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# TIDAL CHARACTERISTICS AND DATUMS OF LAGUNA MADRE, TEXAS

Silver Spring, Maryland
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U.S. DEPARTMENT OF COMMERCE
National Ocean Service

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Stephen K. Gill
James R. Hubbard
Gary Dingle

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United States
Department of Commerce
Ronald H. Brown, Secretary

National Oceanic and
Atmospheric Administration
D. James Baker, Under Secretary

National Ocean Service
W. Stanley Wilson
Assistant Administrator

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# ACKNOWLEDGEMENTS

The authors would like to acknowledge the contributions of the State of Texas, General Lands Office in initiating the cooperative program with the National Ocean Service that created the data set used in this report. The personnel from the Conrad Blucher Institute (CBI), Texas A&M University Corpus Christi, have been key to the success of the station installation, maintenance, and data collection. Personnel from the NOS Ocean Lake Levels Division, including the Atlantic Operations Section in Chesapeake, VA; the NOS Ocean Systems Development Group; the Measurements Section and the Pacific Group located in Silver Spring, MD were collectively responsible for the success of the program.

# I. INTRODUCTION

The Ocean and Lake Levels Division (OLLD) was established in September 1992 as one of four Divisions in the Office of Oceans and Earth Sciences (OES), National Ocean Service (NOS). OLLD (and predecessor organizations) have been responsible for the management of the United States National Water Level Observation Program. The foundation of this program is the operation of approximately 189 continuously operating stations in the U.S. coastal ocean, including the Great Lakes and connecting waterways, and in U.S. Trust Territories and possessions. The data and information from the National Water Level Observation Network (NWLON) represents one of the most unique and valuable geophysical data sets available.

Through its long term continuous measurements, the NWLON provides the foundation for the determination and maintenance of vertical reference datums used for surveying and mapping, dredging and coastal construction, water level regulation, marine boundary determination, tide prediction and analysis of sea level variations and trends. The stations are also important components of various storm surge monitoring and warning systems and Pacific Basin stations are components of the Tsunami Warning System. The OLLD enters into cooperative agreements with other federal, state and local agencies and governments to achieve mutual objectives through the application of water level measurements to coastal ocean projects. Historically, the largest cooperative programs have been with coastal states for the purpose of establishing vertical reference networks for surveying and mapping, marine boundary, and other purposes (e.g., New Jersey, South Carolina, Florida, Mississippi, Louisiana, California, Alaska and most recently Texas).

The objectives of this report are threefold: 1) to analyze simultaneous water level data sets from a transect of stations covering the Gulf Coast and Laguna Madre using non-harmonic analyses, harmonic analyses, and spectral analysis techniques, 2) based on the past and present analyses, describe in detail the tidal characteristics in Laguna Madre from Corpus Christi Bay south to Port Isabel, Brazos Santiago Pass, and 3) determine which regions of Laguna Madre should be classified as tidal or non-tidal for tidal datum computation purposes according to operational criteria established by NOS for tabulation of the tide.

## II. BACKGROUND

The previous Laguna Madre Technical Report (National Ocean Service, 1983) discussed procedures for collecting and analyzing water level data and computing tidal datums for three stations near Green Island, Laguna Madre, east of the Arroyo Colorado delta. Valuable expertise was derived from processing and analyzing water level data from a low tide range environment. The results presented in this report are an extension of the analyses and procedures developed in the 1983 report and the earlier research by H. A. Marmer (1950).

A Memorandum of Agreement (MOA) was signed in April, 1988 between the Texas General Land Office (GLO) and the director of the Office of Oceanography and Marine Assessment (presently Office of Ocean and Earth Sciences, OES) (see appendix I). This agreement established a framework for a basic program plan and subsequent annual work plans for establishing water level gauges in Texas bays, estuaries and coastal ocean. The Conrad Blucher Institute for Surveying and Science (CBI), Texas A&M University Corpus Christi, was designated by GLO to coordinate field operations south of Freeport and Lamar University (LU) was designated to coordinate operations north of Freeport. In conjunction with CBI and LU, several NOS/GLO stations have been established in Texas, including Laguna Madre. These stations were established according to NOS standards and procedures and have periodically been inspected by NOS personnel. Using knowledge gained from these installations, and subsequent training and transfer of technology in station establishment and operation, CBI and LU began implementation of a network of State-operated gauges named the Texas Coastal Ocean Observation Network (TCOON). TCOON now consists of dozens of stations throughout the state. The ongoing close cooperation in operating the subset of NOS/GLO stations as well as training, exchanges of data, and development of new instrumentation and data processing algorithms, has provided NOS the opportunity to conduct an in-depth study of the tides in the Gulf of Mexico and more importantly, Laguna Madre. As part of the ongoing agreement, NOS continues to process data for selected TCOON stations.

The long term NOS water level stations now operating in the immediate vicinity of Laguna Madre are listed in Table I. The table also lists the length of continuous series from which the accepted datums have been computed.

## TABLE I. NOS Long-Term Primary Stations - Southern Texas and Laguna Madre

| Station Number | Station Name | Lat.(N) | Long.(W) | Date Installed | Series |
|---|---|---|---|---|---|
| 877 4770 | Rockport | 28°01.4’ | 97°02.8’ | 1948 | 17 yrs |
| 877 5870 | Bob Hall Pier | 27°34.8’ | 97°13.0’ | 1983 | 11 yrs |
| 877 8490 | Port Mansfield | 26°33.3’ | 97°25.8’ | 1964 | 17 yrs |
| 877 9770 | Port Isabel | 26°03.6’ | 97°12.9’ | 1944 | 19 yrs |

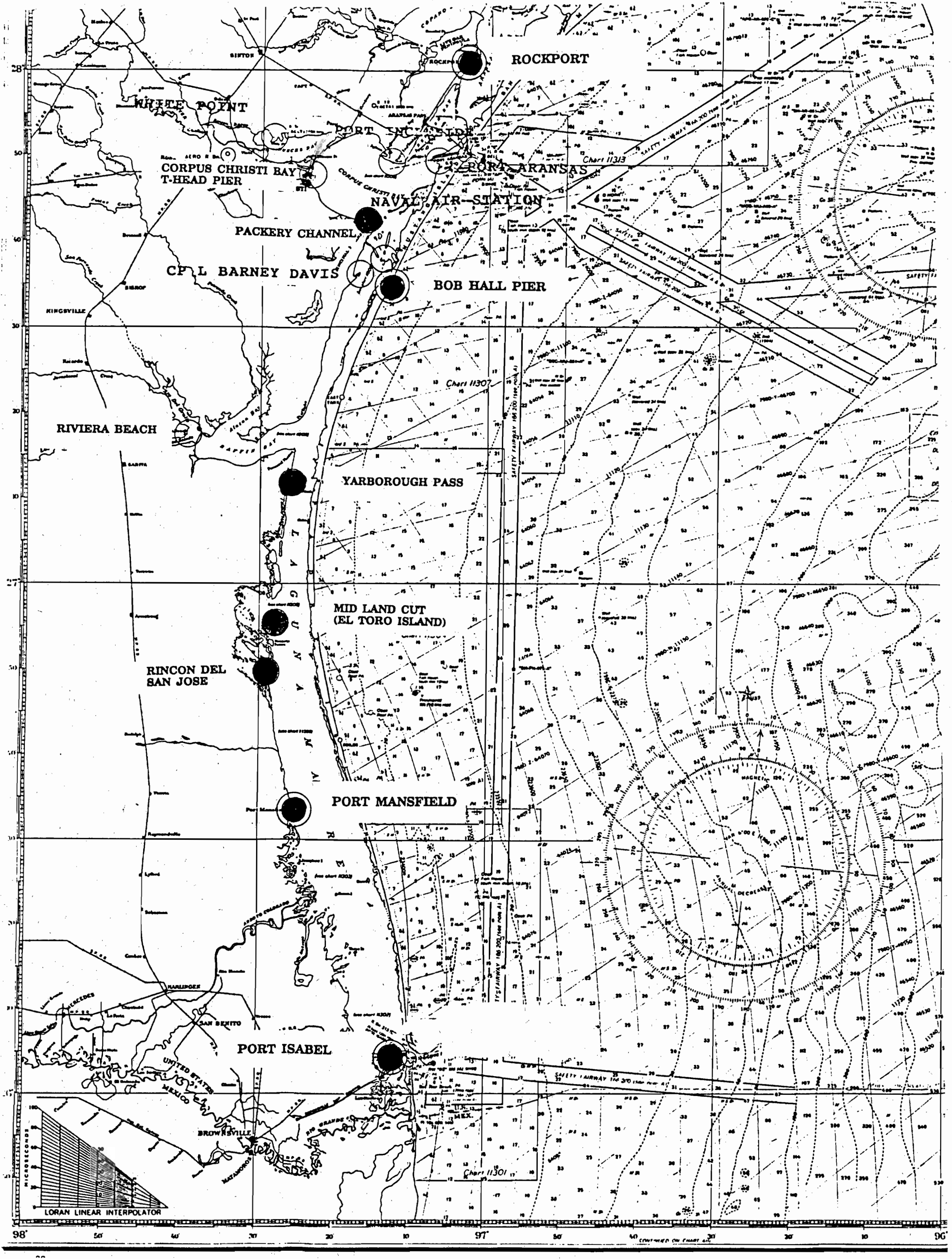
Long-term secondary (subordinate) water level stations were installed between Mansfield Pass and Corpus Christi Bay by NOS/GLO/CBI in order to investigate the transition of the tide from the open coast into the shallow waters of Laguna Madre. NOS routinely processed and analyzed data from the Laguna Madre secondary stations listed in Table II.

## TABLE II. NOS/GLO Cooperative Secondary Stations - Laguna Madre, Texas

| Station Number | Station Name | Lat.(N) | Long.(W) | Date Installed |
|---|---|---|---|---|
| 877 5792 | Packery Channel | 27°38.0’ | 97°13.3’ | 12/01/88 |
| 877 6687 | Yarborough Pass | 27°12.0’ | 97°26.0’ | 3/13/90 |
| 877 7562 | El Toro | 26°56.5’ | 97°27.4’ | 4/04/90 |
| 877 7812 | Rincon Del San Jose | 26°49.5’ | 97°29.5’ | 11/17/90 |

Figure 1 is a sketch showing the relative locations of the stations used in this report. The stations represent a north-south transect of information from which to analyze Laguna madre as a system.

FIGURE 1. Sketch Showing Relative Locations of Laguna Madre Station Locations



# III. TIDE STATION OPERATION AND FIELD PROCEDURES

## Station Configurations

The NWLON stations listed in Table I have two separate measurement systems installed. NOAA has been implementing a Next Generation Water Level Measurement System (NGWLMS) into operations over the past several years (Beaumariage et al, 1987). NGWLMS, when fully implemented, will completely replace the older water level measurement, data collection, and data processing technology used for the past several decades. At each of the NWLON stations, the new NGWLMS field units are being installed and operated simultaneously with the older technology systems for a minimum period of one year. This will ensure data and datum continuity for the historical time series prior to removal of the older technology systems (Gill and Mero, 1990). The NGWLMS field units were installed at the stations listed in Table I in February of 1990. Data comparisons have been completed at each of the stations, and except for Port Isabel, clearance has been given to remove the older systems. Port Isabel should be cleared for removal sometime in 1995, once level ties between the two systems have been checked.

Except for Packery Channel, the long term secondary stations listed in Table II were established with the NGWLMS field units and not the old technology systems. Packery Channel was established in December 1988 with an Analog-to-digital recorder (ADR) gauge which was subsequently removed after comparison with the NGWLMS field unit that was installed in March 1990.

### 1. Support Structures

For the NWLON stations at Port Isabel and Port Mansfield, the support structures are platforms on four piles elevated well above the existing pier structures at approximately 15 feet above Mean Lower Low Water (MLLW). The station at Rockport is elevated slightly above the existing pier structure approximately 5 feet above MLLW. At the open coast pier station on Bob Hall Pier, the station platform is atop three concrete piles approximately 8 feet above the pier deck and 25 feet above MLLW. At each of these NWLON stations, the ADR and bubbler gauges and the NGWLMS data collection platforms (DCP's) are located inside 4'X 6'X 8' fiberglass instrument shelters for protection against the elements.

The secondary stations listed in Table II were established using various levels of modification of existing docks, piers, navigational aid structures and buildings. Unlike the NOS NWLON stations, the NGWLMS DCP's at the secondary stations are housed in small metal boxes (NEMA enclosures) and the large walk-in fiberglass shelters are not used. The stations at Yarborough, El Toro and Rincon del San Jose are accessible by boat only, as they had to be installed near the dredged Intracoastal Waterway where support structures were in place.

### 2. Stilling Wells and Protective Wells

The ADR gauges at the NWLON stations use 12-inch diameter stilling wells with 1-inch diameter orifices in a conical bottom intake. This configuration protects the float and float wire sensor and damps out (stills) the unwanted "noise" of the high frequency wind waves. The ADR configuration at the initial installation at Packery channel used a 6-inch diameter stilling well with a 1/2-inch orifice in the conical intake.

The NGWLMS field units at all locations in Tables I and II use a 6-inch diameter PVC protective well with a double cone 2-inch diameter orifice at the bottom. An 18-inch diameter parallel plate assembly is attached below the orifice. The protective well protects the 1/2/-inch CPVC sounding tube used by the acoustic sensor and the sound tube air thermistors (Edwing, 1991). The 3:1 well-to-orifice diameter ratio and the parallel plates were integrated with the development of the acoustic sensor sampling scheme to alleviate some of the known non-linear error sources of stilling wells used with the old technology systems (Shih and Baer, 1991).

### 3. Tide Staff

At each station there is a vitrified scale tide staff or steel electric-tape-gauge (ETG) attached to the supporting structure. The tide staff/ETG readings are used operationally to process and reference the ADR and Bubbler data to station datum based on routine tide observer readings. Tide observers and tide staffs/ETG's are not required for operational processing of the NGWLMS data since the sensor "zero" is directly leveled to the bench marks (Edwing, 1991) and the data are referenced to station datum without requiring the staff-to-gauge transfer process that ADR/Bubbler gauges undergo. The tide staffs at the NGWLMS locations are used to independently verify the water level heights only during on-site visits by field personnel.

## 4. Water Level Gauges

The ADR gauges used at the NWLON stations and Packery Channel have been Fischer and Porter 1551 or Leupold Stevens 7031 recorders modified by NOS for use in the salt-water coastal zone. The backup gauges are either Metercraft or Bristol nitrogen driven bubbler pressure gauges linked via neoprene tubing to a 3/4-inch diameter brass orifice. ADR gauges record data at 6-minute intervals to 0.01 foot resolution. Bubbler backup gauges produce continuous strip charts that can usually be read to the nearest 0.05 foot. These older technology systems are monitored daily by local tide observers who make time checks, staff readings, and mail the data records to NOS on a monthly basis.

The NGWLMS field units are manufactured by the Sutron Corporation. The field units consist of an AQUATRAK water level acoustic ranging sensor manufactured by Bartex, Inc., and a Sutron 9000 RTU data logging and GOES satellite radio communication unit. The NGWLMS configuration at the NWLON locations in Table I also consist of a Bubbler/Druck or a Bubbler/IMO Pressure Sensor and Sutron 8200 Data Collection Platform used as a backup system. The Druck or IMO pressure ports are teed into the pressure line from the bubbler orifice for digitization of the water level pressure signal.

The acoustic sensors are programmed to take measurements at six-minute intervals with each measurement consisting of 181 one-second interval water level samples centered on each tenth of an hour. The units automatically calculate a mean and a 3-sigma (standard deviation) value, compute the number of outliers outside of a 3-sigma band about the mean, and recalculate the mean and standard deviation of the sample excluding the outliers. The final 6-minute interval mean water level value, the final standard deviation, and the number of outliers in the sample are stored in memory and transmitted over GOES to the satellite downlink every three hours. Elevations are reported with 0.001 meter resolution. The NGWLMS backup pressure systems also record and store data at 6-minute intervals, however only half-hourly values are transmitted via satellite. The systems are also capable of measuring and transmitting up to 11 additional ancillary oceanographic and meteorological parameters such as wind speed and direction. Some of the stations listed in Table II are equipped with ancillary sensors.

The NWLON stations are configured with telephone connections so that data gaps in the routine satellite transmissions can be recovered via telephone. The secondary stations listed in Table II are not configured with either backup pressure gauge systems or telephone connections. To provide backup to collection over satellite, they have been configured with radio links that are used operationally by CBI to retrieve the data. CBI sends a diskette of data to NOS on a monthly basis that is used to fill gaps in the data sent over satellite. As a last resort if remote satellite, telephone, or radio links fail, up to one month of data are stored internally at the DCP and can be recovered on-site manually via laptop computer.

## 5. Network of Bench Marks

A network of bench marks are established and maintained for each station to reference and preserve the established datums (Hicks et al, 1987). The NWLON stations have networks of at least 10 bench marks to document station stability and preserve station datums. There are a minimum of five bench marks at each of the secondary stations. Some of the bench marks at each station are deep rod marks, which have proven to be the most dependable in areas without bedrock. The rods are stainless steel, driven to refusal for depths between 30 and 50 feet depending on resistance. The disks with designation stampings are crimped to the rods. Bench marks are typically established within a one-mile radius of the stations so that datum recovery is possible if some of the bench marks are destroyed. Appendix V lists the descriptions and types of marks at each of the stations.

## Operation, Maintenance, and Leveling

The NOS stations are maintained by the personnel from the Atlantic Operations Section (AOS), Chesapeake, Virginia. AOS personnel also trained CBI personnel in all the aspects of station installation and maintenance. Routine maintenance and leveling of the NWLON stations are performed on an annual basis. CBI has visited and leveled the secondary stations listed in Table II on a more frequent basis, typically every 6-months.

The NGWLMS acoustic sensors are calibrated prior to deployment. Approximately on an annual basis coinciding with the leveling, the acoustic sensors are removed and replaced by a newly calibrated sensor. The removed sensors are then sent back to NOS for calibration checks and any needed repairs (NOS, 1990). CBI is establishing their own independent calibration facility with the assistance of NOS. The acoustic sensor heads are installed, removed and calibrated as a matched set with a calibration tube. The routine levels for all stations have been completed in accordance with established procedures (Hicks et al, 1987). Due to the nature of the terrain, it was necessary at some stations to use portable platforms for tripods and rods to prevent them from sinking into the ground. The instrumentation used were Zeiss Ni2 and B-1 automatic levels and geodetic rods graduated in half-centimeters. Second Order, Class II levels were run at all locations.

This routine "surveying-in" of the water level measurement systems ensures that the data can be vertically referenced and monitored with respect to the land. This connection is "monumented" via the local bench mark networks. The bench mark networks are used to monitor vertical stability of the station platforms and provide the reference datum control points from which surveyors can demarcate vertical datums on the land. In addition, where it feasible, connections to the National Geodetic Spatial Reference System (NGSRS) are made. This allows ties between the tide and water level datums established at each station to be referenced to either National Geodetic Vertical Datum (NGVD) or the new North American Vertical Datum (NAVD88), which are fixed referenced datums adopted as standard geodetic datums for elevation. The feasibility of the connection depends on the closeness of the NGRS bench mark lines to the local water level station bench marks. In addition, CBI has occupied bench marks at some stations with GPS to establish a regional geodetic reference datum specifically for TCOON.

In terms of major station disruption, the station at Rincon del San Jose was severely damaged in 1990 by a barge collision and had to be reinstalled. The station at El Toro has been a consistently bad "data collector" for a variety of reasons and the time series is not as continuous as for the other secondary stations.

# IV. DATA PROCESSING AND DATA QUALITY ASSURANCE

## General

Data processing and production of standard output products were accomplished using general guidelines documented in standard operating procedures (SOP's) (NOS, 1987) and in data quality assurance plans.

Data from the ADR and Bubbler gauges were mailed to NOS on a monthly basis by the local tide observers. Data from the NGWLMS gauges were received automatically by the NGWLMS Data Processing and Analysis System (DPAS) on at least a daily basis through the GOES satellite link. The initial handling of the data varied depending on the type of gauge.

The monthly ADR and bubbler rolls require manual handling during the pre-translation and translation stages of processing. The pre-translation procedures include a preliminary evaluation of data quality using a visual scan and the completion of a comparative reading by a data analyst for each monthly record. The comparative reading uses the tide observer's staff readings and the simultaneous gauge readings to establish a statistical staff-to-gauge relationship or setting that is applied to the time series before tabulation. This transfer of gauge readings to the staff results in the tabulated heights being referenced to a tide staff '0'. Because tide staffs are periodically replaced, levels from the tide staffs to the local bench marks result in the data being referenced to a common station datum for the entire time series. A descriptive review of the manual data handling and data tabulation procedures from which the present automated procedures were developed is found in The Manual of Tide Observations (Coast and Geodetic Survey, 1965).

Data translation is the transfer of ADR punched-paper-tape six-minute data onto magnetic tape using an optical reader and loaded onto the tides processing mini-computer system (CCC3230) for processing and analysis using Automated Tidal Data Processing System (ATDPS) software. A limited amount of data editing is done during the comparative reading and data translation process (e.g. interpolation of small gaps). For the bubbler data, six-minute interval data are not digitized. Using a specialized digitizing table and software, the hourly heights and times and heights of high and low waters are manually digitized off of the strip chart using a cursor and transferred onto a personal computer file. The files are reformatted and loaded onto the mini-computer for completion of the processing using ATDPS.

The NGWLMS DPAS is not yet fully implemented. All standard output products and accepted data series are produced on the CCC3230 using ATDPS. Tabulation and datum computation algorithms, for instance, are not yet operational on DPAS. The 6-minute data from NGWLMS DCP's are accumulated on DPAS during the month. During the first week of every month, the six-minute elevation data for each NGWLMS station are first converted from metric to English units, reformatted, and loaded from DPAS onto the CCC3230. The NGWLMS data and ADR/Bubbler data are then processed using the same procedures and algorithms on the same computer system. NGWLMS data do not require the manual pre-translation preliminary evaluation and comparative reading steps that the ADR/Bubbler data require. The ATDPS is a set of interactive software routines that the data analysts use to produce the monthly tabulated output products of hourly heights, times and heights of high and low waters, monthly mean values of various parameters, and monthly extreme tides. An example of a typical monthly tabulation for a north-south transect of Laguna Madre stations for October 1993 is found in Appendix II.

The ATDPS provides for the editing and break-filling of the six-minute data, the hourly heights, the high and low waters, and the monthly means, as required. The analysts use a combination of computer program diagnostics and knowledge of tidal characteristics and gauge operation to make decisions on editing data. Graphical comparisons with predicted tides and with time series from nearby stations are used to identify and deal with anomalous situations.

The monthly means produced in the tabulation process are used in the tidal datum computation procedures. The ATDPS is designed to allow for the tabulation of the tidal signal from the input six-minute interval data. For tide stations exhibiting moderate to strong tidal signal with continuous six-minute data, the ATDPS produces monthly output products in a highly automated fashion. For stations exhibiting low signal-to-noise ratios, such as those found in Laguna Madre, use of the ATDPS is manually intensive.

The particular computer algorithm used by NOS to tabulate the high and low waters from the 6-minute interval data fits a third degree polynomial to an interval of data near the maxima and minima using the method of least squares. The first derivative of the polynomial is set to zero to find the time of the extreme and the height of the extreme is found by substituting the time value into the polynomial. Potential extremes are found using a moving window search for significant rises and fall in the record. The algorithm includes enforced rules which, if not met, result in diagnostics being output for analyst review. The rules are enforced to tune the algorithm for tabulation of the tide expected from a continuous 6-minute record and include curve fit test failure criteria, the alternating tide rule (i.e., tides must alternate from high to low to high, etc..), a 0.10 foot rule (adjacent high/low waters must be at least 0.10 foot different in height to be counted), and a 2.0 hour rule (adjacent high low waters must be at least 2.0 hours apart in time to be counted). The algorithm is designed to filter through the high frequency noise to produce the tabulation and is highly automatic and successful at stations with regularly reoccurring tidal signals. The higher high and lower low waters each day are determined from the high and low water tabulations from a second algorithm which is designed to expect at least one higher high water and one lower low water within a 25-hour period.

The computer algorithms and SOP's are operationally integrated such that they are extensions of the manual procedures that have been used by NOS to tabulate the tide from older technology analog records. Algorithms and ADP procedures have been designed to provide for data and datum continuity over the historical time series. The manual procedures were used for over a century until the implementation of digital gauges and computers in the mid-1960's. The SOP's are designed to provide as consistent and repeatable results as possible.

The SOP's and data quality assurance programs integrate several manual review and verification steps in the operations. The monthly pre-translation preliminary evaluations and comparative readings are verified by senior oceanographers prior to translating the ADR/Bubbler data. The monthly tabulations produced by the analysts, including break-fills and edits, are completely verified by senior oceanographers on a monthly basis prior to acceptance of the data. On a yearly basis, year-end reviews are performed for the previous calendar year of data for each station. These reviews, which look at the data in the context of nearby stations over a longer time period than the monthly processing time step, are completed by oceanographers other than the analyst assigned to the monthly processing for that station. Lastly, the data are summarized and accepted by oceanographers in a independent of the personnel responsible for collecting the data and for the processing and analysis of the data. During this yearly summarization, the output products and raw data are reviewed along with the annual leveling information at each station over several years. In this manner, the vertical stability of the local bench mark network and the gauge platform over time and the continuity of the vertical reference of the data are checked. Any datum or output products prepared from data that have not gone through this last independent summarization process are considered preliminary.

## Laguna Madre

The NOS procedures and algorithms for tabulating the tide are highly successful at Bob Hall Pier, Rockport, Packery Channel, and Port Isabel. Good, consistent, results are obtained with a minimum of manual intervention. Port Isabel occasionally requires manual intervention because of curve fit failures due to high frequency seiche in the harbor, however the tidal signal is strong and high and low waters can easily be selected.

The NOS procedures and algorithms for tabulating the tide are highly unsuccessful at Yarborough Pass, El Toro, Rincon del San Jose, and Port Mansfield. The tabulation algorithm for a typical month of record produces several lines of diagnostics which indicate curve fit failures or discontinuities in the high and low waters selected because the algorithm is having a difficult time in automatically determining high and low waters from the time series (see attachment III). Each one of these diagnostics must be reviewed and acted upon by the oceanographer. Using visual reviews of the data, the oceanographer attempts to manually tabulate the tide where the algorithm fails. In many cases, the signal is so complex that even the algorithm diagnostic routine fails, thus requiring analyst manual review of all computer selections, whether accompanied by a diagnostic or not. In other cases, the algorithm fails to select obvious tidal extremes that must be manually filled in. Frequent low frequency masking of the tidal signal and the presence of high frequency noise in the record make manual or automated tabulation of the tide difficult. Due to the subjective nature of this process from data with such a low signal-to-noise ratio, the accuracy and repeatability of the completed tabulations cannot be assured.

A comparison of the monthly tabulations in Appendix II show that the tides are not tabulated at various times during the month at the central Laguna Madre stations due to the low amplitude tidal signal and masking by non-tidal effects. These same tides are tabulated for the other outside stations and at Rockport and Packery Channel. The unequal number of tides that are used in the computation of monthly means also lead to invalid comparisons of monthly means among stations because the means themselves are based on an unequal number of high and low waters. In addition, when gaps in data occur, traditional methods for filling breaks in high/low waters and hourly heights fail because there is not the required correlation with the closest stations at daily mean sea level and tidal frequencies. Thus, breaks less than three days, which are typically filled in regions with significant tidal signals, remain unfilled for the stations in central Laguna Madre. For purposes of the spectral analyses and harmonic analyses in this report which require continuous data, small gaps in hourly heights were inferred with estimated sea level values at some of the stations. The analyses were typically run on a year of hourly heights, and inferring a few short gaps representing a small percentage of the total time series has no significant effect on the results.

## V. GENERAL TIDAL CHARACTERISTICS

The tidal characteristics of the Gulf of Mexico are complex and varied and are not typical of much of the U.S. coastal zone (Zetler and Hansen, 1970). Practical descriptions and impacts of the tidal characteristics of the Gulf of Mexico are found in National Ocean Survey (1977), Hicks (1980) and NOS (1983). The tides along the Texas coast are dominated by diurnal tides (one high and one low water per day) although semidiurnal tides (two high waters and two low waters per day) are present during the monthly passes of the moon over the equator. The interplay of the diurnal and semidiurnal tides varies slowly from north to south resulting in different tidal characteristics. The tidal characteristics of Laguna Madre have been discussed previously by NOS (1983), but limited mainly to the southern region, south of Port Mansfield. The earlier publication by Marmer (1950) provided the first tidal study of the entire region and more importantly addressed the tidal/nontidal issue. Hicks (1989) provides a detailed definition of terms used in this report.

Laguna Madre is the largest of the Texas estuaries, extending in an arc 130 miles long and from three to five miles wide from Corpus Christi, southwest to the Rio Grande. The Lagoon has shallow depths generally less than 10 feet, with most areas one foot to five feet in depth. Extensive shoals, mud/sand flats and dredge spoil banks exist throughout the Lagoon. The Intracoastal Waterway runs the length of Laguna Madre at an average depth of 12 feet. Southern Laguna Madre is connected with the Gulf of Mexico through two dredged channels. The largest connection is at Brazos Santiago Pass, which has a 300-foot wide entrance channel maintained at a depth of 36 feet below MLLW. The secondary connection is found at the Port Mansfield Channel, which has a 250-foot wide entrance channel that is maintained to a depth of 13 feet below MLLW. Northern Laguna Madre is connected indirectly to the Gulf of Mexico through channels cut through the John F. Kennedy Causeway into Corpus Christi Bay. The entrance to Corpus Christi Bay to the south and Aransas Bay to the north from the Gulf of Mexico is Aransas Pass, for which the entrance channel is 600 feet wide and maintained at 47 feet below MLLW.

Thus any tidal characteristics of Laguna Madre are the culmination of the tidal characteristics at these entrances and the modification of the Gulf tide as it progresses through the constrictions of the entrances, by the effects of the configuration of the inner bays, and lastly by the shallow waters and configuration of Laguna Madre proper. The effects of wind speed and direction and barometric pressure are also accumulated into the observed water level along with the tide at each step in the progression. The final observed water level variations in Laguna Madre are due to a combination of local and far-field effects, both meteorological and tidal.

The tidal characteristics can be quantified by analyzing the longer term data sets available from the stations in Table I. The Gulf tide entering Aransas Pass is characterized by the observations at Bob Hall Pier, where the Great Diurnal Range of Tide (Gt) is 1.7 feet. After entering through Aransas Pass, the tide has a GT near 1.0 foot in Corpus Christi Bay. To the north at Rockport, the Gt is 0.4 foot. In southern Laguna Madre, the tide after entering Brazos Santiago Pass has a Gt of 1.4 feet as observed at Port Isabel. The Gt diurnal range decreases to approximately 0.3 foot by the time it progresses north to Port Mansfield. Figures 2 and 3 are comparisons plots of spectral analyses for the station pairs of Bob Hall Pier and Rockport and Port Isabel and Port Mansfield. Each of the analyses are derived from three continuous years of hourly heights, although they are not simultaneous.

The relative levels of energy are plotted by frequency. For instance, the spectral plot for Bob Hall Pier shows discrete peaks at 1 and 2 cycles per day (cpd), the diurnal and semidiurnal tide producing frequencies, with lesser peaks at 3 and 4 cpd, the shallow water overtide frequencies. The plot also is featured by significant energy at the lower frequencies (<0.50 cpd) that are equal in magnitude to the diurnal and semidiurnal peaks. Although the lower frequencies contain some energy due to yearly and monthly tidal forcing, most of the energy is due to seasonal and monthly patterns in the meteorological forcing. Rockport also shows significant energy peaks at 1, 2, 3 ,and 4 cpd, however, their magnitudes are all lower than the energy levels found at the low frequencies (<0.5 cpd). Indeed, observations show a much reduced Gt range at Rockport, with increased effects on the water levels due to weather, than the observations outside at Bob Hall Pier.

Figure 3 shows that the spectral differences between Port Isabel and Port Mansfield are even more striking. The spectral plot for Port Isabel is similar to that for Bob Hall Pier, while the spectral plot for Port Mansfield shows even less energy at 1 and 2 cpd than Rockport. Not only are the energy peaks weak at 1 and 2 cpd, but they are far below the energy levels of the lower frequencies. This also confirms the observations, which show a very small range of tide with significant water level variations due to long term and short term weather effects.

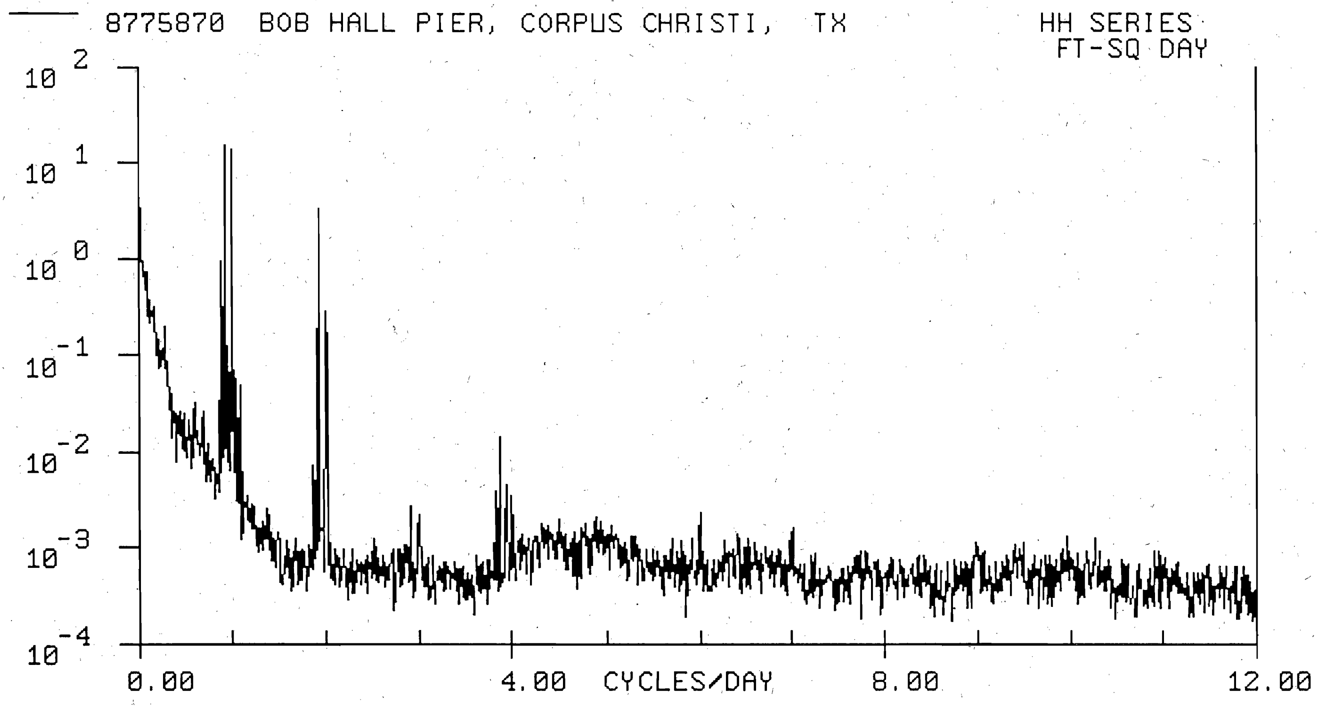
To further quantify these characteristics, comparisons of the results from a sequence of 365-day least-squares harmonic analyses (Zetler, 1982) over periods of several years have been analyzed and the results are summarized in figures 4 through 7 for the same stations pairs as above. The NOS least-squares program (LSQHA) uses one-year of hourly heights as input, and produces amplitudes and phases for a set of 37 harmonic constituents along with a reduction of variance analysis which provides information on the total reduction of variance and the amount of variance due to each individual constituent. Appendix IV is an example harmonic analysis output for Port Isabel, Texas. Each harmonic constituent represents a component of the interaction of the earth-moon-sun system (Hydrographer of the Navy, U.K., 1969) and the amplitudes and phases of each harmonic constituent are referred to as harmonic constants. Given no major changes in sea level or topography, the amplitudes and phases for the major constituents should remain fairly constant from year to year.

The X-axis for figures 4 through 7 are arranged by frequency, with the lower frequency constituents (e.g. Sa and Ssa on the left side, through the diurnal constituents (1 cpd) (e.g. K1 and O1), to the semidiurnal (2 cpd) constituents (e.g. M2 and S2) on the right. The amplitudes of the lower frequency constituents are typically more variable from year to year than the diurnal and semidiurnal constituents, especially at the monthly periods (Msf, Mm, and Mf). At Bob Hall Pier, the amplitudes and phases of all the semidiurnal and diurnal constituents are consistent from year to year. At Rockport (figures 4 and 5), which has less of a tidal signal, the amplitudes are fairly consistent, however the phases are consistent from year to year only for the constituents with the largest amplitudes (e.g. S1, K1 and O1). These plots corroborate the spectral analysis results from figure 3, with the amplitudes of the diurnal and semidiurnal constituents at Bob Hall Pier equal to or greater than the amplitude of the low frequency constituents. At Rockport, the amplitude of the diurnal and semidiurnal constituents are much less than the amplitude of the low frequency constituents. The comparison between Port Isabel and Port Mansfield (figures 6 and 7) is very similar, except that the amplitudes and phases of the constituents are even more variable from year to year than at Rockport. At Rockport, the semidiurnal tide is almost completely damped compared to outside tides and completely damped at Port Mansfield. This results in a extremely weak tidal signal at Rockport and Port Mansfield during time periods of equatorial tides. The diurnal range of tides varies during each month with maximum ranges during the northern and southern maximum declinations of the moon (tropic tides) at which the K1 and O1 diurnal constituents are in phase, to minimum diurnal ranges when the moon is over the equator (K1 and O1 out of phase).

The tidal characteristics shown in the spectral analyses and harmonic analyses are critical to the ability to predict the tide at each location. For a traditional NOS tidal prediction, the amplitudes and phases of the component harmonic constituents are added together in the desired time frame and a composite predicted tide curve is derived. The reliability of any tide prediction in terms of predicting the times and heights of the high and low waters is directly related to the consistency of the amplitudes and phases of the harmonic constituents over time, and their relative contributions to the total variance in the observed time series.

Figures 8 and 9 summarize the results from averaging the reduction of variance statistics over several years of LSQHA runs. The differences between the reduction of variance characteristics outside and inside the bays is readily apparent. The average total reduction of variance and the individual reduction of variance curves are very similar for Bob Hall Pier and Port Isabel, with the lowest frequencies Ssa and Sa contributing significant percentages but not as much as the diurnal tidal frequencies of K1 and O1. The semidiurnal constituent of M2 also contributes a noticeable amount. The total reduction of variance statistics show that from 72 to 76 percent of the total variance in a typical year of hourly heights can be attributed to the constituents plotted. The other 25 percent is due to other non-tidal forcing and meteorological effects not found at the listed frequencies. In reality, because variance attributed to the Ssa, Sa, Mm, Msf, and Mf constituents are not primarily due to tide producing forces, but to the weekly, monthly, and seasonal sea level variations due to meteorological forcing, only about 60 percent of the variance is explained by tidal forcing.

At Rockport and at Port Mansfield, the cumulative reduction of variance percentages (52.4% at Rockport and 53.8% at Port Mansfield) are dominated by the contribution of the low frequency components. These results are consistent with the results shown from the amplitude and phase comparisons and the spectral analyses results and provide clearer evidence of the decreasing tidal signal progressing from the Gulf, and increasing dominance in the water level variations by non-tidal short-term and long term meteorological forcing. The diurnal and semidiurnal constituents account for less than 5 percent of the total at Rockport and less than 2 percent at Port Mansfield. The total reduction of variance from a LSQHA for areas of the globe dominated by the tide is typically near 90 percent for areas such as Gulf of Maine, Gulf of Alaska, and open ocean islands. The results reported here for Port Mansfield and Port Isabel are consistent with those found by Zetler (1980).



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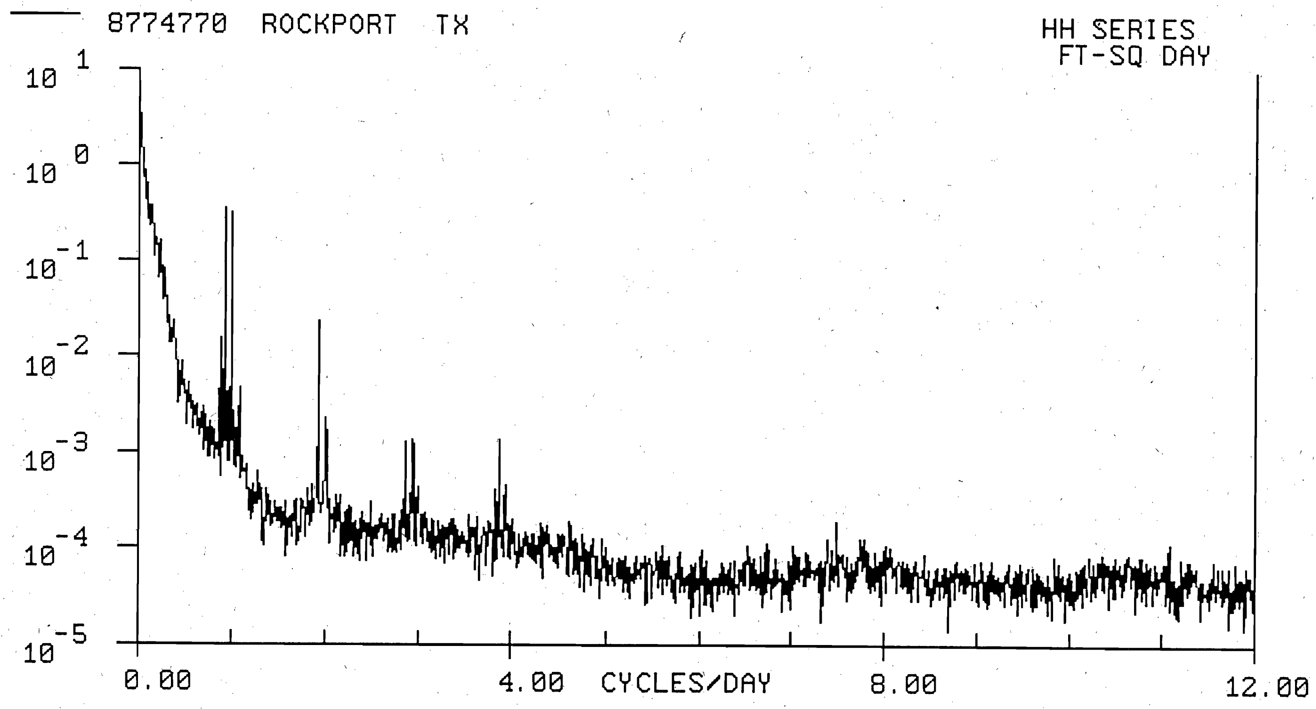

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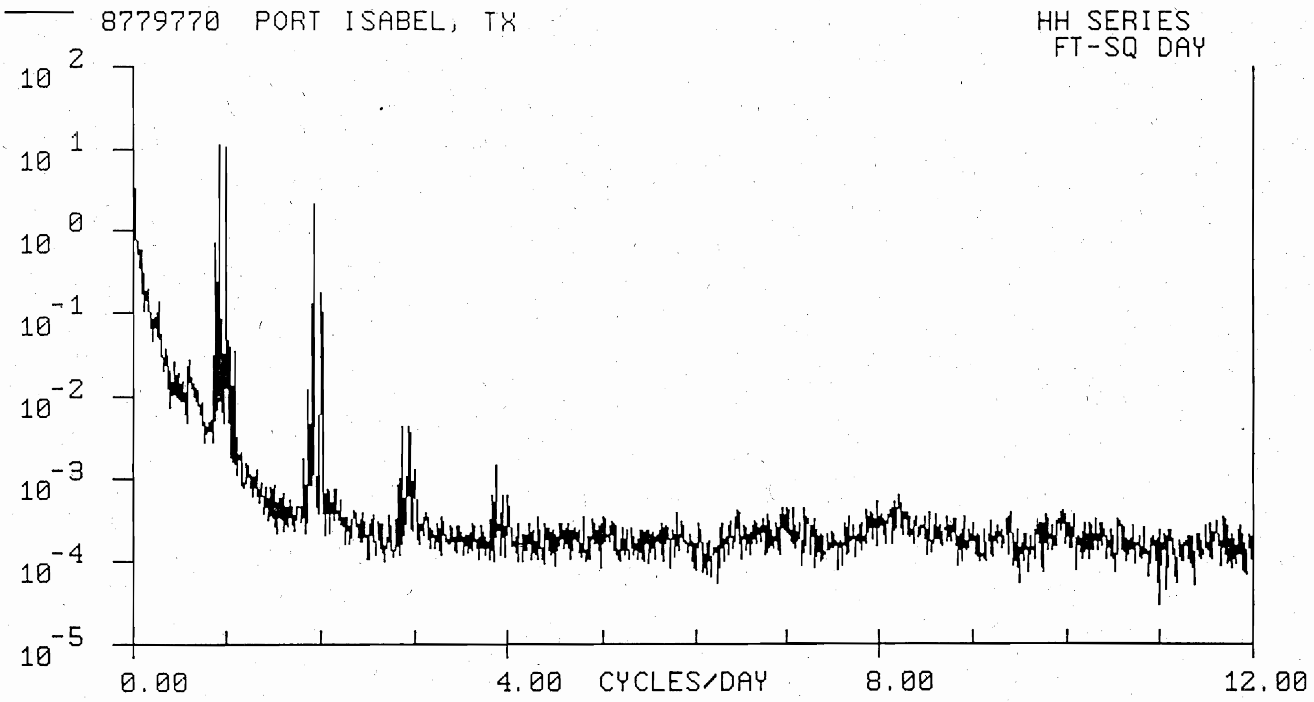
FIGURE 2. Spectral Analysis Plots - 3-year Period - Bob Hall Pier and Rockport



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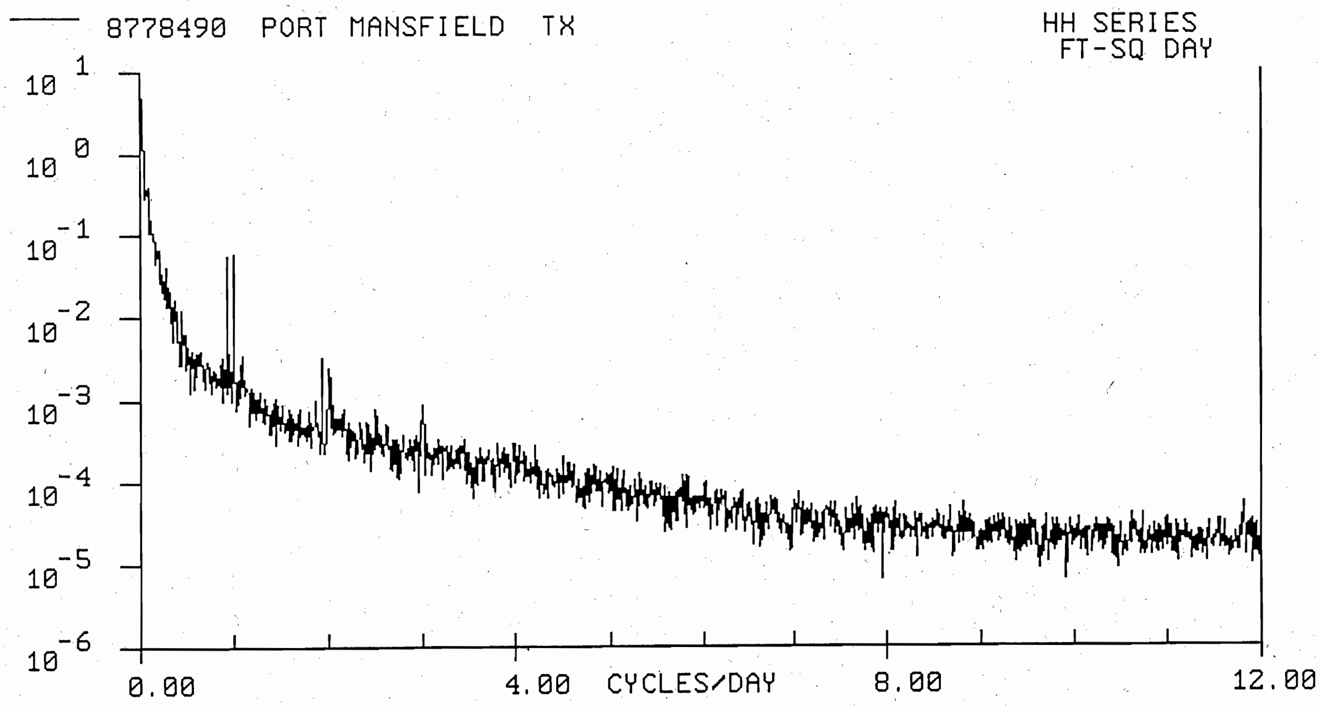

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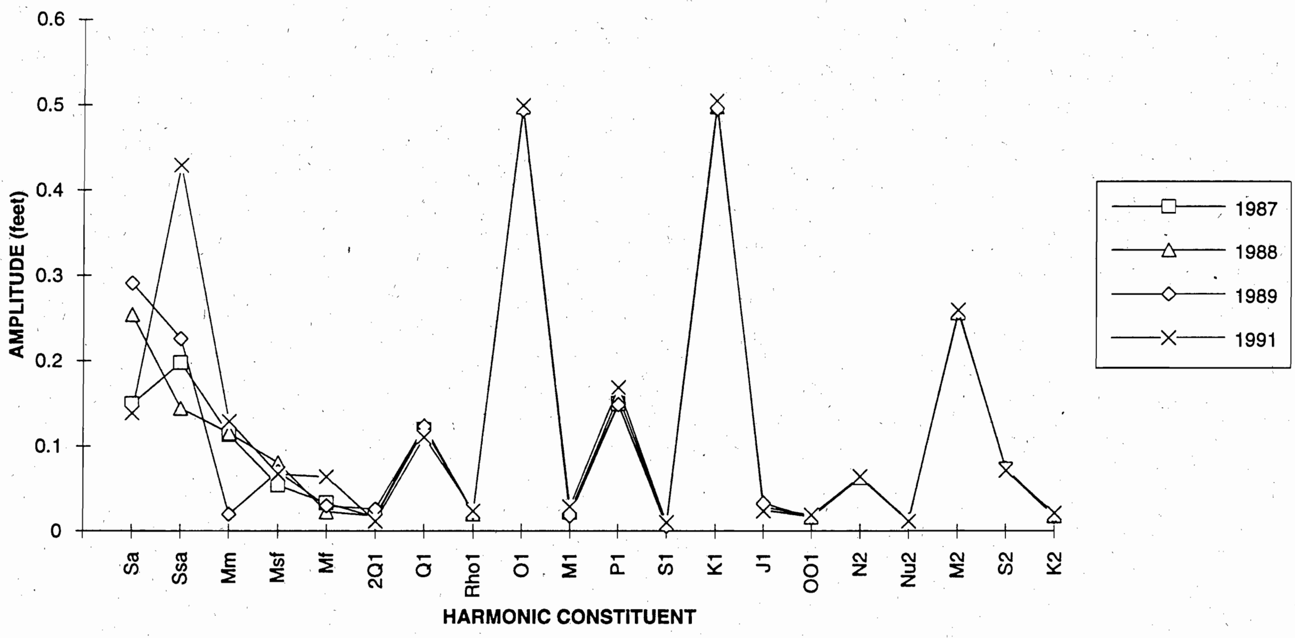
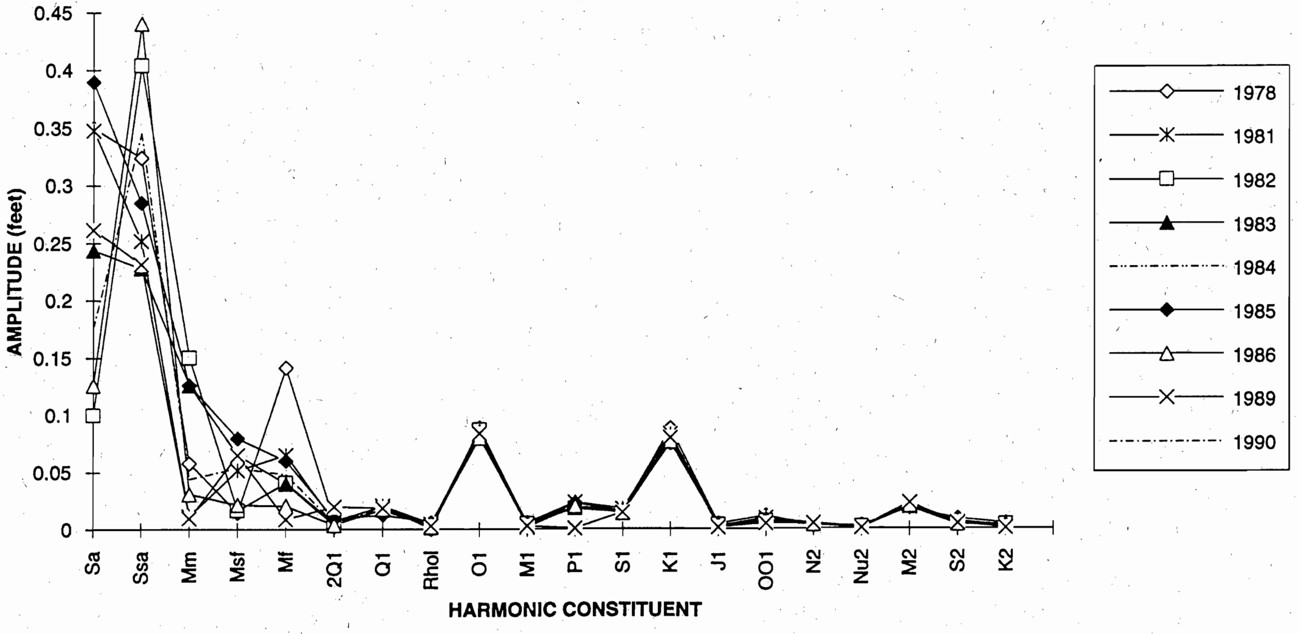
FIGURE 3. Spectral Analysis Plots - 3-year Period - Port Isabel and Port Mansfield



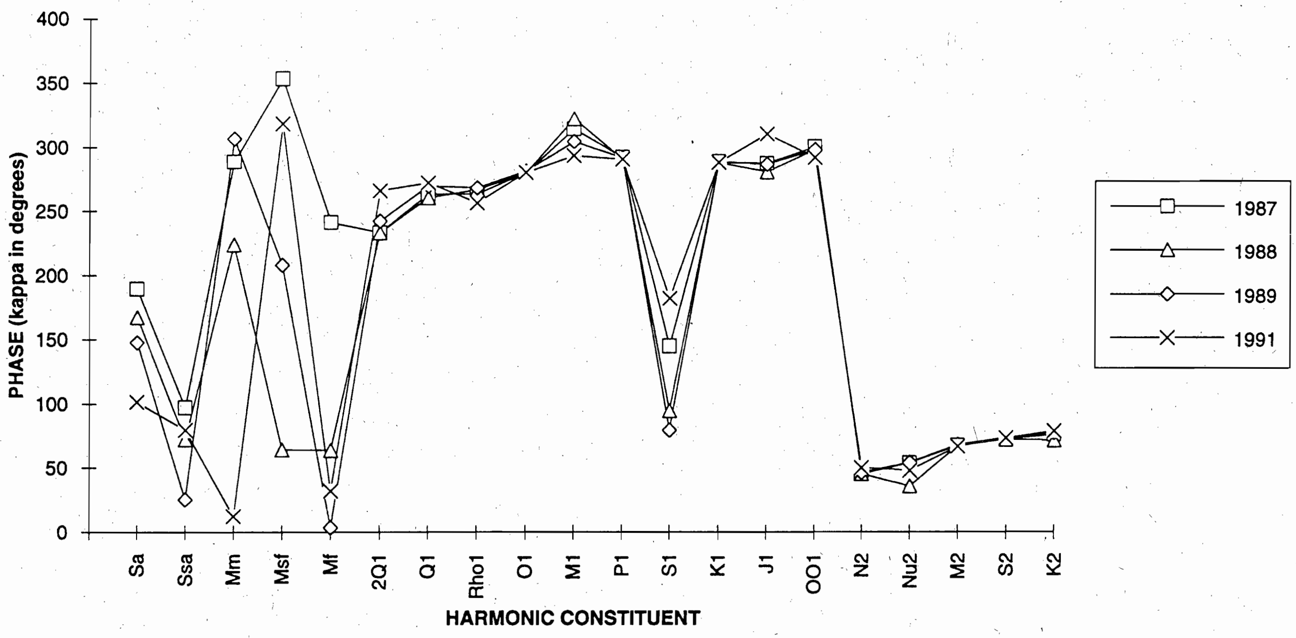
BOB HALL PIER, TEXAS - VARIATION IN AMPLITUDES OF HARMONIC CONSTITUENTS - 1987 THROUGH 1991



ROCKPORT, TEXAS - VARIATION IN AMPLITUDES OF HARMONIC CONSTITUENTS - 1978 THROUGH 1989

FIGURE 4. Variation in Amplitudes of Harmonic Constituents - Bob Hall Pier and Rockport

BOB HALL PIER, TEXAS - VARIATION IN PHASE (KAPPA) OF HARMONIC CONSTITUENTS - 1987 THROUGH 1991



ROCKPORT TEXAS - VARIATION IN PHASES OF HARMONIC CONSTITUENTS - 1978 THROUGH 1990

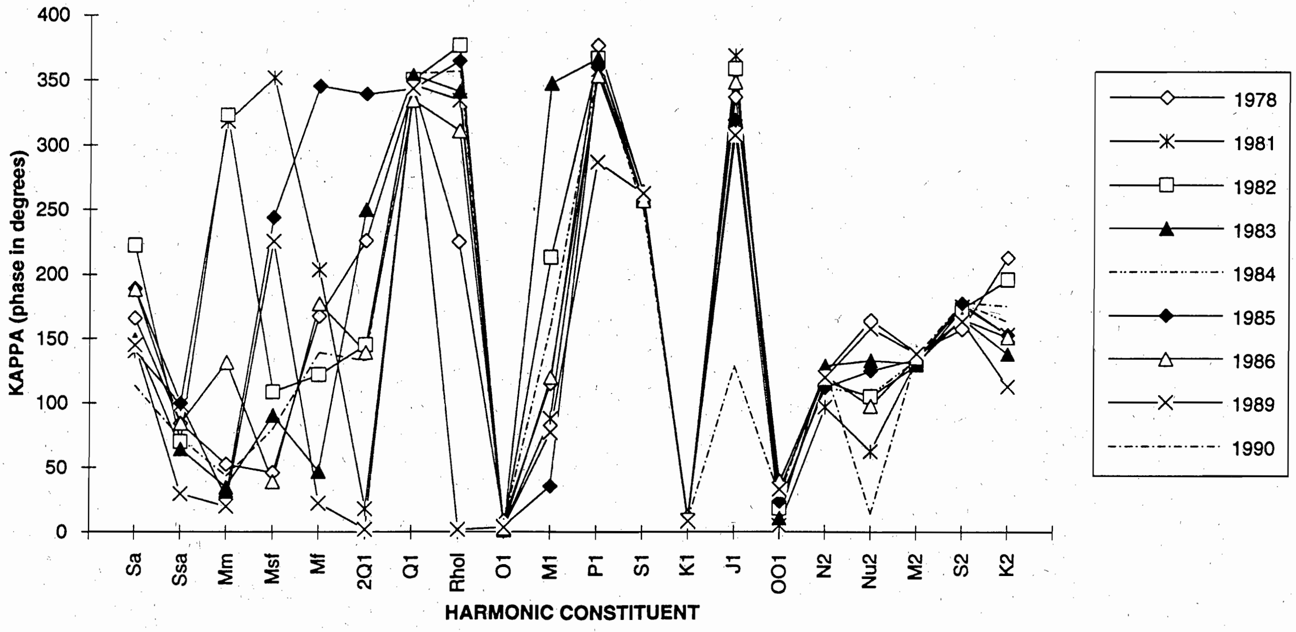
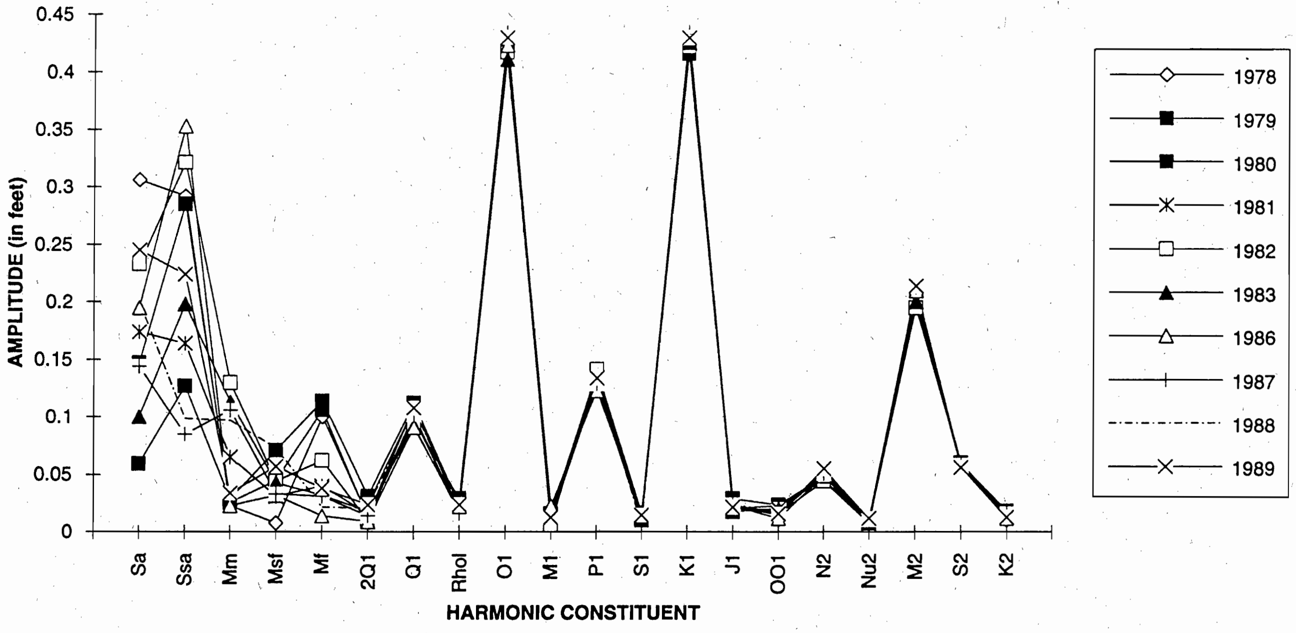


FIGURE 5. Variation in Phase (Kappa) of Harmonic Constituents - Bob Hall Pier and Rockport

PORT ISABEL TEXAS - VARIATION IN AMPLITUDES OF HARMONIC CONSTITUENTS - 1978 THROUGH 1989



PORT MANSFIELD TEXAS - VARIATION IN AMPLITUDES OF HARMONIC CONSTITUENTS - 1978 THROUGH 1989

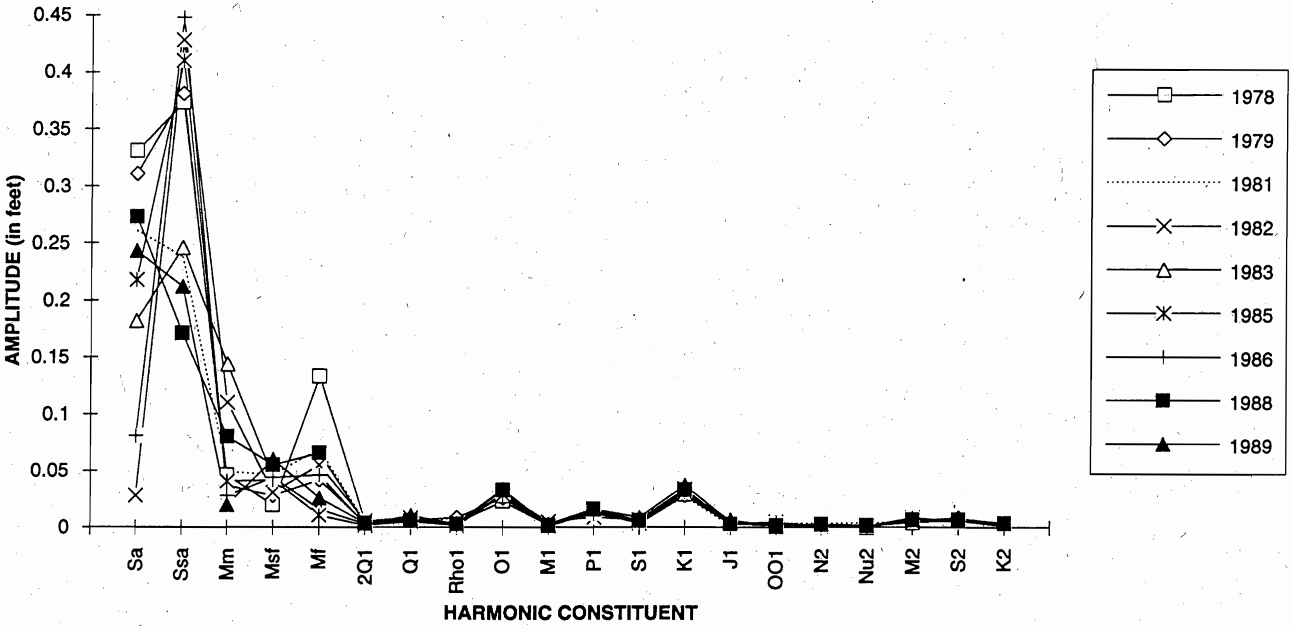
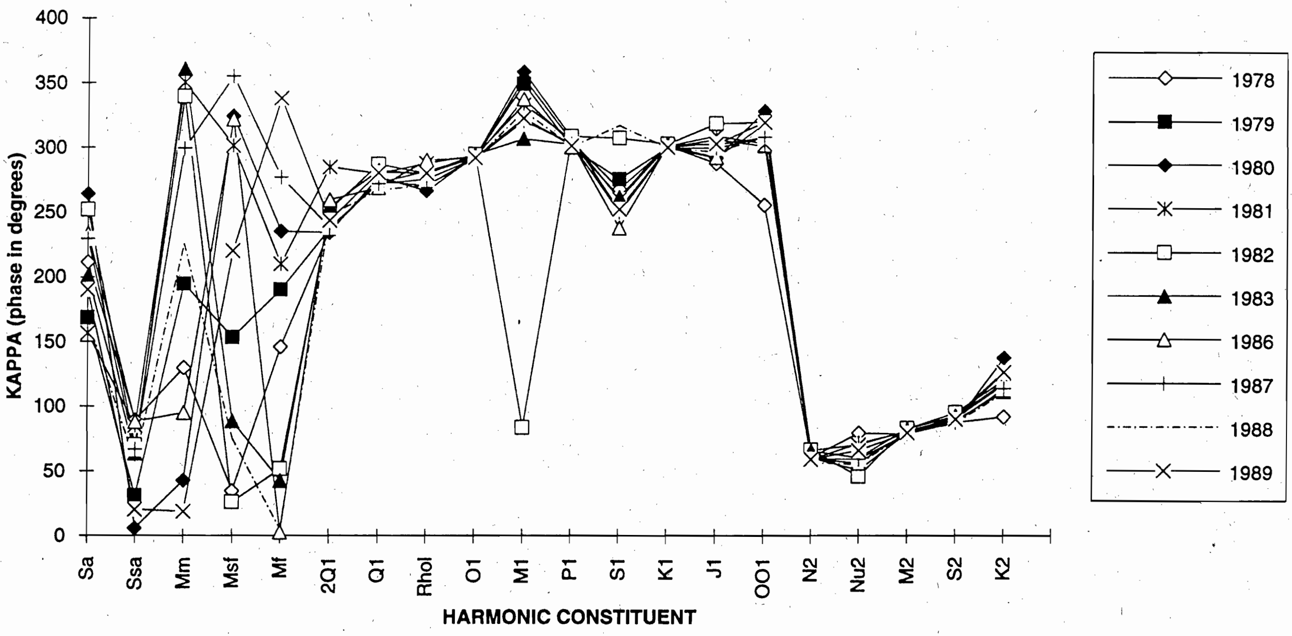


FIGURE 6. Variation in Amplitudes of Harmonic Constituents - Port Isabel and Port Mansfield

PORT ISABEL TEXAS - VARIATION IN PHASES OF HARMONIC CONSTITUENTS - 1978 THROUGH 1989



PORT MANSFIELD TEXAS - VARIATION IN PHASES OF HARMONIC CONSTITUENTS - 1978 THROUGH 1989

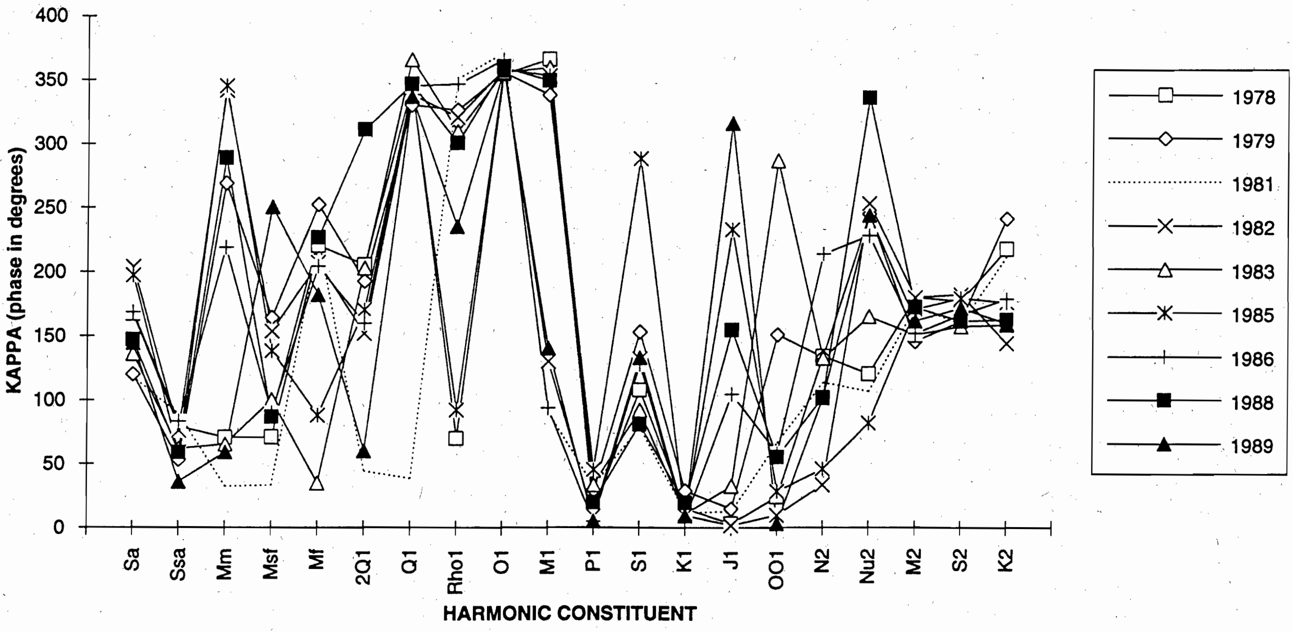
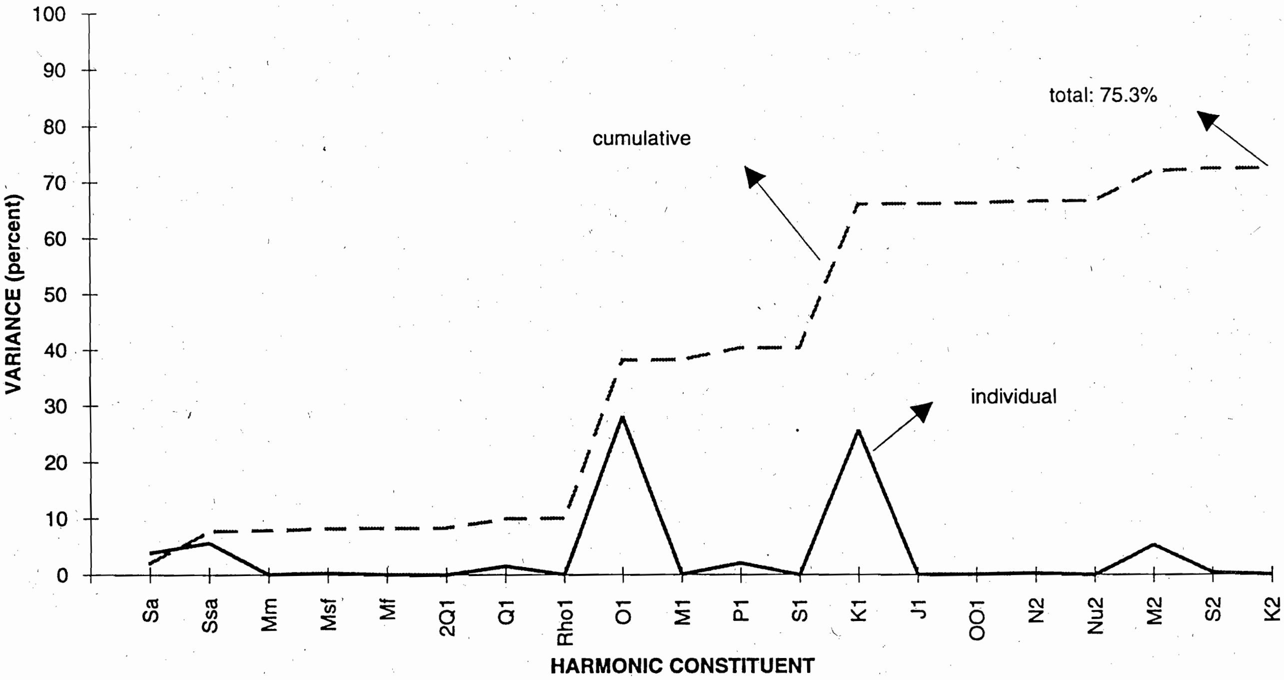


FIGURE 7. Variation in Phases (Kappa) of Harmonic Constituents - Port Isabel and Port Mansfeild

BOB HALL PIER - AVERAGE REDUCTION OF VARIANCE RESULTS FROM FOUR 365-DAY LEAST SQUARES HARMONIC ANALYSES , 1987 THROUGH 1991



ROCKPORT - AVERAGE REDUCTION OF VARIANCE RESULTS FROM NINE 365-DAY LEAST SQUARES HARMONIC ANALYSES, 1989 THROUGH 1990

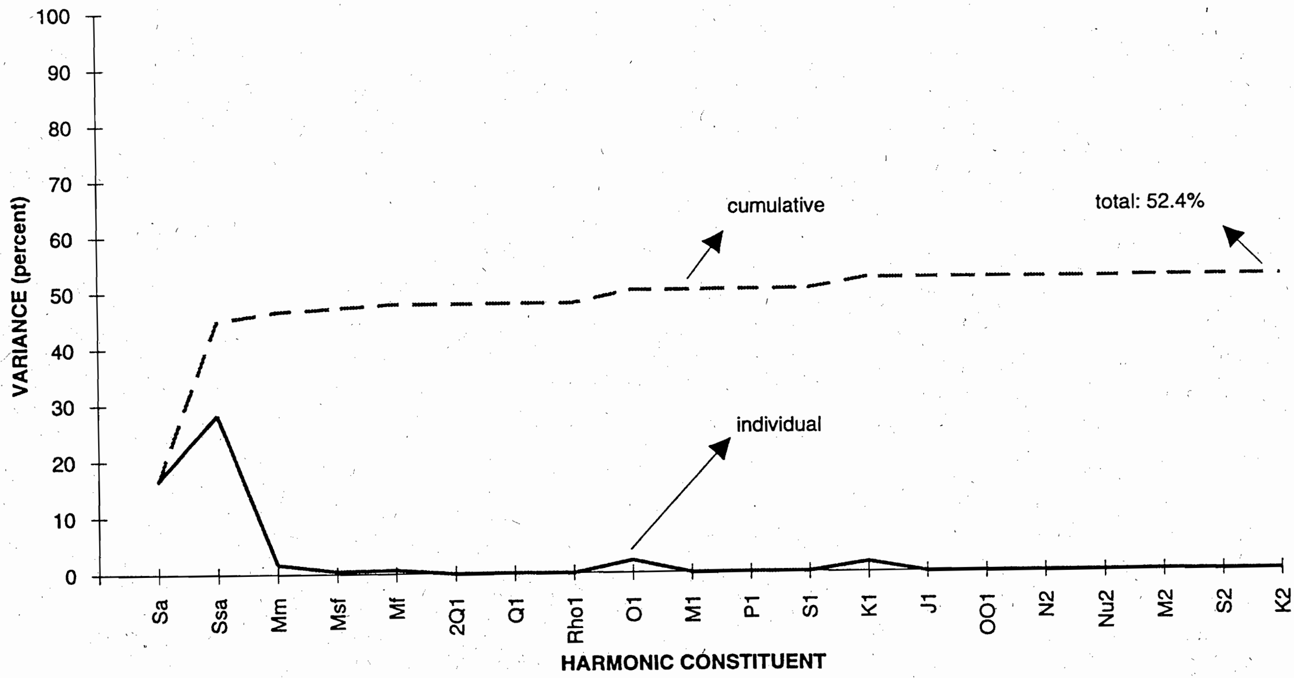
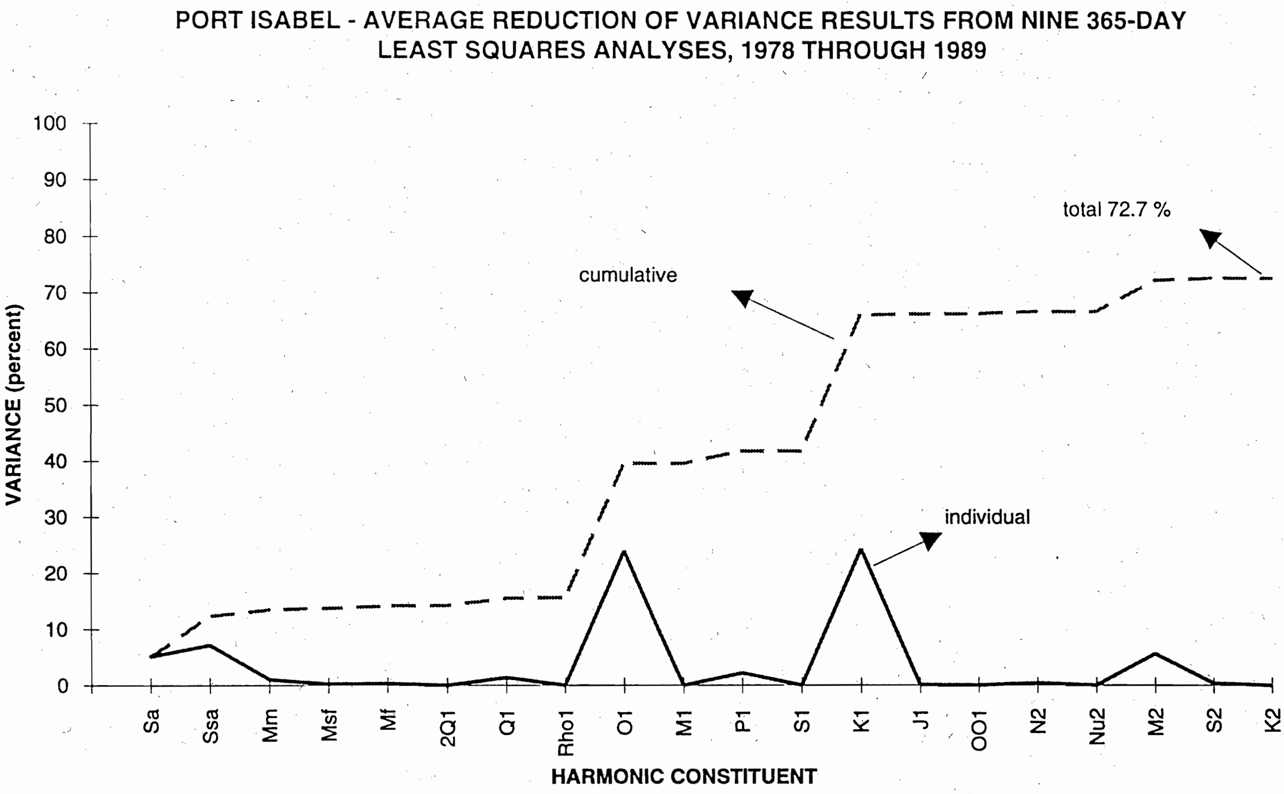


FIGURE 8. Reduction of Variance Results from 365-day Least Squares Harmonic Analyses - Bob Hall Pier and Rockport


PORT ISABEL - AVERAGE REDUCTION OF VARIANCE RESULTS FROM NINE 365-DAY LEAST SQUARES ANALYSES, 1978 THROUGH 1989

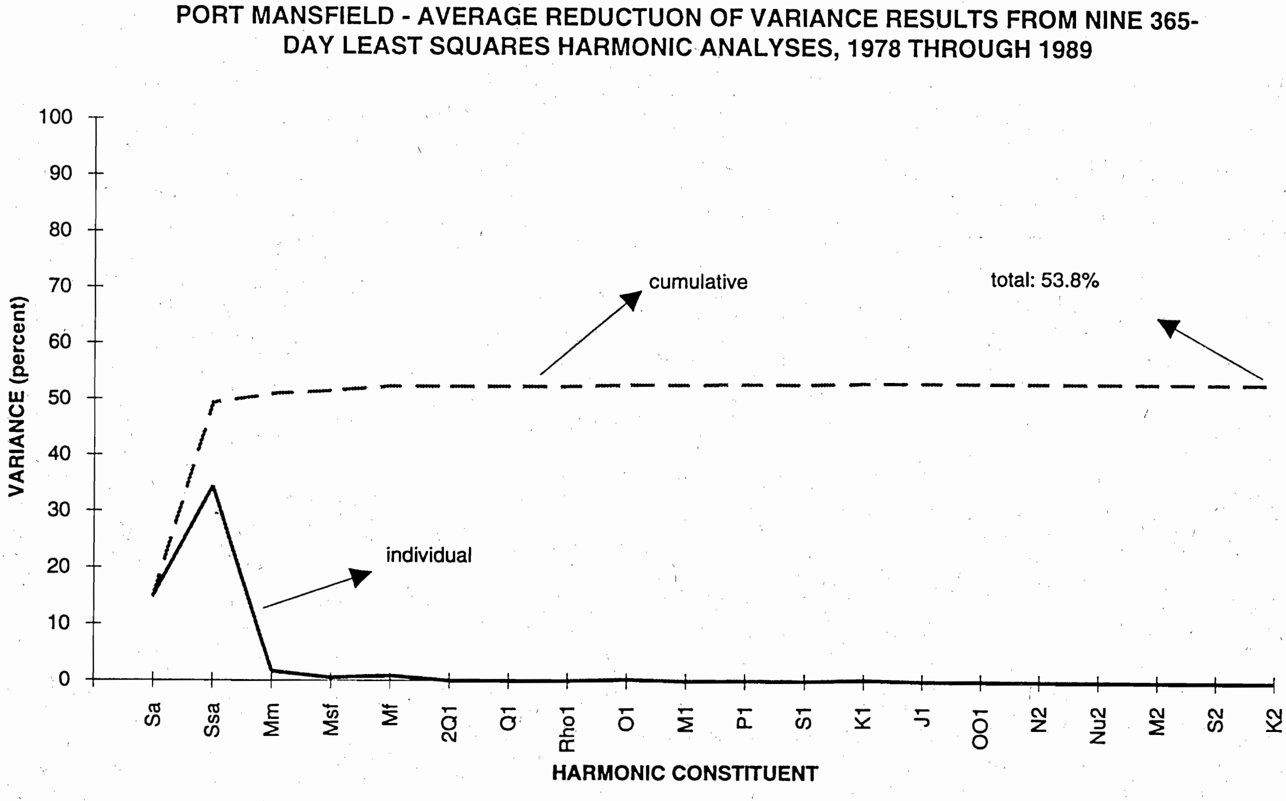

PORT MANSFIELD - AVERAGE REDUCTUON OF VARIANCE RESULTS FROM NINE 365-DAY LEAST SQUARES HARMONIC ANALYSES, 1978 THROUGH 1989

FIGURE 9. Reduction of Variance Results from 365-day Least Squares Harmonic Analyses- Port Isabel and Port Mansfield

# VI. COMPARATIVE ANALYSES: NORTH-SOUTH TRANSECT

Section V. describes the general characteristics of the water level variations, including the tide, progressing from the Gulf of Mexico into Laguna Madre. This section provides detailed information on water level variations within Laguna Madre using simultaneous data from stations along a north-south transect described by the stations in Tables I and II.

## Monthly Mean Sea Levels

Figure 10 is a plot of the simultaneous monthly mean sea level values over a three year period for the entire transect. Although there are many gaps in some of the time series, the high visual correlation among the stations is clear. The variations in monthly mean sea levels are due to large scale seasonal meteorological patterns and the yearly and semi-yearly variations are estimated by the harmonic constituents Sa, and Ssa in a harmonic analysis. The variations show variability from year-to-year, however, maximum monthly mean sea levels tend to occur in March through May and again September through November. The range of the monthly values within a particular year are from 0.5 to 1.0 foot.

## Daily Mean Sea Levels

Daily mean sea level values computed by averaging 25 hours of hourly heights starting each calendar day can be used to look at the daily variations in sea level. Figure 11 is a plot of the simultaneous plot of the daily mean sea level values for the month of September 1993 as an example. Variations in daily mean sea level represent the effects of meteorological forcing during the normal passage of fronts, storms, high pressures, etc.. Each of the stations show a general trend in daily mean sea level during the month, however there are no other obvious visual correlations among all of the stations. Daily variations in mean sea level are typically only a few tenths of a foot, except during discrete events. The most noticeable event is from September 12 through 15, during which time the daily mean sea level variations between Yarborough and Rincon del San Jose are the opposite of each other. A similar, but lesser, effect is seen on September 25 through 28. Clues to this behavior can be obtained from the wind speed and direction data obtained from El Toro during this time period (figure 12). Although there is a gap in data on September 13, it appears that from the 12'th to the 14'th, there is a break in the normal diurnal pattern with sustained winds from one direction, although at relatively low speed. On September 27'th, there is a abrupt change due to a frontal passage, with a change in wind speed and direction. During September, the wind speed and direction have an extremely strong diurnal periodicity. These examples show that periodic local forcing due to the wind is a significant, and frequently dominating, factor in forcing daily water level variations in central Laguna Madre.

The difference in the response to wind events may be due to subtle changes in the topography of Laguna Madre. Although all of Laguna Madre could be considered shallow, NOAA Chart 11306, shows that there are extensive mud flats surrounding El Toro that essentially divide Laguna Madre into a north basin, (Yarborough) and a south basin (Rincon del San Jose), with El Toro in the middle. The gauges at El Toro are able to measure continuous water level variations only because the station is located in the dredged channel of the Intracoastal Water way. It appears that during certain combinations of sea level elevations and wind events, the water levels may become piled up on the south side of the mud flats, while being withdrawn from the northern side.

## Tidal Characteristics

### 1. Time Series Plots

Figure 13 is a simultaneous plot of the 6-minute interval data from the transect for a one-week period in September 1993. During this time period, the tide is in transition from equatorial tides (minimum diurnal range of tide) into tropic tides (maximum diurnal range). This transition is clearly seen for Bob Hall Pier, Port Isabel, Rockport, and Packery Channel, but not at the other stations inside Laguna Madre. During the times when the moon is on the equator, the semidiurnal tides are clearly seen at Port Isabel and at Bob Hall Pier, but not very apparent at any of the other stations.

Figure 13 shows, in a relative sense, a typical example of a time series comparison of the response of Laguna Madre to the input tide at the north and south entrances. Except at Rockport and Packery Channel, the tidal signal is strongly diminished due to frictional effects and the water level variations exhibit response to other local forcing. Figure 14 is a plot for the same time periods, but for stations in central and northern Laguna Madre only. This allows for a higher resolution look at the water level variations than Figure 13 and also includes data obtained from a GLO station at Riviera Beach. Riviera Beach is located at the western end of Baffin Bay which has an entrance to Laguna Madre just north of Yarborough Pass.

Figures 13 and 14 show the out-of-phase water level variations at Yarborough and Rincon from September 3 to 5 that are similar to those found in the daily water levels (figure 11). Port Mansfield exhibits very little variation at all during the time period. Riviera Beach shows a strong diurnal signal, however the variations may not be totally due to the astronomical tide. The El Toro winds for the same week are shown in figure 15. The higher wind speeds on the 3'rd and 4'th may account for the anomalous water levels at Yarborough and Rincon. The high frequency shifts in the wind on the 7'th may account for the higher frequency variations in water levels at the central Laguna Madre stations. The diurnal periodicity of the local winds is highly visible and random looks at the data from El Toro show that this periodicity is present at various levels year around. The response of the water level variations to this diurnal forcing is seen especially at Riviera Beach. The correlation of the east-west winds with water level variations has been investigated in southern Laguna Madre and found to be significant (Porter, 1980).

### 2. Spectral Analyses

Figure 16 is a comparison plot of the spectral analyses run for the one-year simultaneous hourly height time series from September 1992 through August 1993. The vertical and horizontal scales are the same in each spectral plot. These analyses are presented not to discuss high resolution tidal analysis, but to present the general characteristics of the variability of the water levels over a simultaneous one-year period. The comparisons show the transition from outside the Gulf to inside with the spectral energy present at the tidal bands (1 and 2 cpd) decreasing significantly. At the inside stations, the energy peaks of the tidal bands are barely above the background "continuum". The energy present at the low frequency end of the plots dominate the water level variability at the inside stations. The plots illustrate, from a frequency domain vantage point, why the time series plots look as they do and why the tabulation of a tidal signal from the records is so difficult.

### 3. Least Squares Harmonic Analyses

Harmonic analyses and spectral analyses techniques similar to those presented in Section V can be applied to the simultaneous data from the north-south transect. Figure 17 is a transect plot of the reduction of variance results for a set of simultaneous LSQHA's at each station; August 1992 through July 1993. For this time period, the total reduction of variance is approximately 70 percent for Bob Hall Pier and Port Isabel and decrease to between 30 and

40 percent for all "inside" stations. Only the 10 most significant constituents are plotted. The diurnal constituents K1 and O1 are the most significant contributors at Bob Hall Pier and Port Isabel and the third and fourth most significant at Rockport and Packery Channel. The long period semi-annual constituent Ssa is the most significant contributor and the annual constituent is the second most significant contributor at all of the inside stations and typically accounts for most of the total reduction of variance statistic.

As mentioned previously, the amplitudes and phases of annual and semiannual constituents do not reflect tidal forcing, but meteorological forcing of the seasonal weather patterns and circulation patterns of the Gulf of Mexico. The contribution of the diurnal and semidiurnal tidal constituents at Yarborough, El Toro, Rincon, and Port Mansfield are only a few percent of the total. Of these tidal constituents, the diurnal constituent S1, which has a period of exactly one day, is the most significant constituent at Yarborough, El Toro, and Rincon, rather than K1 and O1 , which are the largest at the stations with stronger tidal signals.

The reduction of variance results indicate that the amplitudes of the diurnal and semidiurnal constituents from this analysis should be quite low and the amplitudes for the transect shown in figure 18 confirm this. The plots show similar patterns to the reduction of variance plots. At Yarborough, El Toro, and Rincon, the diurnal constituent S1 has the largest amplitude of the tidal constituents (0.05, 0.02, 0.08 foot, respectively). There is no particular reason in terms of tidal theory and tidal hydrodynamics why this constituent should be amplified proceeding into Laguna Madre. However, a plausible reason may be that the periodicity of the diurnal winds shown in figures 12 and 15 in Laguna Madre are largely in phase with the period of this constituent and the constituent is a reflection of the diurnal wind forcing and not the astronomical tide. Further correlation analyses of the wind and the tidal constituents are recommended. The amplitudes of the Ssa and Sa constituents are typically an order of magnitude higher than the amplitude of any of the diurnal constituents.

Figure 19 shows the variation in the phases of the harmonic constituents from the LSQHA's. To reduce the "noise" in this plot if all constituents were plotted together, it is presented in two parts; the upper plot for the low period constituents and lower plot for the tidal constituents. Due to the "wrap around" nature of the phases from 0 degrees through complete cycle of 360 degrees, it is difficult to assess from which direction the tide has progressed into central Laguna Madre. For clarity, the phase scale on the plots are from 0 to 450 degrees and the phases adjusted accordingly to allow for smooth transition for visual purposes. The upper plot shows that, as expected from the time series plots of monthly means, the phases of the

Ssa, Sa, Mm, Msf and Mf constituents are fairly consistent among the transect stations as seen in figure 19. In the lower plot, there appears to be a somewhat consistent pattern in the phases of the diurnal constituents with the phases becoming later as the tide progresses from the inlets into the inner bays. The progression in phase of tide from Bob Hall Pier to Rockport to Packery Channel and from Port Isabel to Port Mansfield is quite clear. The diurnal constituent S1 shows approximately a 150 degree phase shift between the upper and lower basins of Laguna Madre and may reflect the differing responses of the water level in the basins to the diurnal wind forcing.

### 4. 29-day Harmonic Analyses

One method used by NOS to establish the consistency of the tidal signal observed at any location over time is to look at the changes in the amplitudes and phases of the harmonic constituents computed from a succession of 29-day harmonic analyses. NOS uses a standard 29-day harmonic analysis (Dennis and Long, 1971) for time series less than one year in length. Unlike the NOS LSQHA program, which solves for a set of 37 constituents, the 29-hay harmonic analysis (HA29) program solves directly for 10 of the major harmonic constituents and infers the amplitudes and phases for 16 secondary constituents using relationships from equilibrium theory. The long period annual and monthly constituents are not considered.

Figures 20 and 21 show the comparisons of 12 consecutive harmonic analyses for each of the stations. Stations with regularly recurring tidal signals over time should show very little variability in the amplitudes and phases of the tidal constituents from month to month. The closeness of the amplitudes and phases from month to month for the major diurnal and semidiurnal constituents at Bob Hall Pier is what is expected from a location with a strong tidal signal. Progressing inside from Aransas Pass, variations in amplitude increase only slightly (i.e. are "stable") at Rockport and Packery Channel and the phases of the semidiurnal constituents N2 and S2 become unstable. To the south, the monthly amplitudes and phases show stability at Port Isabel over time. However at Port Mansfield, even though the amplitudes appear stable because they are low amplitude, the phases of the semidiurnal constituents are very unstable. At the inside stations, the K1 diurnal constituent consistently has the highest amplitude, however even the amplitudes show some instability. The phases for all constituents at El Toro, Rincon, and Yarborough have extremely high variability from month to month. It is this lack of "stability" of a regularly recurring tidal signal that makes the systematic tabulation of the tide so difficult at these stations.

FIGURE 10.

LAGUNA MADRE, TEXAS - COMPARISON OF MONTHLY MEAN SEA LEVELS - JANUARY 1990 THROUGH DECEMBER 1993

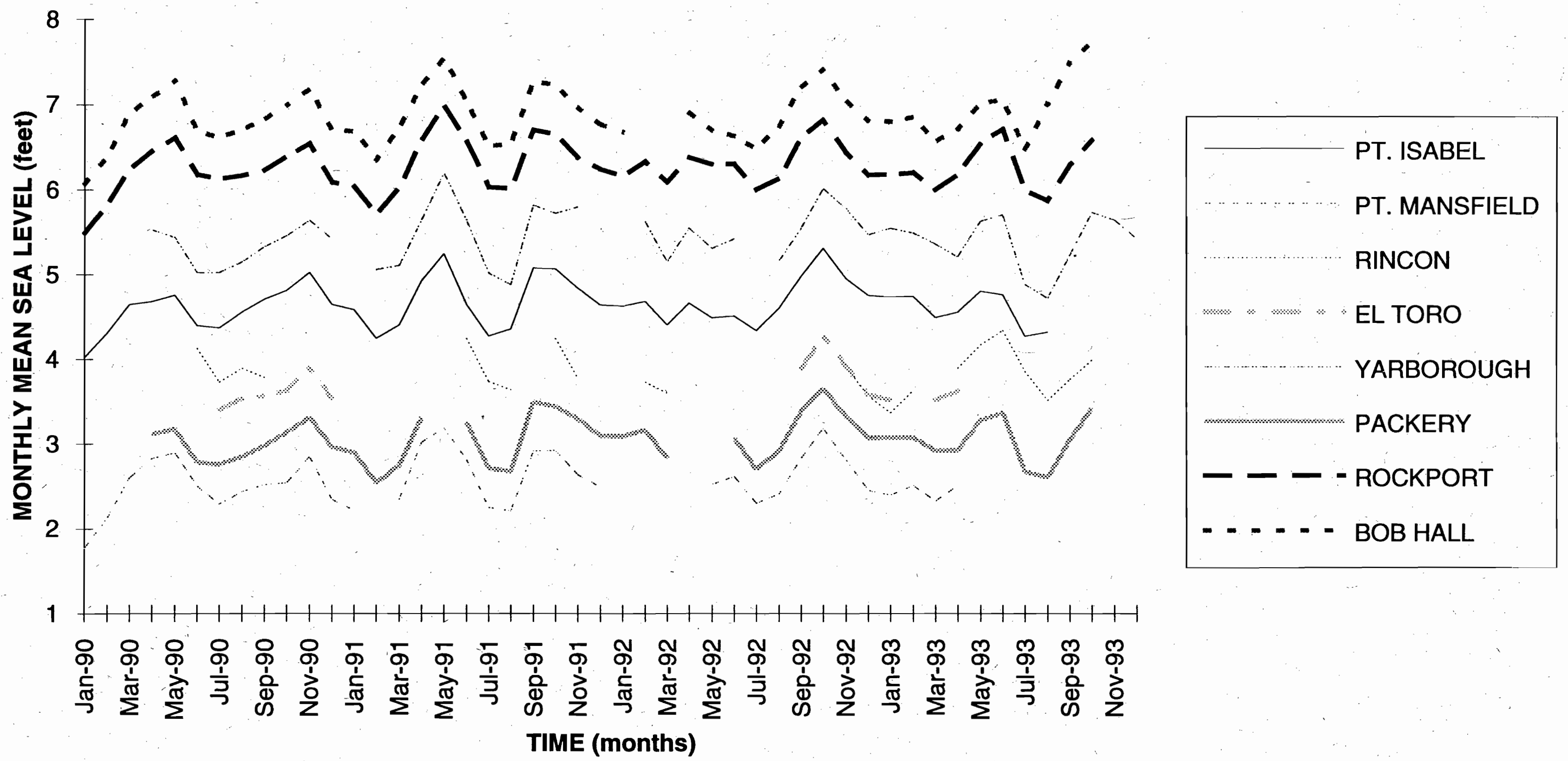


FIGURE 11. **LAGUNA MADRE, TEXAS - COMAPRISON OF DAILY MEAN SEA LEVEL VALUES - SEPTEMBER 1993**

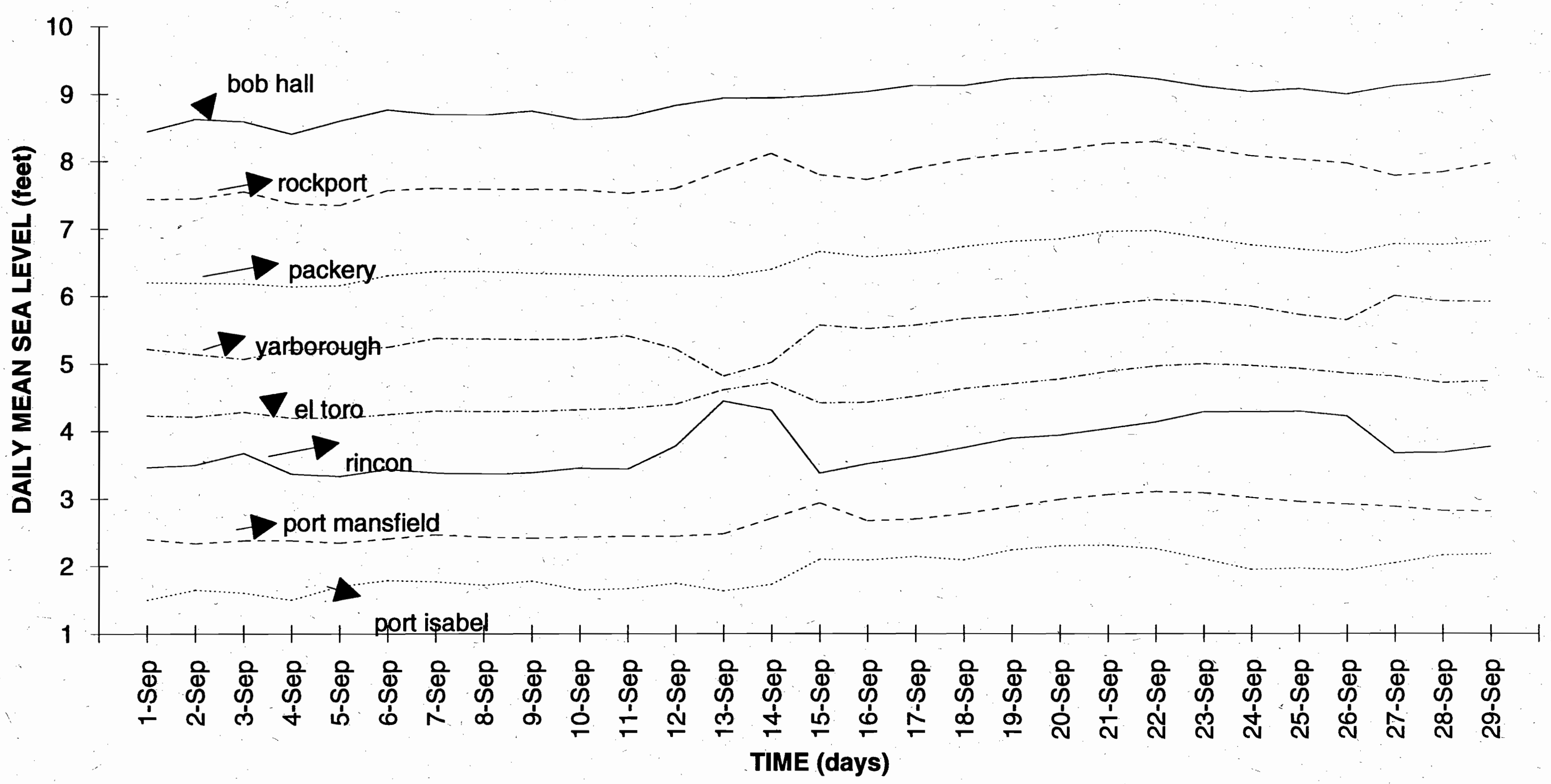


FIGURE 12.

EL TORO, TEXAS - WIND SPEED, GUST , AND WIND DIRECTION - SEPTEMBER 1993

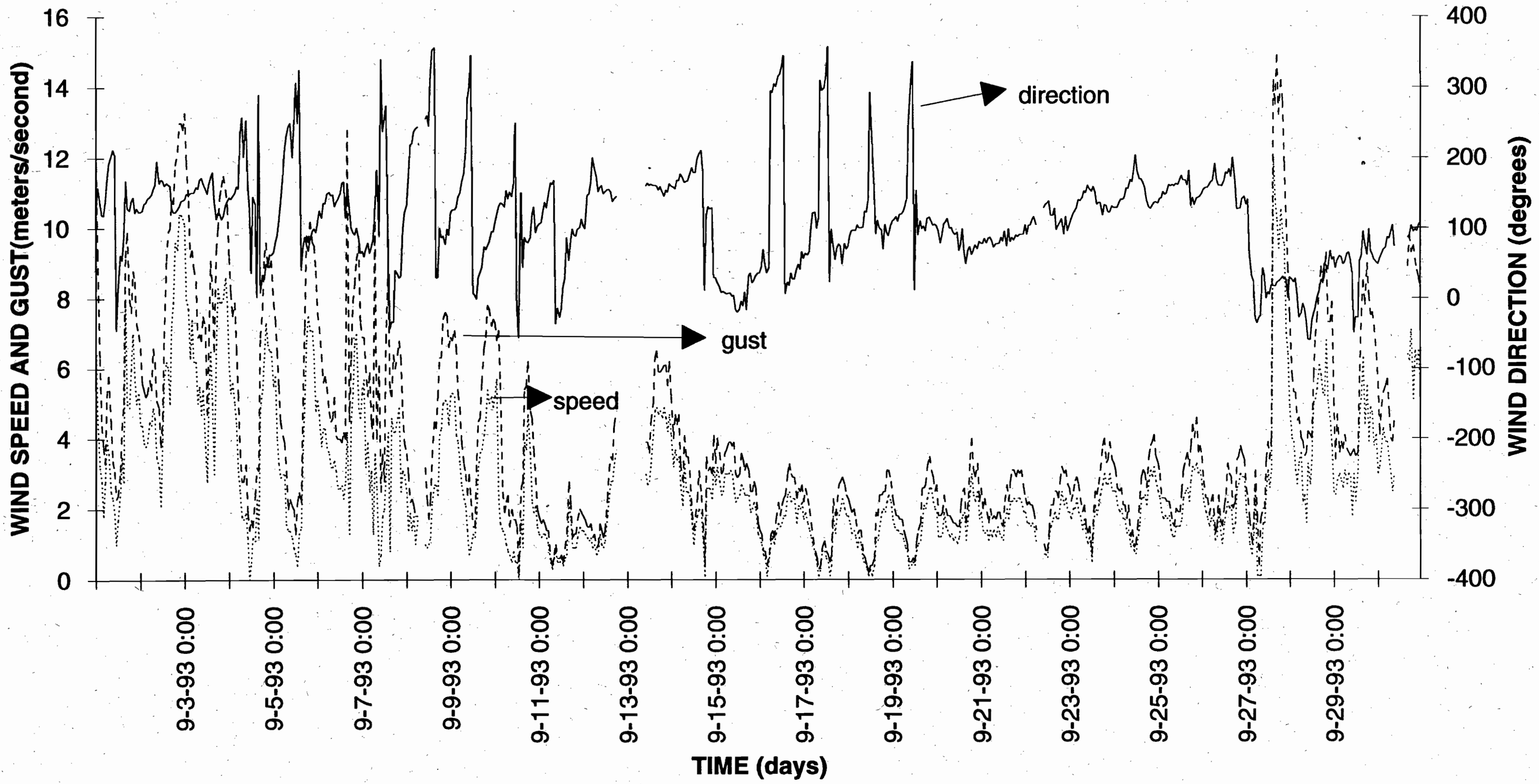


FIGURE 13.

**LAGUNA MADRE, TEXAS - SIMULTANEOUS COMPARISON OF 6-MINUTE INTERVAL DATA - ONE WEEK PERIOD - SEPTEMBER 1 - 7 , 1993**

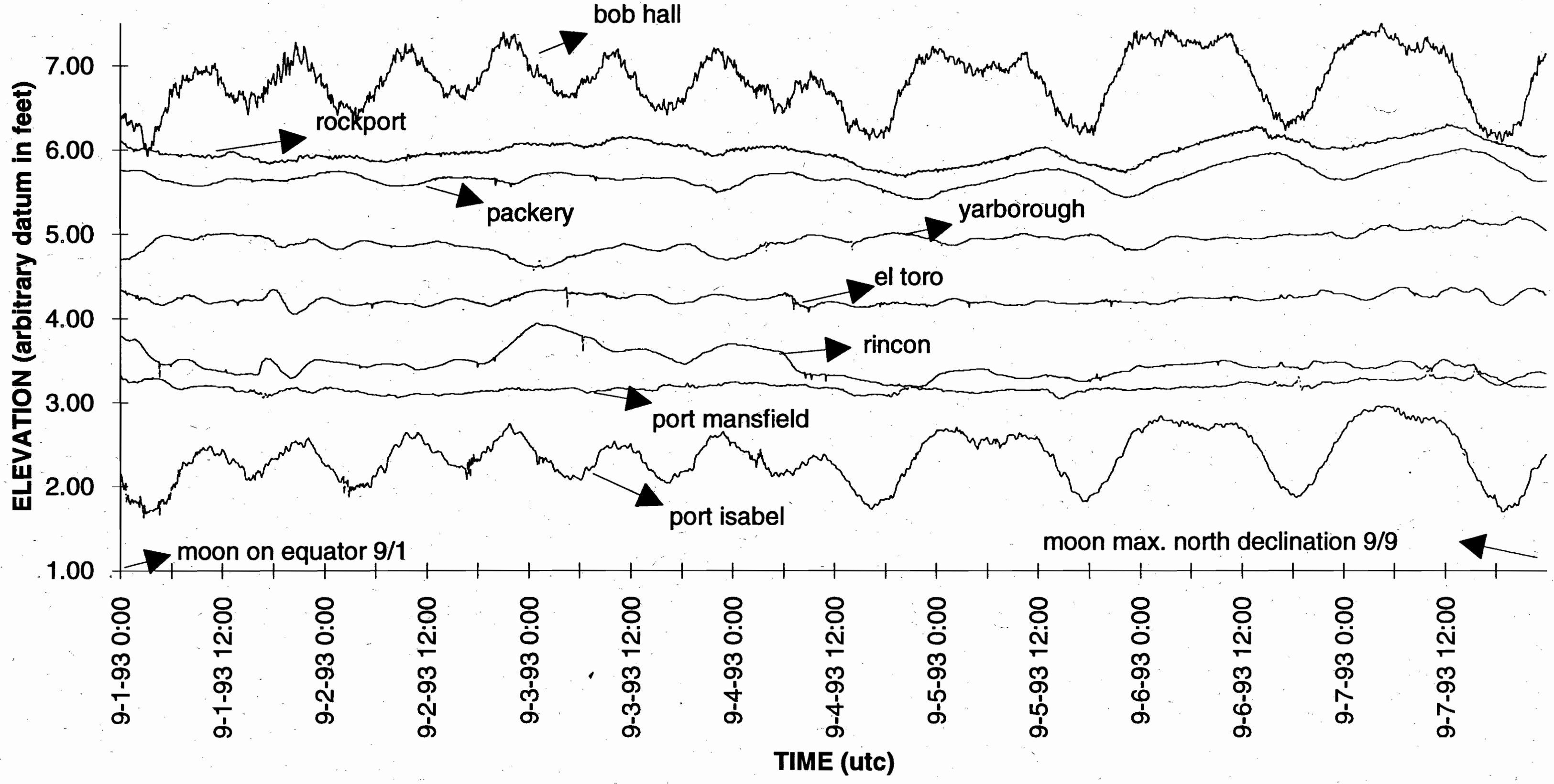


FIGURE 14.

**NORTHERN LAGUNA MADRE - SIMULTANEOUS COMPARISON OF 6-MINUTE INTERVAL DATA - ONE WEEK PERIOD - SEPTEMBER 1 -7, 1993**

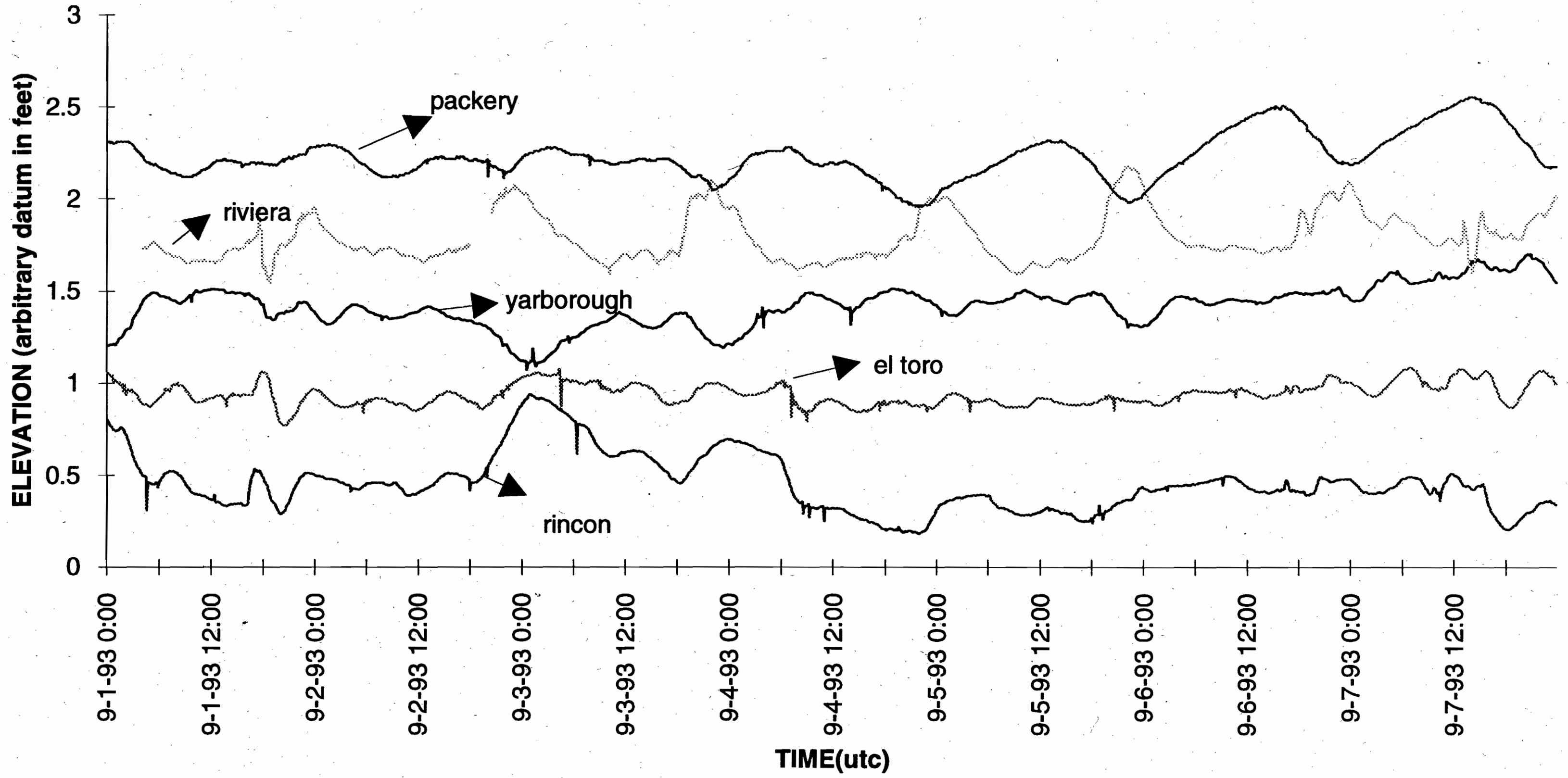
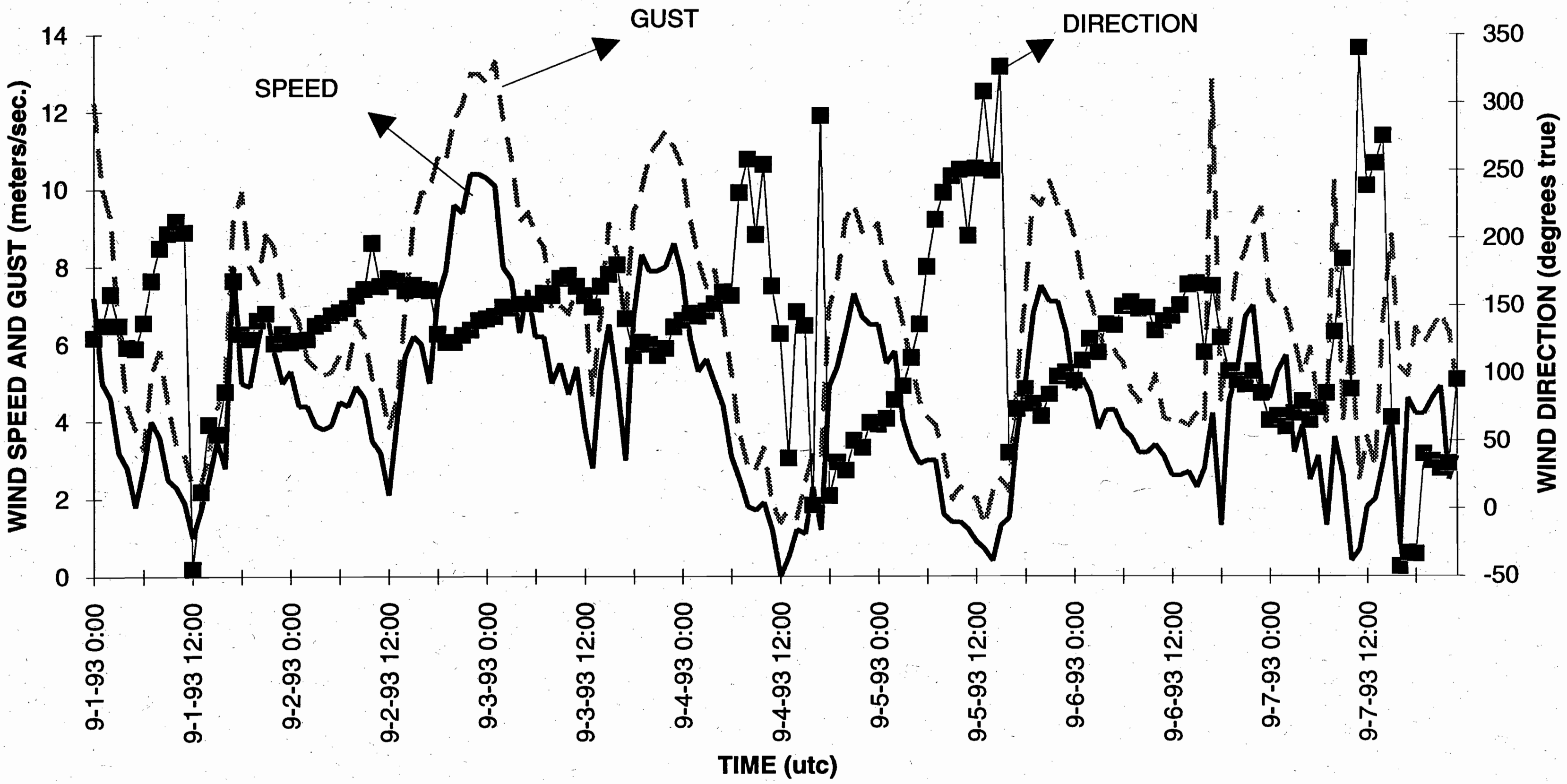


FIGURE 15.
**EL TORO, TEXAS - WIND SPEED, GUST, AND DIRECTION - SEPTEMBER 1 THROUGH 7, 1993**



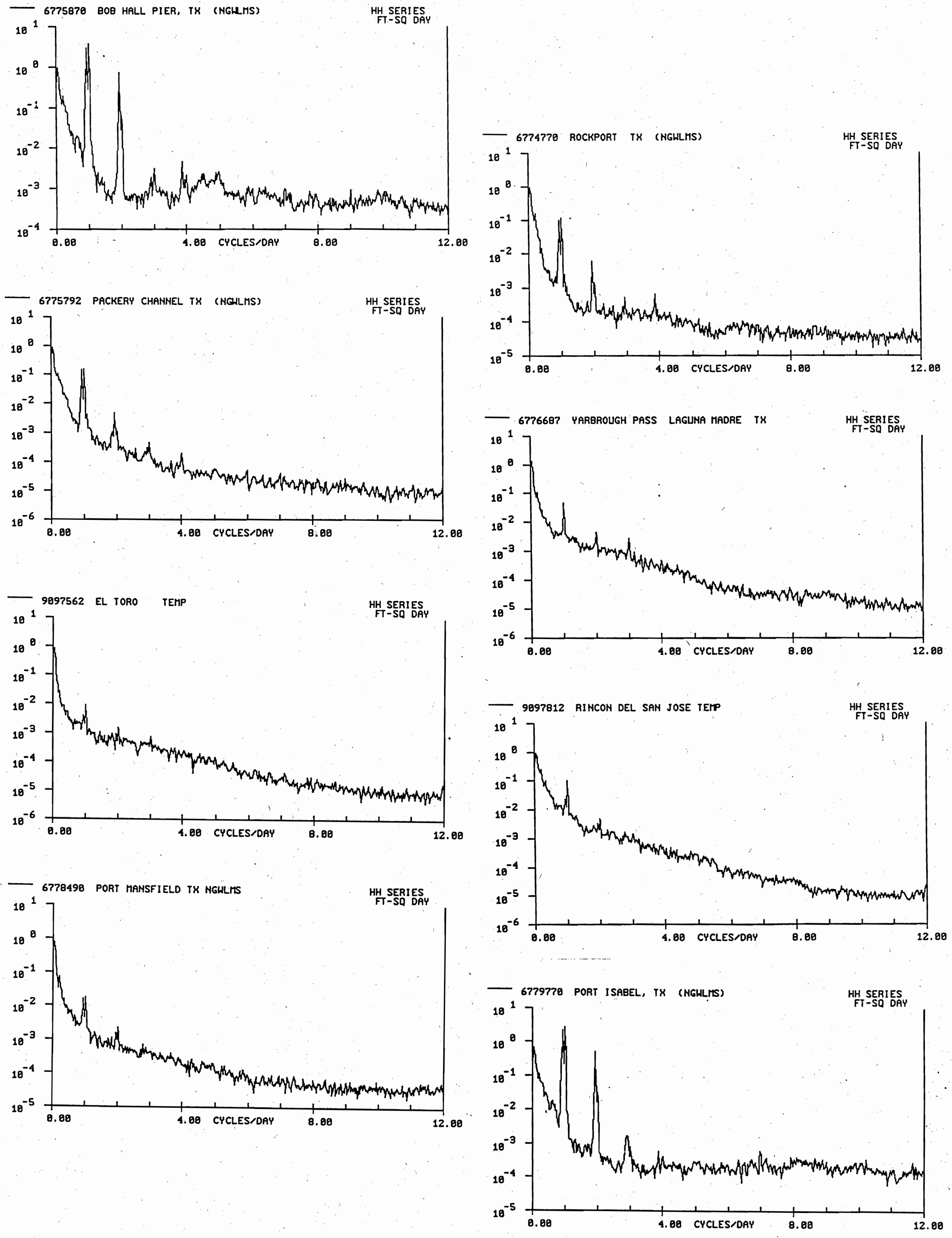


FIGURE 16. Laguna Madre Spectral Analysis Comparison - One Year of Simultaneous Hourly Heights

FIGURE 17.

LAGUNA MADRE, TEXAS: REDUCTION OF VARIANCE FROM SIMULTANEOUS 365 DAY LEAST SQUARES HARMONIC ANALYSES

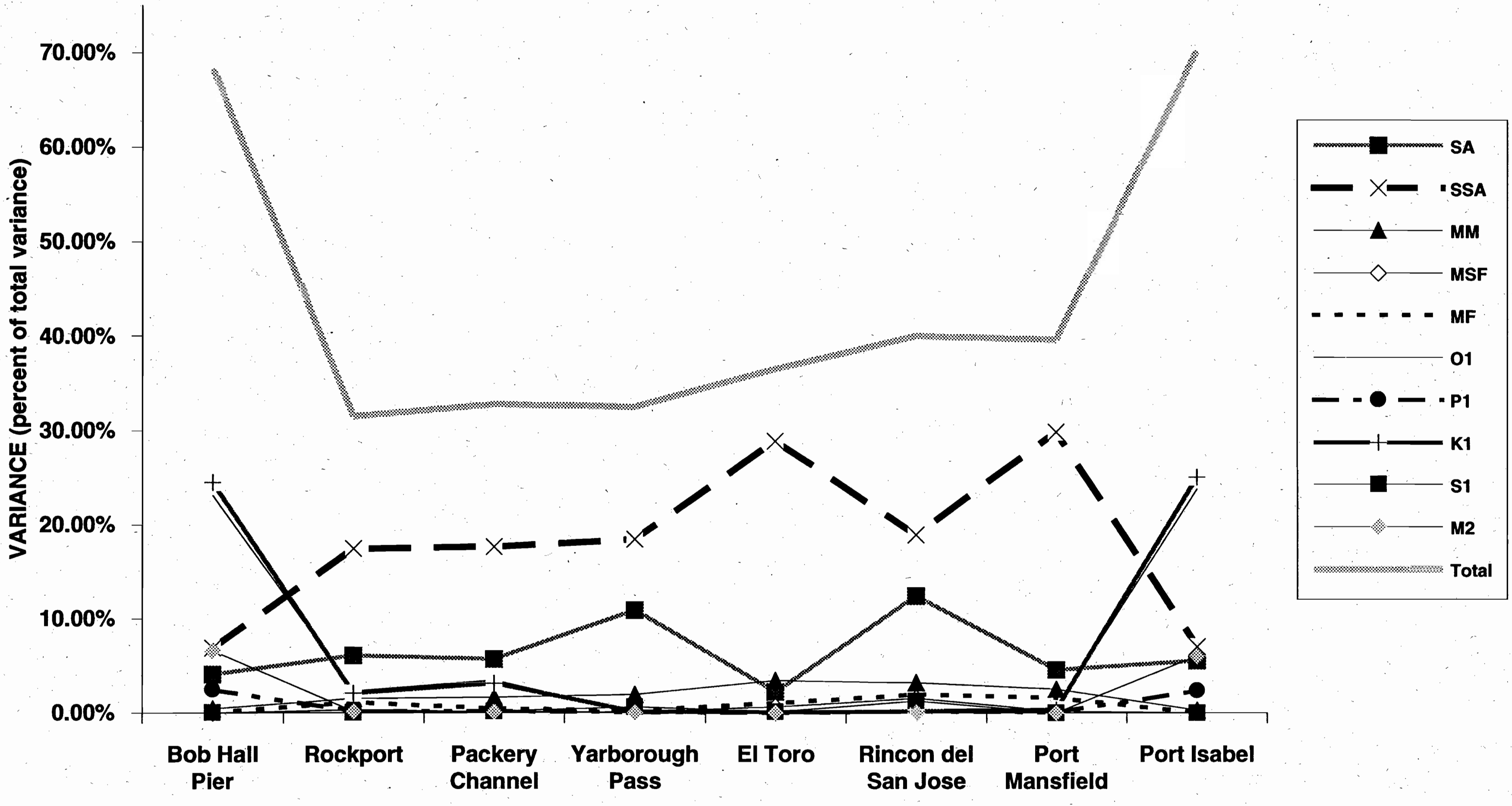
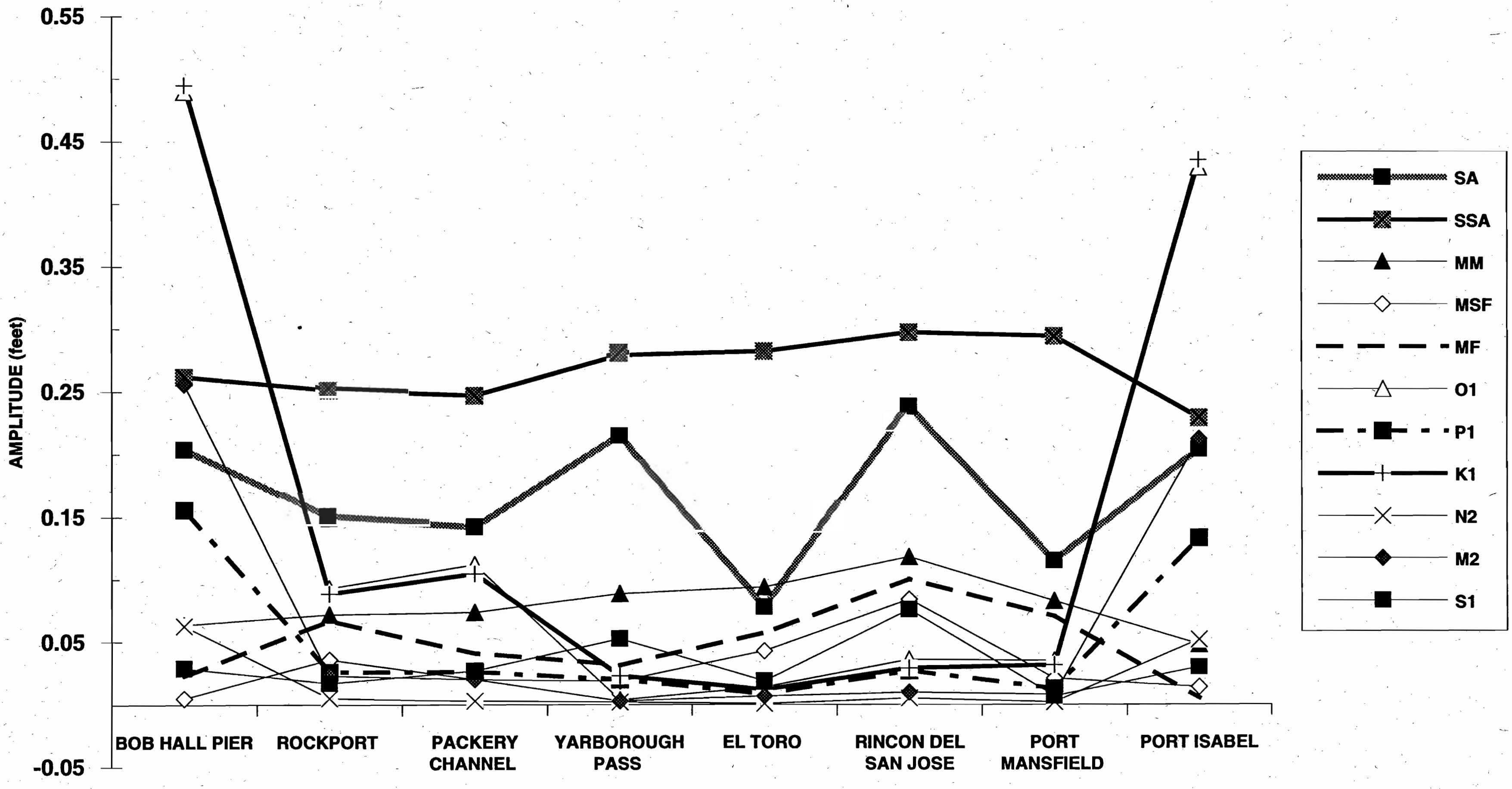
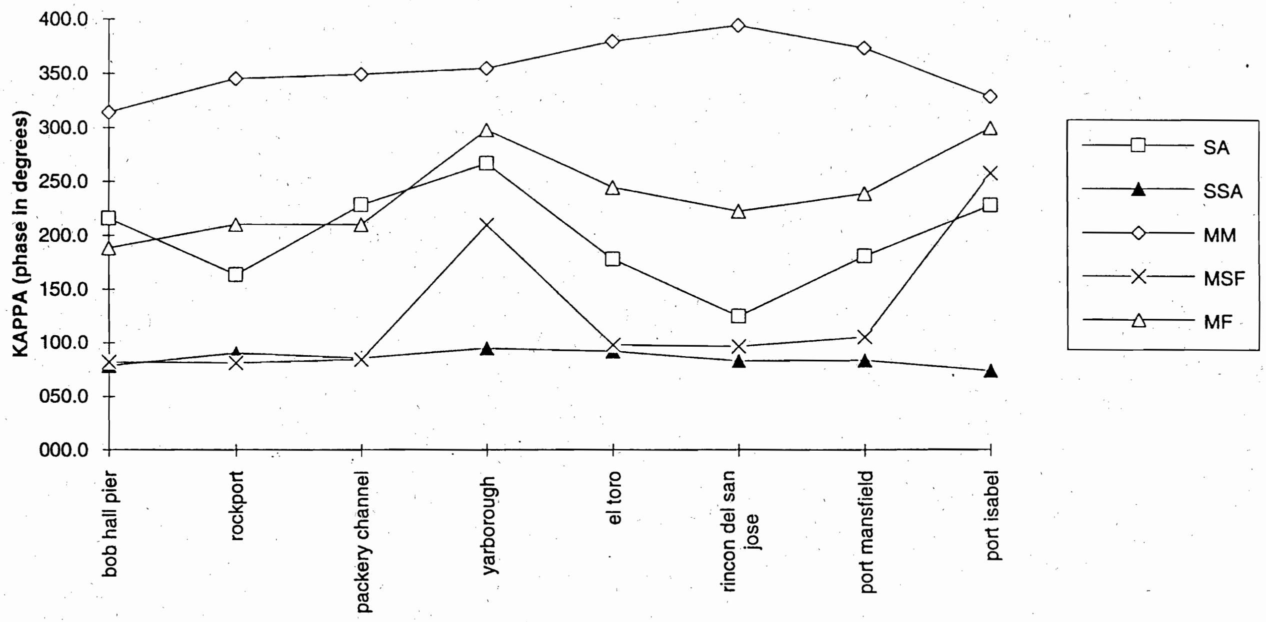


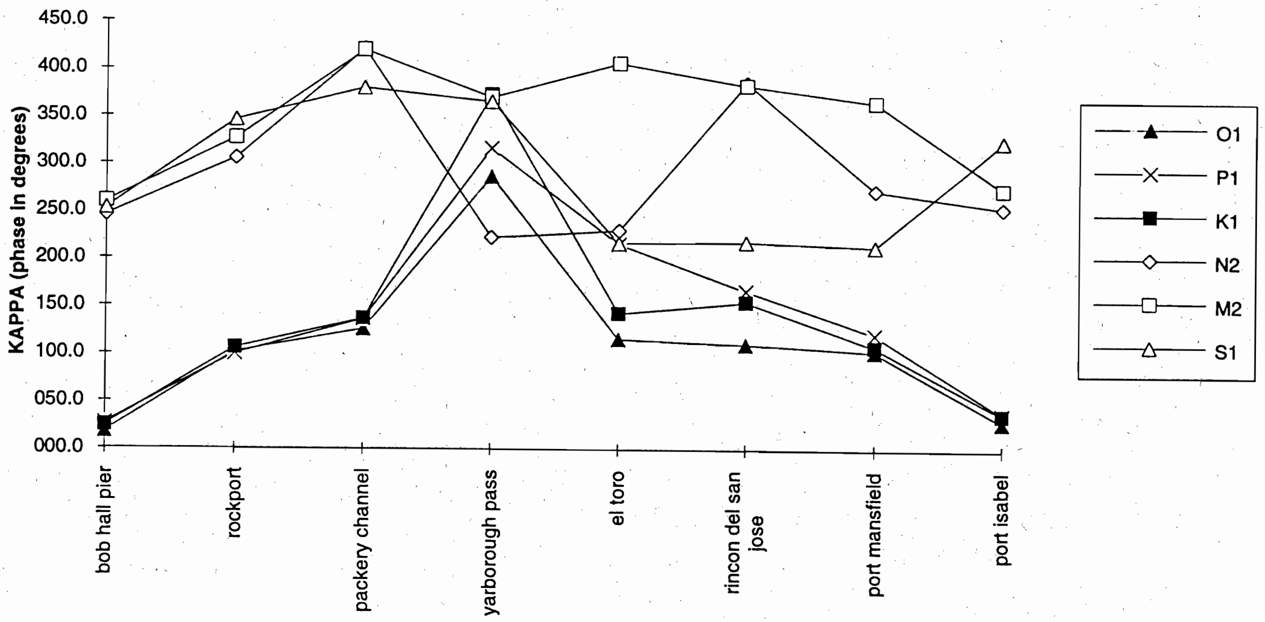
FIGURE 18.

LAGUNA MADRE, TEXAS: VARIATION IN AMPLITUDES OF HARMONIC CONSTITUENTS FOR 365 DAY LEAST SQUARES HARMONIC ANALYSES





LAGUNA MADRE, TEXAS: VARIATION IN PHASES OF LONG PERIOD CONSTITUENTS FROM 365 DAY LEAST SQUARES HARMONIC ANALYSIS

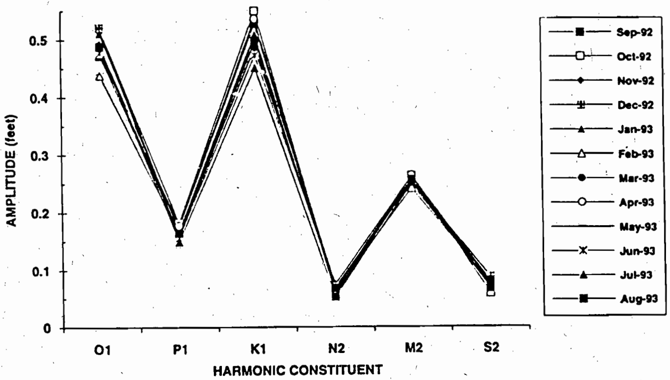


LAGUNA MADRE, TEXAS: VARIATION IN PHASES OF TIDAL HARMONIC CONSTITUENTS FROM 365DAY LEAST SQUARES HARMONIC ANALYSIS

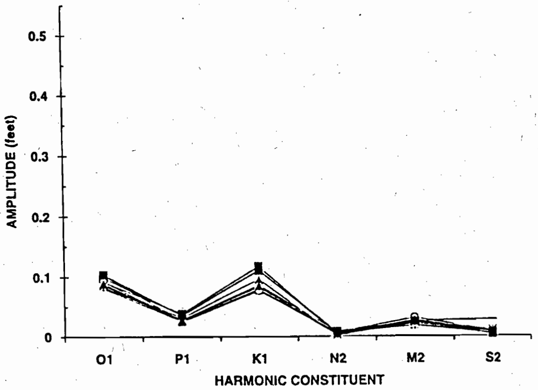
FIGURE 19. Laguna Madre, Texas: Variation in Phases of Long Period and Tidal Constituents from 365 day Least Squares Harmonic Analysis

FIGURE 20. Laguna Madre, Texas - Comparison of Variation in Amplitudes of Harmonic Constituents for 12 Consecutive 29 Day Harmonic Analyses

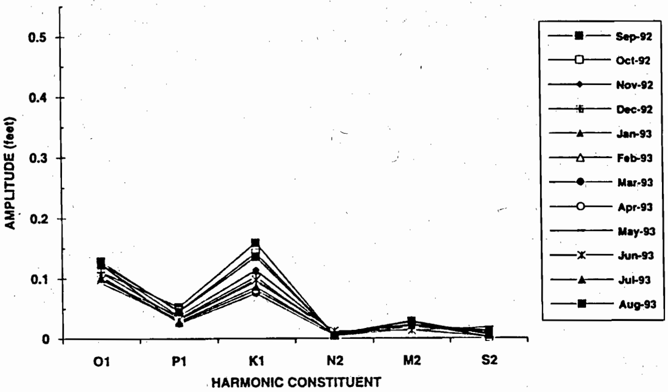
BOB HALL PIER, CORPPUS CHRISTI, TEXAS - VARIATION IN AMPLITUDES OF HARMONIC CONSTITUENTS FOR 12 CONSECUTIVE 29 DAY HARMONIC ANALYSES



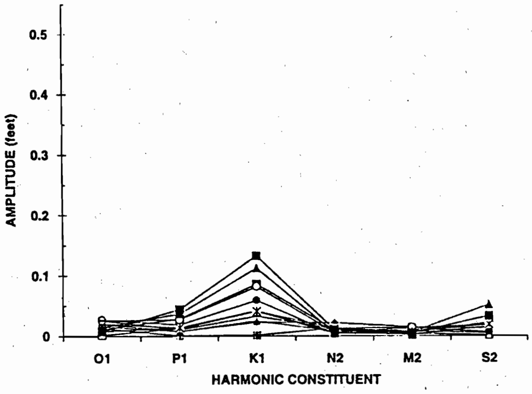
ROCKPORT, TEXAS - VARIATION IN AMPLITUDES OF HARMONIC CONSTITUENTS FOR 12 CONSECUTIVE 29 DAY HARMONIC ANALYSES



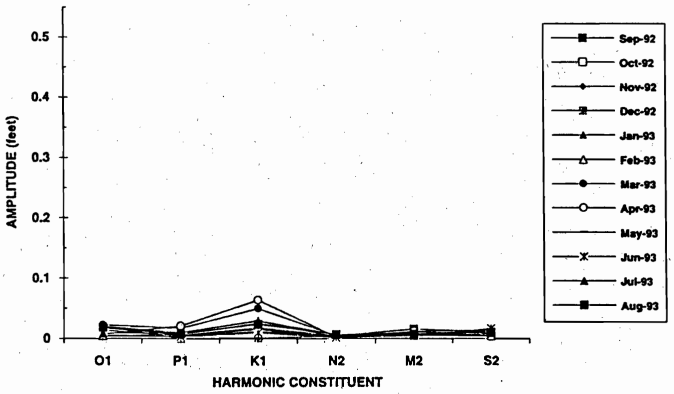
PACKERY CHANNEL, TEXAS - VARIATION IN AMPLITUDES OF HARMONIC CONSTITUENTS FOR 12 CONSECUTIVE 29 DAY HARMONIC ANALYSES



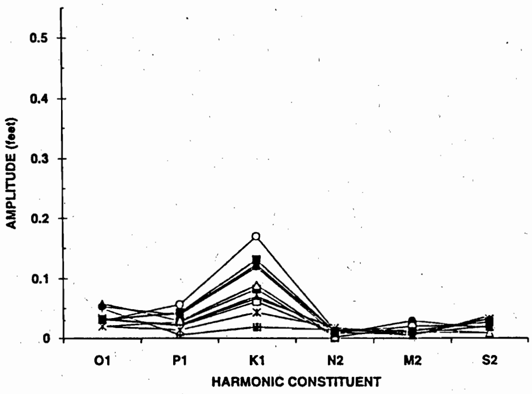
YARBOROUGH PASS, TEXAS - VARIATION IN AMPLITUDES OF HARMONIC CONSTITUENTS FOR 12 CONSECUTIVE 29 DAY HARMONIC ANALYSES



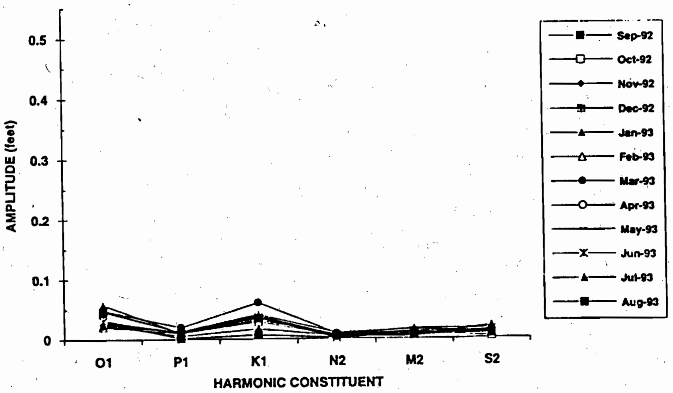
EL TORO, TEXAS - VARIATION IN AMPLITUDES OF HARMONIC CONSTITUENTS FOR 12 CONSECUTIVE 29 DAY HARMONIC ANALYSES



RINCON DEL SAN JOSE, TEXAS - VARIATION IN AMPLITUDES OF HARMONIC CONSTITUENTS FOR 12 CONSECUTIVE 29 DAY HARMONIC ANALYSES



PORT MANSFIELD, TEXAS - VARIATION IN AMPLITUDES OF HARMONIC CONSTITUENTS FOR 12 CONSECUTIVE 29 DAY HARMONIC ANALYSES



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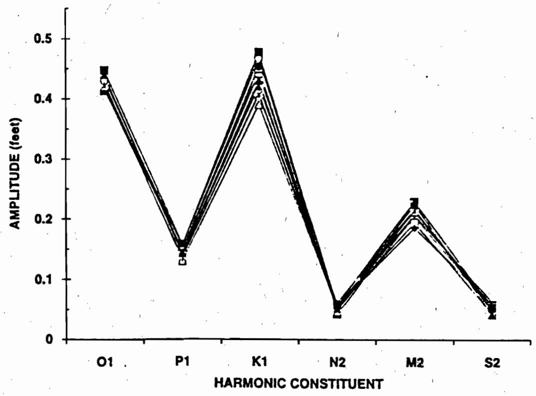
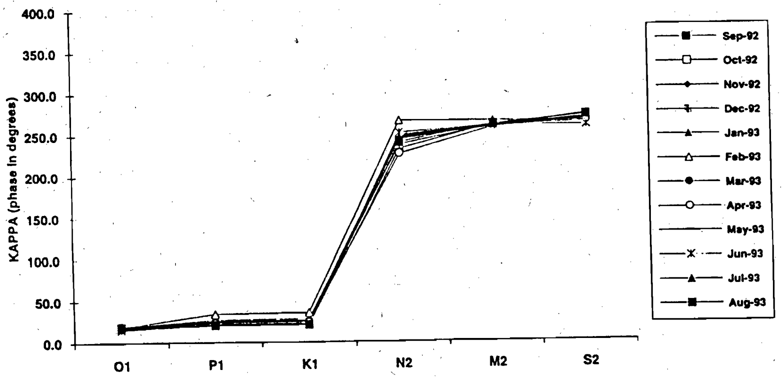
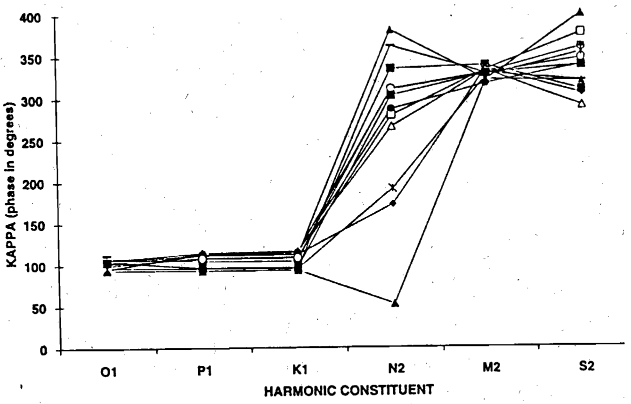


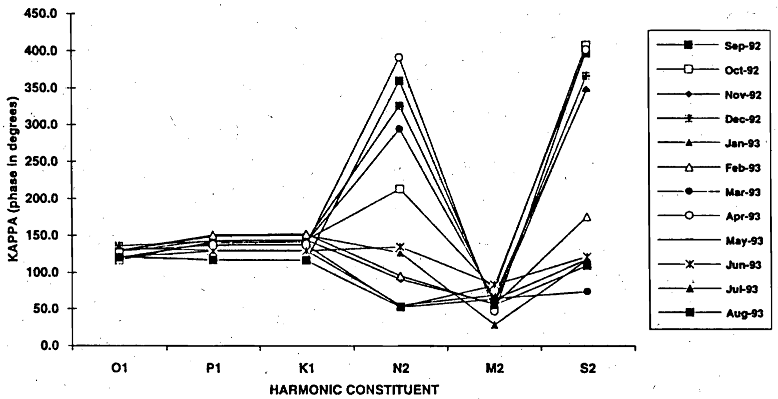
BOB HALL PIER, CORPUS CHRISTI, TEXAS - VARIATION IN PHASES OF HARMONIC CONSTITUENTS FOR 12 CONSECUTIVE 29 DAY HARMONIC ANALYSES



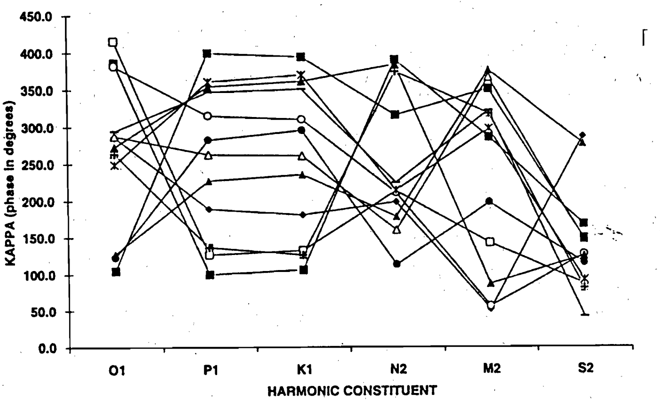
ROCKPORT, TEXAS - VARIATION IN PHASES OF HARMONIC CONSTITUENTS FOR 12 CONSECUTIVE 29 DAY HARMONIC ANALYSES



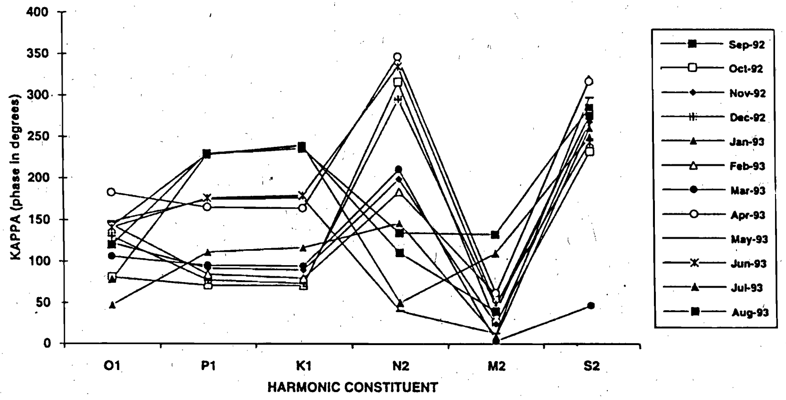
PACKERY CHANNEL, TEXAS - VARIATION IN PHASES OF HARMONIC CONSTITUENTS FOR 12 CONSECUTIVE 29 DAY HARMONIC ANALYSES



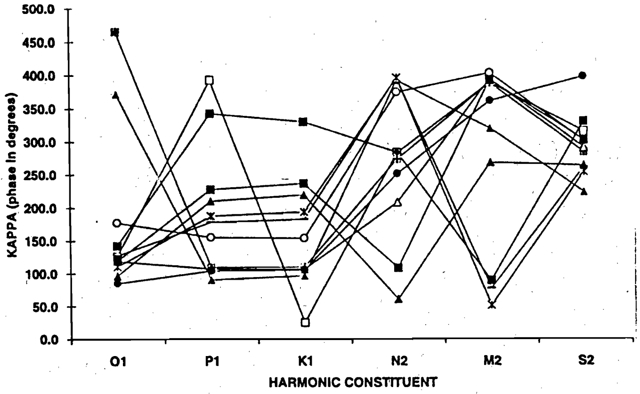
YARBOROUGH PASS, TEXAS - VARIATION IN PHASES OF HARMONIC CONSTITUENTS FOR 12 CONSECUTIVE 29 DAY HARMONIC ANALYSES



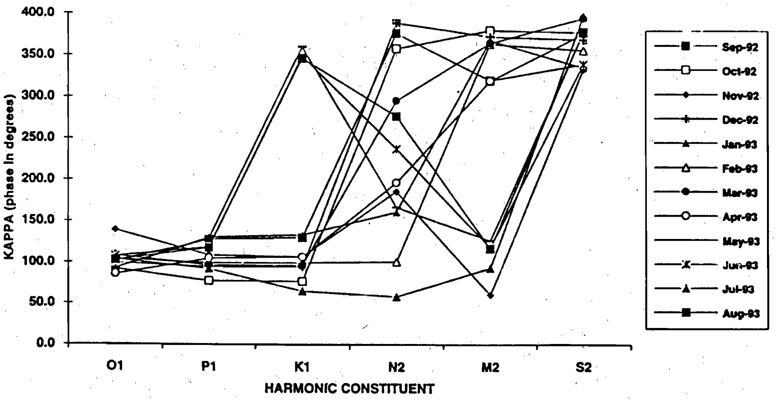
EL TORO, TEXAS - VARIATION IN PHASES OF HARMONIC CONSTITUENTS FOR 12 CONSECUTIVE 29 DAY HARMONIC ANALYSES



RINCON DEL SAN JOSE, TEXAS - VARIATION IN PHASES OF HARMONIC CONSTITUENTS FC 12 CONSECUTIVE 29 DAY HARMONIC ANALYSES



PORT MANSFIELD, TEXAS - VARIATION IN PHASES OF HARMONIC CONSTITUENTS FOR 12 CONSECUTIVE 29 DAY HARMONIC ANALYSES



PORT ISABEL, TEXAS - VARIATION IN PHASES OF HARMONIC CONSTITUENTS FOR 12 CONSECUTIVE 29 DAY HARMONIC ANALYSES

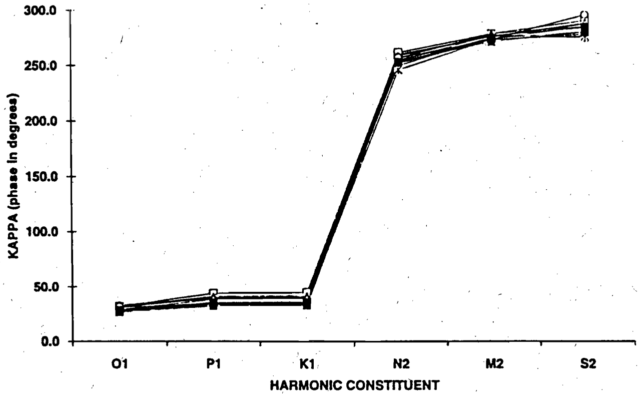


FIGURE 21. Laguna Madre, Texas - Comparison of Variation in Phases of Harmonic Constituents for 12 Consecutive 29 Day Harmonic Analyses

## VII. LONG-TERM SEA LEVEL VARIATIONS

Long-term mean sea level (MSL) observations are available in the Laguna Madre region from the NOS Primary tide stations at Rockport, Port Mansfield, and Port Isabel. Port Isabel has the longest series starting in 1944 with only a few data gaps of less than two years. Port Mansfield data starts in 1964 with a several year break in the late sixties. Rockport data starts in 1948, however there is a long gap from 1954 to 1963 and a shorter gap in the late seventies. Figure 22 is a plot of the yearly mean sea level values for the three stations.

Sea level trends can be estimated by the relative apparent secular trend determined from the yearly mean sea level data as shown in Table III. Relative apparent secular trend is represented by the slope of the least squares line of regression through the yearly means. Variability is represented by the standard error estimate, which is the standard deviation from the line of regression.

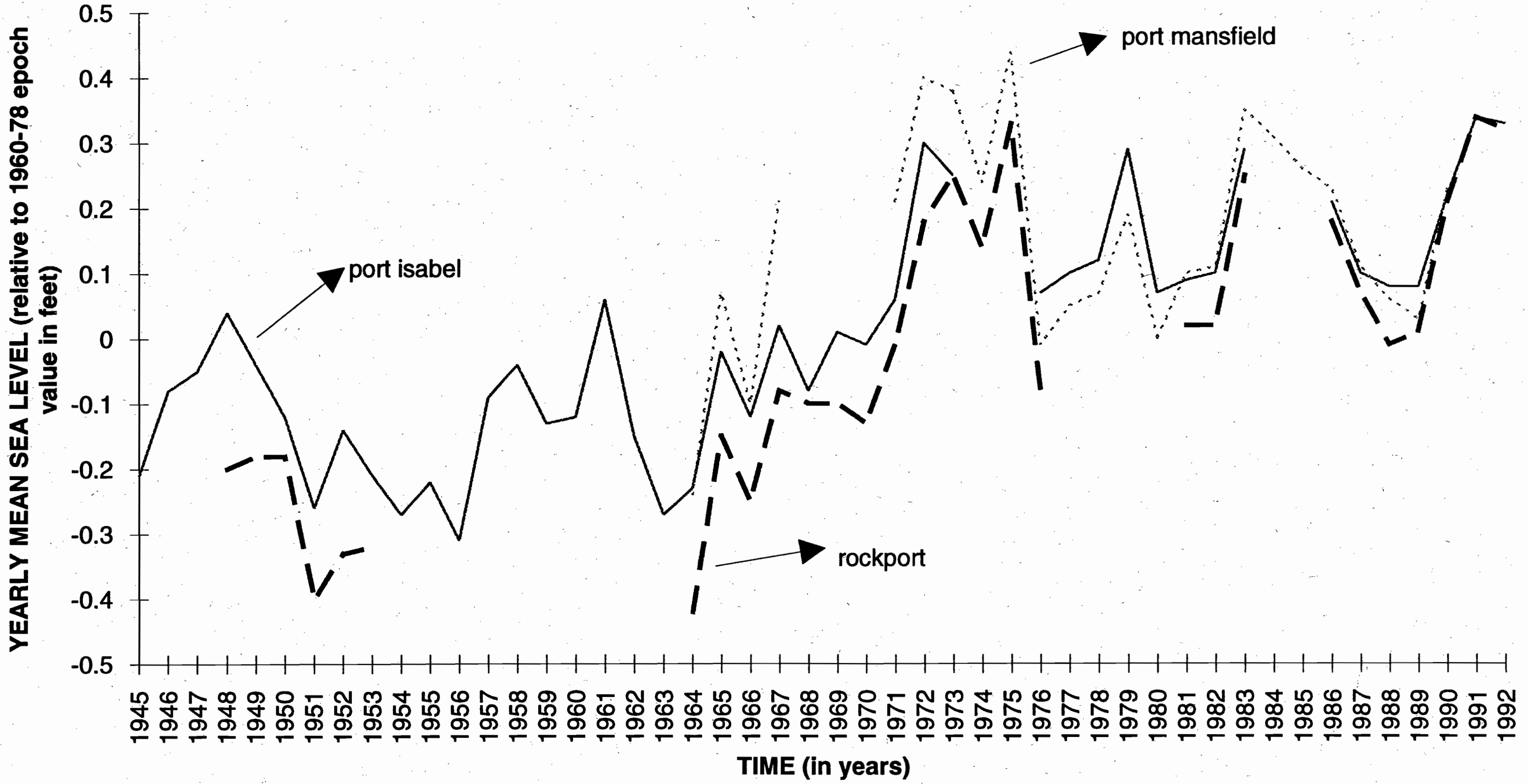
### TABLE III. Southern Texas Coast: Estimated Long-Term Sea Level Trends

| Station | Time Period | (Slope) Trend | Standard Error of Trend | Standard Error of Estimate |
|---|---|---|---|---|
| Rockport | 1950-93 | .014 ft./yr. | .0030 ft./yr. | .132 ft. |
| Port Isabel | 1950-93 | .012 ft./yr. | .0013 ft./yr. | .104 ft. |
| Pt. Mansfield | 1964-93 | .006 ft./yr. | .0036 ft./yr. | .156 ft. |

The trends at Rockport and Port Isabel are very similar. Port Mansfield appears to be anomalous, however only a shorter time period (1964-93) was available. True comparisons must be made over simultaneous time series, as the sea level trends are sensitive to time series length and time period. NOS (1983) found that sea level trends were similar between Port Isabel and Port Mansfield based on a short 12 year common period, 1964-79. Figure 22 shows visually that the recent variability in yearly mean sea levels are similar among the three stations for the most recent data as well. Long term sea level trend estimates for the nation found in Lyles et al (1986) are in the process of being updated.

Unless there are some unknown localized effects, it is reasonable to assume that tide stations installed in central Laguna Madre will have long-term sea level trends similar to Rockport, Port Mansfield, and Port Isabel. Port Isabel has the most continuous time series. Figure 22 also shows that the yearly mean sea level variations are dominated by apparent variations at decadal time scales. Thus the linear trends listed above are being estimated from "noisy" data sets. The highest yearly mean sea level elevations were in the early 1970's, with the 1991-1992 period having the most recent yearly extremes. The amplitudes of these variations are at or above the magnitude of the observed diurnal range of tide inside Laguna Madre.

FIGURE 22. **YEARLY MEAN SEA LEVEL COMPARISON - SOUTHERN TEXAS STATIONS**



# VIII. DATUM COMPUTATION

## General Methodology

NOS uses established procedures (Marmer, 1951) for the computation of tidal datums. Tidal datums are local reference elevations defined in terms of a certain phase of the tide measured at a specific location (Hicks, 1989). The datums are derived from the monthly tabulation of the high and low waters from which the monthly mean values of Mean Higher High Water (MHHW), Mean High Water (MHW), Mean Tide Level (MTL), Diurnal Tide Level (DTL), Mean Low Water (MLW), and Mean Lower Low Water (MLLW) are computed. From these mean values, additional monthly values of Mean Range (Mn), Great Diurnal Range (Gt), Diurnal High Water Inequality (DHQ) and Diurnal Low Water Inequality (DLQ) are derived. Monthly Mean Sea Level (MSL) is computed from the tabulation of the observed hourly heights. Reference is again made to Appendix 4 for an example of the monthly tabulation of these mean values.

For purposes of obtaining an accepted mean value of a tidal datum, NOS uses the concept of a primary determination (Marmer, 1951). A primary determination of a tidal datum is one that is derived from 19 years of continuous observations. The 19 year period constitutes the time period during which all of the significant tidal variations will have completed full tidal forcing cycles, such as the Node Cycle and the Metonic Cycle (Hicks, 1989). NOS designates specific 19 year periods as National Tidal Datum Epochs (NTDE), with the present epoch being the 1960 to 1978 time period. The accepted tidal datums at the primary stations at Rockport and Port Isabel, Texas have been computed from observations over the 1960-78 NTDE.

Given that accepted mean values of tidal datums are defined in terms of a specific NTDE and because it is impossible to operate all required stations for such a long time period in a practical sense, NOS uses the method of comparison of simultaneous observations (Marmer, 1951) between control and subordinate stations to compute equivalent 19 year mean values for stations with shorter series of observations (i.e. the subordinate station). The stations at Port Isabel and Rockport are the closest stations that could provide the primary control for any simultaneous comparisons required in Laguna Madre. Successful use of the methodology requires similarity between stations in tidal characteristics and similarity in water level variations on monthly, seasonal, and yearly time scales. Long term sea level trends and variability over several years must also be similar at both control and subordinate stations.

This methodology breaks down when the water level variations described above are not similar and 19 year equivalent values cannot be obtained. Examples are when even though the tidal characteristics and monthly and yearly mean sea level variations are similar, the long term sea level trends are significantly different, or when the sea level trends and yearly and monthly sea level variations are similar, but the tidal characteristics between control and subordinate stations are significantly different.

## Control for Datum Determination in Laguna Madre

Long-term systematic water level observations have been conducted in the vicinity of Laguna Madre at three station locations as shown in Section VII. Rockport in the upper region, Port Mansfield in the middle region and Port Isabel at the southern end. The long-term data sets recorded at these stations provide the necessary information by which sea level changes and tidal characteristics are analyzed for the purposes of updating the NTDE and determining tidal datums at other subordinate short-term stations through comparison of simultaneous observations.

The NOS Primary station at Rockport is classified as chiefly diurnal with a diurnal range of approximately 0.4 foot and is considered for primary datum control in Corpus Christi Bay and for subordinate stations in the upper regions of Laguna Madre. The NOS Primary tide station at Port Isabel has been shown to be best suited for long-term datum control in southern Laguna Madre for the region up to Port Mansfield ( NOS 1983). Even though it was not used as direct control for tidal datum or mean water level determinations in this report, Port Isabel serves as the basis for the 19 year 1960-78 NTDE in the Laguna Madre region.

The NOS Primary station at Port Mansfield has been classified as chiefly diurnal with a diurnal range of approximately 0.3 foot. Until more data became available during this project, NOS treated Port Mansfield as tidal. It is now evident that this station is at the southern limit for the portion of Laguna Madre where the tidal signal is negligible with respect to the total water level variance and should be only used for long-term sea level control. This finding is consistent with the results of NOS (1983), Zetler (1980) and Porter (1980). Published bench mark elevations for Port Mansfield will be referenced to an equivalent 19 year 1960-78 NTDE mean water level based on simultaneous comparison with Port Isabel.

The analyses found in this report provide the background for this determination at Port Mansfield. The spectral energy of the tidal bands is very small, as are the amplitudes of the tidal constituents. The times series plots exhibit very little correlation with the input tide from the Gulf of Mexico. The spectral energy of the tidal bands and the amplitudes of the diurnal and semidiurnal constituents are overwhelmed by the spectral energy at the low non-tidal frequencies. Even though some portions of the record may appear to be tidal at various times, the numerous occurrences of tidal masking by non-tidal effects dominates the water level variations. The lack of a regularly recurring tidal signal at Port Mansfield makes the use of NOS standard operating procedures not only manually intensive, but inconsistent and unreliable for determination of daily high and low waters and monthly means for use in the computation of tidal datums.

## Datum Computation at Laguna Madre Secondary Stations

### 1. Packery Channel

With its close proximity to the Aransas Channel, the station at Packery Channel in the upper reaches of Laguna Madre, exhibits a well defined diurnal tidal signal, with a diurnal range of approximately 0.4 foot. The tide at Packery Channel, like its closest control station Rockport, is classified as strongly diurnal with one high and one low tide daily. Semidiurnal tides, exhibiting two high and two low waters each tidal day (see figures 13 and 14), appear during time periods of equatorial tides, when the diurnal tides are weakest. However, Packery Channel, is an example of a location where the semidiurnal tides cannot be routinely tabulated during these time periods because the semidiurnal tide is greatly diminished progressing from the Gulf into Laguna Madre. The previous sections describing the tidal characteristics explain this effect. As a result, the mean range of tide (mean high water minus mean low water) and the diurnal range of tide (mean higher high water minus mean lower low water) are basically the same because the diurnal inequalities (Hicks, 1989) are insignificant.

Datums were computed for Packery Channel through a one year simultaneous comparison of tidal observations with the NOS Primary Control station at Rockport. The NOS modified range ratio method of simultaneous comparisons was used to compute tidal datums. This method, used throughout the gulf coast, calculates the mean high water and mean low water from the mean tide level and computed mean range and calculates mean higher high water and mean lower low water from the diurnal tide level and computed diurnal range. Figure 23 compares monthly mean sea level values over a common time period from September 1992 through August 1993. The range ratios and mean sea level differences between Packery Channel and Rockport exhibited good consistency from month to month resulting in a reasonable degree of confidence for the tidal datum values computed for Packery Channel.

### 2. Yarborough Pass

Comparative analysis of monthly means from Yarborough Pass were conducted with both Rockport and with Port Mansfield. The significant water level variations at Yarborough Pass can be mainly attributed to changes in sea level over the course of the month and non-periodic meteorological influences, not to daily periodic tidal forces. The tides are frequently non-existent during portions of each month and the tides tabulated are subjective and the resulting monthly means are unreliable for tidal datum computation. Mean sea level is therefore the most reliable datum to use for vertical reference at this location. The monthly sea level comparisons (figure 23) shows a slightly better correlation with Port Mansfield than with Rockport. Thus for the purposes of datum computation, using Port Mansfield as control, NOS has designated the station at Yarborough Pass as non-tidal and will issue bench mark elevations relative to an equivalent 19 year 1960-78 mean water level based on all hourly water level heights recorded for the period of record. For non-tidal stations, the term mean water level is used instead of mean sea level by convention (Hicks, 1989).

### 3. El Toro

Similar to Yarborough, daily tides cannot be consistently or reliably tabulated at El Toro for tidal datum purposes. Monthly mean sea level comparisons with Port Mansfield show good correlation (figure 23). This combined with the geographic proximity which is important in terms of localized meteorological events makes Port Mansfield the more optimum control. El Toro is designated non-tidal for the purposes of datum computation and bench mark elevations will be issued relative to an equivalent 19 year 1960-78 mean water level based on all hourly water level heights recorded for the period of record. A preliminary value is based on the longest continuous series available, which is only a six-month series in 1990 due to poor data quality from this station. The mean water level value will be updated when a longer continuous series is available.

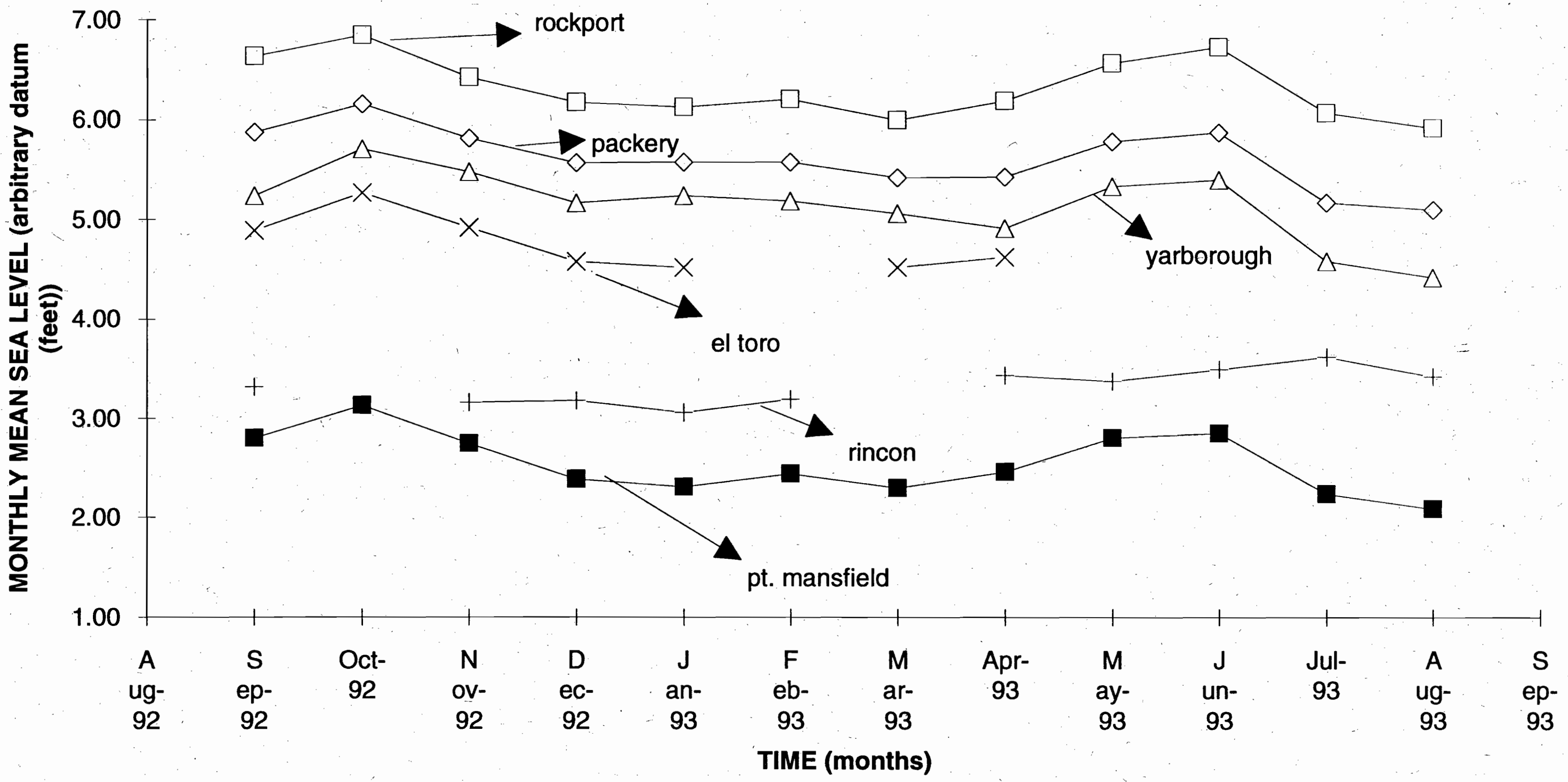
### 4. Rincon del San Jose

The monthly mean sea levels at Rincon del San Jose appear the least correlated with either Port Mansfield or Rockport (see figure 23). However, mean sea level remains the most consistent and reliable datum derived through simultaneous comparison with Port Mansfield. Rincon del San Jose is designated non-tidal for the purposes of datum computation and bench mark elevations will be issued relative to an equivalent 19 year 1960-78 mean water level based on all hourly water level heights recorded for the period of record.

The tidal datums for Packery and the mean water level datums for Yarborough, El Toro, and Rincon del San Jose will be updated as more data become available. Because the monthly and annual water level variations are the most significant, the most accurate datums will be derived from several years of data.

FIGURE 23.

LAGUNA MADRE, TEXAS - COMPARISON OF MONTHLY MEAN SEA LEVELS - SEPTEMBER 1992 THROUGH AUGUST 1993



# IX. SUMMARY

This report represents the latest in a series of NOS efforts to understand the tidal characteristics of Laguna Madre, Texas. NOS has undertaken these studies for the practical application of computing reference datums for use in surveying, mapping, and engineering programs. The most recent effort has been a cooperative program with the State of Texas, GLO. As a result of this program, for the first time, a north-south transect of stations is being occupied with simultaneously operating water level measurement stations. This provides a valuable and growing data set from which to analyze the data and derive practical information. Although involved in the data processing and assisting in the initial station installations, NOS is now largely in a technical consultant role. The State, through CBI and LU, is now successfully operating and maintaining a state-wide network of stations and is collecting and processing data independent of NOS for computation of state datums.

Using previous studies as a base, this report describes the long term interannual, seasonal and monthly water level variations in the Laguna Madre and describes the changes in the tidal characteristics progressing from the Gulf of Mexico to the inside bays and lagoons. The water level variations are characterized by good correlation across the region at the low frequency periods with much lower correlation progressing to the tidal and higher frequencies. As the tidal signal diminishes proceeding into the bays, the non-tidal water level variations dominate the time series record. There is evidence that the diurnal water level variations in central Laguna Madre are forced by the local diurnal winds, rather than the astronomical tide.

The extremely low signal-to-noise ratio in central Laguna Madre prevents the systematic application of NOS procedures for tabulating the tide from 6-minute interval data. The tabulation results are inconsistent and unrepeatable, simply because the tidal signal is so small and frequently masked by non-tidal noise. The NOS procedures for determination of tidal datums also cannot be applied at these central stations, as there are no correlations between control and subordinate stations at the tidal frequencies. As a result, NOS has determined that the stations at Yarborough Pass, El Toro, Rincon del San Jose, and Port Mansfield are classified as non-tidal for purposes of determining NOS tidal datums. Equivalent 19-year mean sea level datums will be computed using simultaneous comparison with mean sea level at Port Mansfield. NOS tidal datums have been computed for Packery Channel using Rockport as control. Applicable datums will be updated at the secondary stations in the future after collection of more data. Due to the large annual and seasonal variability present in the water levels, the most reliable datums will be based on more than one-year of data.

Based on the tidal and spectral analyses and NOS standard procedures for tabulating tides and computing tidal datums, Port Mansfield appears to be near the tidal/non-tidal transition. To the north, the transition zone is somewhere in between Yarborough Pass and Packery Channel. The more dense network of TCOON stations should provide this information in the future.

The long-term stations at Rockport and Port Isabel continue to provide direct tidal datums on the National Tidal Datum Epoch (NTDE) for their respective regions and determine tidal datums at other subordinate short-term stations through comparison of simultaneous observations when an adequate tidal signal is present.

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# APPENDIX I

# MEMORANDUM OF AGREEMENT BETWEEN
# THE STATE OF TEXAS
# GENERAL LAND OFFICE

# AND THE

# U.S. DEPARTMENT OF COMMERCE
# NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
# NATIONAL OCEAN SERVICE
# OFFICE OF OCEANOGRAPHY AND MARINE ASSESSMENT

## Introduction

This Agreement is made and entered into this 18th day of April 1988 by the State of Texas, General Land Office, hereinafter referred to as GLO and the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of Oceanography and Marine Assessment, hereinafter referred to as NOS, in recognition of common interests in determination of tidal datums and other related activities in coastal waters of the State of Texas.

## Authority

NOS is authorized to enter into this agreement by provisions of 33 U.S.C. Section 883e, and GLO by provisions of Chapters 3l and 33 of the Texas Natural Resources Code.

## Elements of the Agreement

### *I. NOS Responsibilities*

a. NOS shall prepare a basic program plan.

b. NOS shall identify an NOS project manager who will coordinate the overall program and provide a technical advisor for technical expertise and assistance to GLO, and provide point of contact for coordinating participation of other State and Federal agencies in tide station site selections and field operations.

c. NOS shall loan as many gages as necessary to meet the annual plan and all associated components for installation. All NOS forms required for program operation of tide stations will be provided.

d. NOS shall analyze and process the tide data for each location where acceptable tide data are collected during the program. Tide data that do not meet NOS minimum data quality control standards will not be published.

e. NOS shall, through the Technology Transfer Program, provide GLO personnel and/or GLO-designated personnel with training to a degree of proficiency that will allow the state to conduct their own data collection, analysis and datum computations.

f. NOS shall retain original tide and associated records resulting from the program and shall furnish copies to GLO upon request.

## *II. GLO Responsibilities*

a. GLO shall provide for the installation, operation, maintenance, and removal of each tide station in accordance with NOS standards and procedures.

b. Upon completion of the program or termination of this agreement between NOS and GLO, all tide gages and associated components shall be returned to NOS in good condition, reasonable wear and tear, and acts of God excepted.

c. GLO shall designate a project manager who will be responsible for the administration of the State's responsibilities and assist with overall coordination of the program.

d. GLO will coordinate its obligations and responsibilities under this agreement with the Conrad Blucher Institute at Corpus Christi State University.

## *III. Joint Responsibilities*

a. GLO project manager and NOS project manager shall develop a mutually agreeable Annual Work Plan that includes specific project direction, implementation schedules, funding provisions, and project requirements.

b. GLO shall define geographical project areas; NOS shall determine gaging requirements within the project areas, and provide staffing and cost estimates for the defined areas.

## *IV. Programming and Funding*

a. Within the terms of this agreement, programming and funding will be accomplished by the respective agencies entering into this agreement in accordance with responsibilities contained herein, subject to availability of funds and proper authorization. Specific programming and funding requirements shall be provided in the Annual Work Plan referenced in Section III.

b. GLO shall reimburse NOS for 100 percent of NOS costs incurred under the terms of this agreement. Included shall be costs associated with the NOS project manager and technical advisor time, travel and per diem, and data analysis and datum computations.

## *V. Terms and Conditions*

a. Press releases or other public announcements regarding this program may be released by NOS or GLO, provided that each consults with the other before doing so.

b. GLO shall hold NOS harmless for liability to third parties for any acts arising out of the performance of official duties by GLO employees in accordance with applicable State and county law. Liability of NOS for acts of its employees is governed by the Federal Tort Claims Act and other pertinent Federal law.

c. This agreement may be amended at any time by the mutual written consent of the agencies concerned.

d. Nothing herein is intended to conflict with current NOS or State directives or applicable law. If the terms of this agreement are inconsistent with existing directives or with applicable law of either of the agencies entering into this agreement, then those portions of this agreement that are determined to be inconsistent shall be invalid; but the remaining terms and conditions of this agreement not affected by any inconsistency shall remain in full force and effect. At the first opportunity for review of the agreement, such changes as are deemed necessary will be accomplished either by an amendment to this agreement or by entering into a new agreement, whichever is most expedient to the interests of both agencies.

Should disagreement arise as to the interpretation of the provisions of this agreement, or amendments and/or revisions thereto, that cannot be resolved at the operating level, the area(s) of disagreement shall be reduced to writing by each agency and presented to the other agency for consideration at least forty-five (45) days prior to forwarding to respective higher quarters for appropriate resolution.

e. This agreement shall become effective upon signature by officials of both respective agencies entering into this agreement, and shall remain in effect for those subsequent years for which an Annual Work Plan is concluded. This agreement may be terminated by mutual agreement or 30 days advanced written notice by either agency. In the event of termination prior to completion of the objectives of the Annual Work Plan, all direct and indirect phasing-out costs shall be paid by the agency requesting termination. Termination costs claimed shall not exceed actual costs incurred as a result of termination of the program.

Garry Mauro
Garry Mauro, Commissioner
General Land Office
State of Texas

4-18-88
Date

Charles N. Ehler
Charles N. Ehler, Director
Office of Oceanography and
Marine Assessment
National Ocean Service

4/18/88
Date

# APPENDIX II

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                              NOAA/NOS (NATIONAL OCEAN SERVICE)
                              TIDES, HIGH AND LOW WATERS (FEET)


6775870 BOB HALL PIER, TX  (NGWLMS)                    TM   OW  D
OCT, 1993
         HIGH             LOW                   HIGH             LOW                   HIGH             LOW
DAY    TIME HEIGHT    TIME HEIGHT     DAY    TIME HEIGHT    TIME HEIGHT     DAY    TIME HEIGHT    TIME HEIGHT
  1     7.4  22.58     3.6  22.31      11  >  4.1  22.96    13.4  22.30      21  >  7.3  22.95
     > 21.7  22.99  > 13.1  21.82            15.2  22.51  > 23.3  21.70                         > 19.6  21.18
  2                                    12  >  6.5  22.87                     22  >  5.6  22.81
     > 23.3  22.55  > 14.7  21.26            17.2  22.65    13.4  22.16                         > 20.5  21.45
  3                                    13  >  7.0  22.89     0.8  21.84      23  >  5.1  22.74
     > 23.0  22.64  > 14.4  21.14          > 19.6  23.07  > 13.7  21.73                         > 19.6  21.91
  4                                    14     6.5  22.56     2.3  21.70      24  >  5.3  23.04    11.4  22.60
                    > 17.2  21.11          > 21.4  23.12  > 12.4  21.65            15.0  22.76  > 23.4  22.12
  5  >  1.8  22.70                     15     8.2  22.68     4.9  22.33      25     5.6  22.98    11.6  22.44
                    > 17.2  20.90          > 21.1  23.28  > 14.2  21.35            17.2  23.04
  6  >  2.7  22.89                     16                                    26  >  5.9  23.09     0.7  22.70
                    > 17.7  21.12          > 23.1  23.08  > 15.2  20.80          > 19.3  22.95  > 13.3  22.34
  7  >  5.3  22.86                     17                                    27     5.6  22.81     1.4  22.50
                    > 19.5  21.50          > 23.3  23.10  > 15.0  20.71          > 19.9  22.79  > 11.9  21.92
  8  >  4.9  23.17                     18                                    28     6.8  22.39     3.0  22.27
                    > 18.9  21.60                         > 16.1  20.88          > 21.8  22.78  > 13.4  21.52
  9  >  5.4  23.35                     19  >  0.0  23.08                     29     6.1  22.39     4.0  22.25
                    > 21.5  21.48                         > 17.1  20.83          > 21.0  22.63  > 14.2  21.58
 10  >  8.1  23.33                     20  >  2.9  23.19                     30     6.9  22.00     3.7  21.54
                    > 20.1  21.63                         > 17.8  21.01          > 20.8  22.18  > 13.5  20.71
                                                                             31
                                                                                 > 22.4  21.79  > 15.0  19.77


MEANS FOR OCT 1, 1993 - OCT 31, 1993


MHW  22.81      MTL-MSL   -0.01      GT            1.56                KEY
MLW  21.61      MHHW      22.90      (DRL)TL      22.12              > HIGHER HIGH/LOWER LOW
MSL  22.23      MLLW      21.34      (DRL)TL-MSL  -0.11
MN    1.20      DHQ        0.08      GMHWI
MTL  22.21      DLQ        0.28      GMLWI


HIGHEST TIDE    23.35    5.4 HRS OCT  9, 1993
LOWEST  TIDE    19.77   15.0 HRS OCT 31, 1993

ARCHIVED  TID  EID  VID     START         STOP     SETTING  CNST   KPT          DATUM IS ..........
93 10 15  255  255  206   93  6  2  0   93 10  1 23       0     0   322
93 11 12  255  255  206   93 10  1 17   93 10  1 23       0     0   185
93 11 12  255  255  206   93 10  2  0   93 10 31  4       0     0   185
93 11 12  255  255  206   93 10 31  8   93 11  1 23       0     0   185
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                                              NOAA/NOS (NATIONAL OCEAN SERVICE)
                                              TIDES, HIGH AND LOW WATERS (FEET)


6774770 ROCKPORT  TX  (NGWLMS)                           TM   OW  D
OCT, 1993
           HIGH              LOW                        HIGH              LOW                        HIGH              LOW
DAY     TIME  HEIGHT     TIME  HEIGHT        DAY     TIME  HEIGHT     TIME  HEIGHT        DAY     TIME  HEIGHT     TIME  HEIGHT
  1   > 10.8    6.81                          11                    >  2.3    6.50
                       > 17.9    6.62              > 15.2    6.76                          21
  2   >  9.5    6.94                          12                    >  2.2    6.59
                       > 19.4    6.57              > 18.5    6.81                          22   >  7.1    6.46   >  1.3    6.24
  3   >  6.3    6.68                          13      5.3    6.89   >  2.8    6.70
                       > 21.3    6.26              > 14.8    7.04      8.7    6.77         23                    >  1.7    6.21
  4   >  9.9    6.60                                                  16.9    6.73              > 12.7    6.53
                       > 21.7    6.21                20.5    6.99                          24                    >  0.7    6.40
  5   > 11.6    6.58                          14                                                > 21.3    6.85
                       > 21.6    6.22                               > 17.5    6.52         25                    >  3.4    6.75
  6                                           15   >  9.6    6.82
      > 12.6    6.62   > 22.7    6.31                               > 18.9    6.52         26   >  9.4    7.18
  7                                           16   >  9.2    6.86
      > 14.1    6.75   > 22.8    6.51                               > 20.5    6.43         27
  8                                           17   >  9.9    6.78                               > 23.3    6.74   > 19.7    6.63
      > 13.3    6.94                                                > 20.8    6.37         28
  9                    >  0.6    6.66         18                                                                 > 17.4    6.36
      > 12.3    7.04                               > 12.1    6.83   > 21.3    6.54         29   >  9.0    6.66
 10   >  9.4    6.81   >  3.2    6.61         19   > 11.6    6.97                                                > 19.1    6.45
                                                                    > 21.2    6.62         30   >  2.0    6.73
                                              20   > 10.2    7.09
                                                                                           31
                                                                                                                 > 18.4    5.06


MEANS FOR OCT 1, 1993 - OCT 31, 1993


MHW   6.81      MTL-MSL    0.01      GT             0.39                        KEY
MLW   6.44      MHHW       6.80      (DRL)TL        6.61                       > HIGHER HIGH/LOWER LOW
MSL   6.62      MLLW       6.42      (DRL)TL-MSL   -0.01
MN    0.37      DHQ       -0.01      GMHWI
MTL   6.63      DLQ        0.02      GMLWI


HIGHEST TIDE     7.18    9.4 HRS OCT 26, 1993
LOWEST  TIDE     5.06   18.4 HRS OCT 31, 1993

ARCHIVED  TID  EID  VID       START         STOP    SETTING  CNST    KPT            DATUM IS ..........
93 10 21  255  255  206   93  8  2  0   93 10  1 23       0      0     91
93 11 12  255  255  206   93 10  1 17   93 10  1 23       0      0    133
93 11 12  255  255  206   93 10  2  0   93 11  1 23       0      0    133
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                                              NOAA/NOS (NATIONAL OCEAN SERVICE)
                                              TIDES, HIGH AND LOW WATERS (FEET)



6775792 PACKERY CHANNEL TX  (NGWLMS)                     TM   OW  D
OCT, 1993
           HIGH              LOW                        HIGH              LOW                        HIGH              LOW
DAY     TIME  HEIGHT     TIME  HEIGHT        DAY     TIME  HEIGHT     TIME  HEIGHT        DAY     TIME  HEIGHT     TIME  HEIGHT
  1   > 11.6    3.50                          11                    >  4.3    3.28         21
                       > 22.3    3.22              > 14.6    3.53                               > 14.2    4.00
  2   > 10.5    3.51                          12                    >( 4.8    3.21)        22                    >  3.0    3.30
                       > 22.5    3.12              > 13.2    3.49                               > 14.9    3.63
  3   > 10.1    3.38                          13                    >  3.6    3.21         23                    >  3.1    3.24
                       > 22.5    2.95              > 13.2    3.68   > 20.7    3.38              > 15.7    3.57
  4   > 10.8    3.39                          14      1.7    3.53      6.1    3.42         24                    >  3.2    3.31
                       > 23.1    2.93              >  8.4    3.54   > 18.8    3.36              >(14.4    3.72)
  5                                           15   >  4.9    3.63                          25                    >  4.2    3.53
      > 12.7    3.38                                                > 21.6    3.30
  6                    >  0.5    2.94         16   >  6.6    3.62                          26   > 11.1    3.91
      > 13.2    3.41                                                > 22.4    3.17                               > 20.9    3.70
  7                    >  0.7    2.97         17   > 11.1    3.55                          27   > 11.4    3.91
      > 15.1    3.50                                                >(22.8    3.10)
  8                    >  2.1    3.14         18                                           28
      > 13.9    3.62                               > 12.7    3.50   > 23.4    3.09                               > 20.9    3.24
  9                    >  2.1    3.22         19                                           29   >  6.1    3.50
      > 13.0    3.74                               > 12.6    3.52                                                > 19.2    3.24
 10                    >  4.1    3.23         20                    >  0.7    3.13         30   >  7.4    3.98
      > 15.9    3.74                               > 13.9    3.64   > 19.0    3.43

                                                                                           31
                                                                                                                 > 21.6    2.41


MEANS FOR OCT 1, 1993 - OCT 31, 1993


MHW   3.61      MTL-MSL   -0.02      GT             0.42                         KEY
MLW   3.20      MHHW       3.61      (DRL)TL        3.40                        >  HIGHER HIGH/LOWER LOW
MSL   3.42      MLLW       3.19      (DRL)TL-MSL   -0.02                      ( )  FLAT TIDE
MN    0.41      DHQ        0.00      GMHWI
MTL   3.40      DLQ        0.01      GMLWI


HIGHEST TIDE     4.00   14.2 HRS OCT 21, 1993
LOWEST  TIDE     2.41   21.6 HRS OCT 31, 1993

ARCHIVED  TID  EID  VID      START          STOP    SETTING  CNST   KPT            DATUM IS ..........
93 10 15  255  255  206   93  7 19  9   93 10  1 23       0     0   140
93 12  3  255  255  206   93 10  1 17   93 10  1 23       0     0    97
93 12  3  255  255  206   93 10  2  0   93 11  1 23       0     0    97
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                                        NOAA/NOS (NATIONAL OCEAN SERVICE)
                                        TIDES, HIGH AND LOW WATERS (FEET)



6776687 YARBROUGH PASS  LAGUNA MADRE  TX                TM   OW  D
OCT, 1993
         HIGH              LOW                                HIGH              LOW                                HIGH              LOW
DAY    TIME  HEIGHT     TIME  HEIGHT                DAY    TIME  HEIGHT     TIME  HEIGHT                DAY    TIME  HEIGHT     TIME  HEIGHT
  1                                          11                                          21  >  4.4   6.06       10.7   5.82
                                                                                                19.2   6.01
  2                    >  1.1   5.34         12  >  8.0   5.66     >  0.1   5.52         22  > 10.6   5.95     >  2.3   5.81
     > 14.3   5.60     > 18.5   5.41
  3                                          13     7.3   5.52     >  1.7   5.37         23
     > 12.9   5.62                                > 15.7   5.69       12.9   5.41
  4                                          14  > 11.6   6.20     >  0.3   5.37         24                    >  1.2   5.81
                                                    17.5   6.10       13.9   5.88              > 15.0   5.92     > 18.2   5.82
  5                                          15                                          25
                                                                   > 22.9   5.82
  6                                          16  >  9.4   5.92                           26
                       > 20.8   5.42
  7  >  4.7   5.52                           17  >  4.2   5.81     >  0.3   5.67         27
                                                                                               > 12.8   6.32
  8                    >  4.3   5.36         18  >  6.3   5.60     >  0.6   5.49         28
     > 13.9   5.51
  9                    >  1.6   5.35         19  >  9.3   5.52     >  0.5   5.20         29
                                                                   > 22.3   5.05                                 > 21.3   5.83
 10  > 11.3   5.88                           20                                          30
                                                 > 16.5   5.43     > 19.4   5.31               > 16.9   6.58
                                                                                         31


MEANS FOR OCT 1, 1993 - OCT 31, 1993


MHW    5.83     MTL-MSL   -0.05     GT             0.32                    KEY
MLW    5.53     MHHW       5.82     (DRL)TL        5.66                    >  HIGHER HIGH/LOWER LOW
MSL    5.73     MLLW       5.50     (DRL)TL-MSL   -0.07
MN     0.30     DHQ       -0.01     GMHWI
MTL    5.68     DLQ        0.03     GMLWI


HIGHEST TIDE     6.58   16.9 HRS OCT 30, 1993
LOWEST  TIDE     5.05   22.3 HRS OCT 19, 1993

ARCHIVED  TID  EID  VID      START          STOP    SETTING  CNST   KPT          DATUM IS ..........
94  1 13  255  255  206   93  6  2  0   93 10 14  7        0     0   154
94  1 13  255  255  206   93 10 14  8   94  1  1 23        0     0   154
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                                   NOAA/NOS (NATIONAL OCEAN SERVICE)
                                   TIDES, HIGH AND LOW WATERS (FEET)


6777562 EL TORRO,  TX  (NGWLMS)                      TM   OW  D
OCT, 1993
          HIGH            LOW                         HIGH           LOW                         HIGH            LOW
DAY    TIME  HEIGHT    TIME  HEIGHT       DAY     TIME  HEIGHT    TIME  HEIGHT        DAY    TIME  HEIGHT    TIME  HEIGHT
 1                                         11
                                                                                       21
 2  >  7.5    4.01                         12                                                                > 18.0    3.67
    > 17.4    3.95   > 12.5    3.84                                                    22
 3                                         13  >  2.5    4.11
                     > 23.4    3.73                              > 19.6    3.88        23
 4  >  3.9    3.84                         14     5.2    4.13    >  8.4    3.99
                                               > 11.5    4.68    > 17.8    4.22        24
 5                                             > 21.4    4.43
                     > 23.4    3.65        15                                          25
 6
                                           16                                          26
 7
                                           17                                          27
 8                                                               > 20.3    4.06           > 16.0    4.23
                                           18                                          28
 9                                             > 12.6    4.19    > 17.1    4.03
                                           19                                          29                      13.6    4.03
10  >  7.8    4.03                                                                        > 17.5    4.14    > 21.7    3.92
                     > 16.3    3.83        20  >  6.4    4.21                          30     2.2    4.06    >  9.8    3.67

                                                                                       31  >  2.4    4.15


MEANS FOR OCT 1, 1993 - OCT 31, 1993


MHW   4.15      MTL-MSL    0.05     GT             0.29                      KEY
MLW   3.89      MHHW       4.16     (DRL)TL        4.02                    >  HIGHER HIGH/LOWER LOW
MSL   3.97      MLLW       3.87     (DRL)TL-MSL    0.05
MN    0.27      DHQ        0.01     GMHWI
MTL   4.02      DLQ        0.01     GMLWI


HIGHEST TIDE     4.68   11.5 HRS OCT 14, 1993
LOWEST  TIDE     3.65   23.4 HRS OCT  5, 1993

ARCHIVED  TID  EID  VID      START          STOP     SETTING  CNST   KPT           DATUM IS ..........
94  2 10  255  255  206   93  9 13  4   93 10  1 23       0      0     67
94  2 24  255  255  206   93 10  1 17   93 10  1 23       0      0    116
94  2 24  255  255  206   93 10  2  0   93 10  7  5       0      0    116
94  2 24  255  255  206   93 10  7  7   93 11  4 13       0      0    116
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                              NOAA/NOS (NATIONAL OCEAN SERVICE)
                              TIDES, HIGH AND LOW WATERS (FEET)


6777812 RINCON DEL SAN JOSE  LAGUNA MADRE  TX            TM   OW  D
OCT, 1993
          HIGH              LOW                   HIGH              LOW                   HIGH              LOW
DAY     TIME  HEIGHT      TIME  HEIGHT  DAY     TIME  HEIGHT      TIME  HEIGHT  DAY     TIME  HEIGHT      TIME  HEIGHT
  1  >   2.1    4.14                     11  >  10.0    4.24
                       >  14.2    4.04                          >  17.2    4.14   21  >   7.5    3.53       4.4    3.30
  2  >   0.9    4.48                     12  >   0.8    4.41                            12.6    3.38      10.3    3.21
                       >  12.8    4.08                          >  15.6    4.19                          >  20.5    3.06
  3  >   0.7    4.34                     13  >   0.9    4.67                      22  >   1.4    3.31   >   7.7    3.08
                       >  22.2    3.86                          >  17.4    4.13
  4  >   3.5    3.98                     14  >   1.0    4.69   >   8.4    4.28   23
                       >  17.6    3.72        >  14.1    4.68      17.0    4.33
  5  >   5.4    3.95                             23.8    4.51                     24  >   5.9    3.62
                       >  16.9    3.75   15                                                              >  15.2    3.50
  6  >   3.6    3.89                                            >  17.4    4.31   25  >   4.9    3.83   >   7.7    3.66
                       >  21.0    3.79   16  >   4.4    4.59
  7                                                             >  19.5    4.29   26  >   8.1    4.09
                                         17  >   1.4    4.61                                             >  18.5    3.95
  8  >   9.7    4.19                                            >  19.1    4.27   27  >(  7.3    4.13)
                       >  13.5    4.04   18      11.9    4.68                                            >  19.4    3.50
  9  >   3.1    4.35                          >  20.9    4.79   >  16.3    4.42   28  >(  6.7    3.93)
                                         19                     >   8.0    4.55                          >  17.5    3.78
 10                                           >  21.7    4.91                     29
                       >  14.6    3.66   20                                            >  16.6    4.26
                                                                                  30
                                                                                                         >  16.7    1.83
                                                                                  31


MEANS FOR OCT 1, 1993 - OCT 31, 1993


MHW   4.22     MTL-MSL    0.03     GT            0.39                    KEY
MLW   3.81     MHHW       4.22     (DRL)TL       4.03                   >  HIGHER HIGH/LOWER LOW
MSL   3.99     MLLW       3.84     (DRL)TL-MSL   0.04                  ( )  FLAT TIDE
MN    0.41     DHQ        0.00     GMHWI
MTL   4.02     DLQ       -0.02     GMLWI


HIGHEST TIDE     4.91   21.7 HRS OCT 19, 1993
LOWEST  TIDE     1.83   16.7 HRS OCT 30, 1993

ARCHIVED  TID  EID  VID     START         STOP     SETTING  CNST   KPT          DATUM IS ..........
93 10 15  255  255  206   93  9 13  8   93 10  1 23       0     0   136
93 11 12  255  255  206   93 10  1 17   93 10  1 23       0     0   170
93 11 12  255  255  206   93 10  2  0   93 11  1 23       0     0   170
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                                              NOAA/NOS (NATIONAL OCEAN SERVICE)
                                              TIDES, HIGH AND LOW WATERS (FEET)


6778490 PORT MANSFIELD, TX  (NGWLMS)                     TM   OW  D
OCT, 1993
           HIGH              LOW                        HIGH              LOW                        HIGH              LOW
DAY     TIME  HEIGHT     TIME  HEIGHT        DAY     TIME  HEIGHT     TIME  HEIGHT        DAY     TIME  HEIGHT     TIME  HEIGHT
  1                                           11                  >  4.5    2.84         21

  2   >  4.6    2.95                          12   > 10.9    2.96                          22   >  6.5    2.71   >  0.7    2.50
                       > 15.5    2.84
  3   >  2.4    2.94                          13                                         23                    >  0.8    2.36
                                                                    > 13.6    2.77
  4                                           14     15.5    3.18                          24
                       > 18.3    2.50                > 22.7    3.17     19.0    3.06
  5   >  7.9    2.66                          15                                         25
                       > 15.8    2.50                               > 19.1    2.97
  6                                           16   >  0.7    3.10                          26

  7                                           17                                         27
                                                                    > 21.8    2.82              > 12.0    3.18
  8                                           18                                         28
                                                   > 15.6    2.94   > 18.9    2.77                               > 19.8    2.65
  9   >  9.9    2.93                          19   >  7.9    3.02                          29   >  8.3    2.85
                                                                    > 20.5    2.82                               > 16.7    2.69
 10                    >  3.5    2.83         20   > 12.0    3.12                          30   >  4.5    3.39
      > 14.9    3.15                               > 23.8    3.25   > 19.6    3.00
                                                                                           31                    >  0.9    1.83


MEANS FOR OCT 1, 1993 - OCT 31, 1993


MHW   3.03      MTL-MSL    0.07      GT             0.35                         KEY
MLW   2.69      MHHW       3.02      (DRL)TL        2.84                        > HIGHER HIGH/LOWER LOW
MSL   2.79      MLLW       2.67      (DRL)TL-MSL    0.05
MN    0.34      DHQ       -0.01      GMHWI
MTL   2.86      DLQ        0.02      GMLWI


HIGHEST TIDE     3.39    4.5 HRS OCT 30, 1993
LOWEST  TIDE     1.83    0.9 HRS OCT 31, 1993

ARCHIVED  TID  EID  VID      START        STOP    SETTING  CNST   KPT            DATUM IS ..........
93 11  4  255  255  206   93  9 27 10   93 10  1 23        0     0    69
          206  245  245   93 10  1 17   93 10  1 23        0     0   141
          206  245  245   93 10  2  0   94  2  1 23        0     0   141
```

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                                                   NOAA/NOS (NATIONAL OCEAN SERVICE)
                                                   TIDES, HIGH AND LOW WATERS (FEET)



6779770 PORT ISABEL, TX  (NGWLMS)                            TM   OW  D
OCT, 1993
            HIGH              LOW                          HIGH              LOW                           HIGH              LOW
DAY       TIME  HEIGHT     TIME  HEIGHT          DAY     TIME  HEIGHT     TIME  HEIGHT          DAY      TIME  HEIGHT     TIME  HEIGHT
  1        8.6    5.50      4.1    5.20           11  >  6.1    6.00                             21  >  7.0    5.99
        > 22.2    5.72   > 15.6    4.86                                > 23.3    4.55                                > 21.0    4.32
  2                                               12  >  7.3    5.62                             22  >  7.8    5.69
                         > 16.4    4.32                 18.7    5.42     14.3    5.14                                > 19.5    4.53
  3  >  0.4    5.30                               13  >  7.5    5.46      0.2    4.75            23  >  5.5    5.58
                         > 16.5    4.21               > 20.6    5.60   > 14.5    4.66                                > 21.3    4.83
  4  >  0.7    5.43                               14     8.5    5.37      3.3    4.85            24  >  7.6    5.79
                         > 17.6    4.16               > 21.1    5.89   > 14.8    4.57                                > 23.9    5.20
  5  >  2.6    5.43                               15     8.7    5.42      5.2    5.20            25  >  6.3    5.74
                         > 18.3    4.08               > 21.7    5.86   > 14.3    4.42                   19.7    5.85   > 13.9    5.44
  6  >  4.4    5.62                               16                                             26  >  5.7    5.99      1.1    5.69
                         > 18.5    4.12               > 23.5    5.54   > 15.2    3.76                 > 20.2    5.88   > 13.7    5.45
  7  >  6.6    5.59                               17                                             27     6.9    5.84      1.7    5.61
                         > 19.2    4.47                                > 16.5    3.67                 > 20.0    5.95   > 13.3    5.20
  8  >  5.5    5.86                               18  >  0.4    5.61                             28
                         > 19.9    4.46                                > 17.1    3.61                 > 22.5    5.63   > 14.2    4.67
  9  >  7.3    5.98                               19  >  2.9    5.58                             29
                         > 22.3    4.47                                > 18.0    3.70                   22.2    5.71   > 13.3    4.75
 10  >  7.1    6.14                               20  >  4.5    5.65                             30  >  6.8    5.80      2.1    5.53
                         > 22.3    4.82                                > 19.3    3.97                 > 23.8    5.57   > 13.8    4.58
                                                                                                 31
                                                                                                                     > 15.9    3.39


MEANS FOR OCT 1, 1993 - OCT 31, 1993


MHW   5.69      MTL-MSL   -0.02      GT             1.28                           KEY
MLW   4.61      MHHW       5.72      (DRL)TL        5.08                         >  HIGHER HIGH/LOWER LOW
MSL   5.17      MLLW       4.44      (DRL)TL-MSL   -0.09
MN    1.08      DHQ        0.02      GMHWI
MTL   5.15      DLQ        0.17      GMLWI


HIGHEST TIDE     6.14    7.1 HRS OCT 10, 1993
LOWEST  TIDE     3.39   15.9 HRS OCT 31, 1993

ARCHIVED  TID  EID  VID      START          STOP    SETTING  CNST   KPT           DATUM IS ..........
93 10 15  255  255  206   93  6  2  0   93 10  1 23        0     0   232
93 11 12  255  255  206   93 10  1 17   93 10  1 23        0     0   194
93 11 12  255  255  206   93 10  2  0   93 11  1 23        0     0   194
```

# APPENDIX III

```
WARNING MESSAGES FOR HL FILE GENERATED FOR STATION 6778490 VERSION 2
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/10/ 2/21.0 TO 93/10/ 3/ 3.4
DOUBLE TIDE AT 93/10/ 2/15.6
TIDE RANGE UNDER MINIMUM AT 93/10/ 3/17.0
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/10/ 4/ 0.5 TO 93/10/ 4/ 6.9
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/10/ 5/ 6.0 TO 93/10/ 5/12.4
DOUBLE TIDE AT 93/10/ 4/18.3
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/10/12/ 0.0 TO 93/10/12/ 6.4
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/10/12/ 7.0 TO 93/10/12/13.4
TIDE RANGE UNDER MINIMUM AT 93/10/11/ 4.5
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/10/12/23.0 TO 93/10/13/ 5.4
DOUBLE TIDE AT 93/10/12/20.3
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/10/16/15.5 TO 93/10/16/21.9
DOUBLE TIDE AT 93/10/16/ 0.7
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/10/17/17.0 TO 93/10/17/23.4
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/10/18/ 5.0 TO 93/10/18/11.4
DOUBLE TIDE AT 93/10/17/ 4.5
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/10/22/10.0 TO 93/10/22/16.4
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/10/23/ 3.5 TO 93/10/23/ 9.9
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/10/23/ 9.5 TO 93/10/23/15.9
DOUBLE TIDE AT 93/10/23/ 0.8
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/10/28/ 5.0 TO 93/10/28/11.4
DOUBLE TIDE AT 93/10/28/ 4.1
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/10/29/ 5.5 TO 93/10/29/11.9
DOUBLE TIDE AT 93/10/28/19.8
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/10/31/11.0 TO 93/10/31/17.4
TIDE RANGE UNDER MINIMUM AT 93/10/31/ 8.4
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/11/ 1/ 5.0 TO 93/11/ 1/11.4
DOUBLE TIDE AT 93/10/31/19.3
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/11/ 3/ 8.0 TO 93/11/ 3/14.4
TIDE RANGE UNDER MINIMUM AT 93/11/ 3/ 5.7
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/11/ 8/19.5 TO 93/11/ 9/ 1.9
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/11/16/ 4.0 TO 93/11/16/10.4
TIDE RANGE UNDER MINIMUM AT 93/11/16/ 0.1
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/11/18/ 4.5 TO 93/11/18/10.9
DOUBLE TIDE AT 93/11/17/23.0
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/11/18/20.5 TO 93/11/19/ 2.9
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/11/20/18.5 TO 93/11/21/ 0.9
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/11/21/ 8.0 TO 93/11/21/14.4
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/11/22/ 6.0 TO 93/11/22/12.4
DOUBLE TIDE AT 93/11/22/ 0.8
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/11/22/19.0 TO 93/11/23/ 1.4
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/11/23/ 1.0 TO 93/11/23/ 7.4
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/11/23/12.5 TO 93/11/23/18.9
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/11/24/22.5 TO 93/11/25/ 4.9
DOUBLE TIDE AT 93/11/24/19.0
CURVE FIT FAILURE IN TIME PERIOD 93/11/26/11.0 TO 93/11/26/13.9
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/11/28/ 5.5 TO 93/11/28/11.9
TIDE RANGE UNDER MINIMUM AT 93/11/27/21.7
DOUBLE TIDE AT 93/11/28/ 0.5
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/11/30/ 5.5 TO 93/11/30/11.9
DOUBLE TIDE AT 93/11/29/17.7
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/12/ 3/ 8.5 TO 93/12/ 3/14.9
TIDE RANGE UNDER MINIMUM AT 93/12/ 2/11.9
DOUBLE TIDE AT 93/12/ 2/18.6
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/12/ 6/ 6.5 TO 93/12/ 6/12.9
TIDE RANGE UNDER MINIMUM AT 93/12/ 6/ 5.0
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/12/ 7/ 3.5 TO 93/12/ 7/ 9.9
TIDE RANGE UNDER MINIMUM AT 93/12/ 6/23.4
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/12/ 8/ 1.0 TO 93/12/ 8/ 7.4
TIDE RANGE UNDER MINIMUM AT 93/12/ 7/ 2.1
DOUBLE TIDE AT 93/12/ 7/14.8
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/12/14/22.0 TO 93/12/15/ 4.4
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/12/15/16.5 TO 93/12/15/22.9
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/12/15/22.5 TO 93/12/16/ 4.9
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```
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/12/16/ 7.0 TO 93/12/16/13.4
TIDE RANGE UNDER MINIMUM AT 93/12/14/15.0
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/12/23/14.0 TO 93/12/23/20.4
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/12/25/23.0 TO 93/12/26/ 5.4
TIDE RANGE UNDER MINIMUM AT 93/12/25/16.2
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/12/27/ 1.0 TO 93/12/27/ 7.4
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/12/28/ 1.5 TO 93/12/28/ 7.9
DOUBLE TIDE AT 93/12/27/18.6
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 93/12/30/21.0 TO 93/12/31/ 3.4
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 94/ 1/ 2/22.5 TO 94/ 1/ 3/ 4.9
TIDE RANGE UNDER MINIMUM AT 94/ 1/ 2/12.4
DOUBLE TIDE AT 94/ 1/ 2/18.0
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 94/ 1/ 4/ 5.0 TO 94/ 1/ 4/11.4
TIDE RANGE UNDER MINIMUM AT 94/ 1/ 3/15.0
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 94/ 1/ 4/23.5 TO 94/ 1/ 5/ 5.9
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 94/ 1/ 7/ 1.0 TO 94/ 1/ 7/ 7.4
DOUBLE TIDE AT 94/ 1/ 6/18.0
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 94/ 1/11/ 7.0 TO 94/ 1/11/13.4
TIDE RANGE UNDER MINIMUM AT 94/ 1/10/ 8.3
DOUBLE TIDE AT 94/ 1/10/16.9
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 94/ 1/14/ 1.0 TO 94/ 1/14/ 7.4
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 94/ 1/14/ 7.0 TO 94/ 1/14/13.4
DOUBLE TIDE AT 94/ 1/13/18.0
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 94/ 1/15/ 1.0 TO 94/ 1/15/ 7.4
TIDE RANGE UNDER MINIMUM AT 94/ 1/14/21.7
DOUBLE TIDE AT 94/ 1/15/ 0.1
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 94/ 1/19/ 8.0 TO 94/ 1/19/14.4
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 94/ 1/20/ 3.0 TO 94/ 1/20/ 9.4
TIDE RANGE UNDER MINIMUM AT 94/ 1/19/ 2.6
FLAT TIDE AT 94/ 1/20/13.6
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 94/ 1/23/16.5 TO 94/ 1/23/22.9
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 94/ 1/24/ 1.0 TO 94/ 1/24/ 7.4
NO SIGNIFICANT CHANGE IN WATER HEIGHT FOR 6 HOURS ON 94/ 1/31/ 5.0 TO 94/ 1/31/11.4
DOUBLE TIDE AT 94/ 1/31/ 1.3
TIDE RANGE UNDER MINIMUM AT 94/ 1/31/16.3
```

# APPENDIX IV

```
    6779770 PORT ISABEL, TX  (NGWLMS)
    Lat.  26  37N Long.  97 128W (  97.21)
    Sep  1, 1992 - Aug 31, 1993
    365 Day Least Squares Harmonic Analysis.
Multiple correlation coefficient with 37 constituents.

     N     Constituent    Total reduction of variance

     1        4 - K1                     0.2515
     2        6 - O1                     0.4881
     3       21 - Ssa                    0.5580
     4        1 - M2                     0.6186
     5       22 - Sa                     0.6745
     6       30 - P1                     0.6982
     7       26 - Q1                     0.7096
     8        3 - N2                     0.7132
     9        2 - S2                     0.7166
    10       18 - M1                     0.7197
    11       20 - Mm                     0.7228
    12       17 - S1                     0.7239
    13       19 - J1                     0.7250
    14       29 - 2Q1                    0.7254
    15       15 - OO1                    0.7258
    16       25 - Rho1                   0.7261
    17       23 - Msf                    0.7263
    18       35 - K2                     0.7265
    19       11 - Nu2                    0.7266
    20       32 - M3                     0.7267
    21       34 - 2MK3                   0.7268
    22       13 - Mu2                    0.7269
    23        8 - MK3                    0.7270
    24       14 - 2N2                    0.7270
    25       24 - Mf                     0.7271
    26        5 - M4                     0.7271
    27       33 - L2                     0.7271
    28       28 - R2                     0.7271
    29       27 - T2                     0.7271
    30       16 - Lamd                   0.7272
    31       10 - MN4                    0.7272
    32       37 - MS4                    0.7272
    33        9 - S4                     0.7272
    34        7 - M6                     0.7272
    35       36 - M8                     0.7272
    36       31 - 2SM2                   0.7272

Constituent (12 - S6  ) reduces residual variance  by 0.0000006

Multiple corr. coef. = 0.8527

Total reduction of variance = 0.7272

Standard deviation of error =   0.3192
```

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6779770 PORT ISABEL, TX  (NGWLMS)
Lat.  26  37N Long.  97 128W (  97.21)
Sep  1, 1992 - Aug 31, 1993
365 Day Least Squares Harmonic Analysis.
Total red. of var. = 0.7272   Std. dev. of error = 0.3192


(Node factors considered)
   MSL     Constit.       H           Kappa        Kpr-K     Kappa Prime      Speed

  4.852     1-M2       0.212         80.38      -165.58        274.8          28.9841
            2-S2       0.051         88.53      -165.58        283.0          30.0000
            3-N2       0.052         61.14      -165.58        255.6          28.4397
            4-K1       0.435        300.37        97.21         37.6          15.0411
            5-M4       0.005        107.59        28.84        136.4          57.9682
            6-O1       0.429        292.87        97.21         30.1          13.9430
            7-M6       0.002        246.63      -136.74        109.9          86.9523
            8-MK3      0.007        191.27       -68.37        122.9          44.0252
            9-S4       0.002        289.18        28.84        318.0          60.0000
           10-MN4      0.002         72.99        28.84        101.8          57.4238
           11-Nu2      0.009         57.26      -165.58        251.7          28.5126
           12-S6       0.000          5.54      -136.74        228.8          90.0000
           13-Mu2      0.008         14.46      -165.58        208.9          27.9682
           14-2N2      0.006        101.22      -165.58        295.6          27.8954
           15-OO1      0.019        309.21        97.21         46.4          16.1391
           16-Lamd     0.003        186.54      -165.58         21.0          29.4556
           17-S1       0.030        228.69        97.21        325.9          15.0000
           18-M1       0.025        312.54        97.21         49.8          14.4967
           19-J1       0.028        300.86        97.21         38.1          15.5854
           20-Mm       0.047        328.81         0.00        328.8           0.5444
           21-Ssa      0.228         73.44         0.00         73.4           0.0821
           22-Sa       0.205        227.56         0.00        227.6           0.0411
           23-Msf      0.014        263.58         0.00        263.6           1.0159
           24-Mf       0.006        310.79         0.00        310.8           1.0980
           25-Rho1     0.015        255.28        97.21        352.5          13.4715
           26-Q1       0.095        274.18        97.21         11.4          13.3987
           27-T2       0.003         87.51      -165.58        281.9          29.9589
           28-R2       0.003          3.25      -165.58        197.7          30.0411
           29-2Q1      0.018        276.62        97.21         13.8          12.8543
           30-P1       0.133        301.72        97.21         38.9          14.9589
           31-2SM2     0.001        169.54      -165.58          4.0          31.0159
           32-M3       0.009        142.15       -68.37         73.8          43.4762
           33-L2       0.005        148.37      -165.58        342.8          29.5285
           34-2MK3     0.008        155.49       -68.37         87.1          42.9271
           35-K2       0.012        116.02      -165.58        310.4          30.0821
           36-M8       0.001        303.64        57.68          1.3         115.9364
           37-MS4      0.002        109.47        28.84        138.3          58.9841
```

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Recapitulation of Harmonic Constant Reduction
Station:  6779770 PORT ISABEL, TX  (NGWLMS)
Lat.  26  37N Long.  97 128W (  97.21)
Length of series:  365 days
Beginning and ending dates of series: Sep  1, 1992 - Aug 31, 1993
Source of constants: N.O.S Least Squares Harmonic Analysis
* EPOCHS AND INTERVALS REFERRED TO LOCAL MERIDIAN EXCEPT AS NOTED

AMPLITUDE RELATIONS                 EPOCH RELATIONS IN DEGREES

M4/M2 =  0.025                      M2-K1-O1 = -512.9
S2/M2 =  0.241                      MKO = -256.4 ( 103.6)
N2/M2 =  0.246                      M2/29. =    2.8
2(K1+O1) =    1.728                 MKO-.5V =
(K1+O1)/M2 =  4.082                 MKO-.5W-90. =
(K1+O1)/(M2+S2) =  3.291


AGE OF INEQUALITIES IN HOURS        MEAN TIDE LEVEL

PHASE AGE =    8.0                  MTL =  0.097
PARALLAX AGE =   35.3
DIURNAL AGE =    6.8


RANGES (FEET)                       RATIOS                  INEQUALITIES

MEAN(MN) =                          SG/MN =                   DHQ =
SPRING(SG) =                        NP/MN =                   DLQ =
NEAP(NP) =                          PN/MN =                 TCHWQ =
PERIGEAN(PN) =                      AN/MN =                 TCLWQ =
APOGEAN(AN) =
GREAT TROPIC(GC) =   1.800
GREAT DIURNAL(GT) =   1.364                  LI(HOURS) =   6.707


LOCAL INTERVALS        *GREENWICH INTERVALS    HARMONIC CONSTANTS INPUT
    (HOURS)                  (HOURS)

   HWI =                   HWI =               K1  0.4349 300.37
   LWI =                   LWI =               O1  0.4289 292.87
TCHHWI = 18.486         TCHHWI =  0.353        P1  0.1326 301.72
TCLLWI =  8.506         TCLLWI = 15.214        MU2 0.0077  14.46
TCLHWI =                TCLHWI =               S2  0.0509  88.53
TCHLWI =                TCHLWI =               M2  0.2116  80.38
                                               M4  0.0053 107.59
                                               M6  0.0016 246.63
                                               N2  0.0520  61.14
```

# APPENDIX V

TEXAS 877 5870

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL OCEAN SERVICE

# TIDAL BENCH MARKS

## BOB HALL PIER, CORPUS CHRISTI, GULF OF MEXICO

LATITUDE: 27°34.8'N LONGITUDE: 97°13.0'W
NOAA CHART: 11307 USGS QUAD: CRANE ISLANDS SW

To reach the tidal bench marks from the intersection of County Park Road 53 and County Park Road 22 on North Padre Island, proceed south on County Park Road 22 for 2.1 miles (3.4 km) to Padre Balli Park, turn left on the park entrance road and proceed east for 0.4 mile (0.6 km), turn right on the beach road and follow this road for approximately 0.3 mile (0.5 km) to Bob Hall Pier. The bench marks are at the entrance to the park, on the pier, and in the park compound. The tide gage and electric tape gage are on the NW corner of the pier.

……

### BENCH MARK STAMPING: HOLIDAY 1980

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NGS Reference Mark
SETTING CLASSIFICATION: Concrete Monument

The bench mark is set flush in the top of a concrete monument on the south side of the entrance road to Padre Balli Park, in line with wooden posts, 101.5 feet (30.9 m) WNW of the centerline of Elliff Road, 37.2 feet (11.3 m) NE of power pole #5, 16.0 feet (4.9 m) SSW of the centerline of the entrance road, 11.5 feet (3.5 m) north of a wooden pole with a metal pipe and shield marking the underground cable route, and level with the ground.

### BENCH MARK STAMPING: 5870 A 1983

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Galvanized Steel Rod

The bench mark is NW of Bob Hall Pier, 21.0 feet (6.4 m) south of the centerline of the park access road leading to Bob Hall Pier, 19.7 feet (6.0 m) SE of the NE corner of the pavement of the parking lot for camping area #1, and 10 feet (3 m) east of the entrance sign for campsite #1. The bench mark is crimped to a galvanized steel rod driven 19 feet (6 m) to refusal, and encased in a 4-inch PVC pipe and concrete kickblock.

TEXAS 877 5870

BOB HALL PIER, CORPUS CHRISTI, GULF OF MEXICO

BENCH MARK STAMPING: 5870 C 1983

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Galvanized Steel Rod

The bench mark is on the Padre Balli Park compound at the end of the park entrance road, 52.8 feet (16.1 m) north of the centerline of the road leading to the beach, 47.0 feet (14.3 m) east of the centerline of the divider street between the park entrance road and the park exit road, and 9 feet (3 m) east of power pole #CPLG 880 SPP 440. The bench mark is crimped to a galvanized steel rod driven 16 feet (5 m) to refusal, and encased in a 4-inch PVC pipe and concrete kickblock.

BENCH MARK STAMPING: 5870 D 1983

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Galvanized Steel Rod

The bench mark is on the Padre Balli Park compound in the median of the park entrance road, 134 feet (41 m) west of the center of the sewer line invert manhole cover located in the median, 52.5 feet (16.0 m) NNE of power pole #4, and 18.3 feet (5.6 m) north of the centerline of the south entrance road. The bench mark is crimped to a galvanized steel rod driven 19 feet (6 m) to refusal, and encased in a 4-inch PVC pipe and concrete kickblock.

BENCH MARK STAMPING: 5870 E 1983

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Galvanized Steel Rod

The bench mark is at the County Park Road 22 entrance to Padre Balli Park, 46.8 feet (14.3 m) south of the south entrance road, 33 feet (10 m) west of power pole #38-1, and 3 feet (1 m) east of the south corner of a brick flower bed. The bench mark is crimped to a galvanized steel rod driven 20 feet (6 m) to refusal, and encased in a 4-inch PVC pipe and concrete kickblock.

TEXAS 877 5870

BOB HALL PIER, CORPUS CHRISTI, GULF OF MEXICO

BENCH MARK STAMPING: 5870 F 1985

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Stainless Steel Rod

The bench mark is NW of Bob Hall Pier near the SW corner of the public restrooms, 78.4 feet (23.9 m) east of an octogon shaped bath house, 73.0 feet (22.3 m) WNW of the centerline of the access road, 59.0 feet (18.0 m) NNW of wooden pole #32 with light, 2.5 feet (0.8 m) WSW of the SW corner of the concrete block restroom, and marked by a metal witness post. The bench mark is level with the ground, crimped to a stainless steel rod driven 56 feet (17 m) to refusal, and encased in a 5-inch PVC pipe and concrete kickblock.

BENCH MARK STAMPING: 5870 G 1985

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Concrete Pier Pile Cap

The bench mark is set flush in the top of the concrete pier pile cap at the inshore end of Bob Hall Pier, 22.8 feet (6.9 m) ESE of a chain link fence gate, 19.2 feet (5.9 m) SE of the SE corner of the restrooms on the pier, 15.0 feet (4.6 m) south of the north face of the pier, and level with the pier.

BENCH MARK STAMPING: 5870 H 1985

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Stainless Steel Rod

The bench mark is at the entrance/exit to Padre Balli Park on the north side of the exit road, 85.0 feet (25.9 m) south of power pole #185, 48.0 feet (14.6 m) NNE of the centerline of the exit road, 2.0 feet (0.6 m) NE of the most NE corner of a concrete block wall, and marked by a metal witness post. The bench mark is level with the ground, crimped to a stainless steel rod driven 46 feet (14 m) to refusal, and encased in a 5-inch PVC pipe and concrete kickblock.

TEXAS 877 5870

BOB HALL PIER, CORPUS CHRISTI, GULF OF MEXICO

BENCH MARK STAMPING: 5870 J 1985

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Concrete Foundation

The bench mark is set flush at the north end of the concrete foundation of the waste disposal station in the Padre Balli Park campground, 64.0 feet (19.5 m) SSW of the end of the pavement at the north end of the campground, 46.0 feet (14.0 m) SSE of power pole #202, 27.0 feet (8.2 m) WNW of the pavement at the east end of the campground, and 0.5 foot (0.2 m) above ground level.

BENCH MARK STAMPING: 5870 K 1985

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Concrete Pier Pile Cap

The bench mark is set flush in the top of the concrete pier pile cap at the offshore end of Bob Hall Pier, 18.0 feet (5.5 m) WNW of the offshore end of the pier, 12.5 feet (3.8 m) SSE of the north face of the pier, 4.3 feet (1.3 m) NNE of the south face of the pier, and level with the pier.

## TEXAS 877 5870

## BOB HALL PIER, CORPUS CHRISTI, GULF OF MEXICO

Tidal datums at Bob Hall Pier, Corpus Christi, Gulf of Mexico are based on the following:

LENGTH OF SERIES = 42 MONTHS
TIME PERIOD = JULY 1985-DECEMBER 1988
TIDAL EPOCH = 1960-1978
CONTROL TIDE STATION = PORT ISABEL (877 9770)

Elevations of tidal datums referred to mean lower low water (MLLW) are as follows:

HIGHEST OBSERVED WATER LEVEL (09/16/88) = 4.94 FEET
MEAN HIGHER HIGH WATER (MHHW) = 1.69 FEET
MEAN HIGH WATER (MHW) = 1.59 FEET
MEAN TIDE LEVEL (MTL) = 0.92 FEET
MEAN LOW WATER (MLW) = 0.25 FEET
MEAN LOWER LOW WATER (MLLW) = 0.00 FEET
LOWEST OBSERVED WATER LEVEL (01/26/87) = -1.62 FEET

Bench mark elevation information:

| | ELEVATION IN FEET ABOVE: | |
|---|---|---|
| BENCH MARK STAMPING | MLLW | MHW |
| HOLIDAY 1980 | 7.09 | 5.50 |
| 5870 A 1983 | 9.27 | 7.68 |
| 5870 C 1983 | 6.51 | 4.92 |
| 5870 D 1983 | 6.99 | 5.40 |
| 5870 E 1983 | 6.39 | 4.80 |
| 5870 F 1985 | 10.02 | 8.43 |
| 5870 G 1985 | 19.00 | 17.41 |
| 5870 H 1985 | 7.18 | 5.59 |
| 5870 J 1985 | 9.16 | 7.57 |
| 5870 K 1985 | 16.95 | 15.36 |

The estimated highest water level to the nearest half-foot is 7.5 feet above mean lower low water. The estimated lowest water level to the nearest half-foot is 3.0 feet below mean lower low water. Estimates are based on observed extreme water levels at Port Isabel (877 9770).

TEXAS 877 4770

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL OCEAN SERVICE

# TIDAL BENCH MARKS

## ROCKPORT, ARANSAS BAY

LATITUDE: 28°01.4'N LONGITUDE: 97°02.8'W
NOAA CHART: 11313 USGS QUAD: ROCKPORT

To reach the bench marks from the intersection of Business State Highway 35 (Brodway) and State Highway 35 in Rockport, proceed south on Broadway for 0.2 mile (0.3 km) to the junction of Broadway and Concho Streets, turn left heading east on Concho Street, follow this road to the right around Rockport Yacht Basin for 0.25 mile (0.40 km) to Texas Parks and Wildlife Marine Laboratory. The bench marks are near the yacht basin. The tide gauge is on the southernmost pier in the yacht basin.

……

### BENCH MARK STAMPING: NO 3 1934

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: USC&GS Tidal Bench Mark
SETTING CLASSIFICATION: Concrete Sidewalk

The primary bench mark is set in the sidewalk at the junction of North Street and Business State Highway 35, 105 feet (32 m) north of the centerline of North Street, 34 feet (10 m) west of the centerline of the southbound Business State Highway 35 lanes, 13 feet (4 m) west of the curb of the highway, 4 feet (1 m) south of the NE corner of the L.M. Bracht building, and about 1 foot (0.3 m) above the level of the highway.

### BENCH MARK STAMPING: NO 4 1948

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: USC&GS Tidal Bench Mark
SETTING CLASSIFICATION: Sea Wall

The bench mark is set flush in the top of the concrete sea wall on the east shore of the yacht basin and near the SE end of the sea wall, 34.8 feet (10.6 m) north of the north edge of the pier leading to the house, 24 feet (7 m) west of the west end of the Texas Parks and Wildlife Marine Laboratory building, and 1 foot (0.3 m) south of a chain link fence with gate.

### BENCH MARK STAMPING: 7 1948

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: USC&GS Tidal Bench Mark
SETTING CLASSIFICATION: Sea Wall

The bench mark is set flush in the top of the concrete sea wall on the east side of the yacht basin, 114 feet (35 m) SE of the SW corner of steps leading to a museum building, 61 feet (19 m) NW of a lamp post, 0.5 foot (0.2 m) east of the upper ledge of the sea wall, and about level with road.

### BENCH MARK STAMPING: 8 1948

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: USC&GS Tidal Bench Mark
SETTING CLASSIFICATION: Concrete Foundation

The bench mark is set in the top of a concrete foundation of an abandoned lamp post on the NE side of the yacht basin, 120 feet (37 m) east of the yacht basin sea wall, 75 feet (23 m) west of the third power line pole from Aransas Bay, and 14 feet (4 m) east of the fourth power line pole from the NE corner of the yacht basin.

### BENCH MARK STAMPING: NO 10 1975

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Concrete Sea Wall

The bench mark is set flush in the center of the concrete sea wall at the north end of the yacht basin, 44.4 feet (13.5 m) SW of a utility pole with light in front of Texas Maritime Museum, 36.5 feet (11.1 m) SE of the centerline of the street around the yacht basin, and 17.2 feet (5.2 m) NE of the NE corner of Bea's bait stand.

### BENCH MARK STAMPING: NO 11 1975

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Retaining Wall

The bench mark is set flush on top of a retaining wall at the east side of the parking lot for Western Auto Store, 49 feet (15 m) west of the centerline of Austin Street, 45.9 feet (14.0 m) north of a drive beside Western Auto, 3.3 feet (1.0 m) south of the NE corner of the retaining wall, and 1 foot (0.3 m) above ground.

TEXAS 877 4770

ROCKPORT, ARANSAS BAY

BENCH MARK STAMPING: NO 12 1975

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Concrete Sidewalk

The bench mark is set flush in the sidewalk at the intersection of Magnolia and North Streets, 51 feet (16 m) west of the SW corner of 1008 East North Street, 41 feet (12 m) east of the centerline of Magnolia Street, 29 feet (9 m) north of the centerline of North Street, and 0.5 foot (0.2 m) above street level.

BENCH MARK STAMPING: NO STAMPING 1

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: Texas Highway Department Bench Mark
SETTING CLASSIFICATION: Concrete Monument

The bench mark is set in the top of a concrete monument in the SW portion of a small city playground and picnic area, 72.8 feet (22.2 m) NW of the flag pole at the south end of the picnic area, 58 feet (18 m) north of a manhole on the east side of Business State Highway 35, 50 feet (15 m) east of the centerline of the highway, and 0.5 foot (0.2 m) above ground.

## TEXAS 877 4770

## ROCKPORT, ARANSAS BAY

Tidal datums at Rockport, Aransas Bay are based on the following:

| | |
|---|---|
| LENGTH OF SERIES | = 9 YEARS |
| TIME PERIOD | = 1980-1988 |
| TIDAL EPOCH | = 1960-1978 |
| CONTROL TIDE STATION | = PENSACOLA, FL (872 9840) |

Elevations of tidal datums referred to mean lower low water (MLLW) are as follows:

| | |
|---|---|
| HIGHEST OBSERVED WATER LEVEL (08/10/80) | = 4.74 FEET |
| MEAN HIGHER HIGH WATER (MHHW) | = 0.36 FEET |
| MEAN HIGH WATER (MHW) | = 0.35 FEET |
| MEAN TIDE LEVEL (MTL) | = 0.18 FEET |
| MEAN LOW WATER (MLW) | = 0.00 FEET |
| MEAN LOWER LOW WATER (MLLW) | = 0.00 FEET |
| LOWEST OBSERVED WATER LEVEL (02/29/84) | = -1.98 FEET |

Bench mark elevation information:

| | ELEVATION IN FEET ABOVE: | |
|---|---|---|
| BENCH MARK STAMPING | MLLW | MHW |
| NO 3 1934 | 4.29 | 3.94 |
| NO 4 1948 | 3.39 | 3.04 |
| 7 1948 | 3.41 | 3.06 |
| 8 1948 | 5.30 | 4.95 |
| NO 10 1975 | 3.51 | 3.16 |
| NO 11 1975 | 5.36 | 5.01 |
| NO 12 1975 | 4.71 | 4.36 |
| NO STAMPING 1 | 5.67 | 5.32 |

TEXAS 877 5792

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL OCEAN SERVICE

# TIDAL BENCH MARKS

## PACKERY CHANNEL, LAGUNA MADRE

LATITUDE: 27°38.0′ LONGITUDE: 97°14.2′W
NOAA CHART: 11309 USGS QUAD: CRANE ISLANDS NW

To reach the tidal bench marks from the intersection of State Highway 358 (South Padre Island Drive) and State Highway 286 in Corpus Christi, proceed SE on State Highway 358 for 10 miles (16 km) to a 'Y', turn or bear right at the 'Y' on Park Road 22 and continue SE for 4.3 miles (6.9 km) across the Intracoastal Waterway on John F. Kennedy (JFK) Causeway/Bridge; turn immediately right under the causeway to the north access road to Coastway Bait and Tackle Shop. The bench marks are at the Bait and Tackle Shop and under the JFK Causeway/Bridge. The tide gauge is on the east side of the Coastway Bait and Tackle Shop.

……

### BENCH MARK STAMPING: 5792 A 1988

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Stainless Steel Rod

The primary bench mark is at the most northerly NW corner of the parking lot at the Coastway Bait and Tackle Shop, 293 feet (89 m) NE of the north face of the north column of the tenth bridge support from the east end of the JFK Causeway, 53.5 feet (16.3 m) NW of the face of the SW timber piling, 30.8 feet (9.4 m) west of the NW timber piling face, 5.5 feet (1.7 m) east of the west bulkhead wall, and 2.0 feet (0.6 m) south of a witness post. The bench mark is 0.2 foot (0.1 m) below the ground, crimped to a stainless steel rod driven 56 feet (17 m) to substantial resistance, and encased in a 5-inch PVC pipe and concrete kickblock.

### BENCH MARK STAMPING: 5792 B 1988

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Stainless Steel Rod

The bench mark is 4.8 feet (1.5 m) from the west face of the center column of the eleventh bridge support from the east end of the JFK Causeway, and 2.5 feet (0.8 m) NNW of a witness post. The bench mark is 0.2 foot (0.1 m) below the ground, crimped to a stainless steel rod driven 36 feet (11 m) to substantial resistance, and encased in a 5-inch PVC pipe and concrete kickblock.

TEXAS 877 5792

PACKERY CHANNEL, LAGUNA MADRE

BENCH MARK STAMPING: 5792 C 1988

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Concrete Foundation

The bench mark is set flush in the concrete tie beam 1.6 feet (0.5 m) north of the north face of the center column of the seventh bridge support from the east end of the JFK Causeway, 3.0 feet (0.9 m) NE of a witness post, and 1.6 feet (0.5 m) above the ground.

BENCH MARK STAMPING: 5792 D 1988

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Stainless Steel Rod

The bench mark is 4.0 feet (1.2 m) south of the south face of the south column of the first bridge support from the east end of the JFK Causeway, and 3.5 feet (1.1 m) SE of a witness post. The bench mark is 0.2 foot (0.1 m) below the ground, crimped to a stainless steel rod driven 60 feet (18 m) to substantial resistance, and encased in a 5-inch PVC pipe and concrete kickblock.

BENCH MARK STAMPING: 5792 E 1988

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Concrete Foundation

The bench mark is set flush in the concrete tie beam 0.8 foot (0.2 m) north of the north face of the south column of the fifteenth bridge support from the east end of the JFK Causeway, 3.8 feet (1.2 m) SSW of a witness post, and 2.5 feet (0.8 m) above the ground.

# TEXAS 877 5792

## PACKERY CHANNEL, LAGUNA MADRE

Tidal datums at Packery Channel, Laguna Madre are based on the following:

LENGTH OF SERIES = 12 MONTHS
TIME PERIOD = SEPTEMBER 1992 - AUGUST 1993
TIDAL EPOCH = 1960-1978
CONTROL TIDE STATION = ROCKPORT (877 4770)

Elevations of tidal datums referred to mean lower low water (MLLW) are as follows:

HIGHEST OBSERVED WATER LEVEL (06/20/93) = 2.22 FEET
MEAN HIGHER HIGH WATER (MHHW) = 0.37 FEET
MEAN HIGH WATER (MHW) = 0.37 FEET
MEAN TIDE LEVEL (MTL) = 0.19 FEET
MEAN LOW WATER (MLW) = 0.01 FEET
MEAN LOWER LOW WATER (MLLW) = 0.00 FEET
LOWEST OBSERVED WATER LEVEL (12/28/89) = -1.04 FEET

Bench mark elevation information:

| | ELEVATION IN FEET ABOVE: | |
|---|---|---|
| BENCH MARK STAMPING | MLLW | MHW |
| 5792 A 1988 | 2.63 | 2.26 |
| 5792 B 1988 | 2.57 | 2.20 |
| 5792 C 1988 | 4.62 | 4.25 |
| 5792 D 1988 | 2.32 | 1.95 |
| 5792 E 1988 | 5.11 | 4.74 |

NOTICE:

Tidal datums at Packery Channel have been computed using a 1-year series. Since seasonal variations have a strong influence on water level variations in the Laguna Madre region, tidal datums are based on a minimum 1-year series. Tidal datums will be periodically updated as longer series become available.

TEXAS 877 6687

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL OCEAN SERVICE

# TIDAL BENCH MARKS

## YARBOROUGH PASS, LAGUNA MADRE

| | | | |
|---|---|---|---|
| LATITUDE: | 27°10.0'N | LONGITUDE: | 97°26.0'W |
| NOAA CHART: | 11304 | USGS QUAD: | YARBOROUGH PASS |

To reach the tidal bench marks from John F. Kennedy Causeway/Bridge, proceed south by boat down the Gulf Intracoastal Waterway (GIWW) for approximately 30 miles (48 km) to a spoil island on the east side of the channel. The bench marks are on the spoil island. The tide gauge is on a platform just north of USCG Buoy #57.

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### BENCH MARK STAMPING: 6687 A 1990

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Stainless Steel Rod

The primary bench mark is on the spoil island just south of Yarborough Pass cut, about 750 feet (229 m) S 75°E of the tide gauge platform, about 100 feet (30 m) east of the approximate waterline. The bench mark is level with the ground, crimped to a stainless steel rod driven 51 feet (16 m) to refusal, and encased in a 6-inch PVC pipe.

### BENCH MARK STAMPING: 6687 B 1990

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Stainless Steel Rod

The bench mark is on the spoil island just south of Yarborough Pass cut, 380.4 feet (115.9 m) S 3°W of Bench Mark 6687 A 1990. The bench mark is level with the ground, crimped to a stainless steel rod driven 44 feet (13 m) to substantial resistance, and encased in a 6-inch PVC pipe.

TEXAS 877 6687

YARBOROUGH PASS, LAGUNA MADRE

BENCH MARK STAMPING: 6687 C 1990

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Stainless Steel Rod

The bench mark is on the spoil island just south of Yarborough Pass cut, 250.6 feet (76.4 m) S 25°E of Bench Mark 6687 B 1990. The bench mark is level with the ground, crimped to a stainless steel rod driven 40 feet (12 m) to substantial resistance, and encased in a 6-inch PVC pipe.

BENCH MARK STAMPING: 6687 D 1990

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Stainless Steel Rod

The bench mark is on the spoil island just south of Yarbourough Pass cut, 370.8 feet (113.0 m) S 20°W of Bench Mark 6687 C 1990. The bench mark is level with the ground, crimped to a stainless steel rod driven 40 feet (12 m) to substantial resistance, and encased in a 6-inch PVC pipe.

BENCH MARK STAMPING: 6687 E 1990

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Stainless Steel Rod

The bench mark is on the spoil island just south of Yarbourough Pass cut, 251.2 feet (76.6 m) S 70°W of Bench Mark 6687 D 1990. The bench mark is level with the ground, crimped to a stainless steel rod driven 44 feet (13 m) to substantial resistance, and encased in a 6-inch PVC pipe.

TEXAS 877 6687

YARBOROUGH PASS, LAGUNA MADRE

Water level datum at Yarborough Pass, Laguna Madre is based on the following:

LENGTH OF SERIES = 12 MONTHS
TIME PERIOD = SEPTEMBER 1992 - AUGUST 1993
TIDAL EPOCH = 1960-1978
CONTROL TIDE STATION = PORT MANSFIELD (877 8490)

Elevations referred to mean water level (MWL) are as follows:

HIGHEST OBSERVED WATER LEVEL (10/31/91) = 1.69 FEET
MEAN WATER LEVEL (MWL) = 0.00 FEET
LOWEST OBSERVED WATER LEVEL (09/13/93) = -1.19 FEET

Bench mark elevation information:

| BENCH MARK STAMPING | ELEVATION IN FEET ABOVE: MWL |
|---|---|
| 6687 A 1990 | 3.74 |
| 6687 B 1990 | 3.23 |
| 6687 C 1990 | 2.60 |
| 6687 D 1990 | 2.85 |
| 6687 E 1990 | 3.87 |

NOTICE:

The astronomical tidal signal at Yarborough Pass is weak relative to high and low frequency non-tidal water level variations due to meteorological forcing, and is commonly masked by these effects. Therefore, NOS has designated this station as non-tidal for purposes of datum determination. Bench marks are referenced to an equivalent 19-year Mean Water Level (MWL) on the 1960-1978 National Tidal Datum Epoch. MWL is computed from an average of the hourly water level heights recorded during the above stated series and adjusted by the designated 19-year control station. Since seasonal variations have a strong influence on water level variations in the Laguna Madre region, MWL is based on a minimum 1-year series. The MWL datum will be periodically updated as longer series become available.

TEXAS 877 7562

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL OCEAN SERVICE

# TIDAL BENCH MARKS

## EL TORO ISLAND, LAGUNA MADRE

| | | | |
|---|---|---|---|
| LATITUDE: | 26°56.5'N | LONGITUDE: | 97°27.4'W |
| NOAA CHART: | 11304 | USGS QUAD: | POTRERO LOPENO NW |

To reach the tidal bench marks from the John F. Kennedy Causeway/Bridge, proceed south by boat down the Gulf Intracoastal Waterway (GIWW) for approximately 46 miles (74 km) to the vicinity of El Toro Island. The bench marks are on the spoil island NE of El Toro Island and SW of Cabin #1140. The tide gauge is located on the west side of the GIWW on the dock of Cabin #1140, NW of green marker #13.

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### BENCH MARK STAMPING: 9007 A 1990

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: CBI Tidal Bench Mark
SETTING CLASSIFICATION: Stainless Steel Rod

The primary bench mark is about 800 feet (244 m) S 48°W of the tide gauge on the dock of Cabin #1140. The bench mark is level with the ground, crimped to a stainless steel rod driven 48 feet (15 m) to substantial resistance, and encased in a 6-inch PVC pipe.

### BENCH MARK STAMPING: 9007 B 1990

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: CBI Tidal Bench Mark
SETTING CLASSIFICATION: Stainless Steel Rod

The bench mark is 277.0 feet (84.4 m) N 60°W of Bench Mark 9007 A 1990. The bench mark is level with the ground, crimped to a stainless steel rod driven 52 feet (16 m) to refusal, and encased in a 6-inch PVC pipe.

### BENCH MARK STAMPING: 9007 C 1990

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: CBI Tidal Bench Mark
SETTING CLASSIFICATION: Stainless Steel Rod

The bench mark is 389.0 feet (118.6 m) N 80°W of Bench Mark 9007 B 1990. The bench mark is level with the ground, crimped to a stainless steel rod driven 40 feet (12 m) to substantial resistance, and encased in a 6-inch PVC pipe.

TEXAS 877 7562

EL TORO ISLAND, LAGUNA MADRE

BENCH MARK STAMPING: 9007 D 1990

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: CBI Tidal Bench Mark
SETTING CLASSIFICATION: Stainless Steel Rod

The bench mark is 292.4 feet (89.1 m) N 78°W of Bench Mark 9007 C 1990. The bench mark is level with the ground, crimped to a stainless steel rod driven 40 feet (12 m) to substantial resistance, and encased in a 6-inch PVC pipe.

BENCH MARK STAMPING: 9007 E 1990

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: CBI Tidal Bench Mark
SETTING CLASSIFICATION: Stainless Steel Rod

The bench mark is 279.8 feet (85.3 m) S 4°W of Bench Mark 9007 A 1990. The bench mark is level with the ground, crimped to a stainless steel rod driven 48 feet (15 m) to substantial resistance, and encased in a 6-inch PVC pipe.

# TEXAS 877 7562

# EL TORO ISLAND, LAGUNA MADRE

Water level datum at El Toro Island, Laguna Madre is based on the following:

LENGTH OF SERIES = 6 MONTHS
TIME PERIOD = JULY - DECEMBER 1990
TIDAL EPOCH = 1960-1978
CONTROL TIDE STATION = PORT MANSFIELD (877 8490)

Elevations referred to mean water level (MWL) are as follows:

HIGHEST OBSERVED WATER LEVEL (11/3/91) = 1.89 FEET
MEAN WATER LEVEL (MWL) = 0.00 FEET
LOWEST OBSERVED WATER LEVEL (2/20/91) = -0.71 FEET

Bench mark elevation information:

| BENCH MARK STAMPING | ELEVATION IN FEET ABOVE: MWL |
|---|---|
| 9007 A 1990 | 3.61 |
| 9007 B 1990 | 3.02 |
| 9007 C 1990 | 4.28 |
| 9007 D 1990 | 4.12 |
| 9007 E 1990 | 3.91 |

## NOTICE:

The astronomical tidal signal at El Toro is weak relative to high and low frequency non-tidal water level variations due to meteorological forcing, and is commonly masked by these effects. Therefore, NOS has designated this station as non-tidal for purposes of datum determination. Bench marks are referenced to an equivalent 19-year Mean Water Level (MWL) on the 1960-1978 National Tidal Datum Epoch. MWL is computed from an average of the hourly water level heights recorded during the above stated series and adjusted by the designated 19-year control station. Seasonal variations have a strong influence on water level variations in the Laguna Madre region. MWL based on a 6-month series is preliminary and should be used with discretion. The MWL datum will be periodically updated as longer series become available.

TEXAS 877 7812

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL OCEAN SERVICE

# TIDAL BENCH MARKS

## RINCON DE SAN JOSE, LAGUNA MADRE

| | | | |
|---|---|---|---|
| LATITUDE: | 26°48.1'N | LONGITUDE: | 97°28.2'W |
| NOAA CHART: | 11304 | USGS QUAD: | POTRERO LOPENO SW |

To reach the tidal bench marks from Port Mansfield, proceed north by boat on the Gulf Intracoastal Waterway (GIWW) for approximately 15.5 miles (25.0 km) to USCG Day Beacon Green #25 on the west side of the channel. The bench marks are on a spoil island east of Day Beacon #25. The tide gauge is on a 6 x 6-foot (2 m x 2 m) pile supported platform 33 feet (10 m) east of Day Beacon #25.

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### BENCH MARK STAMPING: 7812 A

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Stainless Steel Rod

The primary bench mark is about 850 feet (259 m) N 65°E of Day Beacon #25. The bench mark is level with the ground, crimped to a stainless steel rod driven 43 feet (13 m) to refusal, and encased in a 6-inch PVC pipe.

### BENCH MARK STAMPING: 7812 B

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Stainless Steel Rod

The bench mark is about 295 feet (90 m) S 80°E of Bench Mark 7812 A. The bench mark is level with the ground, crimped to a stainless steel rod driven 40 feet (12 m) to refusal, and encased in a 6-inch PVC pipe.

### BENCH MARK STAMPING: 7812 C

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Stainless Steel Rod

The bench mark is about 197 feet (60 m) S 60°E of Bench Mark 7812 B. The bench mark is level with the ground, crimped to a stainless steel rod driven 44 feet (13 m) to refusal, and encased in a 6-inch PVC pipe.

TEXAS 877 7812

RINCON DE SAN JOSE, LAGUNA MADRE

BENCH MARK STAMPING: 7812 D

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Stainless Steel Rod

The bench mark is about 260 feet (79 m) S 20°E of Bench Mark 7812 C. The bench mark is level with the ground, crimped to a stainless steel rod driven 40 feet (12 m) to refusal, and encased in a 6-inch PVC pipe.

BENCH MARK STAMPING: 7812 E

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Stainless Steel Rod

The bench mark is about 230 feet (70 m) S 60°W of Bench Mark 7812 D. The bench mark is level with the ground, crimped to a stainless steel rod driven 40 feet (12 m) to refusal, and encased in a 6-inch PVC pipe.

## TEXAS 877 7812

## RINCON DE SAN JOSE, LAGUNA MADRE

Water level datum at Rincon de San Jose, Laguna Madre is based on the following:

LENGTH OF SERIES = 10 MONTHS
TIME PERIOD = SEPTEMBER 1992 - AUGUST 1993
TIDAL EPOCH = 1960-1978
CONTROL TIDE STATION = PORT MANSFIELD (877 8490)

Elevations referred to mean water level (MWL) are as follows:

HIGHEST OBSERVED WATER LEVEL (05/02/91) = 2.00 FEET
MEAN WATER LEVEL (MWL) = 0.00 FEET
LOWEST OBSERVED WATER LEVEL (01/07/94) = -2.23 FEET

Bench mark elevation information:

| BENCH MARK STAMPING | ELEVATION IN FEET ABOVE: MWL |
|---|---|
| 7812 A | 3.03 |
| 7812 B | 5.57 |
| 7812 C | 4.86 |
| 7812 D | 5.69 |
| 7812 E | 2.63 |

NOTICE:

The astronomical tidal signal at Rincon De San Jose is weak relative to high and low frequency not-tidal water level variations due to meteorological forcing, and is commonly masked by these effects. Therefore, NOS has designated this station as non-tidal for purposes of datum determination. Bench marks are referenced to an equivalent 19-year Mean Water Level (MWL) on the 1960-1978 National Tidal Datum Epoch. MWL is computed from an average of the hourly water level heights recorded during the above stated series and adjusted by the designated 19-year control station. Seasonal variations have a strong influence on water level variations in the Laguna Madre region. MWL based on a 10-month series should be used with discretion. The MWL datum will be periodically updated as longer series become available.

TEXAS 877 8490

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL OCEAN SERVICE

# TIDAL BENCH MARKS

## PORT MANSFIELD, LAGUNA MADRE

| | | | |
|---|---|---|---|
| LATITUDE: | 26°33.6'N | LONGITUDE: | 97°25.4'W |
| NOAA CHART: | 11304 | USGS QUAD: | PORT MANSFIELD |

To reach the tidal bench marks from the Port Mansfield water tower in town on Texas Highway 186 (Port Mansfield Drive), proceed east on Texas Highway 186 for approximately 0.2 mile (0.3 km) to the end of the road at Laguna Madre. The bench marks are along Texas Highway 186 and in the harbor area. The tide gauge is on the first fishing pier north of Texas Highway 186.

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### BENCH MARK STAMPING: 600 RL 1950PT 7+470

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: USE Traverse Station
SETTING CLASSIFICATION: Concrete Monument

The bench mark is set in the top of a concrete monument at the junction of Port Mansfield Drive, Water Street, and Bayshore Drive, 65 feet (20 m) south of the junction of Bayshore Drive and Water Street, 50.2 feet (15.3 m) south of the centerline of Port Mansfield Drive, 41.5 feet (12.6 m) west of the centerline of Water Street, and 0.4 foot (0.1 m) above the ground.

### BENCH MARK STAMPING: NO 1 1964

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: USC&GS Tidal Bench Mark
SETTING CLASSIFICATION: Concrete Headwall

The primary bench mark is set in a concrete headwall of a small culvert at the end of Port Mansfield Drive, 23 feet (7 m) SE of a small cottage, 16.5 feet (5.0 m) west of a sea wall, and 3.9 feet (1.2 m) NNW of the south end of the culvert.

TEXAS 877 8490

PORT MANSFIELD, LAGUNA MADRE

BENCH MARK STAMPING: NO 2 1964

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: USC&GS Tidal Bench Mark
SETTING CLASSIFICATION: Concrete Headwall

The bench mark is set in the SE corner of the headwall of a small concrete box that serves as an intake for a 14-inch concrete drain midway between a boat ramp and a warehouse, 197 feet (60 m) SW of the SW face of the warehouse, 98 feet (30 m) NW of the seaward edge of the dock, and 0.5 foot (0.2 m) west of the SE corner of the concrete box.

BENCH MARK STAMPING: LEGION 1939 1962

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: USC&GS Reference Mark
SETTING CLASSIFICATION: Concrete Monument

The bench mark is set on top of a concrete monument at the intersection of White Street and Port Mansfield Drive, 77 feet (23 m) NW of the centerline of Port Mansfield Drive, 73 feet (22 m) east of the centerline of White Street, 49 feet (15 m) NE of power pole #46265, and 1.5 feet (0.4 m) below ground.

BENCH MARK STAMPING: LEGION NO 5 1939 1962

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: USC&GS Reference Mark
SETTING CLASSIFICATION: Concrete Monument

The bench mark is set in the top of a concrete monument at the intersection of White Street and Port Mansfield Drive, 240 feet (73 m) west of the centerline of Farm Road 606, 53 feet (16 m) north of the centerline of Port Mansfield Drive, 22 feet (7 m) west of the centerline of White Street, 3 feet (1 m) north of a power line pole, and 0.1 foot (0.03 m) above ground.

BENCH MARK STAMPING: LEGION 2 1969

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: USC&GS Triangulation Station
SETTING CLASSIFICATION: Concrete Monument

The bench mark is set in the top of a concrete monument at the intersection of Port Mansfield Drive and Ware Street, 49.5 feet (15.1 m) SE of the centerline of Port Mansfield Drive, 42.4 feet (12.9 m) east of power pole #A 6276, 15 feet (5 m) west of a fire hydrant, and level with the ground.

TEXAS 877 8490

PORT MANSFIELD, LAGUNA MADRE

BENCH MARK STAMPING: 8490 B 1978

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Concrete Retaining Wall

The bench mark is on the north side of Port Mansfield harbor on the west side of a public boat ramp, 50.0 feet (15 m) north of the east end of the gas dock at Port Mansfield Marina, 48.0 feet (15 m) SE of the NE corner of the Port Mansfield marina building, 37.3 feet (11.4 m) east of the SE corner of the marina building, and 19 feet (6 m) south of the south side of the steps leading to the boat ramp.

BENCH MARK STAMPING: 8490 C 1990

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Stainless Steel Rod

The bench mark is about 360 feet (110 m) SSW of the Port Mansfield water tower, 227.0 feet (69.2 m) ENE of the SE corner of the Port Mansfield Marina secondary parking lot, and 56.0 feet (17.1 m) NNW of the centerline of Port Mansfield Drive. The bench mark is 0.2 foot (0.1 m) below the ground, crimped to a stainless steel rod driven 44 feet (13 m) to refusal, and encased in 4-inch PVC pipe with cap and concrete kickblock.

BENCH MARK STAMPING: 8490 D 1990

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Stainless Steel Rod

The bench mark is about 900 feet (274 m) SSW of the Port Mansfield water tower, 159.0 feet (48.5 m) NE of the centerline of the entrance to Port Mansfield Marina, 79.2 feet (24.1 m) ESE of the centerline of Port Mansfield Drive, and 78.4 feet (23.9 m) NNW of a light pole. The bench mark is crimped to a stainless steel rod driven 44 feet (13 m) to refusal and encased in a 4-inch PVC pipe with a cap and concrete kickblock.

TEXAS 877 8490

PORT MANSFIELD, LAGUNA MADRE

BENCH MARK STAMPING: 8490 E 1990

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Stainless Steel Rod

The bench mark is 0.3 mile (0.5 km) west of the east end of Port Mansfield Drive, 148.3 feet (45.2 m) NE of a power pole, 106.6 feet (32.5 m) SW of the SW corner of a parking lot, and 2.0 feet (0.6 m) south of a witness post. The bench mark is 0.3 foot (0.1 m) below the ground, crimped to a stainless steel rod driven an unspecified depth, and encased in a 5-inch PVC pipe and concrete kickblock.

BENCH MARK STAMPING: 8490 F 1993

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Stainless Steel Rod

The bench mark is at the intersection of Port Mansfield and North Shore Drives, 67.6 feet (20.6 m) NNW of the centerline of Port Mansfield Drive, 46.9 feet (14.3 m) west of the SW corner of the residence at 201 North Shore Drive, and 2.0 feet (0.6 m) south of the SW corner of a garage. The bench mark is level with the ground, crimped to a stainless steel rod driven 42 feet (13 m) to refusal, and encased in a 5-inch PVC pipe and concrete kickblock.

BENCH MARK STAMPING: 8490 G 1993

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Concrete Foundation

The bench mark is set flush in the concrete foundation of the Port Mansfield water tower, 169.9 feet (51.8 m) NW of the centerline of Port Mansfield Drive, 86.3 feet (26.3 m) WSW of the centerline of a dirt road leading to a trailer park, and level with the ground.

TEXAS 877 8490

PORT MANSFIELD, LAGUNA MADRE

Water level datum at Port Mansfield, Laguna Madre is based on the following:

LENGTH OF SERIES = 17 YEARS
TIME PERIOD = 1971-1989
TIDAL EPOCH = 1960-1978
CONTROL TIDE STATION = PORT ISABEL (877 9770)

Elevations referred to mean water level (MWL) are as follows:

HIGHEST OBSERVED WATER LEVEL (11/03/82) = 2.77 FEET
MEAN WATER LEVEL (MWL) = 0.00 FEET
LOWEST OBSERVED WATER LEVEL (03/09/65) = -1.45 FEET

Bench mark elevation information:

| BENCH MARK STAMPING | ELEVATION IN FEET ABOVE: MWL |
|---|---|
| 600 RL 1950PT 7+470 | 12.33 |
| NO 1 1964 | 5.61 |
| NO 2 1964 | 6.25 |
| LEGION 1939 1962 | 13.77 |
| LEGION NO 5 1939 1962 | 13.61 |
| LEGION 2 1969 | 11.52 |
| 8490 B 1978 | 5.69 |
| 8490 C 1990 | 10.30 |
| 8490 D 1990 | 11.29 |
| 8490 E 1990 | 9.64 |
| 8490 F 1993 | 7.95 |
| 8490 G 1993 | 11.84 |

NOTICE:

The astronomical tidal signal at Port Mansfield is weak relative to high and low frequency non-tidal water level variations due to meteorological forcing, and is commonly masked by these effects. Therefore, NOS has designated this station as non-tidal for purposes of datum determination. Bench marks are referenced to an equivalent 19-year Mean Water Level (MWL) on the 1960-1978 National Tidal Datum Epoch. MWL is computed from an average of the hourly water level heights recorded during the above stated series and adjusted by the designated 19-year control station.

TEXAS 877 9770

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL OCEAN SERVICE

# TIDAL BENCH MARKS

## PORT ISABEL, PORT ISABEL TURNING BASIN, LAGUNA MAD

LATITUDE: 26° 3.6′ N LONGITUDE: 97° 12.9′ W
NOAA CHART: 11301 USGS QUAD: PORT ISABEL

To reach the tidal bench marks from the old lighthouse at Port Isabel, proceed west on State Highway 100 for 0.9 mile (1.4 km) to a road leading to Port Isabel Turning Basin, turn left onto the road and continue south for 0.7 mile (1.1 km) to the Port Isabel Navigation District warehouse. The bench marks are in the vicinity of the warehouse, Port Road, and the Port Isabel High School complex. The tide gage and staff are approximately 80 feet (24 m) north of the NE corner of the warehouse.

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### BENCH MARK STAMPING: 2 1944

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: USC&GS Tidal Bench Mark
SETTING CLASSIFICATION: Concrete Deck

The bench mark is set in the concrete wharf deck at the NE corner of the warehouse, 40 feet (12 m) SW of the NE concrete edge of the wharf, 23.5 feet (7.2 m) SE of the NW edge of the concrete deck, and 1.5 feet (0.5 m) SW of the NE corner of the warehouse.

### BENCH MARK STAMPING: 400 RL 1950 22+100

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: COE Bench Mark
SETTING CLASSIFICATION: Concrete Driveway

The bench mark is located at the warehouse, 82.3 feet (25.1 m) SW of a transformer pole, 52 feet (16 m) west of the centerline of the paved roadway, 24.5 feet (7.5 m) NW of the NW corner of the warehouse, and level with the driveway which runs around the warehouse.

### BENCH MARK STAMPING: 9

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: COE Bench Mark
SETTING CLASSIFICATION: Concrete Monument

The bench mark is set in the top of a concrete monument at the Port Isabel Turning Basin, approximately halfway between the water tower and the abandoned oil dock, 275 feet (84 m) east of the centerline of Port Road, 150.0 feet (45.7 m) SW of a power pole with a light and a transformer, 149 feet (45 m) south of the centerline of the east-west road, and 0.2 foot (0.1 m) below the ground level.

TEXAS 877 9770

PORT ISABEL, PORT ISABEL TURNING BASIN, LAGUNA MAD

### BENCH MARK STAMPING: NO 10 1973

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: USC&GS Tidal Bench Mark
SETTING CLASSIFICATION: Concrete Headwall

The bench mark is set flush in the top of a headwall on the east side of the road leading to the warehouse, 73.0 feet (22.3 m) SSE of two oil pipe line valves, 38.4 feet (11.7 m) south of a power pole, and 29.0 feet (8.8 m) east of the centerline of Port Road.

### BENCH MARK STAMPING: NO 11 1972

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Concrete Flagpole Base

The bench mark is set in the SW corner of a concrete flagpole base in the Port Isabel High School complex, 40.7 feet (12.4 m) north of the NW corner of the main building, 39.7 feet (12.1 m) east of the NE corner of the cinder block building housing restrooms, and 1.3 feet (0.4 m) east of the east edge of the sidewalk.

### BENCH MARK STAMPING: NO 12 1972

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Concrete Footing

The bench mark is set in the SW corner of the concrete footing of the SSE leg of the Port Isabel water tower located in the vicinity of the Port Isabel High School complex, 44.7 feet (13.6 m) east of the east wall of the office building, and 8.5 feet (2.6 m) north of the south side of a rectangular chain link fence around the water tower.

### BENCH MARK STAMPING: NO 13 1972

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Concrete Seawall

The bench mark is set flush in the top of the sea wall in the SE section of the Port of Port Isabel, approximately 300 feet (91 m) north and across the east-west road between the Port and the Turning Basin, 76.5 feet (23.3 m) north of the centerline of the east-west road, 24 feet (7 m) east of the east edge of the pier, and 1.9 feet (0.6 m) south of the north headwall of the sea wall.

## TEXAS 877 9770

## PORT ISABEL, PORT ISABEL TURNING BASIN, LAGUNA MAD

### BENCH MARK STAMPING: NO 7 1953

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: USC&GS Tidal Bench Mark
SETTING CLASSIFICATION: Concrete Footing

The bench mark is set in the concrete footing for an anchor bitt near the warehouse, 96.5 feet (29.4 m) east of the centerline of Port Road, 55 feet (17 m) north of the NE corner of the warehouse, 30.4 feet (9.3 m) SE of the east corner of the tide station instrument shelter, and 30.5 feet (9.3 m) SW of the east face of the bulkhead.

### BENCH MARK STAMPING: X 1406 1982

MONUMENTATION: Metal Rod
AGENCY/DISK TYPE: NGS Bench Mark
SETTING CLASSIFICATION: Stainless Steel Rod in Sleeve

The bench mark is located in the vicinity of the abandoned Port Isabel oil dock, 120 feet (37 m) south of Bench Mark NO 13 1972, 43.6 feet (13.3 m) south of the centerline of the paved road, 42.5 feet (13.0 m) west of a power pole with a meter box, and 4 feet (1 m) SSW of power pole #234. The bench mark is the highest point of a stainless steel rod in sleeve surrounded by a pipe with a stamped access cover.

TEXAS 877 9770

PORT ISABEL, PORT ISABEL TURNING BASIN, LAGUNA MAD

Tidal datums at PORT ISABEL, PORT ISABEL TURNING BASIN, LAGUNA MAD are based on the following:

LENGTH OF SERIES = 19 YEARS
TIME PERIOD = 1960-1978
TIDAL EPOCH = 1960-1978
CONTROL TIDE STATION = FIRST REDUCTION

Elevations of tidal datums referred to mean lower low water (MLLW) are as follows:

HIGHEST OBSERVED WATER LEVEL (08/09/1980) = 7.33 FEET
MEAN HIGHER HIGH WATER (MHHW) = 1.40 FEET
MEAN HIGH WATER (MHW) = 1.33 FEET
MEAN TIDE LEVEL (MTL) = 0.76 FEET
MEAN LOW WATER (MLW) = 0.19 FEET
MEAN LOWER LOW WATER (MLLW) = 0.00 FEET
LOWEST OBSERVED WATER LEVEL (06/14/1978) = -2.96 FEET

Bench mark elevation information:

| | ELEVATION IN FEET ABOVE: | |
|---|---|---|
| BENCH MARK STAMPING | MLLW | MHW |
| 2 1944 | 11.71 | 10.38 |
| 400 RL 1950 22+100 | 11.74 | 10.41 |
| 9 | 3.17 | 1.84 |
| NO 10 1973 | 10.44 | 9.11 |
| NO 11 1972 | 19.16 | 17.83 |
| NO 12 1972 | 18.71 | 17.38 |
| NO 13 1972 | 4.75 | 3.42 |
| NO 7 1953 | 11.30 | 9.97 |
| X 1406 1982 | 5.55 | 4.22 |