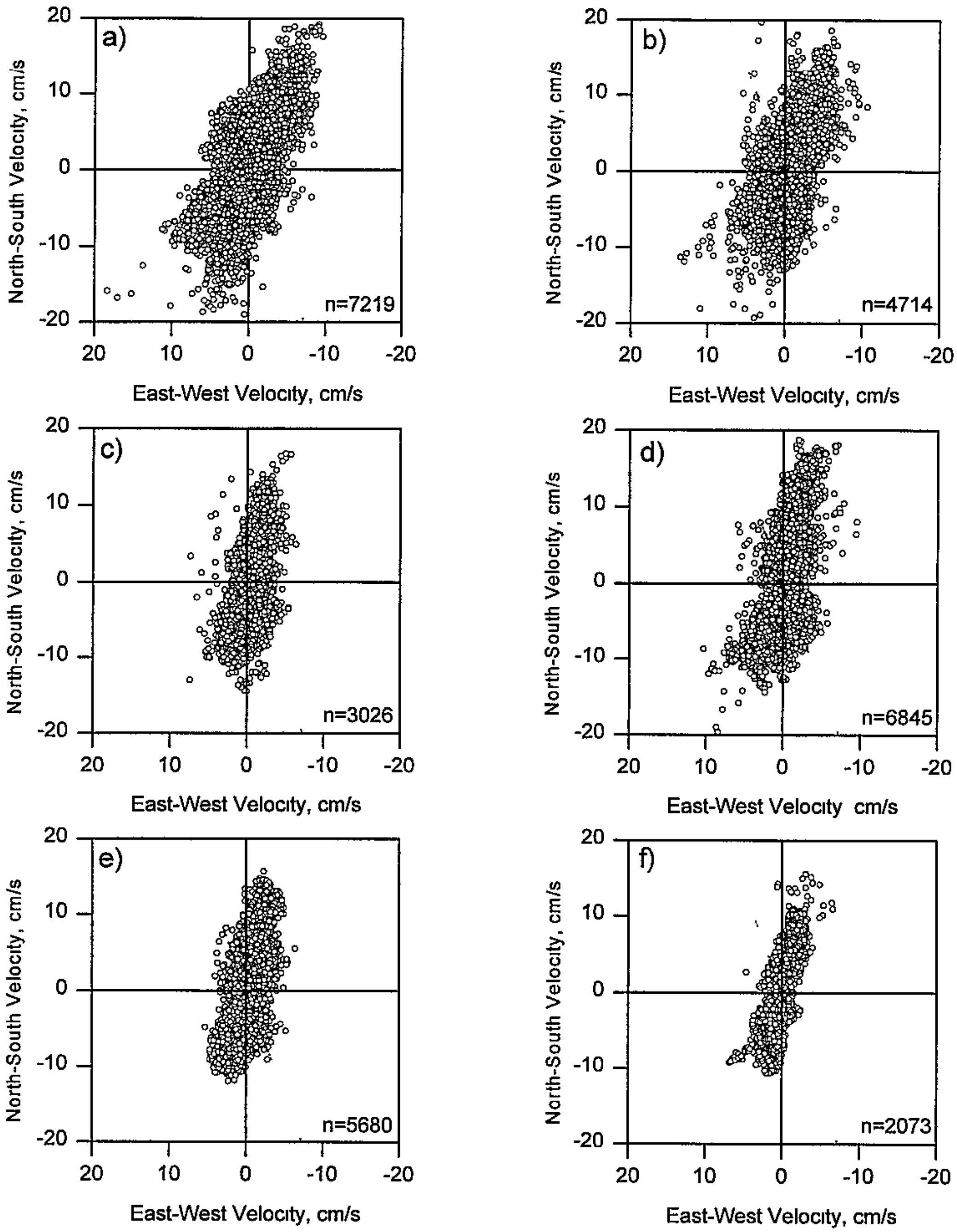

Figure 4 10a-f Scatter plots for March, 1995, to August, 1995, respectively

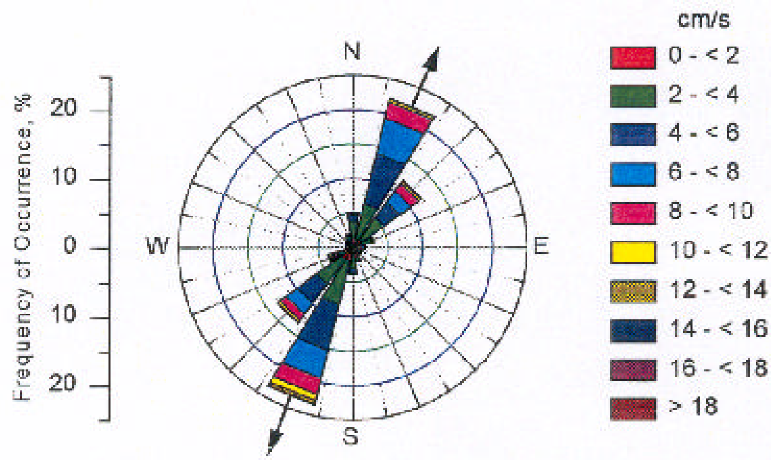

Figure 4.11. Current rose for September, 1994.

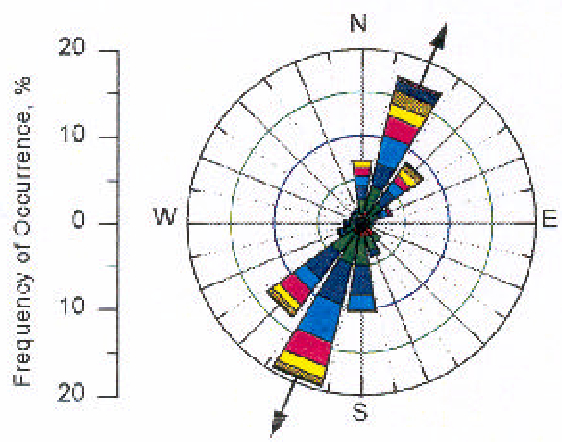

Figure 4.12. Current rose for November, 1994.

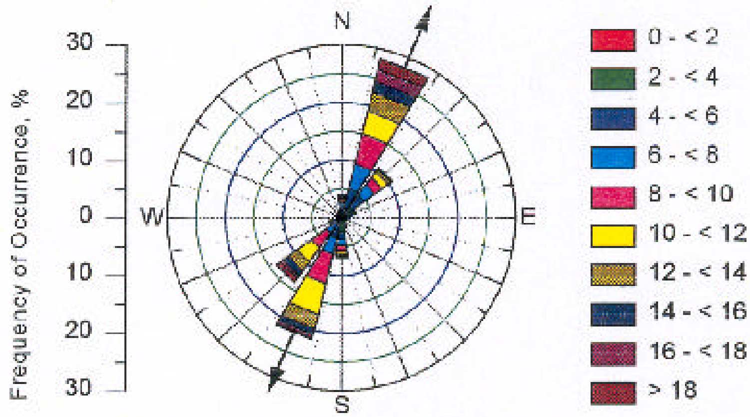

Figure 4.13. Current rose for January, 1995.

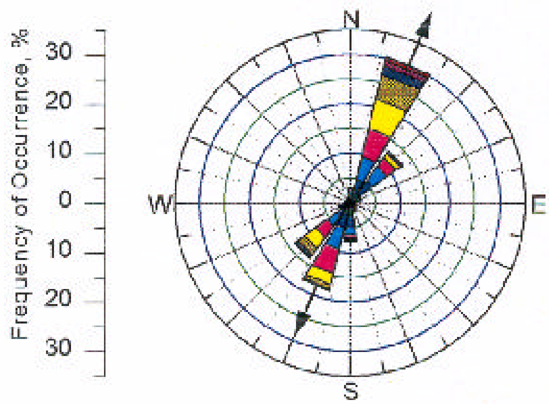

Figure 4.14. Current rose for February, 1995.

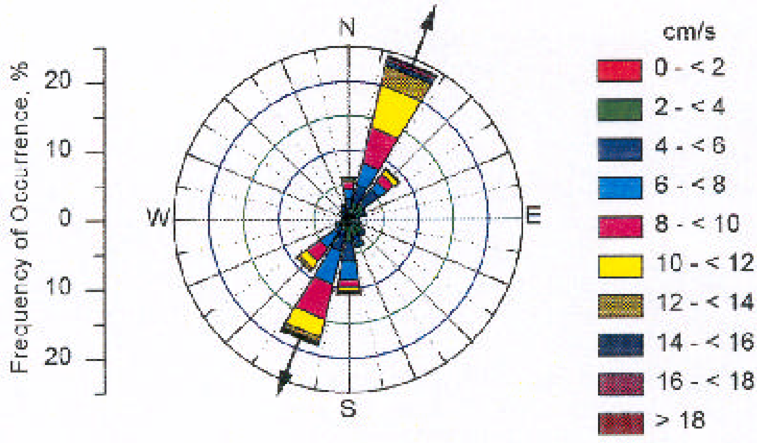

Figure 4.15. Current rose for March, 1995.

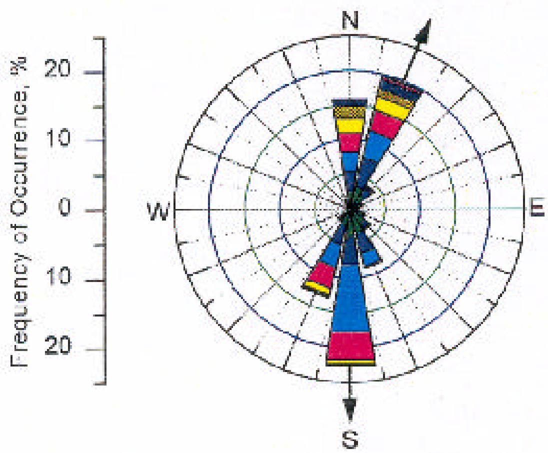

Figure 4.16. Current rose for June, 1995.

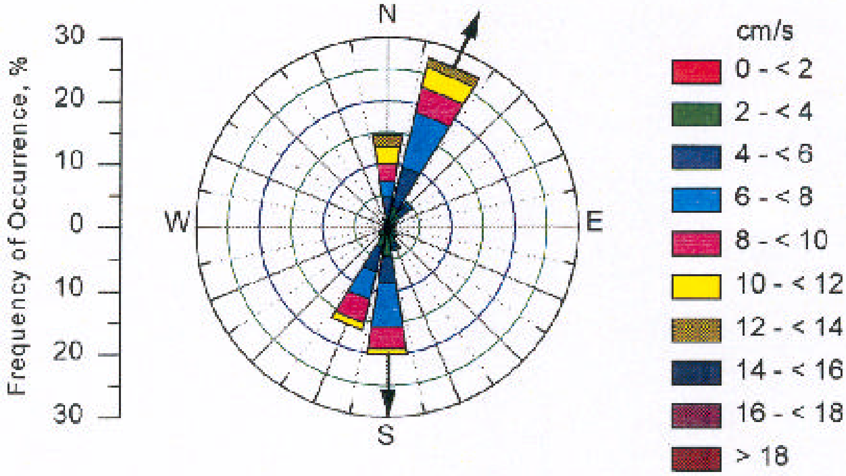

Figure 4.17. Current rose for July, 1995.

Table 4.2. Frequency of occurrence, mean, and standard deviation of magnitude of current.

	Frequency of Occurrence, %					Mean ± 1
Month	**0 - < 4 cm/s**	**4 - < 8 cm/s**	**8 - < 12 cm/s**	**12 - < 16 cm/s**	**> 16 cm/s**	**SD, cm/s**
9/94	50.1	37.9	10.3	1.7	0	4.0 ± 2.3
11/94	42.0	36.4	15.5	5.4	0.6	5.4 ± 3.6
1/95	19.7	27.2	32.7	13.7	6.7	8.4 ± 4.6
2/95	21.1	34.9	30.5	11.3	2.2	7.5 ± 3.9
3/95	27.4	36.5	28.9	5.8	1.4	6.7 ± 3.8
6/95	29.9	43.7	19.7	5.7	1.0	6.2 ± 3.5
7/95	28.6	45.6	22.2	3.6	0.0	6.1 ± 3.1

The magnitude of the flow was less than 8 cm/sec (0.26 ft/sec) 88% of the time, less than 4 cm/sec (0.13 ft/sec) 50% of time, and the mean flow was 4 cm/sec. In September, the predominant orientation of the flow was towards the north-northeast and south-southwest. During September, 70% of the flow was directed towards the south-southwest (23%), north-northeast (22%), southwest (13%), or northeast (12%). In November, 1994, the magnitude of the flow increased with the onset of winter conditions and the mean flow increased by 35% to 5.4 cm/sec (0.18 ft/sec). The flow was less than 8 cm/sec (0.26 ft/sec) 78% of the time and less than 4 cm/sec (0.13 ft/sec) 42% of the time. During November, approximately 60% of the flow was directed towards the south-southwest (20%), north-northeast (17%), southwest (13%), or northeast (9%). Approximately 10% of the time the flow was towards the south driven by the north winds associated with the passage of fronts and about 7% of the time the flow was towards the north driven by the south or southeast wmds, which typically precede the passage of a front.

In January, 1995, the mean flow ıncreased to 8.4 cm/sec (0 28 ft/sec) and the flow was less than 8 cm/sec (0 26 ft/sec) 47% of the tıme (less than 4 cm/sec (0 13 ft/sec) only 20% of the time), between 8 and 16 cm/sec 46% of the tıme and greater than 16 cm/sec (0.52 ft/sec) approximately 7% of the time During January, 75% of the tıme the flow was towards the north-northeast (28%), south-southwest (22%), southwest (14%), or northeast (11%). Durıng February, 1995, the mean flow was 7.5 cm/sec (0 25 ft/sec) and the flow was less than 8 cm/sec (0.26 ft/sec) 56% of the tıme, between 8 to 16 cm/sec 42% of the time, and greater than 16 cm/sec (0.52 ft/sec) 2% of the time In February, 75% of the flow was dırected towards the north-northeast (30%), south-southwest (18%), southwest (14%), or northeast (13%) and 8% of the tıme the flow was towards the south.

In March, 1995, the mean flow was 6 7 cm/sec (0 22 ft/sec) and the flow was less than 8 cm/sec (0.26 ft/sec) 64% of the tıme, between 8 to 16 cm/sec 35% of the tıme, and greater than 16 cm/sec (0 52 ft/sec) approxımately 1% of the tıme During March, 61% of the flow was dırected towards the north-northeast (24%), south-southwest (19%), northeast (9%), or southwest (9%) and 11% of the time the flow was directed towards the south During June and July, the mean flow was 6.2 and 6.1 cm/sec, respectıvely and durıng both months the flow was less than 8 cm/sec (0 26 ft/sec) about 75% of the time and between 8 to 16 cm/sec about 25% of the tıme Durıng June, 72% of the flow was dırected towards the south (23%), north-northeast (20%), north (16%), or south-southwest (13%) Durıng July, 80% of the flow was dırected towards the north-northeast (28%), south (20%), south-southwest (17%), or north (15%)

Components of Flow

Fıgures 4 18 and 4.19 present examples of the current changıng from tıdally-domınated to wind-domınated flow durıng the passage of a front. On January 23 at 0 00 CST, a strong north front passed through the regıon producıng average wınd speeds as great as 15 m/sec (33 mph) Prıor to the passage of the front, the current was prımarıly tidally drıven and wıthın the range of ± 10 cm/sec (0.33 ft/sec) and the wınd speed was typically less than 10 m/sec (22 mph) Durıng periods of relatively strong wınds, the wind-drıven component of the current increases. Typıcally, the wind-drıven component ıs expected to be about 3% of the wınd velocity (Hsu 1988). On January 23 at 0:00 CST, the wind velocity ıncreased to approximately 15 m/sec (33 mph) from the north, producıng an ıncrease ın current velocity to approxımately 15 to 20 cm/sec (0.5-0.66 ft/sec) towards the south. The data generated durıng thıs study ındicates that the wınd speed must exceed approxımately 10 m/sec (22 mph) to generate substantial wind-

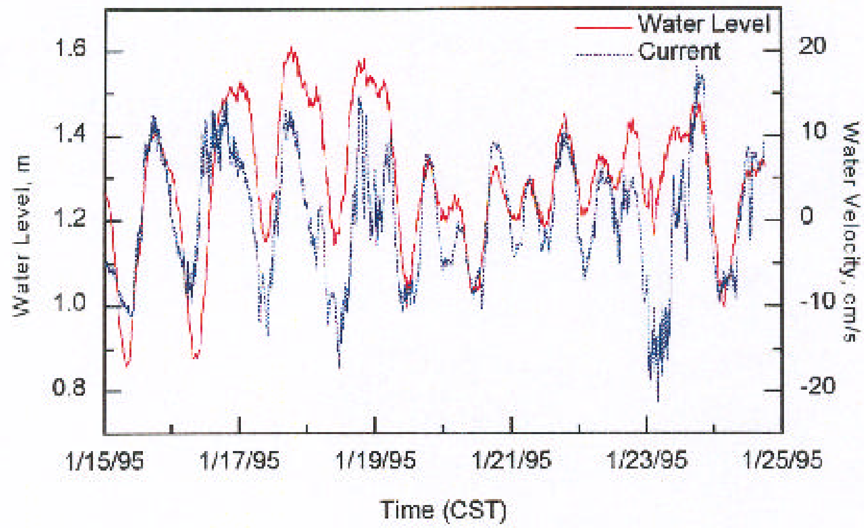

Figure 4.18. Time-series of water level at Port Isabel and current at FIX 1.

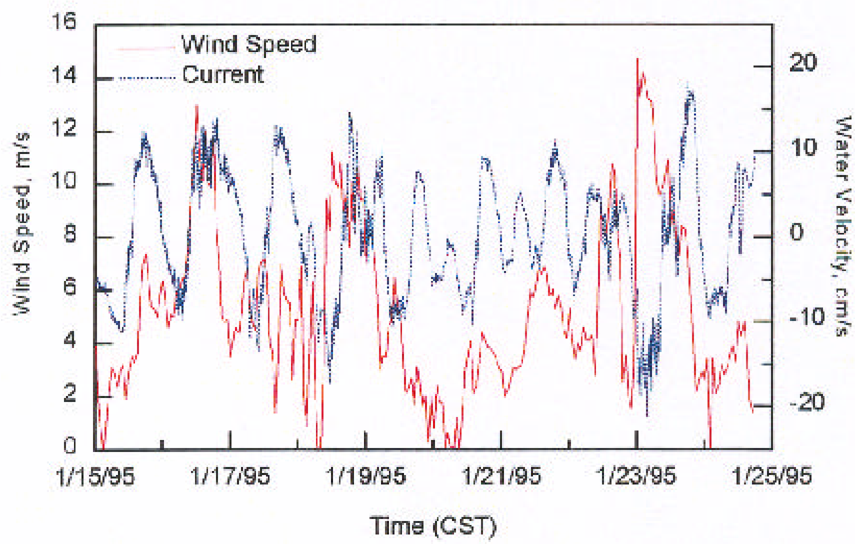

Figure 4.19. Time-series of wind speed at Arroyo Colorado and current at FIX 1.

induced currents. After the wind speed decreased to less than 10 m/sec (22 mph), the current changed direction, and the flow was approximately 15 cm/sec (0.5 ft/sec) towards the North, even though the wind direction remained from the North. This northward directed flow appears to be a return flow associated with the relaxation of a wind-induced set-up along the longitudinal axis of the laguna, which damps out typically within one oscillation.

Spectral Analysis

To identify the components of variations in current, water level, and wind, spectral analyses were performed for a 1-month records of the times series for representative months with nearly continuous records. Presented in Figures 4.20 to 4.23 are spectra of the de-meaned (removed average value) current, water level, and wind for September, 1994; February, 1995, March, 1995; and June, 1995, respectively. Spectra of the current were calculated for the north-south component, east-west component, and flow along the principal direction. A linear regression was performed on the north-south and east-west components to determine the principal direction of flow for each individual month. Spectra were also calculated for the water level at South Padre Island Coast Guard Station and Arroyo Colorado. Spectra for the wind forcing were calculated using the north-south and east-west components, as well as the magnitude of the wind speed.

Spectral analysis of the currents (Panel a) show that peaks occur primarily at diurnal and semi-diurnal periods, approximately at 25.6, 24.1, and 12.4 hr, for each of the months. Spectra of water level at South Padre Island indicate that spectral peaks occur primarily at diurnal and semi-diurnal periods, coinciding with those of the currents. However, the diurnal and semi-diurnal variations are almost completely attenuated at the Arroyo Colorado, and the variations in water level occur primarily at lower frequencies. During the months of September and June, there is a strong diurnal signal ($T_p \approx$ 24 hr) in the wind forcing, especially predominant in the east-west component. The wind forcing during the winter months, February and March, occurs primarily at low frequencies, less than 24 hr, associated with the passage of fronts.

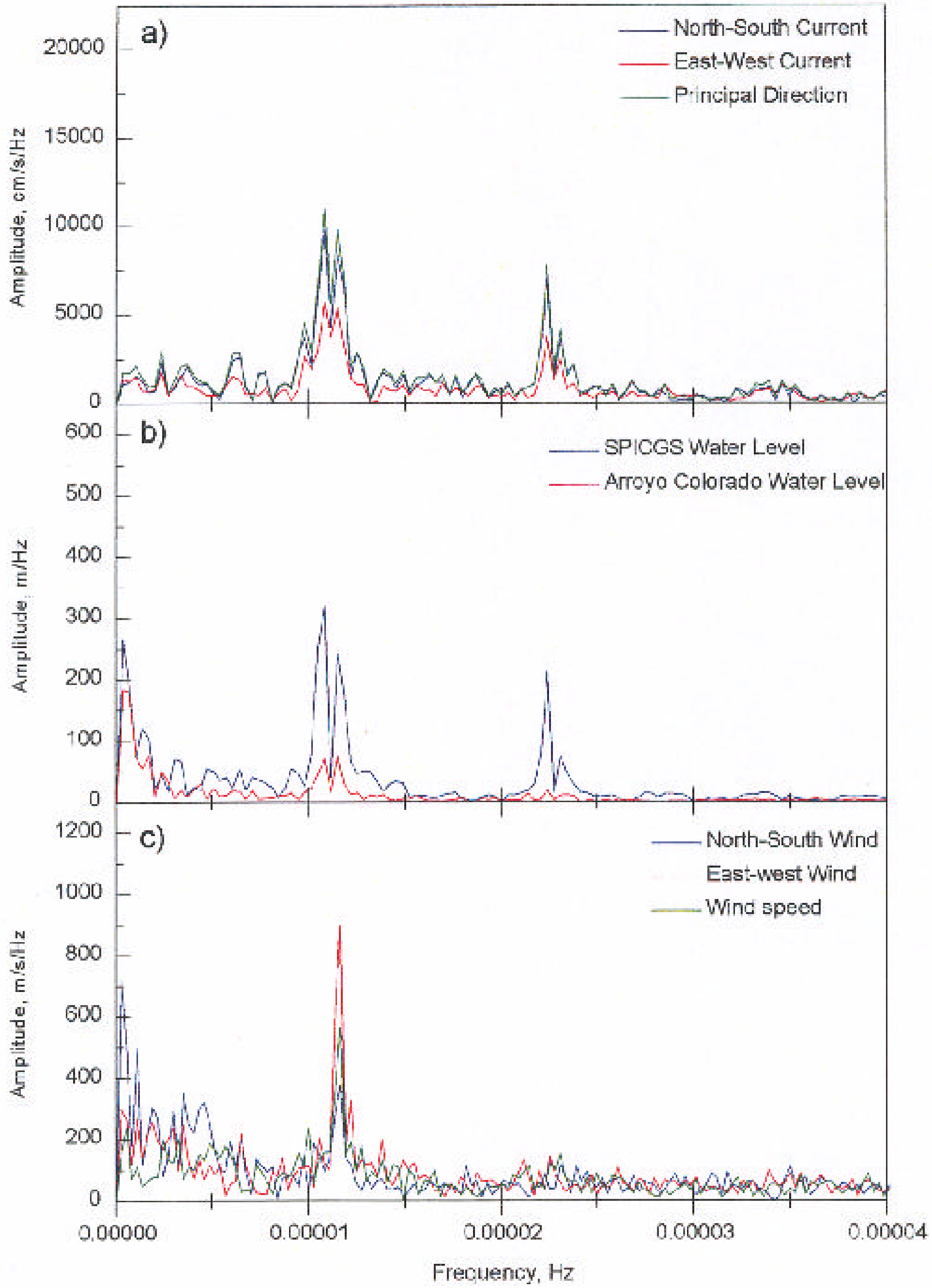

Figure 4.20. Spectra of current, water level and wind, September, 1994.

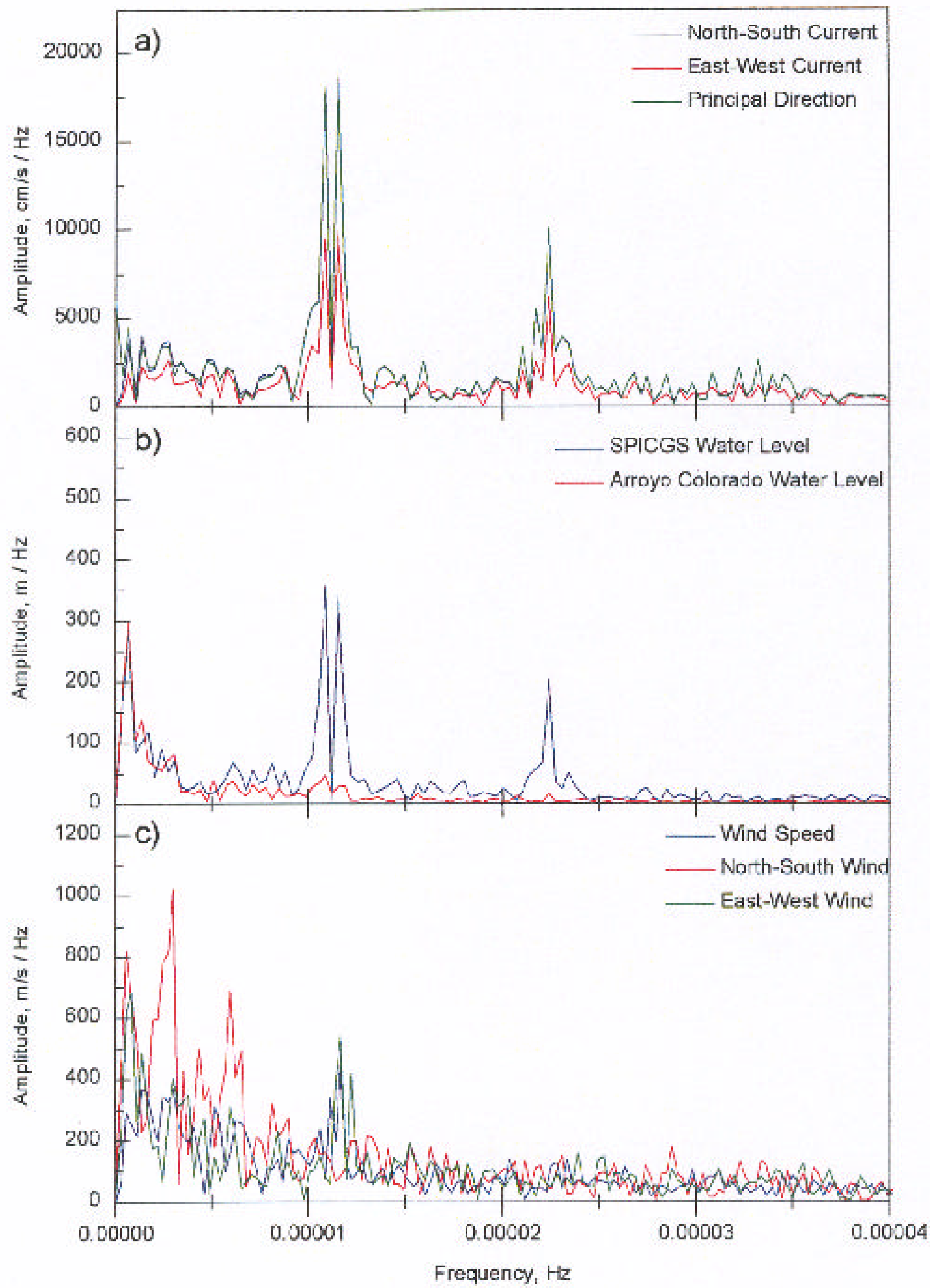

Figure 4.21. Spectra of current, water level and wind, February, 1995.

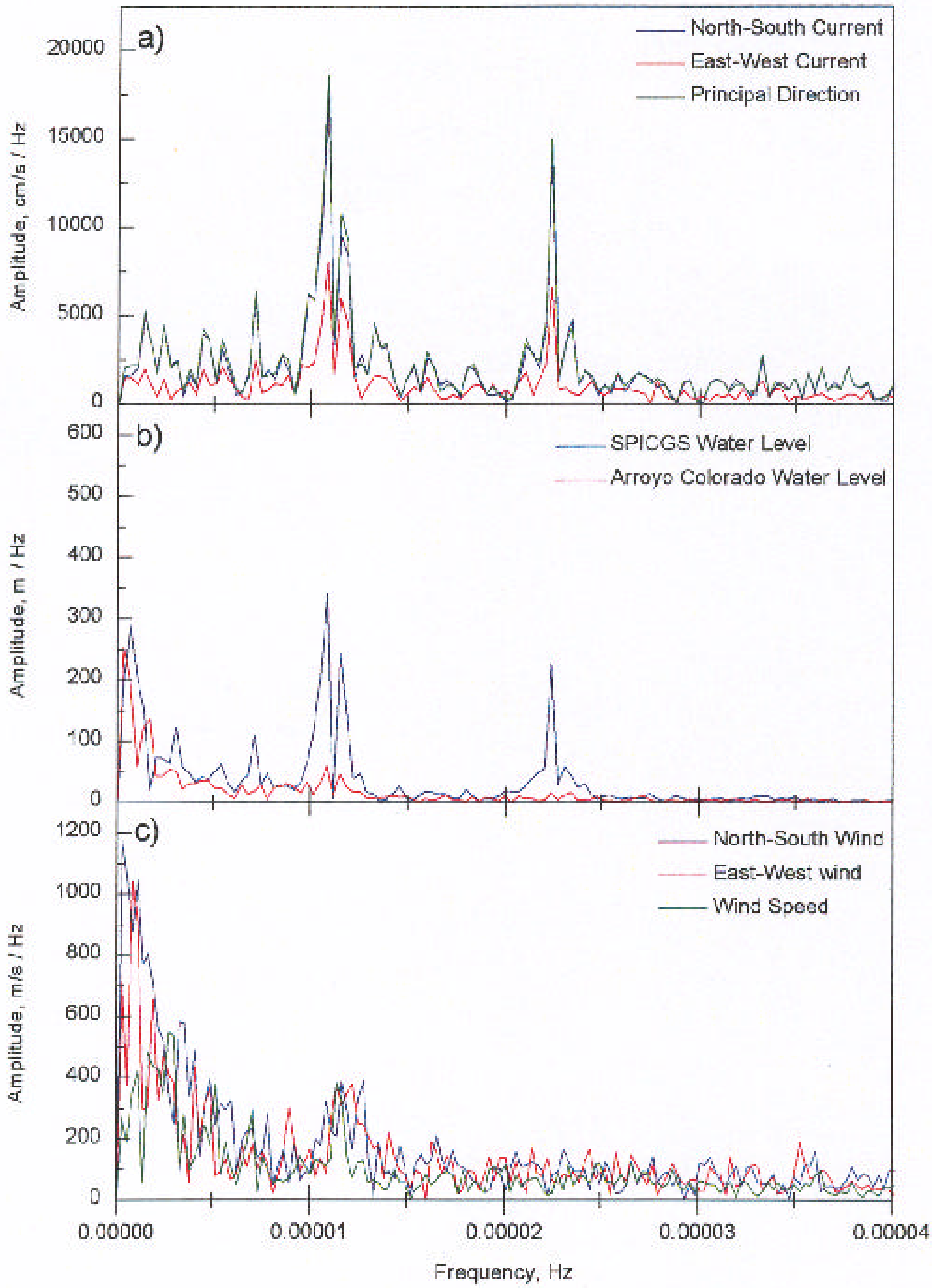

Figure 4.22. Spectra of current, water level, and wind, March, 1995.

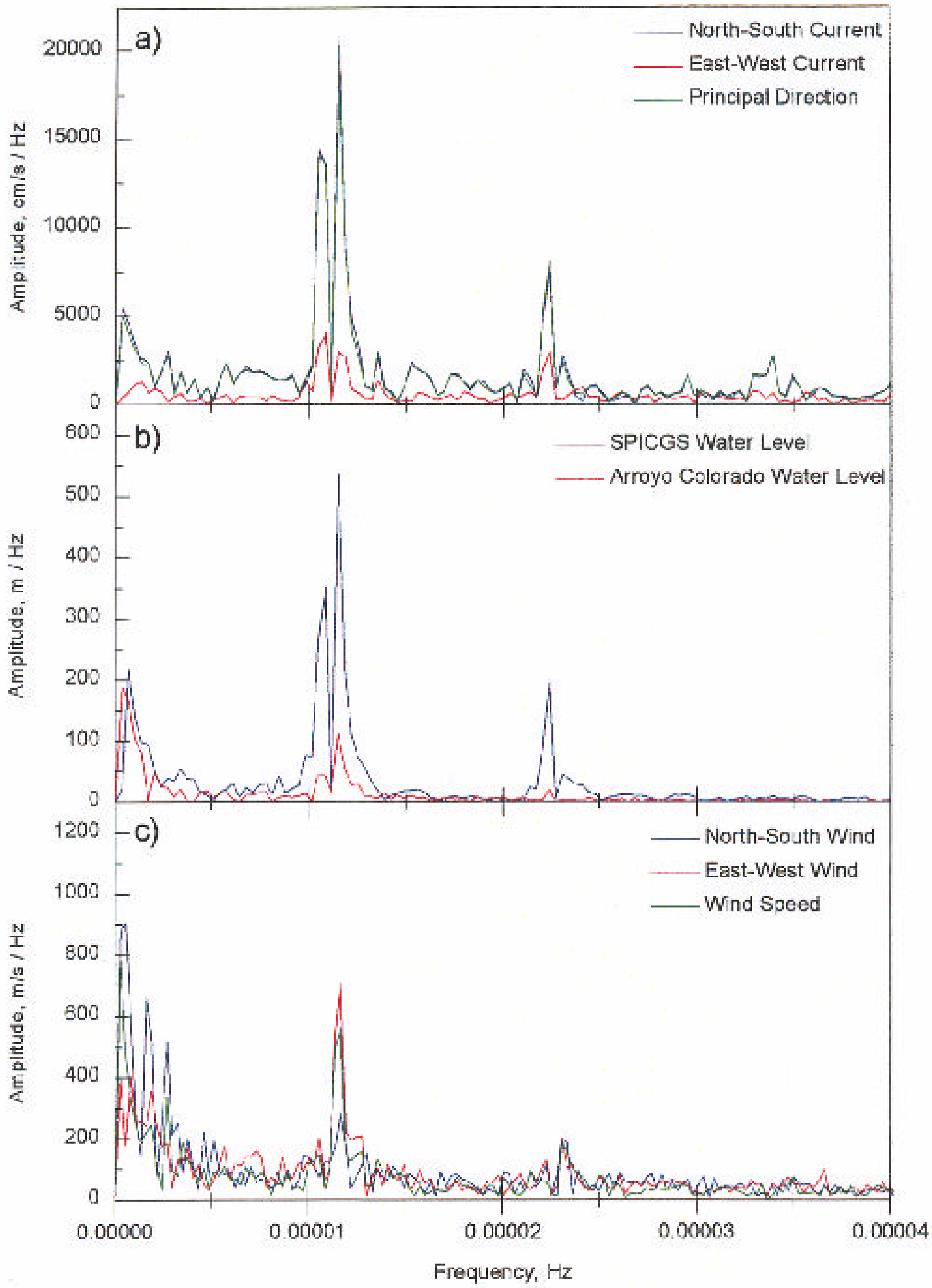

Figure 4.23. Spectra of current, water level, and wind, June, 1995.

5. Sediments and Their Resuspension[5]

This chapter presents the sediment resuspension data generated in this study Sediments in shallow-water environments are resuspended by various hydro-meteorological processes that include tidal currents, wind-driven currents, wind-generated waves, and wave-induced currents Resuspension of sediment is site specific and dependent upon numerous factors including water depth, bottom type (e.g., presence or absence of vegetation, sediment grain size, bottom configuration), and proximity to sediment sources, as well as fetch, the distance that the wind blows over water In shallow-water systems with fine-grained sediments, similar to Laguna Madre, wind-generated waves are often the dominant mechanism for sediment resuspension (Ward, *et al* 1984, Shideler 1984, Pejrup 1986, Schoellhammer 1995) There are numerous implications of increased sediment resuspension, which include increased sediment transport resulting in shoaling of maintained channels, and increased light attenuation, which may reduce available seagrass habitat

Previous Investigations

Sediments in Laguna Madre are derived from two sources, sand from the barrier island and suspended material from the mainland drainage, such as the Arroyo Colorado Shepard and Rusnak (1957) found that the surficial sediment distribution of the study area consists of primarily sand on the eastern side of the laguna, most probably transported from the barrier island by wind action, with the sand content decreasing with distance from the barrier island (Figure 5 1) In the deeper portions of the study area and near the mouth of the Arroyo Colorado, the silts and clays begin to dominate the surficial sediment distribution

Breuer (1962) observed that the turbidity in lower Laguna Madre was highly variable; however, the most important factor influencing the distribution of turbidity was the presence or absence of vegetation. Breuer also found that the turbidity was less over a sandy bottom, such as along the bay side of South Padre Island, and greater over a silt or clay bottom, such as in the deeper portion of the study area In shallow water, the dominant forcing mechanism for resuspension of sediment was the wind, and in deeper water tidal currents increased in importance James, *et al* (1977) inferred circulation and sediment transport patterns from satellite imagery of suspended sediment. Figure 5.2 shows the suspended sediment distribution (from James, et al. 1977) during flood tide and south winds of approximately 8 m/sec (18 mph). This image shows a turbid plume which crosses the GIWW in the vicinity of the high shoaling

[5] Written by Cheryl A Brown and Nicholas C Kraus, Conrad Blucher Institute for Surveying and Science, Texas A&M University-Corpus Christi

reach; however, the eastern portion of the study area, which is predominantly vegetated, has substantially lower suspended sediment. Satellite images, such as Figure 5.2, indicate that the suspended sediment distributions are similar for various hydrodynamic conditions.

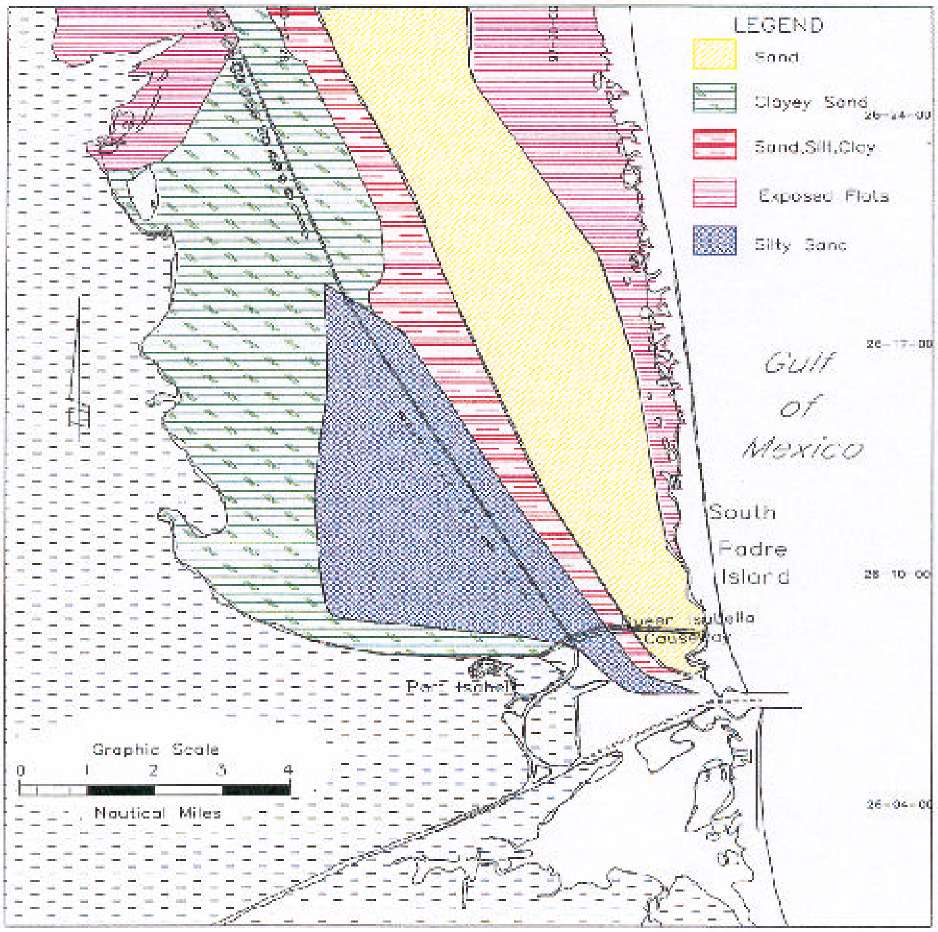

Figure 5.1. Surficial sediment distribution for study area (after Shepard and Rusnak 1957).

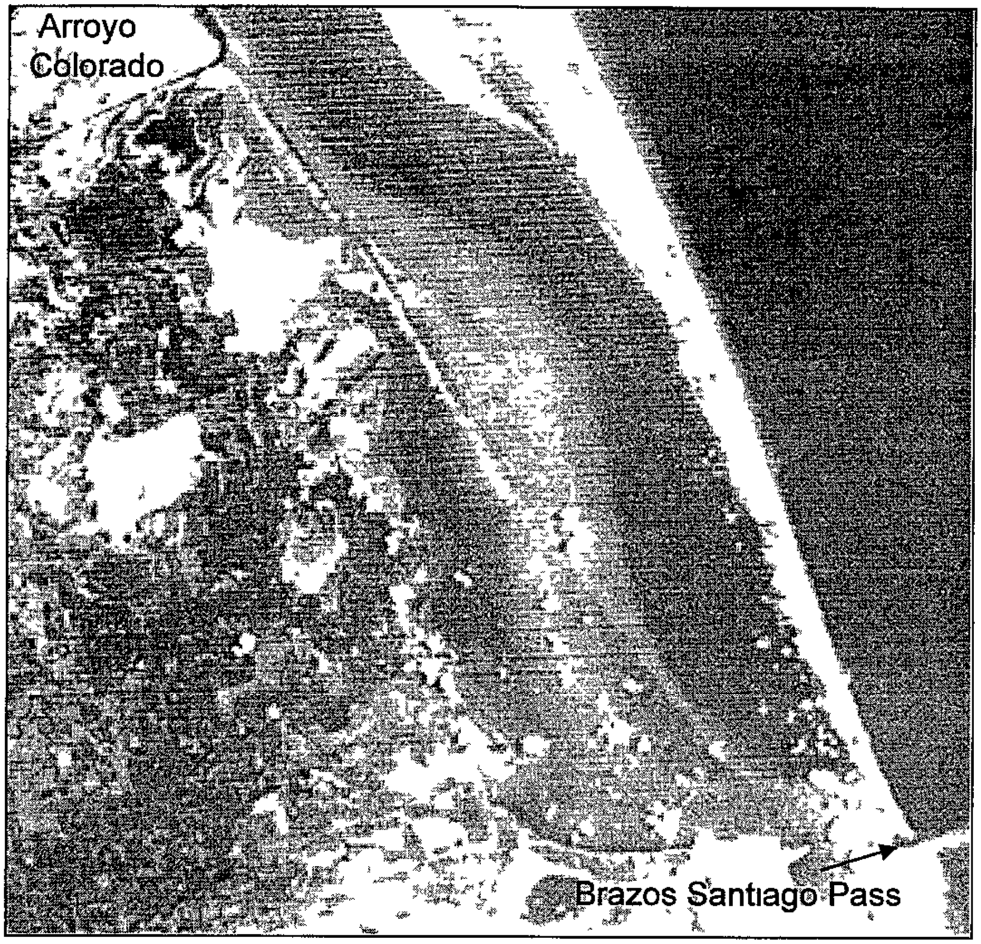

Figure 5 2 LANDSAT image of suspended sediment pattern, May, 1973 (from James, *et al* 1977)

Concentration of Suspended Solids

Figure 5 3 shows the concentration of suspended solids at FIX 1, FIX 2, and FIX 3 for August 30, 1994, to January 1, 1996. Prior to dredging activities (September, 1994), the concentration of suspended solids was typically less than approximately 200 mg/L During dredging and post-dredging activities (October to mid-April), the variation in the concentration of suspended solids increased and the concentration of suspended solids frequently exceeded 400 mg/L. A portion of the increase in concentration of suspended solids immediately subsequent to dredging may be attributable to changes in the meteorological conditions and the increased frequency of passage of fronts In August and September, 1995, the concentration of suspended solids returned to levels similar to those observed prior to dredging As discussed in Chapter 4, August and September are typically the calmest months of the year, with winds out

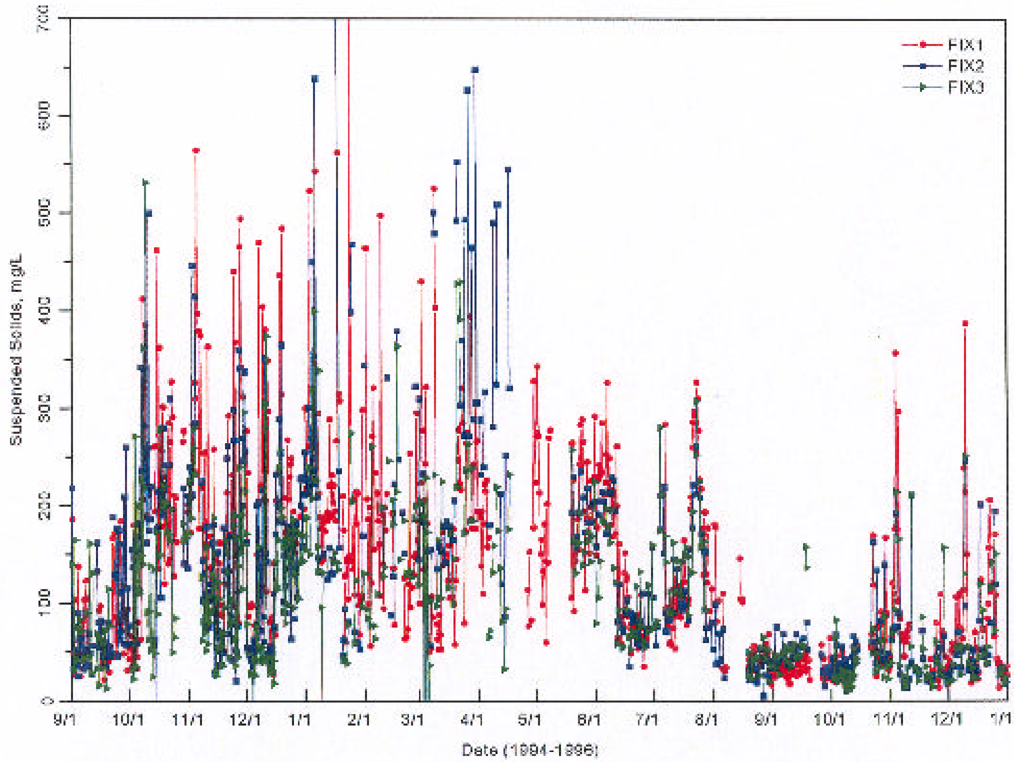

Figure 5.3. Suspended solids at FIX 1, 2, and 3, September 1, 1994, to January 1, 1996.

of the east. From mid-October through December, 1995, the variability in the concentration of suspended solids increased with the onset of winter conditions.

Table 5.1 summarizes the results of the filtration analysis for FIX 1, FIX 2, and FIX 3. Mean and standard deviations were computed using data when simultaneous samples were collected at all three platforms Prior to dredging, the concentration of suspended solids was approximately 80 mg/L with a standard deviation of approximately 50 - 60 mg/L at all three stations The concentration of suspended solids was fairly uniform between stations During the pre-dredging and during-dredging phases, there were no statistical differences between the stations (one-way ANOVA, p<0 05). During dredging activities, the concentration of suspended solids increased approximately three-fold at FIX 1, 2, and 3 One year subsequent to dredging activities, the total suspended solids at all three stations are less than levels measured prior to dredging activities.

Table 5.1. Summary of statistics for suspended solids at FIX 1, FIX 2, and FIX 3.

Period	Date (1994-1995)	Number of Samples	Mean and Standard Deviation, mg/L		
			FIX 1	FIX 2	FIX 3
Pre-Dredging	Aug 31 - Sep 25, 1994	18	80 4 ± 47 1	68 1 ± 48 4	71 3 ± 37 8
During Dredging	Sep 26 - Oct 29, 1994	23	236 5 ± 115 2	191 1 ± 82 3	176 2 ± 111 4
1-Year Post Dredging	Aug 31 - Sep 25, 1995	14	33 9 ± 9 0	55 7 ± 14 0	50 6 ± 26 1

Figures 5 4 and 5.5 show histograms of frequency of occurrence of concentration of total suspended solids at FIX 1, FIX 2 and FIX 3 for September, 1994, through August, 1995. In September, 1994, prior to dredging, the concentration of suspended solids for all of the water samples collected at FIX 1 and FIX 3 was less than 200 mg/L, and 95% of the samples at FIX 2 contained less than 200 mg/L of suspended solids. The majority of the samples (~ 70 to 80%) collected at FIX 1, FIX 2, and FIX 3 contained less than 100 mg/L. During October, the concentration of suspended solids increased at all three stations The concentration of suspended solids at FIX 1 and FIX 2 was similar with approximately 50% of the samples containing less than 200 mg/L, 40% of the samples having between 200 and 400 mg/L, and about 3 to 4% of the samples containing greater than 400 mg/L of suspended solids. FIX 3 had lower levels of suspended solids with 78% of the samples having concentrations of less than 200 mg/L, 20% of the samples containing between 200 to 400 mg/L, and 2% having more than 400 mg/L During November through January, the levels of suspended solids at FIX 1 was similar

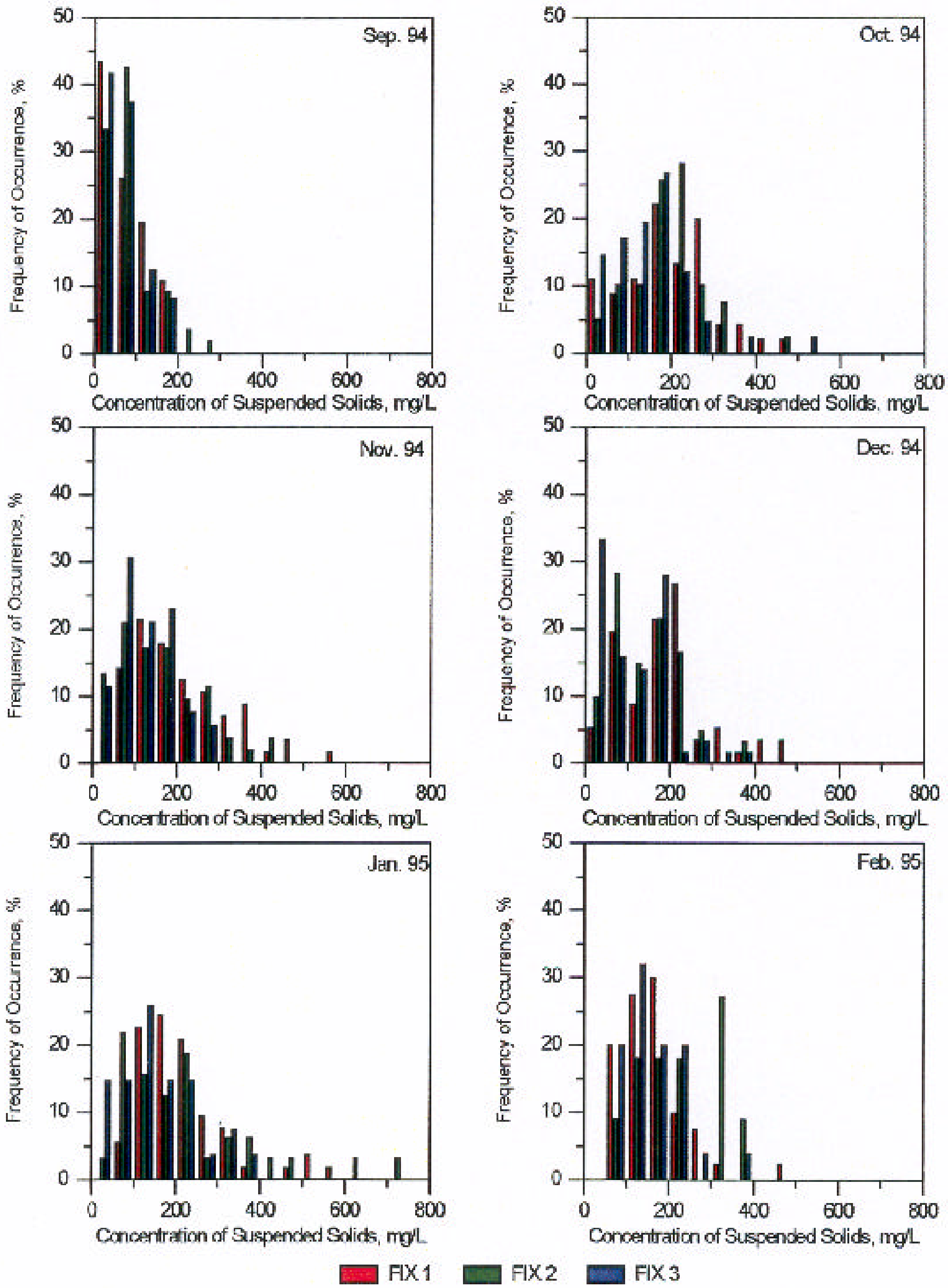

Figure 5.4. Frequency of occurrence of suspended solids, September, 1994, to February, 1995.

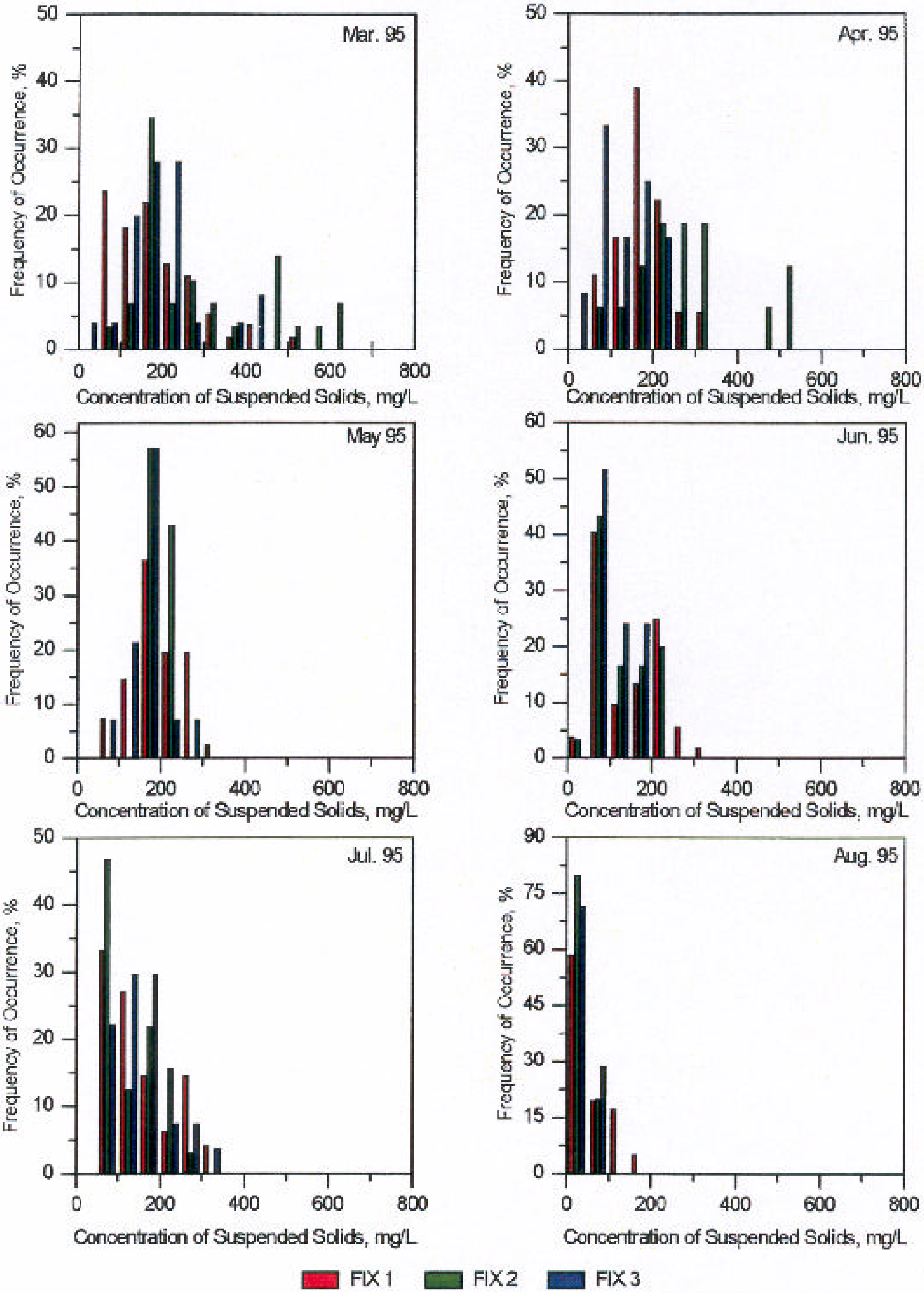

Figure 5.5. Frequency of occurrence for suspended solids, March, 1995 to August, 1995.

with each month approximately half of the samples containing less than 200 mg/L, about 40% having between 200 to 400 mg/L, and 7% containing more than 400 mg/L During November at FIX 2, 69% of the samples contained less than 200 mg/L, 27% had between 200 to 400 mg/L, and 4% contained more than 400 mg/L of suspended solids During October through February, the concentration of suspended solids at FIX 3 was lower than that observed at FIX 1 and FIX 2, with between 70 to 90% of the samples containing less than 200 mg/L of suspended solids, and the levels of suspended solids did not exceed 400 mg/L during November through February

During March through June, about 60% of the samples collected at FIX 1 contained less than 200 mg/L of suspended solids with the remainder of the samples containing between 200 to 400 mg/L In July, 75% of the samples collected at FIX 1 contained less than 200 mg/L and the remainder of the samples had between 200 and 400 mg/L During April, May, and July, approximately 80% of the samples at FIX 3 contained less than 200 mg/L and the remainder of the samples had between 200 and 400 mg/L and during June all of the samples contained less than 200 mg/L. During June and July, approximately 80% of the samples collected at FIX 2 contained less than 200 mg/L and the remainder of the samples had between 200 and 400 mg/L. In August, 1995, the concentration of suspended solids returned to levels similar to that measured prior to dredging activities with 78% of the samples collected at FIX 1 containing less than 100 mg/L (22% contained between 100 and 200 mg/L) and all of the samples collected at FIX 2 and FIX 3 having less than 100 mg/L

6. Light Attenuation[6]

This chapter contains a description of surface and underwater photosynthetically active radiation (light) as well as a discussion of the importance of maintaining underwater light levels for seagrass growth and production. Light attenuation data collected during the first year of this monitoring effort are presented together with a discussion of the trends observed, based on preliminary statistical analyses for detecting impacts of dredging activities

Introduction

Seagrasses are often considered a cornerstone of health and productivity in coastal environments In the Laguna Madre, seagrasses are the predominant primary producers and constitute about 80% of all seagrasses along the Texas coast (Quammen and Onuf 1993). Finfish landings in the Laguna are consistently the highest in Texas and are highly correlated with extensive seagrass beds (Texas Department of Natural Resources 1979) Although many factors influence seagrass growth (e g., temperature, salinity, and nutrients), underwater light availability is the single most important factor governing the growth and distribution of seagrasses (Dunton 1994, Kenworthy and Haunert 1991) Worldwide, there has been a greater than 50% decline in seagrass areal coverage over the last couple of decades, much of it presumably as a result of decreased water clarity and quality (see Dennison *et al* 1993 for review) The loss of seagrass habitat is closely correlated with reductions in underwater light as a result of either natural or anthropogenic factors.

Light in the wavelength range between 400 and 700 nm is referred to as photosynthetically active radiation (PAR) and is the energy source driving photosynthesis in all plants. The basic unit of light for any given wavelength is a photon. The amount of photosynthesis that a plant can carry out is directly proportional to the number of photons received by the photosynthetic apparatus. Light absorption in the water column decreases the energy (photons) available to plants to drive photosynthesis. For submerged plants the light environment is the result of the collective interaction of light with processes of reflection, absorption, and scattering (Figure 6 1) The reflection of light is primarily important only at the surface, where photons interact directly with the air-water interface. Once in the water column, light is either scattered or absorbed by the interaction of photons with water molecules and with the dissolved or particulate materials within the water. Different materials (e.g., water, dissolved substances, suspended solids, and phytoplankton) will scatter or absorb photons in a characteristic manner.

[6] Written by James E Kaldy and Kenneth H Dunton, University of Texas Marine Science Institute.

Scattering effectively increases the path length that a given photon travels and increases the probability that the photon will be absorbed (Kirk 1994) Although their size is large in relation to the wavelengths of light, particles with diameters greater than 2 µm are the primary agents of light scattering within the water column Thus, as a result of scattering and absorption the underwater light environment is diffuse (i.e., not unidirectional) and highly variable both temporally and spatially

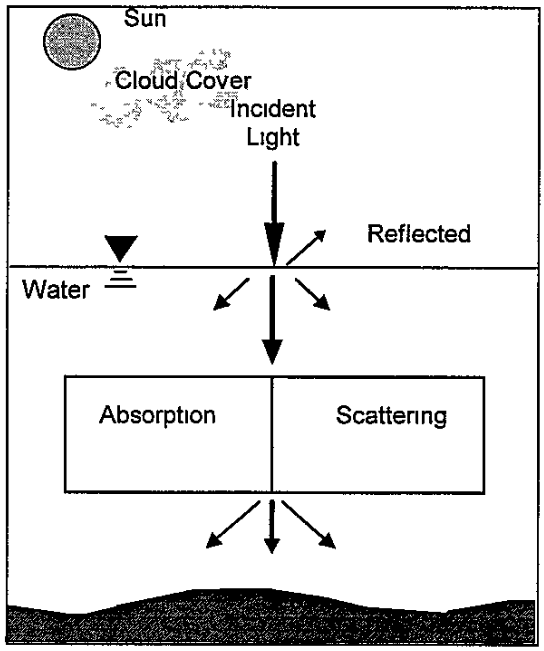

Figure 6 1 Schematic of light path, showing various components of attenuation (after Kirk 1994)

The terminology associated with quantifying the underwater light environment is complex Strictly speaking, irradiance is defined as the radiant flux incident on a receiving surface from all directions per unit surface area and is measured in units of Watts m^{-2} (LI-COR Inc , 1979) Irradiance is often used synonymously with photon flux which refers to the number of photons reaching a surface from all directions per unit surface area per unit time (mol photons m^{-2} s^{-1}) There is no official International System of Units (ISU) unit of photon flux A mole of photons is defined as Avogadro's number of photons (6.022 x 10^{23} photons) However, because the mole is an ISU unit, all of the prefixes associated also apply, e g , µmol photons / m^2 s^{-1} These units are particularly useful because photosynthesis is a quantum process which is dependent on the number of photons of PAR reaching the photosynthetic apparatus

Traditionally, oceanographers have defined the photic zone as the depth to which 1% of surface irradiance (SI) penetrates (Kirk 1994) This definition is useful for defining the portion of the water column with sufficient irradiance for growth and survival of phytoplankton (existing as individual cells) in coastal and oceanic systems. Seagrasses however, maintain 60 to 80% of their total biomass in below-ground tissues, i.e. roots and rhizomes (Dunton 1994). These underground tissues are dependent upon the above-ground fraction to supply fixed carbon and oxygen for respiration. As a result, seagrasses require substantially more light than phytoplankton A recent literature survey (Duarte 1991) concluded that worldwide, seagrasses require approximately 11% SI The state of Florida recently set water clarity guidelines at 10% SI in an attempt to prevent further loss of seagrasses habitat. However, based on a survey of seagrass biologists in the United States, Kenworthy and Haunert (1991) argued that seagrasses required between 18 and 25 % SI annually Recent research, coupling plant physiological measurements and maximum depth distribution with long-term continuous *in situ* light measurements have shown that the annual minimum light requirements for *Halodule wrightii* are close to 18% SI (Dunton 1994, Onuf 1996, Kenworthy and Fonseca 1996) and that *Thalassia testudinum* requires more than 14% SI (Lee and Dunton 1996)

The primary objective in this study was the long-term characterization of the underwater light environment near a dredged material placement site in the lower Laguna Madre These data will provide estimates of the duration of turbidity as a result of dredged material placement and the influence of wind- and tidal-driven dredged material resuspension Additionally, these data should promote evaluation of the area for the colonization of seagrass habitat, either through natural recruitment or facilitated development

The objectives of the light attenuation component of the study were to

1. Continuously monitor *in situ* levels of surface and underwater light
2. Assess changes in water transparency and the underwater light field in relation to dredging activities.
3. Determine the duration of dredging impacts on the underwater light environment

Data Collection and Analysis Methods

Continuous *in situ* surface and underwater light levels were monitored using the sensors and dataloggers described in Chapter 2 Data (surface and underwater irradiance values) were downloaded from the datalogger, printed, proofed for anomalies, corrected and added to the database Data quality was assured by comparing trends in the data collected at the platform to analogous data sets collected in the region as part of other independent research Light meter problems are usually reflected in large night-time deviations in irradiance from zero. In two cases, light data from a station located adjacent to FIX 2 (courtesy of Dr. C. Onuf, National

Biological Survey) were used to fill gaps due to equipment failure Using overlapping data, a mathematical relationship was developed between the data sets ($y = 0.852x + 1.841$, $r^2 = 0.76$), which was then applied to Onuf's data for the specific replacement period (where x represents the uncorrected (raw) value, and y the corrected value) Overall, less than 10% (44 days) of the underwater light data were replaced with Onuf's data as outlined Additionally 36 days (less than 8%) of the terrestrial data was obtained from the UT-Pan American Coastal Studies Laboratory (see Chapter 2 for details).

Attenuation coefficients quantify the amount of light absorbed in the water column, providing an index of water transparency Light attenuation coefficients (k) were calculated using the Bouger-Lambert Law:

$$k = \frac{\ln\left(\frac{I_o}{I_z}\right)}{z}$$

where I_0 is incident (surface) irradiance, I_Z is irradiance at depth z (average site depth in meters) and k is the attenuation coefficient (m^{-1}) Average water depth was based on data collected during monthly maintenance visits (n = 13)

Differences in the attenuation coefficient during various phases of the project (pre-dredging *vs* during-dredging *vs*. 1-year post-dredging) were examined by applying a one-way ANOVA. The sample sizes (n = 24, 26, and 33) were similar for the comparison. Statistical analysis was carried out using PC SAS (SAS Institute 1990) on a 486 PC If statistically significant differences were found ($p < 0.05$) then a Tukey's multiple comparisons test was used to determine where the differences occurred.

Results

Prior to dredging activities (August and September 1994), the sediments around FIX 1 consisted of consolidated fine sand and clay. However, after passage of the dredge there was a thick layer of unconsolidated sediments The layer appeared to have flowed over the surface of the hard bottom The average particle size was 18.0 µm, the mode was 4 7 µm (C Brown pers comm), and bulk samples contained about 65% water by weight In October 1994, immediately following the dredging activities, the unconsolidated layer was about 12 cm (5 inches) deep, decreasing to 5 cm (2 inches) by February, 1995, and to approximately 2 cm (less than an inch) by April, 1995. By June 1995, about nine months after dredging activities, this unconsolidated layer was no longer measurable at the platform

Continuous surface and underwater irradiance data were collected at FIX 1 during September, 1994, through December 12, 1995 (Figure 6 2) Surface irradiance was variable on daily and seasonal time scales Variability between days was large, with values ranging between 2 and 60 mols m^{-2} d^{-1}, and was probably related to changes in atmospheric conditions (e.g., cloud and fog cover) Seasonal patterns in surface irradiance were evident with the highest average light values (47 mols m^{-2} d^{-1}) occurring during the summer and lowest average light values (20 mols m^{-2} d^{-1}) occurring during the winter. These seasonal variations were the result of changes in planetary declination, which results in variable daylength and distance from the sun

Underwater irradiance was quite dynamic and relatively uncoupled from surface irradiance. During the pre-dredging phase (August 31 to September 25, 1994), average underwater irradiance ranged between 1.2 and 17 mols m^{-2} d^{-1} Dredging proceeded from south to north, beginning south of FIX 1 on September 26, 1994, concluding on October 29, 1994 Underwater light levels decreased as dredging progressed northward with minimal light values of almost 0 mols m^{-2} d^{-1} occurring on October 8, 1994, about 12 days after dredging began On 63% of the 246 days between October 8, 1994 and June 11, 1995, daily underwater light values were less than 1 mol photons m^{-2} d^{-1}. Underwater light increased during the summer and early fall (June through October, 1995) with values ranging from almost 0 to 18 mols m^{-2} d^{-1}. During late October and November average underwater irradiance decreased ranging from about 0 to 9 mols m^{-2} d^{-1}, which may in part be related to the passage of cold fronts and higher chlorophyll levels, possibly related to the brown tide (Dunton and Kaldy, unpublished data)

The percentage of surface irradiance reaching the sea-bed and light attenuation coefficients were calculated on a daily basis (Figure 6.3) During the pre-dredging period, average underwater light was 25% SI with as much as 45% SI reaching the seabed During dredging activities, PAR on the seabed dropped to levels ranging between 0 and 5% SI, which was an 80 to 100% reduction in light. During the period from September 26, 1994 to June 11, 1995, average SI was 4 5% (values ranged from almost 0 to 20% SI) During summer and early fall 1995 (June to October), underwater light averaged 15% and ranged from almost 0 to 45% SI. With the onset of winter conditions, underwater light decreased, as noted above, resulting in lower SI values (8 8% SI). Overall, on 87% of the 468 day study period, underwater light was less than 20% SI

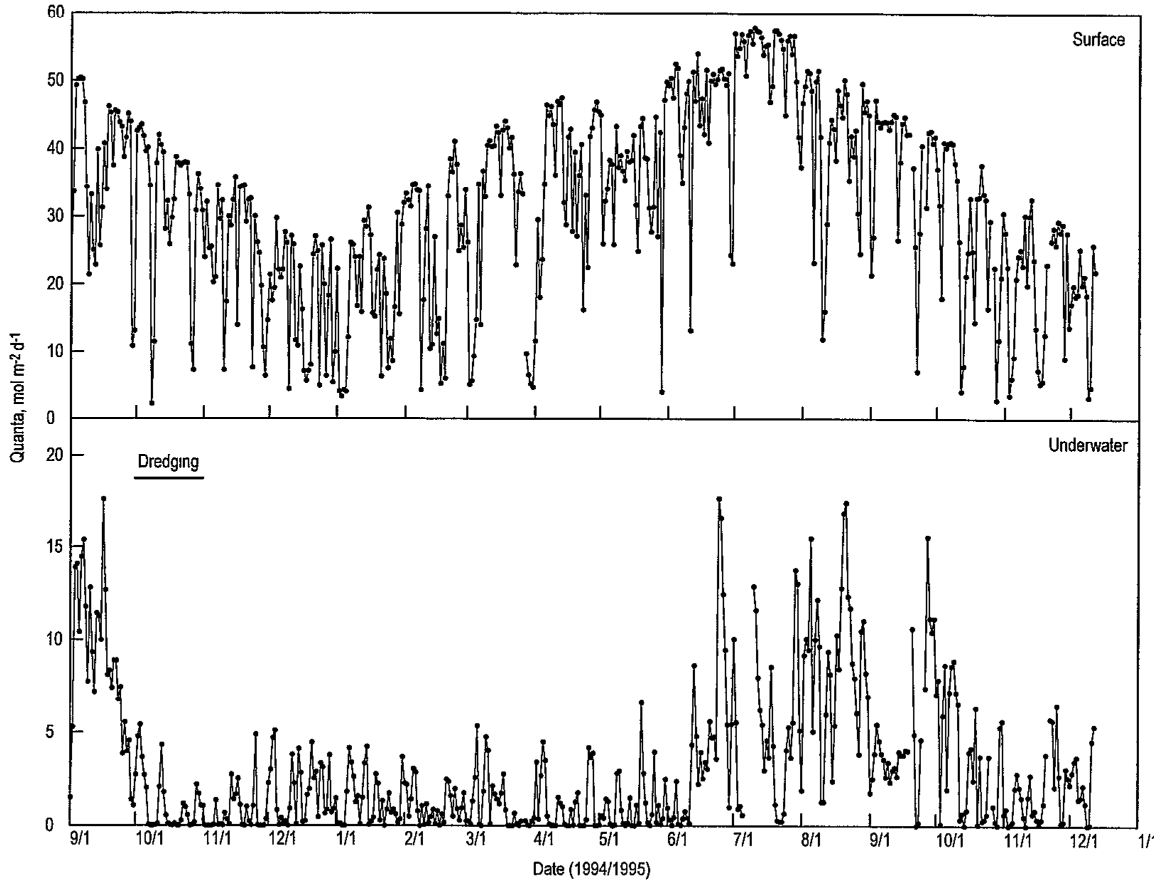

Figure 6 2 Surface and underwater irradiance from September, 1994, to December, 1995

Attenuation coefficients (k values) during the pre-dredging phase averaged 1 1 m^{-1} with values ranging between 0.6 and 2.4 m^{-1} (Figure 6 3) With the onset of dredging activities, k values increased three-fold to an average of 3.3 m^{-1} and ranged between 2 and 6 5 m^{-1}. Between October, 1994 and June, 1995, k values averaged 3.3 m^{-1} and ranged between 1 and 9 m^{-1} During summer and early fall 1995 (June through October), k values were about 50% lower, averaging 1 7 m^{-1} and ranging between 0 7 and 5 m^{-1} With the onset of winter (October through December), the average k value increased to 2.4 m^{-1} Light attenuation coefficients exhibited the same trends as the concentration of suspended materials (Figure 5.3), indicating that the underwater light environment is probably a function of the amount of suspended materials including sediments and plankton

Differences in attenuation coefficients between project phases, pre-dredging, during dredging, and 1 year post-dredging were statistically significant ($p < 0\ 0001$). The mean k values during pre-dredging, dredging and 1-year post-dredging were 1 1, 3 3 and 2 0 m^{-1}, respectively (Table 6 1) Tukey's multiple comparisons test indicated that all phases were significantly different from each other ($p < 0.05$)

Table 6.1. Summary of statistical analysis of attenuation coefficients.

Phase	Interval (year)	Number of Days (n)	Mean and Standard Deviation of k (m^{-1})	Mean and Standard Deviation of Underwater PAR (mol m^{-2} d^{-1})
Pre-Dredging	Aug 31 - Sep 25 (1994)	26	1 1 ± 0 4[a]	9 5 ± 4 1
During-Dredging	Sep 26 - Oct 29 (1994)	33	3 3 ± 1 6[b]	1 5 ± 1 8
1- Year Post Dredging	Aug 31 - Sep 25 (1995)	24	2 0 ± 0 2[c]	3 7 ± 2 1

[a b c] represent statistically significant differences ($p < 0\ 05$)

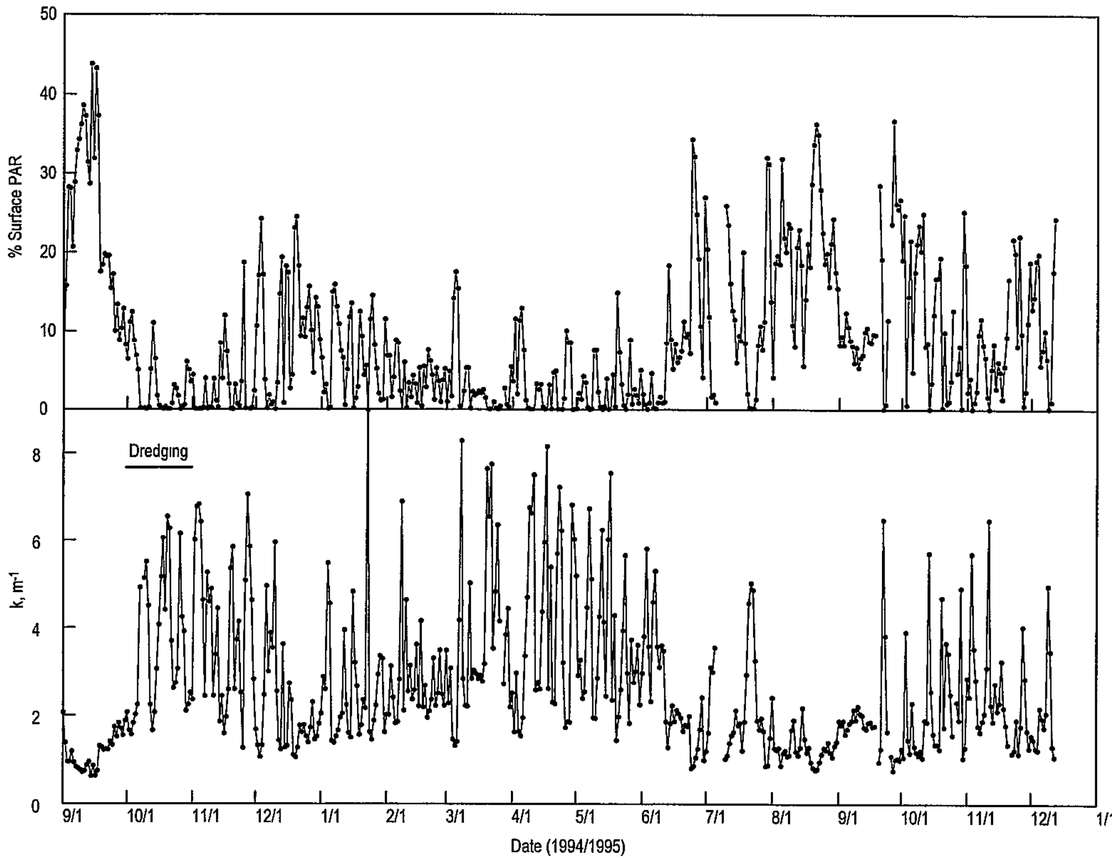

Figure 6 3 Percent surface PAR and light attenuation coefficient at FIX 1

Discussion

One of the more interesting aspects of the underwater light data was the relatively weak relationship of underwater light to surface irradiance Although summer irradiance tended to be higher than winter, the underwater light levels were highly variable, thus obscuring the seasonal signal evident in the surface irradiance data These data suggest that the underwater light environment was controlled by the amount of materials suspended in the water column. Dunton (1994) documented a similar uncoupling of terrestrial and submarine light in the upper Laguna Madre, which was attributed to scattering and absorption by materials in the water column During a 6-month study in several South Texas estuaries, including the upper Laguna Madre, total suspended solids (TSS; including phytoplankton and sediments) accounted for 75 to 100% of the light attenuation within the water column (Dunton *et al* in press). Underwater light levels in lower Laguna Madre, near Port Mansfield, have been shown to be significantly reduced as a result of resuspension of dredged material 18 months after dredging activity had ceased (Onuf 1994). Variability in underwater light at FIX 1 is most likely related to strong wind that generated waves, which probably resuspended materials from the unconsolidated sediment layer. The gradual dissipation of this layer may be associated with the high *k* values and low light levels observed during the period between October, 1994 and June, 1995. Other sources of suspended sediments include the deep, unvegetated area to the west of the GIWW (Figures 1.2 and 5 2) However, the lack of baseline data (from 1994) prevents rigorous statistical analysis At least one full dredging cycle must be monitored with one prior year of baseline measurements to permit an acceptable statistical comparison

Estuarine and coastal waters are generally characterized by attenuation coefficients (*k* values) ranging between 0.2 and 3.0 m^{-1}, with extremes of more than 10 m^{-1} (Kirk 1994). In Texas estuaries, *k* values generally range between 0 5 and 2.5 m^{-1} (Dunton *et al.* 1994) During this study, attenuation coefficients as large as 9 m^{-1} were observed Under low light conditions, small changes in irradiance have a dramatic impact on *k* values, however, the ecological significance is minimal since the light levels associated with these high *k* values are well below seagrass compensation irradiance

Extreme *k* values are generally the result of large-scale disturbance caused by either natural or anthropogenic forces (Zimmerman *et al* 1991 and references therein). The only large-scale disturbance that occurred in the lower Laguna Madre during this time period (August 1994 to December 1995) was the maintenance dredging of the GIWW with the subsequent deposition of dredged material in the vicinity of FIX 1 Although the persistent bloom of the brown tide in the upper Laguna Madre has reduced underwater light levels by 50% (Dunton 1994), its impacts in lower Laguna appears to be restricted to the winter when water is advected south from the upper Laguna as a result of cold fronts (Dunton and Kaldy, unpubl data) During the winter months, brown tide (phytoplankton) may also contribute to light attenuation, however, chlorophyll *a* values were typically less 15 µg Chl *a* l^{-1}, which is 50 to 70% lower than values recorded in the upper Laguna Madre (Dunton, unpubl data) In addition, because of its short duration, the long-term impact on underwater light levels is probably minimal. Dunton *et al* (in press) concluded that there was a strong relationship between chlorophyll *a* values and light attenuation in the upper Laguna Madre ($r^2 = 0\ 65$), but in the Nueces estuary the relationship was not as strong ($r^2 = 0\ 42$). The stronger relationship in upper Laguna Madre was a result of the ongoing brown tide bloom Based on the relatively low chlorophyll levels in lower Laguna Madre, it is unlikely that underwater light was greatly reduced by brown tide The association of dredging activities (including the deposition and dissipation of unconsolidated sediments) with increased light attenuation suggests that decreased underwater light availability may be a direct result of resuspended dredged materials

The apparent discrepancies between attenuation coefficients and TSS concentrations (Tables 5.1 and 6 1) are probably related to the types of measurements represented and sample size The measurements of TSS and PAR are inherently different. Total suspended solids concentrations are based on instantaneous samples taken in the early morning and early evening and as such are not integrative. PAR values are based on measurements made once a minute throughout the day and averaged over a 24 hour period.

One objective of this study was to quantify the duration of dredging impact upon the underwater light environment Preliminary analysis of available data indicates that attenuation coefficients were significantly different ($p < 0\ 0001$) between the project phases with highest values during dredging, lowest values during pre-dredging and intermediate values about 1 year post-dredging. The maximum impact with respect to underwater light levels can be defined as a continuous, relatively long-term decrease in underwater light to levels that are below 18% SI Preliminary analysis of the available data indicates that the period of dredging impact on light attenuation extended to approximately 246 days (October 8, 1994 to June 11, 1995) after the initiation of dredging, based on very low underwater light levels and high attenuation coefficients (Figure 6 3) Almost one year after maintenance dredging activities, underwater light levels were significantly lower than pre-dredging values, presumably as a result of sediment resuspension. Although the pre-dredging data set is rather small ($n = 26$), the much higher k values recorded during and subsequent to dredging suggests that this activity has had a significant impact on underwater irradiance Seasonal wind patterns may contribute to detected differences in attenuation Although wind data (Figures 4 2 and 4 3) indicates that September 1994 was relatively calm, one of the implicit assumptions of the statistical analysis presented here is that climate conditions were identical during September 1995 Consequently, our findings should be regarded as preliminary Ideally, definitive quantification of the temporal extent of dredging activity impacts on underwater light will require a long-term data set, including a year of baseline data collected prior to dredging activities and extending at least 24 months thereafter

FIX 1 is located in about 1.6 m of water, which is deeper than the lower limit of seagrass growth and colonization in parts of the lower Laguna Madre However, there are seagrass populations in lower Laguna Madre which are persistent in water depths averaging 1 7 m, but light levels in these areas tend to be greater than in this study (Dunton and Kaldy, unpubl. data) The underwater irradiance data collected as part of this project are generally 50 to 60% below the requirements of seagrasses (Dunton 1994, Dunton and Tomasko 1994, Kaldy and Dunton 1993, Kenworthy and Haunert 1991), presented in Table 6 2 Presently, seagrasses do not occur in the vicinity of the monitoring platforms, and as long as underwater light remains low, there is little chance that seagrass colonization (natural or transplanted) will occur. Recent transplanting efforts on dredged materials in the lower Laguna Madre have met with limited success (Dunton and Kaldy, unpublished data)

Table 6.2. Summary of average annual minimum light requirements for Texas seagrasses and observed light environment at FIX 1.

Seagrass	Minimum Percent Surface Irradiance	Mol photons m^{-2} yr^{-1}
Halodule wrightii	18[a]	2200
Thalassia testudinum	> 14[b]	> 1600
Syringodium filiforme	> 15[c d]	> 1600
FIX 1	9	1100

[a]Dunton 1994, [b]Lee and Dunton 1996, [c]Dennison 1991, and [d]Kenworthy *et al* 1991

Conclusions

1 The findings in this chapter should be regarded as preliminary, since the baseline data set is of brief duration Rigorous statistical analysis of the effects of dredging on light attenuation will require a full year of data collection prior to and following a dredging event (as a minimum).

2 Underwater light levels during the monitoring period were variable. Pre-dredging (August and September 1994) average underwater PAR was 9.5 mols m^{-2} d^{-1}. During and subsequent to dredging (October 1994 to June 1995) average underwater PAR decreased by 87% to 1 2 mols m^{-2} d^{-1}, while in summer 1995 (June to October) average underwater PAR increased to 66% of pre-dredging values (6 3 mols m^{-2} d^{-1}) Fall 1995 (October and November) underwater PAR decreased to 2 0 mols m^{-2} d^{-1}, but was about 50% higher than the preceding year when dredging took place

3 Preliminary analysis indicates that open-bay dredged-material placement appears to have a maximal impact on underwater light levels for about 246 days (October 1994 to June 1995) after initiation of dredging (PAR < 18% SI); however, a statistically significant difference in light attenuation coefficients (k values) one year after the cessation of dredging activities was also detected A continuous in situ underwater light record for an entire dredging cycle is required to quantify the duration of low light associated with dredging activities.

4. Subsequent to dredging, the underwater light environment was 50 to 60% below the light requirements of seagrasses These low underwater light levels are not presently suitable for seagrass habitat. Underwater light did not exhibit the seasonal patterns seen in surface irradiance, probably as a result of materials suspended in the water column

6. Light Attenuation[6]

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Introduction

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7. Seagrass Distribution[7]

This chapter presents field and laboratory methods, analysis techniques, and results of the seagrass distribution study Included is a discussion of the importance of seagrass communities and a review of previous surveys of the seagrass communities in the lower Laguna Madre

Introduction

Seagrass ecosystems support substantial amounts of estuarine and near-shore marine production Unfortunately, impacts that can be attributed to increasing human populations and development in many coastal regions worldwide have resulted in diminished coverage of seagrass with concomitant disruption of associated food webs In response, many on-going research projects have focused on assessing health and minimizing damage to these important ecosystems.

Much of the widespread degradation and disappearance of seagrass habitats in developed coastal areas worldwide have been attributed to dredging and dredged material disposal (Thayer *et al* 1975, Merkord 1978, Onuf 1994) Deleterious effects on seagrasses directly attributable to dredging activities include physical removal or burial of plants and light attenuation resulting from sediment resuspension (Cambridge and McComb 1984, Orth 1976, Thorhaug 1985, Pulich and White 1991, Quammen and Onuf 1993) Significant reduction in production may also occur due to less obvious alterations of the seagrass environment Although seagrass production may increase due to nitrogen and phosphorus resuspension in the water column induced by dredging activities (Ingle 1952, Fourqurean *et al* 1992), the nutrient increases can reduce seagrass production when phytoplankton and drift algae blooms increase, reducing light available for seagrass photosynthesis (Backman and Barilotti 1976, Dennison and Alberte 1985, Dunton 1990) In addition, nutrient-related increases in the growth of epiphytic organisms on blade surfaces may also contribute to light attenuation, significantly inhibiting seagrass production (Sand-Jensen 1977, Van Montfrans *et al* 1984, Twilley *et al* 1985, Tomasko and Lapointe 1991)

In the long-term, dredging may alter the hydraulic character of a system by producing dramatic changes in patterns of sediment transport and deposition, as well as tidal current alteration (Jones 1981). Seagrass loss may result from scour near channel margins, particularly during storms and other temporary high energy events. Increase in average wave height, which

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may result from changes in depths and wave shoaling patterns, contribute to destruction of seagrass meadows along channel edges (Larkum and West 1990). Seagrass meadows exposed to increased erosion may be lost, which may give rise to increased sediment transport, thus resulting in higher turbidity (light attenuation) and wave energies (scour), in turn causing further seagrass loss (Larkum 1976, West and Larkum 1979) In addition, changes in sediment grain size composition may significantly affect seagrass distribution and species composition (Buesa 1974, Larkum and West 1990) Sediment stability and sediment characteristics, such as texture, depth, and composition are also important determinants of seagrass productivity (Kirkman 1978, Thomas 1983, and Fourqurean *et al.* 1992)

The cumulative impact of dredging and dredged material disposal on seagrass meadows in the Laguna Madre is an issue of contention between environmental groups, federal and state resource managers, and those concerned with maintaining the navigability of the GIWW The purpose of the seagrass monitoring component of this study is to provide information on the response of seagrasses to maintenance dredging of the GIWW in the lower Laguna Madre The objectives of this study were:

1. To quantitatively compare seagrass occurrence and biomass before and after (1 year) dredging activities.
2. To assess long-term changes in seagrass biomass and distribution by comparison with historical data

Laguna Madre

About 80% of all seagrasses found along the Texas coast are found in the Laguna Madre, where they cover approximately 730 km^2 (263 mi^2), or about three quarters of submerged substrate in 1988 (Onuf 1996[b]) Five species in two families are found in the Laguna Madre: shoal grass (*Halodule wrightii*) and manatee grass (*Syringodium filiforme*) in the family Potamogetonaceae, and turtle grass (*Thalassia testudinum*), clover grass (*Halophila englemannii*), and widgeon grass (*Ruppia maritima*) in the family Hydrocharitaceae (Withers 1996) Shallow depths, in conjunction with low levels of suspended material have been suggested as the key factors leading to the expansive seagrasses in the Laguna Madre (Quammen and Onuf 1993).

Despite restricted circulation, limited freshwater inflow, higher rates of evaporation than precipitation, long periods of high water temperature, and episodes of hypersalinity (Onuf 1996[a]), the Laguna Madre is one of the most productive bays on the Texas Gulf Coast Seagrasses and associated epibenthic, benthic, and epiphytic invertebrate communities form the basis of food webs that include many commercially and ecologically important species (Withers 1996) Commercial finfish landings in the Laguna Madre averaged 52% of the total inshore catch statewide between 1972 and 1976 (Texas Department of Water Resources 1979) The total economic impact of the recreational fishery in 1986 was over 237 million dollars (Ponwith and Dokken 1996) The Laguna Madre also provides an important habitat for resident and migratory wading birds, shorebirds, gulls and terns, divers (e g , pelican, cormorant), and waterfowl Seventy-eight percent of the North American population of Redheads (*Aythya americana*) winter in the Laguna Madre and feed nearly exclusively on shoal grass roots and rhizomes (McMahan 1968) Shoal grass is also an important part of the diet of wintering American Widgeon (*Anas americana*) and Pintail (*A acuta*)

Previous Investigations - Lower Laguna Madre

The earliest descriptions of Laguna Madre were made in the late 1920's (Pearson 1929, Burr 1929-1930), but there was no mention of seagrasses Information on seagrass systems in the lower Laguna Madre was first presented by Breuer (1961) as a part of an ecological survey from 1953 to 1959. Maps of seagrass coverage generated in 1955, 1957 and 1961 showed a northward extension in coverage for all five species (Singleton 1964) In addition, he found beds of shoal grass colonizing areas in Redfish Bay, where the species had not been previously documented. In 1965, a northward extension was documented for manatee grass to approximately half-way between Three Islands and the Arroyo Colorado, and shoal grass continued expanding its range from 1962 to 1965 in Redfish Bay (McMahan 1965). On the west shore of Redfish Bay, shoal grass went from a "light to moderate to dense stand" over the study period with small stands of clover grass becoming less common along the GIWW (McMahan 1968) In 1978, manatee grass communities were established as far north as the land-cut and dominated areas of southern Redfish Bay (Merkord 1978) From 1974 to 1976 he documented two manatee grass aggregates that underwent a 144 and 210 percent increase, respectively, in one year in the area between Three Islands and Redfish Bay Turtle grass distribution expanded after 1966, but remained confined to Port Isabel Bay. Widgeon grass was almost totally absent from samples by 1976, while clover grass was common and widespread in the lower Laguna Madre (Merkord 1978) Merkord also provides the first biomass data on seagrasses from the lower Laguna Madre

Particularly evident between 1966 (McMahan 1968) to 1974 was a decline in seagrass coverage in the deepest parts of Port Isabel Bay (Merkord 1978) Areas that had previously supported seagrasses (Breuer 1961, McMahan 1968) were observed to be barren of vegetation in 1974 (Merkord 1978), with an estimated 9650 ha of Port Isabel Bay bottom devoid of seagrasses Unvegetated portions of Redfish Bay did not appear to have increased and remained relatively constant from 1966 to 1974 (Merkord 1978)

In 1988, Onuf (1996[a]) resurveyed areas in Port Isabel Bay previously surveyed by McMahan (1968) and Merkord (1978) The decline in shoal grass continued, along with progressive colonization, by less saline tolerant species, manatee grass and turtle grass (Quammen and Onuf 1993) Between 1967 and 1988, shoal grass coverage in the lower Laguna Madre declined from 550 km^2 to 220 km^2 (60%) Coverage by other seagrass species, predominantly manatee grass and turtle grass, increased by 270% over the same period Bare bottom areas in the bay expanded by 280% (50 km^2 to 190 km^2) (Quammen and Onuf 1993). Vegetation loss in the lower Laguna Madre was primarily concentrated in the deeper parts of Port Isabel Bay, west of the GIWW

Methods

Field Techniques

Three surveys of the seagrass meadows in the southern portion of lower Laguna Madre were conducted, two quantitative surveys and one interim qualitative survey Permanent transects were established and a baseline survey was conducted approximately one month prior to maintenance dredging (188 sites) Follow-up sampling was conducted along the permanent transects at each established sampling site approximately 6 and 12 months after the baseline survey (Table 7 1) Seagrass samples were collected, utilizing techniques and methodologies developed by Dr Christopher Onuf (National Biological Survey) in order to duplicate the 1988 survey as closely as possible Seagrass beds were sampled along three latitudinal transects, 26° 8', 26° 10' and 26° 11', extending from the eastern to western shore. Additional transects were established along latitudes 26° 6' and 26° 13', extending from the GIWW to the western shore of the Laguna Madre. In addition, two transects were established west of the GIWW, Transects B and Z, for the purpose of comparison with previous data and to examine any wind-driven encroachment of dredged material onto the western meadows Transects were further sub-divided into ten east and west short transects delineated by their respective side of the GIWW (east or west) and latitude (Figure 7 1). Whenever possible, survey transects duplicated those established in earlier studies (Merkord 1978, Onuf 1996[a]). Additional sites were established to delineate seagrass meadow boundaries between and along latitudinal transects Coordinates for each station site were established and re-sampled using a Magellan 5000 Pro GPS and Starlink Differential GPS (± 3 m).

Table 7.1. Dates of seagrass surveys and number of sampling sites.

Survey	Date Conducted	Number of Sampling Sites
Pre Dredging	8/29/94-9/3/94	188
Interim	3/16/95-3/21/95	154
1-Year Post Dredging	9/3/95-9/10/95	186

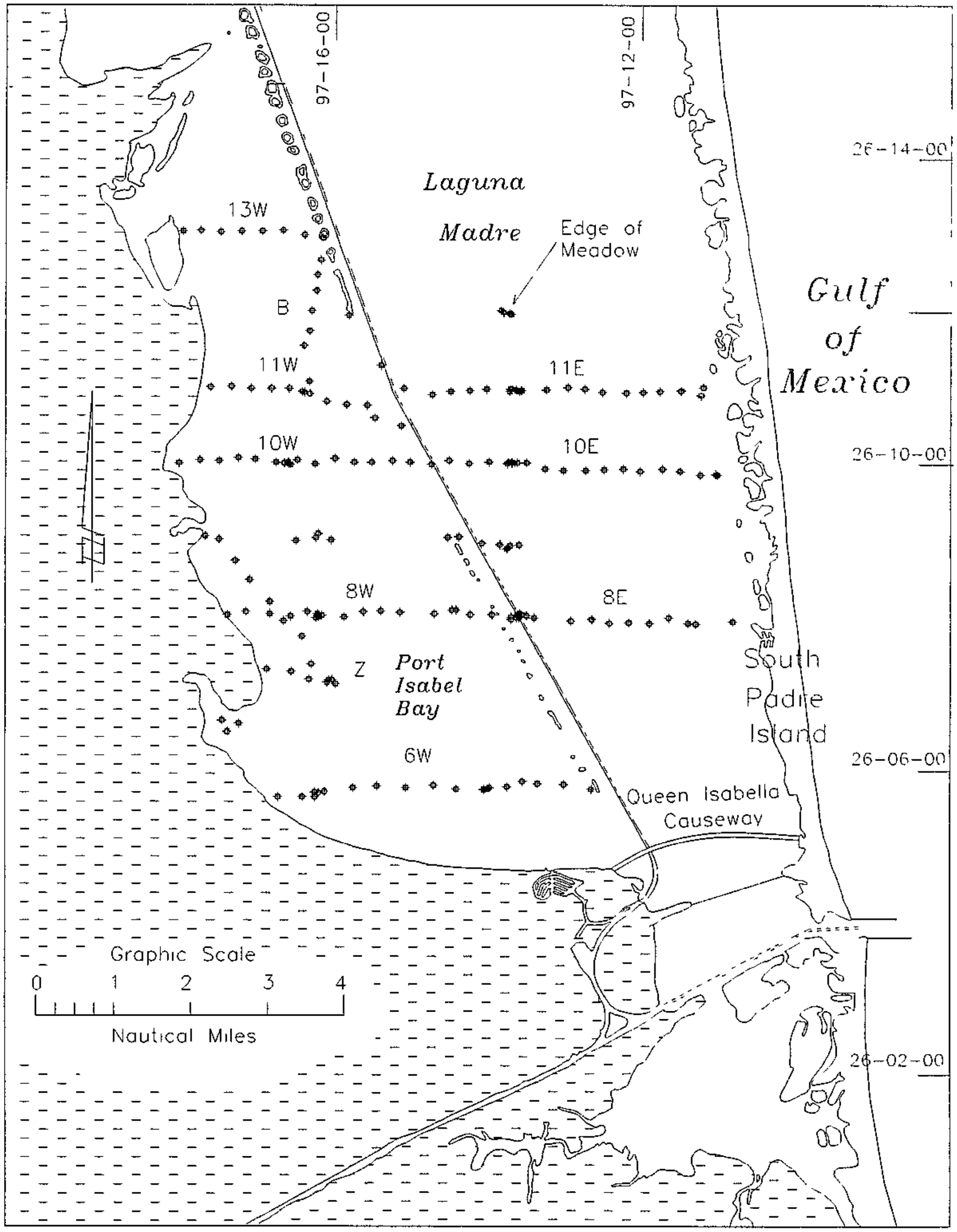

Figure 7 1 Location of seagrass sampling locations in Port Isabel Bay and northwestern flats Short transects are labeled with E=east and W=west

Four core samples (10-cm diameter) were collected at approximately 366-m (0 2 nautical mile) intervals along each transect Cores were extracted from the bed at equidistant intervals along the leeward rail of the 7-m research vessel (from bow to stern) using a PVC corer Seagrass and macroalgal species presence and relative dominance based on visual estimates of rhizome abundance were recorded for each sample in the field If vegetation was not encountered, the site was reported as bare Prior to sampling, two cores were randomly selected for biomass determination (if seagrasses were present) Biomass samples were washed through a 1-mm mesh screen to remove sediments, tagged, placed in ice, and returned to the laboratory Additional parameters recorded at each site were visibility (20-cm diameter Secchi Disc), salinity (temperature-compensated refractometer), depth (cm) and sediment type (visual)

Laboratory Work

Two hundred sixty-eight individual core samples (36%) were collected and returned to the laboratory for biomass determination, including core samples from 134 sites re-sampled 1 year after dredging Samples were frozen until processed Laboratory procedures follow those established in surveys conducted in 1988 (Onuf 1996[a]) Laboratory processing involved washing each sample and sorting into individual seagrass species, macroalgal, and detrital components Seagrass species identification was based on morphological criteria All sorted core components containing seagrass species were further separated into above-ground (green portion of blade), below-ground (roots), unpigmented blade (shoot tissue lacking pigment, below the above-ground component), and attached dead blades A total of 1,593 components were processed in this study Biomass was determined as both dry weight and ash-free dry weight (g/m^2) All components were dried approximately one hour, until reaching a constant weight at 60°C, then ashed at 530°C for 3 hr. Mass of the processed components was determined using a precision balance with an accuracy of ± 0 0001 g

Analysis

Analysis of data collected during this study involved the following

1 Compilation of seagrass species frequency of occurrence in cores collected during all surveys. Percent occurrence is calculated based on both total seagrass species frequency of occurrence in core samples (Table 7 2) and species occurrence as a fraction of all core samples collected (Table 7.3)

2 Compilation of descriptive statistics to be used in comparison of observed biomass To facilitate comparison with previous studies, both ash-free weight and dry weight were employed in the analysis of data.

3. Statistical software (JMP, ver 3, SAS Institute) is used to perform a paired *t*-test, assuming unequal variance and multiple regression on transformed data. Biomass values were tested for statistically significant differences (α = 0 05) between surveys at each resampled site Refer to Ott (1993) for specific details on statistical implications and assumptions of the paired *t*-test and multiple regression

Results

Patterns of Species Occurrence

Dominant species representation in core samples collected from seagrass communities in the Port Isabel Bay area were found to vary between proximal sites and also between replicate cores collected at each site. Figure 7 2 shows the dominant seagrass species distribution and the location of bare areas (regions without hatching) inferred from on-site visual estimates of rhizome abundance within core samples Distributions are inferred from the three sampling surveys, without the use of aerial photographs to interpolate between sampling locations Seagrass communities east of the GIWW are comprised predominantly of dense stands of turtle grass interspersed with manatee grass Along the eastern and western edges of the turtle and manatee grass meadows are fringes of shoal grass Shoal grass beds occur as a broad band several hundred meters wide, on shallow flats along most of the eastern shore of Port Isabel Bay north of the city of South Padre Island Directly west of the city, shoal grass is much less abundant, being frequently encountered as small stands along the margin of large turtle and manatee grass meadows Shoal grass is also found just east of the GIWW, generally forming a border a few meters in width at deep edges of the turtle and manatee grass meadows. To the west, seagrass species are more equally distributed (Table 7 2) West of the GIWW manatee grass dominated the western shore and shoal grass in a band east of that Turtle grass and clover grass occupied smaller patches centrally and to the north, respectively. East-west contrast in manatee grass growth patterns was noted during the study period, with mono-specific patches more common on the west side. Clover grass was more common on the west side of the GIWW (Total number of cores; East =2, West =81). The contribution of macroalgae to collected cores was generally greater east of the GIWW. Throughout the study, bare bottom occurrence in cores was more common west of the GIWW, particularly in the deeper region of the study area

Turtle grass was the most commonly encountered species during the study, present in approximately 32% of all cores Overall, abundance of turtle grass, as a percentage of all cores collected, showed no significant change (p = 0 1791) from the Pre-Dredging Survey (30%) to

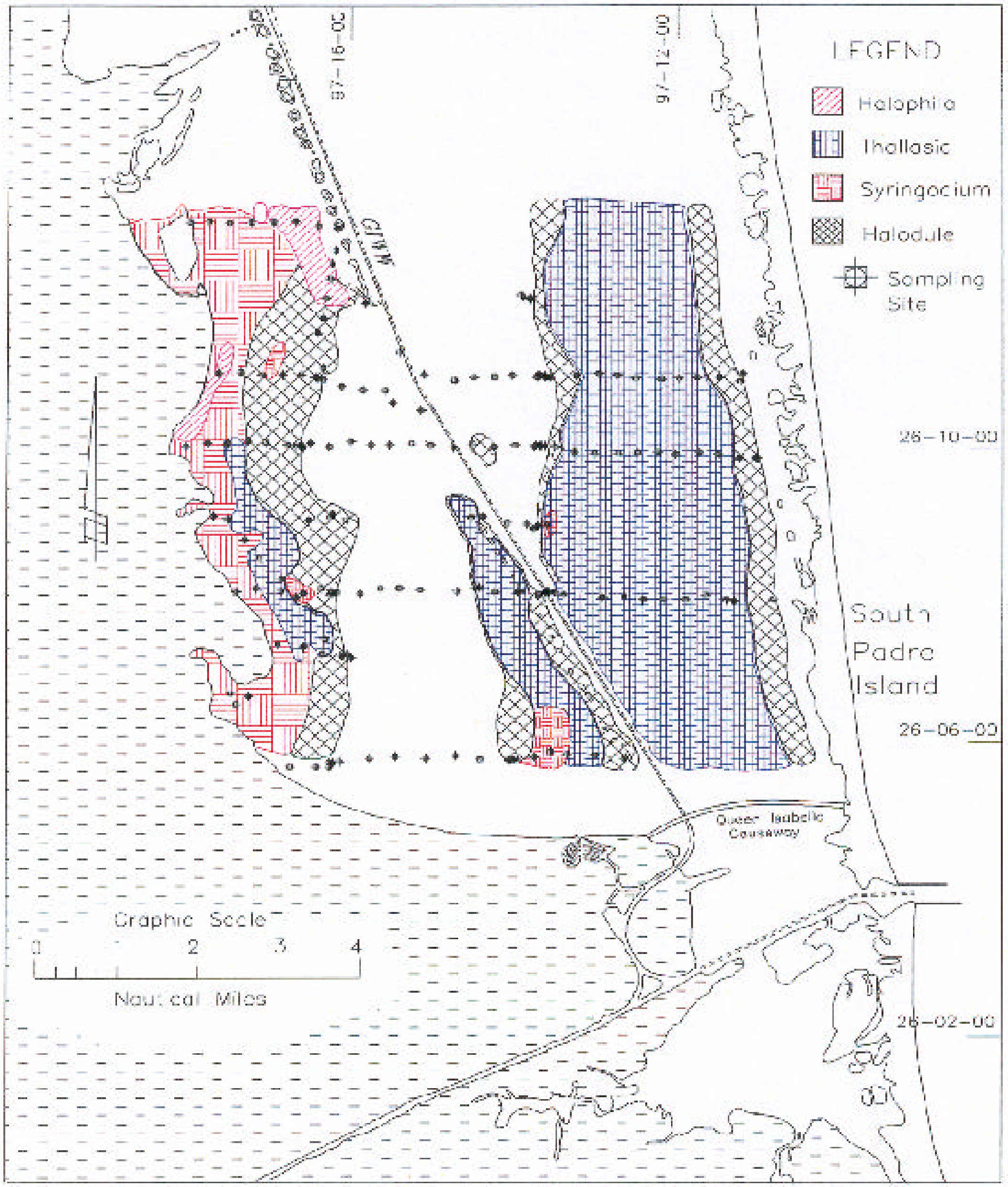

Figure 7.2. Dominant seagrass distribution inferred from visual estimates of seagrass rhizome abundance within core samples.

Table 7 2 Occurrence of seagrass species, macroalgae, and presence of bare bottom in cores collected in the lower Laguna Madre, 1994 and 1995

		Pre Dredging Survey (9/94)							Interim Survey (3/95)							1-Year Post Dredging Survey(9/95)						
Transect	Location	Tt	Sf	Hw	He	Alg	Bare	Num Cores	Tt	Sf	Hw	He	Alg	Bare	Num Cores	Tt	Sf	Hw	He	Alg	Bare	Num Cores
6	W	12	21	10	0	22	42	75	11	19	4	1	7	47	75	14	13	5	0	16	49	75
8	E	52	11	5	0	57	4	65	52	11	6	0	47	5	65	51	17	5	0	54	6	65
8	W	27	7	10	0	30	53	90	10	3	7	0	7	48	65	22	8	12	0	25	52	90
10	E	42	10	8	0	43	25	80	37	16	4	1	38	28	80	31	17	4	1	27	24	60
10	W	3	11	17	9	6	42	75	1	11	20	9	4	44	75	3	15	15	1	24	45	75
11	E	39	11	7	0	43	34	129	39	15	11	0	30	30	85	41	10	8	0	28	34	85
11	W	7	4	13	6	11	25	50	1	15	14	6	2	18	50	3	9	9	4	1	22	40
13	W	2	0	10	8	0	0	15								0	3	14	9	0	0	15
B	W	0	0	25	14	1	16	45								0	5	19	11	1	19	45
Z	W	42	26	16	2	45	9	75	19	7	8	0	11	8	35	44	21	6	1	36	18	75
Total	E	133	32	20	0	143	63	376	128	42	21	1	115	63	230	123	44	18	1	109	64	210
Percent Occurrence	E	58	14	9	0	62	27	----	56	18	9	<1	50	27	----	59	21	9	<1	52	31	
Percent Change	E	----	----	----	----	----	----	----	-2	+4	N C	+<1	-12	N C	—	+1	+7	N C	<1	10	+4	----
Total	W	93	69	97	39	115	187	425	42	55	53	16	31	165	300	86	74	80	26	103	205	415
Percent Occurrence	W	22	16	23	9	27	44	----	14	18	18	5	10	55	----	20	18	19	6	25	50	—
Percent Change	W	—	----	----	----	----	----	----	8	+2	5	-4	17	+11	—	2	+2	-4	3	2	+6	----
Total	E + W	226	101	117	39	258	250	655	170	97	74	17	146	228	530	209	118	98	27	212	269	625
Percent Occurrence	E + W	30	22	12	4	28	20	–	32	18	14	3	27	43	----	33	19	16	4	34	43	----

Notes Tt *Thalassia testudinum*, Sf *Syringodium filiforme*, Hw *Halodule wrightii*, He *Halophila englemannii*, Alg algae, Bare no vegetation N C = No change
Totals shown represent the number of times an indicated seagrass species, drift algae, or bare area was present in core samples taken for each short transect, distinguished by the respective side of the GIWW Totals and percent occurrence are compiled for seagrass species, algae, and bare core occurrence for each survey

the Post-Dredging Survey (33%) East of the GIWW, turtle grass showed little change in abundance To the west, percent occurrence declined by a total of only 2% over the study period.

Manatee grass, the next most common species, comprised approximately 17% of total observations. The proportion of manatee grass in samples increased east of the GIWW (Pre-Dredging 14%, Interim Survey 18%, Post-Dredging 21%) To the west a smaller proportional increase was observed (Pre-Dredging 16%, Interim Survey 18%, Post-Dredging 18%) Averaged over all surveys, shoal grass comprised 14% of the total observances No change was noted for this species from the east side of the GIWW (9%) However, to the west, shoal grass abundance declined slightly (Pre-Dredging 23%, Interim Survey 18%, Post-Dredging 19%). Clover grass was uncommon averaging 2.5% It was found almost exclusively on the west side where post-dredging samples yielded 3% fewer cores containing the species To the east, clover grass was very rare.

Bay-wide occurrence of macroalgae varied between surveys In September 1994, prior to dredging macroalgae was present in 39% of all cores By the Interim Survey (March 1995), the abundance of macroalgae had declined to approximately 27% and then subsequently became more abundant, post-dredging (September 1995) 34% Variation in macroalgae abundance between surveys west of the GIWW was more pronounced than that observed to the east but on both sides of the embayment the frequency of algae encountered in core samples follows the bay-wide trend

For the entire study area, the occurrence of cores that did not contain any seagrass rhizomes became 5% more common in samples collected post-dredging. The increase in bare cores was mostly responsible to an increase on the west side of the GIWW at or near seagrass bed margins (Pre-Dredging 44%, Post-Dredging 49%). No large expansion in bare area was recorded at transect sites where cores were collected (Pre-Dredging, 250, Interim Survey 228, 1-Year Post-Dredging 269)

Seagrass coverage in areas that might be affected by dredging activities due to spatial orientation and proximity, i e , western portions of transects, leeward of prevailing winds, showed little change from the baseline survey (Table 7 2). The only exception was Transect 11, where the occurrence of clover grass declined from six occurrences during the Pre-Dredging Survey to one occurrence in the 1-Year Post-Dredging Survey Algal presence within cores was found to be more common on the west side of Transect 10 post-dredging than either previous surveys (Total Occurrence, Pre-Dredging = 6, Interim = 4, Post-Dredging = 24).

Historical Data Comparison and Biomass Patterns

Descriptive statistics are shown in Table 7 3, with summarized data from 1974 (Merkord 1978) with 1988 (Onuf 1996[a]) Values presented in Table 7.3 are calculated from biomass samples, i.e. cores containing submergent aquatic vegetation Turtle grass dominated seagrass species in terms of both percent occurrence and biomass where present Turtle grass occurred in 70% of all samples, followed by manatee grass (43%), shoal grass (34%) and clover grass (13%) In terms of biomass where present, species were in the order turtle grass > shoal grass > manatee grass > clover grass Macroalgae was dominant with respect to percent occurrence, but generally accounted for a small fraction of total vegetative biomass within a core sample (Table 7.3) Large differences in visual species counts from pre- to post-dredging surveys, not likely to be explained by random sampling error, are not detected by percent occurrence calculations

Table 7.3. Percent occurrence and total biomass of seagrass and macroalgae containing cores in the lower Laguna Madre (above and below ground dry weight). Included are data from previous studies.

Component	Percent Occurrence			Biomass, g/m² Mean ±1 S. E.			
	Onuf (1988) *n=132*	Pre-Dredging (9/94) *n=90*	1-Year Post (9/95) *n=75*	Merkord[1] (1974)	Onuf[2] (1988)	Pre-Dredging (9/94)	1-Year Post-Dredging (9/95)
Thalassia testudinum	17	70 0	69 3	424 7 ± 201 6 (*n=2*)	373 ± 62 4	548 9 ± 42 9 (*n*=88)	411 5 ± 41 6 (*n=72*)
Syringodium filiforme	48	44 4	41 3	210 1 ± 73 1 (*n=6*)	138 ± 16 0	80 4 ± 9 4 (*n*=50)	84 3 ± 10 0 (*n=43*)
Halodule wrightii	66	38 8	29 3	203 6 ± 59 4 (*n=5*)	77 6 ± 7 6	98 5 ± 14 7 (*n*=38)	97 9 ± 23 0 (*n=34*)
Halophila englemannii	13	16 7	9 3	NA	6 1 ± 1 8	31 9 ± 6 0 (*n*=12)	7 4 ± 3 1 (*n=7*)
Macroalgae	73	75 6	73 3	NA	70 5 ± 12 1	35 3 ± 8 3 (*n*=94)	31 9 ± 7 4 (*n=70*)

1 Data presented from Merkord's thesis are taken from those sites within the present study area
2 Data taken from published material, where percent occurrence and mean biomass are representative of calculations made for the entire lower Laguna Madre

Total turtle grass biomass showed a substantial, but not statistically significant[1] decrease over the study period (decline of 137 g/m^2, p = 0 1966) The Pre-Dredging Survey values are greater than those values reported by Merkord (1978) and Onuf (1996[a]) for turtle grass biomass. Post-Dredging (1-year) Survey results for turtle grass fall within one standard error of the earlier works (Figure 7 3) All other samples show similarity in total biomass from the pre- to post-dredging surveys, the exception being the uncommon seagrass, clover grass (n = 12 and n = 7, respectively) Macroalgal biomass was found to be reduced from levels reported by Onuf in 1988 (decline of 37 g/m^2) Manatee grass also was found at diminished levels when compared to 1988 data

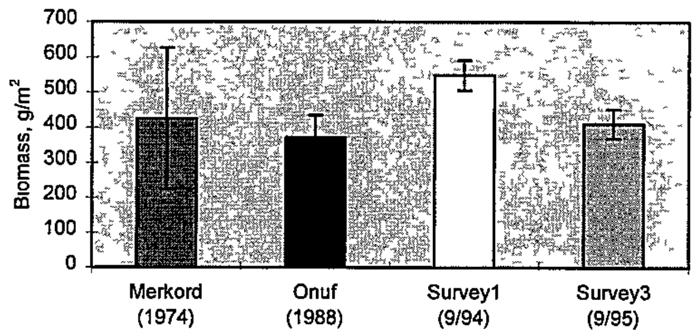

Figure 7 3 Comparison of total turtle grass biomass with historical surveys

Above-ground ash-free dry biomass values are presented in Table 7 4 and Figure 7 4, with the error bar indicating one standard error. All above-ground biomass for the major species declined over the one year time period and are lower than that report by Onuf in 1988 (Onuf 1996[a]) Clover grass does not follow this trend. However, little biomass data were collected due to infrequency of occurrence in the study area Macroalgal mean biomass for both surveys are considerably lower than that reported in 1988

Paired t-test

A paired *t*-test, assuming unequal variance, was conducted for those sampled sites where seagrass species and related components were present in both pre- and post-dredging surveys (Tables 7 4 and 7 5) Table 7.4 shows the significance for paired t-tests of pre versus post dredging above-ground ash-free biomass The values in Table 7 5 represent total dry biomass at the resampled sites No statistically significant differences were observed, except in the case of above-ground turtle grass (dry weight p<0 01, ash-free dry weight p<0 01) However, each of the three seagrass species biomass components show minor declines during the one-year study

[1] Standard error and its interpretation in comparisons of normal distributions, via the Central Limit Theorem, as discussed by Ott (1993)

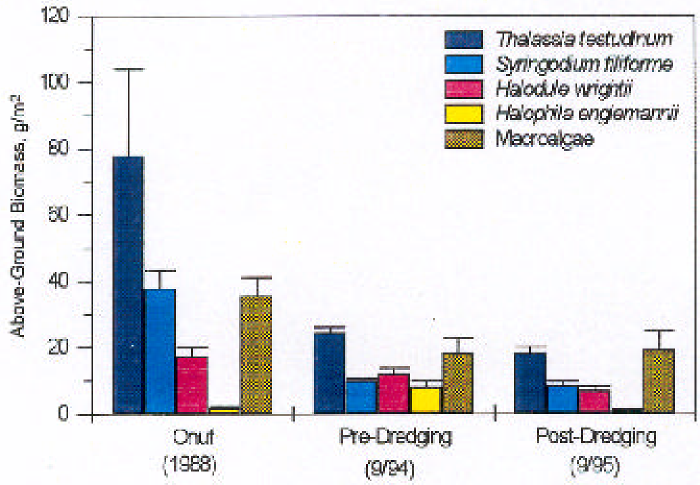

Figure 7.4. Comparison of mean above-ground biomass for the lower Laguna Madre.

Table 7.4. Mean ash-free dry weight of above-ground seagrass components from the lower Laguna Madre with significance of paired t-test (α = 0.05).

Component	**Above-ground biomass, g/m²**			
	Onuf (1988)	**Pre-Dredging (9/94)**	**1-Year Post-Dredging (9/95)**	**p (d.f.)**
Thalassia testudinum	77.8 ± 26.2	24.4 ± 1.7	18.3 ±1.8	<0.01 (26)
Syringodium filiforme	37.8 ± 5.6	9.8 ± 0.9	8.5 ± 1.2	0.22 (13)
Halodule wrightii	17.5 ± 2.5	11.9 ± 2.0	6.8 ± 1.5	0.56 (13)
Halophila englemannii	1.8 ± 0.4	8.0 ± 1.8	1.1 ± 0.2	0.37 (2)
Macroalgae	35.6 ± 5.5	18.4 ± 4.3	19.2 ± 5.9	0.44 (38)

Table 7.5. Paired *t*-test summary of total dry biomass (α=0.5).

Survey	**Mean Composition of Biomass**							
	Turtle grass		**Manatee grass**		**Shoal grass**		**Macroalgae**	**Detritus**
	A.G.	**B.G.**	**A.G.**	**B.G.**	**A.G.**	**B.G.**	**Total**	**Total**
Pre-Dredging	28.9	498.9	10.6	59.7	12.5	99.3	23.5	159.9
1-Year Post-Dredging	19.6	421.8	9.6	55.5	10.3	72.6	29.0	188.0
p-value	<.01	0.1	0.7	0.8	0.4	0.3	0.5	0.6
d.f.	28	34	15	15	15	15	39	56

A.G. denotes above-ground; and B.G. denotes below-ground, and d.f. is degrees of freedom.

period In addition, macroalgal and detrital fractions indicate a slight increase in biomass over the sampling period (9/94 - 9/95)

Multiple regression is used to examine for localized differences in turtle grass above-ground biomass over this study area to determine if particular regions of seagrass beds are more or less effected of the study period In order to normalize the distribution of biomass data the following transformations were necessary; (dry weight $(g/m^2)^{0\ 6}$-1)/2, (ash-free dry weight $(g/m^2)^{0\ 6}$-1)/2 The effect Survey, Short Transect and the cross product Survey* Short Transect are shown in Tables 7 6 and 7 7 A significant difference in turtle grass above-ground biomass was not detected, Survey by Short Transect (dry weight p = 0.6273, ash-free dry weight p = 0 5458)

Table 7.6. Effect test, survey, short transect, and survey*short transect on turtle grass above-ground dry biomass.

Source	Nparm	DF	Sum of Squares	F Ratio	p-value
Survey	1	1	843 7596	4 2041	0 0126
Short Transect	7	7	2779 5259	1 9785	0 0638
Survey*Short Transect	7	7	1058 5107	0 7535	0 6273

Note DF is degrees of freedom

Table 7.7. Effect test, survey, short transect, and survey*short transect on turtle grass above-ground ash-free dry biomass.

Source	Nparm	DF	Sum of Squares	F Ratio	p-value
Survey	1	1	653 3097	4 3381	0 0195
Short Transect	7	7	2439 9015	2 3145	0 0303
Survey*Short Transect	7	7	899 5285	0 8533	0 5458

Note DF is degrees of freedom

Discussion

Total seagrass species occurrence within all samples collected did not show a dramatic change between surveys (Table 7.2) Turtle grass was less abundant on the west side of the GIWW during the later surveys, yet not so much that definitive conclusions may be drawn from the change in the frequency of occurrence Direct burial of seagrass beds with dredged material may have contributed to the slight decline in abundance of turtle grass over the study period, as is thought to have been observed at two sites on the western portion of Transect 8 This is further supported by slight increases in bare core occurrence, particularly during the Interim survey Although correlation may exist, it would be speculative to infer that burial of seagrasses, either directly or via subsequent sediment transport, is responsible because of the high variability in species occurrence observed in samples collected from the west side of the GIWW.

Generally, large variations in total seagrass biomass over a given area make assessment of seagrass meadow conditions difficult on a quantitative basis (Thayer *et al* 1975, Tomasko and Lapointe 1991). This fact is reflected in this study where high regional variability leads to a low degree of precision in statistical tests of total species biomass The results of this study suggest a decline in only turtle grass total biomass Further evidence of a decline in turtle grass biomass is supported by a reduction in above-ground dry and ash-free weights (Table 7 4 and 7 5) The reduction in above-ground biomass was not found to be concentrated in any specific area within Port Isabel Bay (Table 7 6 and 7 7). This decline is difficult to interpret if related to earlier data sets (Merkord 1978, Onuf 1996[a]), because the Pre-Dredging Survey findings of total seagrass biomass appear unusually elevated and may be the result of exceptional growth conditions during the previous season (Figure 7.3). In addition, the observed decline in turtle grass biomass (Table 7 3) may be explained by interannual variation for this species (Zieman 1968). Except for turtle grass and the uncommon clover grass, the other seagrasses and macroalgae appear little affected over the study period with regard to total biomass The above-ground component of shoal grass suggests that, although total biomass was not affected for this species, photosynthetically-active portions of the plants may have suffered a setback during the period of study. The other seagrass species also show a decline in above-ground biomass, although not at a level of statistical significance

Cumulative percent occurrence of seagrass species encountered on similar transects as Merkord (1978) and Onuf (1996[a]) support hypothesized trends in seagrass systems of Port Isabel Bay Since 1988, turtle grass has expanded its range in the lower Laguna Madre , while shoal grass has shown a decline in abundance (Table 7 3) This trend is evident when compared to the 1988 survey, but was not apparent over the short time period of this study Distribution studies of this type would not likely provide the resolution necessary to detect gradual fluctuating trends in seagrass populations over the short-term. Manatee grass populations have remained relatively constant since 1988 and may have colonized all suitable depths (Onuf 1994; Onuf 1996[a]) However, biomass values of manatee grass were lower than reported for 1988 Quammen and Onuf (1993) discuss, in detail, possible factors inducing changes in seagrass dominance in the lower Laguna Madre It is apparent that moderated hypersalinity is at least partly responsible for the shift in dominant seagrasses to less saline tolerant species (Quammen and Onuf 1993) Macroalgal abundance approximates the 1988 findings In contrast, algal biomass, where present, was found to be substantially lower than values reported in earlier works (Table 7.3). It should be noted that data reported from 1988 by Onuf (1996[a]) includes samples collected in South Bay and along the south shore of the laguna west of Port Isabel, which were not sampled during this study.

The results of this study show overall a small reduction in above-ground biomass over the period of study for the dominant seagrass species. This decline in biomass was not widely found to be statistically significant and may not be held alone as evidence of dredging activity impact The trend in lower biomass among seagrasses during the post-dredging samples may be attributed to interannual and seasonal variation. Effects of changing ambient water temperature, salinity, nutrient availability and/or illumination originating from natural fluctuations may have contributed to the lower values (Zieman 1968, Fourqurean *et al* 1992, Onuf 1994, Dunton 1994) In addition, changes in freshwater inflow to a system may also effect seagrass biomass (Thayer *et al* 1975; Onuf 1994)

Effects of shading on seagrass meadows caused by elevated turbidity levels during and subsequent to dredging activities would not likely be distinguishable in the short term (less than a few years) Likewise, increased epiphytic shading attributable to abnormally high nutrient fluxes (Sand-Jensen 1977, Van Montfrans *et al* 1984, Twilley *et al* 1985, Tomasko and Lapointe 1991) resulting from the resuspension of bottom sediments would not likely be observable in short-term studies of autotrophic biomass. Discernible changes in seagrass abundance resulting from shading are generally long-term (at least 2 to 3 years), as rhizomal nutrient reserves may temporarily sustain seagrass populations in times of increased stress (Onuf 1996[b]). As a result, longer-term studies are recommended for assessing the response of seagrass populations to shading events.

Conclusions

1 *Thalassia testudinum* shows a statistically significant decline in above-ground biomass over the study period, September 1994, to September 1995. However, this reduction was not concentrated in any particular region of the study area The difference in biomass is within the range of interannual variation for this species

2. No other seagrass species shows a statistically significant change in biomass (above-ground or below-ground) over the time period.

3. High variation in seagrass biomass, particularly annual variation, but also seasonal and local, leads to high levels of noise in statistical models over short time periods (1 year) It would therefore, be advantageous to obtain biomass data over longer time periods to include confounding sources of variation in the modeling of seagrass response to stress events

8. Interactions in the Lower Laguna Madre[8]

This chapter discusses several interactions between meteorological and hydrodynamic parameters, that have been found to be of significance for sediment resuspension and light attenuation. As described in previous chapters, sediment is resuspended by various mechanisms, including tidal currents, and wind generated waves.

Tidal Influence on Resuspension

In the study area, tidal influence on sediment resuspension is minimal. Figure 8 1 shows a time history of water level, magnitude of the current, turbidity, suspended solids, and wind speed during tidally-dominated flow. This plot corresponds to a period when wind forcing was minimal (average wind speed less than 5 m/sec or 11 mph) The magnitude of the tidally-dominated flow was typically less than 15 cm/sec (0.5 ft/sec) which shows the weak to moderate strength typical of the currents in lower Laguna Madre The turbidity and suspended solids during this period were at minimal levels (average values of 35 ntu and 32 mg/L, respectively) In order for sediment to move, the current velocity at the bottom must exceed a certain, threshold value For a uniform current and 0.15-mm sand, this velocity is expected to be in the range of 10 to 20 cm/sec or 0.33 to 0.66 ft/sec (Komar 1976) The currents in the study area exceed this threshold level during peak ebb or flood tide, or during strong winds. Turbidity data indicate that the astronomical tidal current in the study area is not of sufficient magnitude to resuspend sediment for normal conditions Although the tidal current is not significant in resuspending sediment, the current is a mechanism for transporting sediment once it is resuspended by some other force, such as by oscillatory wave action

Sediment Response and Recovery Time to Wind Forcing

Strong winds, such as those associated with the passage of fronts, produce short-lived (about 24-hr duration), high-turbidity events Figure 8 2 contains an example of the response of turbidity, underwater light levels, and suspended solids, to local wind forcing prior to, during, and subsequent to the passage of a front. The shift in turbidity readings on January 24th indicates when the Hydrolab unit was replaced, showing that biofouling of the turbidity sensor was

[8] Written by Cheryl A Brown and Nicholas C Kraus, Conrad Blucher Institute for Surveying and Science, Texas A&M University-Corpus Christi

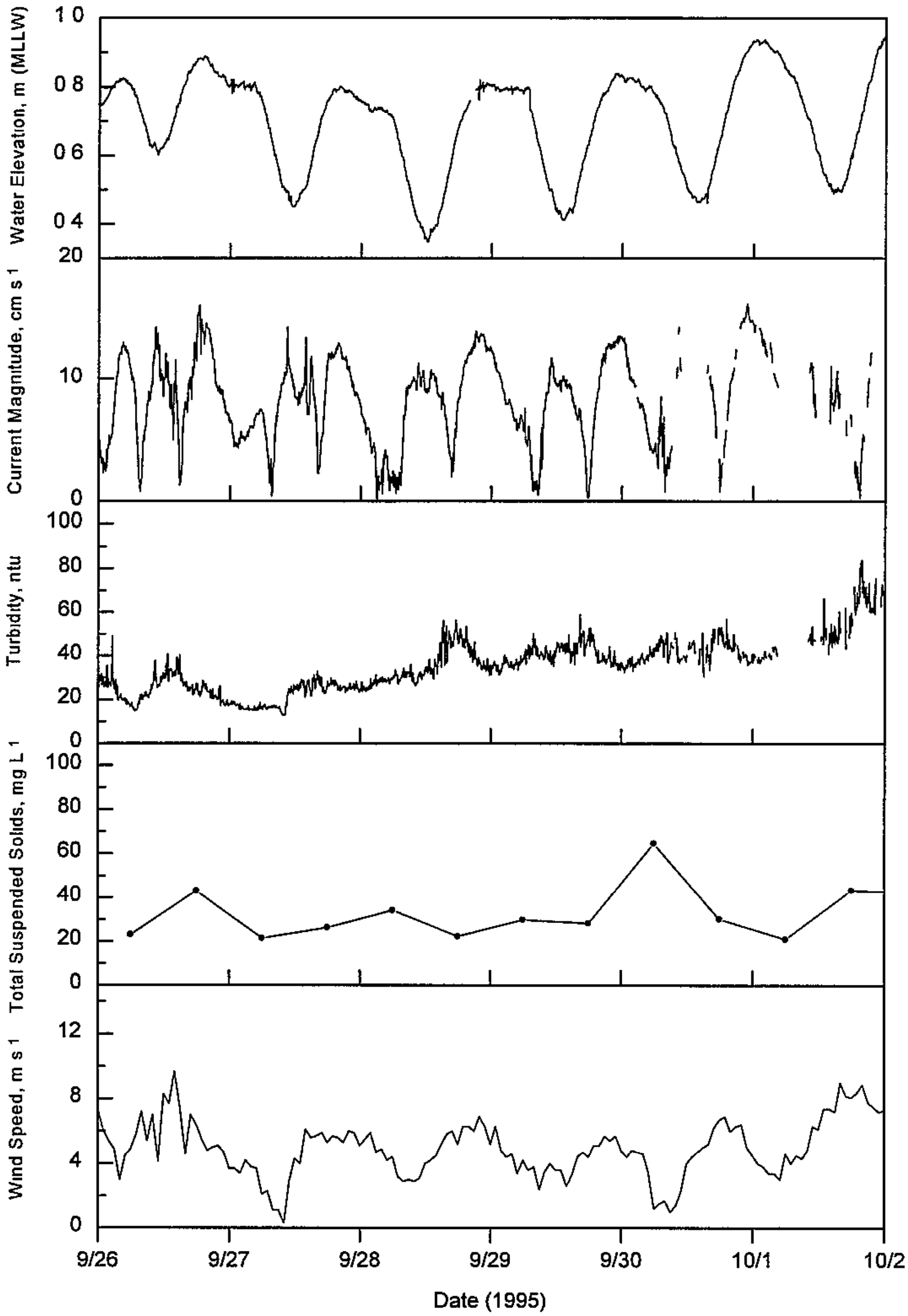

Figure 8 1 Water level, current, turbidity, suspended solids, and wind speed, during tidally-dominated flow

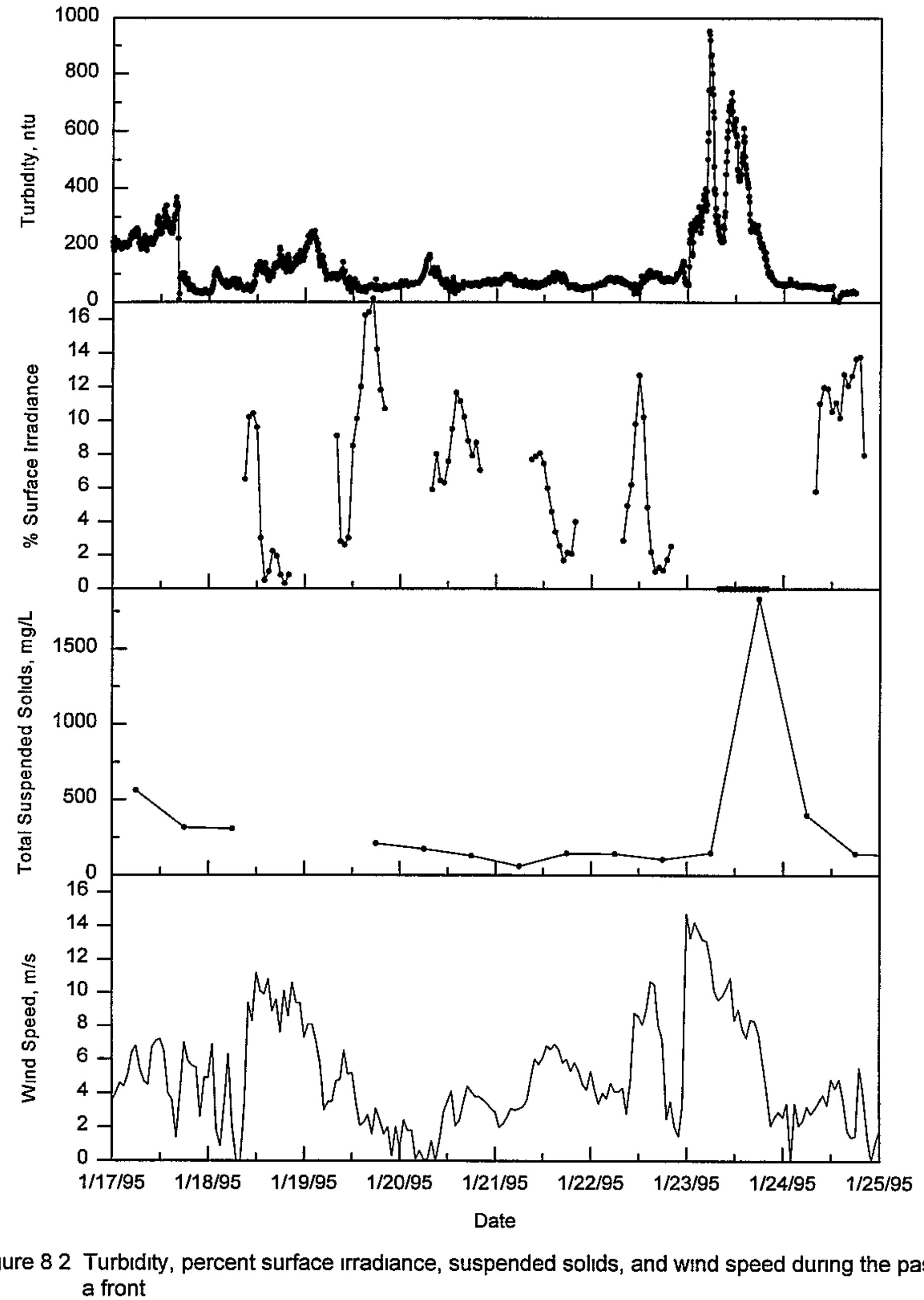

Figure 8 2 Turbidity, percent surface irradiance, suspended solids, and wind speed during the passage of a front minimal during January 17 to 24, 1995. At approximately 0:00 CST on January 23rd, a strong north front passed through the study area Prior to the passage of the front, the wind speed was less than 5 m/sec (11 mph), the turbidity was approximately 70 ntu, the percent surface irradiance reaching the bottom ranged between approximately 4 to 14%, and the concentration of suspended solids was about 150 mg/L. At 0 00 CST on January 23rd, the average wind speed attained a maximum velocity of 15 m/s (34 mph). Concurrent with this increase in wind speed, at approximately 5 00 CST, the turbidity increased to 950 ntu, and the concentration of suspended solids reached a peak level of 1800 mg/L. The impact of the passage of the front on underwater light levels is shown by the reduction in the percent surface irradiance to 0% on January 23rd The 5-hr lag between the peak wind speed and the generation of the peak turbidity may be associated with the time for the front to travel from Arroyo Colorado to the study area, as well as the time required for wind-generated waves to develop and suspend sediments through the water column

Subsequent to the wind speed decreasing to approximately 10 m/sec (22 mph) at 8:00 CST, there was a corresponding decrease in turbidity to 200 ntu at approximately 9 00 CST At 11:00 CST, there was a second increase in wind speed to 11 m/sec (25 mph), which produced another peak in the turbidity of 700 ntu occurring at 11:00 CST. At 21:00 CST, the wind speed decreased to 2 m/sec (4 mph), and the turbidity returned to pre-front conditions of 60 to 70 ntu at approximately 22:00 CST. On January 24th, the underwater light levels increased to approximately 12 to 14% surface irradiance and the concentration of suspended solids returned to pre-frontal levels (150 mg/L). Typically, it is seen that the response time for sediment suspension subsequent to the initiation of the forcing mechanism is on the order of one hour After the passage of the front, the turbidity, suspended sediment, and light levels return to pre-frontal conditions usually within 24 hours.

As discussed in Chapter 4, the increase in wind speed associated with the passage of this front approximately doubled the current speed (see Figure 4.19) Because sediment transport is a function of the cube of the velocity, an increase in velocity to 20 cm/sec (0 66 ft/s) would result in a transport rate approximately 8 times greater. A threshold velocity (10 to 20 cm/sec or 0.33 to 0 66 ft/sec) was also found, that is, the current velocity has to exceed a certain value for incipient motion of the sediment The increase in water velocity associated with the front sets sediment into motion because the threshold is overcome. It appears that when the wind speed exceeds approximately 10 m/sec (22 mph), there is a corresponding substantial increase in turbidity. Stronger winds that accompany the passage of a front also generate waves, which contribute to suspending sediment through wave orbital action on the bottom and mixing in the water column The threshold wind velocity (10 m/sec or 22 mph) for resuspension of sediment is consistent with other studies conducted in similar environments (shallow, wind-driven environment with fine-grained bottom sediments), such as in Chesapeake Bay (Ward *et al* 1984).

Seasonal Trends in Suspended Solids, Light Attenuation, and Wind Speed

Because the concentration of suspended solids, light attenuation, and wind speed are inter-related, they exhibit similar seasonal trends. Comparison of Figures 5 2 and 6.3 show that the concentration of suspended solids and light attenuation were at minimal levels during the summer, and, during the winter and spring, the levels and variability of each increased Figure 8 3 shows a one-year time-series of total suspended solids and current velocity (north-south and east-west components) at FIX 1 for the interval of September 1, 1994 to September 1, 1995 Seasonal trends are evident in both the magnitude of the current and concentration of suspended solids The current velocities and concentration of suspended solids are minimal in September, 1994 and August, 1995 Beginning in October, 1994 and continuing through April, 1995, the magnitude and variability of the currents and suspended solids increase. Peaks in current velocity associated with fronts correspond to episodes of high levels of suspended solids

Figure 8.4 shows a one-year time-series of concentration of suspended solids and wind speed (hourly and low-pass filtered) for the interval of September 1, 1994 through September 1, 1995. The seasonal trends in the wind speed are similar to those discussed in the previous paragraph, with minimal wind speeds occurring in September, 1994 and late August, 1995 During the winter the magnitude and variability of the wind speed increases Peaks in low-pass filtered wind speed correspond well with peaks in suspended solids

Figure 8 5 shows the monthly mean and standard deviation of light attenuation, total suspended solids, and wind speed. During September, 1994, prior to dredging, the mean light attenuation, suspended solids, and wind speed were at a minimal levels, because of the relatively calm meteorological conditions characteristic of September During dredging operations (October, 1994), both the mean light attenuation and total suspended solids increased approximately three-fold, while the mean wind speed increased approximately 50% The total suspended solids and light attenuation level remained elevated throughout the winter and spring, 1995. During November, 1994, there was an approximate 12% increase in mean wind speed, and a corresponding 15% increase in the light attenuation; however, the mean suspended solids remained constant In December, 1994, there was a 25% decrease in the mean wind speed and a corresponding decrease of 50% in the mean light attenuation During December, 1994, through April, 1995, there was a steady increase in the average wind speed and light attenuation, while the suspended solids remained constant at approximately 200 mg/L A component of this

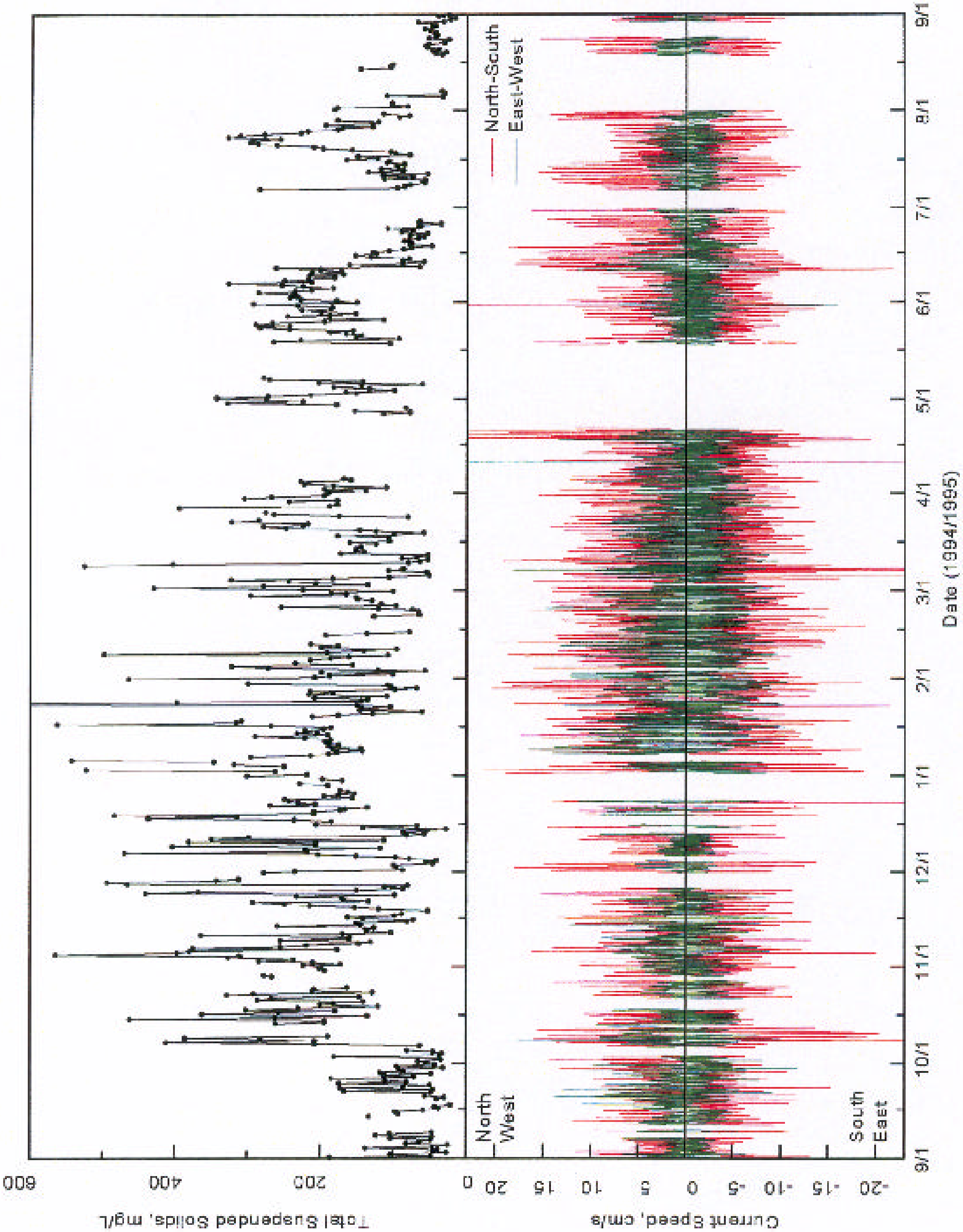

Figure 8.3. Time series of suspended solids and components of current at FIX 1, September, 1994 to September, 1995.

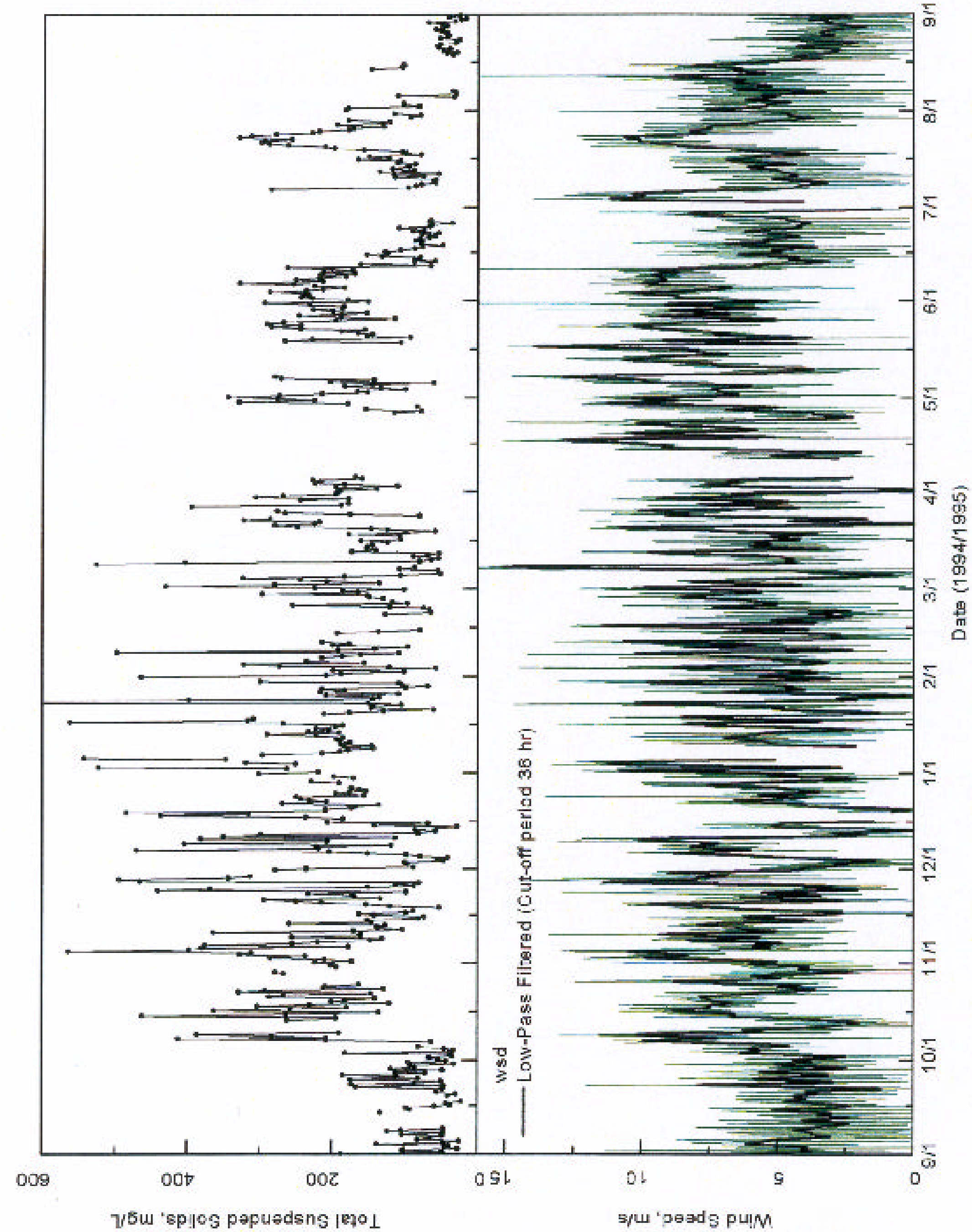

Figure 8.4. Time series of suspended solids and wind speed at Arroyo Colorado, September, 1994 to September, 1995.

increase in light attenuation in the absence of an increase in suspended solids may be due to light attenuation by other factors, such as phytoplankton During May through August, 1995, the mean wind speed declined and there was corresponding decrease in the mean and variability of the light attenuation In August, 1995, light attenuation levels returned to levels similar to those measured during the pre-dredging phase in September, 1994 However, in 1995 the mean wind speed did not return to a level as low as that of September, 1994 During September, 1995 through November 1995, there was an increase in mean wind speed and light attenuation However, during this period, the light attenuation and suspended solids did not return to levels as high as those experienced immediately subsequent to dredging This is probably because the dredged material was transported out of the placement areas and vicinity of FIX 1.

The differences in the trends between the light attenuation and suspended solids is most probably attributable to differences in sampling frequency between the two parameters. The suspended solids are based on two samples per day collected at mid-depth, while the light attenuation is a more continuous parameter, with the sensor integrating the effect over depth and daylight hours Also, there is not a direct relationship between light attenuation and suspended solids because light attenuation has numerous causes as discussed in Chapter 6

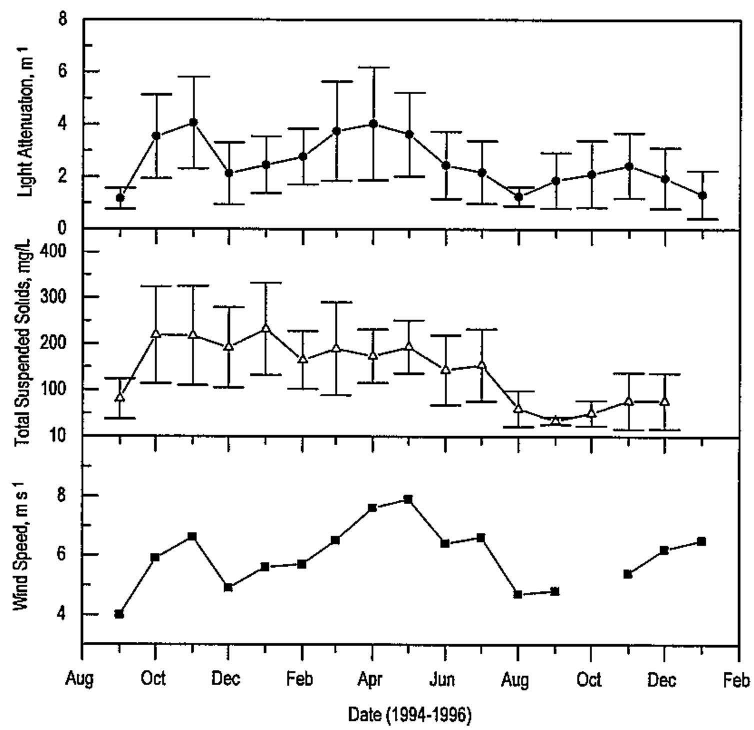

Figure 8 5 Mean and standard deviation of light attenuation, total suspended solids, and wind speed

Relationship Between Suspended Solids And Current

To examine predominant directions of sediment transport, concentration of total suspended solids versus north-south and east-west components of current velocity (Figures 8 6 and 8.7, respectively) were plotted, based on the 6-min average of current velocity at the time of water sample collection The transport of sediment is approximately equally distributed between the north-south directions (Figure 8 6), especially when the level of suspended solids is less than 300 mg/L. When the suspended solids is greater than 300 mg/L, there is a slight asymmetry with more sediment being transported towards the north The transport of sediment is also approximately equally distributed between the east-west directions, especially when the suspended solids are less than 300 mg/L. At higher levels (greater than 300 mg/L), there is a slight asymmetry with more sediment being transported towards the east.

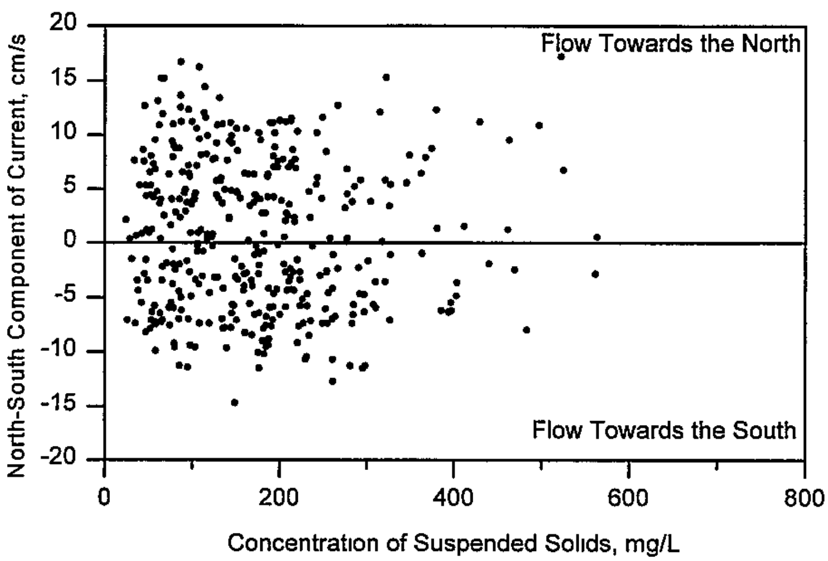

Figure 8 6 Suspended solids versus north-south component of current

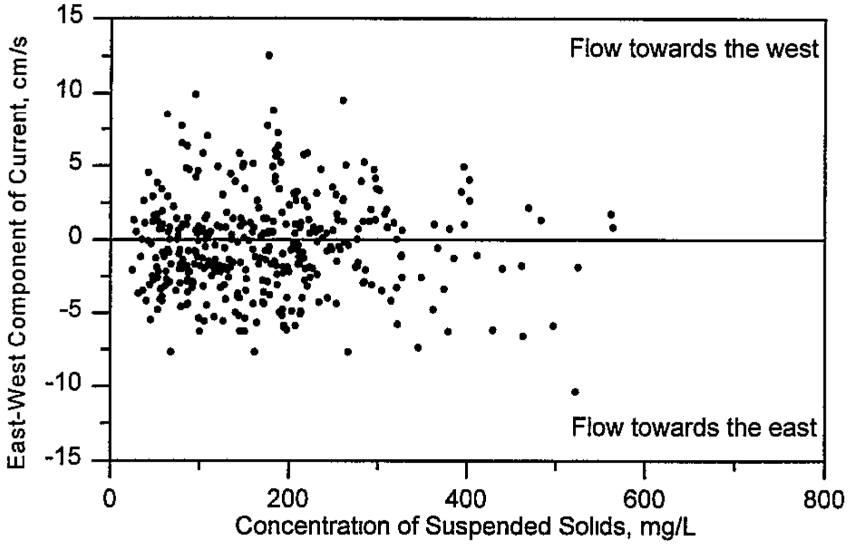

Figure 8.7 Suspended solids versus east-west component of current

Relationship Between Suspended Solids and Wind Speed

Figure 8.8 shows the relationship between average daily total suspended solids and average daily wind speed measured from May, 1995, through October, 1995, a time of primarily southeast winds. A critical threshold level of 4 m/sec (9 mph) is identified, which the wind speed must exceed before the concentration of suspended solids begins increasing linearly. The relationship between suspended solids and wind speed can be expressed as

$$TSS = 39.2 \pm 13.9 \qquad \text{for } U \leq 4.0 \text{ m/sec}$$

$$TSS = -111.1 + 38.0U \qquad \text{for } U > 4.0 \text{ m/sec}$$

where U is the average daily wind speed in m/sec (mean of 24 hourly-average wind speeds), and TSS is the average daily concentration of suspended solids (mg/L). The constant value for weak wind was computed by averaging all data points when the wind speed was less than 4 m/sec (9 mph). The linear function, was fit using least-squares linear regression for the data when the wind speed was greater than 4 m/sec (9 mph). The correlation coefficient (r^2) for the linearly increasing relationship is 0.72. Because the bottom stress is quadratic in water velocity, and the surface stress is quadratic in wind velocity, the current speed is linear with wind speed (~3% of wind speed) for wind-dominated flow. Resuspension is thus expected to be a linear function of wind speed.

Sources of variability in the relationship between total suspended solids and wind speed are: 1) sampling frequency and location for suspended solids, 2) advection of water masses into study area, and 3) the implicit relation between wind speed and wave action. Because the water samples were collected twice daily (6:00 AM and 6 00 PM) at mid-depth, rather than continuously throughout the water column, there is an error associated with the estimation of the mean daily suspended solids This error would be less during uniform meteorological conditions, such as the calm months of August and September, and greater during the passage of fronts, which produce large variations in the concentration of suspended solids within short periods of time, typically on the order of several hours An additional source of suspended solids at a site is advection of material into the study area by the current Observations in the study area indicated that local wind-generated waves are the dominant mechanism for sediment resuspension in the study area It is the oscillatory motion associated with these waves that resuspends the sediment, rather than the wind speed Wave generation is a function of the wind speed; however, there are other factors such as wind direction, duration, and fetch (the distance the wind is blowing over) Despite these factors that might lend ambiguity, the above equation relating between total suspended solids and wind speed appears reliable and useful for modeling

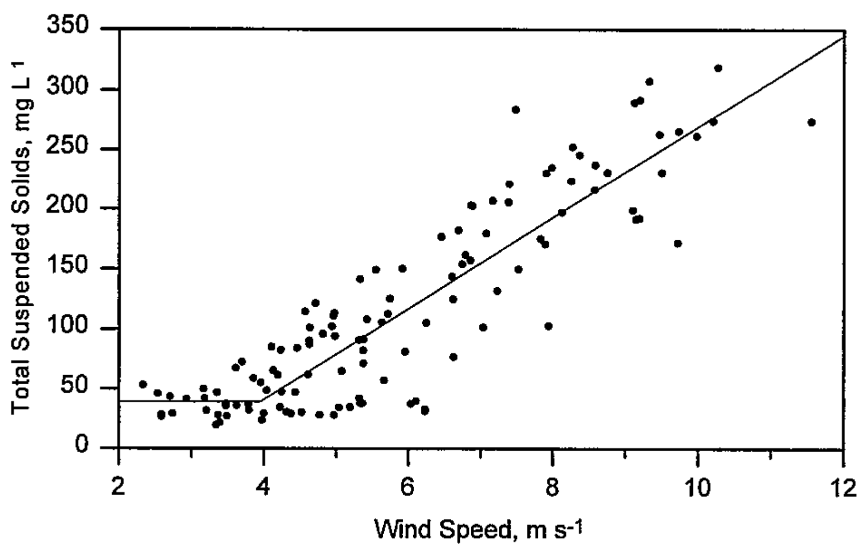

Figure 8 8 Total suspended solids versus wind speed

Relationship Between Suspended Solids and Light Attenuation

As discussed in Chapter 6, light attenuation in the study area is primarily controlled by suspended solids To develop predictive relationships for light attenuation, the contribution to light attenuation must be separated into individual components, which can then be combined to determine the total attenuation. To obtain the strongest relationship between suspended solids and light attenuation, an interval was selected when a possible contribution to light attenuation by brown tide was believed to be minimal, which is during the summer when there is less chance of brown tide being advected into the study area from the upper Laguna Madre by north winds Presented in Figure 8.9 is the relationship between the average daily suspended solids at FIX 1 and the average daily light attenuation coefficient generated using data from May, 1995, to October, 1995. During the summer months (when chlorophyll-a levels are minimal), total suspended solids account for approximately 80% of the variance in the light attenuation.

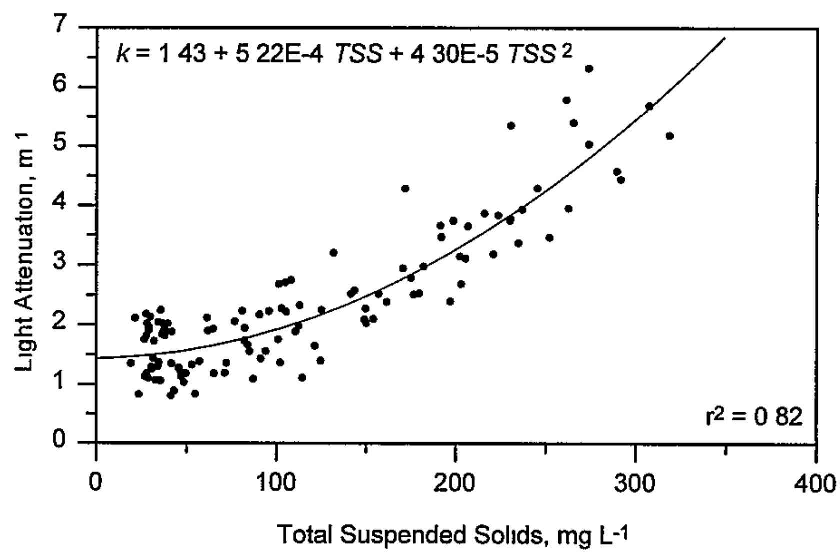

Figure 8 9 Light attenuation versus total suspended solids

Relationship Between Light Attenuation and Wind Speed

Figure 8 10 presents the relationship between the average daily light attenuation and average daily wind speed (computed using the 24-hr interval prior to the last light measurement) developed from data for May, 1995, through October, 1995 If the wind speed is less than about 6 m/sec (13 mph), the light attenuation coefficient is uniform at approximately 1 6 m^{-1}. When the average daily wind speed exceeds the threshold of 6 m/sec (13 mph), there is an increasing linear relationship between average daily light attenuation and wind speed The relationships between the light attenuation and wind speed can be expressed as.

$$k = 1.60 \pm 0.43 \qquad \text{for } U \leq 5.8 \text{ m/sec}$$

$$k = -2.98 + 0.79U \qquad \text{for } U > 5.8 \text{ m/sec}$$

where U is the average daily wind speed (m/sec), and k is the light attenuation coefficient (m^{-1}) The first linear function (a constant) was determined by taking the mean of all data points, when the wind speed was less than 5.8 m/sec (13 mph). The second linear function, was developed using least-squares linear regression for the data when the wind speed was greater than 5.8 m/sec (13 mph) and has a correlation coefficient of 0 76 (r^2) A slightly stronger relationship exists between light attenuation and wind speed, than between suspended solids and wind speed. This is probably because the average daily light attenuation is based on more continuous measurements than for the suspended solids Relationships were developed using various averaging intervals for the wind speed (instantaneous, 3 hr, 6 hr) However, averaging the 24 hours prior to the last light reading provided the strongest relationship. The reason for the difference between the critical threshold of 10 m/sec (22 mph) discussed in the previous section, and the average daily wind speed threshold of 5.8 m/sec (13 mph), is probably because the second threshold is based on an average daily (24-hour interval) wind speed

Because the light attenuation is strongly dependent upon local wind forcing, once a threshold of 6 m/sec (13 mph) is exceeded, (as discussed in Chapter 3, the wind speed in the study area exceeds this critical velocity for 50% of year), it is imperative to examine local wind forcing when assessing changes in the light environment In the pre-dredging time period (August 31 - September 25, 1994), the threshold wind velocity was only exceeded on one day However, in the one-year post-dredging time period (August 31 - September 25, 1995), the threshold velocity was exceeded on 5 days, which could be the source of the statistically significant difference in light attenuation coefficients between the pre-dredging and 1-year post-dredging phases (see Chapter 6). In addition, there is a statistically significant difference in the wind conditions between September, 1994, and September, 1995 When the wind forcing is less than 6 m/sec (13 mph), the light attenuation coefficient is uniform at about 1.6 ± 0.4 m^{-1}, which could be assumed to approximate the background light attenuation coefficients in the absence of wind forcing. Figure 8.11 shows that both the pre-dredging and 1-year post-dredging mean light attenuation coefficients fall within one standard deviation of this background level

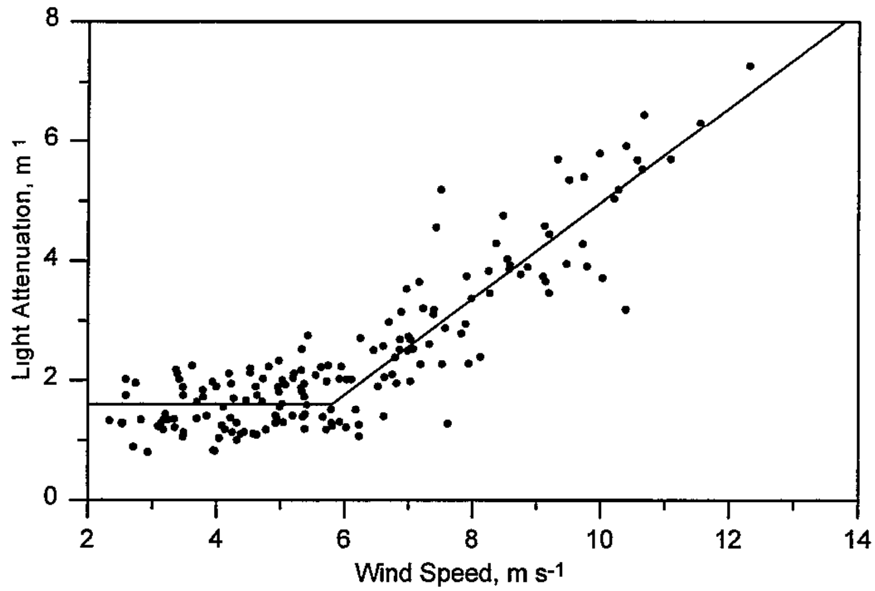

Figure 8 10 Relationship between light attenuation and wind speed for May to October, 1995

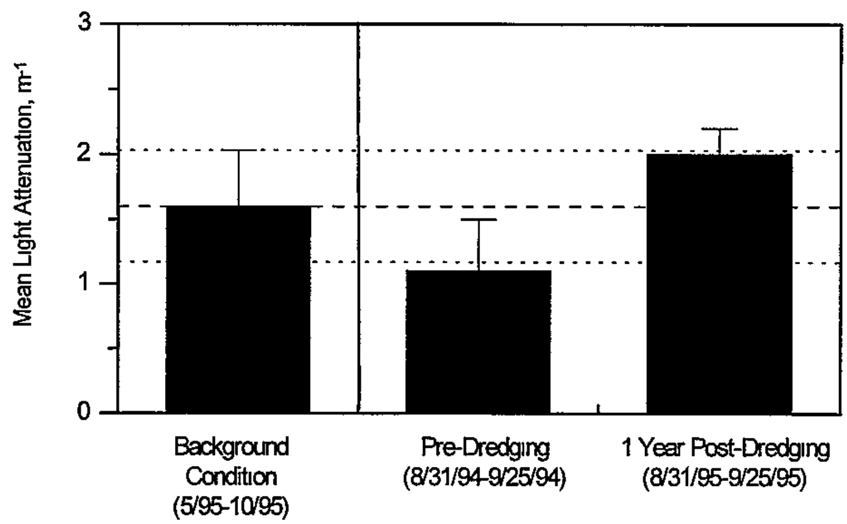

Figure 8 11 Comparison of low-wind forcing background condition, and mean pre- and post-dredging light attenuation

Differences in Light Attenuation in Seagrass Bed and at FIX 1

Figure 8 12 shows a comparison of average daily light attenuation at FIX 1 and in a seagrass bed, located to the west of the GIWW approximately 3.5 miles south-southeast of FIX 1 (Lat. 26° 07' 58", Long. 97° 14' 19") in water depth of about 1 5 m or 5 ft (data provided by Dr Kenneth H. Dunton, UTMSI). The dashed lines indicate the mean values of light attenuation (3.8 and 0 6 m^{-1}, respectively). During this time period, the minimum average daily light attenuation at FIX 1 is approximately 2 m^{-1} As the wind increases, there is a corresponding two- to three-fold increase in the light attenuation at FIX 1, to 7-8 m^{-1} In the seagrass bed, the minimum light attenuation is less than 0.5 m^{-1}, and when the wind increases there is a corresponding increase in light attenuation In the seagrass bed, the maximum attenuation coefficients reached during strong winds are approximately 2 m^{-1}, or 30-40% of the levels at FIX 1, and during calm conditions the light attenuation coefficients are approximately 10% that at FIX 1

Figure 8.13 shows the relationship between light attenuation and wind speed generated using data from May 1-23, 1995 In the seagrass bed, the threshold wind velocity for light attenuation increases by about 50% to 9 m/sec (20 mph). This increase in the threshold wind velocity is probably due to the sediment trapping and stabilization of the seagrasses, as well as the attenuation of waves and flow by the seagrass bed The low correlation coefficient for the linearly increasing region of the relationship for the seagrass bed is probably due to turbid water being advected into the grass bed during strong wind conditions

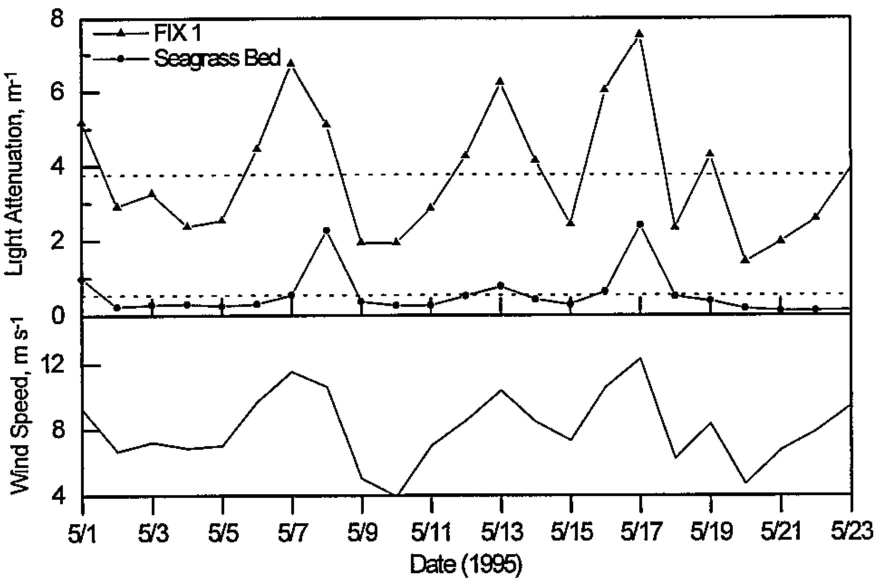

Figure 8 12   Time series of average daily light attenuation in study area and seagrass bed

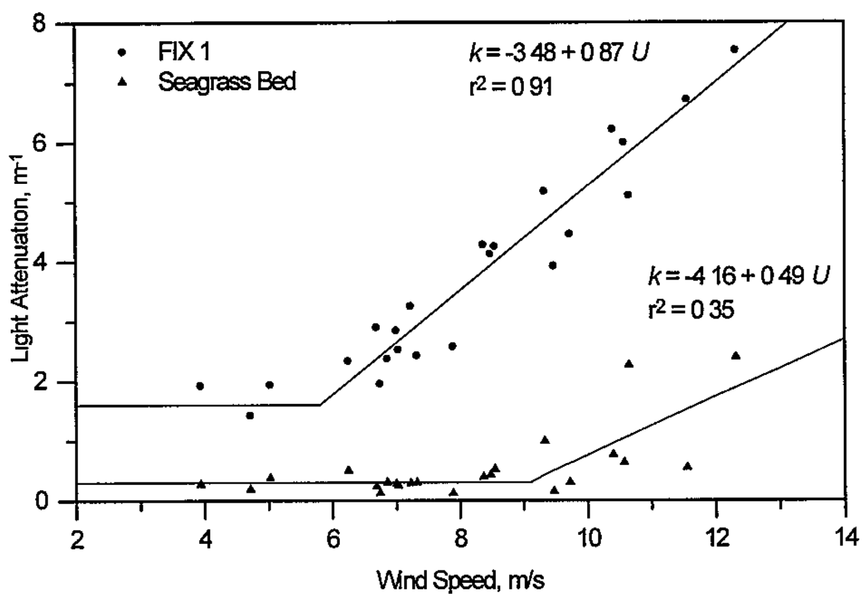

Figure 8 13   Relationship between light attenuation and wind speed at FIX 1 and in seagrass bed

Hypothesis for Loss of Seagrasses

Figure 8.14 shows the composite, dominant seagrass distribution, inferred from the three sampling surveys (9/94 to 9/95) described in Chapter 7, with respect to the 1-m (3-ft) depth contour (referenced to MLLW) The 1-m (3-ft) contour, which outlines the depression in the study area, has a similar configuration as the boundary of the region devoid of seagrasses (bare region is denoted by absence of color hatching), suggesting that low light levels are the reason for the absence of seagrasses. In 1965, this bare region was vegetated with *Halodule wrightii* and *Syringodium filiforme* (McMahan 1968). The surveys of Merkord (1978) and Onuf (1994) documented the existence of this bare region. Onuf (1994) attributed this loss of seagrass coverage to reduction in the underwater light environment associated with maintenance dredging of the GIWW

An alternative hypothesis for the loss of the seagrass in the deeper portions would be increased light attenuation associated with the increased suspended sediment introduced into the Laguna Madre by runoff associated with flooding from hurricanes and breaching of the barrier island (see discussion in Chapter 3) and increased runoff associated with higher than normal precipitation levels (see Figure 3.2) In addition, subsequent to 1965 there was a relatively rapid increase in rate of sea level rise at Port Isabel (see Figure 4 4), which would have implications for light attenuation in the study area If these seagrass beds were at a depth which was near their lower depth limit for this system, then an extended period (5-10 years) of low light levels and increased depth might result in loss of seagrasses. The historic dredging analysis (Figure 3 2) showed that the sedimentation rate for the GIWW was approximately double the typical rates during the 6-year interval subsequent to Hurricane Beulah (Sep. 8-21, 1967). An increase in the sedimentation rate implies that more suspended particulates were present in the system and, as a result, turbidity levels were higher Once seagrasses began to decline, more sediment would be suspended due to the presence of bare bottom, thereby reducing the light levels and causing the loss of more seagrasses, forming a positive feedback loop Because the sediments in the deeper portion of the study area are finer grained (primarily silty-sand and clayey-sand –see Figure 5 1) than the sediment to the east of the GIWW, the finer-grained sediment will be more easily suspended during strong winds producing higher turbidities Also, current measurements made in this study and LANDSAT images indicate that the current tends to preferentially flow in this region, and turbid water masses would thereby be advected into the deeper region, during all hydrodynamic conditions These currents would possibly repeatedly resuspend the fine-grained material.

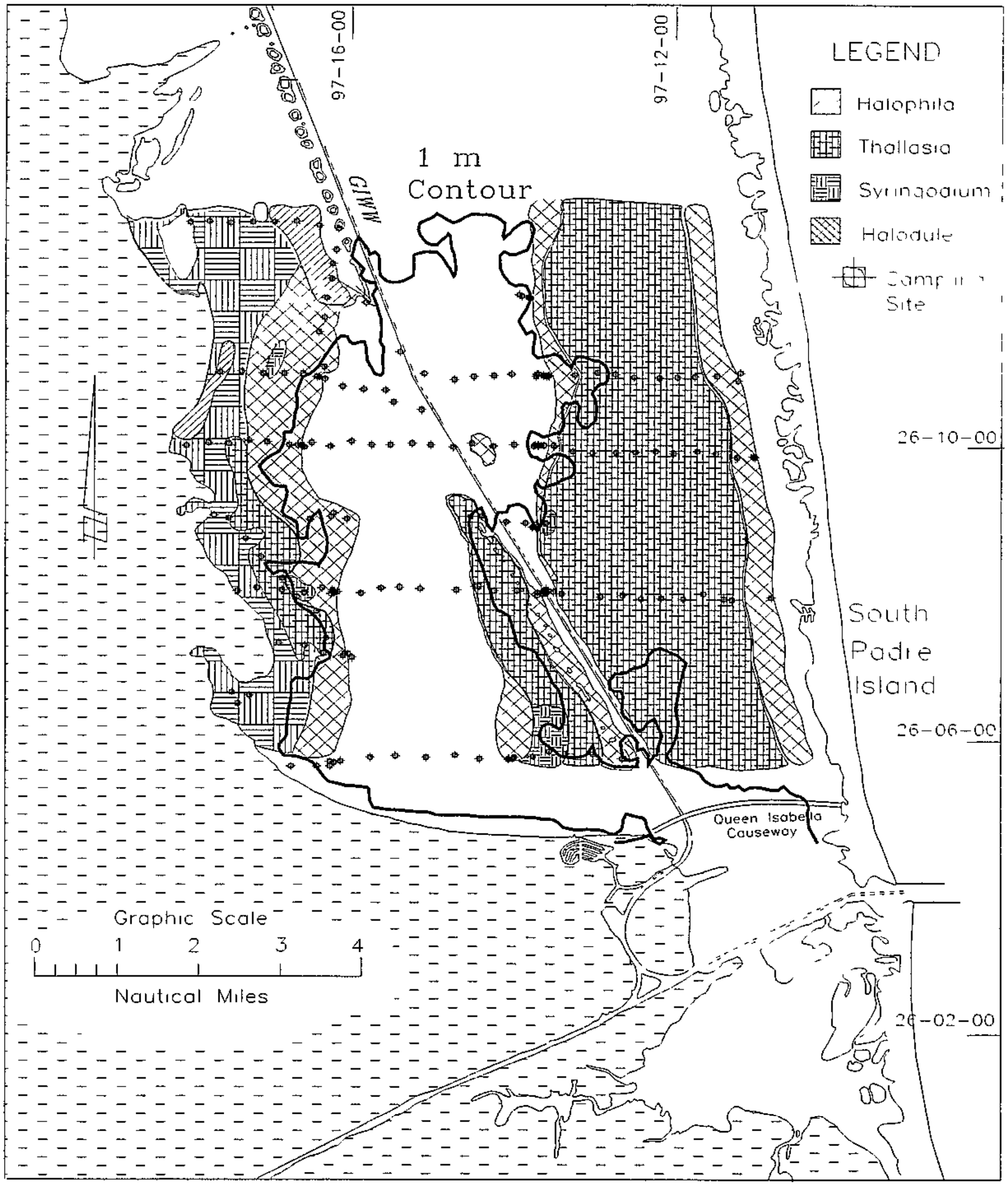

Figure 8 14 Comparison of seagrass distribution and 1-m depth contour

The GIWW was constructed in this region between 1945 to 1948, and maintenance dredging was performed for approximately 20 years prior to McMahan's survey; however, during this period there was no loss of seagrasses, and McMahan reported the region as having "moderately heavy" *Halodule wrightii* (McMahan 1968) During the 9-year period (1965-1974) between McMahan's and Merkord's surveys, this bare region formed Inspection of the turbidity patterns in LANDSAT images (see Figure 5.2) indicate that the region, now devoid of vegetation, had consistently higher turbidities during various hydrodynamic conditions in 1972 and 1973. It is also interesting to note that seagrasses are present adjacent to the GIWW south of the high shoaling reach

9. Conclusions and Recommendations[9]

The conclusions and recommendation of this report are preliminary based on the data available from the first year of a 2.5-year data-collection effort A more thorough analysis will be performed when the longer-term data sets are available at the end of the 2 5 year monitoring period

Since the construction of the GIWW, the sedimentation rate in the high shoaling reach of the lower Laguna Madre has remained fairly uniform. However, extreme meteorological events, such as hurricanes, can dramatically increase the shoaling rate. The average shoaling rate in this reach is 250,000 cu yd of material per year, which is equivalent to a uniform shoaling rate of 2 2 ft per year The elevated shoaling rates in the study area result from a wide-area circulation pattern produced by a depression in the bathymetry in the southern portion of the lower Laguna Madre The high shoaling reach is situated in the region where the GIWW crosses this geomorphic feature.

Hydrographic surveys conducted in the vicinity of the open-bay placement area show that the majority of the loss of sediment from the open-bay placement areas occurs within 8 months subsequent to maintenance dredging, and the bathymetry returns to a configuration similar to that measured prior to dredging There is little change in the bathymetry in either the open-bay placement areas or the GIWW during the 8- and 13-month post-dredging surveys

Long-term current measurements show there is a consistent cross-channel flow in the vicinity of the open-bay placement area, which is present throughout the year during all hydrodynamic conditions (tidal phases and wind conditions). The current in this region is typically within the range of 10-15 cm/sec (0 33-0 5 ft/sec), and oriented in the north-east, and south-west directions During flood tide, this northeast directed current will deposit suspended material in GIWW

Wind-generated waves and wind-generated currents are the dominant mechanisms for sediment resuspension in the study area Typically, when the wind speed exceeds a threshold level of about 10 m/sec (22 mph), there is a corresponding increase in the levels of suspended solids as well as in light attenuation, which is consistent with other studies in similar shallow-water environments (Ward, *et al* 1984) During the passage of fronts, the turbidity levels increase within 1-2 hours of the initiation of the wind forcing, and the turbidity levels typically return to pre-frontal conditions within 24 hours.

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It is difficult to distinguish the effects of dredged material placement techniques on sediment resuspension and light attenuation in the study area because of the seasonal and interannual variability in meteorological conditions (e.g., wind speed and direction, and passage of fronts) Prior to dredging in late September and October 1994, the concentration of suspended solids and light attenuation were at minimal levels due to the calm seasonal meteorological conditions characteristic of September. Subsequent to dredging, the suspended solids and light attenuation became more variable and increased three-fold. By June, 1995, the sediment concentration and underwater light return to levels similar to those observed prior to dredging.

Open-bay dredged-material placement techniques appear to have a maximal impact on underwater light for about 246 days after initiation of dredging. A statistically significant difference in light attenuation coefficients (*k* values) was detected one year after the cessation of dredging However, this difference may be due to variability in background conditions or interannual variation in the meteorological conditions, which is supported by a statistically significant difference in wind speed Subsequent to dredging, the underwater light environment was 50 to 60% below the light requirements of seagrasses. A continuous *in situ* underwater light record for at least one entire dredging cycle is required to quantify the duration of low light associated with dredging

The dominant seagrass distribution is similar to that observed in other studies of the seagrass community of this region *Thalassia testudinum*, the most commonly occurring species in the study area, showed a statistically significant decline in above-ground biomass during the study period (September, 1994-September, 1995) However, this difference in biomass is within the range of interannual variation for this species No other seagrass species showed any statistical change in biomass over the study period. The location of the unvegetated region in the deeper portion of the study area, has a similar configuration as the 1-m (3-ft) depth contour, implying that low light levels were the reason for the loss of the seagrass meadow in this region. A hypothesis is presented which suggests that higher than normal suspended particulates and sea level rise, may be the cause of this loss of seagrasses

Recommendations for Reducing Dredging

The environmental impacts associated with maintenance dredging could be lessened in the region of lower Laguna Madre between Port Isabel and the Arroyo Colorado by reducing the frequency of maintenance dredging in the high shoaling reach. One recommendation for reducing the dredging requirements is to eliminate dredged material placement in the region with cross-channel flow (Stations 45+000 to 70+000), thus removing the sediment source adjacent to the GIWW. The material dredged in this reach could be placed in adjacent dredged material placement areas either to the north or south of the high shoaling reach, such as by augmenting existing emergent islands or open bay disposal to the south, or the material could be removed from the system (upland or offshore placement) To the south of the high shoaling reach, seagrasses have established on the dredged material placed in these areas If the sediment placed in the dredged placement areas in the high shoaling reach was stabilized, such as by building levees or emergent islands, the region would be subjected to high erosional forces If the stabilizing material were able to withstand the currents and erosion, the current would be deflected to the north or south of the region where the currents cross the GIWW, translating the high shoaling reach to the north or south

Due to the predominant cross channel flow in the region between Stations 45+000 and 70+000 this region will always shoal more rapidly than the surrounding region even if the sediment source is removed. One possibility to reduce the dredging frequency and cost would be to over dredge an additional 2.5 ft in this reach in addition to eliminating dredged material placement in the high shoaling reach, which may extend the dredging cycle by approximately 1 year (assuming similar shoaling rates).

Recommendations for Future Data-Collection Efforts

Due to the variability in background conditions and the strong dependence of light attenuation and suspended solids on wind conditions, a longer pre-dredging period is recommended to assist in determining the background conditions Interseasonal and interannual variation make it difficult to discern differences in light attenuation and suspended solids Therefore, it would be beneficial to continue monitoring through at the minimum one complete dredging cycle

Because oscillatory wave action is the major mechanism for resuspension of sediment, (wind speed is the forcing mechanism for generation of the waves), it is recommended that a pressure gauge be added to the suite of instruments at the monitoring platform The pressure gauge in conjunction with the ADV, will provide the directional wave spectra (wave height, direction, and period) and water level measurements. The wave and water level data will be used for developing predictive relationship for sediment resuspension, which take into account wave height, period, current, and water depth An additional benefit of the pressure gauge, will be continuous depth measurement for use in calculation light attenuation coefficients and for use in future numerical modeling efforts

One limitation of the present sampling techniques, is that water samples are collected twice daily at 6:00 AM and 6.00 PM. The conditions when these samples are collected may not be representative of the average daily conditions One recommendation is to collect a composite water sample that is more representative of the average daily conditions.

An additional recommendation is to investigative alternative hypotheses for the loss of seagrasses, including assessing changes in suspended sediment patterns or turbidity levels, changes in land use and runoff into the Laguna Madre, and the impact of rise of sea level

Benefits of Data-Collection Effort

This monitoring effort is providing the first long-term measurements of the physical processes in the lower Laguna Madre The comprehensive data set will be invaluable for calibration and verification of numerical models of the circulation, sediment resuspension, light attenuation, and seagrass productivity, under consideration by the Interagency Coordination Team Data generated in this study have also been utilized by other scientists and graduate students at University of Texas Marine Science Institute, University of Texas Pan American - Coastal Studies Laboratory, and Texas A&M University-Corpus Christi.

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Appendix A: Chronology Of Events

Presented in this appendix is a chronology of events for this monitoring effort, including installation of the platform, surveys, and servicing of the platforms. During the one year period between September 1, 1994, and August 31, 1994, there was approximately 100 days of field work, including routine maintenance, repair and replacement of instrumentation, and synoptic surveys

Table A.1. Chronology of events for September, 1994, through March, 1996.	
Date (1994-1996)	**Event**
12 Aug 94	Received authorization to proceed
12-27 Aug 94	Equipment procurement and testing; coordinated planning, mobilization for pre-dredging survey
28 Aug 94	Began installation of FIX 1, 2, and 3, performed synoptic survey
29 Aug 94	Completed installation of FIX 1, 2, and 3, performed synoptic survey
30 Aug 94	Installed equipment on platforms, conducted seagrass sampling, performed synoptic survey, and commenced data collection at FIX 1.
31 Aug 94	Performed synoptic survey, conducted seagrass sampling
1 Sep 94	Performed synoptic survey, conducted seagrass sampling.
2 Sep 94	Performed bathymetric survey, conducted seagrass sampling
9 Sep 94	Replaced Isco bottles at FIX 1
11 Sep 94	Replaced Isco bottles at FIX 2 and 3
12 Sep 94	Replaced and post-calibrated Hydrolab
14 Sep 94	Retrieved and replaced PAR sensor datalogger at FIX 1.
18 Sep 94	Replaced and post-calibrated Hydrolab
20 Sep 94	Cleaned instruments at FIX 1
21-22 Sep 94	Performed synoptic survey, replaced Isco bottles at FIX 1, 2, and 3
22 Sep 94	Replaced and post-calibrated Hydrolab.
26 Sep 94	Cleaned instruments at FIX 1
30 Sep 94	Replaced and post-calibrated Hydrolab, submitted progress report
2 Oct 94	Cleaned instruments at FIX 1, replaced Isco bottles at FIX 1, 2, and 3
2-3 Oct 94	Conducted seagrass sampling
5 Oct 94	Cleaned instruments at FIX 1
5-7 Oct 94	Performed synoptic during-dredging survey
10 Oct 94	Replaced and post-calibrated Hydrolab
12 Oct 94	Retrieved and replaced PAR sensor datalogger at FIX 1
13 Oct 94	Cleaned instruments at FIX 1, replaced Isco bottles at FIX 1, 2, and 3
17 Oct 94	Replaced and post-calibrated Hydrolab
22 Oct 94	Replaced and post-calibrated Hydrolab.
25 Oct 94	Cleaned instruments at FIX 1
25-26 Oct 94	Attempted additional during-dredging survey, aborted due to weather
28 Oct 94	Replaced Isco bottles at FIX 1, 2, and 3
30 Oct 94	Replaced and post-calibrated Hydrolab
1 Nov 94	Cleaned instruments at FIX 1
4 Nov 94	Submitted progress report
5 Nov 94	Replaced and post-calibrated Hydrolab
7 Nov 94	Cleaned instruments at FIX 1, replaced Isco bottles at FIX 1, 2, and 3
11 Nov 94	Replaced and post-calibrated Hydrolab
16-17 Nov 94	Performed post-dredging bathymetric survey.
18 Nov 94	Replaced and post-calibrated Hydrolab, replaced Isco bottles at FIX 1, 2, and 3; performed synoptic survey, National Biological Survey installed 2 additional PAR sensors in the vicinity of the placement areas
22 Nov 94	Replaced and post-calibrated Hydrolab
30 Nov 94	Replaced and post-calibrated Hydrolab, replaced Isco bottles at Fix 1, 2, and 3
2 Dec 94	Cleaned instruments at FIX 1
7 Dec 94	Replaced and post-calibrated Hydrolab, submitted progress report

Table A.1. Chronology of events for September, 1994, through March, 1996.	
Date (1994-1996)	Event
12 Dec 94	Replaced and post-calibrated Hydrolab
15 Dec 94	Installed new data collector at FIX 1
19 Dec 94	Replaced and post-calibrated Hydrolab.
28 Dec 94	Replaced and post-calibrated Hydrolab
7 Jan 95	Replaced and post-calibrated Hydrolab; replaced Isco bottles at FIX 1, 2, and 3
9 Jan 95	Field cleaned Hydrolab; replaced batteries, and reset radio
13 Jan 95	Installed new data collector and software at FIX 1, submitted progress report
17 Jan 95	Replaced and post-calibrated Hydrolab
18 Jan 95	Replaced Isco bottles at FIX 1, 2, and 3.
24 Jan 95	Installed track for ADV at FIX 1, replaced and post-calibrated Hydrolab
27 Jan 95	Field cleaned Hydrolab unit, ADV, and fluorometer
31 Jan 95	Replaced and post-calibrated Hydrolab
4 Feb 95	Cleaned instruments at FIX 1
8 Feb 95	Submitted progress report.
9 Feb 95	Replaced and post-calibrated Hydrolab, replaced Isco bottles at FIX 1, 2, and 3
16-19 Feb 95	Conducted Interim seagrass survey
20 Feb 95	Replaced and post-calibrated Hydrolab; replaced Isco bottles at FIX 1, 2, and 3
24 Feb 95	Cleaned instruments at FIX 1
28 Feb 95	Replaced and post-calibrated Hydrolab
6 Mar 95	Cleaned instruments at FIX 1, Replaced and post-calibrated Hydrolab.
13 Mar 95	Cleaned instruments at FIX 1, submitted progress report
14 Mar 95	Cleaned instruments at FIX 1, Replaced and post-calibrated Hydrolab
16-21 Mar 95	Conducted interim seagrass survey
18 Mar 95	Replaced Isco bottles at FIX 1, 2, and 3
21 Mar 95	Cleaned instruments at FIX 1, Replaced and post-calibrated Hydrolab
23 Mar 95	Replaced Isco bottles at FIX 1, 2, and 3
28 Mar 95	Presented data at Technical Review Meeting, Cleaned instruments at FIX 1; Replaced and post-calibrated Hydrolab
2 Apr 95	Cleaned instruments at FIX 1, Replaced and post-calibrated Hydrolab, Replaced Isco bottles at FIX 1
3 Apr 95	Submitted progress report
10 Apr 95	Cleaned instruments at FIX 1
18 Apr 95	Cleaned instruments at FIX 1, Replaced and post-calibrated Hydrolab; Cleaned sensor and replaced datalogger for PAR sensor
21 Apr 95	Replaced ADV at FIX 1
22-23 Apr 95	Attempted to replace ADV at FIX 1
25 Apr 95	Cleaned instruments at FIX 1, Replaced and post-calibrated Hydrolab, Replaced ADV
3 May 95	Replaced ADV
8 May 95	Submitted progress report
9 May 95	Replaced ADV, Replaced and post-calibrated Hydrolab, Replaced Isco bottles at FIX 1, 2, and 3.
16-17 May 95	Attempted 6-month post-dredging survey, aborted due to weather
18 May 95	Cleaned instruments at FIX 1, Replaced and post-calibrated Hydrolab, Replaced Isco bottles at FIX 1, 2, and 3, Replaced ADV and fluorometer
24 May 95	Serviced PAR sensors at FIX 1

Table A.1 Chronology of events for September, 1994, through March, 1996.	
Date (1994-1996)	**Event**
25 May 95	Cleaned instruments at FIX 1, Replaced and post-calibrated Hydrolab, Replaced Isco bottles at FIX 1, 2, and 3
1 Jun 95	Cleaned instruments at FIX 1, Replaced and post-calibrated Hydrolab; Replaced Isco bottles at FIX 1, 2, and 3
8 Jun 95	Cleaned instruments at FIX 1, Replaced and post-calibrated Hydrolab, Replaced Isco bottles at FIX 1, 2, and 3.
19 Jun 95	Cleaned instruments at FIX 1; Replaced and post-calibrated Hydrolab, Replaced Isco bottles at FIX 1, 2, and 3
27 Jun 95	Cleaned instruments at FIX 1, Replaced and post-calibrated Hydrolab, Replaced Isco bottles at FIX 2 and 3, Removed water sampler at FIX 1 (faulty cable)
27-30 Jun 95	Performed 6-month post-dredging bathymetric survey
30 Jun 95	Serviced PAR sensors at FIX 1
6 Jul 95	Cleaned instruments at FIX 1, Replaced and post-calibrated Hydrolab, Replaced Isco bottles at FIX 2 and 3; Re-installed water sampler at FIX 1, Replaced batteries at FIX 1.
18 Jul 95	Cleaned instruments at FIX 1; Replaced and post-calibrated Hydrolab, Replaced Isco bottles at FIX 1, 2, and 3
27 Jul 95	Cleaned instruments at FIX 1, Replaced and post-calibrated Hydrolab, Replaced Isco bottles at FIX 1, 2, and 3
7 Aug 95	Cleaned instruments at FIX 1, Replaced and post-calibrated Hydrolab; Replaced Isco bottles at FIX 1, 2, and 3, Removed ADV signal processing unit
18 Aug 95	Cleaned instruments at FIX 1, Replaced and post-calibrated Hydrolab, Replaced Isco bottles at FIX 1, 2, and 3, Rep ADV signal processing unit
29 Aug 95	Cleaned instruments at FIX 1, Replaced and post-calibrated Hydrolab, Replaced Isco bottles at FIX 1, 2, and 3
3-10 Sep 95	Conducted 1-year post-dredging seagrass survey
7 Sep 95	Cleaned instruments at FIX 1; Replaced and post-calibrated Hydrolab, Replaced Isco bottles at FIX 1, 2, and 3
19 Sep 95	Attempted to service stations, aborted due to weather.
25 Sep 95	Cleaned instruments at FIX 1, Replaced and post-calibrated Hydrolab, Replaced Isco bottles at FIX 1, 2, and 3
2 Oct 95	Cleaned instruments at FIX 1, Replaced and post-calibrated Hydrolab; Replaced Isco bottles at FIX 1 and 2, Repaired water sampler at FIX 3
Oct - Nov 95	*Note Station serviced, however, documentation missing*
1 Nov 95	Cleaned instruments at FIX 1, Replaced and post-calibrated Hydrolab, Replaced Isco bottles at FIX 1, 2, and 3, Replaced ADV at FIX 1
10 Nov 95	Cleaned instruments at FIX 1, Replaced and post-calibrated Hydrolab, Replaced Isco bottles at FIX 1, 2, and 3
21 Nov 95	Cleaned instruments at FIX 1, Replaced and post-calibrated Hydrolab, Replaced Isco bottles at FIX 1, 2, and 3, problem with TNC, Water sampler malfunctioned at FIX 1, Replaced ADV.
30 Nov 95	Cleaned instruments at FIX 1, Replaced and post-calibrated Hydrolab, Replaced Isco bottles at FIX 1, 2, and 3, Replaced intake hoses on water samplers
12 Dec 95	Cleaned instruments at FIX 1, Replaced and post-calibrated Hydrolab; Replaced Isco bottles at FIX 1, 2, and 3
12-15 Dec 95	Performed 1-year post-dredging bathymetric survey
	Cleaned instruments at FIX 1, Replaced and post-calibrated Hydrolab,

Table A.1. Chronology of events for September, 1994, through March, 1996.	
Date (1994-1996)	**Event**
21 Dec 95	Replaced Isco bottles at FIX 1, 2, and 3, Replaced ADV probe, Removed ADV signal processing unit.
27 Dec 95	Cleaned instruments at FIX 1, Replaced and post-calibrated Hydrolab, Replaced Isco bottles at FIX 1, 2, and 3, Replaced ADV signal processing unit.
8 Jan 96	Cleaned instruments at FIX 1; Replaced and post-calibrated Hydrolab, Replaced Isco bottles at FIX 1, 2, and 3
19 Jan 96	Cleaned instruments at FIX 1, Replaced and post-calibrated Hydrolab, Replaced Isco bottles at FIX 1, 2, and 3, ADV intermittently exposed, lowered ADV
31 Jan 96	Cleaned instruments at FIX 1, Replaced and post-calibrated Hydrolab, Replaced Isco bottles at FIX 1, 2, and 3
13 Feb 96	Cleaned instruments at FIX 1, Replaced and post-calibrated Hydrolab, Replaced Isco bottles at FIX 1, 2, and 3
26 Feb 96	Cleaned instruments at FIX 1; Replaced and post-calibrated Hydrolab; Replaced Isco bottles at FIX 1, 2, and 3, Replaced batteries and voltage regulators at FIX 1, 2, and 3
4 Mar 96	Cleaned instruments at FIX 1, Replaced and post-calibrated Hydrolab, Replaced Isco bottles at FIX 1, 2, and 3
15 Mar 96	Cleaned instruments at FIX 1, Replaced and post-calibrated Hydrolab, Replaced Isco bottles at FIX 1, 2, and 3
25 Mar 96	Cleaned instruments at FIX 1, Replaced and post-calibrated Hydrolab, Replaced Isco bottles at FIX 1, 2, and 3.

Appendix B: Wind, Water Level And Current Data

Presented in this appendix are time-series of wind speed and direction at Arroyo Colorado, water level at South Padre Island Coast Guard Station, and current data (north-south and east-west components) at FIX 1 for September, 1994 through August, 1995. The wind direction is defined as 0 deg representing wind from the north, and the direction increasing with clockwise rotation Current flow towards the north and west are defined as positive

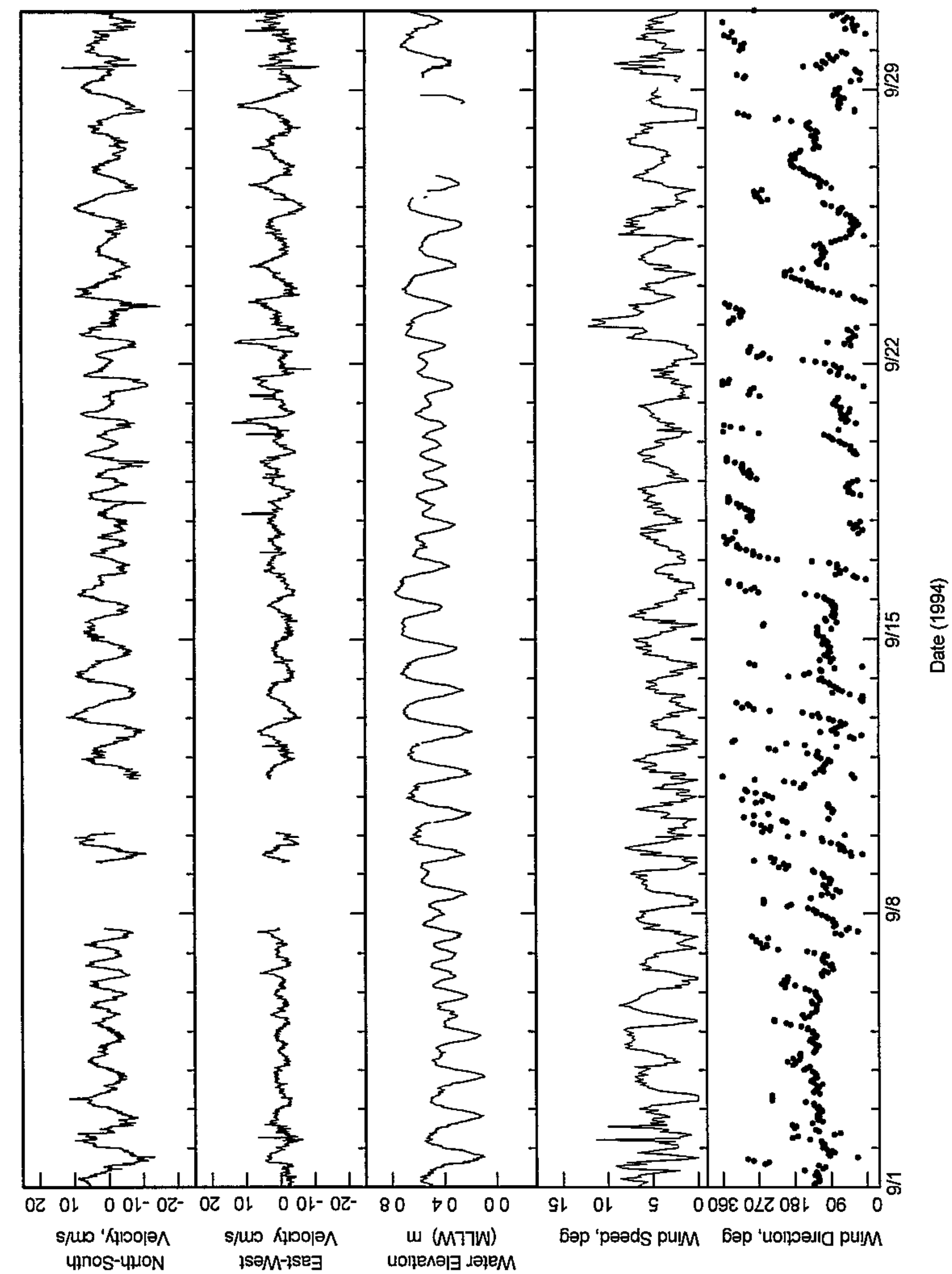

Figure B 1 Current velocity, water elevation, wind speed, and wind direction, September, 1994

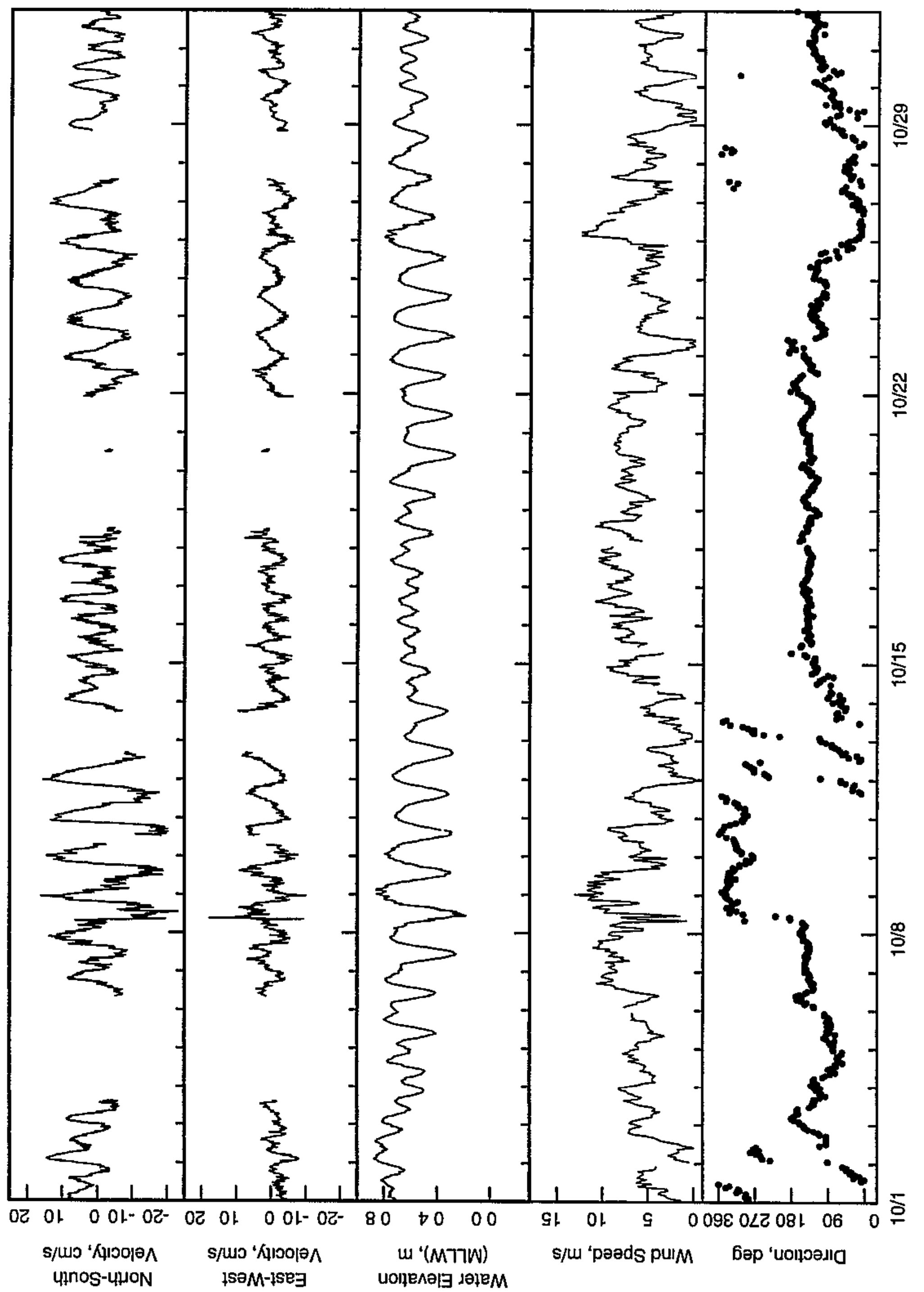

Figure B 2 Current velocity, water elevation, wind speed, and wind direction, October, 1994.

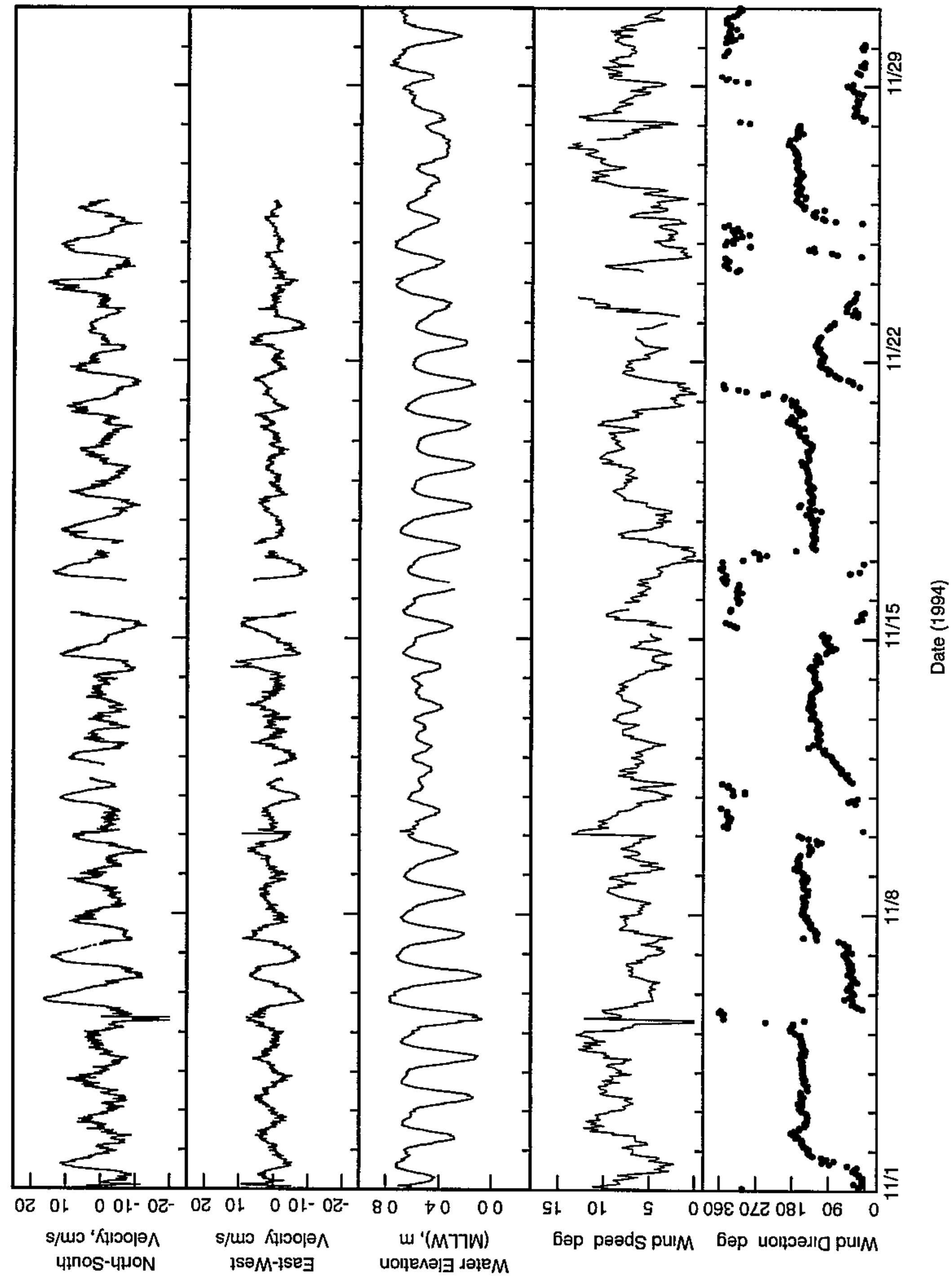

Figure B 3 Current velocity, water elevation, wind speed, and wind direction, November, 1994

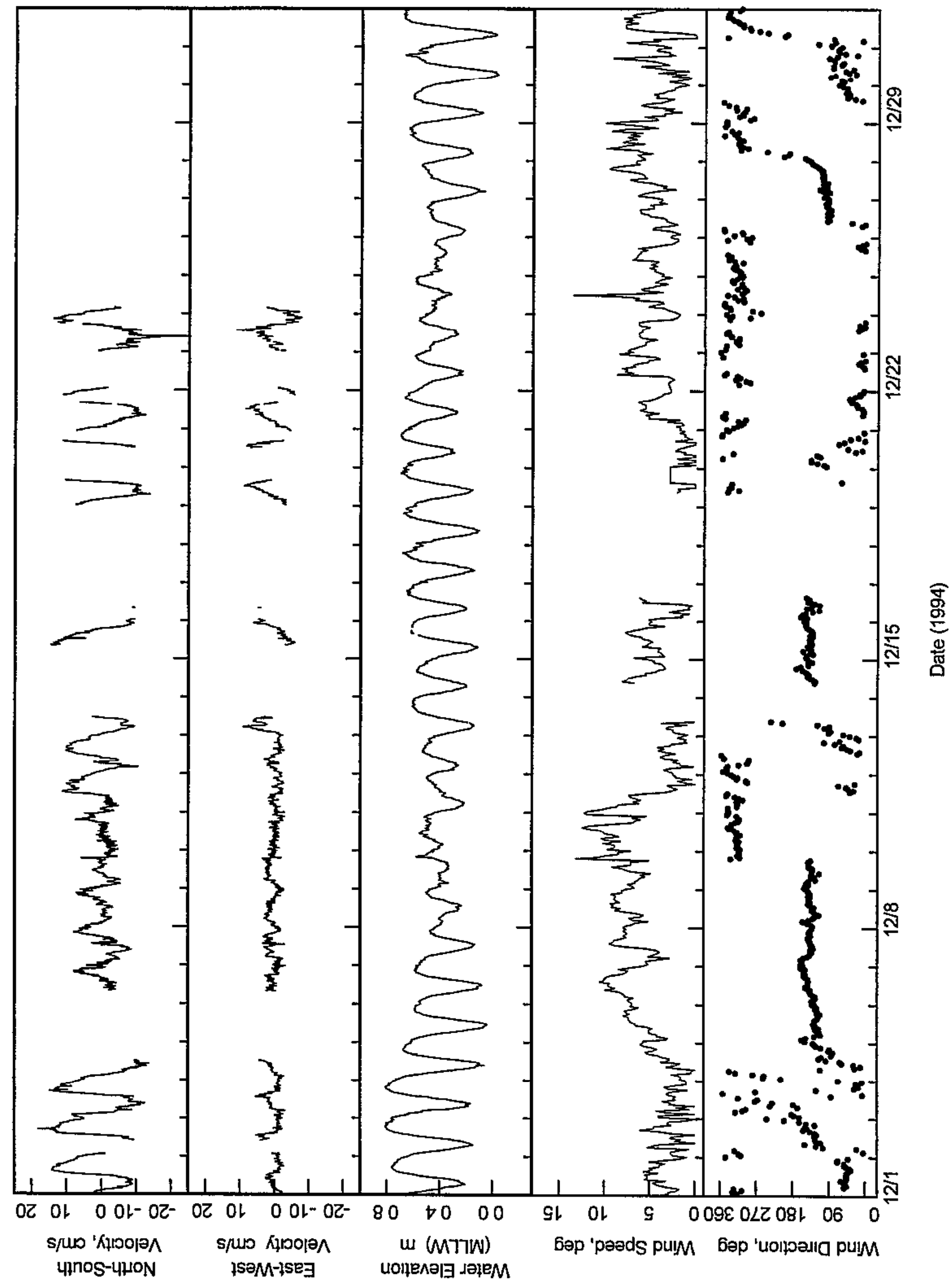

Figure B 4 Current velocity, water elevation, wind speed, and wind direction, December, 1994

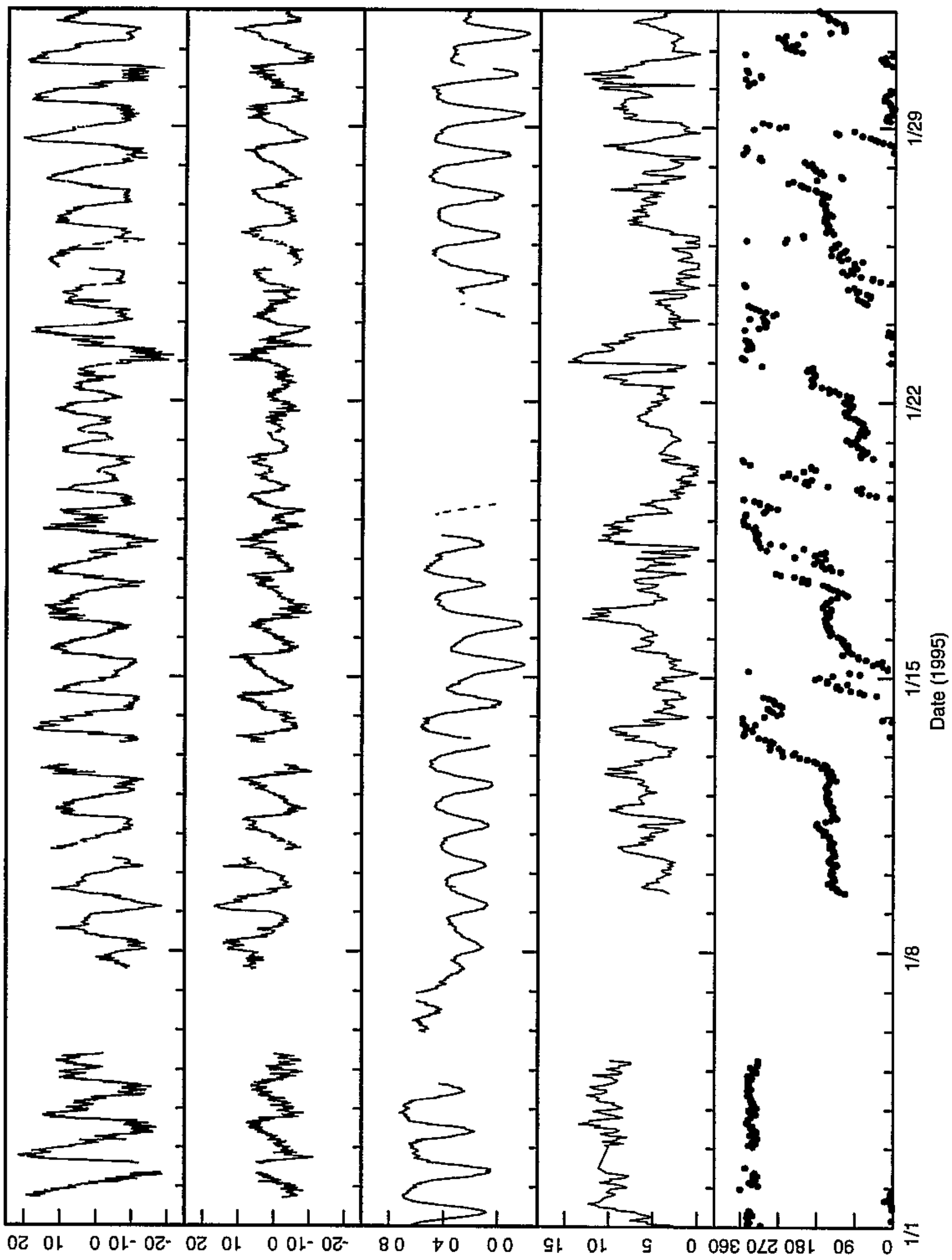

Figure B 5 Current velocity, water elevation, wind speed, and wind direction, January, 1995.

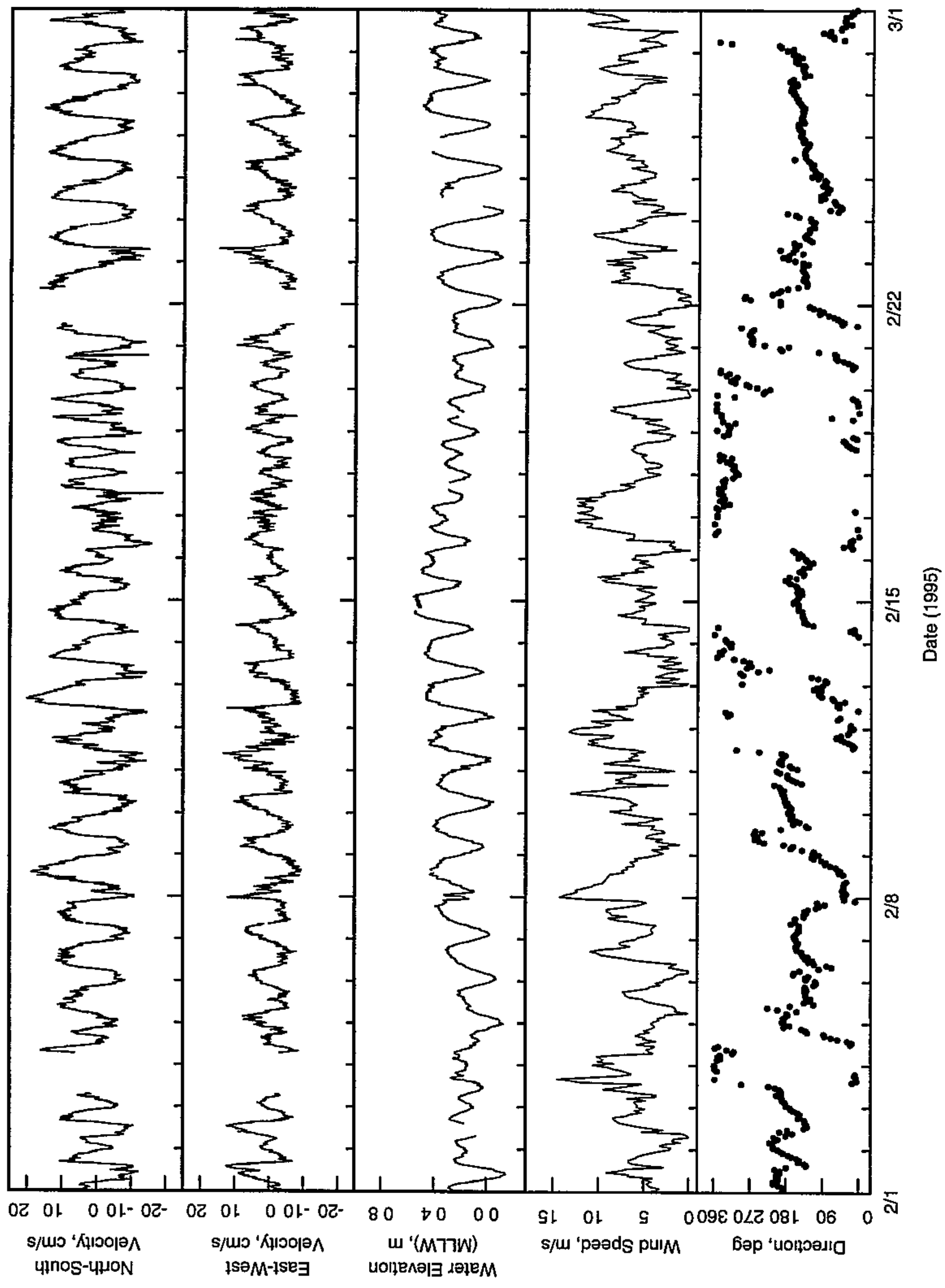

Figure B.6 Current velocity, water elevation, wind speed, and wind direction, February, 1995

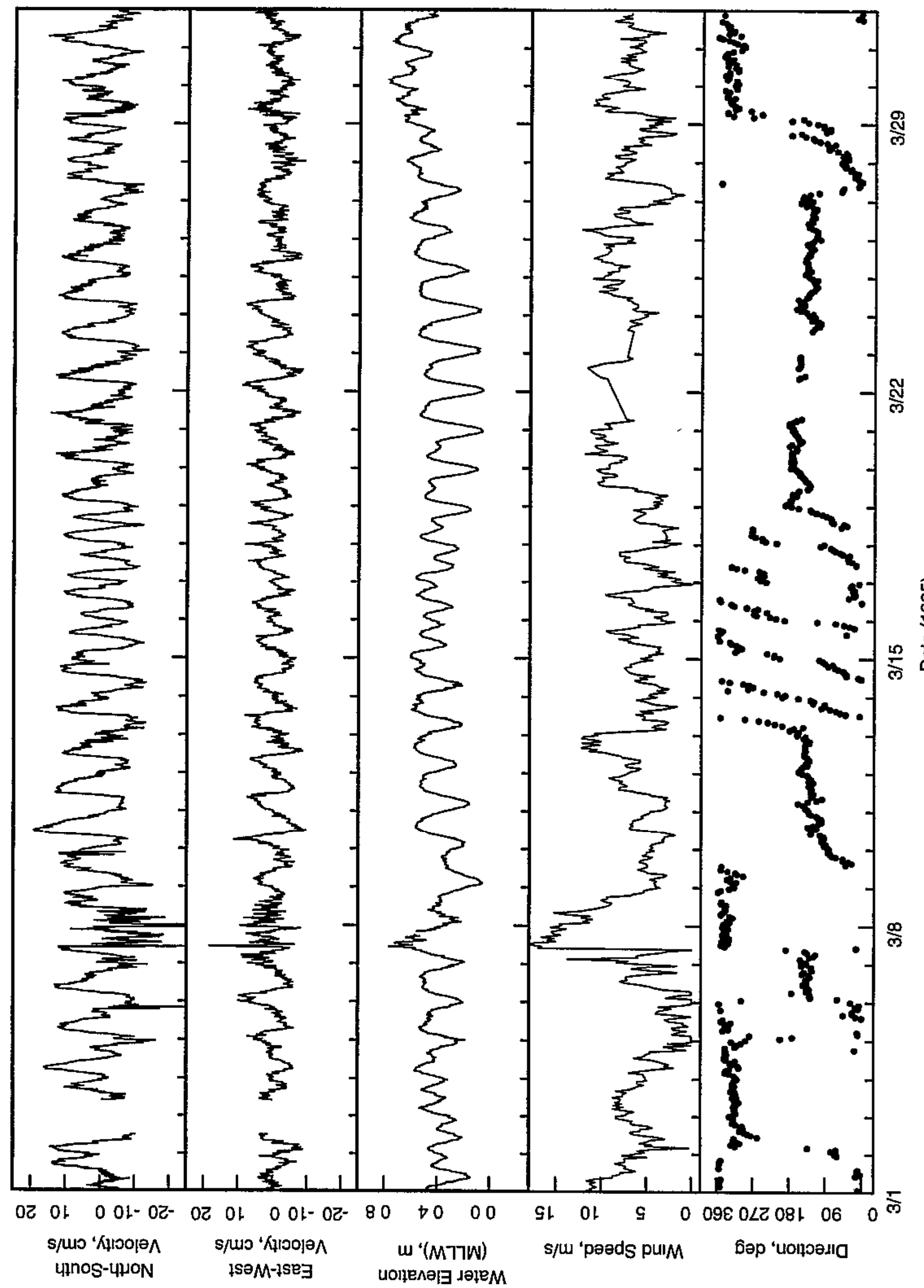

Figure B 7 Current velocity, water elevation, wind speed, and wind direction, March, 1995

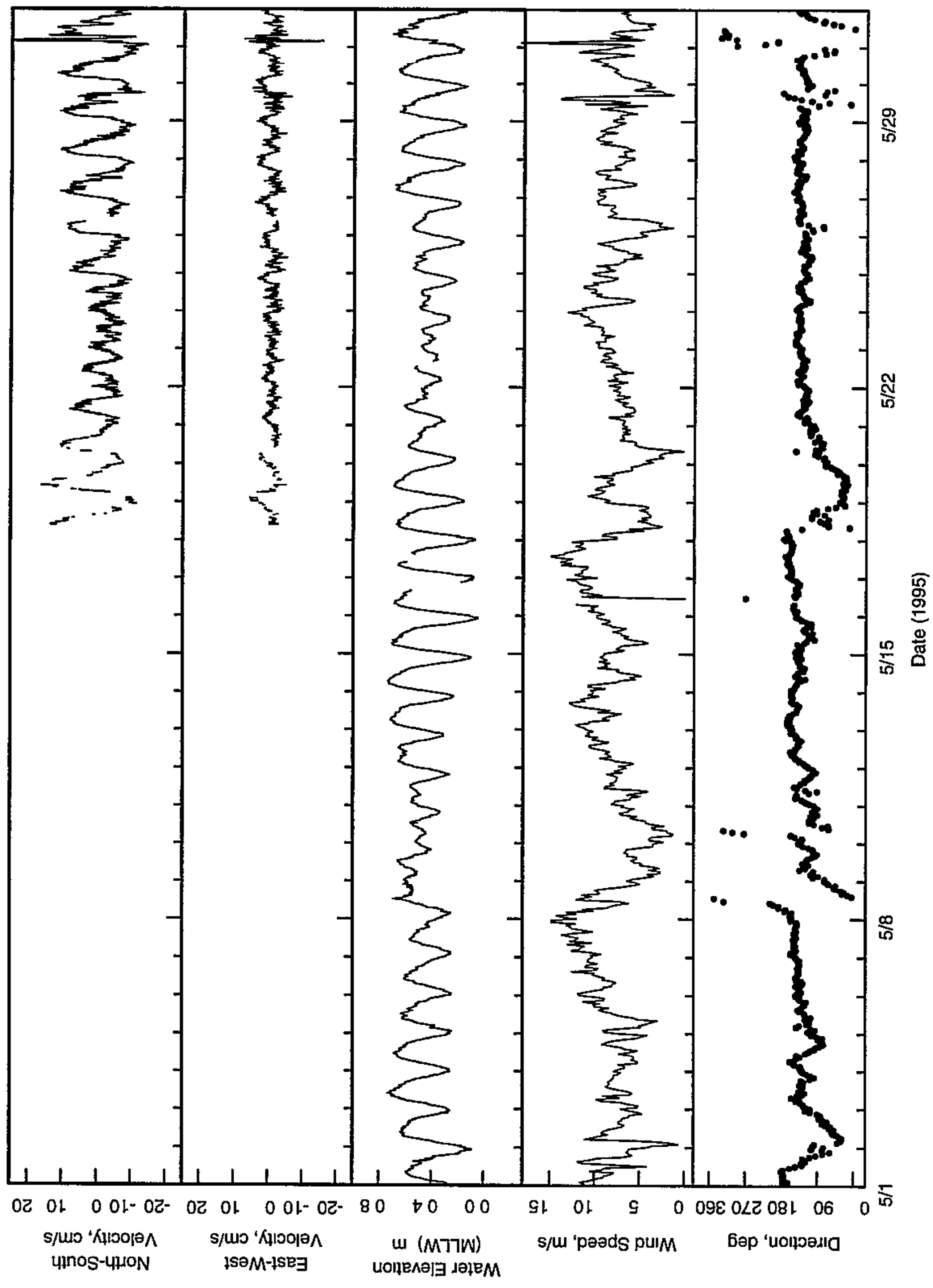

Figure B.8. Current velocity, water elevation, wind speed, and wind direction, May, 1995.

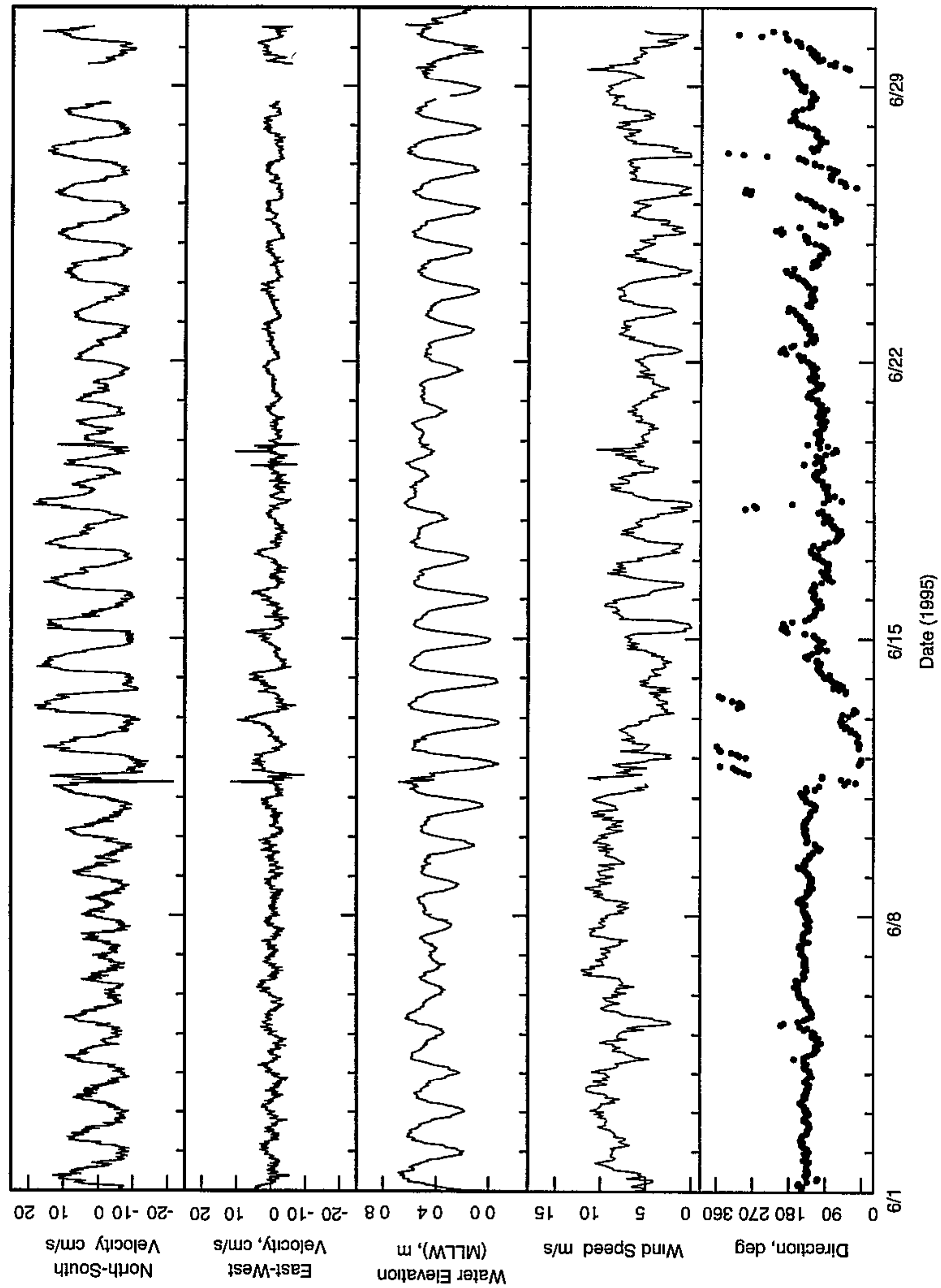

Figure B 9 Current velocity, water elevation, wind speed, and direction, June, 1996.

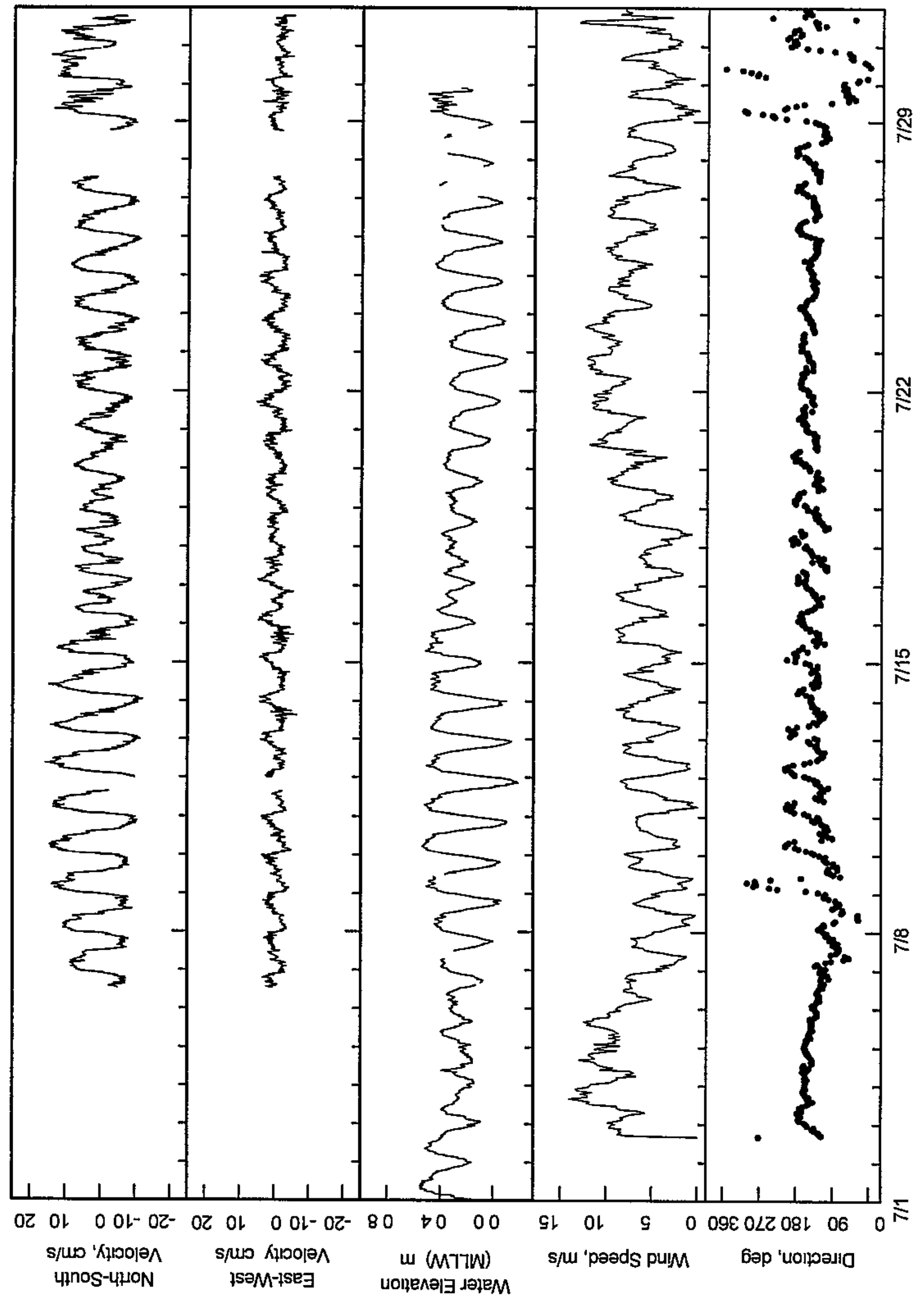

Figure B 10 Current velocity, water elevation, wind speed, and wind direction, July, 1996

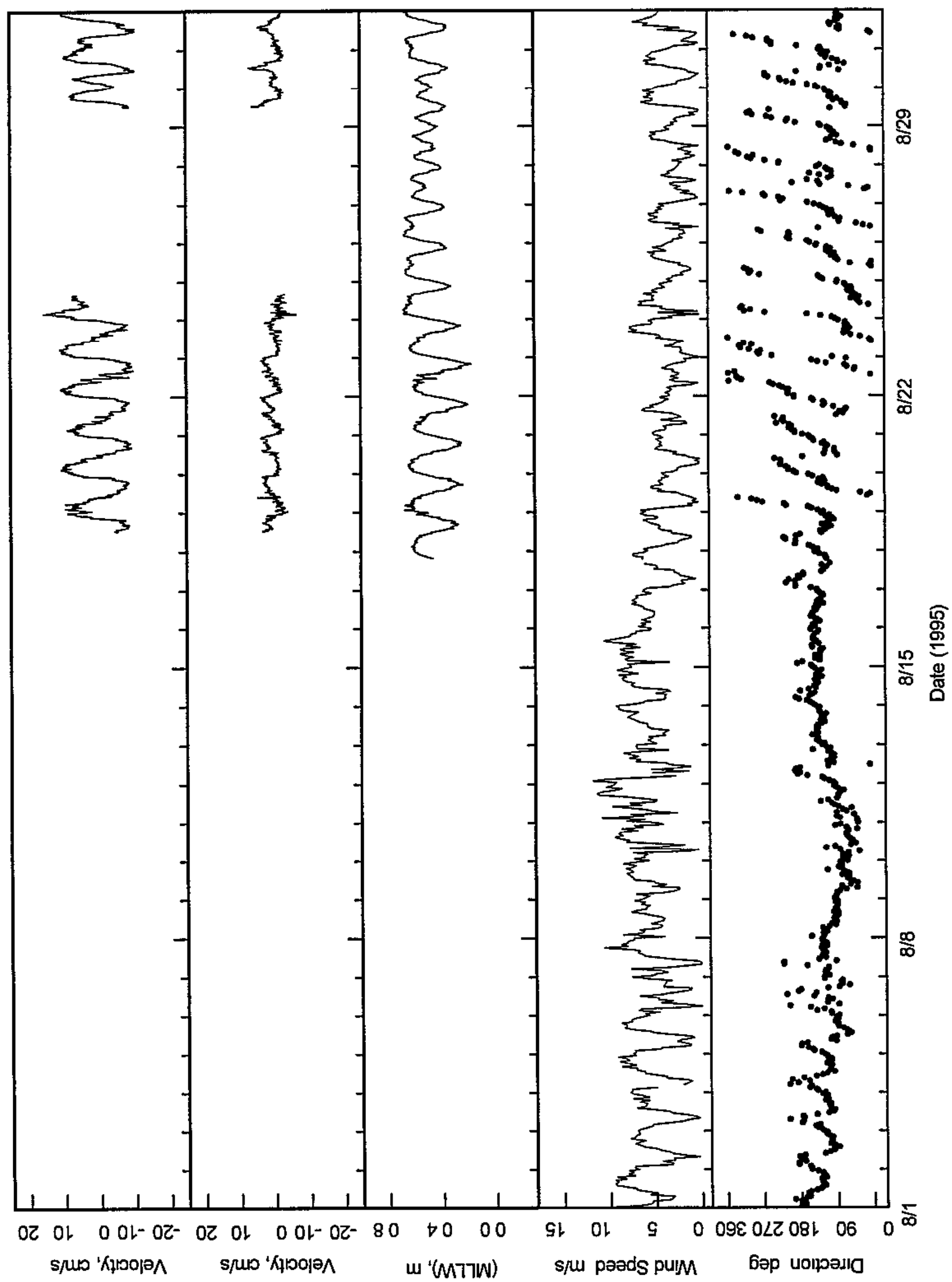

Figure B 11 Current velocity, water elevation, wind speed, and wind direction, August, 1996