

METHODOLOGY ON COASTAL CONSTRUCTION
CONTROL LINE ESTABLISHMENT

by

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PREFACE

This report presents an update of the methodology and procedures to the original 1984 report which was published after a public work shop with consulting coastal engineers. In the eighteen years since 1984, the basic theory and methodology of establishing the Florida Coastal Construction Control Line (CCCL) have been applied to the 24 coastal counties along the Florida Atlantic and Gulf coasts with good results. Minor refinements and modifications have been made from time to time to the numerical models in the long study period of the program to enhance the quality of the analysis of the parameters essential to the studies, but the basic theory and methodology have not been changed.

An illustration of the CCCL in Pinellas County and related numerical analysis presents all the refinements and modifications to the numerical models calculating the combined storm tide elevations and corresponding erosions. Some frequently asked questions related to the technical aspect of the methodology in public hearings are addressed in Addendums A and B with a number of cases of concern to the inquisitors. Discussions and notes in the peer review program carried out in the 1992 to 1994 period are presented in Addendum C.

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METHODOLOGY

ON

"COASTAL CONSTRUCTION CONTROL LINE ESTABLISHMENT"

I. INTRODUCTION

The coastal engineering phenomena leading to the rationale for the Coastal Construction Control Line (CCCL) are:

Shoreline Erosional Trends
Shoreline Fluctuations (Both Seasonal and Storm Induced) and,
Storm Surges and Associated Waves.

The general objective of the CCCL program is, as required by Florida statute, to define the zone of impact of a one hundred year storm event along the sandy outer coastline segments of the State of Florida. This program is implemented on a county-by-county basis. The Florida Department of Environmental Protection (DEP) permitting program applies seaward of the CCCL with the two-fold purpose of ensuring: (1) the protection of the adjacent shoreline, and (2) the integrity of structures.

Due to the sparsity of specific data which would identify directly the appropriate location for the CCCL, a series of numerical models and calculation procedures is employed and combined with historical hurricane and erosion data to establish the recommended CCCL position.

II. METHODOLOGY

The establishment of the recommended location of the CCCL requires calculation of the 100 year storm surge and accompanying waves and shoreline erosion. These models and their implementation are based on the best data generally available and on data collected specifically for the purpose of this program. In particular, an extensive set of nearshore and beach profiles is taken at intervals of approximately 1,000 ft with all profiles extending out to approximately the thirty foot depth contour. The field data are valuable input to the computer models; however, the field program will be described elsewhere.

2.1 Introduction

As noted previously, because storm surge data are quite sparse (especially long-term storm surge data) and because most tide gages and high water marks collected are in locations which are not representative of open coast conditions, it is necessary to use numerical models with long-term historical hurricane characteristics which are relatively insensitive geographically, although there are, for example, trends in the hurricane parameters.

2.2 Parameterized Hurricanes

Each hurricane is unique in its structure, shape, size, translational characteristics, etc. However, it is generally agreed that when considering many hurricanes, it is valid to employ the concept of an idealized or parameterized hurricane. In this approach, a hurricane is represented by five parameters:

- Δp = the central (lowest) barometric pressure relative to the ambient pressure usually reported in inches of mercury (in. Hg) or millibars of mercury. Δp is a measure of the intensity of the hurricane,
- R = radius to the band of maximum winds, usually reported in nautical miles. R is a measure of the size of the hurricane,
- V_F = forward translational speed of the hurricane, usually reported in knots,
- θ = forward translational direction, defined as the direction from which a hurricane originates,
- L = landfall location or some other parameter positioning the hurricane at some time during the hurricane's close proximity to the area of primary concern.

2.3 Classification by Path Relative to Shoreline

Hurricanes causing appreciable storm tides in the vicinity of a county shoreline are classified as either "landfalling", "alongshore" or "exiting" storms, depending on their paths relative to the shoreline orientation. Reasonably good data are available describing the characteristics of such storms, from approximately 1900 to 1987. For purposes of establishing the statistical characteristics, the frequency and direction data contained in References (1) and (2) are merged for a segment of the coast usually extending from 100 n.mi. to 150 n.mi up and down coast, i.e., a total length of 200-300 n.mi.

The hurricane direction is defined here as the azimuth of hurricane translation direction at the time of landfall, or, if an alongshore storm, when in close proximity to the site.

The designation of a storm as "landfalling", "exiting", or "alongshore" is somewhat arbitrary as storms travel over a continuous range of directions and there is not a particular direction relative to the shoreline for which the storm tide-generating characteristics change markedly. Moreover, one directional distribution is applied for all three types of storms. Figure II-1 shows the location of Pinellas County, FL and Figure II-2 presents an example of the directional distribution for Pinellas County. It is important to note that the manner in which the track of a hurricane is characterized for the purposes of this study is different for landfalling, exiting and alongshore hurricanes. For landfalling and exiting hurricanes, the track is specified by a location of landfall (or exit) and direction, whereas for the alongshore storms, the track is specified by an offshore distance and a track direction. Figure II-3 presents a definition sketch of the three types of hurricanes.



Figure II-1 General Location of the Study Area

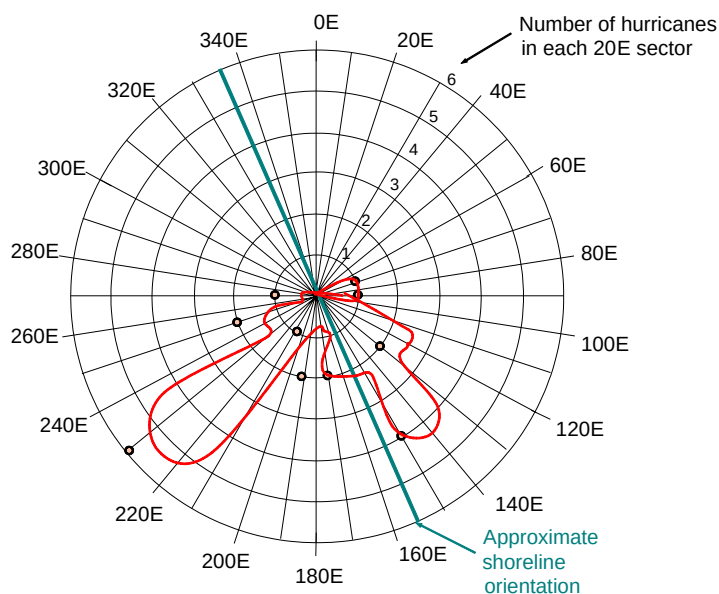


Figure II-2 Direction Distribution of Historical Hurricanes in a 300 n. mi. Segment of Coast Comprising the Pinellas Coastline

For purposes of this study, landfalling and exiting hurricanes are considered to be of possible significance if they made landfall within a 250 nautical mile segment of the coast comprising the study area. Generally, this segment is centered approximately near the mid-point of the county of interest. Usually an offshore limit of alongshore storms is on the order of 50 to 100 nautical miles. Figure II-4 shows the sectors of propagation paths for the three types of hurricanes for Pinellas County.

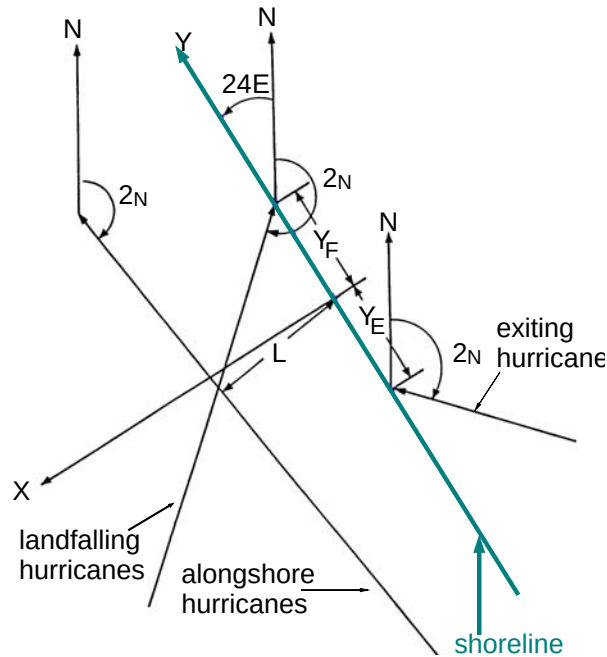


Figure II-3 A Definition Sketch of Three Types of Hurricanes

For purposes of computer representation, the cumulative probability distribution is developed from Figure II-2 and is presented in Figure II-5.

In the following discussion of the remaining parameters defining the idealized hurricane, Pinellas County will be used as an illustrative example. Figure II-6 presents the cumulative probability distribution of radius to maximum winds for landfalling and exiting hurricanes, and Figure II-7 presents the same for alongshore hurricanes.

In the following discussion of the remaining parameters defining the idealized hurricane, Pinellas County will be used as an illustrative example. Figure II-6 presents the cumulative probability distribution of radius to maximum winds for landfalling and exiting hurricanes, and Figure II-7 presents the same for alongshore hurricanes.

The cumulative probability distribution of central pressure deficit for landfalling and alongshore hurricanes is presented in Figure II-8 and Figure II-9 presents the same information for exiting hurricanes.

Examination of historical hurricane data has demonstrated that for landfalling storms the distributions for radius to maximum winds and central pressure deficit are not independent. The correlation is such that the hurricanes with the more extreme central pressures tend to be smaller. Figure II-10 presents the ranges of R and Δp for the 300 n.mi. coast comprising the area of interest. The relationship of R and Δp is incorporated into the simulations to generate hurricanes in accordance with historical trends. For purposes of computer application, the joint cumulative probability distribution of R is modified to conform to the limited range shown on Figure II-10 for any specific Δp selected within the range of -0.9 to -2.5 in. Hg, the first limit corresponding approximately to hurricane winds.

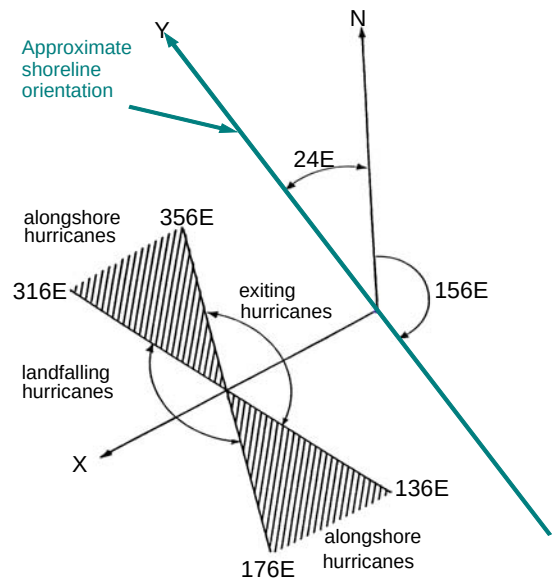


Figure II-4 Designation of Alongshore, Landfalling and Exiting Hurricanes Depending on Track Directions Relative to Shoreline Orientation

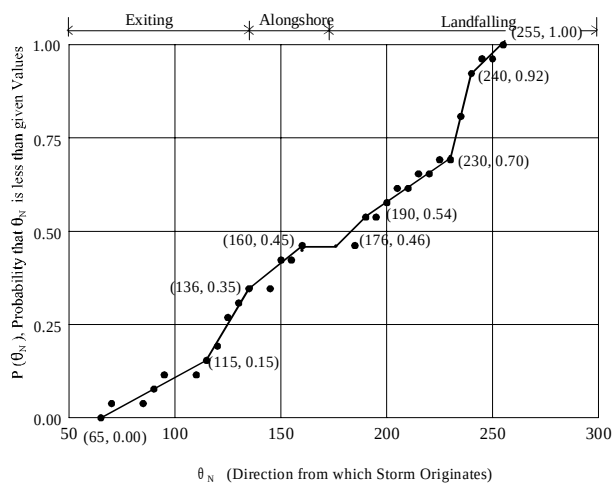


Figure II-5 Cumulative Probability Distribution of Hurricane Track Direction

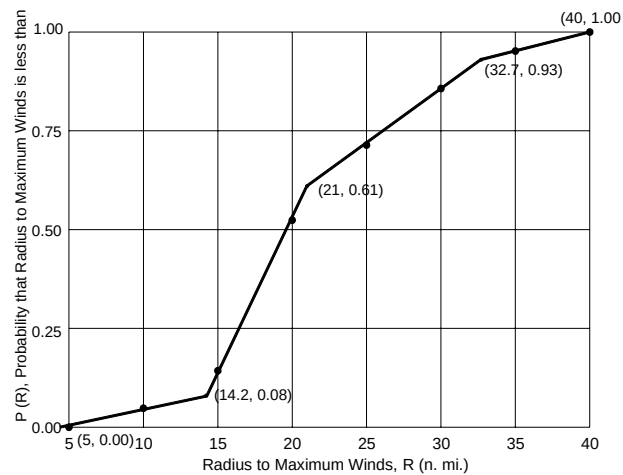


Figure II-6 Cumulative Probability Distribution of Radius to Maximum Winds, R, for Landfalling and Exiting Hurricanes

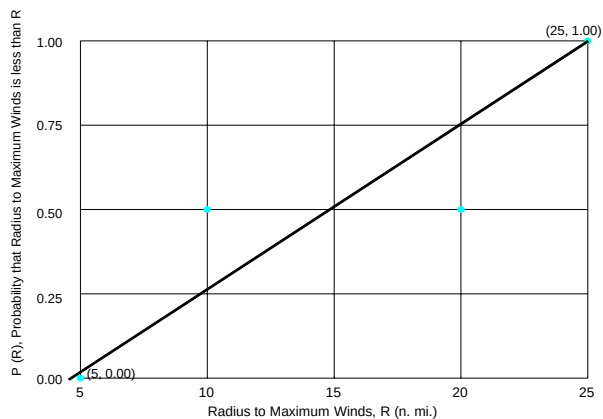


Figure II-7 Cumulative Probability Distribution of Radius to Maximum Winds, R, for Alongshore Hurricane

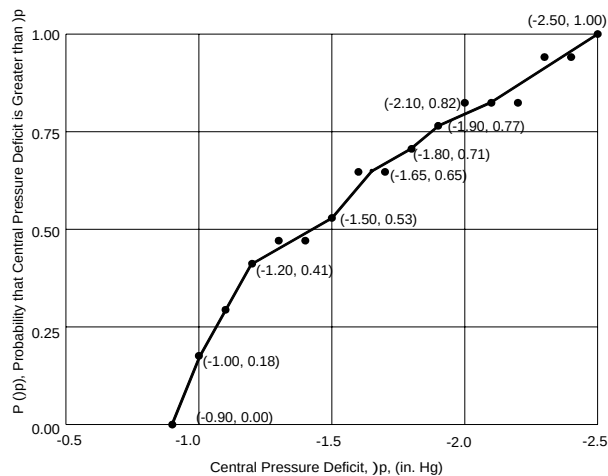


Figure II-8 Cumulative Probability Distribution of Central Pressure Deficit, Δp , for Landfalling and Alongshore Hurricanes

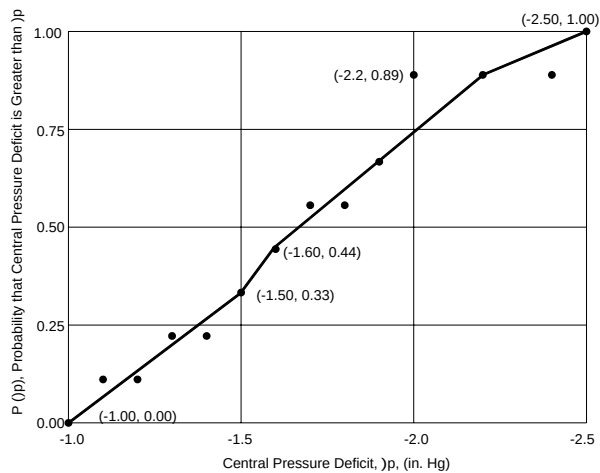


Figure II-9 Cumulative Probability Distribution of Central Pressure Deficit, Δp , for Exiting Hurricanes

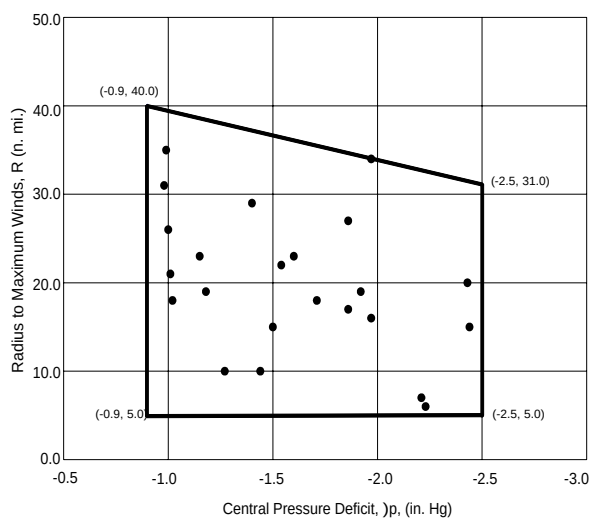


Figure II-10 Historical Trend of Central Pressure Deficit, Δp , and Radius to Maximum Winds, R

The cumulative probability distribution of the forward speed of translation for landfalling, exiting and alongshore hurricanes is presented in Figure II-11.

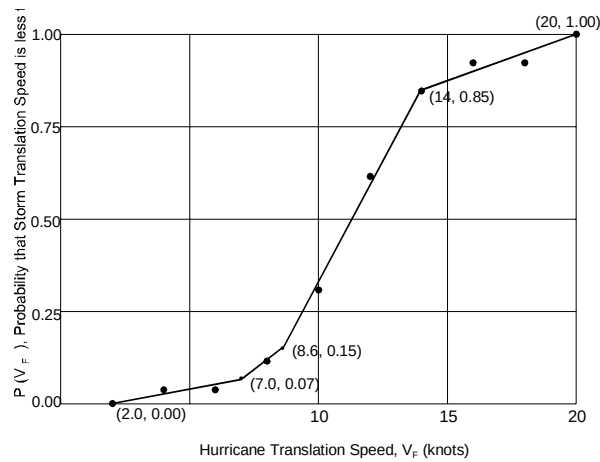


Figure II-11 Cumulative Probability Distribution of Hurricane Translation Speed, V_F , for Landfalling, Alongshore and Exiting Hurricanes

For the landfalling and exiting hurricanes, the track position is determined by the y coordinate, Y_F and Y_E , representing the landfalling or exiting point, respectively, as defined in Figure II-3. Figure II-12 presents the cumulative probability distribution for the actual landfalling position, Y_F , for landfalling and exiting hurricanes. Figure II-13 presents the cumulative probability distribution for the actual offshore distance, X_L , for alongshore hurricanes.

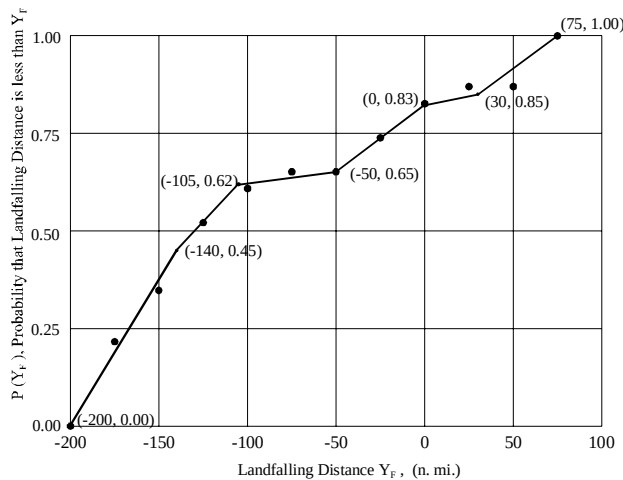


Figure II-12 Cumulative Probability Distribution of Landfalling Distance, Y_F , for Landfalling and Exiting Hurricanes

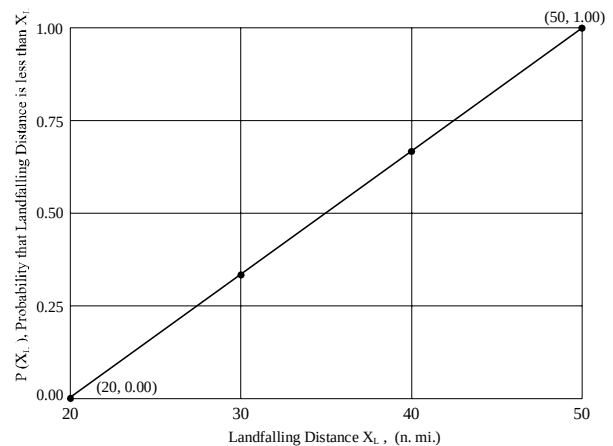


Figure II-13 Cumulative Probability Distribution of Offshore Distance, X_L , for Alongshore Hurricanes

To generate a parameter (say R) in accordance with the statistical distribution, a random number is generated between 0 and 1 and the associated R value interpolated from the cumulative probability distribution. Since the cumulative probability distribution (cdf) is the integral of the probability density distribution (pdf), the slope of the cdf is proportional to the probability of occurrence and thus the method above yields the correct population of the parameter (in this case, R).

2.4 General Overview of Storm Surge Numerical Models and Procedures

In the establishment of the return period vs storm surge relationship, two numerical models were employed to obtain the best combination of accuracy, detail and economy. The first model employed is a two-dimensional (2-D) variable grid numerical model and may extend over a shoreline length of 100-200 n.mi. The purpose of the 2-D model is two-fold: (1) to verify and develop confidence in the 2-D model by comparing predicted storm surges with those caused by storms of record, and (2) to provide a data base of storm tides for calibration of the faster and more economical one-dimensional (1-D) model. As inferred, the 2-D model is much more expensive to run than the 1-D model. The ratio of run times is approximately 200:1 to 400:1.

The flow chart presented in Figure II-14 describes the general methodology and relationship of the two numerical models to the overall computational process.

The following sections describe each of the two numerical models, with illustrative examples from Pinellas County.

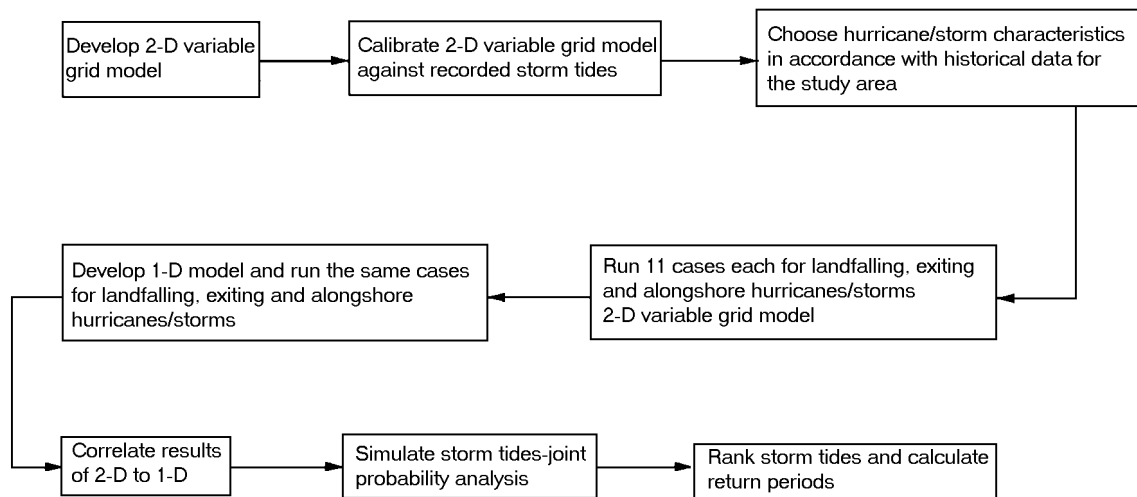


Figure II-14 Flow Chart of Methodology

2.5 Features and Solution of the Two-Dimensional Numerical Model

As noted previously, this is a variable grid two-dimensional model for the offshore and coastal areas which carries out the generation of storm tides for Pinellas County. The grids of the model are arranged in such a way that

- 1) The finest grids cover the coastal areas of Pinellas county to yield detailed information for the study. Fine grids are also used in locations where calibration of the model results against measured storm tides is going to take place.
- 2) The coarsest grids cover the areas where detailed information is not needed.
- 3) A number of grids varying gradually in size are used for the transition from the coarsest to the finest grids.

This arrangement of the varying grid system of the two-dimensional model gives good efficiency of computing time utilization. The size of the finest grid is 1,000 ft. x 5,000 ft. and the coarsest 28,423 ft. x 29,802 ft. The two-dimensional model covers an area of 185.40 n.mi. x 322.49 n.mi. (122 grids x 155grids) with the northwest-southeast grid lines oriented approximately parallel with the southern half of the Pinellas County shoreline. Figure II-15 shows the grid system layout.

The two-dimensional storm surge model is an implicit finite difference system in which the three governing differential equations are the two vertically averaged equations of momentum and the equation of continuity. The solution to the equations is carried out by a fractional time step procedure. The

advantage of this fractional time step procedure is that it is time and space centered to first order. The finite difference equations appropriate for implicit solution are solved by the “double sweep” method, and will be described later in this section. The surface (wind) and bottom (friction) shear stresses, the barometric pressure, the Coriolis effect, the components of slope of the water surface and the boundary conditions are all incorporated into the solution process.

Inlets and barrier islands which are too small to be resolved by the normal grid sizes are represented in the model by a special treatment. The boundary conditions specified on the two-dimensional model are that the water surface displacements on the boundaries where water is present are equal to the barometric head, due to atmospheric pressure variations. The normal discharge at these boundaries is that necessary to satisfy the volume requirement by the rising and falling water surface occurring at the boundaries. Although this is an approximation, if the boundaries are sufficiently distant from the site of interest, any extraneous effects of this approximation should be small. The second type of boundary condition is the no-flow requirement which ensures that the flows are zero normal to grid lines where land elevations exist that are higher than the adjacent water elevations. At times when the elevation of a rising water surface exceeds the land elevation of an adjacent grid block, that block is flooded by a simple algorithm and vice versa for the “deflooding” from grid blocks at times that the falling water surface leaves a block exposed. The effects of vegetation on bottom and surface friction factors are accounted for in an approximate manner.

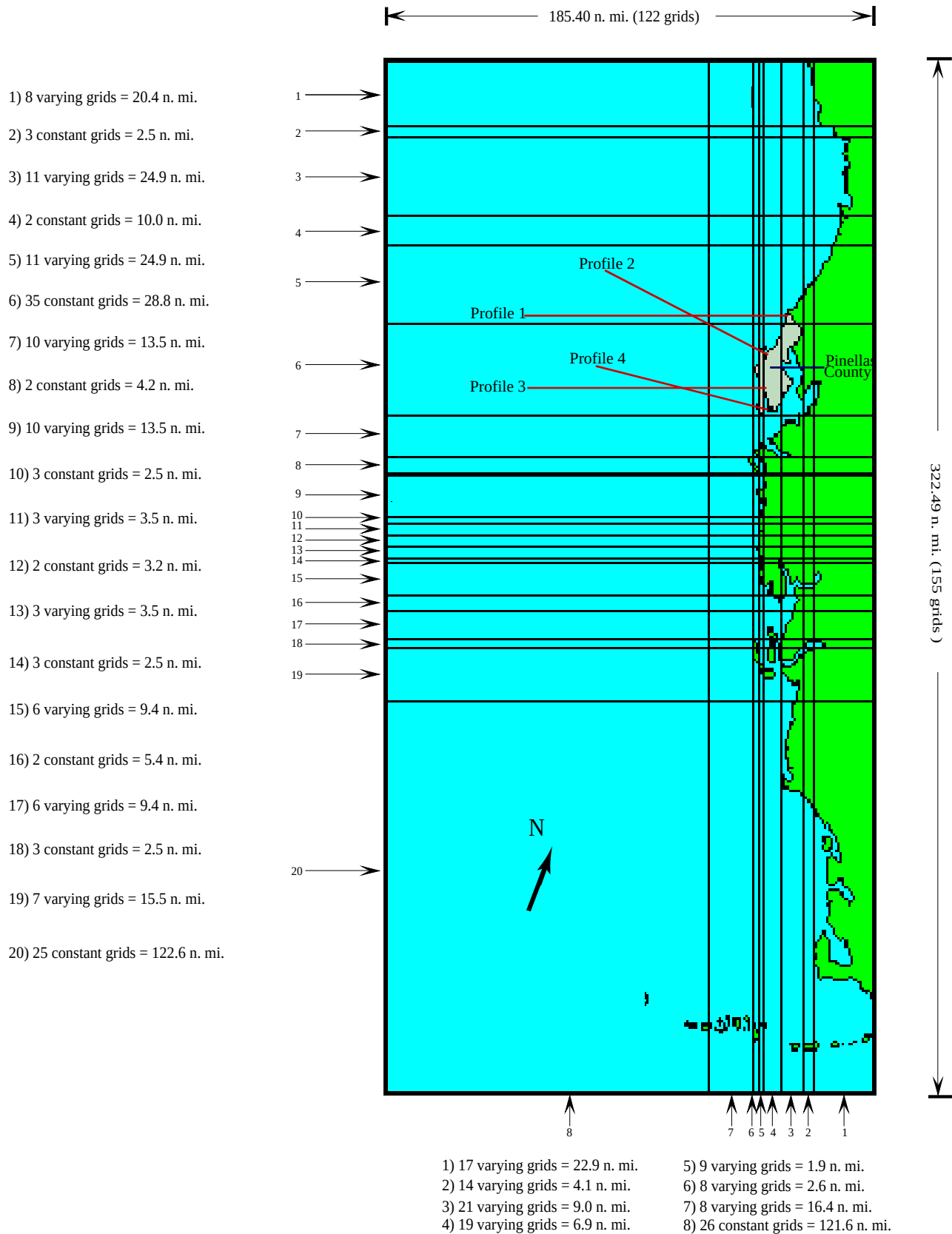


Figure II-15 Grid System Layout for Pinellas County

Governing Differential Equations For Two-Dimensional Numerical Model

The governing differential equations for the two-dimensional model are the two vertically averaged equations of momentum and the equation of continuity, given by:

Momentum Equations

$$\frac{\partial q_x}{\partial t} + \frac{q_x}{D} \frac{\partial q_x}{\partial x} + \frac{q_y}{D} \frac{\partial q_x}{\partial y} = -gD \frac{\partial n}{\partial x} - \frac{D}{\rho} \frac{\partial p}{\partial x} + \frac{\tau_{w_x}}{\rho} - \frac{\tau_{b_x}}{\rho} - \beta q_y \quad (1)$$

$$\frac{\partial q_y}{\partial t} + \frac{q_x}{D} \frac{\partial q_y}{\partial x} + \frac{q_y}{D} \frac{\partial q_y}{\partial y} = -gD \frac{\partial n}{\partial y} - \frac{D}{\rho} \frac{\partial p}{\partial y} + \frac{\tau_{w_y}}{\rho} - \frac{\tau_{b_y}}{\rho} + \beta q_x \quad (2)$$

Continuity Equation

$$\frac{\partial n}{\partial t} + \frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} = 0 \quad (3)$$

in which

- q_x = volumetric transport component per unit width in the x direction
- q_y = volumetric transport component per unit width in the y direction
- t = time
- D = total water depth ($h+\eta$) including the still water depth, h and the storm surge, η
- η = storm surge above mean water level
- x = horizontal coordinate, directed offshore
- y = horizontal coordinate direction according to the left-hand coordinate system
- g = gravitational constant
- ρ = mass density of water
- p = barometric pressure
- τ_{w_x} = wind shear stress component in the x direction
- τ_{w_y} = wind shear stress component in the y direction
- τ_{b_x} = bottom shear stress component in the x direction
- τ_{b_y} = bottom shear stress component in the y direction
- f = Darcy-Weisbach friction coefficient
- β = Coriolis parameter = $2\Omega \sin\psi$
- Ω = angular speed of earth rotation = 7.27×10^{-5} rad/sec
- ψ = latitude of site of interest

The surface and bottom shear stress components are related to the wind speed W and discharge components by

$$\tau_{w_x} = \rho K W W_x \quad \text{and} \quad \tau_{w_y} = \rho K W W_y \quad (4)$$

$$\tau_{b_x} = \frac{\rho f |q| q_x}{8D^2} \quad , \quad \tau_{b_y} = \frac{\rho f |q| q_y}{8D^2} \quad \text{where } |q| = \sqrt{q_x^2 + q_y^2} \quad (5)$$

in which K is an air-sea friction coefficient developed by Van Dorn (3); and depends on the wind speed,

W, as follows:

$$K = \begin{cases} 1.1 \times 10^{-6} & \text{for } W < W_{cr} \\ 1.1 \times 10^{-6} + 2.5 \times 10^{-6} (1 - W_{cr} / W)^2 & \text{for } W \geq W_{cr} \end{cases} \quad (6)$$

where $W_{cr} = 23.6$ ft/sec.

The quantity, f , is the Darcy-Weisbach bottom friction coefficient and varies with depth, bottom roughness and vegetation, if present. For purposes of this study, f was developed by Christensen and Walton (4) of the University of Florida and is presented in Figure II-16.

Finite Difference Forms of Governing Differential Equations

The finite difference representations of Equations (1), (2) and (3) are expressed as follows with the convective terms (i.e., $\frac{q_x}{D} \frac{\partial q_x}{\partial x}$, etc) omitted in preparation for an implicit type of solution. The solution to

the equations will be carried out in a fractional time step procedure. This procedure is schematized in Figure II-17. The advantage of this fractional time step procedure is that it is time and space centered to first order.

The finite difference equations for the first portion of the fractional time step that are appropriate for the implicit method of solution are:

$$A_i \eta_{i,j}^{n+1/2} + B_i q_{x_{i,j}}^{n+1} + C_i \eta_{i,j}^{n+1/2} = D_i \quad (7)$$

$$A_i^* q_{x_{i+1,j}}^{n+1} + B_i^* n_{i,j}^{n+1/2} + C_i^* q_{i,j}^{n+1} = D_i^* \quad (8)$$

where Equation (7) represents the momentum equation in the x-direction and Equation (8) represents the continuity equation; these two equations are to be solved simultaneously. The second set of simultaneous equations representing flow in the y-direction which is solved subsequent to the solution of the first set is:

$$A_j \eta_{i,j}^{n+1/2} + B_j q_{x_{i,j}}^{n+1} + C_j \eta_{i,j-1}^{n+1} = D_j \quad (9)$$

$$A_j^* q_{y_{i,j+1}}^{n+1} + B_j^* n_{i,j}^{n+1/2} + C_j^* q_{i,j}^{n+1} = D_j^* \quad (10)$$

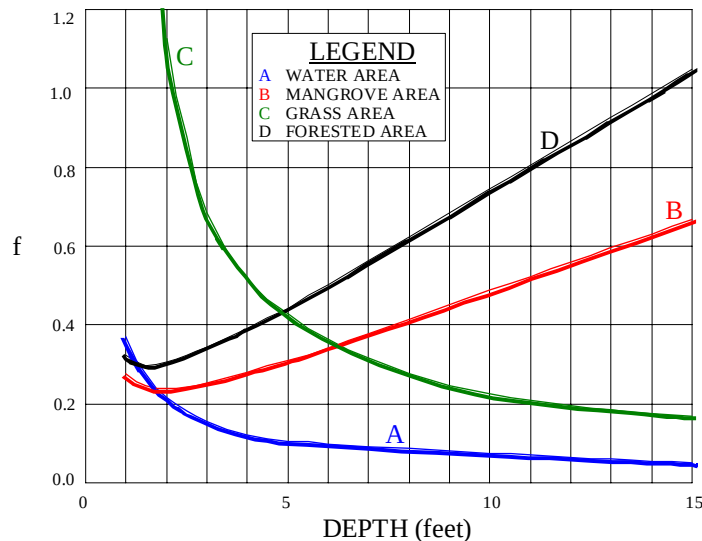
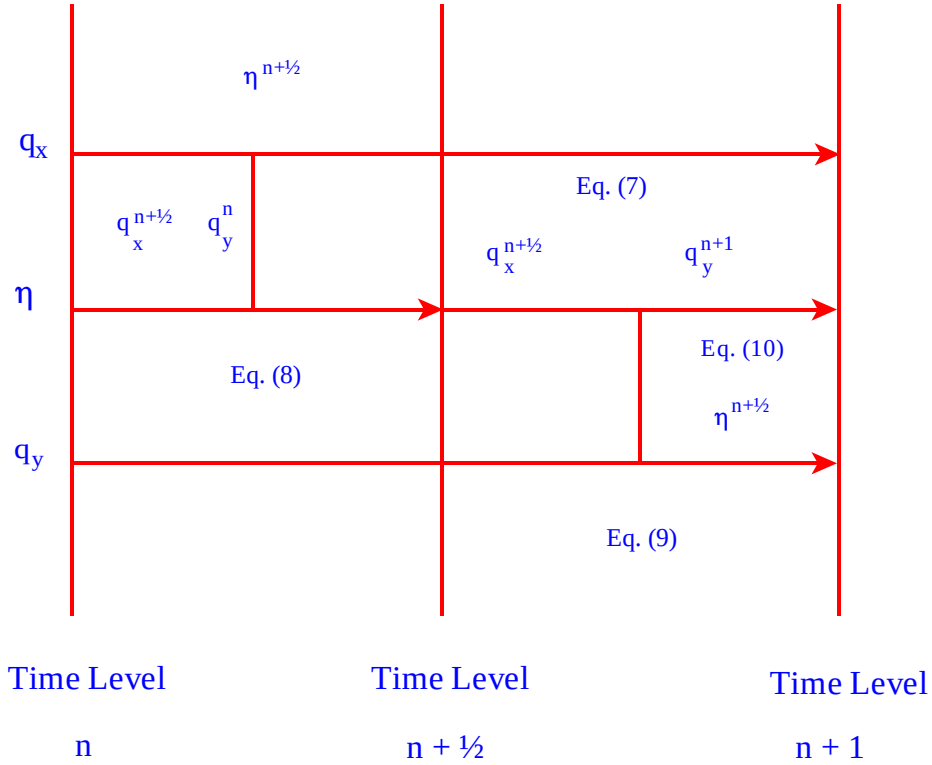


Figure II-16 Bottom Friction Coefficients for Various Bottom Conditions



Notes: (1) Vertical links denote equations that are solved simultaneously.
(2) Values adjacent to the horizontal bars indicate the time level of the different variables entering into the computation.

Figure II-17 Schematic of Implicit Method of Solving Momentum and Continuity Equations

Inlet and Barrier Island Representation as Hydraulic Elements

Inlets and barrier islands represent features which are too small to be resolved by the normal grid sizes ($\approx$ miles) of the numerical model. Thus, these features are termed "sub-grid" features and must be represented by a special treatment.

The domain of interest here is the two adjacent half grid blocks with a sub-grid feature imbedded in the grid line common to the grid blocks, see Figure II-18. The grid line can be oriented in either the x or y -direction and here is indicated generically as in the l -direction with the direction of flow occurring in the s -direction. The sub-grid feature can consist of the following combinations:

- a barrier of a prescribed height, and frictional characteristics, extending over the full length, DL of the grid line,
- a barrier of prescribed height, width, W_B and frictional characteristics. The remaining width, $(DL - W_B)$, of the grid line is considered too high for flow to occur over the top,
- a barrier of prescribed height, width and frictional characteristics with an inlet of designated width, W_I , depth and frictional characteristics occupying a portion of the grid line length.

The computer program allows flow to occur over the barrier if the average water elevation as determined from the two adjacent grid blocks exceeds the barrier elevation. In addition the appropriate flow occurs through the inlet, if present.

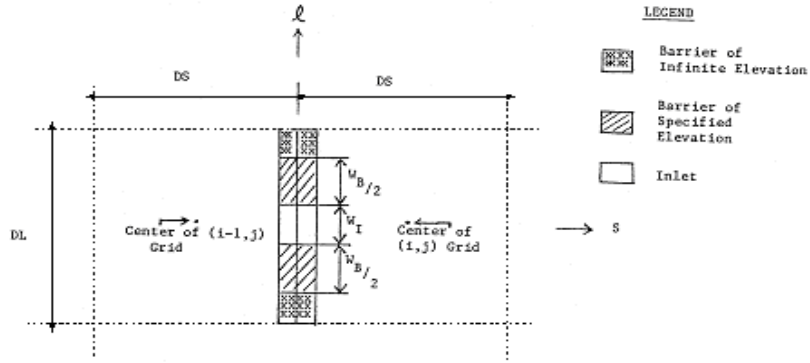


Figure II-18 Region of Interest in Description of Sub-Grid Features

The section below describes the methodology for representing the barrier/inlet features and of incorporating this representation into the numerical formulation.

Methodology

Consider the following simplified form of the momentum equation expanded in the s direction (direction of flow).

$$\frac{\partial q_s}{\partial t} = -g(h + \eta) \frac{\partial \eta}{\partial s} - \frac{f|q_s|q_s}{8(h + \eta)^2} \quad (11)$$

in which q_s is the average discharge per unit width in the s -direction and $h + \eta$ represents the total water depth. The application of Equation (11) is relatively straight forward to a normal grid block in which there are no sub-grid features. This results in the following finite difference form.

$$q_{s_i}^{n+1} = \frac{1}{F_2} \left[q_{s_i}^n - F_1 g(\overline{h + \eta}) \frac{(\eta_i^n - \eta_{i-1}^n)}{DS} \right] \quad (12)$$

in which

$$F_1 = 1 \quad (13)$$

$$F_2 = 1 + \frac{f|q_s|DT}{g(h + \eta)^2}$$

In order to utilize the existing framework for solution of the finite difference equations, Equations (12) and (13) are modified slightly to

$$q_{s_i}^{n+1} = \frac{1}{F_2'} q_{s_i}^n - F_1' g(\overline{h + \eta}) \frac{(\eta_i^n - \eta_{i-1}^n)}{DS} \quad (14)$$

The paragraphs below describe the rationale for determining the factors F_1' and F_2' .

The only invariant in the flow in the s-direction is the total discharge. Thus we first integrate Equation (11) over the ℓ -direction to obtain Q , then integrate over the s-direction between the centers of the i-1 and i grid cells. The results of the first integration is

$$\frac{\partial Q_s}{\partial t} = -gW(h + \eta) \frac{\partial \eta}{\partial s} - \sum \frac{f W q |q|}{8(h + \eta)^2} \quad (15)$$

in which W represents the local width at some locations, i.e. $W=W(s)$. The last term which represents the flow resistance involves a sum since the flow properties at various locations along the grid line differ. In order to express this flow term as a function of $Q|Q|$, we consider that the flow over the grid line will be friction-dominated, i.e., will be represented by equations for the head loss across the grid line and by introducing entrance and exit loss terms.

$$\Delta \eta_{GL} = \frac{f_I Q_I^2 DS_I}{8g(h + \eta)_I^3 W_I^2} + \frac{(K_{en} + K_{ex})_I Q_I^2}{2g(h + \eta)_I^2 W_I^2} = \frac{f_B Q_B^2 DS_B}{8g(h + \eta)_B^3 W_B^2} + \frac{(K_{en} + K_{ex})_B Q_B^2}{2g(h + \eta)_B^2 W_B^2} \quad (16)$$

or

$$\frac{Q_B}{Q_I} = \sqrt{\frac{\alpha_I}{\alpha_B}} \quad (17)$$

in which

$$\alpha_I = \frac{f_I DS_I}{8g(h + \eta)_I^3 W_I^2} + \frac{(K_{en} + K_{ex})_I}{W_I^2 (h + \eta)_I^2} \quad (18)$$

and a similar expression applies to α_B . Equation (15) can now be expressed as

$$\frac{\partial Q_s}{\partial t} = -gW(h + \eta) \frac{\partial \eta}{\partial s} - G |Q_s| Q_s \quad (19)$$

where $G = \frac{f DS}{8(h + \eta)^2 W}$, Normal Section

Sub-Grid Contribution

$$G_I = \alpha_I W_I (h + \eta)_I, \text{ Inlet Only Present and Active} \quad (20)$$

$$G_B = \alpha_B W_B (h + \eta)_B, \text{ Barrier Only Present and Active}$$

$$G_{IB} = \left[\frac{G_I}{\left(1 + \sqrt{\frac{\alpha_I}{\alpha_B}}\right)^2} + \frac{G_I}{\left(1 + \sqrt{\frac{\alpha_B}{\alpha_I}}\right)^2} \right], \text{ Both Barrier and Inlet Present and Active}$$

To carry out the integration of Equation (19) in the ℓ -direction, it is necessary to know the approximate distribution $\frac{\partial \eta}{\partial s}$ of with s . Inspection of Equation (19) reveals that

$$\frac{\partial \eta}{\partial s} \approx \frac{1}{w^m (h + \eta)^n} \quad (21)$$

where

$$m, n = \begin{cases} 1, 1 & \text{if inertia - dominant} \\ 2, 3 & \text{if friction - dominant} \end{cases}$$

For purpose here, we will consider that

$$\frac{\partial \eta}{\partial s} = K \frac{1}{(h + \eta)^2 w^2} \quad (22)$$

in which K represents a constant to be determined by equating the result from integrating Equation (22) with the total (known) $\Delta \eta$ between the centers of the two adjacent grid cells. For the grid-line where both inlets and barriers are present, the right hand-side of Equation (22) will be represented by the respective widths of inlets and barriers. The result is then

$$\begin{aligned} \Delta \eta = K \left[\frac{Ds_1}{(h + \eta)_I^2 W_I^2} + \frac{Ds_2}{(W_I + W_B)} \left(\frac{W_I}{(h + \eta)_I^2 W_I^2} + \frac{W_B}{(h + \eta)_B^2 W_B^2} \right) + \frac{Ds_3}{(h + \eta)_3^2 W_3^2} \right] \\ \equiv K\mu \end{aligned} \quad (23)$$

which defines μ as the bracketed term in Equation (23). Equation (19) can now be integrated over the total length of the domain of interest to yield

$$DS \frac{\partial Q}{\partial t} = -g \sum W_s (h + \eta)_s \left(\frac{\partial \eta}{\partial \ell} \right) \Delta s - Q|Q| \sum G_s \Delta s \quad (24)$$

which can be simplified to

$$DS \frac{\partial Q}{\partial t} = -g \sum \frac{K \Delta s}{W_s (h + \eta)_s} = Q|Q| \sum G_s \Delta s \quad (25)$$

in which the sub-grid term entering into the two summations should be considered as effective values and will be expressed in detailed form later. Reducing Equation (25) to the form of Equation (11) by dividing by $(D1 \cdot DS)$, and inserting the expression for K

$$\frac{\partial q}{\partial t} = -\frac{g}{DLDS} \sum \frac{\Delta \eta_s \Delta s}{\rho W_s (h + \eta)_s} - \frac{DS}{DL} q|q| \sum G_s \Delta s \quad (26)$$

$$\frac{\partial q}{\partial t} = -g(h + \eta) \frac{\Delta \eta}{\Delta s} \frac{1}{\mu DL (h + \eta)} \sum \frac{\Delta s}{W_s (h + \eta)_s} = \frac{DL}{DS} q|q| \sum G_s \Delta s \quad (27)$$

Thus, by comparison with Equation (14), we see that the expressions for F_1 and F_2 are

$$F_1' = \frac{1}{DL(h + \eta)} \left[\frac{Ds_1}{W_I(h + \eta)_I} + \frac{Ds_2}{(W_B + W_I)} \left(\frac{W_I}{W_I(h + \eta)_I} + \frac{W_B}{W_B(h + \eta)_B} \right) + \frac{Ds_3}{(h + \eta)_3} \right] \quad (28)$$

$$F_2' = 1.0 + \frac{DL}{DS} \left[G_I + G_2 + (G_I, G_B \text{ or } G_{IB}) \right] |q| DT \quad (29)$$

Boundary Conditions

To complete formulation of the problem, boundary conditions must be specified at the boundaries of the grid presented in Figure 14. On the "open" (water) boundaries, the water surface is specified to be that associated with the barometric pressure, i.e.,

$$\eta_{B_{i,j}} = \left(\frac{p_\infty - p_{i,j}}{\rho g} \right) \quad (30)$$

in which p_∞ denotes the far field barometric pressure. In addition, on the open boundary grid cells, it is specified that only discharge components perpendicular to the boundaries occur and that these discharges on the exterior boundaries of the grid system are those required to satisfy the continuity equation (Equation 8).

On the "closed" boundaries, i.e., at the shoreline where land elevations are higher than the adjacent water elevations, a no-flow boundary condition is specified perpendicular to that boundary. However, "flooding" and "deflooding" of grid blocks adjacent to the boundaries can occur. Flooding occurs when the water level is greater by a specified small amount than the ground elevation of an adjacent grid block. When this condition exists, the grid block is activated by a simple allocation of this excess elevation on the newly activated block and in subsequent time steps the grid block is incorporated into the normal calculation scheme. Deflooding occurs when the water level on a grid block drops below a specified level leaving a very small depth on that block. The block is "deactivated" and the excess water placed on the adjacent grid.

The solution is started from an initial condition of zero water surface displacement and zero discharge components. The hurricane system is translated along a specified path at a designated speed. At each time step, the hurricane effects (represented by the pressure and wind stress components) on each cell are calculated and the finite-difference equations (Equations 7, 8, 9, and 10) employed. The results are updated values of η , q_x and q_y for each cell.

Implicit Solution of the Finite Difference Equations

The solution for each time step progresses by first solving Equations (7) and (8) simultaneously for each j grid line sweeping over all values of i . This establishes the values of η^{n+1} and q_y^{n+1} for the entire (i, j) field. The procedure is then repeated for Equations (9) and (10) in which this pair of equations is solved simultaneously for η^{n+1} and q_x^{n+1} for the entire (i, j) field. This latter pair of equations is expressed sequentially for each value of i , then solved for all values of j , for that particular i grid line. The expressions for the various coefficients are presented as follows.

$$A_i = g(\overline{h + \eta}) \frac{\Delta t}{\Delta x}$$

$$B_i = 1 + \frac{f |q_{i,j}^n|^{\Delta t}}{8(h + \eta)^2}$$

$$C_i = -A_i$$

$$D_i = q_{x_{i,j}}^n + \Delta t \frac{(\overline{h + \eta})}{\rho} \frac{\partial p}{\partial x} + \frac{\tau_{w_{x_{i,j}}}}{\rho} - \beta(\overline{q_y})^n$$

$$A_i^* = \frac{\Delta t}{4\Delta x}$$

$$B_i^* = 1.0$$

$$C_i^* = -\frac{\Delta t}{4\Delta x}$$

$$D_i^* = r_{i,j}^n - \frac{\Delta t}{4\Delta x} (q_{x_{i+1}}^n - q_{x_i}^n) - \frac{\Delta t}{2\Delta x} (q_{y_{i,j+1}}^n - q_{y_{i,j}}^n)$$

$$\overline{q}_{y_{i,j}}^n = \frac{1}{4} [q_{y_{i-1,j}}^n + q_{y_{i,j}}^n + q_{y_{i-1,j+1}}^n + q_{y_{i,j+1}}^n]$$

$$|q_{y_{i,j}}^n| = \sqrt{\left(q_{x_{i,j}}^n\right)^2 + \left(\overline{q}_{x_{i,j}}^n\right)^2}$$

$$A_j = \frac{g(\overline{h + \eta})}{2} \frac{\Delta t}{\Delta x}$$

$$B_J = 1 + \frac{f |q_{i,j}^n|^{\Delta t}}{8(\overline{h + \eta})^2}$$

$$C_j = -A_j$$

$$D_j = q_{y_{i,j}}^n + \Delta t - \left[\frac{g(\overline{h + \eta})}{2\Delta x} \Delta t + \left(\eta_{i,j}^n - \eta_{i,j-1}^n \right) - \frac{h + \eta}{\rho} \frac{\partial p}{\partial y} + \frac{\tau_{w_{y_{i,j}}}}{\rho} + \beta(\overline{q_x})^n \right]$$

$$\overline{q}_{x_{i,j}}^n = \frac{1}{4} q_{x_{i,j}}^n + q_{x_{i,j-1}}^n + q_{x_{i-1,j}}^n + q_{x_{i+1,j-1}}^n$$

$$|q_{x_{i,j}}^n| = \sqrt{\left(\bar{q}_{x_{i,j}}^n\right)^2 + \left(q_{y_{i,j}}^n\right)^2}$$

$$A_j^* = \frac{\Delta t}{2\Delta y}$$

$$B_j^* = 1.0$$

$$C_j^* = -A_j^*$$

$$D_j^* = \eta_{i,j}^{n+1/2} - \frac{\Delta t}{4\Delta x} \left(q_{x_{i+1,j}}^n - q_{x_{i,j}}^n \right) - \frac{\Delta t}{4\Delta x} \left(q_{x_{i+1,j}}^{n+1} - q_{x_{i,j}}^{n+1} \right)$$

With the coefficients now specified, the method of solving the sets of simultaneous equations will be described. The method is termed the "doubled sweep" method in which the first sweep involves "conditioning" two sets of auxiliary coefficients (E_i, F_i, E_i^*, F_i^*). The second sweep determines the values of η and q and, in the process, incorporates the required boundary conditions. The procedure will be illustrated for Equations (7) and (8) and it is noted that the same procedure is applicable to solving Equations (9) and (10). The procedure commences by establishing two auxiliary equations with four variables (E_i, F_i, E_i^*, F_i^*) which are initially unknown,

$$\eta_{i,j}^{n+1/2} = E_i q_{x_{i,j}}^{n+1} + F_i \quad (31a)$$

$$q_{x_{i+1,j}}^{n+1} = E_i^* \eta_{i,j}^{n+1/2} + F_i^* \quad (31b)$$

Equations (31a) and (31b) are substituted in Equations (7) and (8) and the results simplified to yield

$$q_{x_{i,j}}^{n+1} = -\frac{C_i}{A_i E_i + B_i} \eta_{i-1,j}^{n+1/2} + \frac{D_i - A_i F_i}{A_i E_i + B_i} \quad (32a)$$

$$\eta_{i,j}^{n+1/2} = -\frac{C_i^*}{A_i^* E_i^* + B_i^*} q_{x_{i,j}}^{n+1} + \frac{D_i^* - A_i^* F_i^*}{A_i^* E_i^* + B_i^*} \quad (32b)$$

Comparison of Equations (31) and (32) establishes the values of the unknown coefficients in terms of the known coefficients (E_i, F_i, E_i^*, F_i^*), ($A, B, \dots, A^*, B^*, \dots$). The expressions are

$$E_i = \frac{C_i^*}{A_i^* E_i^* + B_i^*}, \quad F_i = \frac{D_i^* - A_i^* F_i^*}{A_i^* E_i^* + B_i^*} \quad (33)$$

$$E_{i-1}^* = -\frac{C_i}{A_i E_i + B_i}, \quad F_{i-1}^* = \frac{D_i - A_i F_i}{A_i E_i + B_i} \quad (34)$$

To illustrate the manner in which boundary condition information is incorporated into the procedure, suppose that the water surface level, η , is specified at $i = \text{IMAX}$ and that q_x is specified as zero

at $i = 2^8$. The first sweep commences by noting (from Equation 31a)

$$\begin{aligned} E_{IMAX} &= 0.0 \\ F_{IMAX} &= \eta_{IMAX,j}^{n+1/2} \end{aligned} \quad (35)$$

With the values of E_{IMAX} and F_{IMAX} known, E_{IMAX-1}^* and F_{IMAX-1}^* can be calculated from Equation (34), then values of E_{IMAX-1}^* and F_{IMAX-1}^* computed from Equation (33) and so on. E_i^* and F_i^* are set equal to

$$E_i^* = F_i^* = 0.0 \quad (36)$$

in accordance with the boundary condition and Equation (31b). This completes the first sweep and establishes all the coefficients over the grid line.

The second sweep simply consists of applying Equations (32) from small i to large i (IMAX). In summary, the "double sweep" procedure as presented here progresses from large i to small i for the first sweep (conditioning the E , F , E^* , F^* coefficients), and then progresses back from small i to large i for the second sweep (determining the η , q_x and q_y at the $(n+1)^{th}$ time step.

Dynamic Wave Set-Up

When waves break, a shoreward directed force in addition to the wind stress, is exerted on the water in the surf zone. This causes an additional rise in water level termed "wave set-up". This effect has been studied extensively in the laboratory [Saville (5), Bowen et al. (6)], and tide gage measurements during severe storms have confirmed its importance in nature. Most of the information relative to wave set-up has been developed for "regular" waves, that is for a wave train in which each wave is the same as the preceding wave. Waves in nature, however, are not regular and tend to occur in groups. An analytic study by Lo (7) has shown that for natural wave trains there is a dynamic wave set-up that is approximately 50% larger than would be predicted by a static treatment. In order to evaluate this result, model studies were conducted in the large University of Florida wave tank. It was found that the experimental and analytical results by Lo were in approximate agreement.

The maximum dynamic wave set-up, η'_{max} , across the surf zone can be shown to be approximately

$$\eta'_{max} = 0.285 \left[1 - 2.82 \left(\frac{H_b}{gT^2} \right)^{1/2} \right] H_b \quad (37)$$

which includes the dynamic factor of 50% and in which T is the wave period and H_b is the breaking wave height based on the deep water significant wave height, H_o , taken approximately as

$$H_b = 0.94 H_o \quad (38)$$

The deep water significant wave height is determined from an extension of a method recommended for hurricane generated waves as summarized in the Shore Protection Manual (8),

$$(H_o)_{max} = 16.5 e^{R(\Delta p/100)} \left(1 + \frac{0.208 V_F}{\sqrt{U_R}} \right) \quad (39)$$

§It is noted that other combinations of boundary conditions at the two ends for the grid line could be accommodated. Also, internal boundary conditions of the type $q_{x_{i,j}}^{n+1}$ are satisfied by the choice of coefficients: $E_{i-1}^* = F_{i-1}^* = 0$.

where R = radius to maximum winds in nautical miles, Δp = central pressure deficit in inches of mercury, V_F = translation speed of hurricane in knots, and U_R = maximum sustained wind speed in knots. For purposes here, the local effective deep water significant wave height is based on the local winds, U , at the surf zone area of interest and the maximum winds in the hurricane, $U_{\max}$, as

$$H_o = (H_o)_{\max} \left(\frac{U}{U_{\max}} \right)^2 \quad (40)$$

Equations 37, 38, 39 and 40 provide the basis for determining the maximum dynamic wave set-up within the surf zone. The computed value of $\eta'_{\max}$ was added to the nearshore storm surge. It is stressed that $\eta'_{\max}$ represents the maximum dynamic wave set-up across the surf zone and that this value varies with time (because the wind speed varies with time). The value of $\eta'_{\max}$ was computed at each time step for the shoreward grid, and added to the corresponding surge value resulting from wind stress, barometric pressure and the effect of astronomical tide to yield the combined total storm tide history.

With the combined total storm tide history thus determined, it is a simple matter to search in the computer to obtain the maximum of the combined total storm tide at the site of interest.

2.6 Features of the One-Dimensional Numerical Model

As noted earlier, a simple one-dimensional numerical model was developed and calibrated to allow the statistics to be generated based on simulation (calculations) of many hurricanes and associated storm tides.

The one-dimensional numerical model is described as follows. A transect line is established which is approximately perpendicular to the bottom contours. The characteristics (Δp , R , θ_N , V_F and track) of the hurricane are defined and the hurricane is advanced along the track line. The water surface displacement (boundary condition) at the seaward end of the transect line is taken as the static response of the water surface to the barometric pressure deviation at that point. The locations of the four transect lines for Pinellas County are shown in Figure II-15. Figures II-19, II-20, II-21 and II-22 present the profiles of the four transect lines and their one-dimensional grid representations.

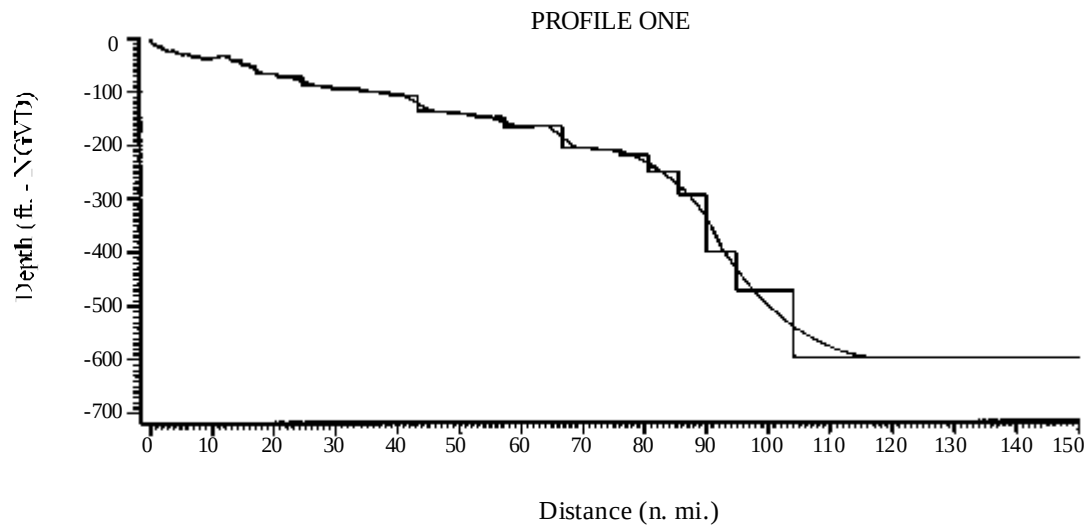


Figure II-19 Profile One of the Transect Line One and Its One-Dimensional Grid Representation

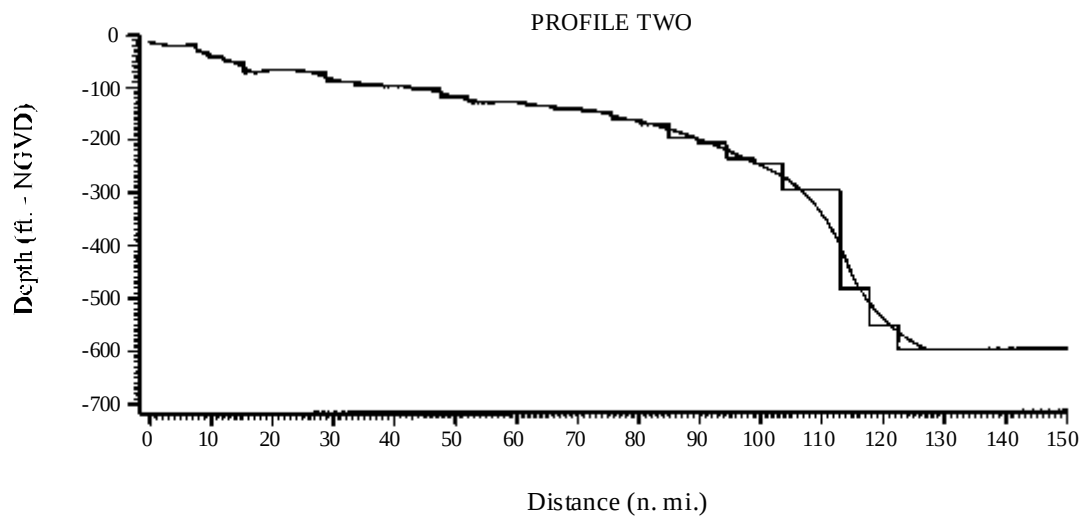


Figure II-20 Profile Two of the Transect Line Two and Its One-Dimensional Grid Representation

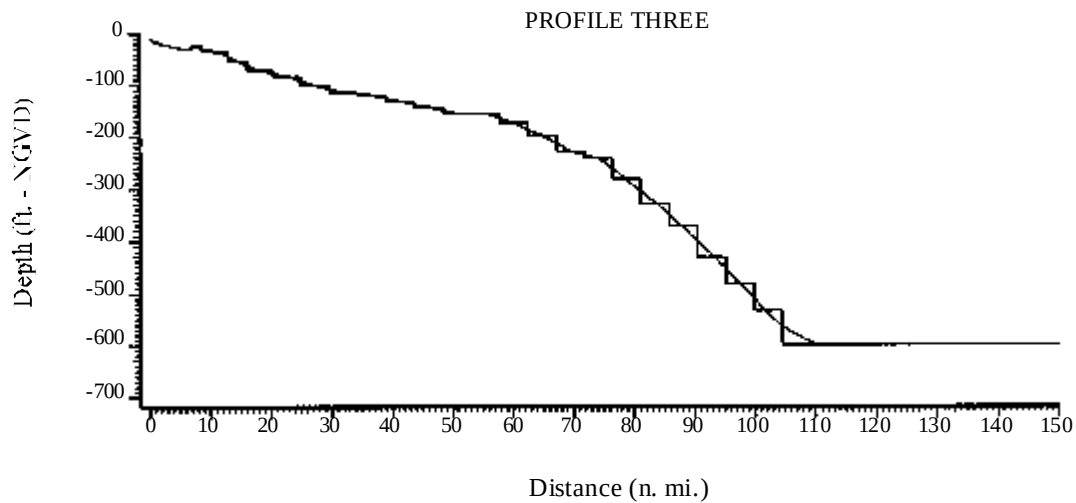


Figure II-21 Profile Three of the Transect Line Three and Its One-Dimensional Grid Representation

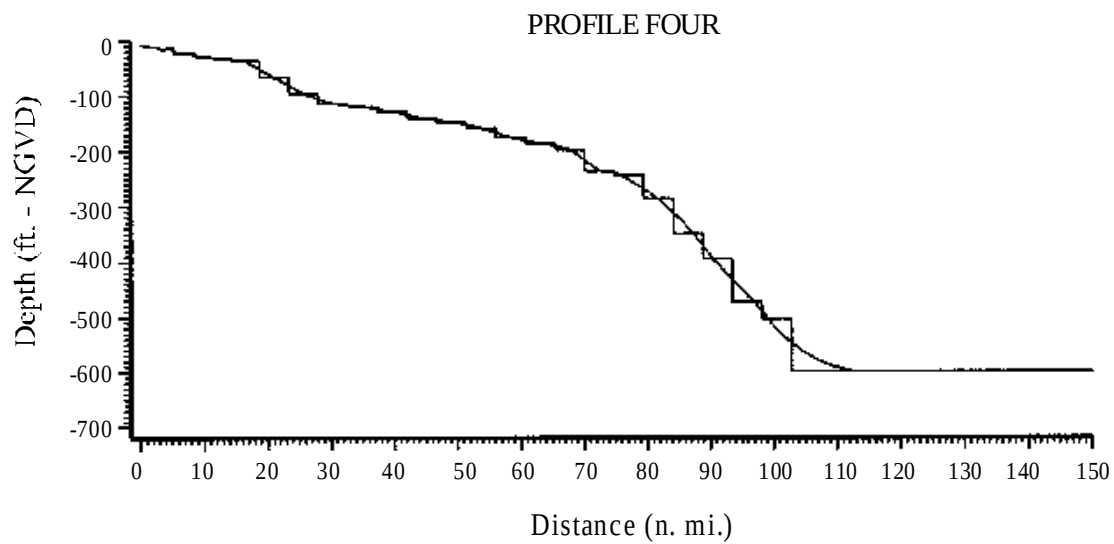


Figure II-22 Profile Four of the Transect Line Four and Its One-Dimensional Grid Representation

Governing Differential Equations For One-Dimensional Numerical Model

The one-dimensional numerical model is significantly less expensive and simpler to run and is used in the long-term simulation phase, in order to generate the required data within budgetary constraints. The justification for using the one-dimensional model is that it can be adequately calibrated with the rather complete two-dimensional model.

The one-dimensional numerical model is the Bathystropic Storm Tide Model by Freeman, Baer and Jung (9) (1957) and is static in the x-direction model. The governing differential equations in the x and y directions are:

$$\frac{\delta \eta}{\delta x} = \frac{1}{gD} \left(\frac{\tau_{w_x}}{\rho} - \beta q_y \right) - \frac{1}{\rho g} \frac{\delta p}{\delta x} \quad (41)$$

$$\frac{dq_y}{dt} = \frac{1}{\rho D} \left(\tau_{w_y} - \tau_{b_y} \right) \quad (42)$$

in which all variables are evaluated along the transect line perpendicular to shore and passing through the site.

Finite Difference Forms of Governing Differential Equations

The finite difference forms of the governing one-dimensional differential equations (Equations (1) and (2) are:

$$\left(q_{y_i}^{n+1} = \frac{1}{BB} q_{y_i}^n + \frac{\Delta t}{\rho} \tau_{w_{y_i}} \right) \quad (43)$$

$$\eta_{i+1}^{n+1} = \eta_i^{n+1} + \frac{\Delta x}{gD_i} \left(\frac{\tau_{w_{x_i}}}{\rho} - \beta q_{G_i}^{n+1} \right) + \frac{p_i^{n+1} - p_{i+1}^{n+1}}{\rho g} \quad (44)$$

where

$$BB = 1.0 + \frac{f \cdot \Delta t |q_{y_i}^n|}{D_i} \quad (45)$$

where the variables are as defined previously for the two-dimensional model.

Initial and Boundary Conditions for the One-Dimensional Model

The one-dimensional model is initiated from a condition of rest ($q_y = 0$) and zero water surface displacement ($\eta = 0$). The only boundary condition required is that at the seaward end ($i = 1$) of each transect where the “barometric tide” is imposed as

$$\eta = \frac{p_\infty - p_i}{\rho g} \quad (46)$$

Explicit Solution of the Finite Difference Equations

Equations (41) and (42) are solved sequentially for each time step with the hurricane advanced along its specified track with the initial position of the hurricane at a sufficient distance to allow the longshore transport q_y to be free of any artificial transients. The solutions of these equations are straight forward and free of any potential instabilities. At the landward grid the wave set-up is superposed as described previously for the two-dimensional model.

2.7 Long-Term Simulation

With the statistical characteristics of historical hurricanes available and the simple one-dimensional model calibrated as described previously, the long-term simulation (2,000 years, generally) is carried out. The first phase of the simulation comprises the selection of the hurricane characteristics in accordance with the historical data. In each storm, this involves the following (also, see Figures II-14 and II-23).

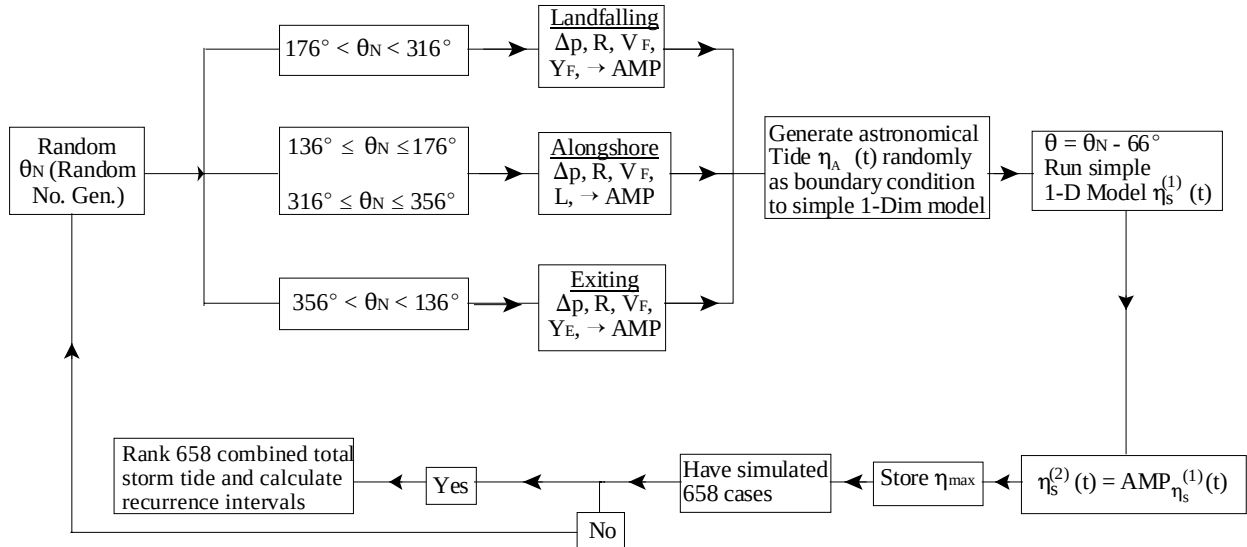


Figure II-23 Flow Chart for Storm Tide Simulations for Pinellas County (After Calibration to Determine $(AMP)_{LF}$, $(AMP)_{ALONG}$ and $(AMP)_{EXIT}$)

- 1) Quantifying Δp , R , V_F , θ_N and hurricane track in accordance with the historical probabilities (Section 2.2).
- 2) For these characteristics, a random astronomical tide from the hurricane season is generated as a boundary condition to the one-dimensional numerical model and the model is run to determine the storm surge at the site of interest. This storm surge is then adjusted in accordance with the factors obtained from the two-dimensional model calibration runs.
- 3) For the landward grid and each time step, the contribution due to dynamic wave set-up is included to yield the combined total storm tide.
- 4) Determine whether enough storms have been simulated for the n-year simulation.
- 5) After the required number of storms and associated storm tides have been simulated, the peak water levels for each storm are ranked and the return period, TR , is calculated, according to

$$TR = \frac{2000}{M} \quad (47)$$

where M is the rank of the combined total tide level. (For example, if the simulation was carried out for a 2,000 year period, the highest combined total tide level would have a return period of 2,000 years, etc.) Finally, by presenting these results on semilog paper, it is possible to interpolate for the return periods of interest, i.e., $TR = 10, 50, 100$ and 500 years.

III. APPLICATIONS OF STORM SURGE METHODOLOGY WITH SPECIFIC ILLUSTRATION BY EXAMPLE TO PINELLAS COUNTY

3.1 Two-Dimensional Model (Appendix A)

As noted previously, the two-dimensional model is first verified using storms of record and then employed to generate a data base for calibration of the one-dimensional model.

Verification With Storms of Record

Several examples will be presented comparing measured and calculated storm tides for storms of record. In these comparisons, an attempt was made to extract the astronomical tide and only tide measurements were generally used for comparison since the more abundant high water marks can be shown to contain significant extraneous effects. The calculated storm tides were based on a parameterized hurricane which is undoubtedly responsible for some of the differences between the measured and computed tides. The parameters were allowed to change along the hurricane path in accordance with measurements of these parameters.

The storm tides located for calibration for Pinellas County were those produced by hurricanes of September, 1947 and June 1966 (Alma). The parameters for the hurricanes used for input into the two-dimensional model are presented in Table III-1. Water level measurements for the hurricanes were available at Venice Inlet, Ft. Myers and Cedar Key and the comparisons are presented in Figures III-1, III-2 and III-3 for the 1947 hurricane and III-4, III-5 and III-6 for the 1966 hurricane (Alma), respectively. It is seen that although the peak surges due to these hurricanes were not large (2.0 to 3.0 ft), there is generally reasonable agreement between the peak measured and computed storm surges at Venice Inlet and Ft. Myers, with the maximum deviation being less than 0.5 ft. At Cedar Key, the measured is 1.1 ft. and 0.5 ft. higher than the computed for the 1947 and the 1966 hurricanes, respectively. Similar discrepancies occur at Cedar Key in other county's analysis. The cause might be an error in datums.

Comparisons conducted for Franklin County included Hurricanes Agnes (1972) and Eloise (1975) with measurements available from the St. Marks tide gage. These input data for these hurricanes are presented in Tables III-2 and III-3 and the comparisons are presented in Figures III-7 and III-8 for Hurricane Agnes and Hurricane Eloise, respectively. For Hurricane Agnes, the peak measured tide exceeds the computed by approximately 0.8 ft, whereas for Hurricane Eloise, the peak computed tide exceeds the measured by approximately 0.5 ft; on average this is considered reasonable agreement.

TABLE III-1
Input Parameters for Calibration Hurricanes

Hurricane of September 1947					
date	time (EST)	Δp (in Hg)	Y_F (knots)	R (n. mi.)	θ_N (degrees)
9/17	1300	-1.95	7.35	34.0	74.22
	1900	-1.95	5.31	34.0	90.00
9/18	0100	-1.95	6.51	34.0	107.90
	0700	-1.39	12.97	34.0	117.56
	1300	-1.39	17.82	34.0	116.68
	1900	-1.39	22.11	34.0	122.87
9/19	0100	-1.39	20.83	34.0	121.88
	0700	-1.39	12.17	34.0	109.18

Starting coordinates:

$X_s = -80.45$ n.mi.

$Y_s = -136.31$ n.mi.

Landfalling coordinates:

$X_F = -8.40$ n.mi.

$Y_F = -117.25$ n.mi.

Hurricane Alma of 1966					
date	time (EST)	Δp (in Hg)	Y_F (knots)	R (n. mi.)	θ_N (degrees)
6/8	0100	-0.98	15.64	23.0	196.42
	0700	-1.22	15.03	23.0	183.37
	1300	-1.27	15.10	23.0	173.27
	1900	-1.15	17.16	23.0	158.85
6/9	0100	-1.22	17.88	23.0	147.04
	0700	-1.27	9.17	23.0	168.88
	1300	-0.95	7.45	23.0	216.39
	1900	-1.07	11.98	23.0	234.26
6/10	0100	-0.46	11.98	23.0	234.26

Starting coordinates:

$X_s = -80.45$ n.mi.

$Y_s = -136.31$ n.mi.

Landfalling coordinates:

$X_F = -8.40$ n.mi.

$Y_F = -117.25$ n.mi.

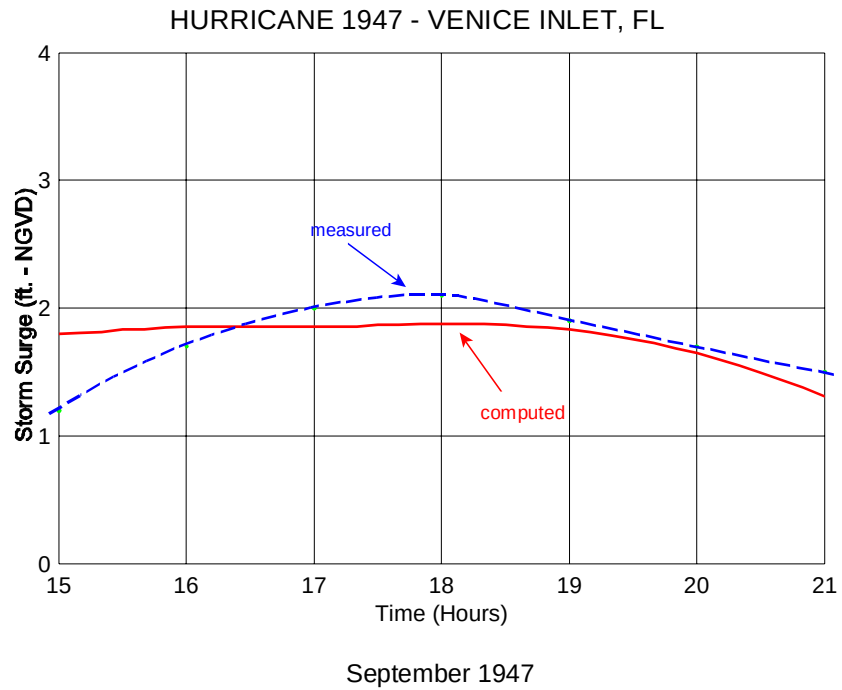


Figure III-1 Comparison between Measured and Computed Storm Tide at Venice Inlet, Florida for the September 1947 Hurricane

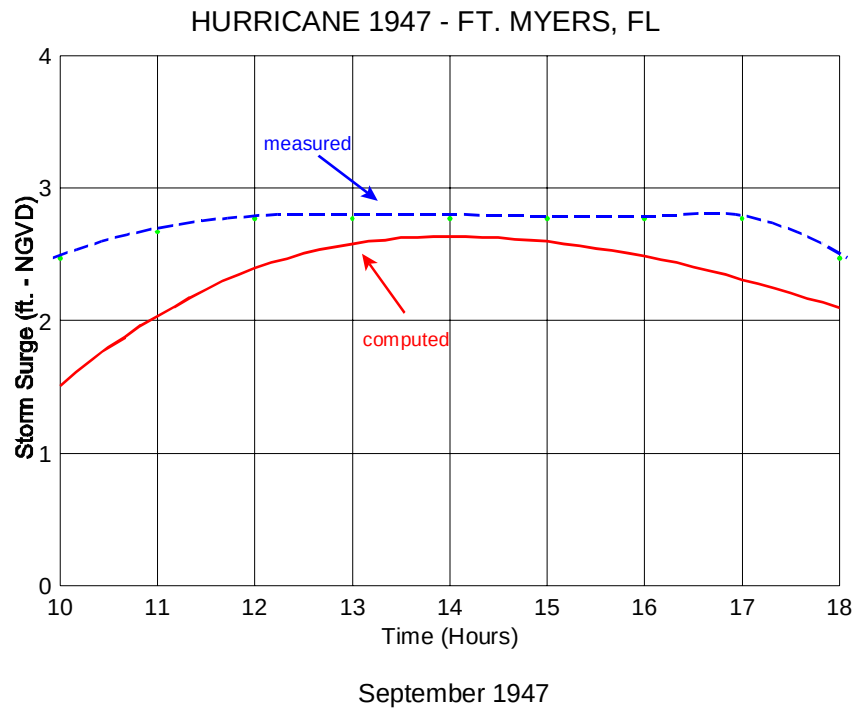


Figure III-2 Comparison between Measured and Computed Storm Tide at Ft. Myers, Florida for the September 1947 Hurricane

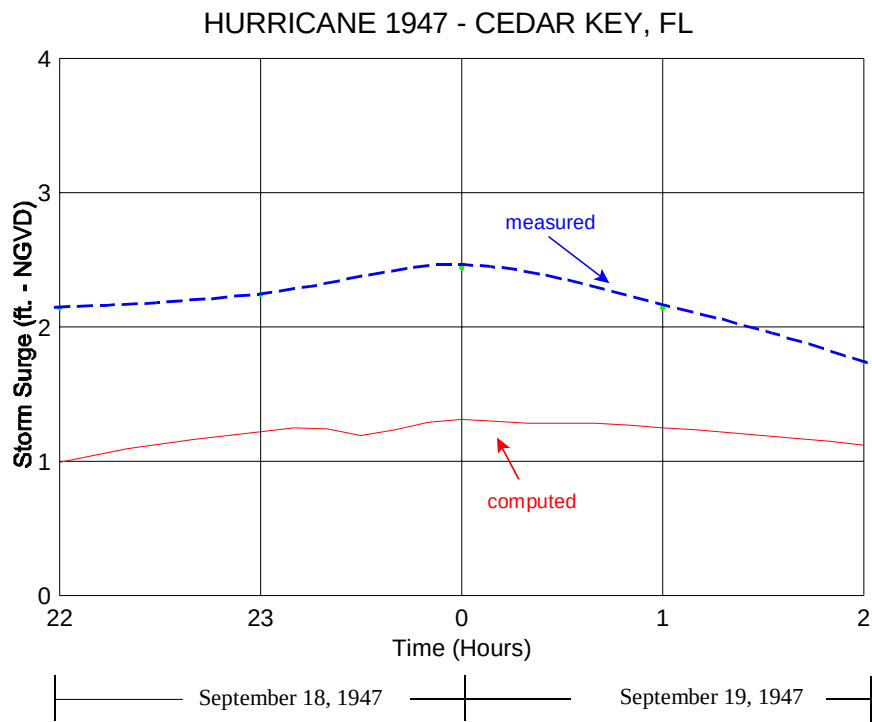


Figure III-3 Comparison between Measured and Computed Storm Tide at Cedar Key, Florida for the September 1947 Hurricane

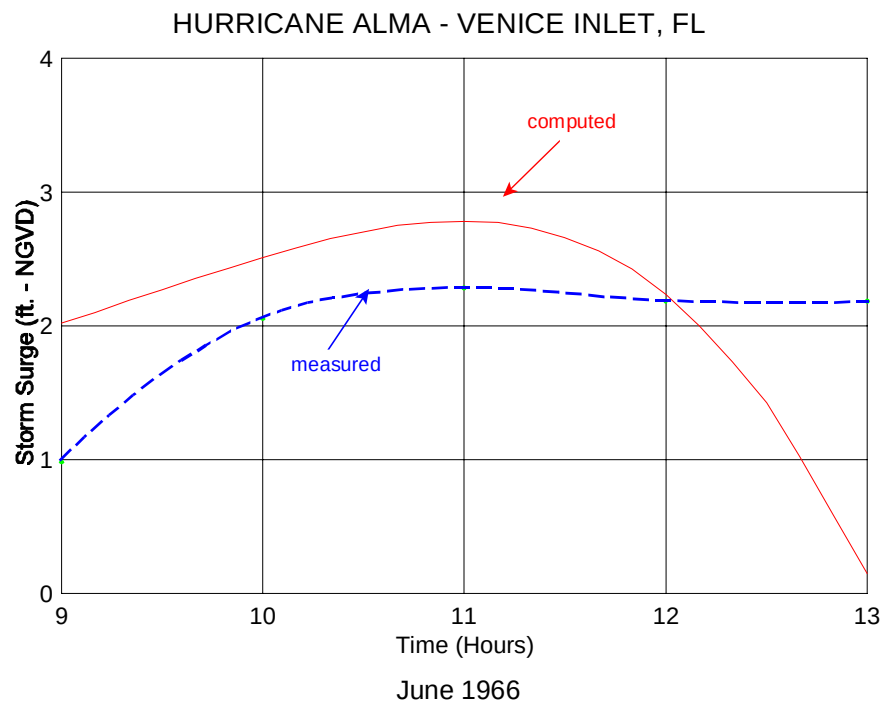


Figure III-4 Comparison between Measured and Computed Storm Tide at Venice Inlet, Florida for Hurricane Alma of June 1966

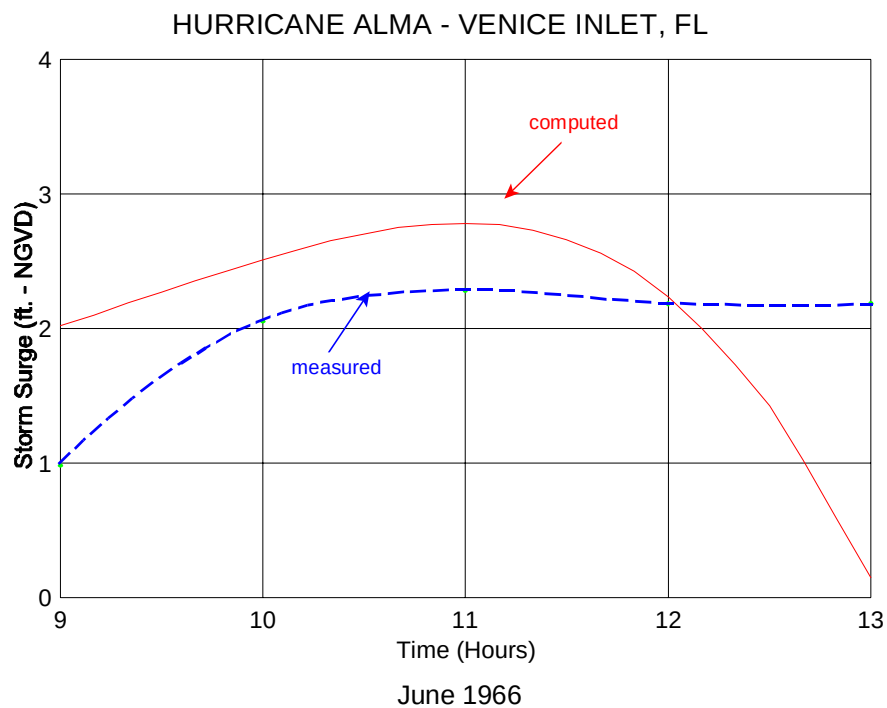


Figure III-5 Comparison between Measured and Computed Storm Tide at Ft. Myers, Florida for Hurricane Alma of June 1966

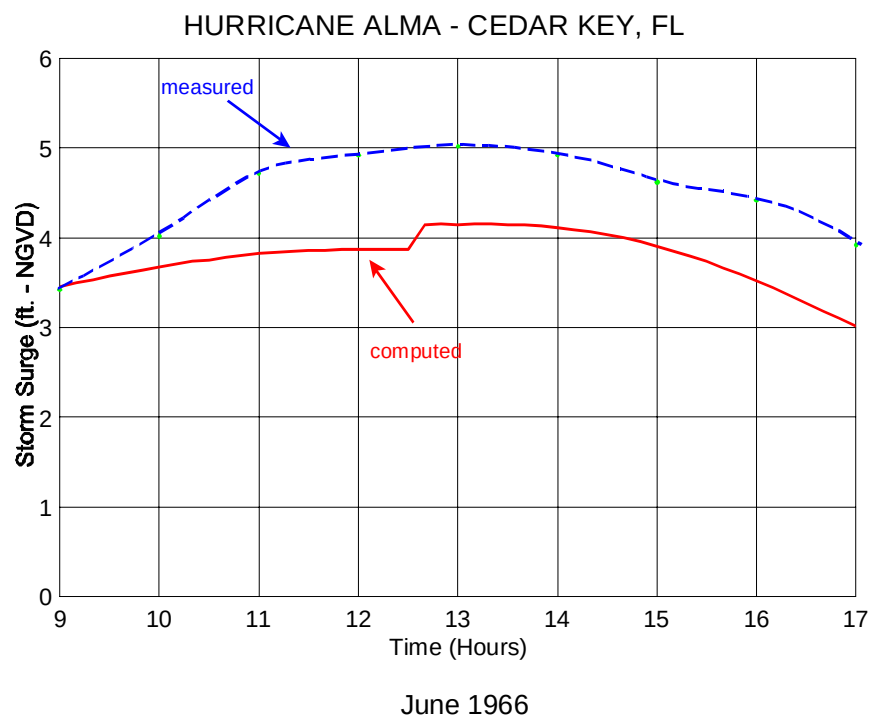


Figure III-6 Comparison between Measured and Computed Storm Tide at Cedar Key, Florida for Hurricane Alma of June 1966

TABLE III-2
Input Parameters for Calibration Hurricane
Hurricane Agnes (June, 1972)

date	time	Δp	Y_F	R	θ_N
	(EST)	(in Hg)	(knots)	(n. mi.)	(degrees)
6/18	1900	-0.92	12.0	20	180.0
6/19	0100	-1.04	13.0	20	180.0
	0700	-1.04	11.0	20	134.5
	1300	-0.89	9.7	20	201.1
	1900	-0.79	10.0	20	205.8
6/20	0100	-0.68	11.2	20	224.1
Starting coordinates:			Landfalling coordinates:		
$X_s = 220.0$ n.mi.			$X_F = 4.2$ n.mi.		
$Y_s = 45.4$ n.mi.			$Y_F = 40.2$ n.mi.		

TABLE III-3
Hurricane Eloise (September, 1975)

date	time	Δp	Y_F	R	θ_N
	(EST)	(in Hg)	(knots)	(n. mi.)	(degrees)
9/22	0100	-0.59	10.0	18	175.0
	0700	-0.80	7.1	18	187.1
	1300	-0.98	11.2	18	224.3
	1900	-1.33	15.2	18	223.5
9/23	0100	-1.63	20.0	18	205.8
	0700	-1.72	28.5	18	190.5
	1300	-0.91	27.8	18	205.9
Starting coordinates:			Landfalling coordinates:		
$X_s = 292.2$ n.mi.			$X_F = -31.8$ n.mi.		
$Y_s = 238.3$ n.mi.			$Y_F = 76.6$ n.mi.		

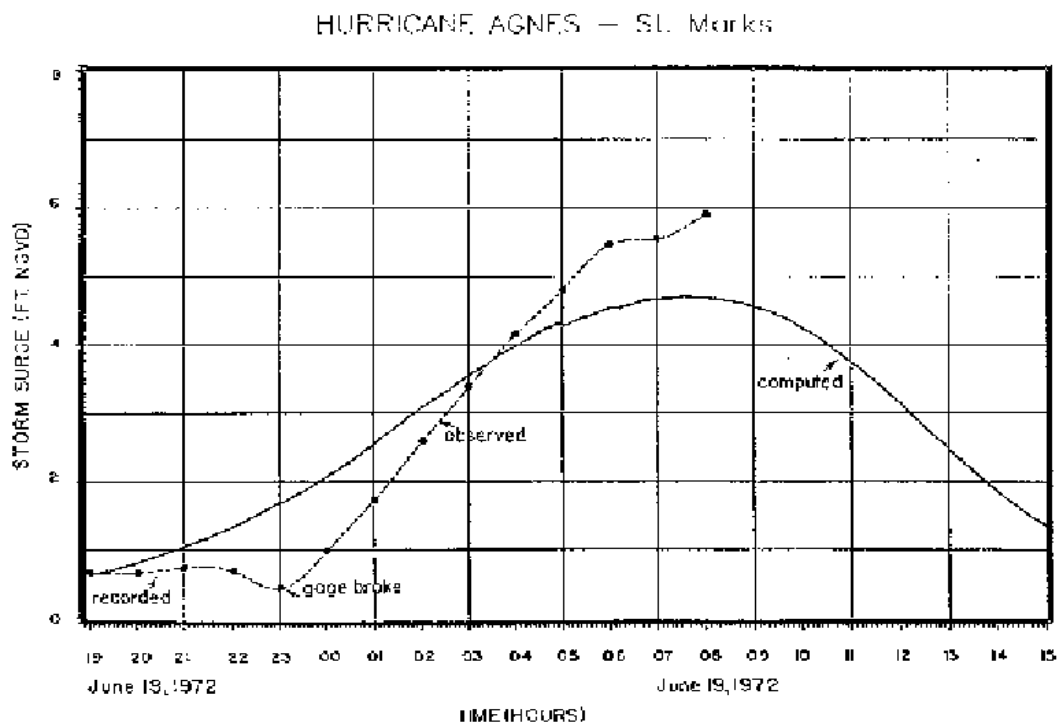


Figure III-7 Comparison between Measured and Computed Storm Tide at St. Marks, Florida for Hurricane Agnes (1972)

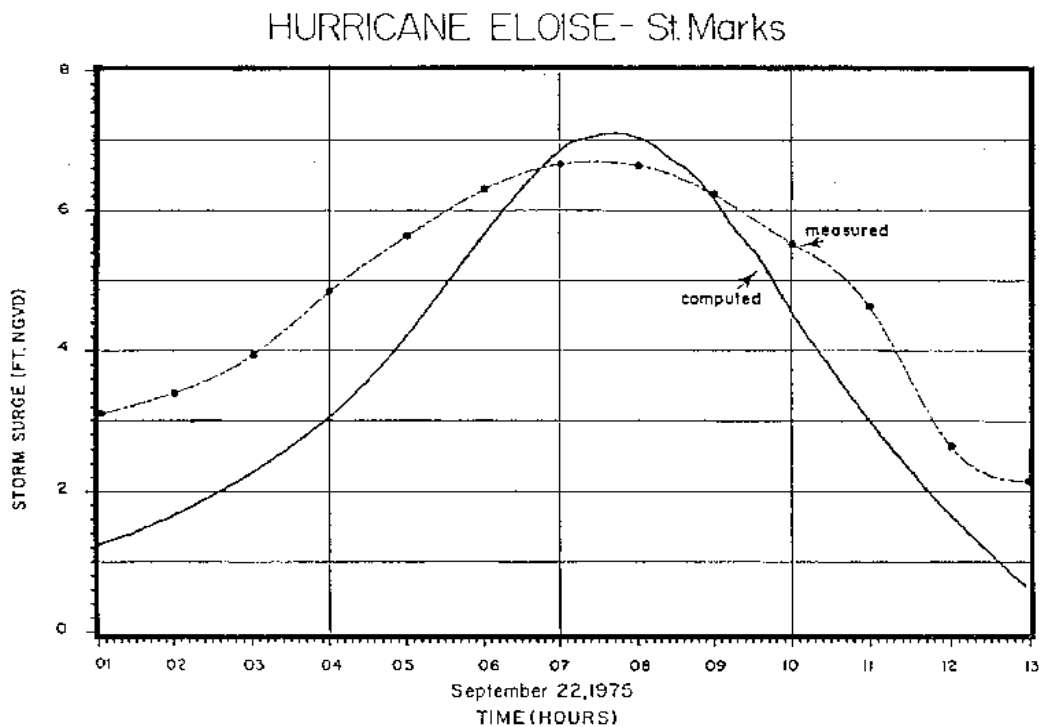


Figure III-8 Comparison between Measured and Computed Storm Tide at St. Marks, Florida for Hurricane Eloise (1975)

In the CCCL study for Nassau County, comparisons were carried out for Hurricane Dora (1964) and Hurricane David (1979), using the input parameters presented in Tables III-4 and III-5, respectively. Measurements were available at Fernandina Beach and Mayport. The comparisons are presented in Figures III-9, III-10, III-11 and III-12. In general the average agreement is considered good.

In summary of the comparisons shown (and others available but not shown for Dade, Broward and Walton Counties), the agreement between measured and computed storm surges is considered good. We regard this comparison/validation phase as useful in demonstrating the validity of the model and ensuring that the nearshore bathymetry/topography is represented adequately. Differences that exist in the peak surges are believed to be due to the wind field structure of the specific hurricanes, i.e., a measure of the deviation from the idealized hurricane used as input and other factors such as the difference in air-sea temperature which influences the wind surface stress coefficient.

Generation of Data Base For Calibration of One-Dimensional Model

With the two-dimensional model validated, a data base is generated spanning the hurricane parameters of interest. This data base is subsequently employed for calibration of the one-dimensional model which includes more severe approximations to the physics of the hurricane problem.

To illustrate the range of hurricane parameters included in the data base, Tables III-6a, III-6b, III-7a, III-7b, III-8a and III-8b present the cases selected for Landfalling, Alongshore and Exiting Storms in the Pinellas County vicinity. Note that eleven storms are selected for each hurricane path category. The last columns in these tables contain the maximum storm surges for the coastal terminus of the four transects shown in Figures II-19, II-20, II-21 and II-22 and will be discussed in the next section.

TABLE III-4
Input Parameters for Calibration Hurricane
Hurricane Dora (September, 1964)

date	time (GMT)	Δp (in Hg)	Y_F (knots)	R (n. mi.)	θ_N (degrees)
9/8	1800	-1.48	1	20	98.80
9/9	0000	-1.35	8.0	20	104.60
	0600	-1.21	10.3	20	112.88
	1200	-1.27	6.0	20	120.13
	1800	-1.51	6.0	20	99.41
9/10	0000	-1.45	6.1	20	99.41
	0600	-1.39	8.7	20	96.62
	1200	-1.30	6.1	20	96.62
	1800	-1.25	3.5	20	90.00
Starting coordinates: $X_s = 165.43$ n.mi. $Y_s = 90.00$ n.mi.			Landfalling coordinates: $X_F = 5.17$ n.mi. $Y_F = 36.00$ n.mi.		

TABLE III-5
Input Parameters for Calibration Hurricane
Hurricane David (September, 1979)

date	time (GMT)	Δp (in Hg)	Y_F (knots)	R (n. mi.)	θ_N (degrees)
9/3	1200	-1.14	10.4	10	150.14
	1800	-1.17	8.4	10	162.07
9/4	0000	-1.20	11.3	10	166.07
	0600	-1.23	11.0	10	175.52
	1200	-1.23	13.3	10	168.75
	1800	-1.23	10.0	10	184.92
9/5	0000	-1.17	10.2	10	189.78
	0600	-1.05	14.2	10	190.46
	1200	-0.98	14.2	10	190.46
Starting coordinates: $X_s = 51.70$ n.mi. $Y_s = 150.00$ n.mi.			Offshore coordinates: $X_L = 15.51$ n.mi. $Y_L = -60.00$ n.mi.		

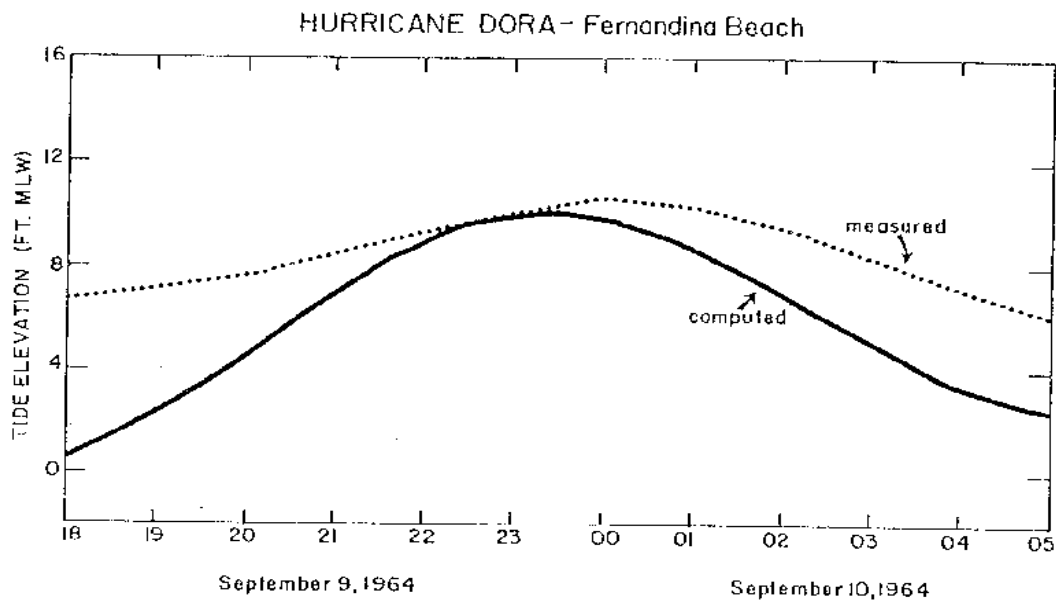


Figure III-9 Comparison between Measured and Computed Storm Tide at Fernandina Beach, Florida for Hurricane Dora (1964)

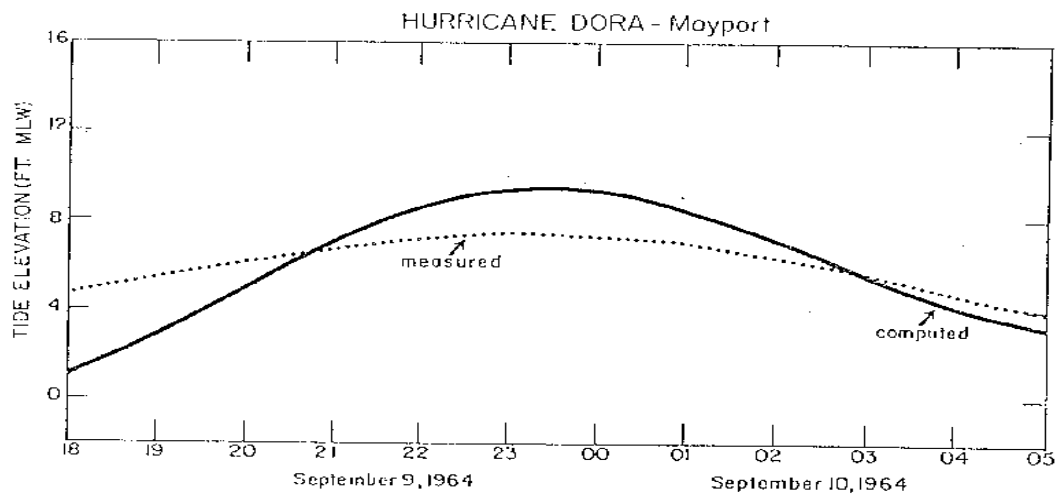


Figure III-10 Comparison between Measured and Computed Storm Tide at Mayport, Florida for Hurricane Dora (1964)

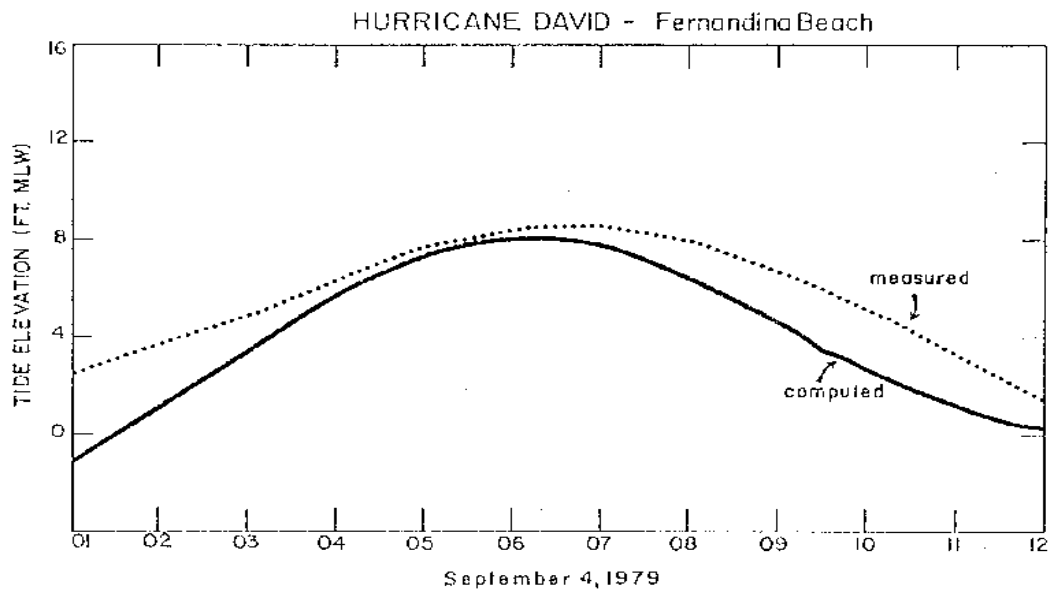


Figure III-11 Comparison between Measured and Computed Storm Tide at Fernandina Beach, Florida for Hurricane David (1979)

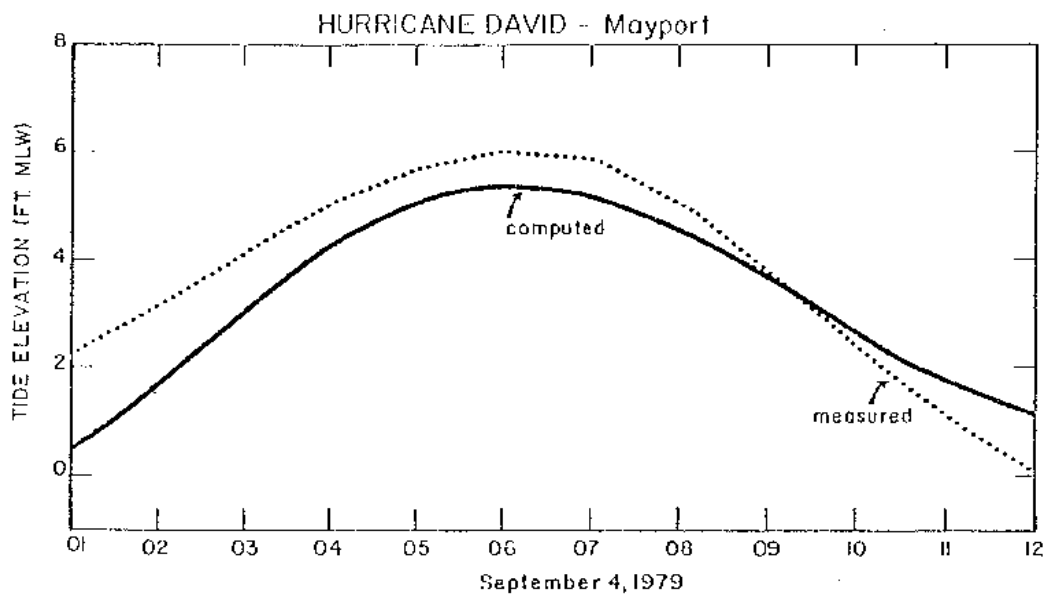


Figure III-12 Comparison between Measured and Computed High Water Mayport, Florida for Hurricane David (1979)

Table III-6a
Parameters Defining 11 Landfalling Model Hurricanes Used in Calibrating the
One-Dimensional Model with the Two-Dimensional Model

MODEL STORM	Δp (in. Hg)	R (n. mi.)	V_F (knots)	θ_N (degrees)	Landfalling Coordinates (n. mi.)		Starting Coordinates (n. mi.)	
					X_F	Y_F	X_s	Y_s
1	-1.4	22	13	230	-20	30	142.45	-16.58
2	-1.4	32	13	230	-20	30	142.45	-16.58
3	-1.4	12	13	230	-20	30	142.45	-16.58
4	-1.0	22	13	230	-20	30	142.45	-16.58
5	-1.8	22	13	230	-20	30	142.45	-16.58
6	-1.4	22	17	230	-20	30	110.73	-7.49
7	-1.4	22	9	230	-20	30	109.77	-7.21
8	-1.4	22	13	260	-20	30	143.98	70.88
9	-1.4	22	13	200	-20	30	97.40	-91.57
10	-1.4	22	13	230	-20	-10	142.45	-56.58
11	-1.4	22	13	230	-20	70	142.45	23.42

Table III-6b
Calibration of Landfalling Model Hurricanes

Model Storm	$\eta_{\max}$ (ft. NGVD)							
	Profile 1		Profile 2		Profile 3		Profile 4	
	1-D	2-D	1-D	2-D	1-D	2-D	1-D	2-D
1	11.55	11.45	11.12	11.27	10.98	12.32	10.29	9.80
2	11.31	11.73	12.84	12.73	12.94	14.34	12.86	12.26
3	10.81	10.23	7.97	8.43	7.51	8.65	6.59	6.39
4	9.60	9.74	8.99	9.27	9.03	10.13	8.28	7.99
5	13.52	13.26	13.27	13.29	12.96	14.46	12.28	11.66
6	12.14	11.75	11.67	11.90	11.69	12.90	10.94	10.26
7	10.94	10.54	10.55	10.03	10.27	10.99	9.63	8.79
8	12.65	13.07	11.10	11.17	10.00	10.87	9.63	8.89
9	9.65	9.53	10.83	9.87	10.98	11.20	11.55	9.03
10	1.35	1.47	5.12	4.07	2.92	3.29	7.67	6.28
11	8.54	9.36	5.84	6.95	6.25	7.53	5.61	5.86

Table III-7a
Parameters Defining 11 Alongshore Model Hurricanes Used in Calibrating the
One-Dimensional Model with the Two-Dimensional Model

MODEL STORM	Δp (in. Hg)	R (n. mi.)	V_F (knots)	θ_N (degrees)	Landfalling Coordinates (n. mi.)		Starting Coordinates (n. mi.)	
					X_L	Y_L	X_s	Y_s
1	-1.4	18	13	155	20	-5	17.05	-173.97
2	-1.4	24	13	155	20	-5	17.05	-173.97
3	-1.4	12	13	155	20	-5	17.05	-173.97
4	-1.0	18	13	155	20	-5	17.05	-173.97
5	-1.8	18	13	155	20	-5	17.05	-173.97
6	-1.4	18	17	155	20	-5	17.63	-140.98
7	-1.4	18	9	155	20	-5	17.64	-139.98
8	-1.4	18	13	170	20	-5	60.88	-168.98
9	-1.4	18	13	140	20	-5	-26.58	-167.45
10	-1.4	18	13	155	-5	-5	-7.95	-173.97
11	-1.4	18	13	155	45	-5	42.05	-173.97

Table III-7b
Calibration of Alongshore Model Hurricanes

Model Storm	$\eta_{\max}$ (ft. NGVD)							
	Profile 1		Profile 2		Profile 3		Profile 4	
	1-D	2-D	1-D	2-D	1-D	2-D	1-D	2-D
1	6.08	4.43	3.16	3.14	6.36	6.20	5.67	3.82
2	7.27	5.52	3.92	3.81	7.49	7.29	6.70	4.71
3	4.60	3.17	2.36	2.30	4.89	4.72	4.34	2.71
4	4.70	3.53	2.25	2.25	4.95	4.89	4.29	2.96
5	7.47	5.38	4.11	4.06	7.77	7.45	7.06	4.73
6	6.28	5.13	3.18	4.07	6.56	6.58	5.80	4.23
7	5.89	4.28	3.14	2.98	6.15	5.38	5.54	3.31
8	8.30	6.80	5.23	5.18	7.77	7.63	7.02	4.99
9	4.12	2.40	1.99	1.47	5.02	4.74	4.43	2.69
10	9.92	8.77	8.94	7.57	9.19	9.57	10.09	7.47
11	3.24	2.67	1.29	1.79	3.25	3.37	2.47	1.99

Table III-8a
Parameters Defining 11 Exiting Model Hurricanes Used in Calibrating the
One-Dimensional Model with the Two-Dimensional Model

MODEL STORM	Δp (in. Hg)	R (n. mi.)	V_F (knots)	θ_N (degrees)	Landfalling Coordinates (n. mi.)		Starting Coordinates (n. mi.)	
					X_E	Y_E	X_s	Y_s
1	-1.4	22	13	100	5	0	-135.11	-94.50
2	-1.4	32	13	100	5	0	-135.11	-94.50
3	-1.4	12	13	100	5	0	-135.11	-94.50
4	-1.0	22	13	100	5	0	-135.11	-94.50
5	-1.8	22	13	100	5	0	-135.11	-94.50
6	-1.4	22	17	100	5	0	-107.75	-76.05
7	-1.4	22	9	100	5	0	-106.92	-75.49
8	-1.4	22	13	80	5	0	-158.98	-40.88
9	-1.4	22	13	120	5	0	-94.34	-136.72
10	-1.4	22	13	100	5	-25	-135.11	-119.50
11	-1.4	22	13	100	5	25	-135.11	-69.50

Table III-8b
Calibration of Exiting Model Hurricanes

Model Storm	$\eta_{\max}$ (ft. NGVD)							
	Profile 1		Profile 2		Profile 3		Profile 4	
	1-D	2-D	1-D	2-D	1-D	2-D	1-D	2-D
1	1.51	1.32	2.89	1.26	5.18	4.59	7.80	4.89
2	1.64	1.69	3.14	1.57	5.22	4.71	6.81	4.37
3	1.38	0.89	1.99	0.85	5.04	4.26	8.64	5.63
4	1.09	1.03	2.01	0.95	3.88	3.52	5.85	3.95
5	1.95	1.60	3.80	1.57	6.50	5.66	9.74	5.85
6	1.49	1.43	2.81	1.31	5.13	4.41	7.53	4.67
7	1.53	1.31	2.97	1.33	5.23	4.58	8.02	5.15
8	0.49	0.84	5.59	3.01	4.05	3.35	9.23	6.21
9	4.31	2.47	2.90	1.89	7.03	6.44	8.11	4.93
10	0.76	1.44	0.71	1.43	0.93	1.55	0.65	1.18
11	6.85	4.85	9.23	6.56	8.64	7.92	8.80	6.54

3.2 One-Dimensional Model

In the following, the results will be presented of calibrating the one-dimensional model with the data base generated by the two-dimensional model. In addition, the results of the long-term simulation will be illustrated.

Calibration With Two-Dimensional Model Results

The one-dimensional numerical model represents the physics of storm surges in a much more simplified manner than does the two-dimensional model. Simplifications in the 1-D model include, but are not limited to:

- a) The onshore dynamics of the storm surge are not represented,
- b) Only the hurricane pressure and wind stresses along the transect selected are taken into account, and
- c) Convergences and divergences of flow are not represented.

Because of the omission of these and other realistic features from the one-dimensional model and the comprehensive nature of the validated two-dimensional model, the latter is considered as a reliable basis for calibrating the one-dimensional model.

Comparisons of the one-dimensional and two-dimensional peak surges along the four transect lines for Pinellas County are shown in Figures II-19, II-20, II-21 and II-22 and for each of the hurricane categories are presented in Tables III-6a, III-6b, III-7a, III-7b, III-8a and III-8b and in Figures III-13a through III-15b. In each of these twelve graphs, best fit least squares curves are shown of the form

$$(\eta_{\max})_{2-D} = K(\eta_{\max})_{1-D} + C \quad (48)$$

where for perfect agreement, a value of unity would be obtained for K and a value of 0 for C. For landfalling storms, the range of K is 0.86 to 1.06 and the range of C is 0.17 to 0.56. For alongshore storms, the range for K is 0.75 to 1.02 and -1.04 to 0.58 for C. For exiting Storms, the range of K is 0.56 to 0.84 and -0.36 to 0.68 for C. These values are employed in the subsequent long-term simulation which uses the one-dimensional model.

Table III-9 presents the ranges of K and C values for the three categories of storms for all the counties studied in the CCCL program.

3.3 Long-Term Simulations

As noted previously, long-term simulations are carried out using the one-dimensional numerical model, usually for a duration of at least 500 years. The study of historical occurrence ensures along with the directional distribution (presented for Pinellas County in Figure II-5) that the correct number and category of hurricanes are selected.

The long-term simulation is carried out for each transect selected, the peak total storm surges ranked and their return periods calculated in accordance with Equation. (47).

For Pinellas County, five 2,000 year simulations were carried out and averaged for each of the four transect lines. The return period vs peak total storm tide relationships for these transects are presented in Figure III-16 and are summarized for selected specific return periods in Table III-10. It is seen that the 100 year peak storm tide ranges from 9.9 ft (above MSL) for the southern profile to 11.5 ft for the northern profile.

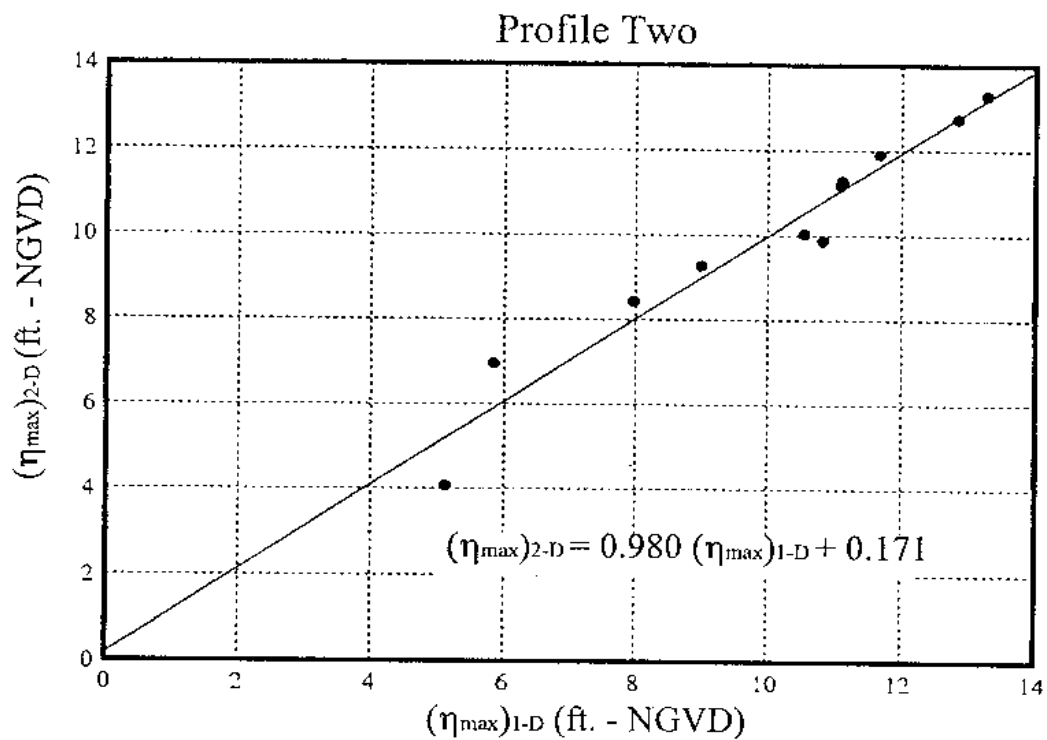
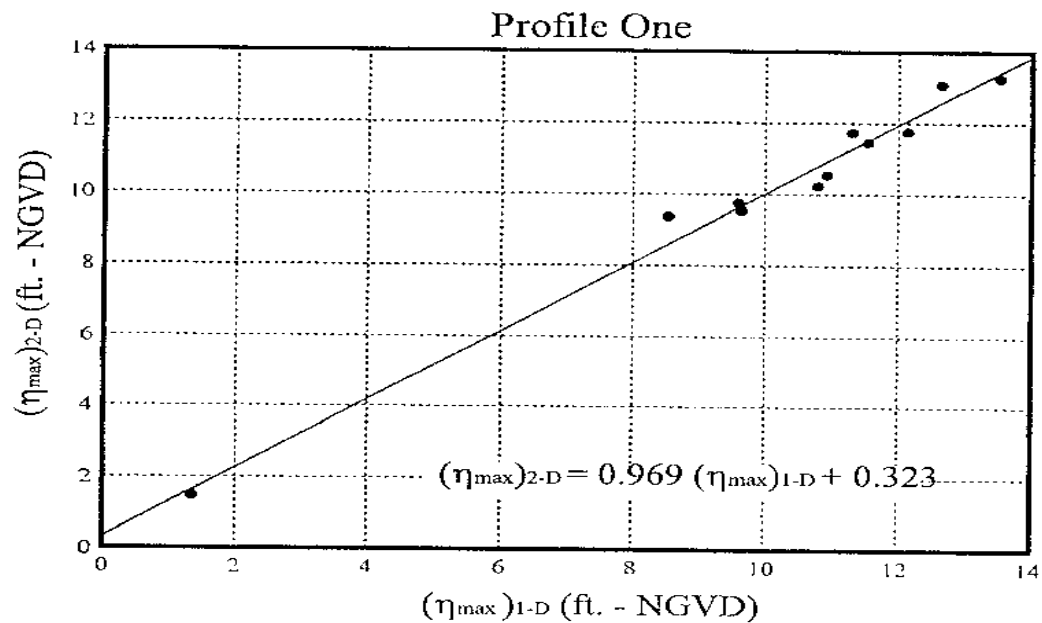


Figure III-13a Calibration Relationship between the One-Dimensional and the Two-Dimensional Calculations of Peak Surges at Profile One and Profile Two Transect Lines of Pinellas County for Landfalling Hurricanes

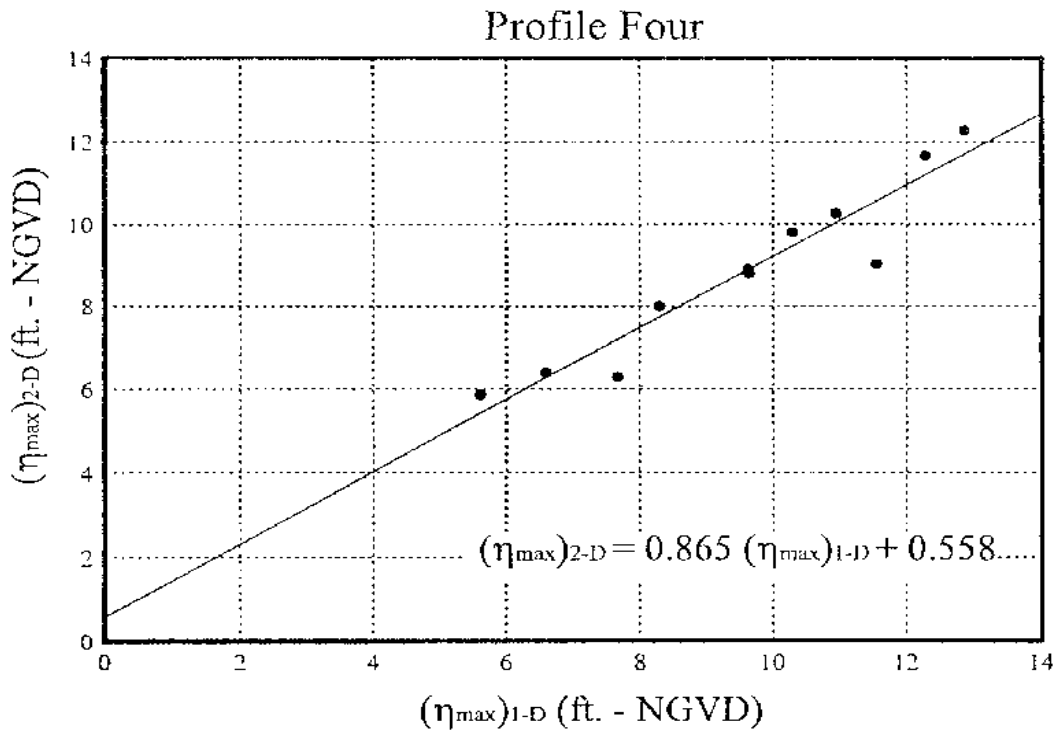
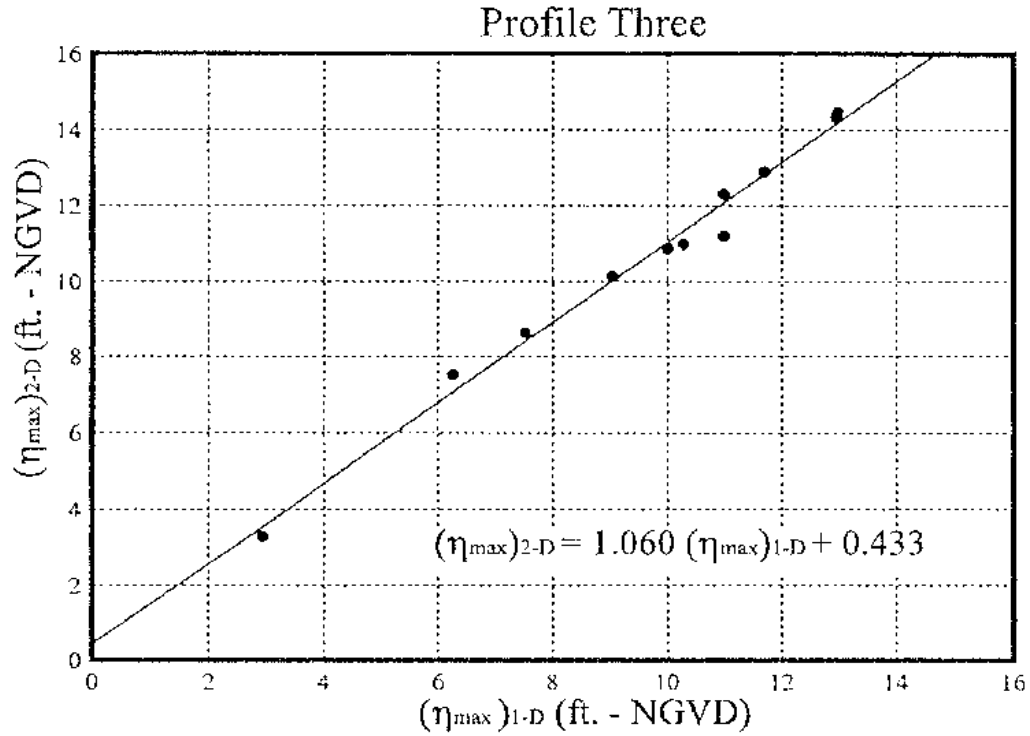


Figure III-13b Calibration Relationship between the One-Dimensional and the Two-Dimensional Calculation of Peak Surges at Profile Three and Profile Four Transect Lines of Pinellas County for Landfalling Hurricanes

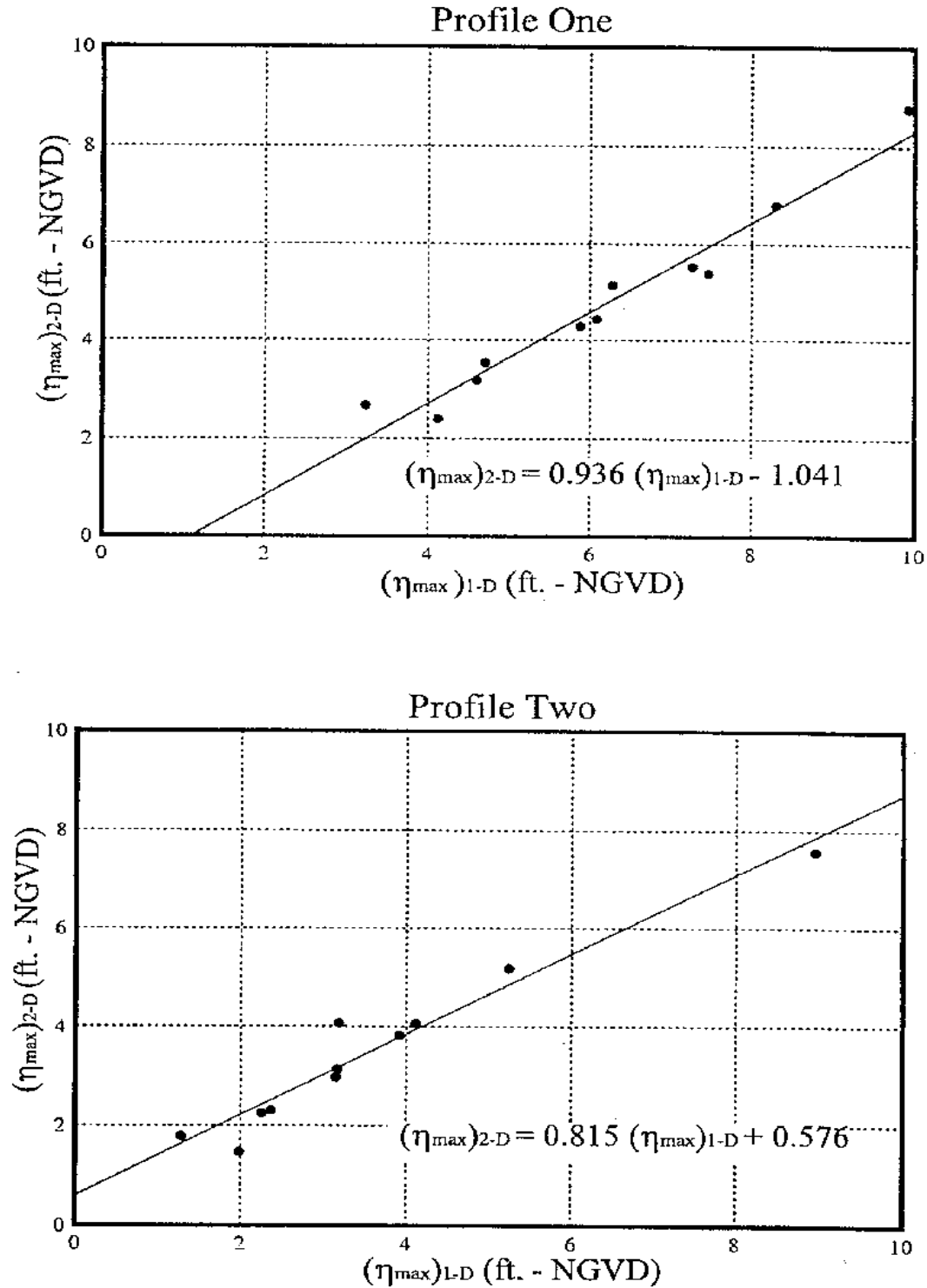


Figure III-14a Calibration Relationship between the One-Dimensional and the Two-Dimensional Calculations of Peak Surges at Profile One and Profile Two Transect Lines of Pinellas County for Alongshore Hurricanes

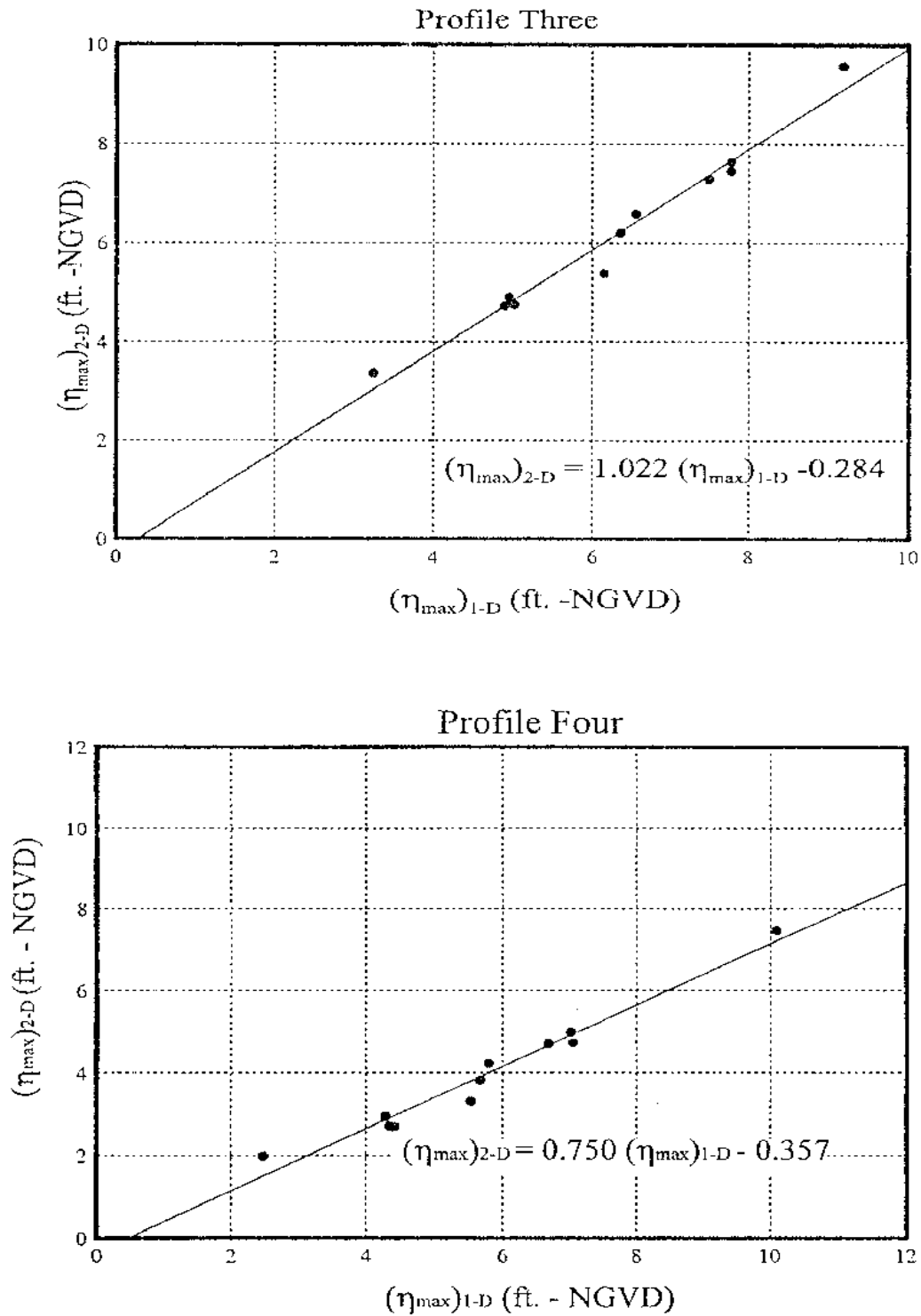


Figure III-14b Calibration Relationship between the One-Dimensional and the Two-Dimensional Calculations of Peak Surges at Profile Three and Profile Four Transect Lines of Pinellas County for Alongshore Hurricanes

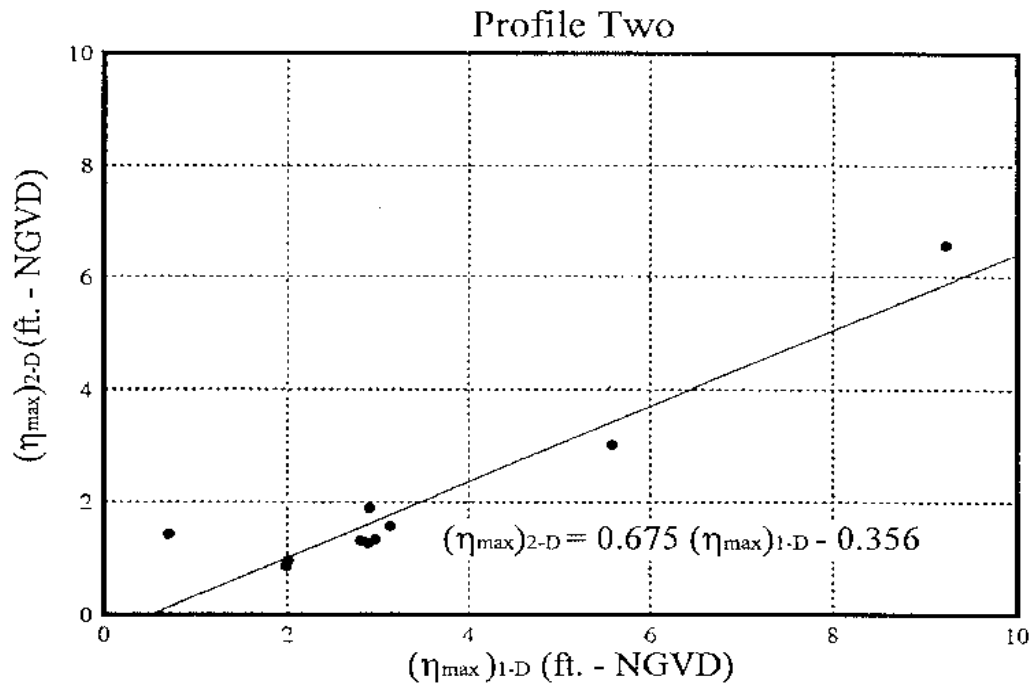
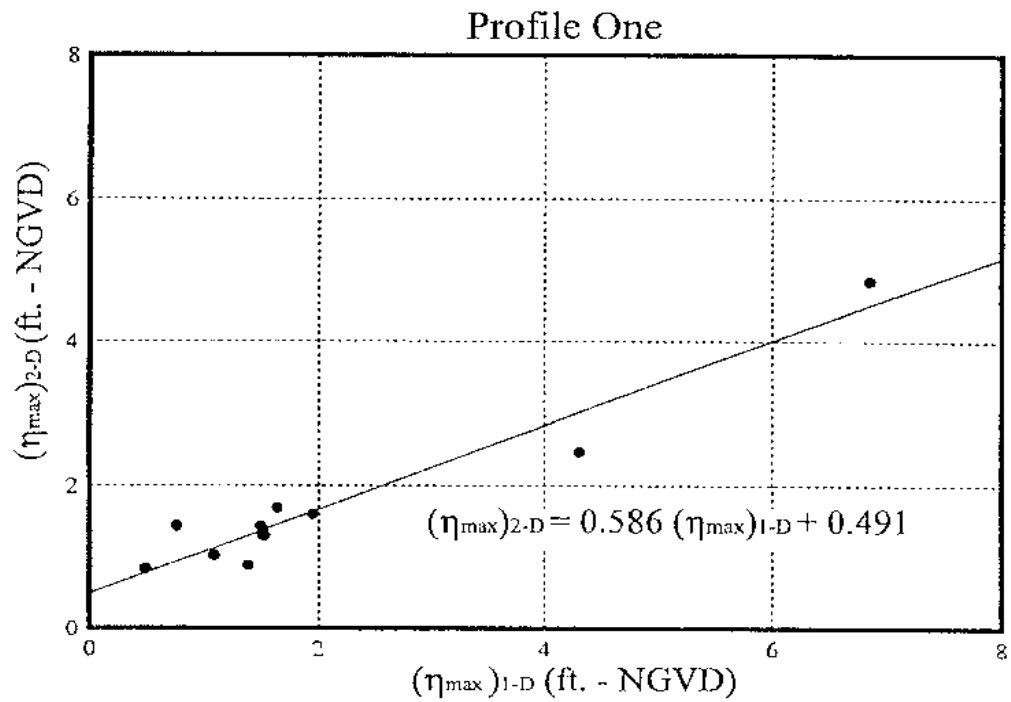


Figure III-15a Calibration Relationship between the One-Dimensional and the Two-Dimensional Calculations of Peak Surges at Profile One and Profile Two Transect Lines of Pinellas County for Exiting Hurricanes

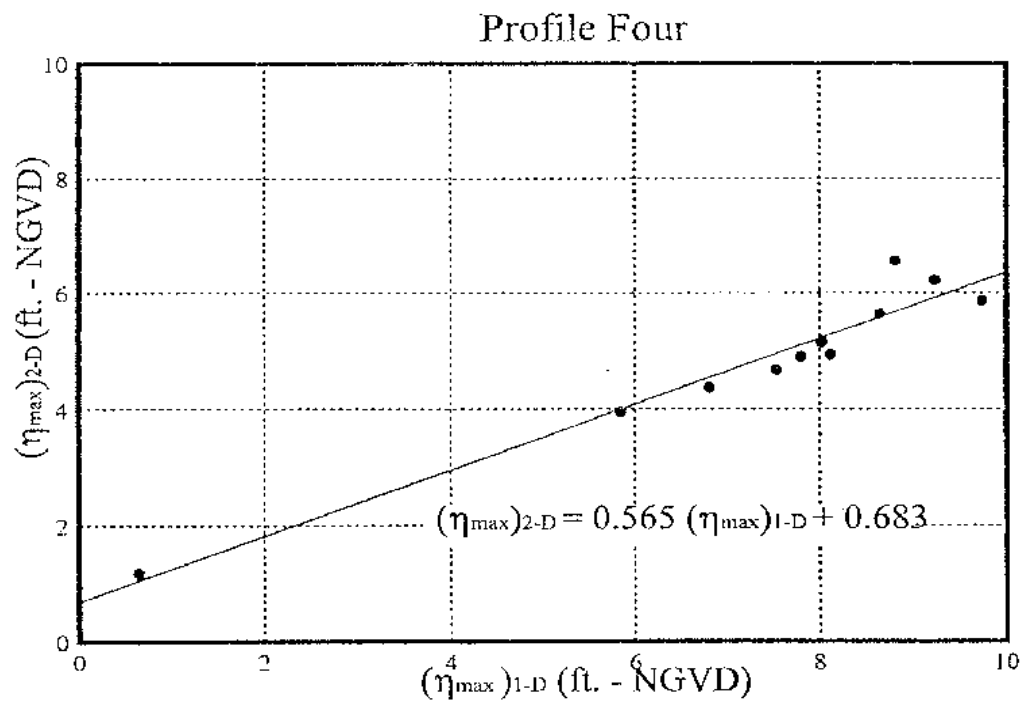
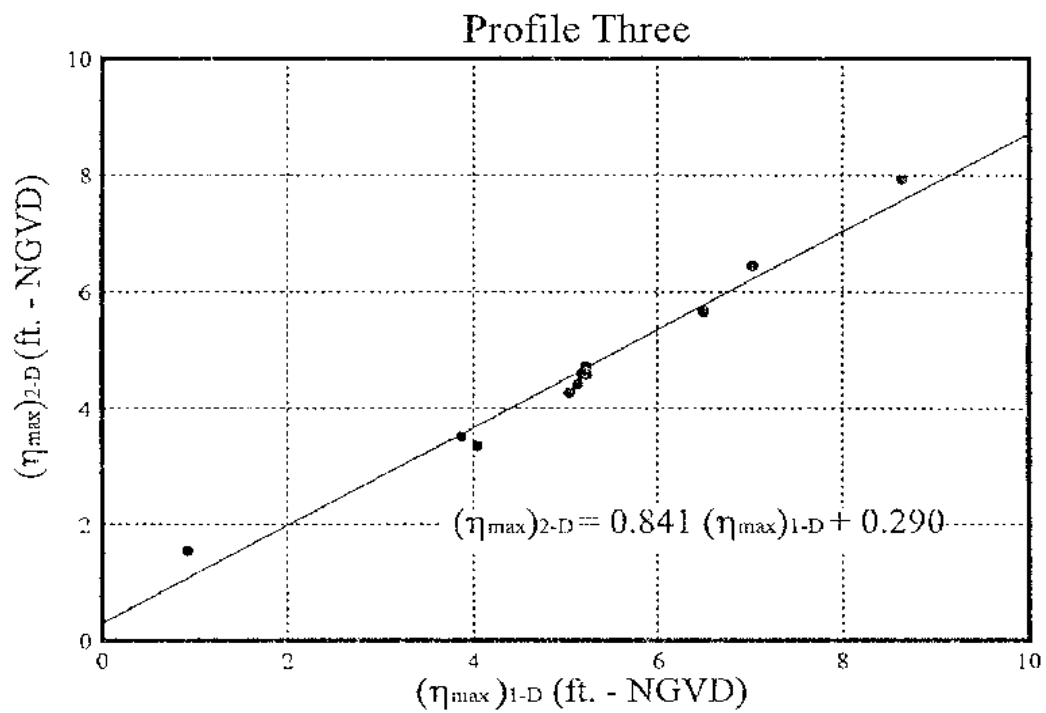


Figure III-15b Calibration Relationship between the One-Dimensional and the Two-Dimensional Calculations of Peak Surges at Profile Three and Profile Four Transect Lines of Pinellas County for Exiting Hurricanes

TABLE III-9

Values of 1-D/2-D Peak Storm Surge Correlation for Counties Completed to Data

County	Date of Study	Range of K and C					
		Landfalling Hurricanes		Alongshore Hurricanes		Exiting Hurricanes	
		K	C	K	C	K	C
Broward	1981	1.07*		1.07*		***	
Charlotte	1984	1.09-1.14		0.93-1.00		0.93-0.94	
Dade	1981	1.03		1.34		1.13	
Franklin	1983	0.95-1.18		***		***	
Walton	1982	0.99-1.05		***		***	
Nassau	1982	0.93-0.99		0.84-0.90**		0.84-0.90**	
Franklin	September 1983	0.95-1.18	n/a	n/a	n/a	n/a	n/a
Charlotte	April 1984	1.09-1.14	N/a	0.93-1.00	N/a	0.92-0.94	N/a
Martin	July 1984	1.05-1.07	N/a	n/a	n/a	0.98-0.99	N/a
Gulf	August 1985	0.32-1.57	0.78-1.07	n/a	n/a	n/a	n/a
Indian River	October 1986	1.03-1.12	(-0.44)-0.43	0.90-0.95	0.33-0.63	0.94-0.96	0.03-0.17
Escambia	November 1986	1.07-1.12	N/a	n/a	v/a	n/a	n/a
Manatee	March 1987	1.05-1.10	0.14-0.22	0.91-0.99	0.40-0.43	0.90-0.92	0.09-0.12
St. Johns	June 1987	0.99-1.18	(-0.53)-0.67	0.92-0.99	0.24-1.05	0.92-0.97	0.02-0.19
Flagler	September 1987	0.99-1.19	(-0.04)-0.23	0.85-1.00	0.03-0.25	0.90-0.99	0.00-0.11
St. Lucie	March 1988	1.05-1.10	(-0.20)-0.14	0.80-0.89	0.70-0.90	0.99-1.00	0.03-0.13
Sarasota	August 1988	1.05-1.17	(-0.36)-0.56	1.00-1.05	0.30-0.39	0.91-0.93	0.04-0.19
Volusia	July 1989	0.96-1.15	(-0.25)-1.54	0.92-0.93	0.77-1.03	0.90-0.97	(-0.16)-0.36
Collier	November 1989	0.96-1.12	(-0.00)-0.26	0.84-0.98	0.82-1.26	0.55-0.83	0.13-2.14
Lee	July 1990	0.93-1.13	(-0.21)-2.45	0.91-1.03	(-1.44)-0.76	0.78-1.12	(-0.46)-1.06
Okaloosa	January 1991	1.09-1.12	(-0.05)-0.42	N/a	n/a	n/a	n/a
Palm Beach	April 1992	1.05-1.07	(-0.04)-0.03	N/a	n/a	1.02-1.03	(-0.01)-(-0.06)
Bay	September 1994	0.90-1.17	(-0.31)-1.33	0.75-0.97	0.73-1.15	N/a	n/a
Pinellas	1995	0.86-1.06	0.17-0.56	0.75-1.02	(-1.04)-0.58	0.56-0.84	(-0.36)-0.68

* The calibration of the landfalling and alongshore hurricanes was combined.

** The calibration of the alongshore and exiting hurricanes was combined.

*** Due to their very small relative frequency of occurrence, alongshore and exiting hurricanes were not included.

Pinellas County

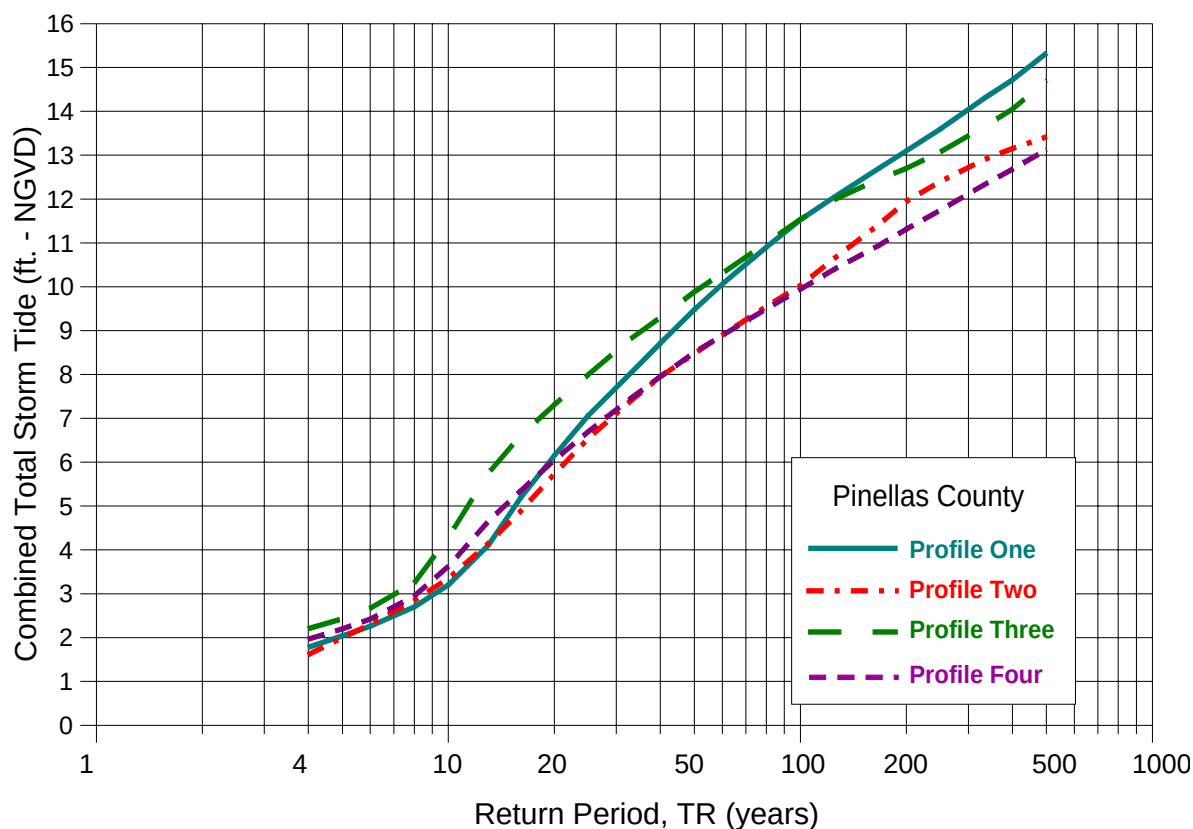


Figure III-16 Combined Total Storm Tide Elevation Versus Return Period for Four Transect Lines in Pinellas County

Table III-10

Combined Total Storm Tide Values for Various Return Periods

Return Period,	Combined Total Storm Tide Level* above NGVD (ft.) (ft.)			
TR (years)	Profile One	Profile Two	Profile Three	Profile Four
500	15.3	13.4	14.7	13.1
200	13.1	12.0	12.7	11.3
100	11.5	10.0	11.5	9.9
50	9.5	8.5	9.9	8.5
20	6.2	5.7	7.3	6.1
10	3.2	3.4	4.3	3.6
5	2.0	2.0	2.4	2.2

*Includes contributions of: wind stress, barometric pressure, dynamic wave set-up and astronomical tide.

IV. EROSION CALCULATION METHODOLOGY

4.1 Introduction

The erosion calculation methodology is based on measurements of beach profiles, both in an equilibrium and post-storm state and reasonable approximations to the physics, where necessary. These methods have been under development for approximately seven years and the numerical models are continually being upgraded, both as new and improved information becomes available and in our continuing attempt to include as much realism (for example, overwash) in the numerical model as possible.

4.2 Equilibrium Beach Profiles

A number of theories have been advanced attempting to describe the properties of and mechanisms associated with equilibrium beach profiles.

Based on a data set comprising more than 500 beach profiles ranging from the eastern tip of Long Island to the Texas-Mexico border, see Figure IV-1, the following form for an equilibrium beach profile was identified

$$h(x) = Ax^m \quad (49)$$

in which A and m are scale and shape parameters, respectively. Figure IV-2 presents normalized beach profiles for various m values. It is seen that for $m < 1$, the profile is concave upward as commonly found in nature. Figure IV-3 demonstrates the effect of the scale parameter, A.

The data from the 502 beach profiles were evaluated employing a least squares procedure to determine the A and m values for each of the profiles. The results of this analysis strongly supported a value of $m = 0.667$, (see Figure IV-4). It can be shown that a value of $m = 2/3$ corresponds to uniform wave energy dissipation per unit water volume in the surf zone. The physical explanation associated with this mechanism is as follows. As the wave propagates through the surf zone, coherent wave energy is converted to turbulent energy by the breaking process. This turbulent energy is manifested as eddy motions of the water particles, thus affecting the stability of the bed material. Any model must acknowledge that a particular sand particle is acted on by constructive and destructive forces. The model here addresses directly only the destructive (destabilizing) forces. It was reasoned that the parameter A depends primarily on sediment properties, and secondarily on wave characteristics, i.e.

$$A = F(\text{Sediment Properties, Wave Characteristics}) \quad (50)$$

where “F()” denotes “function of” and it would be desirable to combine wave and sediment characteristics to form a single dimension less parameter.

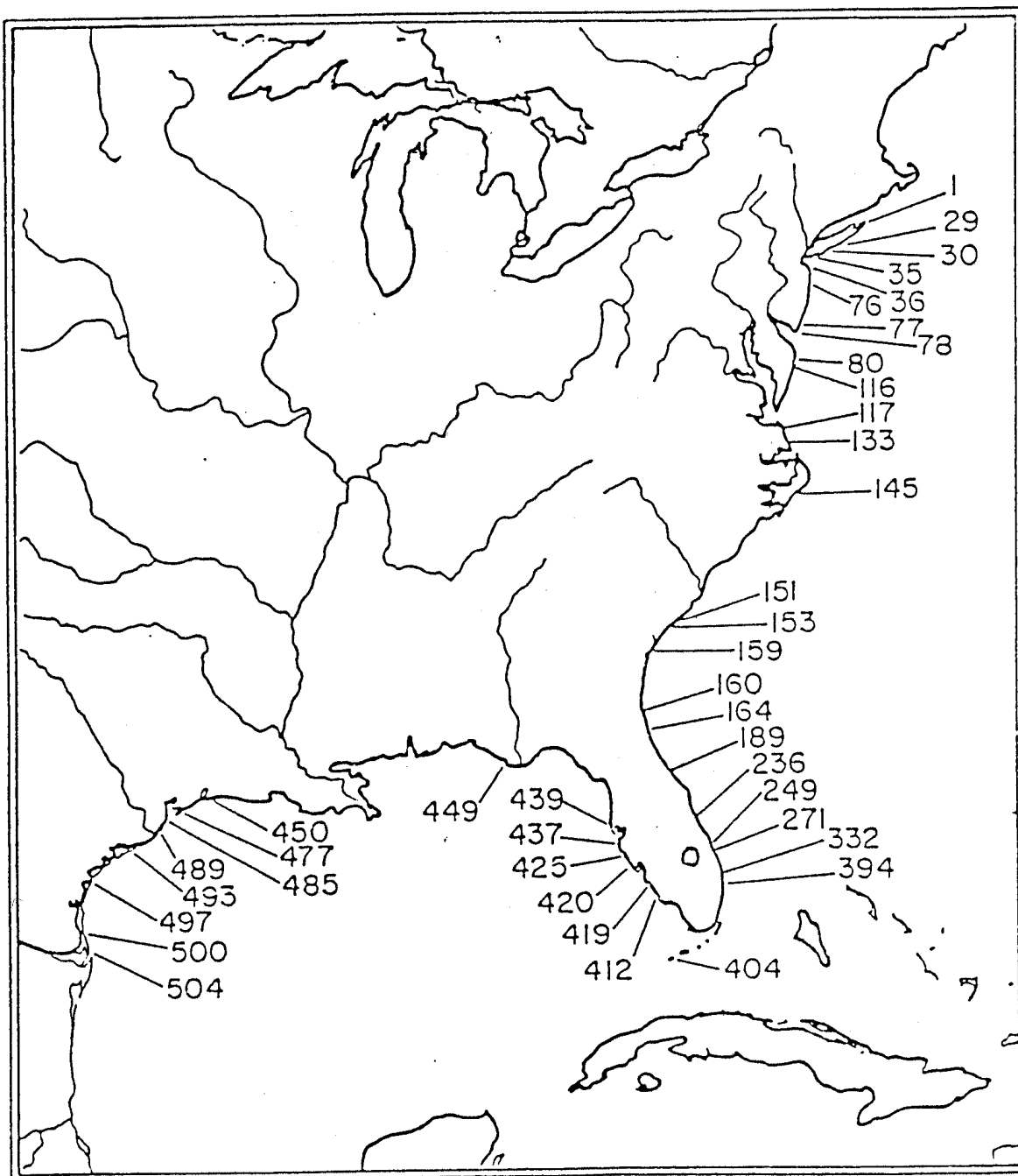


Figure IV-1 Location Map of the 502 Profiles Used in the Analysis (from Hayden, et al. 1975)

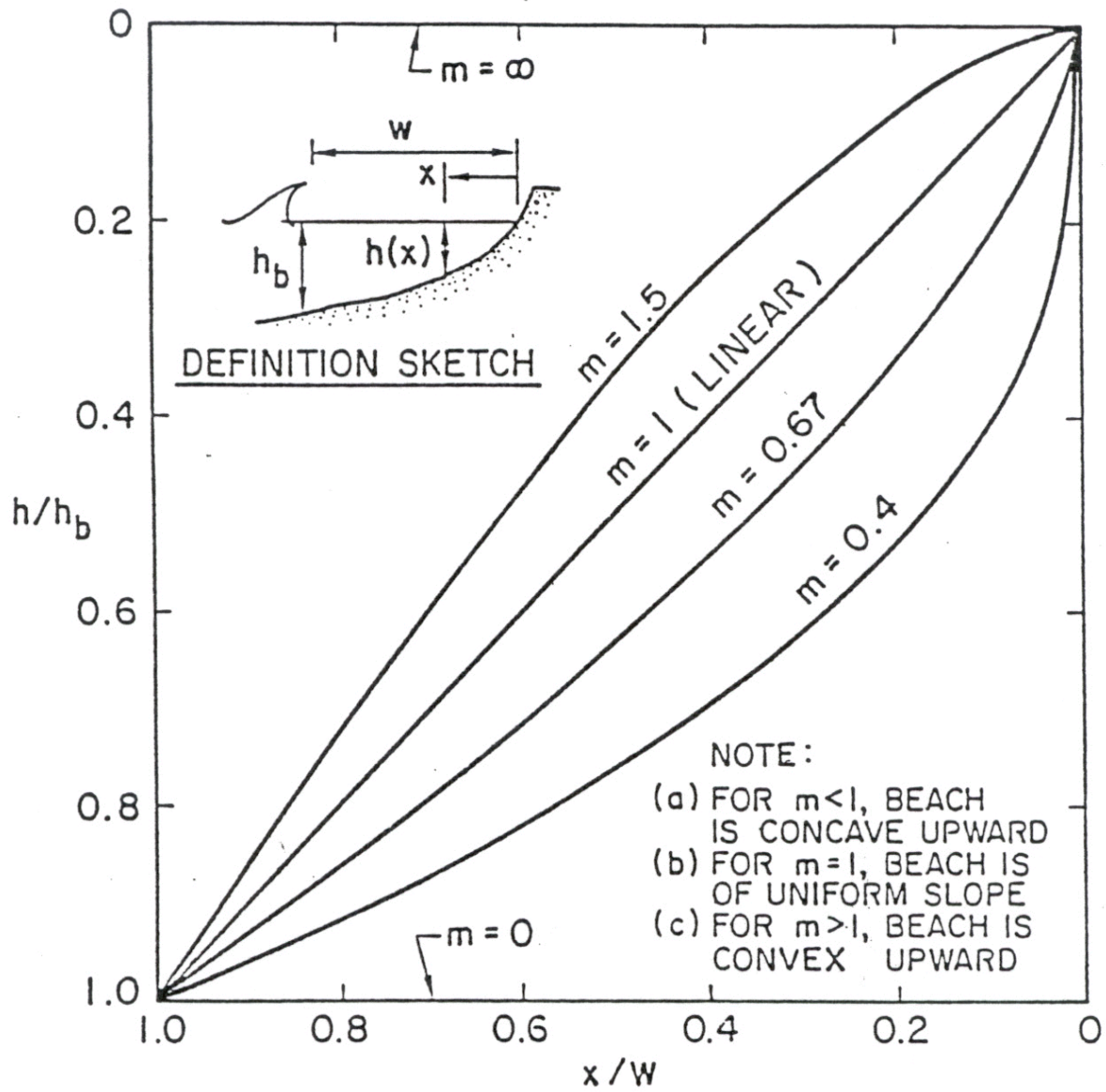


Figure IV-2 Characteristics of Dimensionless Beach Profile for Various m Values (from Dean, 1977)

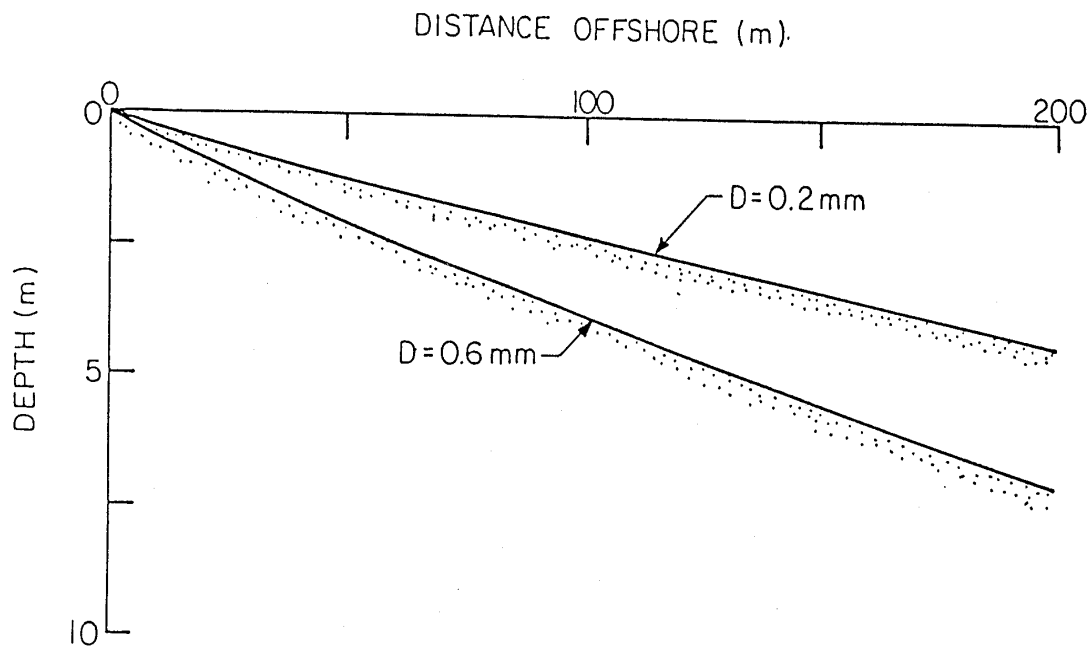


Figure IV-3 Equilibrium Beach Profiles for Sand Sizes of 0.2 mm and 0.6 mm $A(D = 0.2 \text{ mm}) = 0.1 \text{ mm}^{1/3}$,
 $A(D = 0.6 \text{ mm}) = 0.20 \text{ mm}^{1/3}$

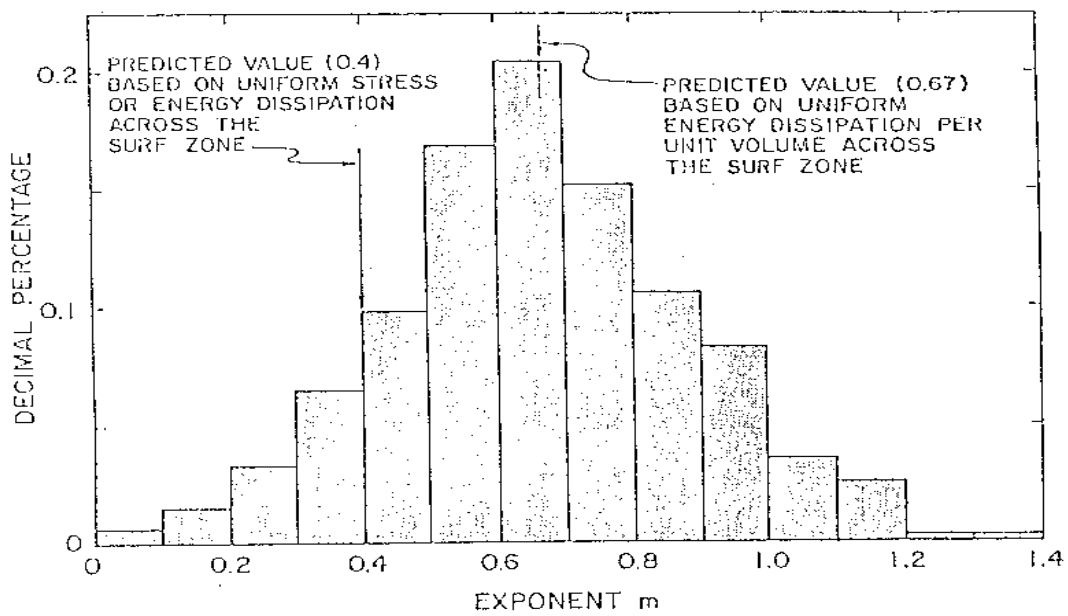


Figure IV-4 Histogram of Exponent m in Equation $h = Ax^m$ for 502 United States East Coast and Gulf of Mexico Profiles (from Dean (11), 1977)

A portion of Mr. Brett Moore's M.S. Thesis (12) was directed toward an improved definition of the scale parameter, A . Moore combined available laboratory and field data to obtain the results presented in Figure IV-5, thereby extending considerably the previous definition of A . Some of the individual beach profiles used in the development of Figure IV-5 are interesting. For example, Figure IV- 6 presents the actual and best least squares fit to a beach consisting of "sand particles" 15-30 cm in diameter (approximately the size of a bowling ball). Figure IV-7 presents the same information for a beach reported to be composed almost entirely of whole and broken shells. Figure IV-8 shows a profile with a bar present resulting in one of the poorer fits to the data. It is emphasized that the analytical form (Equation (50)) describes a monotonic profile.

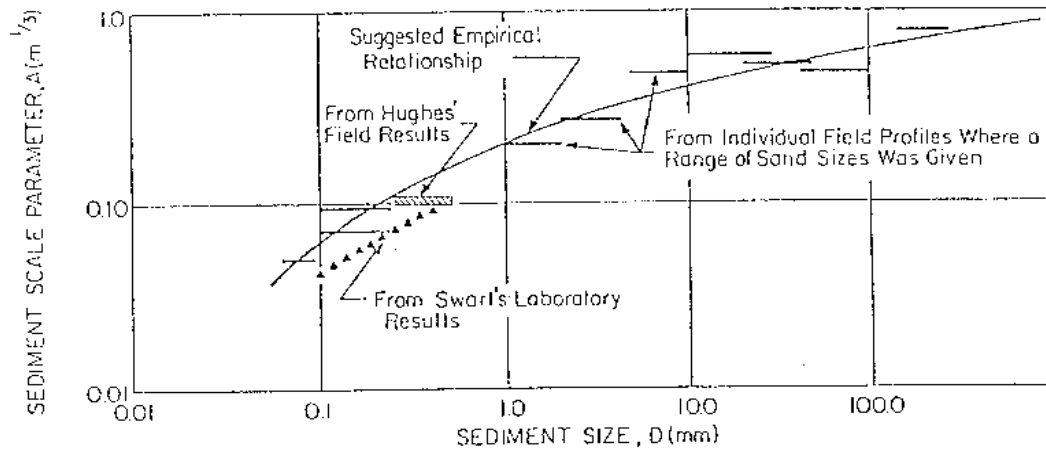


Figure IV-5 Beach Profile Factor, A , vs. Sediment Diameter, D , in Relationship $h = Ax^{2/3}$ (Modified from Moore (12), 1982)

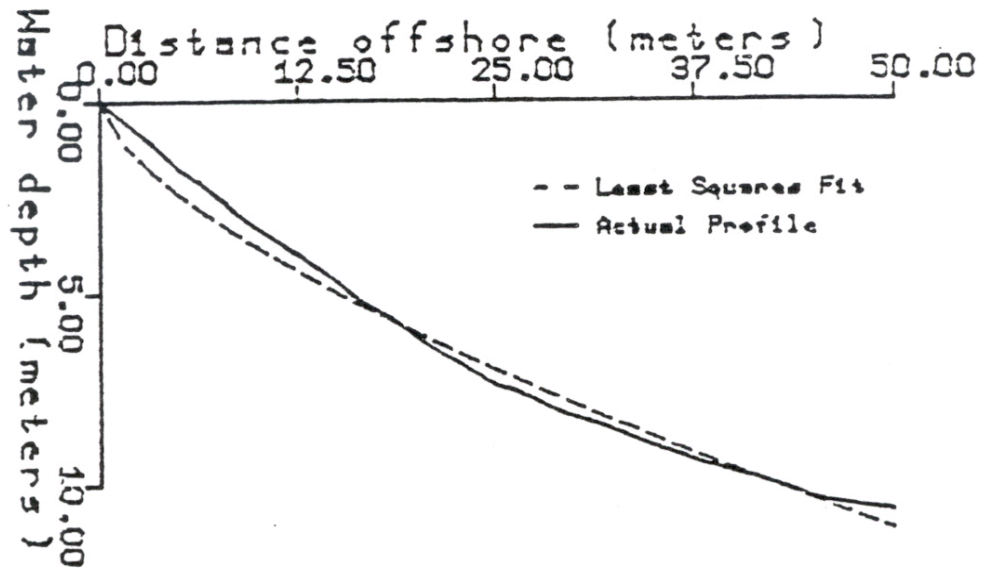


Figure IV-6 Profile P4 from Zenkovich (1967). A Boulder Coast in Eastern Kamchatka. Sand Diameter: 150 mm - 300 mm. Least Squares Value of $A = 0.82 \text{ m}^{1/3}$ (from Moore (12), 1982)

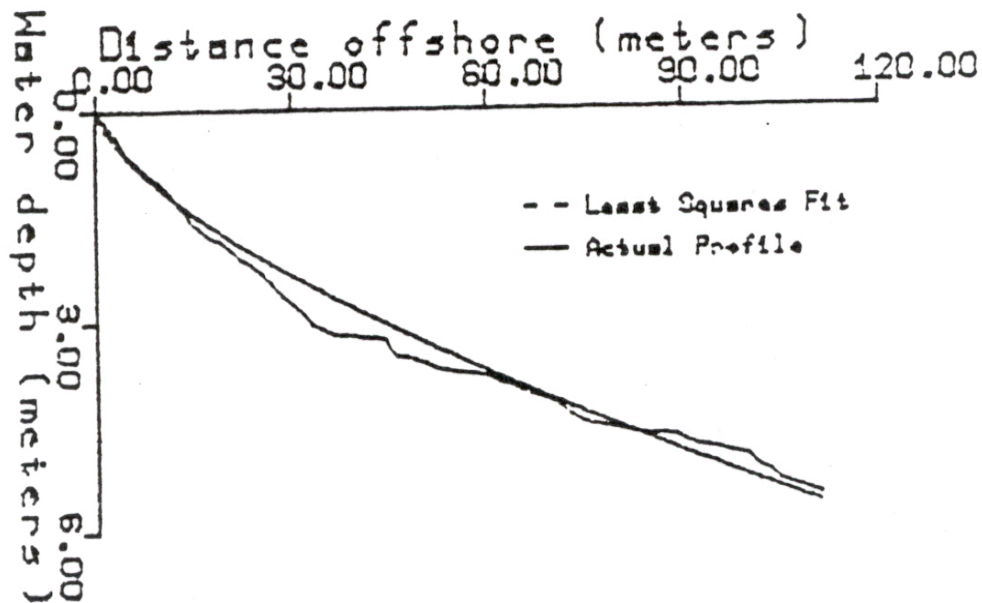


Figure IV-7 Profile P10 from Zenkovich (1967). Near the End of a Spit in Western Black Sea. Whole and Broken Shells. $A = 0.25 \text{ m}^{1/3}$ (from Moore (12), 1982)

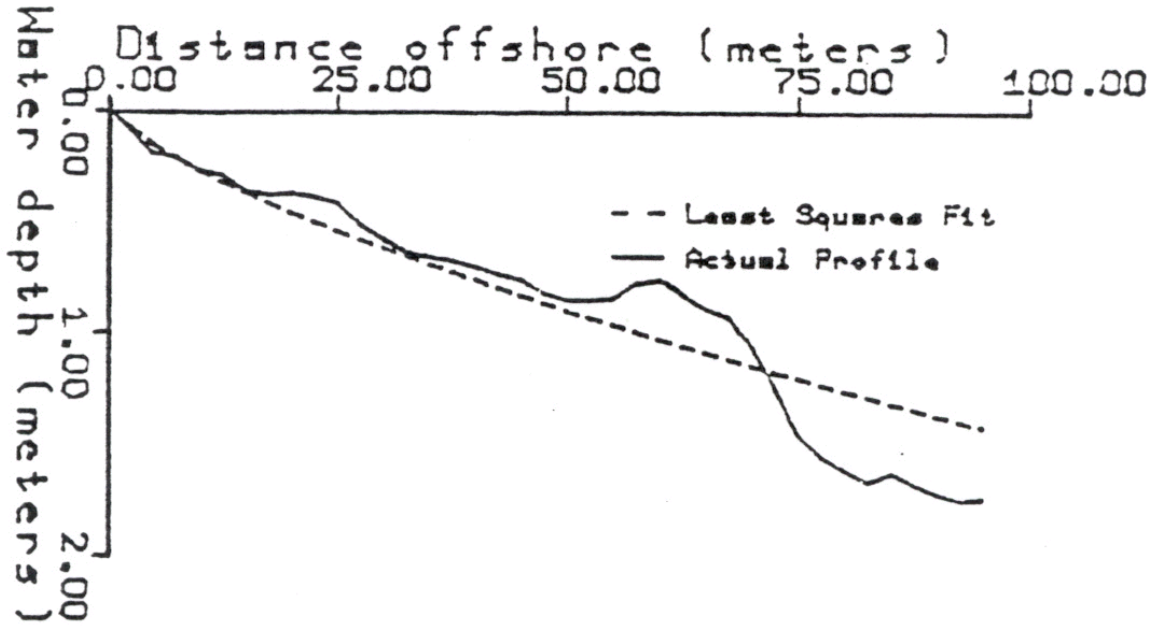


Figure IV-8 Profile from Zenkovich (1967). Eastern Kamchatka. Mean Sand Diameter: 0.25 mm. Least Squares Value of $A = 0.07 \text{ m}^{1/3}$ (from Moore (12), 1982)

4.3 Cross-Shore Transport Models

It has been noted that most equilibrium profiles correspond to uniform energy dissipation per unit volume with the scale of the profile represented by the parameter A which depends primarily on sediment characteristics and secondarily on wave characteristics, i.e.

$$h(x) = Ax^{2/3} \quad (51)$$

The parameter, A , and the uniform energy dissipation per unit volume, ν^* , are related for linear spilling waves by

$$A = \left(\frac{24}{5} \frac{\nu^*}{\rho g^{3/2} \kappa^2} \right)^{2/3} \quad (52)$$

It can be shown that for the spilling breaker assumption and linear waves, the energy dissipation per unit volume, ν , is proportional to the product of the square root of the water depth and the gradient in depth,

$$\nu = \frac{5}{16} \rho g^{3/2} \kappa^2 h^{1/2} \frac{\partial h}{\partial x} \quad (53)$$

Thus it is clear that an increase in water level such as due to a storm surge will cause wave energy dissipation to increase beyond the equilibrium value. It is also known that the beach responds by erosion of sediment in shallow water and deposition of this sediment in deeper water (Figure IV-9). It therefore appears reasonable to propose as a hypothesis that the offshore sediment transport, Q_s , per unit width is given by

$$Q_s = K(\nu - \nu^*) \quad (54)$$

where K is a rate constant that hopefully does not vary too greatly with scale. Moore (12) evaluated this relationship using large scale wave tank data of Saville (13) and found

$$K = 2.2 \times 10^{-6} \text{ m}^4 / \text{n} \quad (55)$$

Figure IV-10 presents comparisons of predicted cumulative erosion for various values of K with the measured values obtained from Saville's wave tank tests.

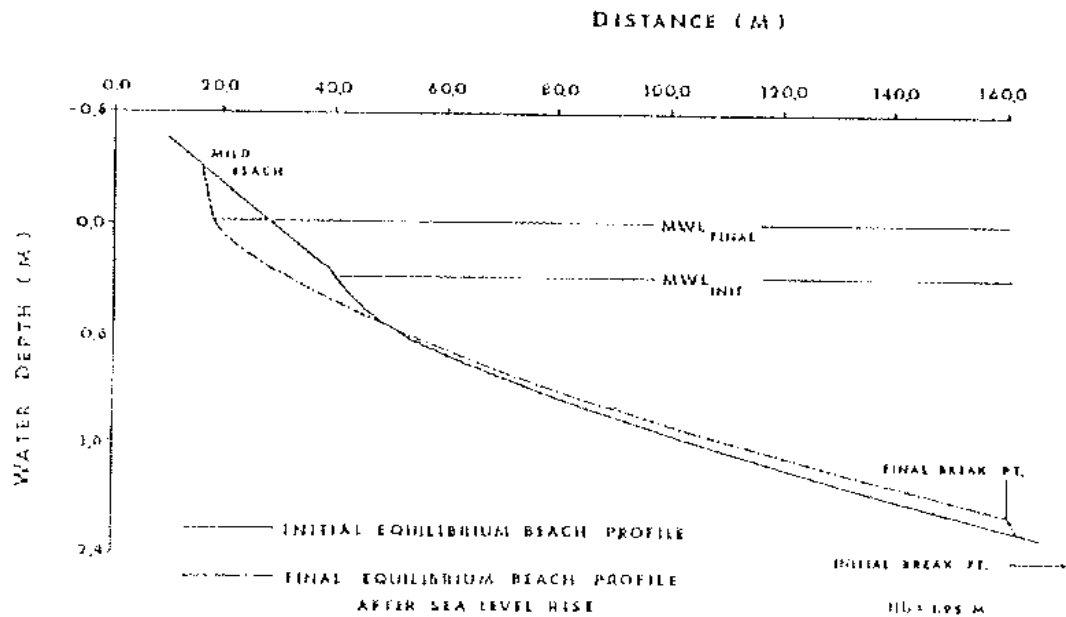


Figure IV-9 Model Simulation of a 0.5 Meter Sea Level Rise and Beach Profile Response with a Relatively Mild Sloping Beach (from Moore (12), 1982)

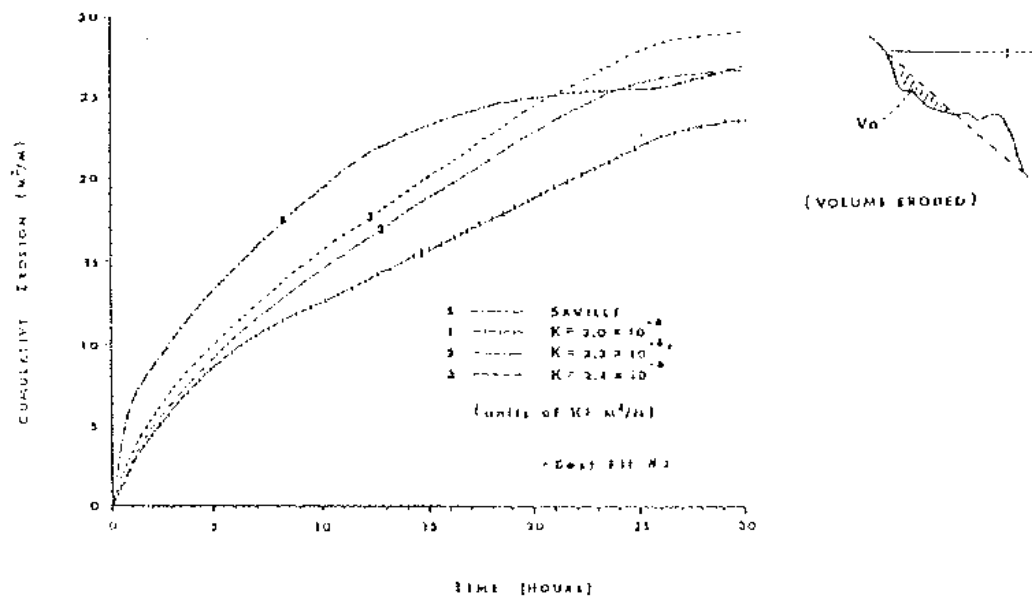


Figure IV-10 Effect of Varying the Sediment Transport Rate Coefficient on Cumulative Erosion During the Simulation of Saville's (1957) Laboratory Investigation of Beach Profile Evolution for a 0.2 mm sand size (from Moore (12), 1982)

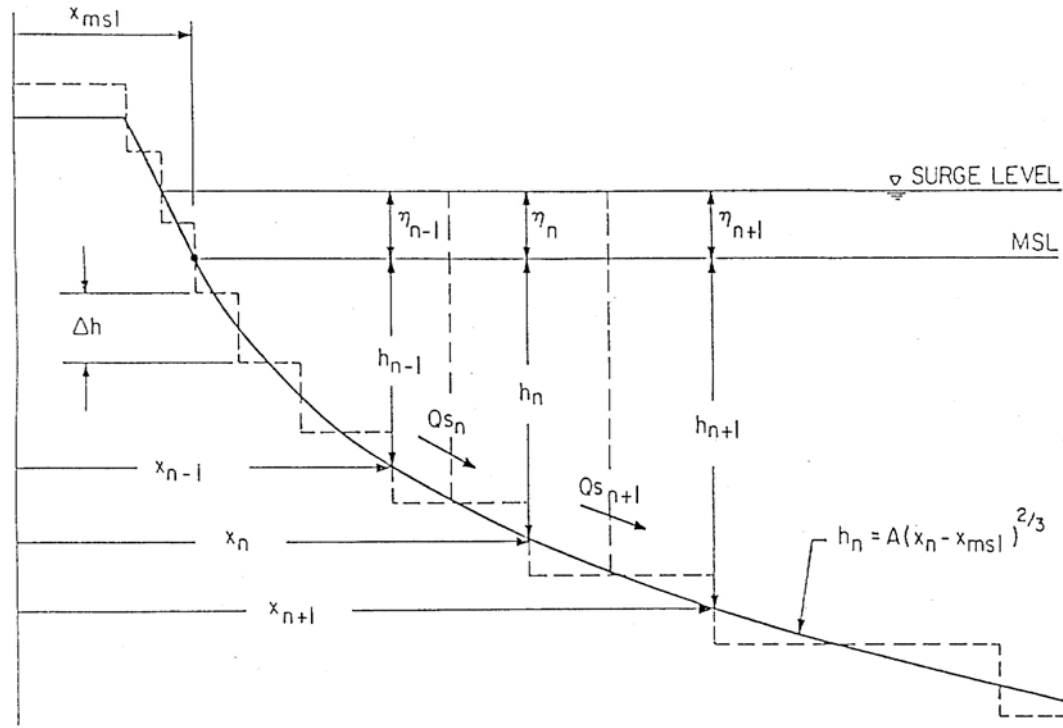


Figure IV-11 Model Representation of Beach Profile, Showing Depth and Transport Relation to Grid Definitions (from Kriebel (14), 1982)

4.4 Prediction of Beach and Dune Erosion Due to Severe Storms by Kriebel's Model

Mr. David Kriebel carried out a Master's thesis on this subject. He incorporated previous work and developed considerable original contributions to this problem, including the capability to model single storm events and long-term scenarios in which many storms occur.

Profile Schematization

The profile was schematized as a series of depth contours, h_n , the locations of which are specified by coordinates, x_n , measured from an arbitrary baseline, see Figure IV-11. The profile is thus inherently monotonic and at each time step, the x_n values of each of the active contours is updated.

Governing Equations

As in most transport problems, there are two governing equations. One is an equation describing the transport in terms of a gradient or some other feature. The second is a continuity or conservation equation which accounts for the net fluxes into a cell.

As discussed previously, the offshore transport is defined by Equation (54) in terms of the excess energy dissipation per unit volume. Specifically, in finite difference form

$$\text{where } v_{n+1} = K_D \frac{h_{n+1}^{5/2} - h_n^{5/2}}{(h'_{n+1} + h'_n)(x_{n+1} - x_n)} \quad (56)$$

$$K_D = \frac{\gamma}{4} \kappa^2 \sqrt{g} \quad (57)$$

The sand conservation equation is

$$\Delta x_n = \frac{K \Delta t}{\Delta h} (v_n - v_{n+1}) \quad (58)$$

Method of Solution of Finite Difference Equations

A number of methods could be employed for solving Equations. (54) and (58). For example, explicit methods would be fairly direct and simple to program; however, the maximum allowable time increment would be relatively small resulting in a program which is quite expensive to run. Implicit methods are somewhat more difficult to program, but have the desirable feature of remaining stable with a much greater time step. Because of the planned application to long-term simulation in which for a 500 year time period and on the order of three hundred storms would be modeled, each with an erosional phase of six to twelve hours, an implicit method was adopted. This method will not be described in detail here except to note that a double sweep approach is used in which the Q_{s_n} values and the x_n values are updated simultaneously at each time step. For Δh values of 1 ft, and a time step of thirty minutes, the system of equations was stable.

The boundary conditions used were somewhat intuitive. At the shoreward end of the system, erosion proceeded with a specified slope above a particular depth, h^* . The depth, h^* , is the depth that the equilibrium slope and the slope corresponding to the beach face are the same. Thus a unit of recession of the uppermost active contour causes an erosion of the profile above the active contour that is "swept" by this specified slope. This material is then placed as a source into the uppermost active contour. The offshore boundary condition is that the active contours are those within which wave breaking occurs. If an active contour extends seaward, thereby encroaching over the contour below to an extent that the angle of repose is reached, the lower contour (and additional lower contours if necessary) are displaced seaward to limit the slope to that of the angle of repose.

Application of Method to Computation of Idealized Beach Response

Kriebel (14) carried out computations for a number of idealized cases, some of which are reviewed below.

Response to Static Increased Water Level - Figure IV-12 presents the beach recession due to a static increase in water. The beach responds as expected. In the early stages, the rate of adjustment is fairly rapid with the latter adjustments approaching the equilibrium recession in an asymptotic manner. Of special relevance is that the response time to equilibrium is long compared to the duration of most severe storm systems, such as hurricanes. The form of the response presented in Figure IV-12 is reminiscent of that for a first order process in which the time rate of change of beach recession, R , is represented as

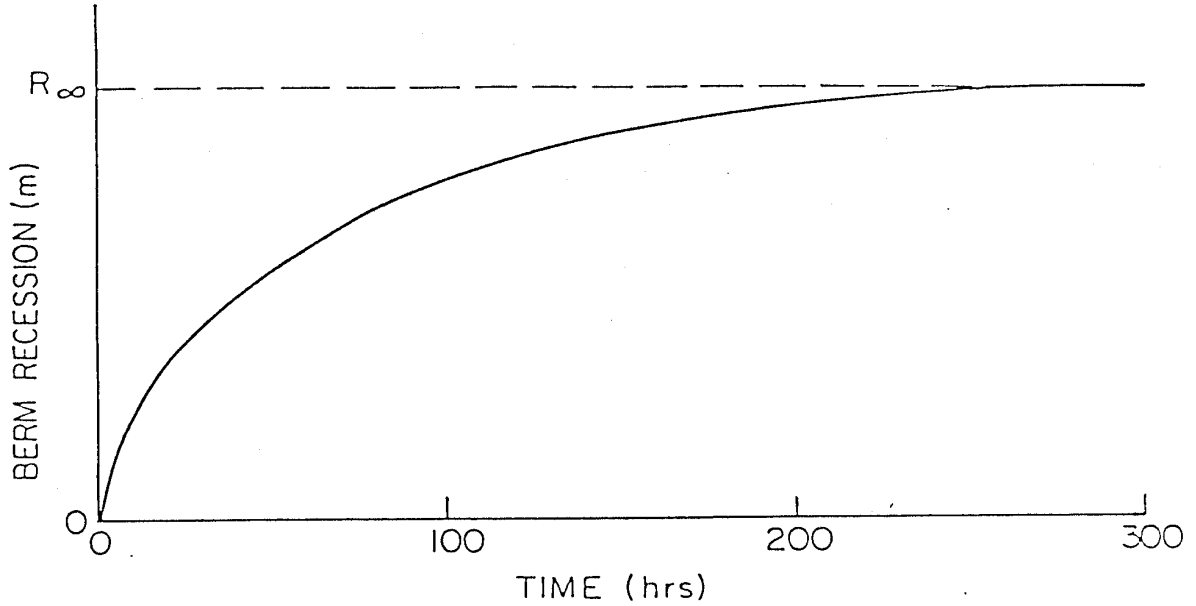


Figure IV-12 Characteristic Form of Berm Recession Versus Time for Increased Static Water Level (from Kriebel (14), 1982)

$$\frac{dR}{dt} = -KR \quad (59)$$

for which the solution is

$$\frac{R(t)}{R_{\infty}} = (1 - e^{-Kt}) \quad (60)$$

Figure IV-13 presents a comparison of the response from the numerical model and Equation. (60). This similarity forms the basis for a very simple and approximate numerical model of beach and dune profile response. Such a model has been developed, is used currently in the CCCL program and will be described in the next section.

Effects of Various Wave Heights - Considering a common increased water level, but storms with different wave heights, the larger wave heights will break farther offshore causing profile adjustments over a greater distance and thus a greater shoreline recession. Simulations were carried out to examine evolution of the beach under different wave heights with the results presented in Figure IV-14. As expected, the greater shoreline recessions are associated with the larger wave heights. Surprisingly, however during the early phases of the evolution, the larger wave heights do not cause proportionally larger erosions. Thus, for storms of short duration, the sensitivity of the maximum erosion to breaking wave height may not be large.

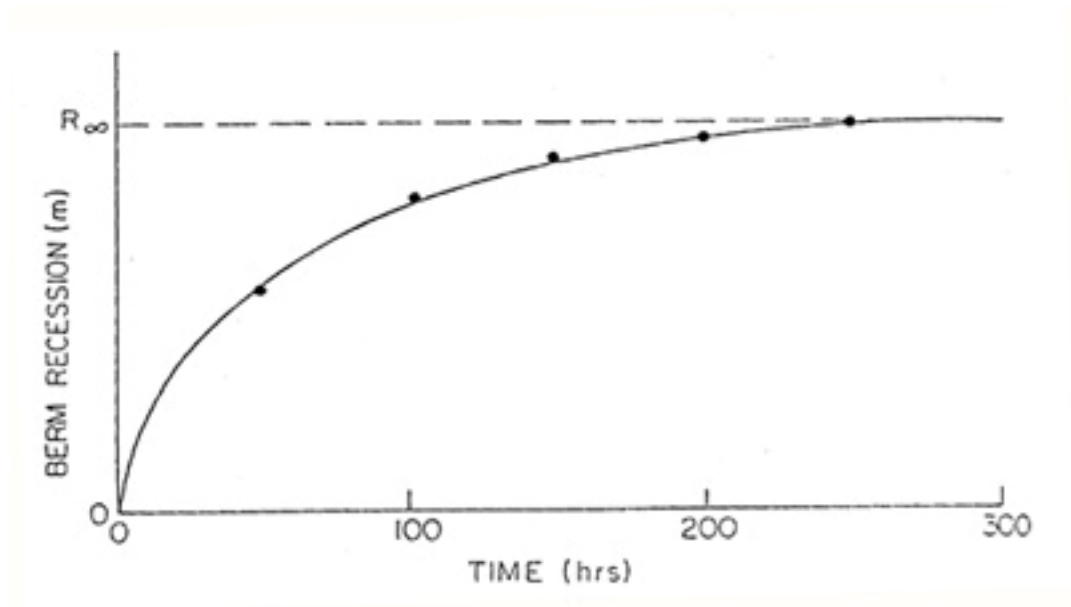


Figure IV-13 Comparison of Asymptotic Berm Recession from Model (—) and as Calculated by Equation (60) (••)

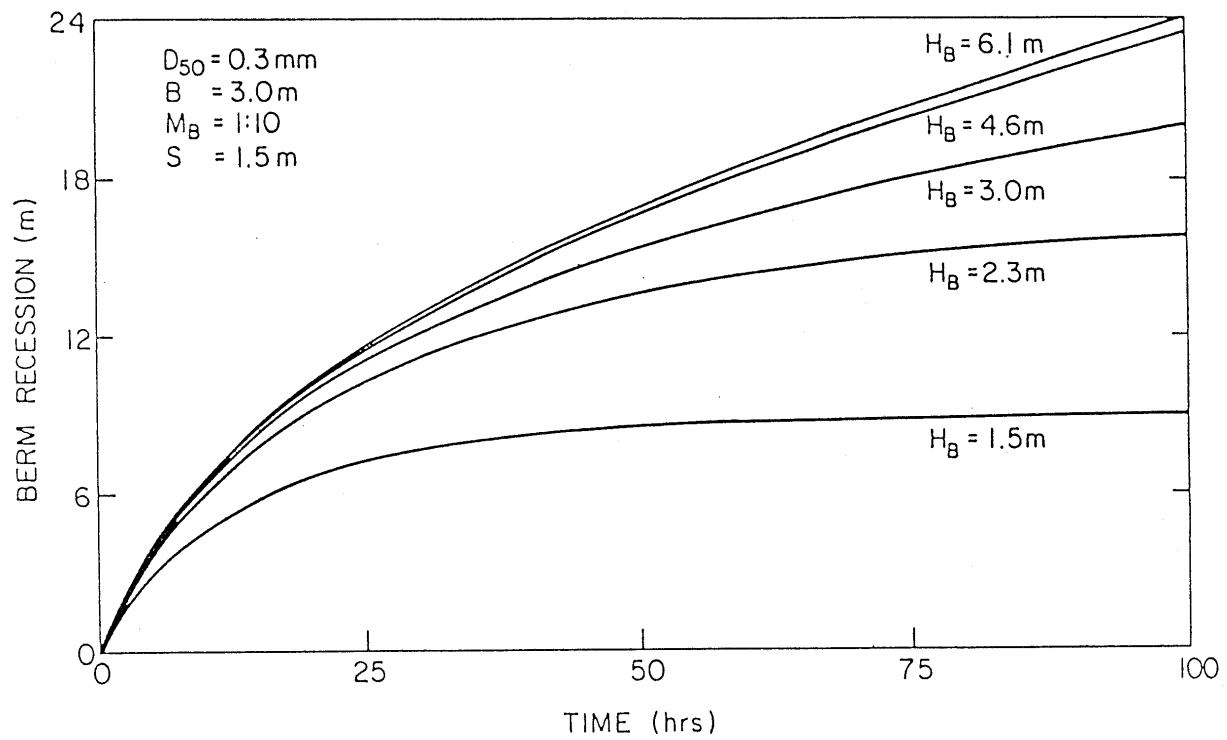


Figure IV-14 Effect of Breaking Wave Height on Berm Recession (from Kriebel, 1982)

Effects of Various Storm Tide Levels - The counterpart to the previous case is that of a fixed wave height and various storm water levels. The results of these simulations are presented in Figure IV-15. In contrast to the previous case, the various storm tide levels cause recession rates in the early stages of the process which are nearly proportional to the storm water level.

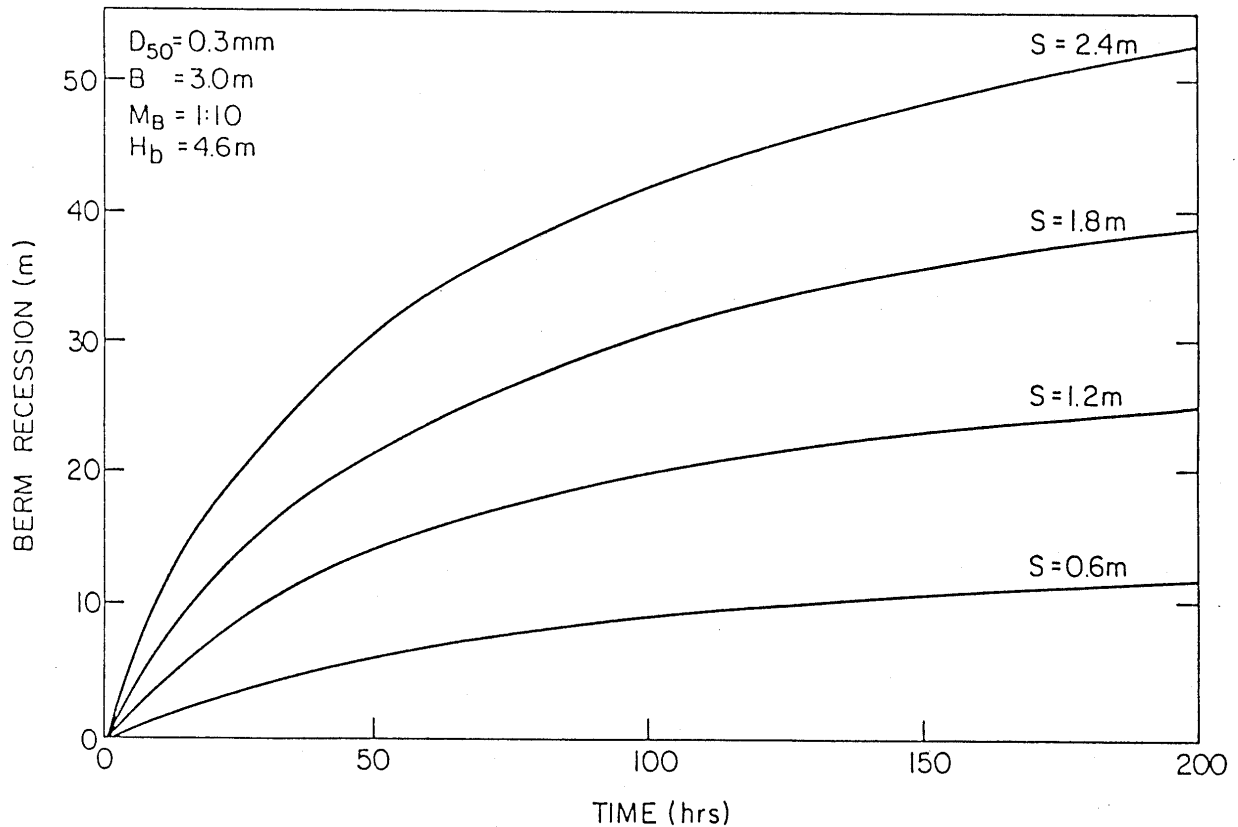


Figure IV-15 Effect of Static Storm Surge Level on Berm Recession (from Kriebel, 1982)

Effect of Sediment Size on Berm Recession - The effect of two different sediment sizes on amount and rate of berm recession is shown in Figure IV-16. The equilibrium recession of a coarser material is much less; however, the equilibrium is achieved in a much shorter time than that for the finer sediment. The explanation for the lesser equilibrium erosion for the coarser material is that since the beach is steeper, the waves break closer to shore and thus less material is required to be transferred offshore to establish an equilibrium profile out to the breaking depth (considered to be the limit of motion). Presumably the explanation for the slower approach to equilibrium for the finer material is that, as will be shown by consideration of the initial and equilibrium profile geometries, a much greater volume of sediment must be moved a greater distance to establish equilibrium.

Effect of Storm Duration - The effect of storm duration on shoreline recession was investigated by considering a fixed wave height and an idealized storm tide variation, expressed as

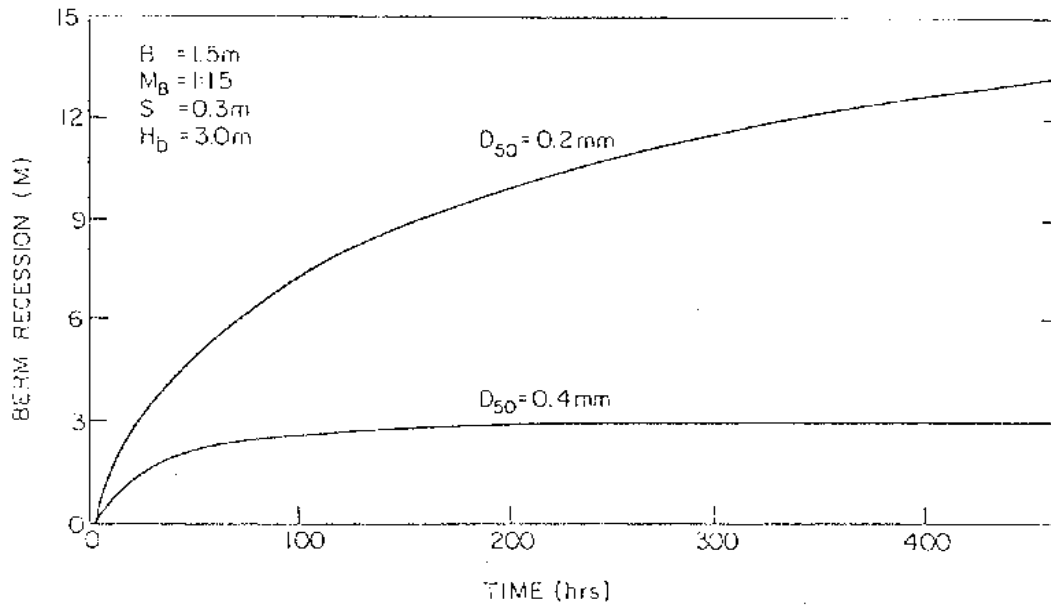


Figure IV-16 Effect of Sediment Size on Berm Recession (from Kriebel, 1982)

$$\eta = 1.2 \cos^2 \left(\frac{\sigma(t-18)}{2} \right), \quad |t-18| < \frac{T}{2} \quad (61)$$

$$= 0, \quad |t-18| > \frac{T}{2}$$

in which $T (= 2\pi/\sigma)$ is the total storm duration in hours. The results are presented for three storm durations in Figure IV-17. For the shortest storm duration ($T = 12$ hours), the potential volume eroded is approximately $70 \text{ m}^3/\text{m}$ whereas the computed actual maximum volume eroded is $10 \text{ m}^3/\text{m}$. With increasing storm tide duration, the computed actual maximum volume eroded increases. Tripling the storm tide duration to 36 hours doubles the maximum volume eroded to $20 \text{ m}^3/\text{m}$. It is noted that this is only approximately 28% of the potential volume eroded, again underscoring the likelihood that most storms will only reach a fraction of their potential erosion limit. This feature also highlights the significance of cumulative effects of sequential storms and of the need to better understand the recovery process (especially the rates), a portion of the cycle not addressed in this project.

Application of Method to Long-Term Beach and Dune Response Simulations

The previous section has described the application of the model to idealized examples of beach and dune response. The model can also be applied to more realistic situations in which the initial beach and dune conditions are specified along with time-varying waves and tides.

Evaluation of Method by Hurricane Eloise Erosion Data - Kriebel carried out an evaluation of the method by comparing erosion computations for Hurricane Eloise (1975) with measurements reported by Chiu (16). Although the wave and tide conditions were not measured along the beaches of Bay and Walton Counties (Florida) of interest, some tide data were available and wave heights were estimated. Erosion was computed for twenty combinations of dune slope, wave height and peak surge. It was found that the volumetric erosion ranged from 21 to $38 \text{ m}^3/\text{m}$ compared to average measured values of 18 to $20 \text{ m}^3/\text{m}$ for Bay and Walton ranged

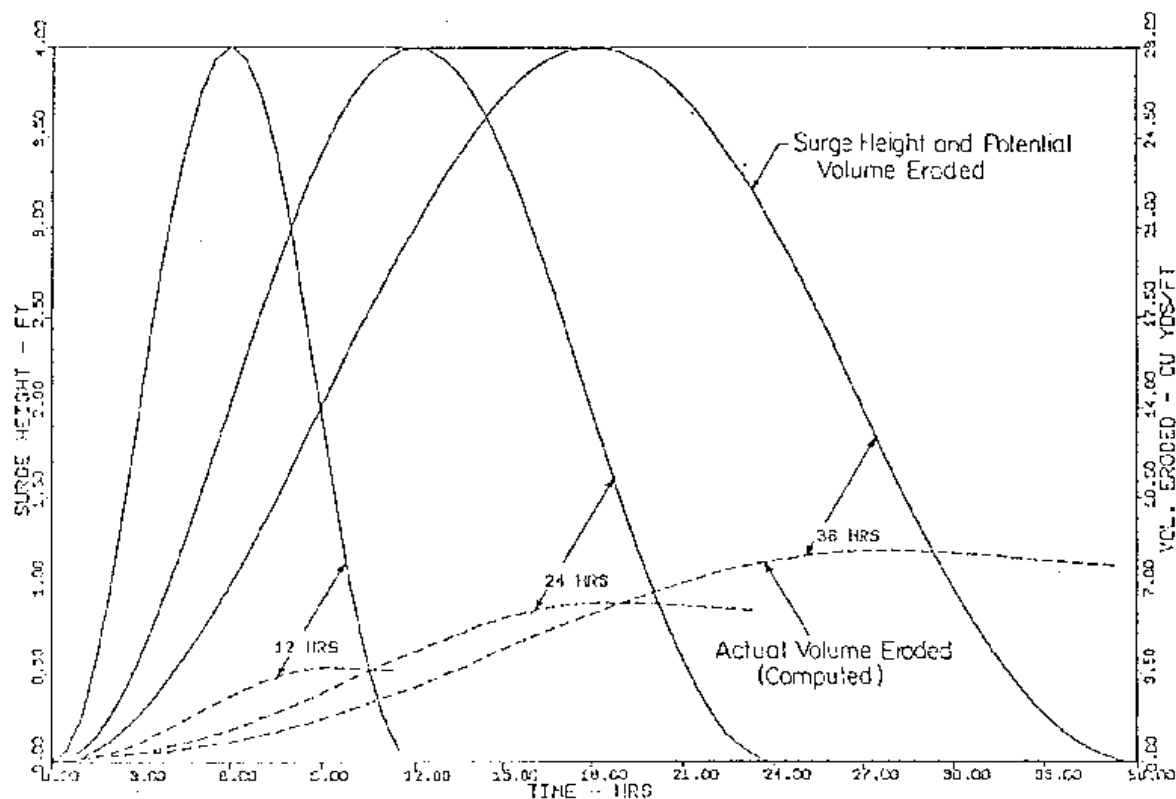


Figure IV-17 Comparison of the Effects of 12, 24, and 36 hrs. Storm Surge on Volumetric Erosion (from Kriebel, 1982)

from 21 to Counties, respectively and an average of $25 \text{ m}^3/\text{m}$ near the area of peak surge. Although the predicted values are somewhat larger than the observed, Chiu (16) states that the beaches had started to recover at the time of the post-storm surveys, with approximately $5 \text{ m}^3/\text{m}$ of sand having returned to the beach. Thus the maximum eroded volume would be $30 \text{ m}^3/\text{m}$ compared to a maximum calculated value of $38 \text{ m}^3/\text{m}$, a difference of approximately 27%. This reasonably close agreement was considered adequate recognizing the uncertainty in the storm tide employed in the computations; therefore no further calibration of the model was considered warranted. It is of interest that the erosion potential associated with the peak tide is approximately nine times that predicted for the time-varying conditions included in the computations. This again reinforces the fact that most storms in nature cause only a fraction of the potential erosion associated with the maximum conditions in the storm.

Long-Term Simulation - With the model reasonably verified for the Bay and Walton Counties area of Florida, a long-term simulation of beach and dune erosion was carried out. The hurricane wind and pressure fields were idealized in accordance with a representation published by Wilson (17). The five idealized hurricane parameters

- Δp = Maximum Pressured Deficit
- R_{max} = Radius to Maximum Winds
- V_F = Hurricane System Translational Speed
- β = Hurricane Translational Direction
- Y_F = Landfall Point

were selected by a Monte Carlo method in accordance with the historical characteristics of hurricanes in the general area. For each hurricane, the storm tide was calculated using the Bathystrophic Storm Tide Model of Freeman, Baer and Jung (9). With the time-varying storm tide and wave height calculated, the beach and dune

model was applied until maximum erosion was achieved. As the recovery mechanism is not yet understood to a degree for realistic modeling and because hurricanes occur approximately on a biennial basis, the erosion for successive hurricanes was assumed to commence from a fully recovered condition. This is clearly an approximation as the recovery process occurs at several orders of magnitude slower than the erosion process. Study of some recovery stages from severe storms has shown that up to seven years may be required to achieve approximately 90% recovery. The duration required for recovery from milder storms would, of course, be less.

Figure IV-18 presents a "flow chart" describing the elements of the long-term simulation. In the Bay-Walton Counties area, hurricanes making landfall within ± 150 n.mi. of these counties were considered requiring a total of 393 hurricanes to simulate a 500 year record. return periods associated with various dune recessions as determined from the simulations are presented in Figure IV-19. As examples, the dune recessions for return periods of 10, 100 and 500 years are 4 m, 12 m and 18 m, respectively. Based on these results, Hurricane Eloise is judged to represent a 20 to 50 year erosional event; however based on results from a storm surge analysis, Hurricane Eloise was a 75 to 100 year coastal flooding event.

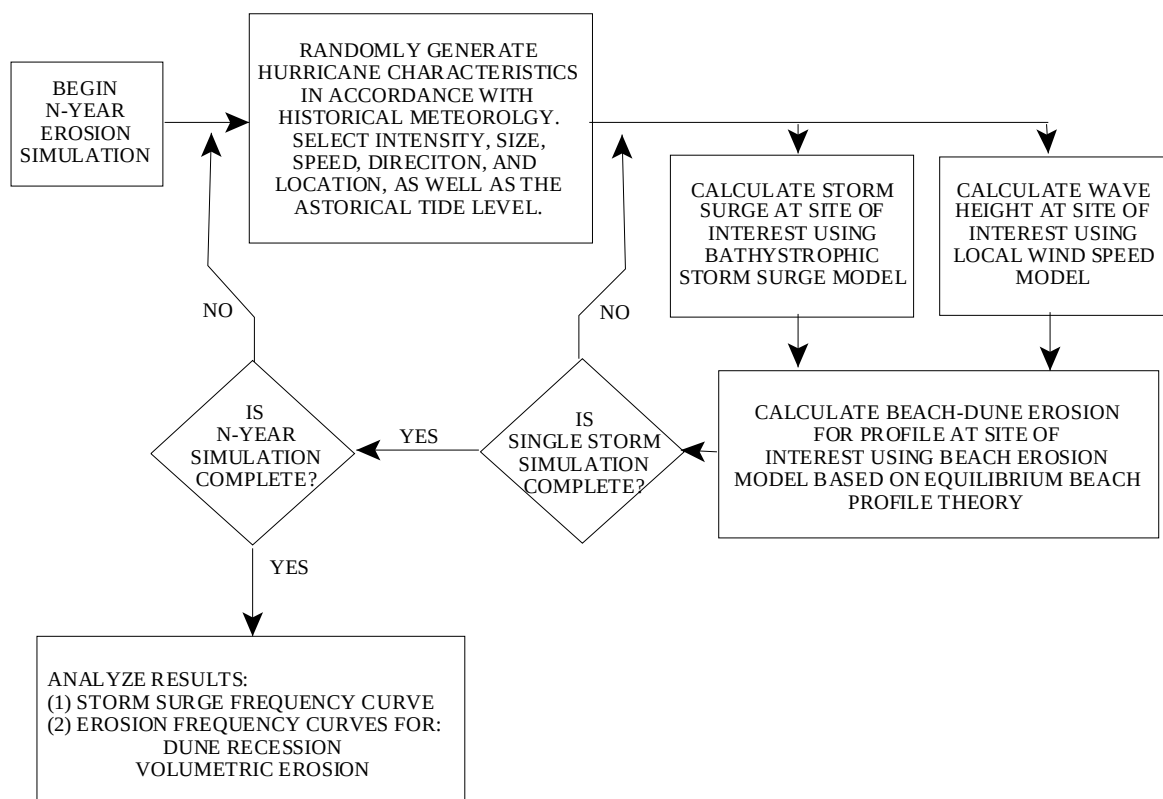


Figure IV-18 Flow Diagram of N-year Simulation of Hurricane Storm Surge and Resulting Beach Erosion (from Kriebel, 1982)

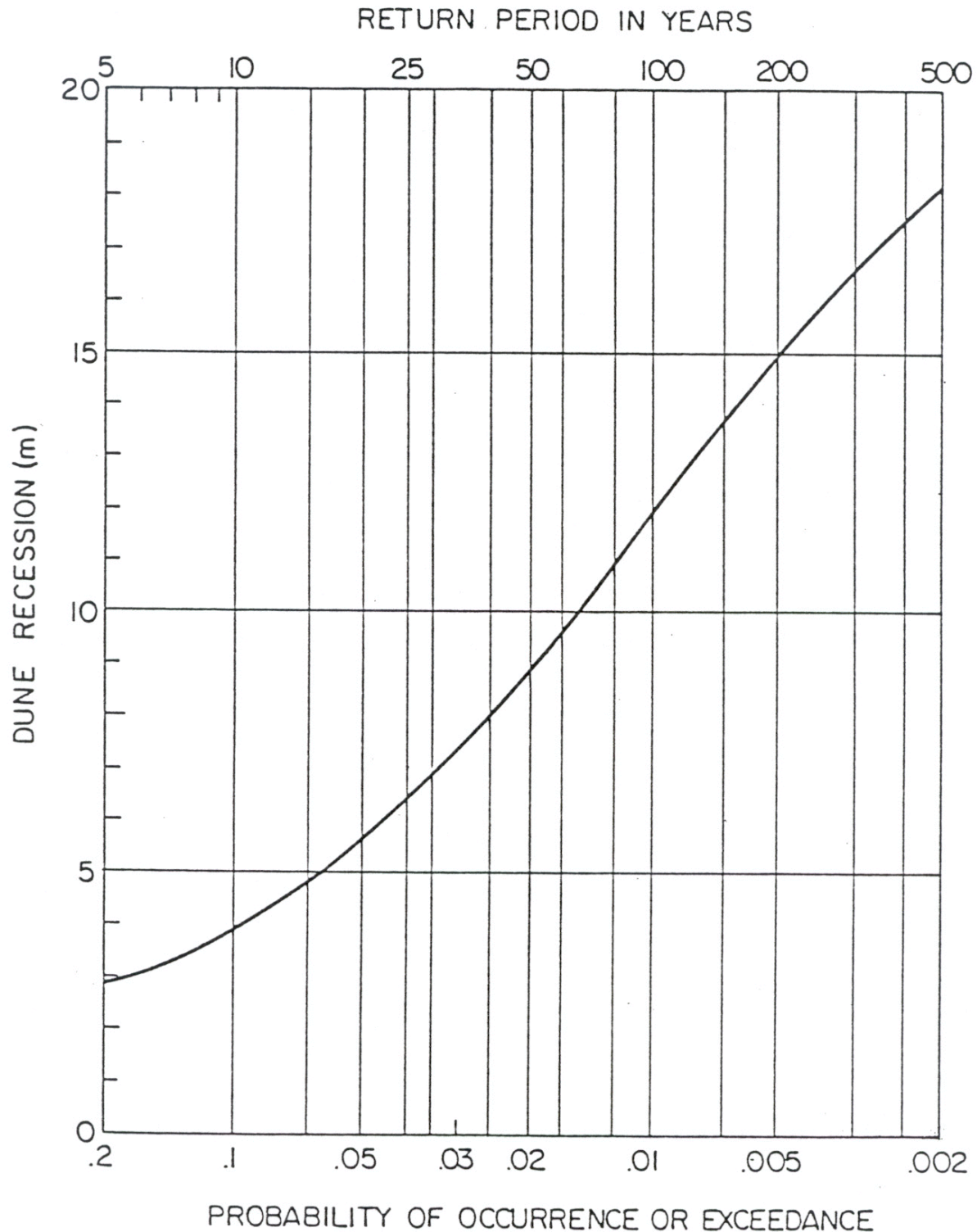


Figure IV-19 Average Frequency Curve for Dune Recession, Developed by Monte Carlo Simulation, Bay-Walton Counties, Florida (from Kriebel, 1982)

It is also possible to present the results of the erosion simulations in a manner that is of maximum relevance to individuals or agencies responsible for shoreline management. This type of presentation is demonstrated for the Bay-Walton County area in Figure IV-20. This plot includes the contributions from storms and sea level rise. As examples, without any erosion mitigation measures within the next 50 years, the erosion

due to sea level rise (regarded as a certainty or probability of 100%) is expected to be approximately 15 ft. Within 50 years, the probability of dune erosion occurring to a distance of 40 ft is 85% and for distances of 60 and 80 ft, the corresponding probabilities are 32% and 9%, respectively. Through the use of figures such as these it would be possible to weigh the costs of certain erosion control measures against the potential of damage if those measures are not carried out.

These procedures provided, for the first time, a basis for conducting the necessary technical studies to implement the erosion component calculations of the Flood Insurance Act of 1973 which provides for the application of methodology to provide the basis for insurance rates for flooding and erosion coastal hazards. Although the flooding component of this act has been implemented, the erosion component has not.

4.5 Prediction of Beach and Dune Erosion Due to Severe Storms by Simple Model

For computational ease and economy, a much simpler erosion model was developed and is applied in the CCCL process. This model is not physically-based, yet retains the overall characteristic response described previously in the Kriebel model.

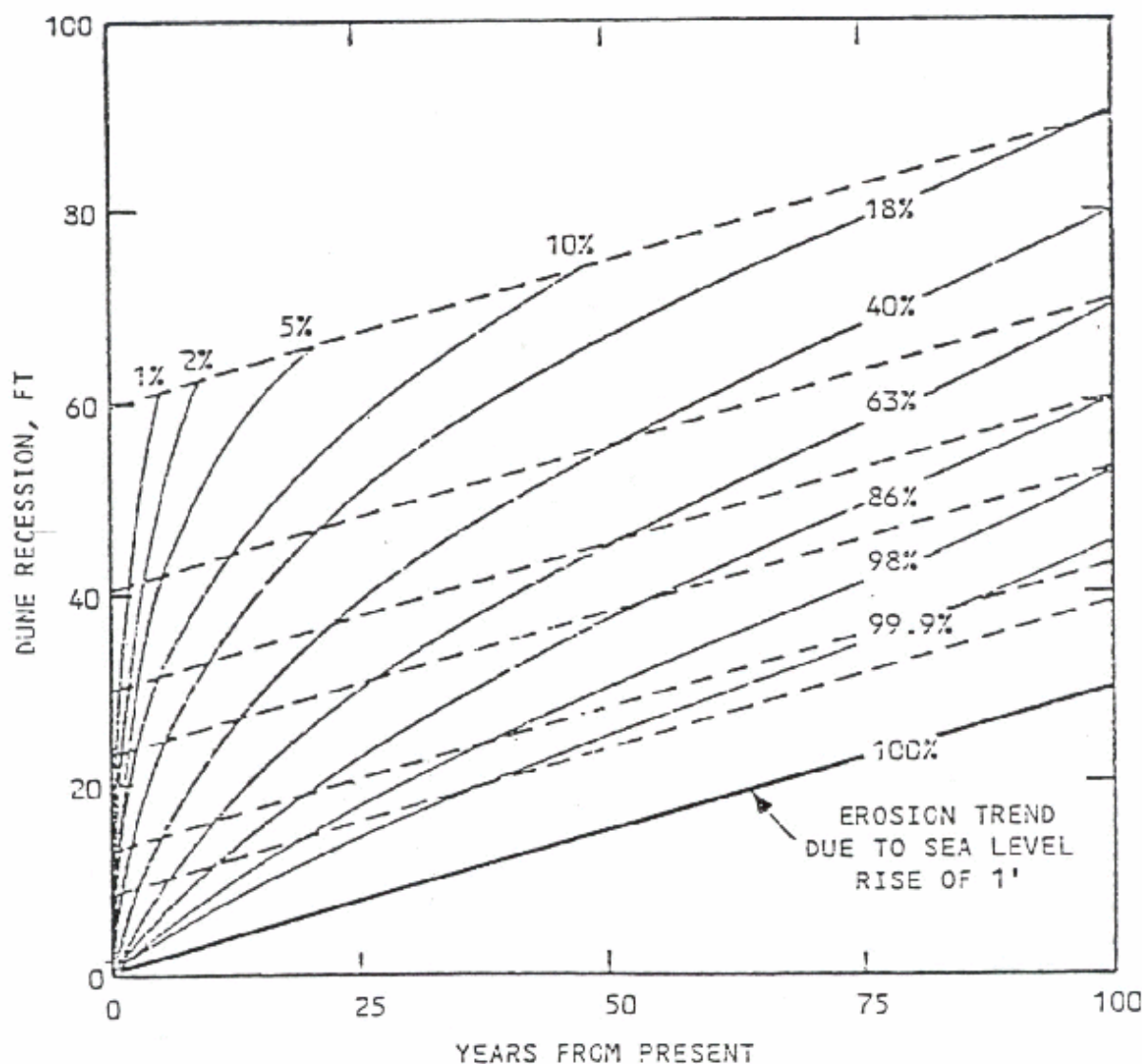


Figure IV-20 Probability or Risk of Dune Recession of Given Magnitude Occurring at Least Once in N-years, Bay-Walton Counties, Florida (from Kriebel, 1982)

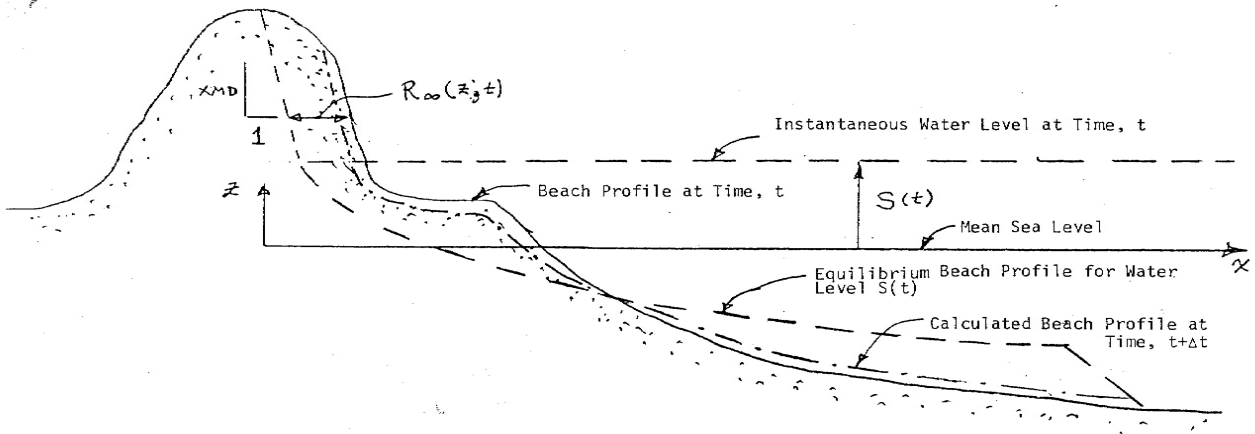


Figure IV-21 Features of Simplified Beach Erosion Model

The model is based on the characteristic response exhibited in Figure IV-13 and Equation. (60) rewritten for reference purposes as

$$\frac{R(t)}{R_{\infty}} = (1 - e^{-Kt}) \quad (62)$$

At each time step, for the instantaneous value of the time-varying water level $S(t)$ and the selected breaking wave height, H_b , the equilibrium profile and the associated equilibrium recession, R_{∞} , from the existing profile is established, see Figure IV-21. The characteristics of the equilibrium profile are:

- (1) the eroded volume above the "hinge point" equals the deposited volume below the hinge point,
- (2) The equilibrium profile is in accordance with Equation (49) with the scale parameter either specified by the user, or determined as a best-least squares fit to the measured profile during the field program, and
- (3) the equilibrium profile above the instantaneous water level is characterized by a uniform slope, XMD , on the order of 2 or 3 as determined by post-storm profile measurements following Hurricane Eloise 1975) and other storms.

With the equilibrium profile established, the erosion occurring from time t to time $t+\Delta t$, Δx is given by

$$\Delta x = x(t + \Delta t) - x(t) - R_{\infty}(1 - e^{-K\Delta t}) \quad (63)$$

where, through calibration with Kriebel's model, a K value of 0.075 sec^{-1} has been found.

Figures IV-22 and IV-23 present examples of application of the erosion model to two ranges in Martin County.

4.6 Augmentation of the Erosion Predicted by the Model for Recommending Position of CCCL

As noted previously, the erosion model accounts only for cross shore sediment transport and has been verified against the average erosion occurring in Hurricane Eloise, see Figure IV-24. As documented by Chiu, there are a number of factors which result in considerable variability about the mean value. Probably the greatest causes of this variability are the gradients in longshore sediment transport as a result of the relatively small scale of the hurricane system, and natural variability due to inhomogeneities in the system (sand size, consolidation, offshore bay system, etc.). Regardless, the variability of erosion is recognized and as documented by Chiu (16) in Hurricane Eloise, the maximum erosion was approximately 2.5 times the average erosion factor is incorporated in the erosion considerations employed in the recommended CCCL position by

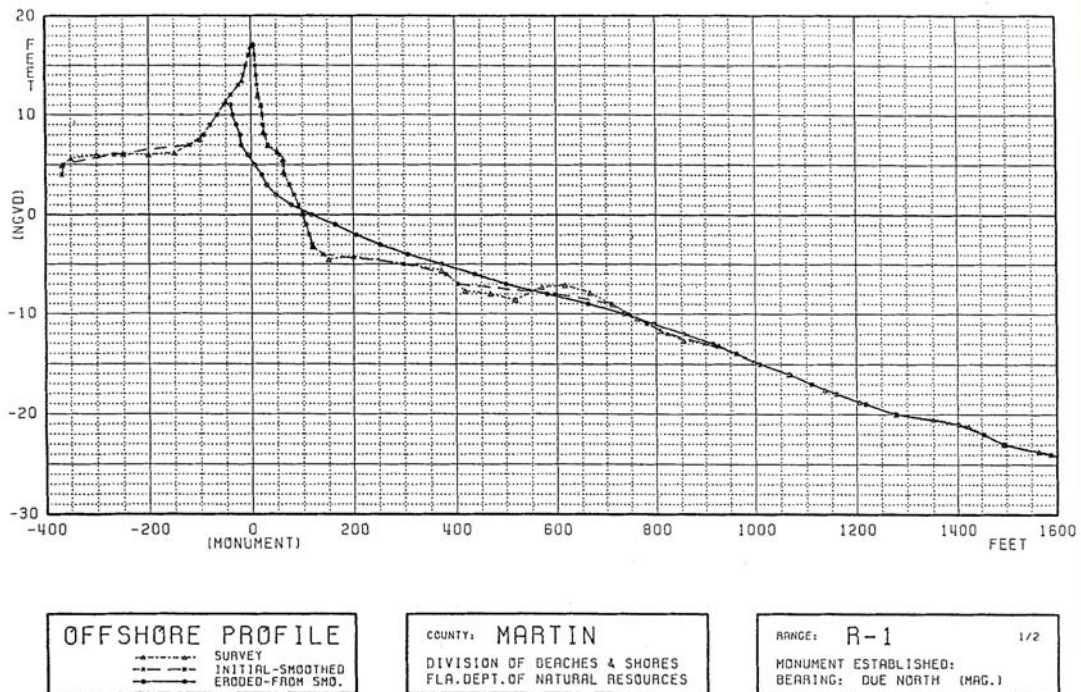


Figure IV-22 Results of Applying Erosion Model to Range R-1, Martin County (Hutchinson Island), 100 Year Storm Tide, Average Erosion

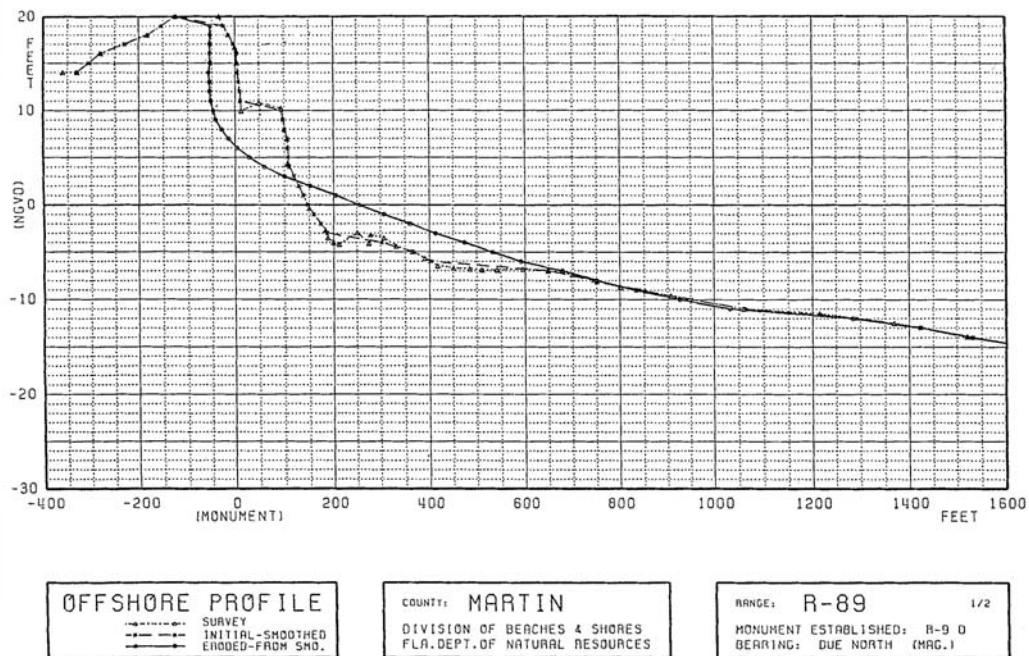


Figure IV-23 Results of Applying Erosion Model to Range R-89, Martin County (Jupiter Island), 100 Year Storm Tide, Average Erosion

modifying Equation (63) as follows

$$\Delta x = -(2.5) R_{\infty} (1 - e^{-k\Delta t}) \quad (64)$$

which, due to the long beach response time compared to the time scale of storms, results in a profile which is in approximate accord with the 2.5 factor.

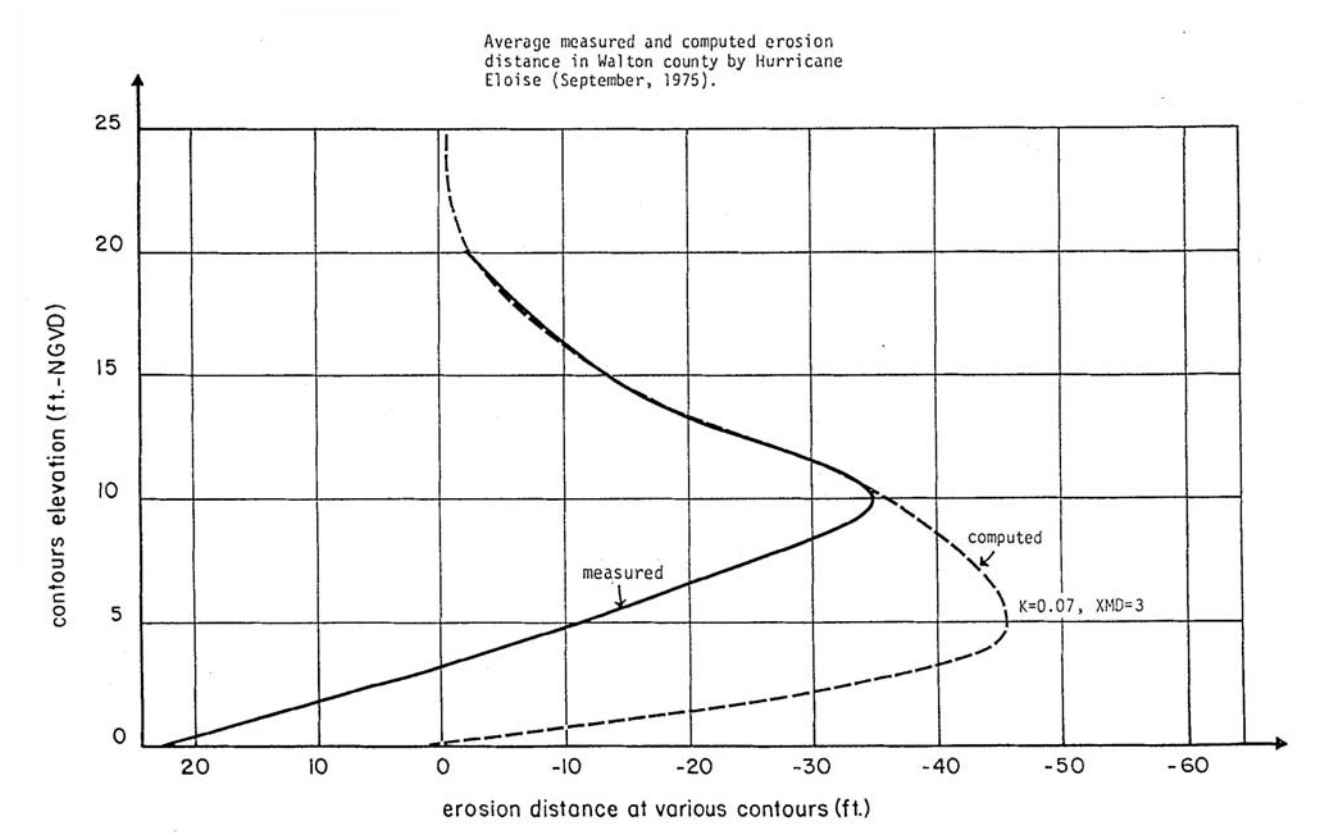


Figure IV-24 Calibration of Simplified Erosion Model by Comparison with Erosion Occurring at Various Elevations Due to Hurricane Eloise

V. WAVE HEIGHT DECAY CALCULATIONS

5.1 Introduction

If calculated erosion is not governing, the final recommended Coastal Construction Control Line position is based on the location where the significant wave height has attenuated to three feet. This three feet criterion is consistent with the Federal Emergency Management Administration (FEMA) criterion for delimiting the so-called "High Velocity Zone" and is considered to be the wave height (significant) at which structural damage is considered to be substantial. This is presumably in recognition of the rather large piling forces and uplift forces that waves of this magnitude can induce. (The wave force is proportional to H^n where $2 < n < 3$.) A potential storm related factor not presently included in the methodology that could cause significant damage is storm-tide induced current across barrier islands (the potential velocity due to a 2 ft tide difference across a submerged barrier island is on the order of 10 ft/sec.).

The following section describes the methodology for calculating wave height decay.

5.2 Methodology

As waves propagate, energy can be added to or removed from the wave system. The most common mechanism for energy addition is by wind blowing over the water surface. Principal mechanisms for energy loss (or dissipation or reflection) include wave breaking due to shoaling water, turbulent losses due to damping by vegetation and wave reflection by buildings. In the present application, energy input by winds is neglected due to the short distances considered, for example the wave height decay usually occurs over a maximum distance of 600-800 ft. The National Academy of Sciences (NAS) (18) has developed recommended methodology for calculating wave decay due to the various mechanisms noted above. The method employed in the CCCL establishment is basically that recommended by the NAS report. Each of the decay mechanisms is described briefly below; the interested reader is referred to the 1977 NAS report for greater detail.

Wave Height Decay Due to Shoaling Water

The maximum wave height, H , which can be supported in a water depth, h , is

$$H = 0.78 h \quad (65)$$

a result developed by McCowan for shallow water waves.

Wave Height Decay Due to Vegetation

Consider waves propagating through a stand of vertical cylindrical elements of diameter, D , (representing for example tree trunks) at a uniform spacing, S . For a water depth, h , an initial wave height, H_I , and a propagation distance, Δx , the wave height, H_T , after propagation through the stand of elements is

$$H_T = \frac{H_I}{1 + AH_I \Delta x} \quad (66)$$

in which

$$A = \frac{C_D D}{3\pi S^2 h} \quad (67)$$

where C_D is the hydrodynamic drag coefficient (taken as 1.0 in this study) associated with flow about the elements. Equation (67) would be modified, for vegetative elements extending only partially over the depth.

Wave Height Decay Due to Buildings

Buildings serve to reduce the transmitted wave energy by blocking the waves and causing energy reflection. For an incident wave encountering buildings with a proportionate blockage density, B (perpendicular to the direction of wave propagation), the incident and transmitted wave heights are related by

$$H_T = \sqrt{(1 - B)} H_I \quad (68)$$

If n rows of buildings, each with the same blockage density, are present, the corresponding result is

$$H_T = (1 - B)^{n/2} H_I$$

Combined Effects of Topography, Vegetation and Buildings

For an incident wave height, H_I , and both vegetation and buildings effects present, the transmitted wave height is

$$H_T = \frac{1}{1 + AH_I \Delta x} (1 - B)^{n/2} H_I$$

If the transmitted wave height as calculated by Equation (69) is greater than the depth-limited value given by Equation (65), the wave height is set equal to the depth-limited value.

VI. LONG-TERM EROSIONAL CONSIDERATIONS

6.1 Introduction

Prior sections have described methodology for calculating the erosion associated with a single severe storm event. In addition to erosion due to relatively short-term events, the recommended location of the CCCL includes consideration of any long-term erosion trends.

6.2 Methodology

The methodology employed presently consists of accessing those studies which have focused on and identified long-term erosional trends. These studies usually incorporate comparison of early surveys (in chart form) and perhaps comparison of early and more recent aerial photography. Additionally, as counties are resurveyed as part of this study, these data are examined to determine long-term trends.

Studies of value may be directed toward a particular county or may be broad in scope, such as the National Shoreline Study (19) of the U.S. Army Corps of Engineers. Some of the early studies by the University of Florida, Coastal Engineering Laboratory quantified longterm erosion around the State (20), Figure VI-1.

With the long-term erosion rate established, the recommended location of the CCCL includes accounting for a 5 year duration of this erosion. That is, if the long-term erosion rate is 5 ft/year and the methodology described heretofore indicates that the CCCL should be located x feet from shore, then the recommended position is specified at $x + 25$ ft. from shore.

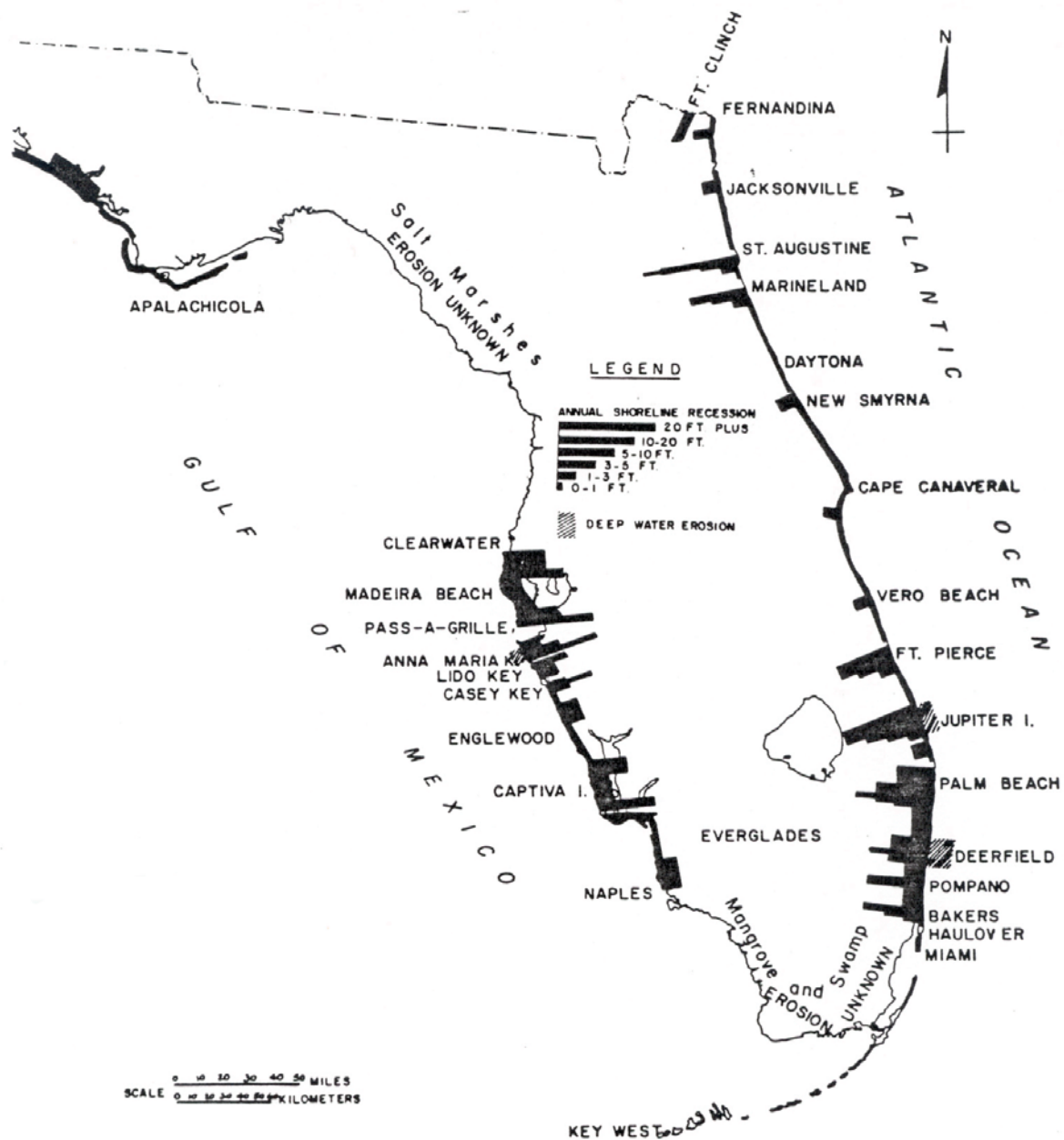


Figure VI-1 General Erosion Conditions in Florida (Bruun, Purpura and Morgan, 1962)

VII. OVERALL VERIFICATIONS OF CCCL METHODOLOGY

As might be expected, due to the relative rarity of storms of the 100 year severity level and of the difficulty in conducting meaningful measurement/observations before and after such a storm, there is only limited direct data available to evaluate the CCCL methodology. Two examples which provide varying degrees of evaluation/confirmation are presented below.

7.1 Hurricane Agnes, St. George Island, Franklin County

This example is of interest, in part, because the extent of storm impact was discovered after the recommended position of the CCCL had been established.

Slightly to the west of the center of St. George Island (Range 105-106), the recommended position of the CCCL was some 500 ft landward of the mean sea level contour. The position of the line was challenged by a developer who, by counsel, requested a delay from the Governor and Cabinet to develop proof that the recommended line was too far landward; the delay was granted. After the delay was granted, DNR located aerial photographs flown on June 21, 1972, the day after the passage of Hurricane Agnes, which documented the almost completed destruction of the only road along this portion of St. George Island and landward of Monuments 104 and 105. The roadway is located some 100 ft landward of the recommended position of the CCCL, see Figures VII-1(a) and (b) and photographs on display as a part of the workshop in 1984. It is noted that the storm tide accompanying Hurricane Agnes in Franklin County is believed to be on the order of a 40 year event with the erosion event on the same order.

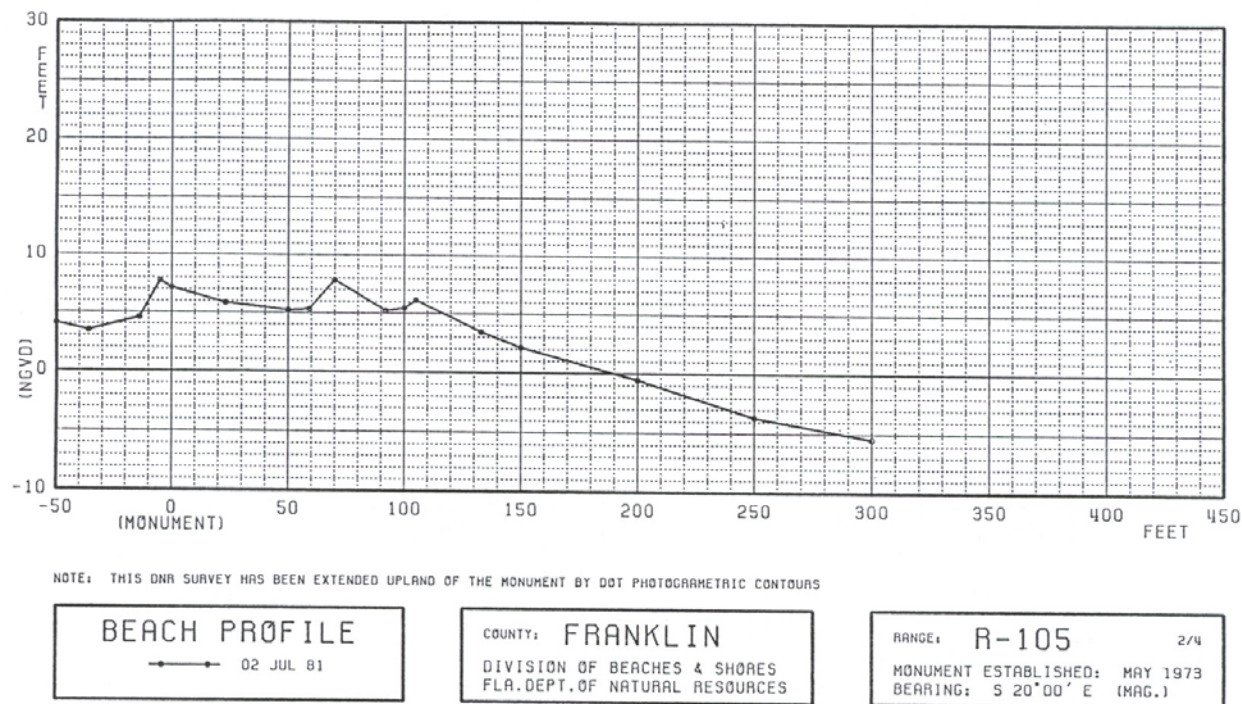


Figure VII-1(a) Beach Profile at Range R-105 on St. George Island. A Location of Severe Overwash and Damaged Roadway Due to Hurricane Agnes, 1972 (see Figure VII-1(b) for Extension of this Profile)

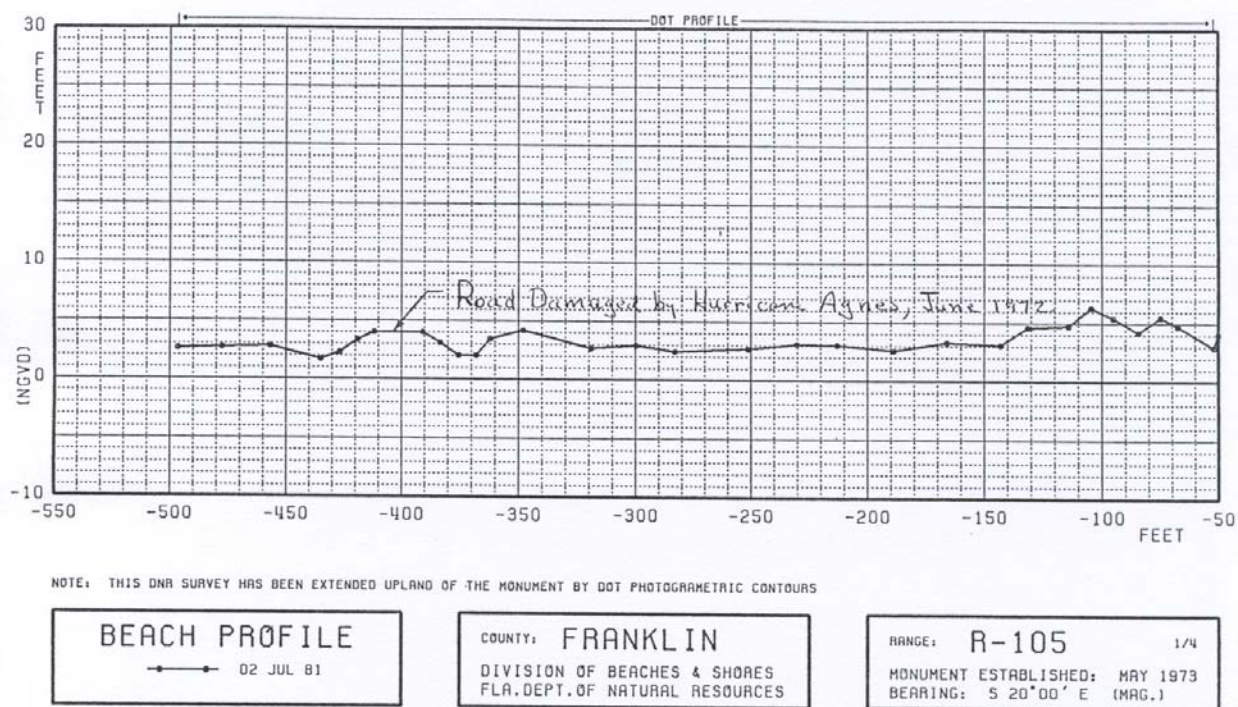


Figure VII-1(b) Continuation of Profile Across St. George Island, Range R-105, Showing Location of Damaged Road Due to Hurricane Agnes, 1972

It is stressed again that the evidence of storm impact cited in this example was located after the CCCL position had been recommended, we interpret the line location in this area to be somewhat too far Gulfward in the vicinity of Monuments 104 and 105.

7.2 Hurricane Eloise Damage in Walton and Bay Counties

The set-back line was established in Walton and Bay Counties in April, 1975, and August, 1974, respectively. Hurricane Eloise made landfall in Walton County on September 23, 1975, as shown in Figure VII-2. The hurricane storm tide is ranked as a 75-100 year occurrence and, due to the relatively high translational speed of the hurricane, the erosion is ranked only as a 20-50 year event.

Two types of information will be presented by way of comparison of the measured zone of impact versus location of the (then) set-back line. Figures VII-3 and VII-4 compare the eroded zone with the location of the set-back lines in Bay and Walton Counties, respectively. The location of the pre-hurricane vegetation line is also shown. It is clear that the limits of erosion correlate reasonably well with the location of the set-back line.

The second type of information available from Hurricane Eloise relates to the per structure damage costs relative to the location of that structure with respect to the set-back line. Of course the quality of construction is very important in terms of the damage that an individual structure will experience.

Based on a survey of 540 structures (20), Figure VII-5 presents the per structure damage costs as a function of the structure position relative to the set-back line. Of general relevance is the quite steeply rising damage costs as a function of proximity to the shoreline. Of specific interest is that average damage costs for a structure situated on the set-back line were approximately \$8,000, whereas the average damage costs for a structure located 150 ft seaward of the set-back line was in excess of \$200,000.

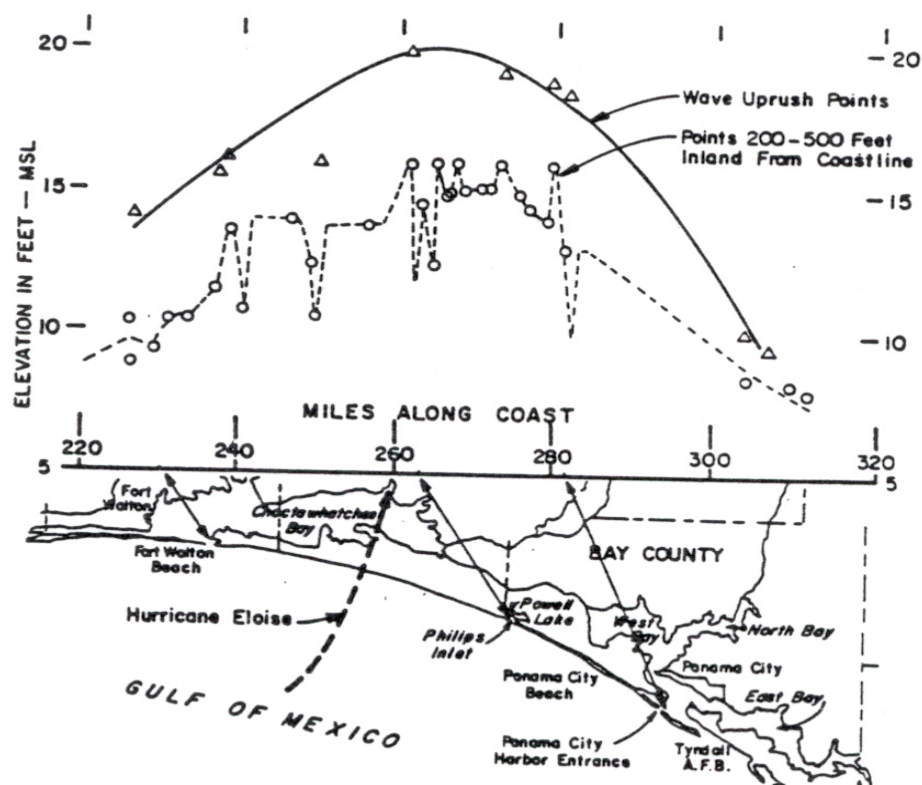


Figure VII-2 Landfall Location of Hurricane Eloise, September 23, 1975 and Some Resulting Tide and Uprush Characteristics (from Chiu, 1976)

BAY COUNTY

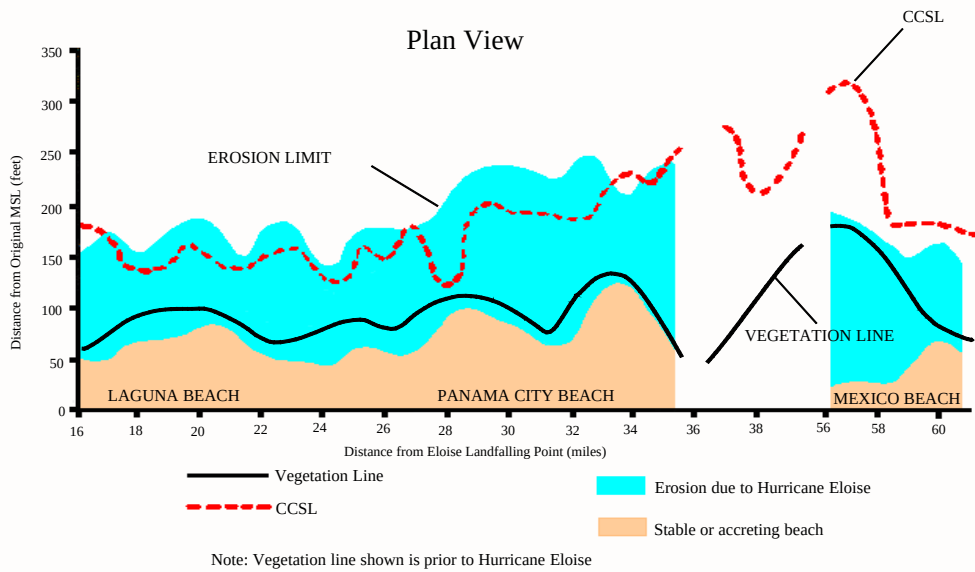


Figure VII.3 Relation of Erosional Characteristics and pre-Eloise Vegetation Line to Set-Back Line, Bay County, Florida (from Chiu (16))

WALTON COUNTY

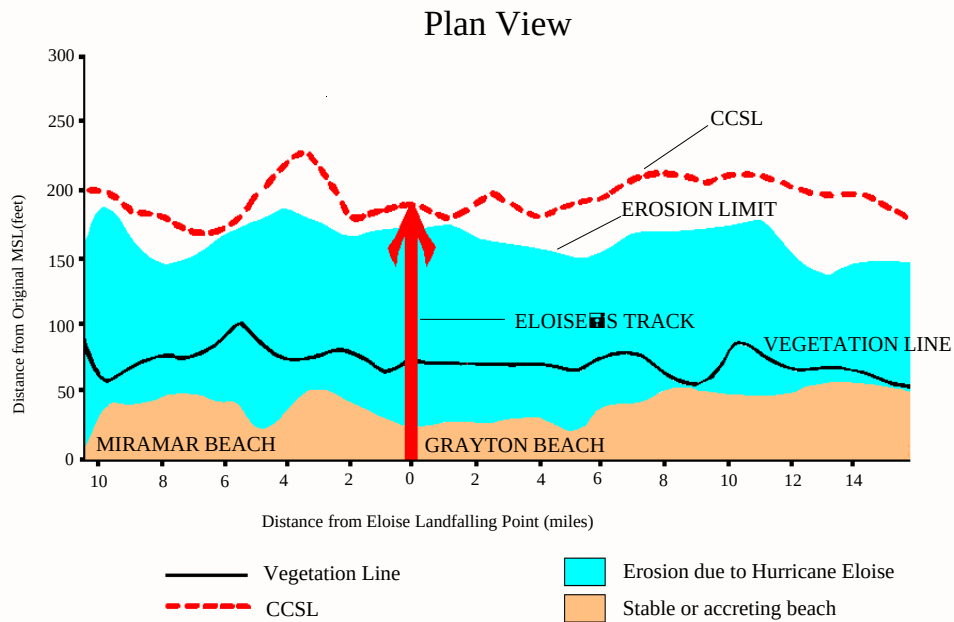


Figure VII.4 Relation of Erosional Characteristics and pr-Eloise Vegetation Line to Set-Back Line, Walton County, Florida (from Chiu (16))

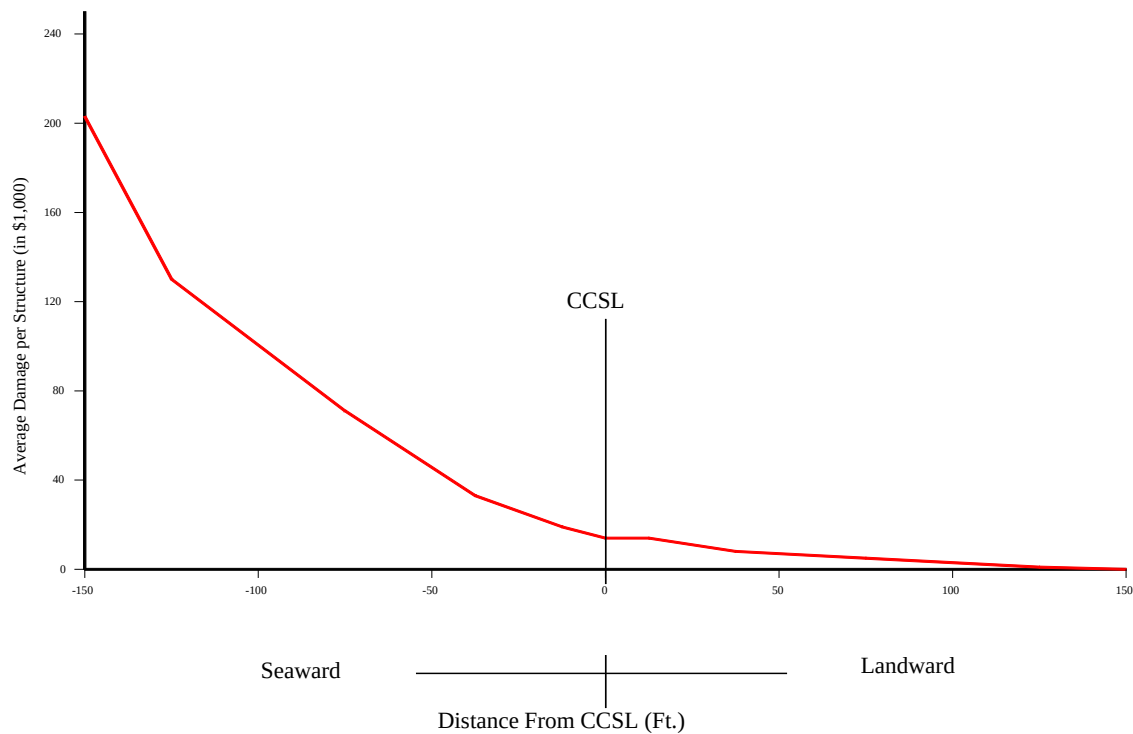


Figure VII-5 Damage to Structures in Relation to Location of Set-back Control Line (based on study of 540 Structures in Bay County After Hurricane Eloise, by Shows, 1978)

7.3 Hurricane Opal Damage along the Florida Panhandle

As a more recent example for the positive effect of the CCCL, the structural damage by Hurricane Opal in October 1995 is shown in Table VII-1 (22) below.

TABLE VII-1
STRUCTURAL DAMAGE OF
MAJOR HABITABLE STRUCTURES (MHS)
SEAWARD OF CCCL ALONG PANHANDLE

<u>County</u>	<u>Number of MHS</u>		<u>Number MHS Damaged</u>	
	<u>Existing</u>	<u>Permitted</u>	<u>Non-Permitted</u>	<u>Permitted</u>
Escambia/Santa Rosa	316	50	157	0
Okaloosa	134	24	53	0
Walton	443	196	71	1
Bay	600	45	341	1
Gulf	316	80	22	0
Franklin	377	181	7	0
Total	2186	576	651	2

Severe damage occurred across the entire Panhandle from Escambia County through Franklin County. The above table indicates that the existing and non-permitted structures suffered a damage rate of 40%, and that the permitted structures under CCCL program with improved construction design and siting suffered only a 0.35% damage rate.

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APPENDIX A
2-D STORM TIDE MODEL*

*This program represents a numerical modeling procedure that is subject to change due to: 1. newly encountered topo-bathymetric and hydraulic boundary conditions, and 2. incorporation of new advancements quantifying coastal processes. This program is applied on a county-by-county basis and is subject to acceptable calibration constraints recommend by the Beaches and Shores Resource Center and approved by Florida Department of Environmental Protection.

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C *****
C
C PROGRAM : 2-D STORM TIDE
C
C -----Note-----
C
C
C DEFINITION OF PARAMETERS:
C
C CASE      20 CHARACTER TITLE TO IDENTIFY A SPECIFIC OUTPUT
C DX        HORIZONTAL GRID DISTANCE, IN NAUTICAL MILES
C DY        VERTICAL GRID DISTANCE, IN NAUTICAL MILES
C DT        TIME INCREMENT FOR EACH TIME STEP, IN HOURS
C PINF      REFERENCE PRESSURE (ATMOSPHERIC) USED TO
C           CALCULATE
C           BAROMETRIC TIDES
C BF        BOTTOM FRICTION COEFFICIENT (0.02 - 0.002)
C RMAX      RADIUS FROM CENTER OF HURRICANE TO THE POSITION
C           OF MAX. WINDS
C YS        INITIAL Y-COORD. OF THE HURRICANE CENTER, IN
C           NAUTICAL MILES
C DP        HURRICANE CENTRAL PRESSURE INDEX, IN INCHES OF
C           MERCURY
C VF        FORWARD VELOCITY OF THE HURRICANE SYSTEM IN
C           KNOTS
C NIT       0
C WSC       WIND SHEAR STRESS COEFFICIENT
C INTERV    TIME STEP INTERVALS AT WHICH TO PRINT OUT
C           AN OUTPUT FOR THE GRID SYSTEM
C THETA     LANDFALL HURRICANE TRACK W.R.T. NORTH AND
C           CLOCKWISE IN DEGREES
C XHB       INITIAL DIST OF THE HURRICANE, IN NAUTICAL MILES
C           (MAY BE OUTSIDE THE GRID SYSTEM, W.R.T. ORIGIN)
C XHE       FINAL DIST OF THE HURRICANE, IN NAUTICAL MILES
C           (MAY BE OUTSIDE THE GRID SYSTEM, W.R.T. ORIGIN)
C TIDE      ASTRONOMICAL TIDAL ADJUSTMENT IN FEET, POSITIVE
C           ABOVE MSL
C XCB       THE X-COORD DIST OF THE LEFT-EDGE OF THE GRID
C           SYSTEM, IN NAUTICAL MILES
C XCF       THE X-COORD DIST OF THE RIGHT-EDGE OF THE GRID
C           SYSTEM, IN NAUTICAL MILES
C YCB       THE Y-COORD DIST OF THE TOP-EDGE OF THE GRID
C           SYSTEM, IN NAUTICAL MILES
C YCF       THE Y-COORD DIST OF THE BOTTOM-EDGE OF THE GRID
C           SYSTEM, IN NAUTICAL MILES
C TMAX      THE MAX DURATION OF THE PROTOTYPE HURRICANE
C           MODEL SYSTEM, IN HOURS
C TMIN      THE TIME AFTER WHICH OUTPUTS ARE GENERATED
C NDELT     0
C B6        CORIOLIS PARAMETER (0 OR 0.0000727)
C NOCVT     SET TO 1, THEN DT, DX, DY IS READ IN SECONDS &

```

```

C          FEET NO CONVERSION TAKES PLACE
C
C
C *****

COMMON /A/ UUX(ISIZE,JSIZE),UUY(ISIZE,JSIZE),P(ISIZE,JSIZE),
-      H(ISIZE,JSIZE),DPDX(ISIZE,JSIZE),DPDY(ISIZE,JSIZE),DX
COMMON /B/ ETA(ISIZE,JSIZE),QX(ISIZE,JSIZE),QY(ISIZE,JSIZE),
-      TIDE,NQBX(JSIZE),DY,NNX,IEND
COMMON /C/ IS,J
COMMON /E/ PINF,DT,NNY
COMMON /F/ JJ
COMMON /H/ IFFACT(ISIZE,JSIZE), IFF1(ISIZE,JSIZE)
COMMON /BAR/ NORBAR(120),IBAR(120),JBAR(120),XLBAR(120),HBAR(120),
-      WBAR(120),FBAR(120),XKEX(120),NORINL(130),IINL(130),JINL(130),
-      WINL(130),DPINL(130),XKENEX(130),FINL(130),XLINL(130)
COMMON /XANDY/ X(ISIZE),Y(JSIZE)

DIMENSION YNM(JSIZE),XNM(ISIZE),
-      ETMX(ISIZE,JSIZE),DXA(ISIZE),DYA(JSIZE),
-      D(ISIZE,JSIZE),NET(ISIZE,JSIZE),
-      CVAR(600,3,39),CTIME(600),IPLOT(78),
-      ETAMAX(39,3),QS(ISIZE,JSIZE),ETAS(ISIZE,JSIZE),
-      QC(250),ETAC(250),AC(250),BC(250),CC(250),DC(250),
-      ACS(250),BCS(250),CCS(250),DCS(250),
-      ETAS0(250),ETAS1(250),ETAS2(250),
-      VTIME(80),VDP(80),VVF(80),VRMAX(80),VTHETA(80),
-      THETAL(50),IJV(ISIZE,JSIZE,2),BF2(ISIZE,JSIZE),
-      FACTX2(ISIZE), WX2(ISIZE)

CHARACTER*20 SYSTEM,DUMMY,CASE

OPEN (4,FILE='n1947.cal')
OPEN (5,FILE='pin2d.sys')
OPEN (7,FILE='n1947.pun')
OPEN (8,FILE='n1947.prt')

12000 FORMAT(/)

C *****
C THE FOLLOWING CODE ADDED FOR PAGING PURPOSES ON THE SUPER COMPUTER *
C *****

DO 1, J=1,JSIZE
  DO 1, I=1,ISIZE
    DPDX(I,J) = 0.0
1 CONTINUE

DO 2, J=1,JSIZE
  DO 2, I=1,ISIZE
    DPDY(I,J) = 0.0
2 CONTINUE

```

```

DO 3, K=1,39
DO 3, J=1,3
DO 3, I=1,600
CVAR(I,J,K) = 0.0
3 CONTINUE

DO 4, K=1,2
DO 4, J=1,JSIZE
DO 4, I=1,ISIZE
IJV(I,J,K) = 0
4 CONTINUE
C ***** END PAGE INIT *****

10 IC2=0
G=32.17
RHOW=1.99
C NFIN=-1
B4=2.33E-08
IICOUN=0

C***** INPUT GRID SYSTEM DATA (DIMENSIONS, *****
C***** CONSTANTS,BATHYMETRY,FRICTION FACTORS) *****

READ(5,20) SYSTEM
WRITE(8,25) SYSTEM
20 FORMAT(A20)
25 FORMAT(1H1,/,1H ,A20)
READ(5,30)XCB,XCF,YCB,YCF,DT,PINF,TIDE,ZLAT,INTERV,THETAC,
- ANGVD,THETAT
30 FORMAT(8F8.2,I3,/,3F8.2)

C *** CALCULATE CORIOLIS PARAMETER ***

ZLAT=ZLAT/57.2956
OMEGA=2.0*3.1416/(24.*3600.)
B6=2.0*OMEGA*SIN(ZLAT)

READ(5,40) NNX,NNY
40 FORMAT(2I4)
READ(5,50) (DXA(I),I=1,NNX)
READ(5,50) (DYA(J),J=1,NNY)
50 FORMAT(8F8.0)
WRITE(8,60)XCB,YCB,PINF,TIDE,DT,XCF,YCF,ZLAT,INTERV,THETAC,
- ANGVD,THETAT,B6
60 FORMAT(1H0,'GRID SYSTEM PARAMETERS',/,1H , ' XCB= ',F9.2,
- ' YCB= ',F9.2,' PINF= ',F8.2,' TIDE= ',F8.2,' DT= ',F10.2,
- ',1H , ' XCF= ',F9.2,' YCF= ',F9.2,' ZLAT= ',F8.2,
- ' INTERV= ',I6,' THETAC= ',F6.2,/,1H ,
- ' NGVD= ',F8.2,' THETAT= ',F6.2,' B6= ',E11.4)
WRITE(8,70)NNX,NNY
70 FORMAT(1H0,' NNX= ',I9,' NNY= ',I9)

```

```

C  WRITE(8,80) (DXA(I),I=1,NNX)
C  WRITE(8,80) (DYA(J),J=1,NNY)
C 80 FORMAT(1H0,10F10.0)

      READ(5,90) NBAR,NINL
C  WRITE(8,95) NBAR,NINL
90 FORMAT(2I3)
C 95 FORMAT(1H0,2I3)
      IF (NBAR.EQ.0) GO TO 130

      DO 110 N=1,NBAR
      READ(5,100) NORBAR(N),IBAR(N),JBAR(N),XLBAR(N),HBAR(N),
-        WBAR(N),FBAR(N),XKEX(N)
C  **** ADJUST HEIGHT OF BARRIER TO MEAN SEA LEVEL ****
      HBAR(N)=HBAR(N)+ANGVD
C  WRITE(8,105) NORBAR(N),IBAR(N),JBAR(N),XLBAR(N),HBAR(N),
C  -        WBAR(N),FBAR(N),XKEX(N)
C ** NOTE : IJV(I,J,NORBAR) IS EQUAL TO N IF A BARRIER EXISTS FOR
C **      GRID (I,J).
      IJV(IBAR(N),JBAR(N),NORBAR(N)) = N
110 CONTINUE

100 FORMAT(I1,1X,2I3,5F10.3)
C 105 FORMAT(1H0,3I3,5F10.3)
      WRITE(8,*)'*****'
      IF (NINL.EQ.0) GO TO 130
      DO 120 N=1,NINL
      READ(5,100) NORINL(N),IINL(N),JINL(N),XLINL(N),DPINL(N),
-        WINL(N),FINL(N),XKENEX(N)
      DPINL(N)=DPINL(N)+ANGVD
C  **** ADJUST DEPTH OF INLET TO MEAN SEA LEVEL ****
C  WRITE(8,115) NORINL(N),IINL(N),JINL(N),XLINL(N),DPINL(N),
C  -        WINL(N),FINL(N),XKENEX(N)
C 115 FORMAT(1H0,3I3,5F10.3)
120 CONTINUE
130 CONTINUE

C  **** READ IN BATHYMETRY. ELEVATIONS=-H, DEPTHS(WATER)=+H. ****
      DO 170 J=1,NNY
      READ(5,185)DUMMY
C  WRITE(8,185)DUMMY
      READ(5,145)(H(I,J),I=1,NNX)
C  WRITE(8,150) (H(I,J),I=1,NNX)
145 FORMAT(10F7.2)
C 150 FORMAT(1H,10F7.2)
C 152 FORMAT(/)
      H(1,J)=-99.
C  ***** ADJUST BATHYMETRY TO MEAN SEA LEVEL *****
      DO 160 I=2,NNX
160 H(I,J)=H(I,J)+ANGVD
170 CONTINUE

```

```

185 FORMAT(A20)
190 FORMAT(10I5)

```

```

DO 210 J=1,NNY
  READ(5,185)DUMMY
  READ(5,190)(IFFACT(I,J),I=1,NNX)
  DO 209 I=1,NNX
    IF (IFFACT(I,J).LT.10) THEN
      IFF1(I,J) = 1
    ELSE IF (IFFACT(I,J).LT.100) THEN
      IFF1(I,J) = 2
    ELSE IF (IFFACT(I,J).LT.1000) THEN
      IFF1(I,J) = 3
    ELSE IF (IFFACT(I,J).LT.10000) THEN
      IFF1(I,J) = 4
    ENDIF
  209 CONTINUE
210 CONTINUE

```

C***** INITIALIZE/CONVERT GRID SYSTEM DATA *****

```

CNM=6076.1
CHS=3600.0
XCB=XCB*CNM
XCF=XCF*CNM
YCF=YCF*CNM
YCB=YCB*CNM
PINF=70.51*PINF
NNXM1=NNX-1
NNXP1=NNX+1
NNYM1=NNY-1
C  NNYP1=NNY+1
IEND=NNX

```

```

X(1)=XCB
Y(1)=YCB
XNM(1)=XCB/CNM
YNM(1)=YCB/CNM

```

```

DO 220 I=2,NNXP1
  X(I)=X(I-1)+(DXA(I)+DXA(I-1))/2.0
220 XNM(I)=X(I)/CNM

```

```

DO 230 J=2,NNY
  Y(J)=Y(J-1)+(DYA(J)+DYA(J-1))/2.0
230 YNM(J)=Y(J)/CNM

```

```

  WRITE(8,240) (J,J=1,10)
240 FORMAT(1H1,/,1H , ' X AND Y DISTANCES (N.MI.)',/,1H0,/1H ,10I10)
  WRITE(8,250) (XNM(J),J=1,NNX)
  WRITE(8,12000)
  WRITE(8,250) (YNM(J),J=1,NNY)

```



```

370 FORMAT(5F7.2)
   WRITE(8,380) I,VTIME(I),VDP(I),VVF(I),VRMAX(I),VTHETA(I)
380 FORMAT(1H ,13X,I2,5X,F5.2,5X,F5.2,5X,F4.1,6X,F4.1,6X,F5.1)
   VTIME(I)=VTIME(I)*CHS
   VDP(I)=VDP(I)*70.51
   VVF(I)=VVF(I)*1.69
   VRMAX(I)=VRMAX(I)*CNM
   VTHETA(I)=(VTHETA(I)+THETAT-THETAC)/57.2956
390 CONTINUE
   RMAX=VRMAX(1)
   DP=VDP(1)
   VF=VVF(1)
   THETA=VTHETA(1)
   THETAT=THETAT/57.2956
   XHB=XHB*CNM
   YHB=YHB*CNM
   TMAX=TMAX*CHS
   TMIN=TMIN*CHS
   IC2=0
   IICOUN=0
C----- CHANGED -----
   DO 3900 J=1,48,2
   JJ=J+1
   READ(4,391) (IPLOT(K),K=J,JJ),THETAL(J)
   WRITE(8,391) (IPLOT(K),K=J,JJ),THETAL(J)
391 FORMAT(I3,1X,I3,F7.2)
   THETAL(J)=THETAL(J)/57.2956
   IF (IPLOT(J).EQ.0) GO TO 3905
3900 CONTINUE
3905 CONTINUE
C-----
   NPLOT=0
   DO 392 JPLOT=1,48,2
   IF(IPLOT(JPLOT).EQ.0.OR.IPLOT(JPLOT+1).EQ.0) GO TO 394
   IJ=(JPLOT+1)/2
   NPLOT=NPLOT+1
   DO 392 JJJ=1,3
   ETAMAX(IJ,JJJ)=0.0
392 CONTINUE
394 CONTINUE
   NPLOT2=NPLOT*2
   WRITE(8,396) (IPLOT(J),J=1,NPLOT2)
396 FORMAT(1H0,'GRIDS FOR PLOTTING: ',/(1H0,
-    10(' ',I3,',',I3,''))))

C*****

   NTIMES=IFIX((TMAX-TMIN)/DT + 0.5) + 1
   WRITE(8,398)NTIMES
398 FORMAT(1H0,'NTIMES (MAIN LOOP VALUE) = ',I4)

CC   STARTING SECTION TO DETERMINE ACTIVE ETA ELEMENTS

```

CC NET(I,J)=0 IF DRY AND =1 IF FLOODED.

```
DO 420 J=1,NNY
DO 420 I=1,NNX
IF(ETA(I,J)+H(I,J)) 400,400,410
400 NET(I,J)=0
ETA(I,J)=-H(I,J)-0.0001
GO TO 420
410 NET(I,J)=1
420 CONTINUE
```

C ESTABLISH REFERENCE HURRICANE VALUES FOR WAVE SETUP
C CALCULATIONS

```
IPARM=2
C WRITE(8,430)
C 430 FORMAT(1H0,' I THR ETA NET QX QY D(53,60)',/)
C
C ***** MAIN LOOP *****
```

```
DO 10500 JJ=1,NTIMES
XJ=JJ-1
T=XJ*DT+TMIN
THR=T/3600.
TS=T
IF (NPARM.EQ.0.OR.IPARM.GT.NPARM) GO TO 2020
IF (T.LE.VTIME(IPARM)) GO TO 2010
IF (IPARM.EQ.1) GO TO 2000
XHB=XHB+(VTIME(IPARM)-VTIME(IPARM-1))*VVF(IPARM-1)
- *COS(VTHETA(IPARM-1))
YHB=YHB+(VTIME(IPARM)-VTIME(IPARM-1))*VVF(IPARM-1)
- *SIN(VTHETA(IPARM-1))
2000 IPARM=IPARM+1
2010 IF (IPARM.GT.NPARM) GO TO 2020
DPCT=(T-VTIME(IPARM-1))/(VTIME(IPARM)-VTIME(IPARM-1))
DP=VDP(IPARM-1)+DPCT*(VDP(IPARM)-VDP(IPARM-1))
RMAX=VRMAX(IPARM-1)+DPCT*(VRMAX(IPARM)-VRMAX(IPARM-1))
VF=VVF(IPARM-1)
THETA=VTHETA(IPARM-1)
TS=T-VTIME(IPARM-1)
2020 CONTINUE
```

C *****
C MOVED 4/12/88

```
IS=0
CALL HURCH0(USQ,IS,J,VF,PINF,DP,RMAX,THETA,RHOW)
USQM=USQ
UMAX=SQRT(USQ)/1.69
C WRITE(8,*) 'DP=', DP
AA=-RMAX*DP*B4
AA2=0.160*VF/SQRT(UMAX)
```

```

      HMAX=16.5*EXP(AA)*(1.0+AA2)
C   TMAX1=8.6*EXP(AA/2.0)*(1.0+AA2/2.0)
C *****
      XH=XHB+TS*VF*COS(THETA)
      YH=YHB+TS*VF*SIN(THETA)
      XHN=XH/CNM
      YHN=YH/CNM
      IF (T.GT.TMAX) GO TO 11000

      DO 2025 J=1,NNY
        DO 2025 I=1,NNX
2025   QS(I,J)=QX(I,J)
        DO 2026 J=1,NNY
          DO 2026 I=1,NNX
2026   ETAS(I,J)=ETA(I,J)
C -----
C   ESTABLISH ACTIVE (DISCHARGE) JUNCTIONS
C   USE BOUNDARY CONDITION OF NO FLOW ACROSS A BOUNDARY
C   NQBX(J) IS THE POSITION OF THE NO FLOW COASTLINE ON THE J'TH COLUM
C -----

      DO 2100 J=1,NNYM1
      DY=DYA(J)
      DO 2090 I=1,NNXM1
      DX=DXA(I)
      IF (JJ.NE.1.OR.NET(I,J).NE.1) GO TO 2030
      CALL HURCH(USQ,I,J,VF,PINF,DP,RMAX,THETA,RHOW,XH,YH)
      ETA(I,J)=0.015625*(PINF-P(I,J))
2030 IF (NET(I,J)*NET(I+1,J)) 2040,2040,2050
2040 QX(I+1,J)=0.001
      NQBX(J)=I+1
2050 CONTINUE
2060 IF(NET(I,J)*NET(I,J+1)) 2070,2070,2080
2070 QY(I,J+1)=0.001
2080 CONTINUE
2090 CONTINUE
2100 CONTINUE

      CALL ETABCS (XH,YH,T,VF,DP,RMAX,THETA,RHOW)
      DO 2110 J=1,NNY
      DO 2110 I=1,NNX
2110 D(I,J)=ETA(I,J)+H(I,J)

C -----
C   THIS PORTION OF PROGRAM FOR SWEEPS IN THE X-DIRECTION
C -----
      IMPDIR=1

      DO 3090 J=2,NNYM1
      DY=DYA(J)

      DO 3001 I=2,NNX

```

```

      CALL HURCH(USQ,I,J,VF,PINF,DP,RMAX,THETA,RHOW,XH,YH)
3001 CONTINUE

      DO 3002 I=2,NNX
        CALL CALLFR(I,J,BF2(I,J))
3002 CONTINUE

      DO 3003 I=2,NNX
        DX=0.5*(DXA(I-1)+DXA(I))
        FACTX2(I) = 1.0
        WX2(I) = 0.5
        IF (IJV(I,J,IMPDIR).NE.0)
          - CALL BARR(IJV(I,J,IMPDIR),I,J,BF2(I,J),DT,FACTX2(I),
          - FACTY,WX2(I),WY,IICOUN,NINL)
3003 CONTINUE

      DO 3030 I=2,NNX

        DX=0.5*(DXA(I-1)+DXA(I))
        DX2=DXA(I)
        IF (NET(I-1,J)*NET(I,J).NE.0.0.AND.WX2(I).LT.400.0) GO TO 3000
        AC(I)=0.0
        BC(I)=0.0
        CC(I)=0.0
        DC(I)=0.0
        GO TO 3010
3000 DBAR=0.5*(D(I-1,J)+D(I,J))
        IF (ABS(DBAR).LT.0.001) DBAR=0.001
        AC(I)=G*DBAR*DT/DX*FACTX2(I)
        QYBAR=0.25*(QY(I-1,J)+QY(I,J)+QY(I-1,J+1)+QY(I,J+1))
        QQ=SQRT(QX(I,J)**2+QYBAR**2)
        IF (WX2(I).GT.0.5) THEN
          BC(I) = WX2(I)
        ELSE
          BC(I)=1.0+BF2(I,J)*QQ*DT/(8.0*DBAR**2)
        ENDIF

        CC(I)=-AC(I)
        DC(I)=QX(I,J)+(-DBAR*DPDX(I,J)/RHOW+UUX(I,J)/RHOW-B6*QYBAR)*DT
3010 IF (NET(I,J).NE.0) GO TO 3020
        ACS(I)=0.0
        BCS(I)=0.0
        CCS(I)=0.0
        DCS(I)=0.0
        GO TO 3030
3020 ACS(I)=DT/(4.0*DX2)
        BCS(I)=1.0
        CCS(I)=-ACS(I)
        DCS(I)=ETA(I,J)-ACS(I)*(QX(I+1,J)-QX(I,J))-DT/(2.0*DY)*
        - (QY(I,J+1)-QY(I,J))
3030 CONTINUE
        IDIR=1

```

```

      CALL DSWEEP(IDIR,NNX,AC,BC,CC,DC,ACS,BCS,CCS,DCS,ETAC,QC,J,NET)

3050 DO 3060 I=1,NNX
      QX(I,J)=QC(I)
3060 ETA(I,J)=ETAC(I)

3090 CONTINUE

C -----
C   THIS PORTION OF PROGRAM FOR SWEEPS IN THE Y-DIRECTION
C -----
      IMPDIR=2
      DO 4090 I=2,NNXM1
      DX=DXA(I)
      DO 4030 J=2,NNY
      DY=0.5*(DYA(J-1)+DYA(J))
      DY2=DYA(J)
      FACTY=1.0
      CALL HURCH(USQ,I,J,VF,PINF,DP,RMAX,THETA,RHOW,XH,YH)
      CALL CALLFR(I,J,BF)
      WY=0.5
      IF (IJV(I,J,IMPDIR).NE.0)
      -CALL BARR(IJV(I,J,IMPDIR),I,J,BF,DT,FACTX,FACTY,WX,WY,IICOUN,NINL)
C -----
      IF (NET(I,J-1)*NET(I,J).NE.0.0.AND.WY.LT.400.0) GO TO 4000
      AC(J)=0.0
      BC(J)=0.0
      CC(J)=0.0
      DC(J)=0.0
      GO TO 4010
4000 DBAR=0.5*(D(I,J-1)+D(I,J))
      IF (ABS(DBAR).LT.0.001) DBAR=0.001
      AC(J)=G*DBAR*DT/(2.0*DY)*FACTY
      QXBAR=0.25*(QX(I,J-1)+QX(I+1,J-1)+QX(I,J)+QX(I+1,J))
      QQ=SQRT(QXBAR**2+QY(I,J)**2)

      IF (WY.GT.0.5) THEN
        BC(J) = WY
      ELSE
        BC(J)=1.0+BF*QQ*DT/(8.0*DBAR**2)
      ENDIF

      CC(J)=-AC(J)
      DC(J)=QY(I,J)-AC(J)*(ETAS(I,J)-ETAS(I,J-1))+(-DBAR*DPDY(I,J)/RHOW+
      - UUY(I,J)/RHOW+B6*QXBAR)*DT
4010 IF (NET(I,J).NE.0) GO TO 4020
      ACS(J)=0.0
      BCS(J)=0.0
      CCS(J)=0.0
      DCS(J)=0.0
      GO TO 4030
4020 ACS(J)=DT/(2.0*DY2)

```

```

      BCS(J)=1.0
      CCS(J)=-ACS(J)
      DCS(J)=ETA(I,J)-DT/(4.0*DX)*((QX(I+1,J)-QX(I,J))+
-      (QS(I+1,J)-QS(I,J)))
4030 CONTINUE
      IDIR=2
      CALL DSWEEP(IDIR,NNY,AC,BC,CC,DC,ACS,BCS,CCS,DCS,ETAC,QC,I,NET)
4050 DO 4060 J=1,NNY
      QY(I,J)=QC(J)
4060 ETA(I,J)=ETAC(J)

4090 CONTINUE

C   REESTABLISH WET AND DRY GRIDS; DRY=0, FLOODED=1
C   START AT IEND-1
C   DRY UP IF ETA+H<=0.0

      DO 5030 J=2,NNYM1
      DO 5030 I=2,NNX
      IS=NNXM1+2-I

      IF (NET(IS,J) .EQ. 0) GO TO 5030
      ETA(IS,J)=0.67*ETA(IS,J)+0.33*ETAS(IS,J)
      IF(ETA(IS,J) + H(IS,J)) 5000,5000,5010

5000 ETA(IS,J)=-H(IS,J)-0.0001
      D(IS,J)=ETA(IS,J)+H(IS,J)
      NET(IS,J)=0
      GO TO 5020

5010 NET(IS,J)=1
      D(IS,J)=H(IS,J)+ETA(IS,J)

5020 CONTINUE
5030 CONTINUE

C REESTABLISH ACTIVE (DISCHARGE) JUNCTIONS
C USE BOUNDARY CONDITION OF NO FLOW ACROSS A BOUNDARY
C NQBX(J) IS THE POSITION OF THE NO FLOW COASTLINE ON THE J'TH COLUMN

      DO 5065 J=1,NNYM1
      DO 5060 I=1,NNXM1
      IF (NET(I,J)*NET(I+1,J)) 5035,5035,5040
5035 QX(I+1,J)=0.001
      NQBX(J)=I+1
5040 CONTINUE
5045 IF(NET(I,J)*NET(I,J+1)) 5050,5050,5055
5050 CONTINUE
      QY(I,J+1)=0.001
5055 CONTINUE
5060 CONTINUE
5065 CONTINUE

```

C----- CHANGED -----

```
DO 6020 NPLT=1,NPLOT
NPLT1=(NPLT-1)*2 + 1
ICUR=IPLOT(NPLT1)
J=IPLOT(NPLT1+1)
DEL=THETAL(NPLT1)-THETAC/57.2956
CDEL=COS(DEL)
SDEL=SIN(DEL)
CALL HURCH(USQ,ICUR,J,VF,PINF,DP,RMAX,THETA,RHOW,XH,YH)
TAUN=UUX(ICUR,J)*CDEL + UUY(ICUR,J)*SDEL
C  TAUP=-UUX(ICUR,J)*SDEL + UUY(ICUR,J)*CDEL
H0=HMAX*USQ/USQM
AAA=SQRT(UUX(ICUR,J)**2+UUY(ICUR,J)**2)
IF (AAA.EQ.0.0) WRITE(8,6015)ICUR,J,UUX(ICUR,J),UUY(ICUR,J)
6015 FORMAT(' ICUR= ',I4,' J= ',I4,' UUX= ',F8.3,' UUY= ',F8.3,/)
IF (AAA.EQ.0.0) AAA=0.0001
H0=H0*ABS(TAUN)/AAA
T0=2.13*SQRT(H0)
HB=0.936*H0
IF (TAUN.GT.0.0) HB=0.1
IF (T0.EQ.0.0) THEN
  WSU = 0.0
ELSE
  WSU=0.19*(1.0-2.82*SQRT(HB/(G*T0*T0)))*HB
ENDIF

6021 WSU1=WSU*1.0
WSU2=WSU*1.5
C  ETAS0(NPLT)=ETA(ICUR,J)
ETAS1(NPLT)=ETA(ICUR,J)+WSU1
ETAS2(NPLT)=ETA(ICUR,J)+WSU2
```

6020 CONTINUE

C ESTABLISH MOST SHOREWARD FLOODED STATION.

C NOTE-NEW SHORE ELEMENTS ARE ACTIVATED ONLY BY FLOODING IN X-DIRECTION

```
DO 6150 J=2,NNYM1
IC=NQBX(J)
DX=DXA(IC-1)
6060 IF(ETA(IC,J)+H(IC-1,J)) 6080,6080,6070

6070 ETA(IC-1,J)=-H(IC-1,J)+0.25*(ETA(IC,J)+H(IC-1,J))
D(IC-1,J)=ETA(IC-1,J)+H(IC-1,J)
NET(IC-1,J)=1
QX(IC,J)=-DX*(ETA(IC-1,J)+H(IC-1,J))/DT
ETA(IC,J)=-H(IC-1,J)+0.75*(ETA(IC,J)+H(IC-1,J))

6080 IF(NET(IC,J+1)) 6090,6090,6110
6090 IF(ETA(IC,J)+H(IC,J+1)) 6110,6110,6100
```

```

6100 ETA(IC,J+1)=-H(IC,J+1)+0.25*(ETA(IC,J)+ H(IC,J+1))
      D(IC,J+1)=ETA(IC,J+1)+H(IC,J+1)
      NET(IC,J+1)=1
      DY=DYA(J+1)
      QY(IC,J+1)=DY*(ETA(IC,J+1)+H(IC,J+1))/DT
      ETA(IC,J)=-H(IC,J+1)+0.75*(ETA(IC,J)+H(IC,J+1))

6110 IF(NET(IC,J-1)) 6120,6120,6140
6120 IF( ETA(IC,J)+H(IC,J-1)) 6140,6140,6130
6130 ETA(IC,J-1)=-H(IC,J-1)+0.25*(ETA(IC,J)+H(IC,J-1))
      D(IC,J-1)=ETA(IC,J-1)+H(IC,J-1)
      DY=DYA(J-1)
      NET(IC,J-1)=1
      QY(IC,J-1)=-DY*(ETA(IC,J-1)+H(IC,J-1))/DT
      ETA(IC,J)=-H(IC,J-1)+0.75*(ETA(IC,J)+H(IC,J-1))
      D(IC,J)=ETA(IC,J)+H(IC,J)
6140 CONTINUE
6150 CONTINUE

C***** STORE ETA VALUES FOR TIME SERIES' OF GRIDS FOR PLOTTING *****
      IC2=IC2+1
      DO 8000 NPLT=1,NPLOT
        JPLOT=(NPLT-1)*2+1
        KPLOT=IPLOT(JPLOT)
        LPLOT=IPLOT(JPLOT+1)
        CVAR(IC2,1,NPLT)=ETA(KPLOT,LPLOT)
        CVAR(IC2,2,NPLT)=ETAS1(NPLT)
        CVAR(IC2,3,NPLT)=ETAS2(NPLT)
C***** FIND MAXIMUM ETA'S OF GRIDS FOR PLOTTING *****
7910 DO 8000 JJJ=1,3
      IF(ETAMAX(NPLT,JJJ).LT.CVAR(IC2,JJJ,NPLT)) ETAMAX(NPLT,JJJ)=
-   CVAR(IC2,JJJ,NPLT)
8000 CONTINUE
C***** FIND MAXIMUM ETA VALUES (NO SETUP) FOR ALL GRIDS *****
      DO 9000 JJJ=1,NNY
        DO 9000 IIII=1,NNX
          IF (ETA(IIII,JJJ).GT.ETMX(IIII,JJJ)) ETMX(IIII,JJJ)=ETA(IIII,
-   JJJ)
9000 CONTINUE
      CTIME(IC2)=T/CHS
      IF (MOD(JJ-1,6).NE.0) GO TO 10020
      WRITE(8,10010) THR,XHN,YHN
      WRITE(6,10010) THR,XHN,YHN
C   WRITE(9,10010) THR,XHN,YHN
10010 FORMAT(1H0,'*****', 'THR=',F10.2,' XHN=',F10.2,' YHN=',F10.2)
10020 CONTINUE
C   IF (NFIN.EQ.14) NFIN=1

10500 CONTINUE

C *****
C ***** END OF MAIN LOOP *****

```


C *****

```
11000 CONTINUE
      WRITE(8,11005)
11005 FORMAT(1H1,/,1H,'TIME SERIES FOR PLOTTING GRIDS',/)
      I5=-1
      DO 11040 J=1,NPLOT
      I5=I5+2
      WRITE(8,11010) IPLOT(I5),IPLOT(I5+1)
11010 FORMAT(1H,'GRID (',I3,',',I3,')')
      WRITE(8,11020) (CTIME(K6),(CVAR(K6,I,J),I=1,3),K6=1,IC2)
11020 FORMAT(1H',F6.2,3F10.3,5X,F6.2,3F10.3,5X,F6.2,3F10.3)
      WRITE(8,11030)
11030 FORMAT(1H1,/)
11040 CONTINUE
      WRITE(7,11050) CASE
11050 FORMAT(A20)
      WRITE(8,11055)
11055 FORMAT(28X,'  SURGE  +ST.WSU  +DYN.WSU',/)
      DO 11090 I=1,NPLOT
      J=(I-1)*2+1
      K=IPLOT(J)
      L=IPLOT(J+1)
      WRITE(7,11060) IPLOT(J),IPLOT(J+1),IC2
11060 FORMAT(2I3,I5)
      WRITE(7,11070) (CTIME(LL),(CVAR(LL,MM,I),MM=1,3),LL=1,IC2)
11070 FORMAT(4F7.2,3X,4F7.2)
      WRITE(8,11080) K,L,(ETAMAX(I,M),M=1,3)
11080 FORMAT(1H,'ETAMAX FOR GRID (',I3,',',I3,') = ',3F11.2)
11090 CONTINUE

      WRITE(8,11100)
11100 FORMAT(1H1,/,', MAXIMUM ETA VALUES FOR ALL GRIDS (NO SETUP)',/)
      DO 11120 JJJ=1,NNY
      WRITE(8,11110) JJJ,(ETMX(IIII,JJJ),IIII=1,NNX)
11110 FORMAT(1H0,I3,3X,10F7.2,/,10(1H',6X,10F7.2,/)
11120 CONTINUE
11130 STOP
      END
```

C-----

C HURCH0 IS SAME AS HURCH WHEN I=0

C-----

```
SUBROUTINE HURCH0 (USQ,I,J,UH,PINF,DP,RMAX,THETA,RHO)
PARAMETER(ISIZE=200,JSIZE=200)
COMMON /A/ UUX(ISIZE,JSIZE),UUY(ISIZE,JSIZE),P(ISIZE,JSIZE),
-      H(ISIZE,JSIZE),DPDX(ISIZE,JSIZE),DPDY(ISIZE,JSIZE),DX
COMMON /XANDY/ X(ISIZE),Y(JSIZE)
```

```
PARAMETER(RHOA=0.0024,UCR=23.6,COR=0.7221E-04)
```

C BEWARE-SOME SIGNS HAVE BEEN MODIFIED TO ACCOUNT FOR LEFT-HANDED COORD

```

XP=-RMAX*SIN(THETA)
YP=RMAX*COS(THETA)
I=1
J=1
20 R=SQRT(XP*XP+YP*YP)

IF(R.LT.2200.0) R=2200.0
RAT=RMAX/R
EXPO=EXP(-RAT)
USG=-DP/(RHOA*R)*RAT*EXPO/COR
UC=SQRT(-DP/RHOA*RAT*EXPO)
ALPHA=ATAN2(YP,XP)
DD = THETA - ALPHA
VPRIME=UH*SIN(DD)
GAMMA=0.5*(VPRIME/UC+UC/USG)
RATIO=SQRT(GAMMA**2+1.0)-GAMMA
U=UC*RATIO*0.9
USQ=U**2
UXX=-USQ*SIN(-ALPHA+0.31)
UYX=-USQ*COS(-ALPHA+0.31)
P(I,J)=PINF+DP*(1.0-EXPO)
DPDR=-DP*RAT/R*EXPO
DPDX(I,J)=DPDR*COS(ALPHA)
DPDY(I,J)=DPDR*SIN(ALPHA)
WSC=1.0E-06
IF(U.LT.OCR) GO TO 30
WSC=WSC+2.5E-06*(1.0-OCR/U)**2
30 CONTINUE
AA=1.0
IF(H(I,J).LT.0.0) AA=0.5
UUX(I,J)=AA*RHO*WSC*UXX
UUY(I,J)=UYX*AA*RHO*WSC

RETURN
END

```

C-----

```

SUBROUTINE HURCH (USQ,I,J,UH,PINF,DP,RMAX,THETA,RHO,XH,YH)
PARAMETER(ISIZE=200,JSIZE=200)
COMMON /A/ UUX(ISIZE,JSIZE),UUY(ISIZE,JSIZE),P(ISIZE,JSIZE),
- H(ISIZE,JSIZE),DPDX(ISIZE,JSIZE),DPDY(ISIZE,JSIZE),DX
COMMON /XANDY/ X(ISIZE),Y(JSIZE)

PARAMETER(RHOA=0.0024,OCR=23.6,COR=0.7221E-04)

```

C BEWARE-SOME SIGNS HAVE BEEN MODIFIED TO ACCOUNT FOR LEFT-HANDED COORD

```

10 XP=X(I)-XH
YP=Y(J)-YH
20 R=SQRT(XP*XP+YP*YP)

```

```

IF(R.LT.2200.0) R=2200.0
RAT=RMAX/R
EXPO=EXP(-RAT)
USG=-DP/(RHOA*R)*RAT*EXPO/COR
UC=SQRT(-DP/RHOA*RAT*EXPO)
ALPHA=ATAN2(YP,XP)
DD = THETA - ALPHA
VPRIME=UH*SIN(DD)
GAMMA=0.5*(VPRIME/UC+UC/USG)
RATIO=SQRT(GAMMA**2+1.0)-GAMMA
U=UC*RATIO*0.9
USQ=U**2
UXX=-USQ*SIN(-ALPHA+0.31)
UYX=-USQ*COS(-ALPHA+0.31)
P(I,J)=PINF+DP*(1.0-EXPO)
DPDR=-DP*RAT/R*EXPO
DPDX(I,J)=DPDR*COS(ALPHA)
DPDY(I,J)=DPDR*SIN(ALPHA)
WSC=1.0E-06
IF(U.LT.UCR) GO TO 30
WSC=WSC+2.5E-06*(1.0-UCR/U)**2
30 CONTINUE
AA=1.0
IF(H(I,J).LT.0.0) AA=0.5
UUX(I,J)=AA*RHO*WSC*UXX
UUY(I,J)=UYX*AA*RHO*WSC

RETURN
END

```

C-----

```

SUBROUTINE ETABCS (XH,YH,TS,VF,DP,RMAX,THETA,RHOW)
PARAMETER(ISIZE=200,JSIZE=200)

```

```

COMMON /A/ UUX(ISIZE,JSIZE),UUY(ISIZE,JSIZE),P(ISIZE,JSIZE),
-      H(ISIZE,JSIZE),DPDX(ISIZE,JSIZE),DPDY(ISIZE,JSIZE),DX
COMMON /B/ ETA(ISIZE,JSIZE),QX(ISIZE,JSIZE),QY(ISIZE,JSIZE),
-      TIDE,NQBX(JSIZE),DY,NNX,IEND
COMMON /C/ IS,J
COMMON /E/ PINF,DT,NNY
COMMON /F/ JJ
COMMON /XANDY/ X(ISIZE),Y(JSIZE)

```

C-----

```

C  THIS SUBROUTINE ESTABLISHES ETAS AT SEAWARD GRID IN BALANCE WITH
C  BAROMETRIC PRESSURE AND SETS ETAS AT TWO LATERAL BOUNDARY ELEMENT
C  ROWS IN BALANCE WITH THE BAROMETRIC PRESSURE
C  ESTABLISH ETA AT OFFSHORE END AND FLOW INTO OFFSHORE ELEMENT DUE
C  TO CHANGES IN ETA
C  JH IS X HURRICANE INDEX

```

C-----

C THIS NEEDS TO BE CHANGED.....

```
USQ=0.0
NNYP1=NNY+1
NNYM1=NNY-1
RHOW=1.99
G=32.2
AA=1.0/(RHOW*G)
AST=0.0
DO 45 J=1,NNY
IF(H(IEND,J)+ETA(IEND,J).LT.0.0) GO TO 45
CALL HURCH(USQ,IEND,J,VF,PINF,DP,RMAX,THETA,RHOW,XH,YH)
TETA=ETA(IEND,J)
ETA(IEND,J)=TIDE-AA*(P(IEND,J)-PINF)+AST
QX(IEND+1,J)=QX(IEND,J)-(ETA(IEND,J)-TETA)*DX/DT
45 CONTINUE
```

C***** ESTABLISH ETA AT TWO LATERAL BOUNDARY ELEMENT ROWS AND BOUNDARY
C***** FLOW, QY(I,1) AND QY(I,NNY) INTO AND FROM THESE ROWS

```
NQBX(NNY)=NQBX(NNYM1)
DO 50 J=1,NNY
NLIMIT=NQBX(J)
50 QX(NLIMIT,J)=0.001
J=1
IBP2=NQBX(2)+2
DO 70 I=IBP2,IEND
IS=IEND+IBP2-I
ISP=IS-1
IF(H(ISP,J)+ETA(ISP,J).LT.0.0) GO TO 70
CALL HURCH(USQ,ISP,J,VF,PINF,DP,RMAX,THETA,RHOW,XH,YH)
TETA= ETA(ISP,1)
AST=0.0
ETA(ISP,J)=TIDE-AA*(P(ISP,J)-PINF)+AST
QY(ISP,J)=QY(ISP,2)+(ETA(ISP,J)-TETA)*DY/DT
70 CONTINUE
J=NNY
IBP2=NQBX(NNYM1)+2
DO 80 I=IBP2,IEND
IS=IEND+IBP2-I
ISP=IS-1
IF(H(ISP,J)+ETA(ISP,J).LT.0.0) GO TO 80
CALL HURCH(USQ,ISP,J,VF,PINF,DP,RMAX,THETA,RHOW,XH,YH)
TETA=ETA(ISP,J)
ETA(ISP,J)=TIDE-AA*(P(ISP,J)-PINF)
QY(ISP,NNYP1)=QY(ISP,NNY)-(ETA(ISP,J)-TETA)*DY/DT
80 CONTINUE
90 RETURN
END
```

C-----

SUBROUTINE CALLFR(I,J,BF)

```

PARAMETER(ISIZE=200,JSIZE=200)

COMMON /A/ UUX(ISIZE,JSIZE),UUY(ISIZE,JSIZE),P(ISIZE,JSIZE),
-   H(ISIZE,JSIZE),DPDX(ISIZE,JSIZE),DPDY(ISIZE,JSIZE),DX
COMMON /B/ ETA(ISIZE,JSIZE),QX(ISIZE,JSIZE),QY(ISIZE,JSIZE),
-   TIDE,NQBX(JSIZE),DY,NNX,IEND
COMMON /H/ IFFACT(ISIZE,JSIZE), IFF1(ISIZE,JSIZE)

DVA = ETA(I,J)+H(I,J)
D2 = DVA
IFA = IFFACT(I,J)
I2 = IFF1(I,J)
IF (I2.EQ.0) I2=1
BF=0.0
TF=0.0
IDIV=10**I2

DO 90 K=1,I2

IDIV=IDIV/10
ITEST=IFA/IDIV
GO TO (50,60,70,80,85),ITEST
50 PHI=1.0
IF (DVA .LE. 10.0) DVA=10.0
D2 = DVA
CALL COMP(PHI,0.0,0.0,5.47,1.0,0.0,DVA,BF,TF,D2)
GO TO 90
60 PHI=0.0
CALL COMP(PHI,0.999,0.34,10.94,0.3,0.0,DVA,BF,TF,D2)
GO TO 90
70 PHI=1.0
CALL COMP(PHI,0.0,0.0,0.91,1.0,0.0,DVA,BF,TF,D2)
GO TO 90
80 PHI=0.0
CALL COMP(PHI,0.969,0.5445,10.94,0.3,0.7,DVA,BF,TF,D2)
GO TO 90
85 PHI=0.0
CALL COMP(PHI,0.64,0.204,10.94,1.0,0.0,DVA,BF,TF,D2)
90 IFA=IFA-ITEST*IDIV

A2=FLOAT(I2)
TF=TF/A2
BF=BF/A2
C *****

BFSUM = BF
TFSUM = TF

C *****

IPM = I+1
DVA = ETA(IPM,J)+H(IPM,J)

```

```

D2 = DVA
IFA = IFFACT(IPM,J)
C  CALL FRICT(IFA,DVA,BF,TF,D2,IFF1(IPM,J))
I2 = IFF1(IPM,J)
IF (I2.EQ.0) I2=1
BF=0.0
TF=0.0
IDIV=10**I2

DO 91 K=1,I2

IDIV=IDIV/10
ITEST=IFA/IDIV
GO TO (51,61,71,81,86),ITEST
51 PHI=1.0
  IF (DVA .LE. 10.0) DVA=10.0
  D2 = DVA
  CALL COMP(PHI,0.0,0.0,5.47,1.0,0.0,DVA,BF,TF,D2)
  GO TO 91
61 PHI=0.0
  CALL COMP(PHI,0.999,0.34,10.94,0.3,0.0,DVA,BF,TF,D2)
  GO TO 91
71 PHI=1.0
  CALL COMP(PHI,0.0,0.0,0.91,1.0,0.0,DVA,BF,TF,D2)
  GO TO 91
81 PHI=0.0
  CALL COMP(PHI,0.969,0.5445,10.94,0.3,0.7,DVA,BF,TF,D2)
  GO TO 91
86 PHI=0.0
  CALL COMP(PHI,0.64,0.204,10.94,1.0,0.0,DVA,BF,TF,D2)
91  IFA=IFA-ITEST*IDIV

A2=FLOAT(I2)
TF=TF/A2
BF=BF/A2
C *****
BFSUM=BFSUM+BF
TFSUM=TFSUM+TF

BF = BFSUM/2.0
TF = TFSUM/2.0
UUX(I,J)=UUX(I,J)*TF
UUY(I,J)=UUY(I,J)*TF

RETURN
END

C-----

SUBROUTINE COMP(PHI,A1,A2,A3,A4,A5,D1,BF,TF,D2)
A6=A4+A5*D2/10.0
IF(A6.GT.1.0)A6=1.0

```

```

TF=TF+A6
D3 = D2
IF(A3.EQ.5.47) D3=D1
TEMP1 = A3*D3
IF (TEMP1.EQ.0.0) TEMP1 = 0.000001
TEMP2 = A2*ABS(D3)**1.333
IF ((A1+TEMP2).EQ.0.0) TEMP2 = 0.000001
IF(PHI.EQ.1.0) GO TO 10
PHI = 1.0/(ABS(A1+TEMP2))**0.5
10 BF = 1.28/((PHI**2)*(ALOG(ABS(TEMP1+1.0)))**2)+BF
RETURN
END

```

C-----

```

SUBROUTINE BARR(N,I,J,F,DT,FACTX,FACTY,WX,WY,IICOUN,NINL)
PARAMETER(ISIZE=200,JSIZE=200)

```

```

COMMON /BAR/ NORBAR(120),IBAR(120),JBAR(120),XLBAR(120),HBAR(120),
- WBAR(120),FBAR(120),XKEX(120),NORINL(130),IINL(130),JINL(130),
- WINL(130),DPINL(130),XKENEX(130),FINL(130),XLINL(130)

```

```

COMMON /A/ UUX(ISIZE,JSIZE),UUY(ISIZE,JSIZE),P(ISIZE,JSIZE),
- H(ISIZE,JSIZE),DPDX(ISIZE,JSIZE),DPDY(ISIZE,JSIZE),DX
COMMON /B/ ETA(ISIZE,JSIZE),QX(ISIZE,JSIZE),QY(ISIZE,JSIZE),
- TIDE,NQBX(JSIZE),DY,NNX,IEND

```

C THE PRESENT TREATMENT IS FOR SUBMERGED BARRIERS ONLY

```

NORB=NORBAR(N)
IM1=I-1
IC=I
JM1=J
JC=J
DL=DY
DS=DX
QC=QX(IC,JC)
IF (NORB.EQ.1) GO TO 10
IM1=I
JM1=J-1
DS=DY
DL=DX
QC=QY(IC,JC)
10 CONTINUE
D1=H(IM1,JM1)+ETA(IM1,JM1)
D3=H(IC,JC)+ETA(IC,JC)

```

C---AVERAGE WATER SURFACE ELEVATION

```

ETABAR=0.5*(ETA(IM1,JM1)+ETA(IC,JC))
W1=DL
W3=DL

```

```

DX1=0.5*(DS-XLBAR(N))
DX3=DX1

C  THIS NEXT LOOP DETERMINES WHETHER THERE IS AN INLET
C  THROUGH THE BARRIER OF CURRENT INTEREST

DO 20 NI=1,NINL
IF (IINL(NI).NE.I.OR.JINL(NI).NE.J) GO TO 20
NINC=NI
WI=WINL(NINC)
IF (NORINL(NI).EQ.NORB) GO TO 30
20 CONTINUE
WI=0.0

C-----DEPTH OVER BARRIER

30 DBAR=ETABAR+HBAR(N)
DXB=XLBAR(N)
FB=FBAR(N)
WB=WBAR(N)
IF (DBAR.LE.0.0) WB=0.0
IF (WI.GT.0.0.OR.WB.GT.0.0) GO TO 40

C  IF DBAR IS GREATER THAN ZERO, BARRIER IS OVERTAPPED

WS=500.
FACT=0.0
GO TO 70

C  THIS SECTION FOR GRID LINES WITH INLET THROUGH BARRIER
C  WHETHER OR NOT BARRIER IS OVERTOPPED

40 DI=DPINL(NINC)+ETABAR
FI=FINL(NINC)
DXI=XLINL(NINC)
CONTINUE
IF (WB.NE.0.0) DX2=DXB
IF (WI.NE.0.0) DX2=DXI
T1=DX1/(D1*W1)
T3=DX3/(D3*W3)
T4=F*DX1/(8.0*W1*D1**2)
T5=F*DX3/(8.0*W3*D3**2)
T21=0.0
T22=0.0
T6=10000.0
T7=10000.0
T8=10000.0
T9=10000.0
IF (WB.EQ.0.0) GO TO 50
T22=WB/(DBAR*WB)**2
T8=FB*DXB/(8.0*WB*WB*DBAR**3)
T9=XKEX(N)/(2.0*DBAR*DBAR*WB*WB)

```



```

50 IF (WI.EQ.0.0) GO TO 60
   IF (DI.GT.0.0) GO TO 55
   GO TO 60
55 T21=WI/(DI*WI)**2
   T6=FI*DXI/(8.0*DI**3*WI**2)
   T7=XKENEX(NINC)/(2.0*DI*DI*WI*WI)
60 ALPHAI=T6+T7
   ALPHAB=T8+T9
   IF (ALPHAI.LT.0.0) WRITE(8,65) ALPHAI,T6,T7
   IF (ALPHAB.LT.0.0) WRITE(8,66) ALPHAB,T8,T9
65 FORMAT(' ALPHAI= ',F8.3,' T6= ',F8.3,' T7= ',F8.3,/)
66 FORMAT(' ALPHAB= ',F8.3,' T8= ',F8.3,' T9= ',F8.3,/)
   SAI=SQRT(ALPHAI)
   SAB=SQRT(ALPHAB)
   T2=(T21*WI*DI+T22*WB*DBAR)*DX2/(WB+WI)
   XMU=T1/(D1*W1)+DX2/(WB+WI)*(T21+T22)+T3/(D3*W3)
C----- ADDED 3/15/1988 -----
   IF (XMU.EQ.0.0) XMU = 0.0000001
C-----
   FACT=2.0/(XMU*DL)*(T1+T2+T3)/(D1+D3)
   TEMP=ALPHAI*WI*DI/(1.0+SAI/SAB)**2+ALPHAB*WB*DBAR/(1.0+SAB/SAI)**2
   WS=(DL/DS)*(T4+T5+TEMP)*ABS(QC)
   WS=WS*DT+1.0
70 CONTINUE
   IF(NORBAR(N).EQ.1) GO TO 80
   FACTY=FACT
   WY=WS
   GO TO 90
80 FACTX=FACT
   WX=WS
90 CONTINUE

250 RETURN
   END

C-----

SUBROUTINE DSWEPT(IDIR,NNI,A,B,C,D,AS,BS,CS,DS,ETAC,QC,JC,NET)
PARAMETER(ISIZE=200,JSIZE=200)

COMMON /B/ ETA(ISIZE,JSIZE),QX(ISIZE,JSIZE),QY(ISIZE,JSIZE),
- TIDE,NQBX(JSIZE),DY,NNX,IEND
COMMON /F/ JJ
DIMENSION A(250), B(250), C(250), D(250), E(250), F(250)
DIMENSION AS(250),BS(250),CS(250),DS(250),ES(250),FS(250)
DIMENSION QC(250),ETAC(250)
DIMENSION NET(ISIZE,JSIZE)

C IF IDIR=1, SWEEP IN X-DIRECTION
C IF IDIR=2, SWEEP IN Y-DIRECTION

NNM1=NNI-1

```

```

      IF (IDIR.EQ.2) GO TO 10

C   CARRY OUT FIRST SWEEP TO CONDITION COEFFICIENTS

      E(NNI)=0.0
      F(NNI)=ETA(NNI,JC)
      ETAC(1)=ETA(1,JC)
      GO TO 20
10  CONTINUE
      E(NNI)=0.0
      F(NNI)=ETA(JC,NNI)
      IF (NET(JC,NNI).EQ.0) F(NNI)=0.0
      ETAC(1)=ETA(JC,NNI)
20  DO 30 I=2,NNM1
      IC=NNM1+2-I
      ICP=IC+1
      DEN=A(ICP)*E(ICP)+B(ICP)
      IF (DEN.EQ.0.0) DEN=1.0
      ES(IC)=-C(ICP)/DEN
      FS(IC)=(D(ICP)-A(ICP)*F(ICP))/DEN
      DEN=AS(IC)*ES(IC)+BS(IC)
      IF (DEN.EQ.0.0) DEN=1.0
      E(IC)=-CS(IC)/DEN
      F(IC)=(DS(IC)-AS(IC)*FS(IC))/DEN
30  CONTINUE

C   CARRY OUT SECOND SWEEP TO ESTABLISH ETA AND Q

      DO 40 I=2,NNI
      IM=I-1
      QC(I)=ES(IM)*ETAC(IM)+FS(IM)
      ETAC(I)=E(I)*QC(I)+F(I)
40  CONTINUE

      E(1)=ETAC(1)
      E(NNI)=ETAC(NNI)
110 RETURN
      END

```

APPENDIX B

1-D STORM TIDE MODEL*

*This program represents a numerical modeling procedure that is subject to change due to:1. newly encountered topo-bathymetric and hydraulic boundary conditions, and 2. incorporation of new advancements quantifying coastal processes. This program is applied on a county-by-county basis and is subject to acceptable calibration constraints recommend by the Beaches and Shores Resource Center and approved by Florida Department of Environmental Protection.

```

CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C
C    ONE-DIMENSIONAL NUMERICAL STORM SURGE MODEL
C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
    DIMENSION CTS(3,5,1200)
    DIMENSION H(250),X(250),ETA(250),QY(250),EMXMN(5,2),DXA(250)

    CHARACTER*10 PROFIL
    CHARACTER*20 COUNTY,CASE

10  FORMAT(A20)
20  FORMAT(A10,I3,4F10.2)
30  FORMAT(8F9.2)
32  FORMAT(10F7.1)
40  FORMAT(11F7.2,3I3)
100 FORMAT(1H )
110 FORMAT(1H1,'ONE-DIMENSIONAL NUMERICAL STORM SURGE MODEL')
120 FORMAT(1H ,A20,4X,A10,/1H ,40(' '),///)
130 FORMAT(1H , 'PROFILE DATA -- (DIST,DEPTH):',/)
135 FORMAT(5(1H ,5(F7.0,F7.2,2X),/))
140 FORMAT(1H-, 'INPUT PARAMETERS:',//1H ,
1      'PINF=',F8.2,T26,'P0=',F8.2,T51,'DP=',F8.2,/1H ,
2      'ZLAT=',F8.2,T26,'RMAX=',F8.2,/1H ,
3      'COR=',E12.4,T26,'VF=',F8.2,/1H ,
4      'THETAC=',F8.2,T26,'THETAN=',F8.2,T51,'THETA=',F8.2,/1H ,
5      'XSITE=',F8.2,T26,'XHC=',F8.2,T51,'XHB=',F8.2,/1H ,
6      'YSITE=',F8.2,T26,'YHC=',F8.2,T51,'YHB=',F8.2,/1H ,
7      'XOFF=',F8.0,T26,/1H ,
8      'DT=',F8.2,T26,'TMAX=',F8.2,T51,'NTIMES=',I5,/1H ,
9      'THETAL=',F8.2)
145 FORMAT(1H ,A20,4X,A10,20X,A20,/1H ,80(' '),///)
150 FORMAT(1H-, 'TIME STEP ',I5,5X,'TIME=',F8.3,' HRS.',5X,'XH=',
1      F9.2,' N.MI.',5X,'YH=',F9.2,' N.MI.',//,1H ,
2      'STORM SURGE, ETA(I) IN FEET ABOVE MSL -- (I,ETA):',//,
3      (1H ,6(I5,F9.3)))
160 FORMAT(1H ,20X,'CONDENSED TIME SERIES OF STORM SURGE ETAS',//1H
,
1      A20,4X,A10,20X,A20,///1H ,
2      2(' TIME SURGE SETUP W/SETUP W/DYNMC '),/)
170 FORMAT(1H ,F5.2,4F8.3,6X,F5.2,4F8.3)
175 FORMAT(F5.2,4F8.3,6X,F5.2,4F8.3)
180 FORMAT(1H-, 'MAXIMUM SURGES FOR ',A20,2X,A10,2X,A20,//1H
,5X,4F8.3)

    OPEN (UNIT=5, FILE='b1dtest.lan', STATUS='old')

    OPEN (UNIT=6, FILE='b1dtest.prt', STATUS='unknown')
    OPEN (UNIT=9, FILE='b1dtest.pun', STATUS='unknown')

```

```

OPEN (UNIT=10, FILE='b1dtest.out', STATUS='unknown')

RHOA=0.0024
RHOW=1.99
G=32.17
PI=3.1416
FRICT=0.0025
CNM=6076.1
CHR=3600.
CHG=70.51
CDEG=180.0/PI
OMEGA=2.0*PI/(24.0*CHR)
BETA2=1.5

C
  READ(5,10) COUNTY
  READ(5,20) PROFIL,IMAX,XSITE,YSITE,THETAL,ANGVD
  READ(5,30) (DXA(I),I=1,IMAX)
  READ(5,32) (H(I),I=1,IMAX)
  THETAL=THETAL/CDEG

  WRITE(6,110)
C  WRITE(7,110)
  WRITE(6,120) COUNTY,PROFIL
C  WRITE(7,120) COUNTY,PROFIL
  WRITE(6,130)
C  WRITE(7,130)
C  WRITE(6,30) (DXA(I),I=1,IMAX)
C  WRITE(7,30) (DXA(I),I=1,IMAX)
C  WRITE(6,32) (H(I),I=1,IMAX)
C  WRITE(7,32) (H(I),I=1,IMAX)

  IMP1=IMAX+1
  XOFF=XSITE*CNM
  X(1)=XOFF
  H(1)=H(1) + ANGVD
  DO 290 I=2,IMAX
    X(I)=X(I-1) + (DXA(I)+DXA(I-1))/2.0
    H(I)=H(I) + ANGVD
290 CONTINUE
  WRITE(6,135) (X(I),H(I),I=1,IMAX)
C  WRITE(7,135) (X(I),H(I),I=1,IMAX)

  XSIT=XSITE*CNM
  YSIT=YSITE*CNM
300 READ(5,10,END=999) CASE
  READ(5,40) DT,THETAC,ZLAT
  READ(5,40) PINF,DP,RMAX,VF,THETAN,XHB,YHB,TMAX,TMIN

  P0=PINF+DP
C change the following angle to 90 for west, 270 for east
  THETA=THETAN-THETAC+270.
  IF (THETA.GT.360.0) THETA=THETA-360.0

```

```

      IF (THETA.LT.0.0) THETA=THETA+360.0
      COR=2.0*OMEGA*SIN(ZLAT/CDEG)
      NTIMES=IFIX(TMAX*CHR/DT)+1
      INTERV=IFIX(CHR/DT/2.0)
      INTER4=4*INTERV
      NSTORE=IFIX(180.0/DT)
      IF (NSTORE.EQ.0) NSTORE=1

      WRITE(6,110)
C     WRITE(7,110)
      WRITE(6,145) COUNTY,PROFIL,CASE
C     WRITE(7,145) COUNTY,PROFIL,CASE
      WRITE(6,140) PINF,P0,DP,ZLAT,RMAX,COR,VF,THETAC,THETAN,THETA,
-       XSITE,XHC,XHB,YSITE,YHC,YHB,XOFF,DT,TMAX,NTIMES,THETAL
C     WRITE(7,140) PINF,P0,DP,ZLAT,RMAX,COR,VF,THETAC,THETAN,THETA,
C     -       XSITE,XHC,XHB,YSITE,YHC,YHB,XOFF,DT,TMAX,NTIMES,THETAL

      PINF=PINF*CHG
      P0=P0*CHG
      DP=DP*CHG
      RMAX=RMAX*CNM
      VF=VF*CNM/CHR
      THETAC=THETAC/CDEG
      THETAN=THETAN/CDEG
      THETA=THETA/CDEG
      DEL=THETAL-THETAC
      CDEL=COS(DEL)
      SDEL=SIN(DEL)
      XHB=XHB*CNM
      YHB=YHB*CNM

      DO 310 I=1,IMP1
      QY(I)=0.0
310  CONTINUE

      DO 320 I=1,5
      EMXMN(I,1)=0.0
      EMXMN(I,2)=0.0
320  CONTINUE

      TIMSC=-DT
      IS=0

      CALL HURCH(IS,X,XSIT,YSIT,XH,YH,PINF,DP,RMAX,VF,THETA,
-       RHOW,RHOA,COR,USQ,P,TAUX,TAUY,CDEL,SDEL)
      USQM=USQ
      UMAX=SQRT(USQ)*CHR/CNM
      AA=-RMAX*DP/(CNM*CHG*100.0)
      AA2=0.160*VF/SQRT(UMAX)
      HMAX=16.5*EXP(AA)*(1.0+AA2)
      TMAX1=8.6*EXP(AA/2.0)*(1.0+AA2/2.0)

```

C---- ***** MAIN TIME LOOP *****

DO 600 NTIME=1,NTIMES

WSU=0.0

TIMSC=TIMSC+DT

XH=XHB+VF*TIMSC*COS(THETA)

YH=YHB+VF*TIMSC*SIN(THETA)

TIMHR=TIMSC/CHR

XHN=XH/CNM

YHN=YH/CNM

ETASUM=0.0

SUMSTR=0.0

CSUM=0.0

DO 500 I=1,IMAX

IS=IMAX-I+1

CALL HURCH(IS,X,XSIT,YSIT,XH,YH,PINF,DP,RMAX,VF,THETA,
- RHOW,RHOA,COR,USQ,P,TAUX,TAUY,CDEL,SDEL)

ETAPR=1.0/(RHOW*G)*(PINF-P)

DX=X(IS+1)-X(IS)

TDPTH=H(IS)+ETASUM

IF (I.EQ.1) TDPTH=H(IS)

IF (TDPTH.GT.0.0) GO TO 400

GO TO 450

C---- TAUN = TAU-NORMAL, TAUP = TAU-PARALLEL

400 TAUN=TAUX*CDEL + TAUY*SDEL

TAUP=-TAUX*SDEL + TAUY*CDEL

SUMSTR=SUMSTR+TAUN*DX/(RHOW*G*TDPTH)

ETA(IS)=ETAPR-SUMSTR

ETASUM=ETA(IS)

TDPTH=H(IS)+ETASUM

BB=1.0+DT*FRICT*ABS(QY(IS))/(TDPTH*TDPTH)

QY(IS)=(QY(IS)+DT/RHOW*TAUP)/BB

CCTIDE=DX*COR*QY(IS)/(G*TDPTH)

CSUM=CSUM+CCTIDE

ETA(IS)=ETA(IS)+CCTIDE

ETASUM=ETA(IS)

IF (IS.NE.1) GO TO 500

450 H0=HMAX*ABS(USQ)/USQM

IF (USQ.GT.0.0) H0=1.0

T0=2.13*SQRT(H0)

HB=0.936*H0

WSU=0.19*(1.0-2.82*SQRT(HB/(G*T0*T0)))*HB

C

WRITE(6,6019)TIMHR,IS,H0,USQM,T0,HB,USQ,HMAX,G,WSU,ETASUM,ETA(IS)

6019 FORMAT(' TIME= ',F9.3,' IS= ',I9,' H0= ',F9.3,/,

- ' USQM= ',F9.3,' T0= ',F9.3,' HB= ',F9.3,/,

- ' USQ= ',F9.3,' HMAX= ',F9.3,' G= ',F9.3,/,

- ' WSU= ',F9.3,' ETASUM= ',F9.3,' ETA(IS)= ',F9.3,/,

```

        ETASUM=ETASUM+BETA2*WSU
        IF ((ETA(IS)+H(IS)).GT.0.0) GO TO 500
        ETA(1)=0.0
        GO TO 510

500 CONTINUE

510 CONTINUE
        NTM=(NTIME-1)/NSTORE+1
        CTS(1,1,NTM)=TIMHR
        CTS(1,2,NTM)=ETA(1)
        CTS(1,3,NTM)=WSU
        CTS(1,4,NTM)=ETA(1)+WSU
        CTS(1,5,NTM)=ETA(1)+1.5*WSU

        DO 520 I=2,5
        IF (CTS(1,I,NTM).GT.EMXMN(I,1)) EMXMN(I,1)=CTS(1,I,NTM)
        IF (CTS(1,I,NTM).LT.EMXMN(I,2)) EMXMN(I,2)=CTS(1,I,NTM)
520 CONTINUE

        IF (MOD(NTIME,INTERV).NE.1) GO TO 600
        IF (MOD(NTIME,INTER4).EQ.1) WRITE(6,110)
        IF (MOD(NTIME,INTER4).EQ.1) WRITE(6,145) COUNTY,PROFIL,CASE
C      WRITE(6,150) NTIME,TIMHR,XHN,YHN,(I,ETA(I),I=1,IMAX)
C      WRITE(6,151) (CTS(1,K,NTM),K=2,5)
151  FORMAT(1H0,'ETA:',F8.3,4X,'WSU:',F8.3,4X,'ETA+WSU:',F8.3,4X,
-          'ETA+1.5*WSU:',F8.3)

600 CONTINUE

C --- ***** END OF MAIN TIME LOOP *****

        DO 605 I=1,5
605  CTS(1,I,NTM+1)=0.0

        WRITE(9,152)NTM
152  FORMAT(I5)

        DO 610 I=1,NTM,2
        IF (MOD(I,100).EQ.1) WRITE(6,110)
        IF (MOD(I,100).EQ.1) WRITE(6,160) COUNTY,PROFIL,CASE
        IF (MOD(I,10).EQ.1) WRITE(6,100)
        IP1=I+1
C      WRITE(6,170) ((CTS(1,J,K),J=1,5),K=I,IP1)
        WRITE(9,175) ((CTS(1,J,K),J=1,5),K=I,IP1)
610 CONTINUE

C      WRITE(11,11) ((CTS(1,J,K),J=1,5,4),K=1,NTM,3)
C 11  FORMAT(2F10.1)

        WRITE(6,180) COUNTY,PROFIL,CASE,(EMXMN(I,1),I=2,5)

```



```

C      WRITE(7,180) COUNTY,PROFIL,CASE,(EMXMN(I,1),I=2,5)
      WRITE(10,180) COUNTY,PROFIL,CASE,(EMXMN(I,1),I=2,5)

      GO TO 300
999  CONTINUE

      STOP
      END

      SUBROUTINE HURCH(IS,X,XSITE,YSITE,XH,YH,PINF,DP,RMAX,VF,THETA,
-          RHOW,RHOA,COR,USQ,P,TAUX,TAUY,CDEL,SDEL)

      DIMENSION X(1)

C---- BEWARE-SOME SIGNS HAVE BEEN MODIFIED TO ACCOUNT FOR LEFT-HANDED
C---- COORDINATES

      UCR=23.6
      IF (IS.NE.0) GO TO 4
      XP=-RMAX*SIN(THETA)
      YP=RMAX*COS(THETA)
      GO TO 6
4     XIS=0.5*(X(IS+1)+X(IS))
      XP=XIS-XH
      YP=YSITE-YH
6     R=SQRT(XP**2+YP**2)
      IF(R.LT.2200.0) R=2200.0
      RAT=RMAX/R
      EXPO=EXP(-RAT)
      USG=-DP/(RHOA*R)*RAT*EXPO/COR
      UC=SQRT(-DP/RHOA*RAT*EXPO)
      ALPHA=ATAN2(YP,XP)
      BETA=THETA-ALPHA
      VPRIME=VF*SIN(BETA)
      GAMMA=0.5*(VPRIME/UC+UC/USG)
      RATIO=SQRT(GAMMA**2+1.0)-GAMMA
      IF(RATIO.LT.1.0E-05) RATIO=1.0E-05
      U=UC*RATIO*0.9
      USQ=U**2
      UXX=-USQ*SIN(-ALPHA+0.31)
      UYY=-USQ*COS(-ALPHA+0.31)
      P=PINF+DP*(1.0-EXPO)
      WSC=1.0E-06
      IF(U.LT.UCR) GO TO 20
      WSC=WSC+2.5E-06*(1.0-UCR/U)**2
20  CONTINUE
      AA=1.0
      TAUX=AA*RHOW*WSC*UXX
      TAUY=AA*RHOW*WSC*UYY
      IF (IS.NE.0) USQ=UXX*CDEL + UYY*SDEL
      IJK=0
      IF (IJK.EQ.0) GO TO 79

```

```

C      WRITE(6,40) I, J, XH, YH, XP, YP, R, RMAX, RAT, P, DPDX, DPDY
C      WRITE(6,50) I, J, EXPO, COR, RH0A, USG, DP, PINF, ALPHA, BETA, VPRIME
C      WRITE(6,60) I, J, UH, GAMMA, RATIO, USQ, U, UXX, UYY
C      WRITE(6,70) I, J, WSC, TAUX, TAU, THETA
40    FORMAT(1H0, 'I=', I3, ' J=', I3, ' XH=', E12.4, ' YH=', E12.4, '
XP=', E12.4
1      , ' YP=', E12.4, ' R=', E12.4, ' RMAX=', E12.4,
2      /1H , ' RAT=', E12.4, '
P(I, J)=', E12.4,
3      ' DPDX(I, J)=', E12.4, ' DPDY(I, J)=', E12.4)
50    FORMAT(1H0, 'I=', I3, ' J=', I3, ' EXPO=', E12.4, ' COR=', E12.4,
1      ' RH0A=', E12.4, ' USG=', E12.4, ' DP=', E12.4, ' PINF=', E12.4,
2      /1H ,
3      E12.4, ' BETA=', E12.4, ' VPRIME=', E12.4)
60    FORMAT(1H0, 'I=', I3, ' J=', I3, ' UH=', E12.4, ' GAMMA=', E12.4,
1      ' RATIO=', E12.4, ' USQ=', E12.4, ' U=', E12.4, ' UXX=', E12.4,
2      ' UYY=', E12.4)
70    FORMAT(1H0, 'I=', I3, ' J=', I3,
1      ' WSC=', E12.4, ' TAUX= ', E12.4, ' TAU=
', E12.4,
2      ' THETA=', E12.4)
79    RETURN
END

```

APPENDIX C

BEACH-DUNE EROSION MODEL*

*This program represents a numerical modeling procedure that is subject to change due to: 1. newly encountered topo-bathymetric and hydraulic boundary conditions, and 2. incorporation of new advancements quantifying coastal processes. This program is applied on a county-by-county basis and is subject to acceptable calibration constraints recommend by the Beaches and Shores Resource Center and approved by Florida Department of Environmental Protection.

```

C*****
C      EROSION MODEL
C
C*****
      DIMENSION DH(200),DX(200),DPTC(200),
-          STAI(10,120),STA(120),XAO(200),
-          X(200,2),NCON(200),
-          XASAVE(200),HASAVE(200)
      DIMENSION XTOT(6),DXTOT(6),NTOT(6)
      DIMENSION NPSTA(10)
      DIMENSION IBND(11),SRG(250),STAMAX(6)

      COMMON /A/ H1(200),XA(200),HA(200),NELM,X1(200),NP,NELM1
      CHARACTER*8 RNG,RNGDAT,DOTDAT,BCHDAT,OFFDAT,DUMMY
      CHARACTER*25 CNTY,SRGDAT
C  Input files
      OPEN(4,'test.prf',STATUS='OLD',ACTION='READ')
      OPEN(5,'test.100',STATUS='OLD',ACTION='READ')
C  Output files
      OPEN(6,'test.dn1',STATUS='UNKNOWN',ACTION='WRITE')
      OPEN(8,'test.dta',STATUS='UNKNOWN',ACTION='WRITE')
      OPEN(9,'testini.smo',STATUS='UNKNOWN',ACTION='WRITE')
      OPEN(10,'testero.smo',STATUS='UNKNOWN',ACTION='WRITE')
      OPEN(12,'test.ava',STATUS='UNKNOWN',ACTION='WRITE')
      OPEN(15,'test.vol',STATUS='UNKNOWN',ACTION='WRITE')

C
C      H(N) VALUES ARE DEPTH VALUES TO CENTER OF ELEMENT.
C      ELEVATIONS ABOVE MEAN SEA LEVEL ARE NEGATIVE.
C
C
      4 FORMAT(I3)
      5 FORMAT(1H1,25X)
      10 FORMAT(10X,F10.2)
      15 FORMAT(F8.4)
      30 FORMAT(5(F7.1,1X,F7.2))
      37 FORMAT(A3)
      40 FORMAT(A8,I3)
      62 FORMAT(1H ,5X,F8.1,3X,F8.1,5X,F8.1)
      65 FORMAT(I3)

      70 FORMAT(A25)
      71 FORMAT(A8)
      72 FORMAT(F7.4,2F7.3,2I3,3F6.1,I4)
      74 FORMAT(11I4)
      75 FORMAT(10F7.1)

10050 FORMAT(1H1,/,34X,A25,
-          /,25X,'SIMULATED DUNE EROSION - DEAN-S MODEL',
-          /,25X,'      FOR APRIL 1988-DNR SURVEY DATA',
-          /,25X,'      100 YEAR STORM TIDE USED',/)
10055 FORMAT(1H0,'NOTE: -XMD/SLOPE=',F5.2,' K VALUE =',F7.3,

```

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-          ' A VALUE = VARIABLE',/,
-      1H , '      -ALL PROFILES CONTAIN OFFSHORE DATA.',/,
-      1H , '      -ALL VOLUME CHANGES ARE CALCULATED FROM
THE',/,
-      1H , '      HIGHEST CONTOUR DOWN TO THE MSL CONTOUR.')
10056 FORMAT(1H0, 'NOTE: -XMD/SLOPE=', F5.2, ' K VALUE =', F7.3,
-          ' A VALUE = ', F6.4,/,
-      1H , '      -ALL PROFILES CONTAIN OFFSHORE DATA.',/,
-      1H , '      -ALL VOLUME CHANGES ARE CALCULATED FROM
THE',/,
-      1H , '      HIGHEST CONTOUR DOWN TO THE MSL CONTOUR.')
10060 FORMAT(1H , '      -EROSION INCREASED BY FACTOR OF 2.5',/)
10065 FORMAT(1H , '      -THIS IS THE ORIGINAL EROSION - NO
ADDITIONS',/,
-      1H , '      (IE, 2.5 FACTORS) HAVE BEEN MADE.',/)
C
    VOLTOT=0.0
    PROF=0.0
    DO 98 I=1,6
    NTOT(I)=0
    XTOT(I)=0.0
98    DXTOT(I)=0.0
C
C-----READ COEFFICIENTS AND STORM SURGE HYDROGRAPHS
C
    READ(5,70) CNTY
    READ(5,70) SRGDAT
    READ(5,72) A,XK,XMD,IFCT25,ICALA,HB,PERIOD,DY,NPROFS
READ(5,65) NHYDRO
C    WRITE(6,82)A,XK,XMD,HB,PERIOD,DY,NPROFS,NHYDRO,IFCT25,ICALA
82  FORMAT(1H , ' A=          ', F7.3, ' XK=          ', F7.3, ' XMD=          ', F7.2, /
-          , ' HB=          ', F7.2, ' PERIOD=       ', F7.2, ' DY=          ', F7.2, /
-          , ' NPROFS=      ', I7, ' NHYDRO=        ', I7, ' IFCT25=      ', I7, /
-          , ' ICALA=       ', I7, /)

C-----IBND VALUES INDICATE PROFILES WHICH USE EACH HYDROGRAPH.

    NBND=NHYDRO+1
    READ(5,74) (IBND(I),I=1,NBND)
C    WRITE(6,74) (IBND(I),I=1,NBND)

C-----SRG IS THE SURGE LEVEL LOCATED AT EACH RANGE.
C-----SRGFCT(1) = ETAMAX(PROFILE 1) / STAMAX(HYDRO 1)

    READ(5,75) (SRG(I),I=1,NPROFS)
C    WRITE(6,75) (SRG(I),I=1,NPROFS)

    DO 100 J = 1,NHYDRO
    READ(5,4)NPSTA(J)
C    WRITE(6,4)NPSTA(J)
    NP=NPSTA(J)
    STAMAX(J)=0.0

```

```

        DO 100 K = 1, NP
        READ(5,10) STAI(J,K)
        IF (STAI(J,K).GT.STAMAX(J)) STAMAX(J)=STAI(J,K)
C      WRITE(6,10)STAI(J,K)
100    CONTINUE
C
C      READ H,X VALUES
        WRITE(8,201)
201    FORMAT('INITIAL SURVEY DATA')
        WRITE(9,202)
202    FORMAT('INITIAL SMOOTHED DATA')
        WRITE(10,203)
203    FORMAT('ERODED-SMOOTHED DATA')
        WRITE(6,10050)CNTY
        IF (ICALA.EQ.1) WRITE(6,10055)XMD,XK
        IF (ICALA.EQ.0) WRITE(6,10056)XMD,XK,A
        IF (IFCT25.EQ.1) WRITE(6,10060)
        IF (IFCT25.EQ.0) WRITE(6,10065)
C
C      READ(4,37)DUMMY
175    READ(4,20,END=9999)RNG,RNGDAT,ICODE,YNORTH,XEAST,AZMUTH
        READ(4,25)DOTDAT,BCHDAT,OFFDAT,NP,NPDOT,NPBCH,NPOFF
20    FORMAT(A8,A8,I2,2F12.3,F7.2)
25    FORMAT(A8,A8,A8,4I3,/)
C
C-----INPUT CONTOUR INFO. OBTAINED BY LOOKING OVER EACH PROFILE.
C
C      READ(1,22000)CRNG,CVAL
22000  FORMAT(A8,F10.0)
C-----
-

        IF (AMOD(PROF,5.0).NE.4.0R.PROF.EQ.0.0) GO TO 1750
        WRITE(6,5)
1750    PROF=PROF+1.0
        DO 176 I=1,200
        X(I,1)=0.0
        X(I,2)=0.0
        X1(I)=0.0
        H1(I)=0.0
        NCON(I)=0
        XA(I)=0.0
176    HA(I)=0.0

        READ(4,30)(X1(I),H1(I),I=1,NP)
        NPOFF=0
        NPDOT=0
        NPBCH=NP

        DO 1760 I=1,NP
        IF (H1(I).LT.-20.0) GO TO 1762

```

```

1760 CONTINUE
1762 NSTOP=I-1

C    FILE 8 CONTAINS INITIAL SURVEY DATA.
      WRITE(8,20)RNG,RNGDAT,ICODE,YNORTH,XEAST,AZMUTH
      WRITE(8,25)DOTDAT,BCHDAT,OFFDAT,NSTOP,NPDOT,NSTOP,NPOFF
      WRITE(8,30)(X1(I),H1(I),I=1,NSTOP)

      IDUNEM = 1
      DO 177 I = 1,NP
      IF (H1(I) .GT. H1(IDUNEM)) IDUNEM = I
177 CONTINUE
      MIN1=1
      DO 178 I = 1,IDUNEM
      IF (H1(I) .LT. H1(MIN1)) MIN1 = I
178 CONTINUE
      MIN2=1
      DO 1781 I = IDUNEM,NP
      IF (H1(I) .LT. H1(MIN2)) MIN2 = I
1781 CONTINUE
      IMAX=IFIX(H1(IDUNEM)+0.2)
      IMIN1=IFIX(H1(MIN1))
      IMIN2=IFIX(H1(MIN2))
      NELM1=IMAX-IMIN1+1
      NELM2=IMAX-IMIN2+1
      NELM=NELM1+NELM2
      NL=NELM
      II=1
      DO 179 I=IMIN1,IMAX
      HA(II)=I
      II = II + 1
179 CONTINUE
      DO 1791 I=IMAX,IMIN2,-1
      HA(II)=I
      II = II + 1
1791 CONTINUE
      DO 2 I=1,NELM
      NCON(I)=1
      2 XA(I)=0.0
      CALL SMOOTH(IDUNEM,1,2)
      CALL SMOOTH(IDUNEM,NP,1)

      NELM1M = NELM1 - 1
      N2=NELM1+1

      DO 17800 M=1,NELM1M
      XASAVE(M) = -XA(M) + X1(IDUNEM)
      HASAVE(M)=-HA(M)
17800 CONTINUE
      XASAVE(NELM1) = X1(IDUNEM)
      HASAVE(NELM1) = -HA(NELM1)
      DO 17820 M=N2,NELM

```

```

        XASAVE(M) = XA(M) + X1(IDUNEM)
        HASAVE(M)=-HA(M)
17820 CONTINUE
C-----FILE 9 CONTAINS INITIAL SMOOTHED CURVE.
        NPDOT = 0
        NPBCH = NL
        NPOFF = 0

        DO 17810 I=1,NL
        IF (HASAVE(I).GT.20.0) GO TO 17812
17810 CONTINUE
17812 NSTOP=I-1

        WRITE(9,20)RNG,RNGDAT,ICODE,YNORTH,XEAST,AZMUTH
        WRITE(9,25)DOTDAT,BCHDAT,OFFDAT,NSTOP,NPDOT,NSTOP,NPOFF
        WRITE(9,30)(XASAVE(I),HASAVE(I),I=1,NSTOP)

        DO 1780 M=1,NELM1
        I=NELM1-M+1
        NCON(I)=2
        XA(I) = -XA(I) + X1(IDUNEM)
        X(M,1)=XA(I)
1780 CONTINUE
        DO 1782 M=N2,NELM
        I=M-NELM1
        XA(M) = XA(M) + X1(IDUNEM)
        X(I,2)=XA(M)
        HA(I)=-HA(M)
        NLS=I
1782 CONTINUE
C-----INITIALIZE 'ACTIVE' PROFILE
        NL=NLS
        X(NELM1,1)=-1000.0
        DO 1783 I=1,NL
1783 XA(I)=X(I,2)
        IF (ICALA.EQ.1) CALL CALCA(A,NL)
        NPDOT = 0
        NPBCH = NL
        NPOFF = 0

C
C-----CONVERT CHARACTER RANGE TO INTEGER RANGE
C
        IRNG=0
        DO 505 I=1,3
        J=I+2
        K=ICHAR(RNG(J:J))
        IF (K.LT.48) GO TO 507
        IRNG=IRNG*10+(K-48)
505 CONTINUE

C-----CHOOSE STORM SURGE HYDROGRAPH ACCORDING TO PROFILE

```



```

507 DO 508 I=1,NHYDRO
    IF (IRNG.GE.IBND(I).AND.IRNG.LT.IBND(I+1)) GO TO 509
508 CONTINUE
509 IHYDRO=I

    NTIMES=NPSTA(IHYDRO)
    SMULT=SRG(IRNG)/STAMAX(IHYDRO)
C    WRITE(6,184)RNG,IRNG,SMULT,STAMAX(IHYDRO),IHYDRO,SRG(IRNG)
184 FORMAT(' RNG,IRNG,SMULT,STAM,IHYDRO,SRG= ',A8,I5,2F7.3,I4,F7.3)

    SSURGE=0.0
    DO 185 I = 1,NTIMES
        STA(I) = STAI(IHYDRO,I) * SMULT
        IF (STA(I).GT.SSURGE) SSURGE=STA(I)
185 CONTINUE
C    WRITE(6,1885)(I,STA(I),I=1,NTIMES)
1885 FORMAT(5(I5,F8.4))

C-----CALCULATE HSTAR TO NEAREST FOOT

    DO 200 I = 1,NL
        XAO(I) = XA(I)
200 CONTINUE
        HS = (0.667 * A**1.5 / XMD)**2
        DXS = (HS / A)**1.5
        HSTAR = HS

C
C    K LOOP - FOR CALIBRATING APPROPRIATE EROSION RATE CONSTANT
C
        DO 300 I = 1,NL
            XA(I) = XAO(I)
300 CONTINUE
            XR = 0.0
            DH(1) = 1.0

C
C    ESTABLISH INSTANTANEOUS WATER LEVEL, ST
C
            DT = PERIOD
            DO 400 I = 2,NL
                DH(I) = (HA(I) - HA(I-1) - DH(I-1)/2.0)*2.0
400 CONTINUE

C
C    NTIMES LOOP - LOOP FOR EACH SURGE VALUE
C
            ZZ=1.0-EXP(-XK*DT)
            NPA=1
            DO 1600 NTIME = 1,NTIMES
                ST = STA(NTIME)
                DO 499 I = 1,NL
                    DPTC(I) = HA(I) + ST
499 CONTINUE

```

```

DPTB = HB/0.8
XB = (DPTB / A) ** 1.5
C
C   ESTABLISH THE INDICES OF STILL WATER LEVEL AND HSTAR
C
    IE = 1
    AA = 100.0
    DO 600 I = 1,NL
    BB = ABS(DPTC(I) - DPTB)
    IF (BB .GT. AA) GO TO 550
    AA = BB
    IE = I
550 IF (ABS(DPTC(I)) .LE. DH(I)/2) IWL = I
    IF (ABS(HSTAR - DPTC(I)) .LE. DH(I)/2) ISTAR = I
600 CONTINUE
    IB=NPA
    DO 1200 IIT = 1,10
    SUM1 = 0.0
    SUM2 = 0.0
    SUM3 = 0.0
    SUM4 = 0.0
    DO 700 I = IB,ISTAR
    SUM1 = SUM1 + (HA(I) + ST - HSTAR) * DH(I) / XMD + DXS * DH(I)
    SUM4 = SUM4 + DH(I)
    SUM3 = SUM3 + XA(I) * DH(I)
700 CONTINUE
    ISP = ISTAR + 1
    DO 800 I = ISP, IE
    SUM4 = SUM4 + DH(I)
    SUM2 = SUM2 + (DPTC(I)/A)**1.5 * DH(I)
    SUM3 = SUM3 + XA(I) * DH(I)
800 CONTINUE
    IEP = IE + 1
    DO 850 I = IEP,NL
    IFILL = I-1
    IF (XR + XB .LT. XA(I)) GO TO 1000
    SUM3 = SUM3 + XA(I) * DH(I)
    SUM4 = SUM4 + DH(I)
    SUM2 = SUM2 + XB * DH(I)
    IFILL = I
850 CONTINUE
1000 CONTINUE
    XRO = XR
    XR = 1.0/SUM4 * (SUM3 - SUM2 - SUM1)
C    BB = (XR - XA(IB)) * XMD - ST - HA(IB) + HSTAR
C    WRITE(6,940) NTIME,IIT,BB,XR,IB,IFILL
940  FORMAT(' NTIME,IIT,BB,XR,IB,IFILL',2I5,2F8.3,2I5)
C+++++
++
C
C    ESTABLISH NEW VALUE OF IB
C

```

```

      IB0 = IB
      BSTAR=XR+DXS-XA(ISTAR)+(DPTC(ISTAR)-HSTAR)/XMD
      BSTAR=BSTAR*ZZ
      XSTAR=XA(ISTAR)+BSTAR
      IB=NPA
C      WRITE(6,1106)
1106  FORMAT(' NTIME, IIT, I, IB, BB, XSTAR, BSTAR, XA(ISTAR), DPTC(I),
- HSTAR, XA(I), ZZ ')
      IB=NPA
      DO 1100 I = NPA, IE
      BB=XSTAR+(DPTC(I)-HSTAR)/XMD-XA(I)
      IF (BB.LT.0.0) GO TO 1110
      IB=I+1
C      WRITE(6,1105) NTIME, IIT, I, IB, BB, XSTAR, BSTAR,
C      - XA(ISTAR), DPTC(I), HSTAR, XA(I), ZZ
1105  FORMAT(4I4, 8F7.2)
      1100 CONTINUE
      1110 CONTINUE
      IF (IB.LT.1) IB=1
      IF ((IB .EQ. IB0) .AND. (ABS(XR0 - XR) .LE. .01)) GO TO 1300
C+++++
++
      1200 CONTINUE
      1300 CONTINUE
C      WRITE(6,1302)
      1302 FORMAT(//)
C
C      CALCULATE DX VALUES
C
      DO 1400 I = IB, IFILL
      IF (I .GT. ISTAR .AND. I .LE. IE) GO TO 1304
      IF (I .GT. IE) GO TO 1350
      DX(I) = XA(I) - (XR + DXS + (HA(I) + ST-HSTAR) / XMD)
      GO TO 1400
      1304 DX(I) = XA(I) - (XR + ((HA(I) + ST)/A)**1.5)
      GO TO 1400
      1350 DX(I) = XA(I) - (XR + XB)
      1400 CONTINUE
      VOLCHG = 0.0
      BA = (1.0 - EXP(-XK*DT))
      DO 1500 I = IB, IFILL
      BB = -DX(I) * BA
      VOLCHG = VOLCHG + BB * DH(I)
      XA(I) = XA(I) + BB
      IF (NCON(NPA).EQ.2.AND.XA(NPA).LT.X(NPA,1)) NPA=NPA+1
      1500 CONTINUE
C      IF (MOD(NTIME,5).NE.0.AND. NTIME.NE.1) GO TO 1510
C      WRITE(6,1505) NTIME, NPA, IB, IWL, ISTAR, IE, ST,
C      - (I, HA(I), XA(I), NCON(I),
C      - X(I,1), X(I,2), I=1, NP)
      1505 FORMAT(1H0, 'NTIME  NPA  IB  IWL  ISTAR  IE  ST',/, 1H ,
- 2I5, I5, I5, I7, I4, F5.2,/, 1H ,

```

```

- '      HA(I)   XA(I) NCON(I)   X(I,1)   X1(I,2)',/,
- (I5,F5.1,F8.1,I8,F10.2,F10.2))
1600 CONTINUE
C
C *** END OF TIME LOOP ***
C
C
      DO 1700 I = 1,NL
      DX(I) = XA(I) - XA0(I)
1700 CONTINUE

      IF (IFCT25.EQ.0) GO TO 1328

      NPA2=NPA
      IE=0
      DO 1322 I=NPA,NL
      IE=I
      IF (DX(I).GT.0.0) GO TO 1323
      XA(I)=XA(I)+1.5*DX(I)
      DXT=DX(I)*2.5
      NB=I
      IF (I.GT.NELM1) GO TO 1322
      IF (XA(I).GT.X(I,1)) GO TO 1322
      XA(I)=X(I,1)
C      DXT=X(I,2)-X(I,1)
      DXT=X(I,1)-X(I,2)
      NPA2=I
1322 DX(I)=DXT
1323 CONTINUE
C      WRITE(6,13222)(I,DX(I),XA(I),HA(I),I=NPA,NL)
13222 FORMAT(I4,3F10.2,/)
C      WRITE(6,13231)(I,XA(I),HA(I),DX(I),I=1,IE)
13231 FORMAT(3(I5,3F7.2))
      NPA=NPA2
C      WRITE(6,13230)NPA,IE,NB,XA(NPA),XA(IE),XA(I),HA(I)
13230 FORMAT(' NPA= ',I3,' IE= ',I3,' NB= ',I3,4F7.2)
      IO=0
      XMIN=10000.0
      DO 1324 I=NPA,NB
      IF (XA(I).GT.XMIN) GO TO 1324
      IF (DX(I).EQ.0.0) GO TO 1324
      XMIN=XA(I)
      IO=I
1324 CONTINUE
C      WRITE(6,13240)IO,XA(IO)
13240 FORMAT(' IO= ',I5,F7.2)
      SUM=0.0
      IF (IO.EQ.0) GO TO 1327
      IBEG=0
      DO 1325 I=1,IO
      XT=XA(IO) - (HA(IO)-HA(I))/XMD
      IF (XT.GT.XA(I)) GO TO 1325

```

```

        IF (IBEG.EQ.0) IBEG=I
        SUM=SUM+XA(I)-XT
        XA(I)=XT
1325  CONTINUE
        II=0
        IF (II.EQ.0) GO TO 1328
        IF (IBEG.EQ.0) GO TO 1327
        DZ=HA(IE)-HA(IBEG)
C      DM=2.0 * SUM / DZ**2
        YMAX=1.5*SUM/DZ
C      WRITE(6,13255) DZ,YMAX,SUM,IBEG
13255  FORMAT(' DZ= ',F9.2,' YMAX= ',F9.2,' SUM= ',F9.2,' IBEG= ',I5)
        DO 1326 I=IBEG,IE
        AA=(HA(IE)-HA(I))/DZ
        XT=XA(I)
        IF (I.LT.IO) XT=XA(IO) - (HA(IO)-HA(I))/XMD
C1326  XA(I)=XT + DM*(HA(IE)-HA(I))
1326   XA(I)=XT + 4.0*YMAX*(AA-AA**2)
1327  CONTINUE

1328  CONTINUE

        DO 17005 I = 1,NL
        DX(I) = XA(I) - XA0(I)
17005  CONTINUE

        NPA2=NPA
        DO 1330 I=NPA,NL
        IF (DX(I).GT.0.0) GO TO 1335
        IF (I.GT.NELM1.OR.XA(I).GT.X(I,1)) GO TO 1330
        NPA2=I
1330  CONTINUE
1335  CHK=XA(NPA2)-X(NPA2,1)
        IF (CHK.LT.-10.0) NPA2=NPA2+1
        NPA=NPA2

1329  S1=0.0
        NPAM=NPA-1
        IF (NPA.EQ.1) GO TO 1721
        DO 1720 I=1,NPAM
        IF (HA(I).GT.0.0) GO TO 1732
1720  S1=S1+(X(I,2)-X(I,1))
1721  DO 1730 I=NPA,NL
        AA=X(I,2)-XA(I)
C      WRITE(6,17221)RNG,I,HA(I),X(I,2),XA(I),AA,S1
17221  FORMAT(A8,I4,5F8.2,/)
        IF (HA(I).GT.0.0) GO TO 1732
        IF (AA.LT.0.0) GO TO 1732
1730  S1=S1+AA
1732  CONTINUE
        VOL=S1/27.0
        VOLTOT=VOLTOT+VOL

```

C-----WRITE INFO FOR REDUCE/INCREASE EROSION.

```
C      CVAL=HA(NPA)
1699 DO 1701 I=1,NL
      IF (HA(I).EQ.CVAL) GO TO 1702
C      IF (DX(I).NE.0.0) GO TO 1702
C      CVAL=CVAL+2.0
C      GO TO 1699
1701 CONTINUE
1702 NRNG=I
C      WRITE(6,1784)RNG,IRNG,NRNG,CVAL,HA(NRNG),DX(NRNG)
1784 FORMAT(' RNG,IRNG,NRNG,CVAL,HA,DX= ',A8,2I5,F7.2,2F7.2)

      WRITE(15,11010)RNG,HA(NRNG),DX(NRNG),XA(NRNG),VOL
11010 FORMAT(A8,4F10.2)
```

C-----*****

```
      WRITE(12,1717) RNG,A
1717  FORMAT(5X,A8,F10.4)
```

C-----*****

```
      WRITE(6,11001)RNG,SSURGE,IMAX
11001 FORMAT(/,1X,A8,'WTL= ',F4.1,
- ', DUNE ELEV.= ',I2,', LOC. RELATIVE TO MONU.(FT.)
DISTANCE
-ERODED (FT.)',/)

      IPRT=0

      DO 1550 IJK = NPA,NL
```

C-----WRITE INFO FOR FIRST POINT IN ERODED PROFILE.

```
      IPRT=IPRT+1
      IF (IPRT.GT.2) GO TO 1531
      H=AMOD(HA(IJK),5.0)
      IF (H.EQ.0) GO TO 1531
      WRITE(6,11000)HA(IJK),XA(IJK),DX(IJK)
1531  IF (HA(IJK) .NE. -25.0) GO TO 1532
      XTOT(6)=XTOT(6)+XA(IJK)
      DXTOT(6)=DXTOT(6)+DX(IJK)
      NTOT(6)=NTOT(6)+1
      WRITE(6,11000) HA(IJK),XA(IJK),DX(IJK)
11000 FORMAT(1H ,15X,F5.1,' FT. CONTOUR: ',10X,F9.1,17X,F9.1)
1532  IF (HA(IJK) .NE. -20.0) GO TO 1534
      XTOT(5)=XTOT(5)+XA(IJK)
      DXTOT(5)=DXTOT(5)+DX(IJK)
      NTOT(5)=NTOT(5)+1
      WRITE(6,11000) HA(IJK),XA(IJK),DX(IJK)
```

```

1534 IF (HA(IJK) .NE. -15.0) GO TO 1536
      XTOT(4)=XTOT(4)+XA(IJK)
      DXTOT(4)=DXTOT(4)+DX(IJK)
      NTOT(4)=NTOT(4)+1
      WRITE(6,11000) HA(IJK),XA(IJK),DX(IJK)
1536 IF (HA(IJK) .NE. -10.0) GO TO 1538
      XTOT(3)=XTOT(3)+XA(IJK)
      DXTOT(3)=DXTOT(3)+DX(IJK)
      NTOT(3)=NTOT(3)+1
      WRITE(6,11000) HA(IJK),XA(IJK),DX(IJK)
1538 IF (HA(IJK) .NE. -5.0) GO TO 1540
      XTOT(2)=XTOT(2)+XA(IJK)
      DXTOT(2)=DXTOT(2)+DX(IJK)
      NTOT(2)=NTOT(2)+1
      WRITE(6,11000) HA(IJK),XA(IJK),DX(IJK)
1540 IF (HA(IJK) .NE. 0.0) GO TO 1550
      XTOT(1)=XTOT(1)+XA(IJK)
      DXTOT(1)=DXTOT(1)+DX(IJK)
      NTOT(1)=NTOT(1)+1
      WRITE(6,11000) HA(IJK),XA(IJK),DX(IJK)
1550 CONTINUE

      WRITE(6,1734)VOL
1734 FORMAT(1H0,13X,'VOLUME ERODED:      ',F10.2,' CUBIC YARDS PER
FOOT
      - ')

      NP=NL -NPA+1
      DO 1551 KK=NPA,NL
      IF (HA(KK).GT.20.0) GO TO 1552
1551 CONTINUE
      NSTOP=NL
      GO TO 1554
1552 NSTOP=KK-1
1554 NP=NSTOP-NPA+1
C      FILE 10 CONTAINS ERODED SMOOTHED CURVE.
      WRITE(10,20)RNG,RNGDAT,ICODE,YNORTH,XEAST,AZMUTH
      WRITE(10,25)DOTDAT,BCHDAT,OFFDAT,NP,NPDOT,NP,NPOFF
      WRITE(10,30)(XA(KK),HA(KK),KK=NPA,NSTOP)
C      FILE 13 CONTAINS A VALUES.
C      WRITE(13,77)RNG,A
      77 FORMAT(A8,F10.4)
      GO TO 175
9999 IF (PROF.LE.1.0) GO TO 99999
      WRITE(6,10050)CNTY
C      WRITE(6,10055)XMD,XK,A
      IF (IFCT25.EQ.1) WRITE(6,10060)
      IF (IFCT25.EQ.0) WRITE(6,10065)
      WRITE(6,1560)
1560 FORMAT(///,6X,'TOTALS FOR ALL PROFILES      LOC. RELATIVE TO
M      -ONU.(FT.)  DISTANCE ERODED (FT.)',/)

```

```

DO 1570 I = 1,6
IF (NTOT(I).NE.0) GO TO 1575
XTOT(I)=0.0
DXTOT(I)=0.0
GO TO 1577
1575 XTOT(I)=XTOT(I)/NTOT(I)
DXTOT(I)=DXTOT(I)/NTOT(I)
1577 CONT=FLOAT(I-1)*5.0
WRITE(6,1580) CONT,XTOT(I),DXTOT(I)
1580 FORMAT(1H ,15X,F5.1,' FT. CONTOUR: ',10X,F9.1,17X,F9.1)
1570 CONTINUE
VOLT=VOLTOT/PROF
WRITE(6,1590)VOLTOT,VOLT
1590 FORMAT(1H0,5X,'TOTAL VOLUME ERODED FOR ALL PROFILES: ',F10.2,/
- 1H ,5X,'AVERAGE VOLUME ERODED FOR ALL PROFILES:
',F10.2,/)
C
99999 CONTINUE
CLOSE(4)
CLOSE(5)
CLOSE(6)
CLOSE(8)
CLOSE(9)
CLOSE(10)
CLOSE(12)

STOP
END

SUBROUTINE SMOOTH(NBEG,NMAX,ICODE)
C
C SUBROUTINE TO SMOOTH SURVEY DATA.
C IF ICODE EQUALS 2, SUBROUTINE HAS BEEN CALLED TO SMOOTH REAR
C OF DUNE; IF ICODE EQUALS 1, SUBROUTINE HAS BEEN CALLED TO
C SMOOTH FRONT OF DUNE. SMOOTHING OCCURS FROM HIGHEST ELEVATION
C TO EITHER FIRST OR LAST SURVEY POINT.
C SUBROUTINE USES SURVEY H AND X VALUES TO SET VALUES FOR XA,
C GIVEN PREVIOUSLY SET HA VALUES (FROM MAIN).
C
COMMON /A/ H1(200),XA(200),HA(200),NELM,X1(200),NP,NELM1
NSTART=NBEG
NFINI=NMAX-1
IF (ICODE .EQ. 2) NFINI = NMAX
IF (ICODE .EQ. 2) NSTART = NBEG - 1
C WRITE(6,10)NSTART,NFINI
10 FORMAT(' NSTART,NFINI ',2I5)
INC = 1
IF (ICODE .EQ. 2) INC = -1

DO 800 I = NSTART,NFINI,INC
H11=H1(I)
H22=H1(I+1)

```



```

        DH=ABS(H11-H22)
        DX=X1(I+1)-X1(I)
        HU=H11
        HL=H22
C      WRITE(6,20)H11,H22,DH,DX,HU,HL
20      FORMAT(' H1,H2,DH,DX,HU,HL ',6F7.2)
        IF (H22.LT.H11) GO TO 100

        HU=H22
        HL=H11
100     NEL1 = NELM1
        NEL2 = NELM
        IF (ICODE .NE. 2) GO TO 200
        NEL1 = NELM1
        NEL2 = 1

200     DO 300 NEL=NEL1,NEL2,INC
        IF (HA(NEL).LT.HU) GO TO 400
300     CONTINUE

C400    WRITE(6,30)NEL,NEL1,NEL2,HA(NEL),HU
30      FORMAT(' NEL,NEL1,NEL2,HA(NEL),HU',3I5,2F7.2)
400     NB=NEL
        NEL2 = NELM
        IF (ICODE .EQ. 2) NEL2=1

        DO 700 N = NB,NEL2,INC
        IF (HA(N).GT.HL) GO TO 600
        XA(N)=XA(N)+DX
        GO TO 700

600     DEL1 = (HU - HA(N))/DH
        XA(N) = XA(N) + DX * DEL1
C      WRITE(6,40)N,HA(N),HL,X(N),XA(N),DEL1
40      FORMAT(' N,HA(N),HL,X(N),XA(N),DEL1 ',I5,5F7.2)
700     CONTINUE

800     CONTINUE
        RETURN
        END
C*****
**

SUBROUTINE CALCA(A,NL)
COMMON /A/ H1(200),XA(200),HA(200),NELM,X1(200),NP,NELM1
XM=2.0/3.0
SUM1=0.0
SUM2=0.0
N=0
XS=0.0
DO 10 I=1,NL
IF (HA(I).LT.0.0) GO TO 10
IF (XS.NE.0.0) GO TO 5

```

```

C      IX=I
      XS=XA(I)
      GO TO 10
5     SUM1=SUM1 + ALOG(XA(I)-XS)
      SUM2=SUM2 + ALOG(HA(I))
      N = N + 1
10    CONTINUE
      XN = FLOAT(N)
      A = EXP((SUM2 - XM*SUM1)/XN)
C      WRITE(6,12)
12    FORMAT('      I      XA(I)      HA(I)',/)
C      WRITE(6,13)(I, XA(I), HA(I), I=1, NL)
13    FORMAT(I5, F10.2, F10.2)
C      WRITE(6,15)SUM1, SUM2, XN, A, XS, IX
15    FORMAT(' SUM1= ', F8.2, ' SUM2= ', F8.2, ' XN= ', F8.2, ' A= ', F8.2,
-        ' XS= ', F8.2, ' IX= ', I5,/)
      RETURN
      END

```