HIGH FREQUENCY STORM HYDROGRAPH DEVELOPMENT

AND

EROSION MODEL CALIBRATION

Prepared for

Division of Beaches and Shores
Department of Natural Resources

Prepared Jointly By

Department of Coastal and Oceanographic Engineering
University of Florida
Gainesville, Florida 32611

and

Beaches and Shores Resource Center
Florida State University
Tallahassee, Florida 32310

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16. Abstract (Limit 200 words)

A methodology was developed and applied to establish idealized high frequency hydrographs that yield the same erosion as the actual hydrographs based on 36 years of wind data. A erosion model was calibrated and evaluated for 4 counties for the Thanksgiving Storm of 1984.

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HIGH FREQUENCY STORM HYDROGRAPH DEVELOPMENT AND EROSION MODEL CALIBRATION

I. GENERAL DISCUSSION

The development of one or more models suitable for generating high frequency (defined as 5 to 25 years) storm surges and eroded profiles involves a number of interrelated variables, including: (1) Waves, (2) Storm surges, (3) Astronomical tides, (4) Winds, and (5) Beach profile characteristics. This is indeed a challenging objective in part due to the poorly documented characteristics of the different variables and the need to consider their correlation, i. e., whether or not they occur simultaneously. The calculation process may be considered sequentially in which first the forcing hydrodynamics will be developed and then applied to calculate the profile response. In order to provide a basis for identifying calculation and/or data components requiring emphasis, it is worthwhile to consider the hydrodynamics and erosion components of the calculation procedure separately and to investigate the factors with the greatest influence first on the hydrodynamics and then on the erosion. By this process it is possible to make, where necessary, rational decisions relating to which variables warrant greater emphasis.

The overall objective of this project is to develop a method for calculating eroded profiles associated with high frequency storm events. This requires first the establishment of the associated forcing function, i. e., the storm hydrographs and waves, and secondly, the application of these forcing functions to calculate the eroded profiles.

The remainder of this report is structured as follows. Section II establishes the relative importance of the various components of the storm surge hydrographs. Section III evaluates the availability and quality of the data sources to meet the needs and this leads to a decision to emphasize the wind, bathymetry and predicted astronomical tides as the basic input data sources. Section IV discusses available erosion models, evaluates the quality of the data sources for calibration and provides calibration results for four counties for the Thanksgiving Storm of 1984. Section V presents the recommended methods for calculating storm surges and the associated waves. Section VI presents the recommended method for developing the model hydrographs based on equivalent erosion potential.

II. COMPONENTS OF THE HYDROGRAPHS

Hydrographs and Terminology

The terminology employed here will consider the term "hydrograph" to include: (1) the storm surge which encompasses all components of anomalous water level, and (2) the associated waves.

Storm Surge

The purpose of this section is to illustrate, for idealized considerations, the relative importance of the various components that comprise the total storm surge, η_T.

The total water level, η_T, within the surf zone which would be relevant to profile erosion is given by

$$\eta_T = \eta_{WS} + \eta_B + \eta_{AST} + \eta_{WSU} \tag{1}$$

in which η_{WS} is the component due to "wind stress", η_B is the component due to barometric pressure reduction, η_{AST} is the astronomical tide component, and η_{WSU} is the wave set up component. Each of the components and their magnitudes will be discussed below.

Wind Stress Component - The water level component due to wind stress depends primarily on the magnitude of the wind speed and the profile characteristics of the continental shelf across which the winds generate the storm surge. As an approximate basis for representing the wind stress component, the continental shelf can be considered to be of uniform slope. For this case, the wind-induced set up at the shoreline is given by

$$\frac{x}{\ell} = \left(1 - \frac{h+\eta_{WS}}{h_o}\right) - A \ln\left(\frac{\frac{h+\eta_{WS}}{h_o} - A}{1-A}\right) \tag{2}$$

in which the reference system shown in Figure 1 is adopted and η_{WS} is the wind surge at any location, x, across the shelf. The quantity A includes the effect of wind stress, τ, in the non-dimensional term

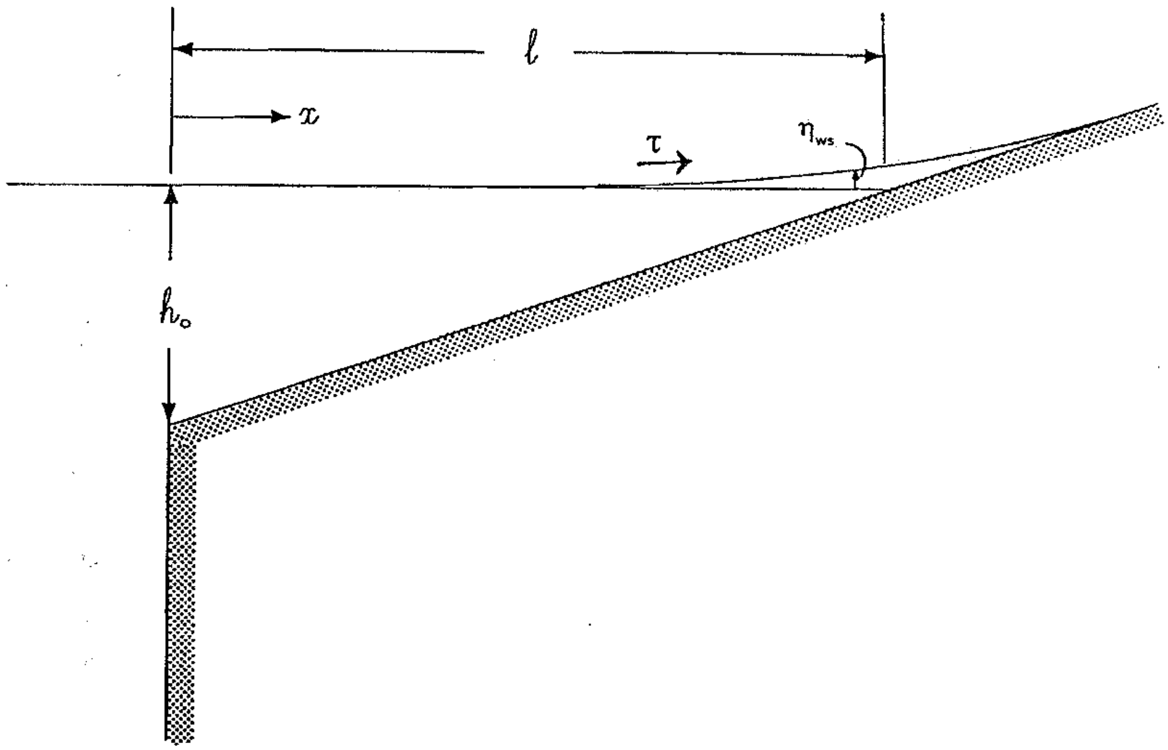


Figure 1 Definition Sketch for Wind Blowing Directly Toward Shore

$$A = \frac{\tau \ell}{\rho g h_o^2} \tag{3}$$

in which ρ is the mass density of water, g is gravity, and h_o is the depth of the continental shelf at its seaward terminus. The wind stress is expressed in terms of a wind stress coefficient developed by Van Dorn (1953)

$$k = \begin{cases} 1.2x10^{-6}, |W| \le W_c \\ 1.2x10^{-6} + 2.25x10^{-6}\left(1 - \frac{W_c}{|W|}\right)^2, |W| > W_c \end{cases} \tag{4}$$

and the shear stress, τ, is defined in terms of the shear stress coefficient, k, as

$$\tau = \rho \; k |W| W_c \tag{5}$$

in which W_c is the shore normal component of the wind stress vector, W.

The storm surge at the shoreline $\eta_{WS}(\ell)$ can be determined from Eq. (2) by setting $x=\ell$, as

$$\frac{\eta_{WS}(\ell)}{h_o} = A \ln\left(\frac{1-A}{\frac{\eta_{WS}(\ell)}{h_o} - A}\right) \tag{6}$$

which must be solved by iteration. Figure 2 plots the ratio $\frac{\eta_{WS}}{h_o}$ versus the parameter A. In order to determine approximate values of A for our areas of interest, it is necessary to first determine the wind stress which depends on wind velocities. Thom (1961) has analyzed wind records from all near coastal weather stations and has plotted graphs depicting the wind speeds for return periods of 2, 50 and 100 years around the continental United States. These are summarized in Table 1 for two and four locations on the east and west coasts of Florida, respectively.

The results in Table 1 were plotted on extreme probability paper and the wind speeds interpolated for return periods of interest shown in Table 2. For return periods ranging from 5 to 25 years the associated range of wind speeds is 40 to 70 mph.

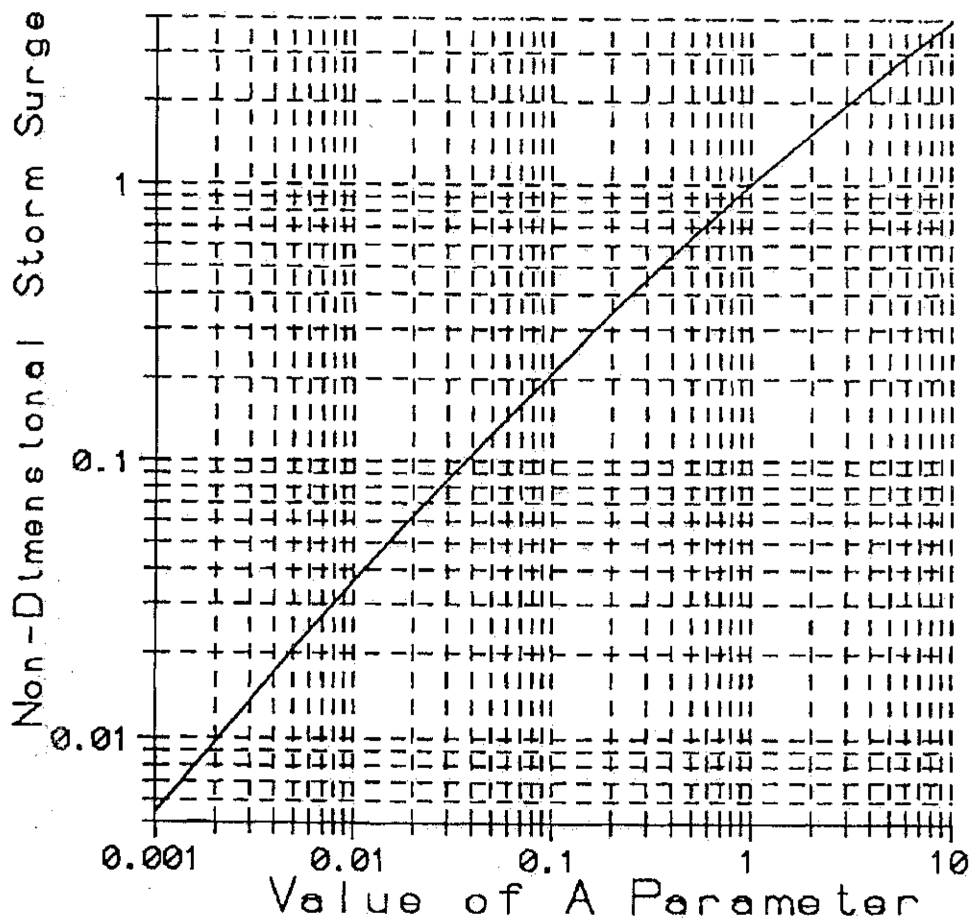


Figure 2 Variation of Non-Dimensional Storm Surge at Shoreline With "A" Parameter

Combining the wind stresses as calculated from Eq. (6) and the range of continental shelf widths (here taken as 5 to 149 miles), the range of A values in Florida is from 1.7×10^{-5} to 1.5×10^{-3} and the range of η_{WS} values is from 0.1 to 4.7 ft.

TABLE 1

"AVERAGE" COASTAL WIND SPEEDS (mph) FOR VARIOUS RETURN PERIODS AND FLORIDA COASTAL LOCATIONS (BASED ON THOM'S RESULTS)

Station	T_R = 2 years	T_R = 50 years	T_R = 100 years
Jacksonville	40	75	120
Palm Beach	38	85	125
Fort Myers	35	69	110
Apalachicola	36	69	110
Panama City	35	77	110
Pensacola	37	77	110

TABLE 2

INTERPOLATED AVERAGE COASTAL WINDS FOR VARIOUS RETURN PERIODS OF INTEREST

Station	Wind Speed (mph) for Given Return Period (years)			
	5	10	15	25
Jacksonville	49	50	64	70
Palm Beach	49	57	62	67
Fort Myers	44	52	56	62
Apalachicola	44	51	55	61
Panama City	45	53	58	63
Pensacola	46	54	58	63

Barometric Tide - The barometric tide is in response to the reduction in atmospheric pressure and can be shown to be given approximately by

$$\eta_B = 1.14 \Delta p \tag{7}$$

in which η_B is in ft of water and Δp is in inches of mercury. Since the approximate threshold for a hurricane is a central barometric pressure reduction of one inch of mercury and since the storms with which we are concerned are considerably less intense, it is concluded that the contribution from the barometric pressure reduction will not be dominant.

Astronomical Tide - The astronomical tide varies substantially around the state and seasonally with two small but not insignificant peaks in the mean tide around the months of February and September. However, all the astronomical tide information including the seasonal information is available in the tide tables and is readily accessed.

Wave Set Up - Wave set up occurs predominantly within the surf zone as a result of wave breaking and the attendant transfer of momentum from the waves to the surf zone. There is a slight set down at the break point with an increasing water level landward across the surf zone. Based on a simplified analysis, the maximum wave set up across the surf zone occurs at the intersection of the mean water level and the beach profile and is approximately 20% of the breaking wave height.

Tide Gage Data

Long term tide gage data are available from seven gages around the Florida coastline and provide a possible source for water level information. The appropriateness of these data for the application here are questionable due primarily to the gage locations. Most of the gages are in sheltered locations; those gages that are on the open coast are usually mounted on piers and, depending on the breaking wave height, are usually located midway within or seaward of the breaking zone thus missing the full effect of the wave set up.

Ebersole (1982) carried out a thorough analysis of anomalies from tide gage recordings along the east coast of the United States. Two of the gages analyzed in Florida were Mayport and Miami. The Mayport gage is in the Navy Mayport Harbor which is not on the open coast whereas the Miami gage is located on a pier on the open coast. The water level anomalies associated with the various return periods are presented in Table 3. The Mayport gage is located adjacent to the St. Johns River and is possibly affected by the freshwater flows. Thus at this gage, there are two extraneous effects which tend to be offsetting. Large outer coast storm surges are not fully manifested at the gage location and thus would tend to bias the gage results downward and flood stages on the river not being representative of outer coast conditions would tend to bias the gage results upward.

TABLE 3

WATER LEVEL ANOMALIES ASSOCIATED WITH TIDE GAGE RESULTS
MAYPORT AND MIAMI BEACH
(From Ebersole 1982)

Station	Water Level Anomaly (ft.) for Given Return Period (years)			
	5	10	15	25
Mayport	2.0	2.2	2.3	2.5
Miami Beach	1.2	1.6	1.8	2.1

<u>Waves</u>

Wave data are available from a number of sources; however, the wave data available from each source do not contain all the necessary attributes for carrying out a beach and dune erosion model. Therefore, it will be required to combine the various characteristics in order to develop the necessary data base. The available wave data bases and their characteristics are described below.

<u>Coastal Data Network</u> - The Coastal Data Network (CDN) wave data are the result of wave gages installed at the locations shown in Figure 3. The durations that the various gages have been in place have varied. At present, no CDN gages are operational, although two "project" gages are. An effort is currently underway to reactivate some of these gages, commencing on the east coast of Florida. The data from the CDN are the most authoritative as they represent direct measurements and are not based on hindcasts.

Wang, et al (1991) have carried out a return period analysis of the CDN data with the results (presented without parentheses) for the various stations listed in Table 4.

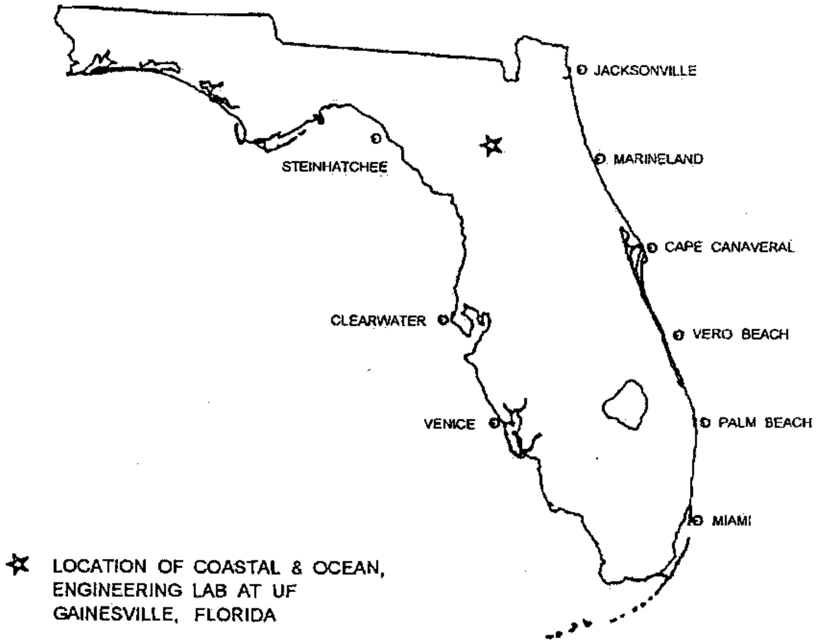


Figure 3 Locations of the CDN Wave Gages

Wave Information Study - The Waterways Experiment Station conducted an extensive hindcast study, termed the Wave Information Study (WIS), for the twenty year period 1956-1975 for the east coast of the United States and the Gulf of Mexico (Jensen, 1983; Huberts and Brooks, 1989). Although these results are not based on measurements, they do have the advantage that they are not affected by, for example, gage malfunctions and thus are more continuous and more analysis has been conducted on these data than for the CDN data. Thus if it can be shown that these data are reliable, information can be extracted that is not readily available from the CDN data. Table 4 compares the CDN and WIS significant wave heights associated with the 2, 5, 10, 15 and 25 year return periods from which it is seen that there is reasonably good agreement, thus providing justification for applying the WIS data.

It is of interest that on the east coast of Florida (at least down to Miami Beach) there is little variation in the significant wave heights associated with the various return periods. Also the WIS wave heights are in reasonable correspondence with the CDN data, thus providing some basis for utilization of the WIS data for which more information including wave height duration is available.

Wave Duration - With the reasonably good correlation between CDN and WIS results for the wave heights associated with the various return periods, the duration results associated with the WIS results can be used with reasonable confidence. These results are presented in Table 5 for various wave heights.

TABLE 4

WAVE HEIGHTS FOR VARIOUS RETURN PERIODS
BASED ON CDN AND WIS[1] DATA

Station	Significant Wave Height (ft.) For Return Period (years)				
	2	5	10	15	25
Jacksonville	10.8 (11.5)	12.1 (12.8)	13.4 (15.1)	14.1 (16.4)	15.1 (18.4)
Marineland	11.2 (11.8)	12.1 (14.1)	14.1 (15.1)	14.8 (15.6)	15.4 (16.7)
Cape Canaveral	8.5 (9.8)	9.2 (10.8)	10.5 (11.2)	10.8 (11.3)	11.5 (11.8)
Vero Beach	8.5 (9.8)	9.2 (10.5)	10.2 (11.5)	11.2 (11.6)	11.8 (12.1)
West Palm Beach	10.2 (9.2)	11.8 (10.8)	13.1 (12.1)	13.8 (12.5)	14.4 (13.1)
Miami	8.2 (8.2)	8.7 (8.9)	9.8 (9.3)	10.3 (9.5)	10.9 (10.0)
Clearwater	6.6 (9.2)	7.8 (10.3)	8.3 (11.3)	9.2 (12.0)	9.5 (12.5)

[1] Note: WIS Data Are in Parentheses.

TABLE 5

DURATIONS OF VARIOUS WAVE HEIGHT EXCEEDANCES
BASED ON WIS HINDCASTS

Station	Duration (Hours) For Significant Wave Heights Greater Than Stated Values. Average and (Maximum) Durations.			
	H_s = 6.6 ft	H_s = 9.8 ft	H_s = 13.1 ft	H_s = 14.8 ft
Jacksonville	20 (186)	8 (33)	4 (6)	3 (3)
Marineland	22 (237)	13 (51)	5 (9)	3 (3)
Cape Canaveral	17 (186)	7 (24)	- (-)	- (-)
Vero Beach	17 (147)	8 (18)	- (-)	- (-)
West Palm Beach	18 (225)	8 (33)	9 (9)	- (-)
Miami	9 (42)	6 (21)	- (-)	- (-)
Clearwater				

III. EVALUATION OF DATA SOURCES

Introduction

This section addresses evaluation of data sources, and as will be indicated later, the wind, bathymetric, and tidal data appear to be most consistent, reliable and of the highest quality. The types of data that would be useful in verifying an erosion model and/or developing a procedure for calculating high-frequency erosion include: (a) Wind data which can serve as a basis for storm surge generation and for wave calculations both in calibration and in application of the methodology, (b) Wave data, (c) Storm surges to be used in calibration, (d) Erosion data which can be used for calibration, and (e) Bathymetry for use in both calibration and application. Each of these sources is reviewed below and the utility of the data for calibration and/or application assessed.

(a) Wind Data

Wind data were obtained for the following near coastal stations for the years noted.

TABLE 6

WIND DATA OBTAINED FOR USE IN THIS STUDY

Station:	Years Available:
Punta Gorda	(1952-1983)
Orlando	(1952-1983)
Apalachicola	(1948-1983)
Daytona Beach	(1948-1983)
Key West	(1948-1983)
Miami	(1948-1983)
Tampa	(1984-1983)
West Palm Beach	(1948-1983)
Jacksonville	(1948-1983)
Pensacola	(1948-1983)
Tallahassee	(1948-1983)
Ft. Myers	(1948-1983)

Although the stations for which some of these data are available are located somewhat inland, "adjustment" procedures exist to render these data more representative of conditions at the coastline. These data include both wind speed and direction at one hourly intervals. The procedure of selecting those wind events which would cause significant storm surge and erosional events will be described later. The wind data will be shown to be one of the two more robust and therefore applicable of the available data types.

(b) Wave Data

Wave data have been collected by the Department of Coastal and Oceanographic Engineering of the University of Florida since 1979. The number of operating stations depended on funding and are generally available for the locations and years presented in Table 7. The actual measurements are made by a near-bottom pressure gage typically located in approximately 30 feet of water, and located 3000 feet (more or less) from the shoreline. For most sites these data have been transmitted to shore through a cable and then relayed back to the Coastal Engineering Laboratory in Gainesville through telephone lines. A few of the gages are internally recording on tape cassettes and in these cases, recovery of the data requires retrieving the gage, replacing the cassette and decoding the tape in Gainesville. Since the gages measure pressure, the data also include the effects of tides and barometric pressure. Although data have been measured since the dates in Column 2 of Table 7, initially, the data were not of high quality and the analysis and archiving of these data were not as complete as for the later times, resulting in the actual data availability shown in Column 3 of Table 7.

(c) Storm Surge Data

Storm surge data would logically be available from either the offshore wave gage data network (CDN) maintained by the University of Florida or from the very sparse network of tide gages which are located on the outer coast and maintained by the National Ocean Survey. Relevant to the utility of these data is that the storm surge is composed of two components: that due to wind stress and that due to wave set up. Both of these components are depth dependent and of course the storm surge which contributes to erosion is that at the shoreline.

The wind stress component increases rapidly toward the shoreline and measurements from the wave gages present certain difficulties in providing a reliable data base. First, these measurements are made routinely only every six hours and it is the pressure on the bottom which is measured. This bottom pressure is the combined result of the water depth overlying the gage (which includes the wind-induced component) and the barometric pressure.

Secondly, these wave gages are located in approximately 30 feet of water depth where the storm surge is relatively small. In view of the limitations noted above, it is doubtful whether meaningful measurements of the wind-induced component of storm surge can be extracted from the CDN data.

TABLE 7

PERIODS FOR WHICH CDN DATA ARE AVAILABLE

Stations	Year in Which Station Instrumented	Years of Improved Data Quality
Jacksonville	(1981)	(1985-1988)
Marineland	(1981)	(1984-1990)
Cape Canaveral	(1981)	(1984-1989)
Vero Beach	(1982)	(1984-1990)
West Palm Beach	(1982)	(1984-1990)
Miami	(1979)	(1984-1990)
Venice	(1982)	(1984-1990)
Clearwater	(1981)	(1984-1990)

The remaining component of storm surge is wave setup and occurs predominantly within the breaker (surf) zone. In fact outside the surf zone, there is a small setdown, i. e., a negative setup as shown in Figure 3. Most tide gages are mounted on piers which extend a substantial distance offshore and depending, on the breaking wave height, likely in the zone of minimal setup. Thus tide gage data do not provide a well-conditioned data base for determining storm surge especially when the surges of interest are on the order of 1 to 3 feet and in most cases, it is estimated that at least half of the total surge occurs landward of the location of the tide gages.

(d) Erosion Data

The primary use of erosion data is in the calibration of a calculation procedure. The ideal characteristics of an erosion data set would be measurements soon before and soon after the storm so that seasonal effects or shoreline change trends would not influence the results. The Thanksgiving Storm during November 27-29, 1984 provides some of the potentially most valuable erosion data for calibration on the east coast. Table 8 presents the survey dates prior to and following this storm and the various affected counties. In areas where there are known to be strong erosional trends, such as Amelia Island (Nassau County), these trends can affect significantly the quality of the data and render them questionable for calibration purposes.

TABLE 8

COUNTIES FOR WHICH SELECTED PROFILES WERE SURVEYED DURING THE NOVEMBER 27-29, 1984 THANKSGIVING STORM

County	Before Storm Survey	After Storm Survey	Years Between Pre- and Post-Storm Surveys
Nassau	9/1982	11/27/1984	2
Duval	1/1974	11/28/1984	10
St. Johns	5,6/1984	11/30/1984	0.5
Flagler	7/1972	11/27/1984	12
Brevard	7,8/1983	1/12/1985	1.3
Indian River	3,8/1983	11/27/1984	1.3 to 1.6

(e) Bathymetric Data

The bathymetric data are very suitable and reliable for the requirements of this study. These data include both those collected in conjunction with the Coastal Construction Control Line (CCCL) Program and the bathymetry farther seaward which is available from the various nautical charts.

(f) Astronomical Tide Predictions

The tide charts prepared by the National Oceanographic and Atmospheric Administration provide an excellent source of unaffected astronomical tides.

Summary of Data Utility

The objectives of this project would be best accomplished through the availability of high quality wind, wave, storm surge, erosion and bathymetric data that would provide a basis for a step-by-step evaluation during the calibration process and a solid foundation for application of the methodology. Realistically, for this project, it appears that at best, limited wave, storm surge, and erosional data exist which will be useful in the calibration and application phases. The most robust data are for the wind, bathymetry, and astronomical tides. This study will rely most heavily on these data in both the calibration and application portions of this study.

IV. EROSION MODELS

Erosion Model Selection

Two erosion models were evaluated, one was selected and calibrated/verified. The two models were the DNR model currently used for the CCCL program and the Kriebel model. The available data base did not allow an adequate basis for discriminating between the two models, that is both models were found to be capable of predicting the erosion equally well. For purposes of consistency within the DNR program, the DNR model is recommended for application.

Calibration

The erosion model is tested and calibrated based on numerical simulations of the 1984 Thanksgiving Storm field data. The 1984 Thanksgiving Storm affected the Florida east coast from November 21 to 24. Beach profile surveys before and after the storm at these affected counties give a large sample of erosion data as shown in Table 8. Pre- and post-storm profiles with no more than two years between surveys for Nassau, St. Johns, Brevard and Indian River counties were selected for calibration.

Due to the lack of open coast storm surge measurements along these counties, numerical estimates by the 1-D storm surge model are carried out. With inputs of offshore wind data for Daytona Beach from the National Weather Service and bathymetric data from CCCL program, three hydrographs with astronomical tide for each county are generated as shown in Appendix B.

Physical parameters in the erosion model are specified as the same as used in the CCCL program. The scaling parameter A, is determined by the individual profile and constant wave heights of 6.5 ft. and 10 ft. are tested for the best calibration. Calculated and measured county average erosion distances at various elevations are compared and shown in Figures 4 through 7.

Evaluation

Ideally, calibration would be carried out with as many documented cases as available. The required data in this case include time varying wave heights over the duration of the erosion event and documentation of the erosion event through measurements as soon before and after the erosion event. Such data are seldom realized due in part to the uncertainty when and where an erosion event will occur and other competing demands after a storm and also

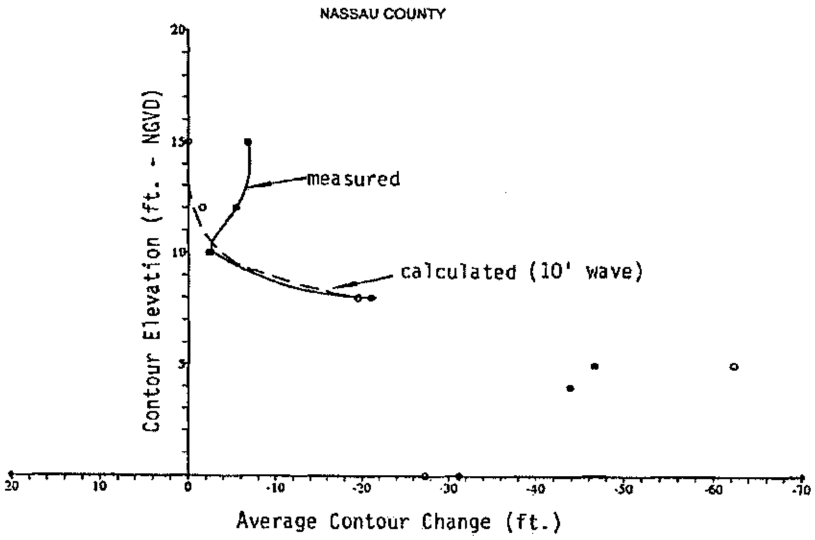


Figure 4 Average Measured and Calculated Contour Changes for Nassau County during the 1984 Thanksgiving Storm

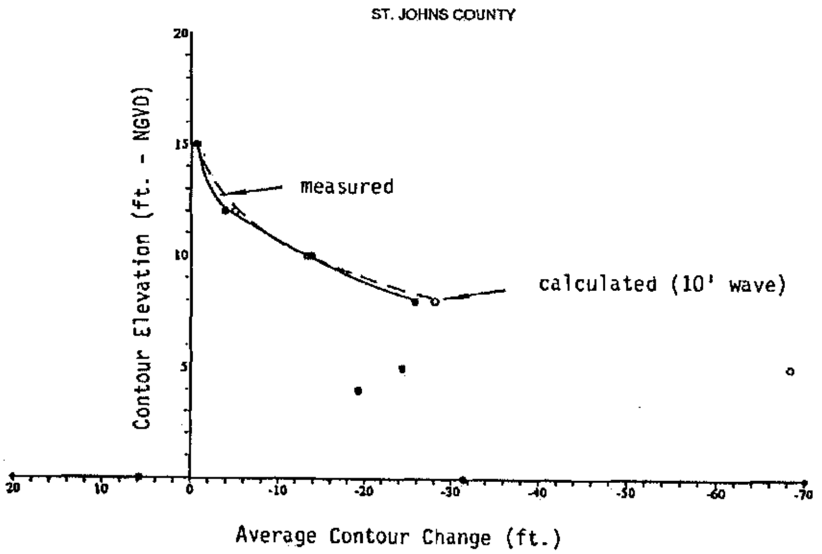


Figure 5 Average Measured and Calculated Contour Changes for St. Johns County during the 1984 Thanksgiving Storm

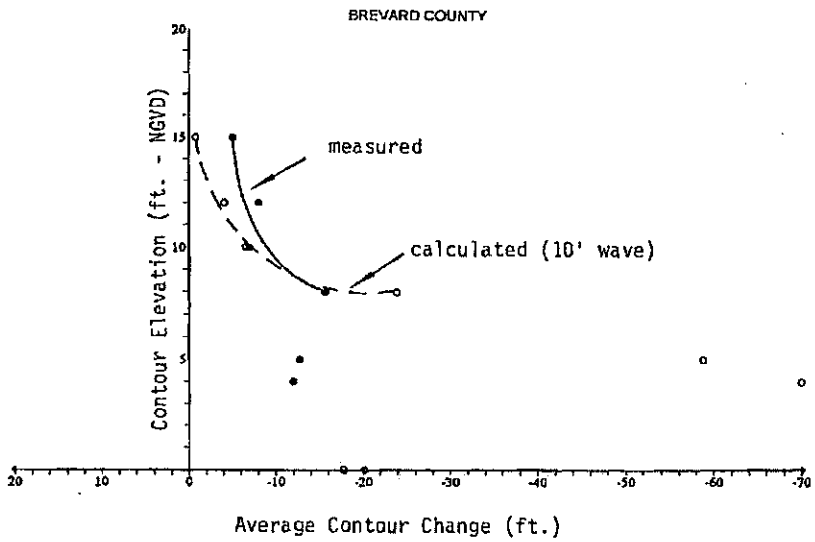


Figure 6 Average Measured and Calculated Contour Changes for Brevard County during the 1984 Thanksgiving Storm

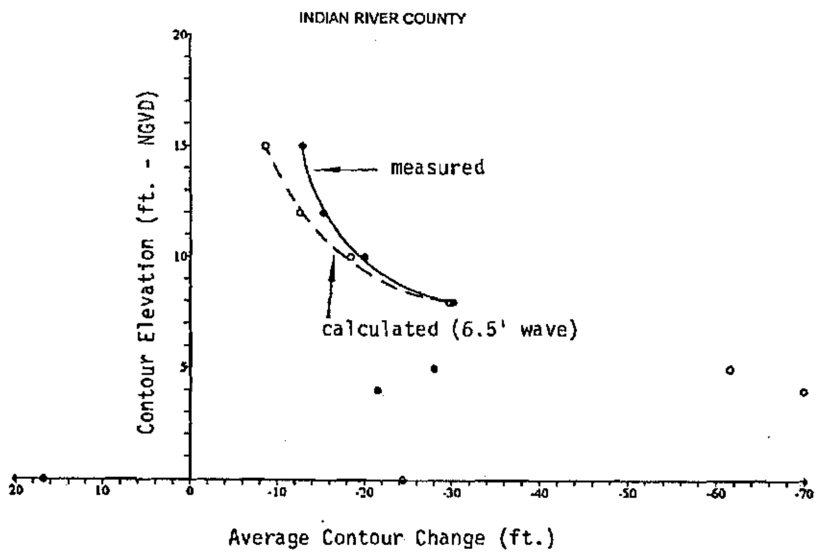


Figure 7 Average Measured and Calculated Contour Changes for Indian River County during the 1984 Thanksgiving Storm

due to the aforementioned lack of water level documentation within the surf zone which is relevant to the erosion models.

It is evident that there is a variability in pre-storm profiles and in storm erosion response of individual profiles. Non-uniform beach recovery between the storm and the post-storm surveys shows around the 5 ft. contour in these counties. Longshore transport effects and long term erosion cause some areas of local accretion and severe erosion as shown in Nassau County.

The preliminary calibration of the model is carried out with all the surveyed profiles available which include 17 in Nassau County, 118 in St. Johns County, 68 in Brevard County and 33 in Indian River County. Results of the calibration show the model estimates match closely to the measured erosion distance between the contours of 8 ft. and 10 ft.

V. RECOMMENDED METHOD FOR STORM SURGE AND WAVE CALCULATION

This section describes the method employed for calculating the storm surge hydrograph and the associated waves. Based on the limitations discussed in Section III, it was decided to utilize the wind and bathymetric data and tide predictions for this purpose.

Screening of Wind Data

The coastal wind data were "screened" to identify those periods when the wind blew predominantly onshore for periods exceeding forty hours. Specifically, the wind events were classified according to those events that had the greatest magnitude of the integral, over a period of 40 hours, of the product of the wind speed and its magnitude for the time that the wind speeds were directed between -90° and +45° to a normal to the coastline. These events were ranked and their return period calculated in accordance with

$$T_R = \frac{N}{n} \tag{8}$$

in which N is the number of years for which wind data are available and n is the order of the event in the ranking.

Storm Surge Calculations

The storm surges resulting from the selected wind events were then calculated using the so-called "Bathystrophic Storm Surge" model developed by Freeman, Baer and Jung (1957). This is the same model that is used in the production runs of the CCCL. In these calculations, the local bathymetry extending out to a water depth of 600 feet was used. The fetch was extended beyond this depth for a distance of 100 miles as described in the next section.

Wave Height Calculations

The shallow water wave model described in the Shore Protection Manual was modified for calculation over a variable depth bathymetry. Note that although this model is referred to as a "Shallow Water Model", it also applies to deep water. The characteristics of the model and the procedure of applying the model over varying bathymetry is described in Appendix A. Because the available wind speeds did not provide a measure of the offshore fetch, sensitivity calculations were carried out to determine the effect of fetch and an "effective fetch" established. This procedure is described in the following paragraph.

The northern CCCL profile in Volusia County was selected for evaluation of the method. Two sets of calculations were carried out. In the first, the fetch was considered to extend from the 600 foot contour to the shoreline as provided in the three to five reference profiles per county utilized in the production runs of the CCCL program. In the second, the fetch was considered to extend an additional 100 miles seaward beyond a depth of 600 feet. Figures 8 and 9 present profile, and wave height and period results for a wind speed of 55 miles per hour for the original profile and an "augmented" fetch of an additional 100 miles beyond a water depth of 600 ft, respectively. It is seen that because the shallow water causes dissipation of wave energy, the wave height is only weakly dependent on the additional 100 mile fetch beyond the 600 foot contour. Because of the uncertainty of the offshore limit of fetch and the relative uncertainty of fetch, it was decided to add an additional 100 miles of fetch at the seaward end of the profile provided.

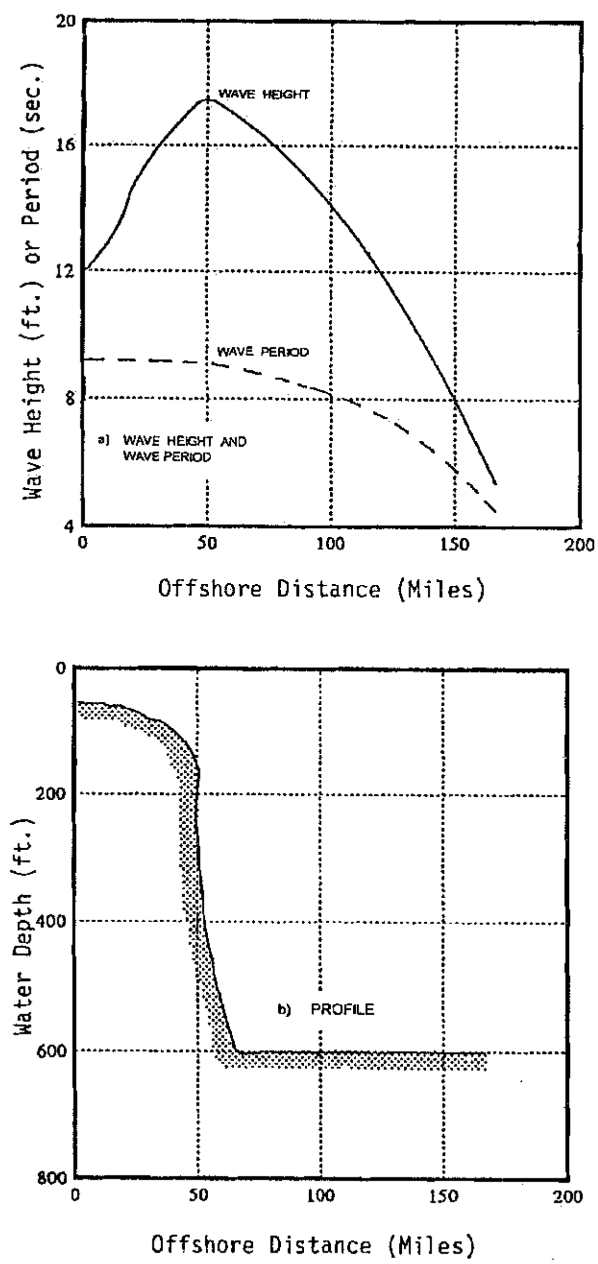
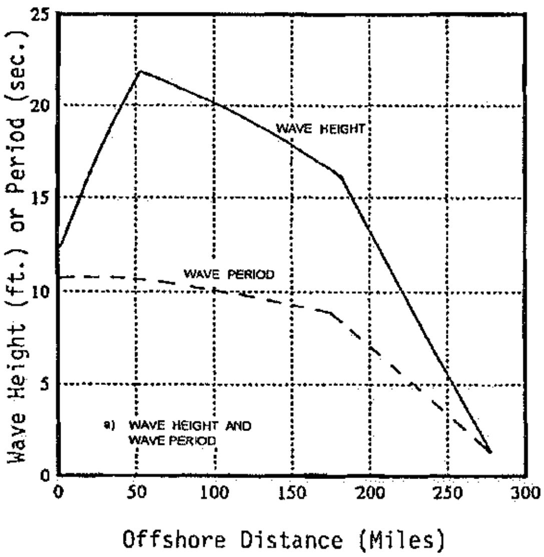


Figure 8 Profile and Wave Height and Period for Uniform Wind Speed of 55 mph North Volusia County Profile



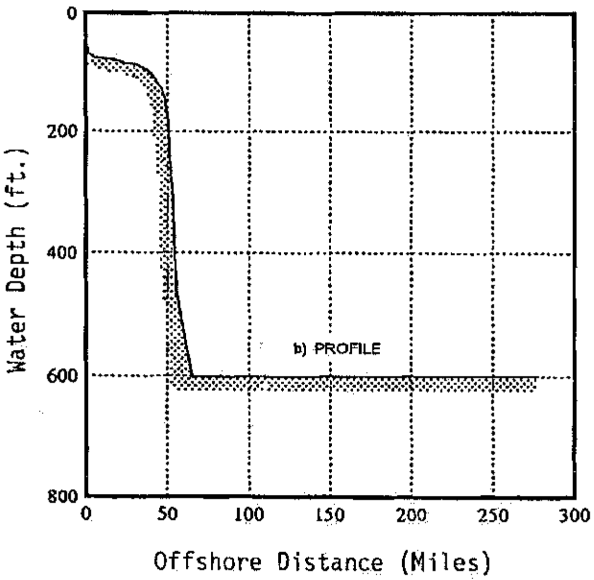


Figure 9 Profile and Wave Height and Period For Uniform Wind Speed of 55 mph North Volusia County Profile. Case of Increased Fetch of 100 Miles beyond a Depth of 600 ft.

VI. METHOD FOR COMPUTING THE MODEL HYDROGRAPHS BASED ON EROSION POTENTIAL

Introduction

Ideally, the return period associated with a particular model hydrograph should be based on its erosion potential rather than its wave height and storm surge. This is particularly important due to the erosional significance of the storm surge duration associated with a certain return period. The following paragraphs describe the manner in which the model hydrographs associated with a particular return period were determined.

Referring to Figure 10, the procedure for determining model hydrographs and associated wave heights for various return intervals will be described using the points between Weather Station locations A and B as an example.

(1) Using the winds from Point "A" determined as described in the previous paragraphs, the storm surges and waves were calculated at all reference profiles established for the production runs in the CCCL program. Periodic astronomical tides were added to the storm surges with an amplitude equal to the average of the mean and spring tides. With these storm surges, waves and astronomical tides, erosion was calculated at approximately every ninth profile along the shoreline. The return periods associated with the contour recessions were then determined in accordance with Eq. (8).

(2) The procedure described in (1) was then repeated for the same locations except now using the wind and wave data from Point B.

(3) For each return period, the interpolated contour recessions associated with each profile location and a particular return period event were then determined based on the weighted distances between Points A and B.

(4) Idealized "Model" hydrographs and wave heights were then determined for each return period and each location that produced the same erosion characteristics at the upper affected elevation contours (usually the 5, 10 and possibly the 15 foot contours). The storm surge hydrograph and waves are then characterized as the superposition of a constant elevation and wave height over a fixed duration and the sinusoidal tide as described earlier. An advantage of this characterization is that it facilitates description and application of the model storm surge hydrograph and waves with the erosion model.

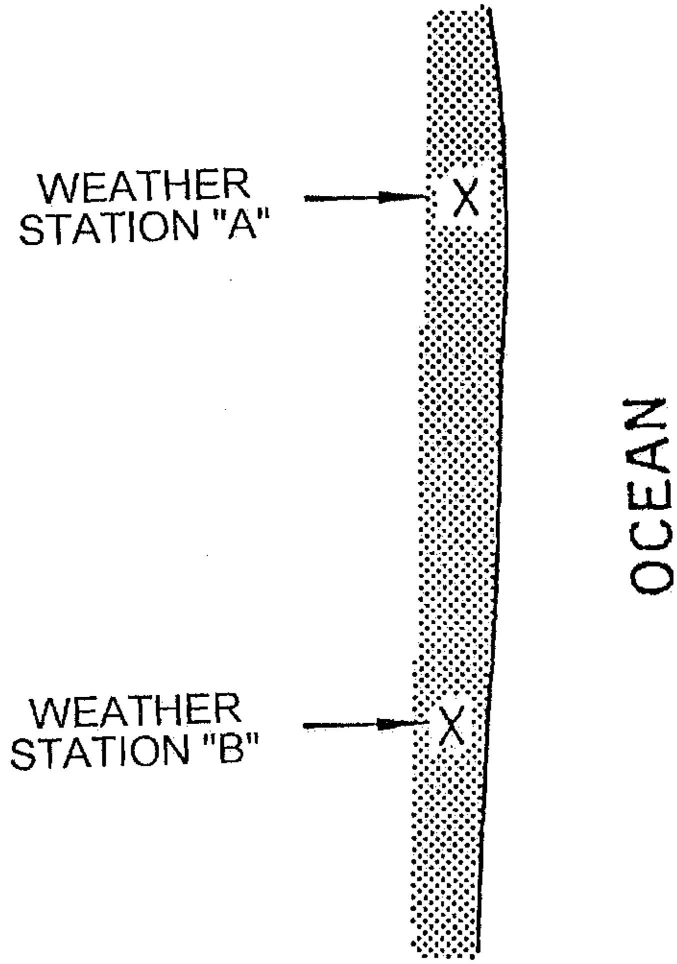


Figure 10 Hypothetical Coastal Weather Station Locations

Summary

The purpose of this study was to develop and apply a methodology to calculate high frequency hydrographs for erosion prediction. Ideally, data would be available that would allow a step by step approach to accomplish this goal. Although substantial data of the necessary types are available, the measurement locations, times, and quality of the data are such that the most appropriate data are determined to be wind, bathymetry and predicted astronomical tides. A methodology has been developed and applied to establish idealized high frequency hydrographs that yield the same erosion as the actual hydrographs based on 36 years of wind data. In this context a "hydrograph" consists of a uniform storm surge of specified height and duration, an astronomical tide with amplitude equal to the average of the spring and mean tidal ranges at the location of interest and a constant wave height, the combination of which yields the same erosion as the actual hydrograph of the same return period. Thus the model hydrograph for a specific return period and location is specified by four parameters: (1) Duration, (2) Storm surge height, (3) Astronomical tide range, and (4) Wave height. These parameters will be presented in graphical and tabular form in the User's Manual that is being prepared.

Recommendations

Although this study has accomplished the goal of development of the necessary parameters and methodology for calculating high frequency erosion events, it is recommended that this study be continued to test the methodology in a "blind-folded" manner against additional historic data that are available. Additionally, due to the importance of this problem and the limited quality of the data available, it is essential that an aggressive effort be made to obtain high quality documentation of future erosional events. Due to the need for pre-storm conditions against which to compare, this will require a continuing program of beach profile monitoring as well as post-storm monitoring.

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APPENDIX A

WAVE GENERATION OVER A VARIABLE BATHYMETRY

The two equations governing wave height and period growth under a wind field of given fetch, F, wind speed, U, in a water depth, h, are:

$$\frac{gH}{U^2} = 0.283\, G_1\left(\frac{gh}{U^2}\right) G_2\left(\frac{gF}{U^2}, \frac{gh}{U^2}\right) \tag{9}$$

and

$$\frac{gT}{2\pi U} = 1.20\, G_3\left(\frac{gh}{U^2}\right) G_4\left(\frac{gF}{U^2}, \frac{gh}{U^2}\right) \tag{10}$$

in which G_n are functions described as

$$G_1 = \tanh\left[0.53\left(\frac{gh}{U^2}\right)^{0.75}\right]$$

$$G_2 = \tanh\left[\frac{0.0125\left(\frac{gF}{U^2}\right)^{0.42}}{G_1}\right]$$

$$G_3 = \tanh\left[0.833\left(\frac{gh}{U^2}\right)^{0.375}\right]$$

$$G_4 = \tanh\left[\frac{0.077\left(\frac{gF}{U^2}\right)}{G_3}\right]$$

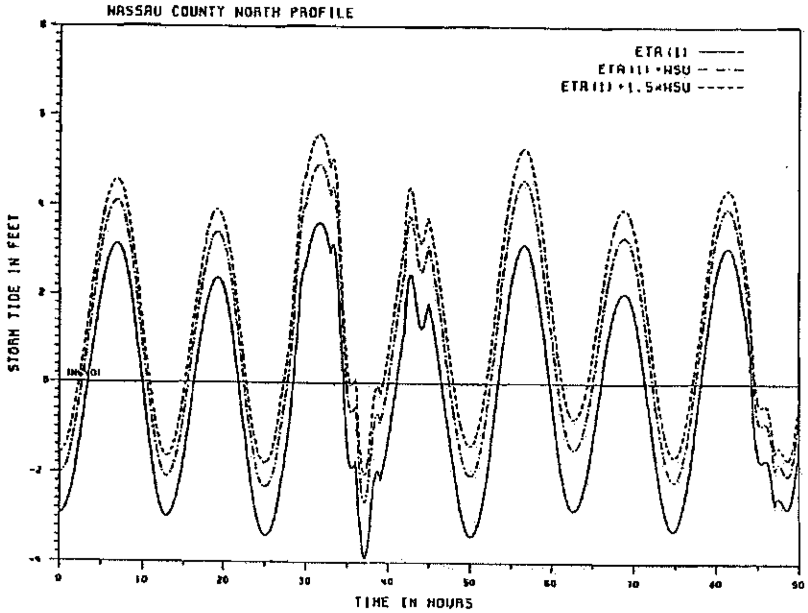
The above equations are based on water of uniform depth and since our application is for variable depth, it is necessary to modify them for this application. Consider a gridded profile and a uniform wind blowing directly toward land. At the preceding grid to that of interest, the "effective fetch" is considered known. At the beginning of the grid of interest, the effective fetches for the wave height and period are determined for the particular depth and the grid length is added to this effective fetch and the new wave height and period calculated from Equations (9) and (10). These equations include a frictional effect and for strong winds, the wave heights in the shallower water may be greater than those which would occur for the particular wind speed. In this combined effect of a greater fetch (due to the grid length contribution) and the smaller depth will result in a wave height decay over the grid length. This is shown in Figure 8 for a wind of 55 mph blowing over the northern CCCL profile in Volusia County.

The only uncertainty that remains is that of the fetch, since this information is not available from the wind speed records. It is clear that use of the shelf width as the fetch would underestimate the fetch, at least in some locations around the Florida peninsula. For example, the width of the continental shelf varies from a minimum of approximately 2.5 miles off Palm Beach to more than 100 miles off the Florida-Georgia border. It is fortunate that the wave height which occurs in shallow water is not overly sensitive to the fetch. As an illustration, Figures 8 and 9 present the wave heights over the north Volusia County profile described earlier for a wind speed of 55 mph and fetches of 100 and 200 miles. Even with this doubling of fetch, the wave height in a water depth of 20 feet is only increased by 8%. Additionally, it can be shown that erosion in the early stages of the erosional event is not overly sensitive to the wave height.

Based on the above, it was decided in the applications to utilize a fetch of 100 miles for all computations.

APPENDIX B

STORM SURGE HYDROGRAPHS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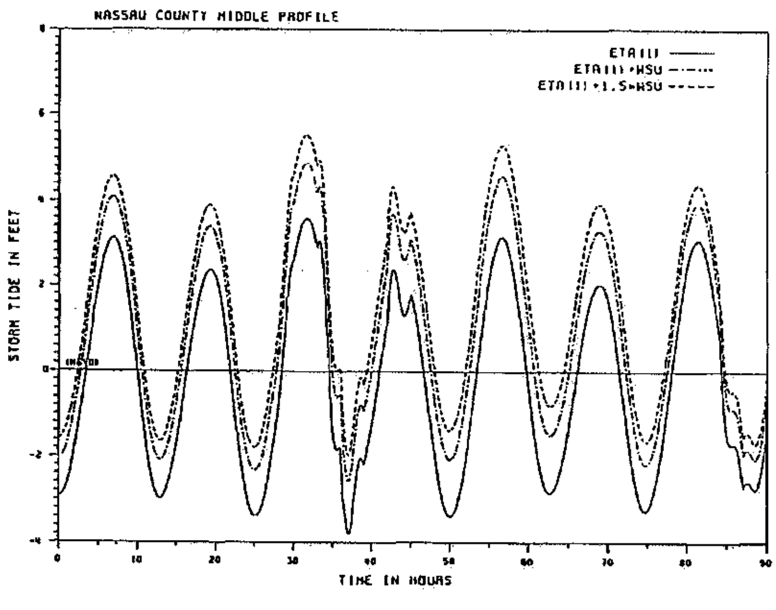
ETA(I)
ETA(I)+HSU
ETA(I)+1.5*HSU
STORM TIDE IN FEET
TIME IN HOURS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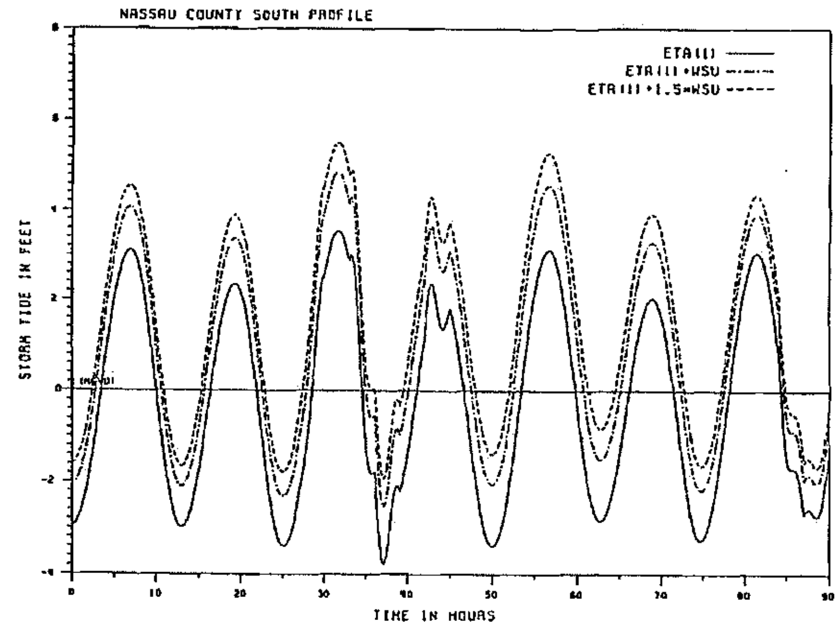
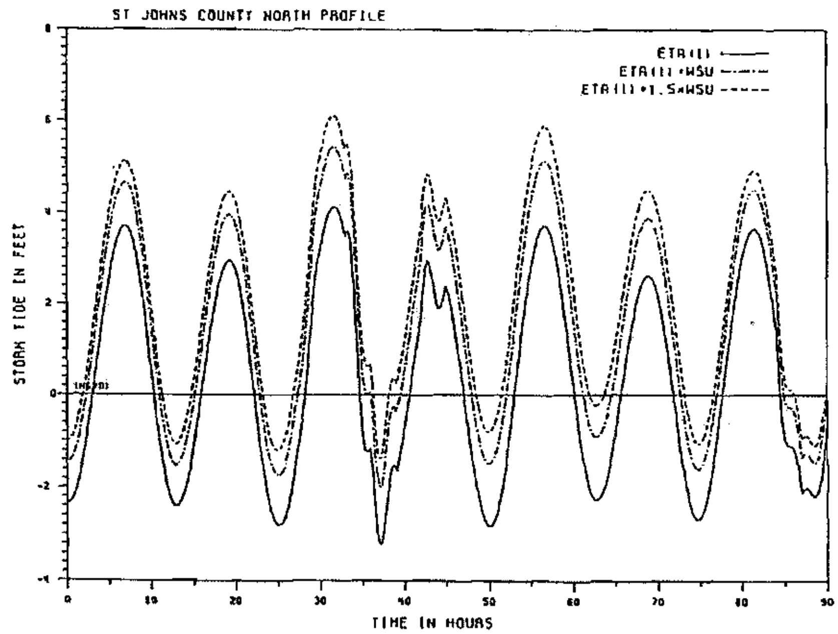
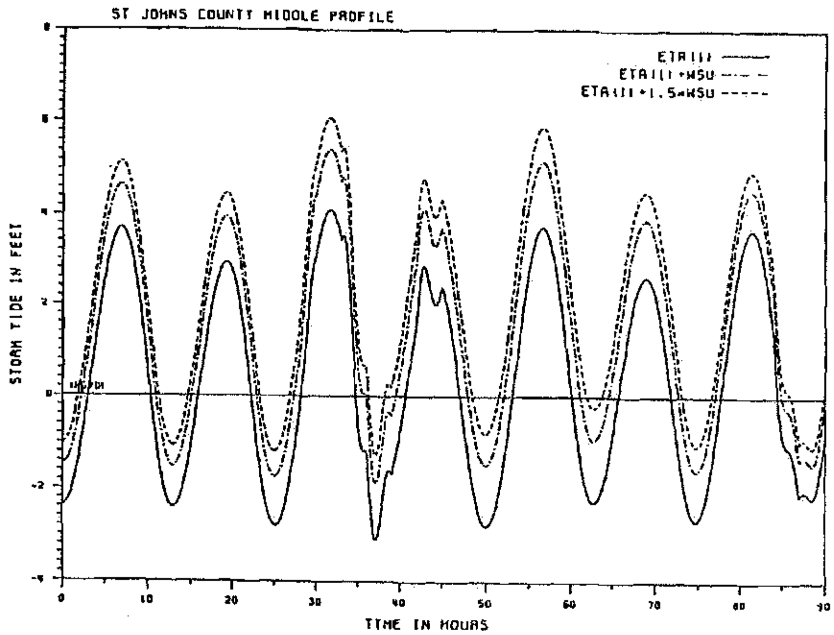
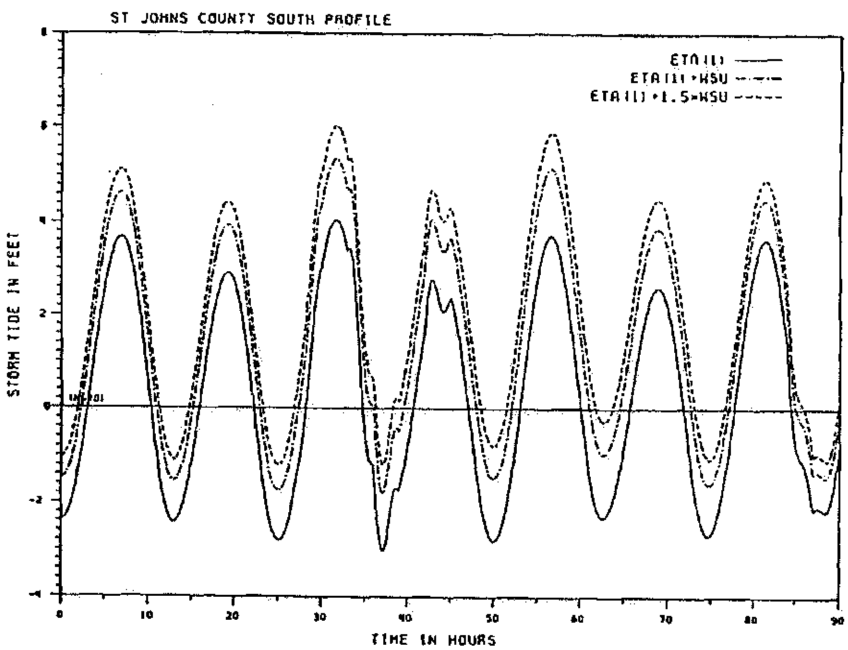
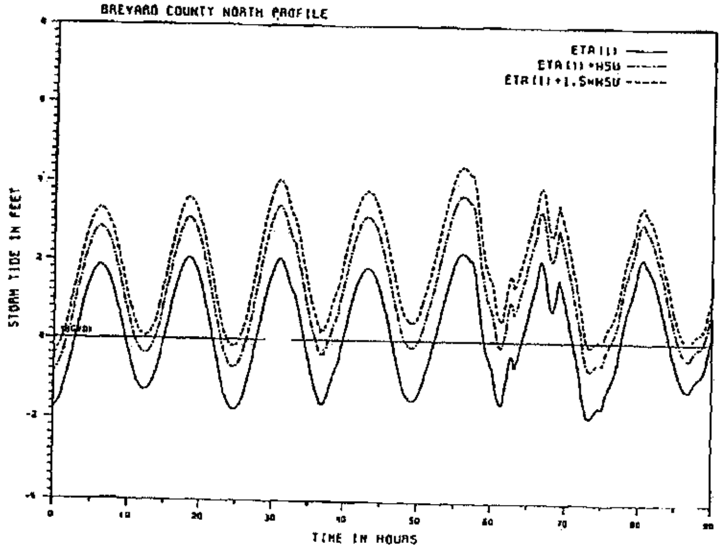
ETA(I)
ETA(I)+HSU
ETA(I)+1.5*HSU
STORM TIDE IN FEET
TIME IN HOURS

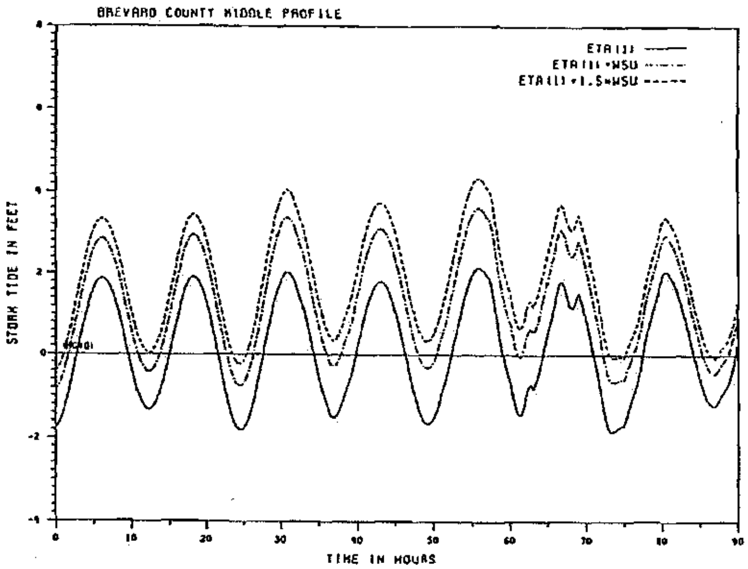

NASSAU COUNTY SOUTH PROFILE
ETA(I)
ETA(I)+WSU
ETA(I)+1.5*WSU
STORM TIDE IN FEET
TIME IN HOURS
(NGVD)
0
10
20
30
40
50
60
70
80
90


ST JOHNS COUNTY NORTH PROFILE
ETA(I)
ETA(I)+WSU
ETA(I)+1.5*WSU
STORM TIDE IN FEET
TIME IN HOURS
(NGVD)
0
10
20
30
40
50
60
70
80
90


ST JOHNS COUNTY MIDDLE PROFILE
ETA(I)
ETA(I)+HSU
ETA(I)+1.5*HSU
STORM TIDE IN FEET
TIME IN HOURS


ST JOHNS COUNTY SOUTH PROFILE
ETA(I)
ETA(I)+HSU
ETA(I)+1.5*HSU
STORM TIDE IN FEET
TIME IN HOURS


BREVARD COUNTY NORTH PROFILE
ETA(1)
ETA(1)+HSU
ETA(1)+1.5*HSU
STORM TIDE IN FEET
TIME IN HOURS


BREVARD COUNTY MIDDLE PROFILE
ETA(1)
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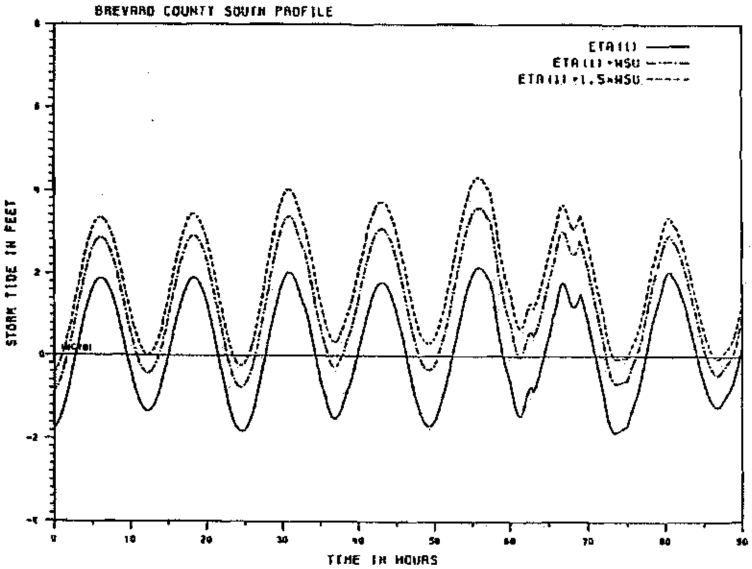
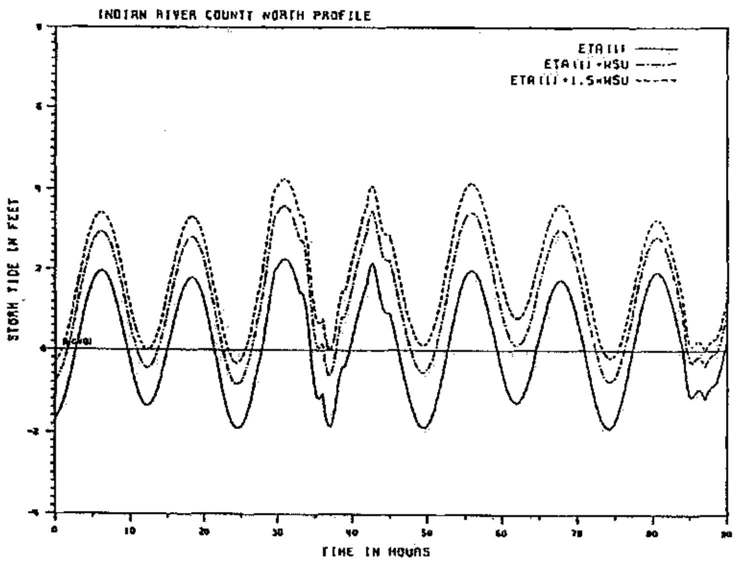
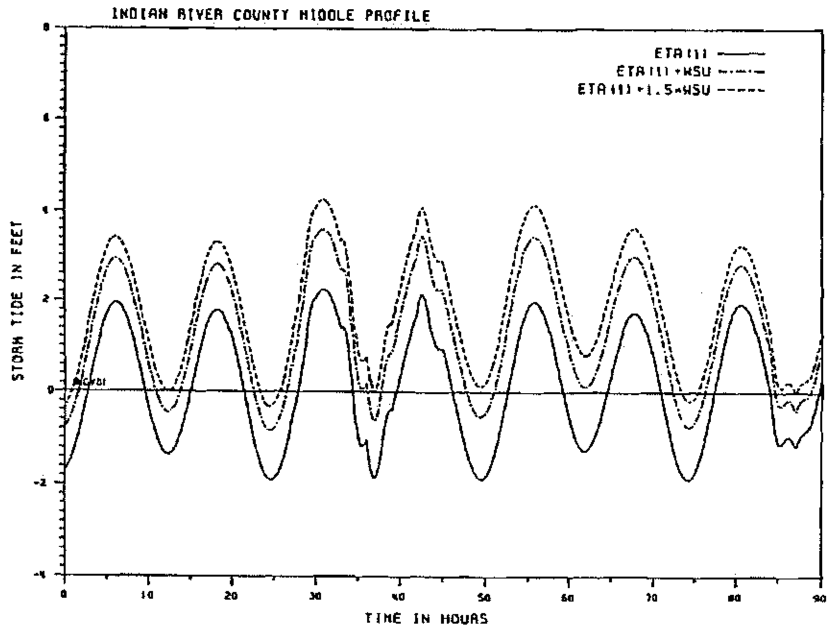
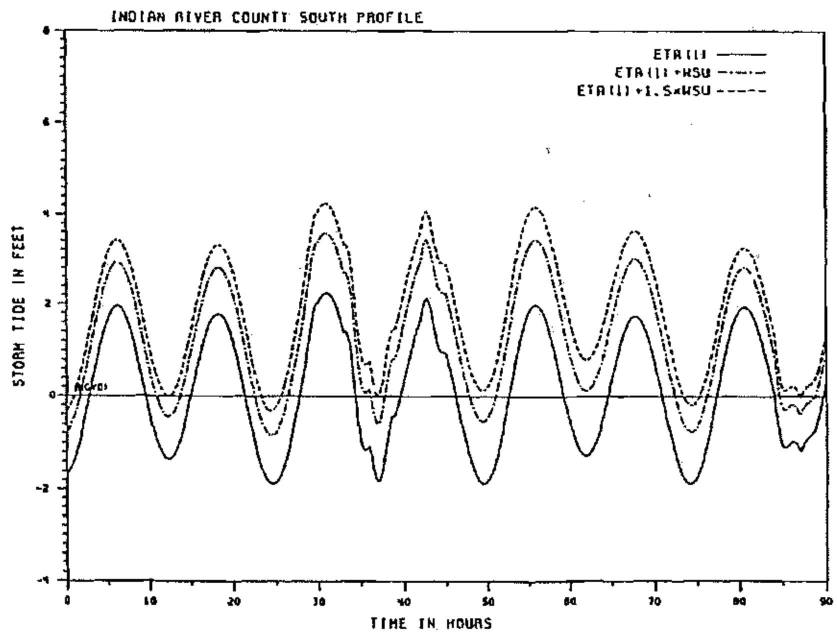
ETA(1)+1.5*HSU
STORM TIDE IN FEET
TIME IN HOURS


BREVARD COUNTY SOUTH PROFILE
ETA(I)
ETA(I)+WSU
ETA(I)+1.5*WSU
STORM TIDE IN FEET
TIME IN HOURS
0
10
20
30
40
50
60
70
80
90
-2
0
2


INDIAN RIVER COUNTY NORTH PROFILE
ETA(I)
ETA(I)+WSU
ETA(I)+1.5*WSU
STORM TIDE IN FEET
TIME IN HOURS
0
10
20
30
40
50
60
70
80
90
-2
0
2


INDIAN RIVER COUNTY MIDDLE PROFILE
ETA(I)
ETA(I)+WSU
ETA(I)+1.5*WSU
STORM TIDE IN FEET
TIME IN HOURS


INDIAN RIVER COUNTY SOUTH PROFILE
ETA(I)
ETA(I)+WSU
ETA(I)+1.5*WSU
STORM TIDE IN FEET
TIME IN HOURS