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INSTRUCTION REPORT CERC-85-2

APPLICATION OF THE DUTCH METHOD FOR ESTIMATING STORM-INDUCED **DUNE EROSION**

by

Francis E. Sargent, William A. Birkemeier

Coastal Engineering Research Center

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May 1985 **Final Report**

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20. ABSTRACT (Continued).

and sediment size, and that the amount of material eroded will equal the deposition (i.e., cross-shore transport). The method has been verified for the Dutch coast based on both field measurements and laboratory experiments. An evaluation using a limited amount of data for the Atlantic and Gulf coasts of the United States found quantitative agreement with the method, justifying its application to storm conditions in the United States. This report discusses the method and identifies its inherent limitations. The procedure may be solved graphically or by using the included FORTRAN computer program.

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PREFACE

This report presents an easy-to-use procedure recently developed by the Dutch for predicting dune and beach erosion under large storm surge conditions. The report was prepared as part of the Storm Erosion Studies Work Unit 31467, Shore Protection and Restoration Program of the Coastal Engineering Research Center (CERC), US Army Engineer Waterways Experiment Station (WES).

This report was prepared by Messrs. Francis E. Sargent and William A. Birkemeier, Hydraulic Engineers, under the direct supervision of Mr. Curt Mason, Chief, Field Research Facility, and Dr. James R. Houston, Chief, Research Division, CERC. Dr. Robert W. Whalin was Chief of CERC.

COL Robert C. Lee, CE, was Commander and Director of WES during the publication of this report. Mr. Fred R. Brown was Technical Director.



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APPLICATION OF THE DUTCH METHOD FOR ESTIMATING STORM-INDUCED DUNE EROSION

PART I: INTRODUCTION

1. When a storm generates large wave and surge conditions, changes in the beach topography and nearshore bathymetry occur, often with significant beach and dune erosion. Until recently, little quantitative information on the prediction of beach and dune erosion existed to aid coastal engineers. The US Army Engineer Coastal Engineering Research Center's (CERC) Shore Protection Manual (1977) gives beach erosion quantities based only upon a qualitative description of a storm.

2. Based on the earlier work of Edelman (1968) and comprehensive model testing, Vellinga (1983) reported on an empirical method developed at the Delft Hydraulics Laboratory, Emmeloord, Netherlands, for estimating dune erosion for a given design storm. Though the method was designed for the Dutch coast, it provides reasonable results for the available data from events along the Gulf and Atlantic coasts of the United States, making it a useful tool for the design of dunes and beach fill projects and for identifying beaches vulnerable to storm damage. The purpose of this report is to describe the method and identify its limitations. The report includes an example problem using the method and an interactive computer program (FORTRAN 77) for applying it.

3. The three basic assumptions underlying the method are that (a) the shape of the poststorm profile is in equilibrium (the procedure does not include time dependency), (b) transport is in the offshore direction, and (c) the amount of material eroded must equal the amount deposited. There is no provision for handling longshore gains or losses to the profile. The concept is illustrated in Figure 1.

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Figure 1. Definition sketch of prestorm and predicted poststorm profiles showing the resulting erosion and accretion zones (Vellinga 1983)

PART II: METHOD OF ANALYSIS

4. The method requires information about the shape of the prestorm profile (x_i , y_i , see Figure 1); the sediment fall velocity, w; the significant deepwater wave height, H_{OS} ; and the peak storm surge level, S .* The prestorm profile should consist of field data taken offshore to a depth at least equal to 0.75 H_{OS} below S (paragraph 6). If actual offshore data are unavailable, it may be possible to estimate the offshore portion of the profile using hydrographic charts or a predicted equilibrium shape (Dean 1977, Everts 1978). This will, however, decrease the accuracy of the method. The fall velocity, w, should correspond to the median sediment diameter, D_{50} , which is representative of the section of the profile that is expected to erode. Typically, D_{50} should be computed based on a composite of samples from the beach and dune zones. The fall velocity can be graphically determined from Figure 2 for a given water temperature and D_{50} .

5. The method is applicable within the varying range of wave steepness, $0.02 \leq H_{os}/L_{o} \leq 0.04$, where L_{o} is the significant deepwater wave length, and assumes a storm surge hydrograph similar to those occurring in the North Sea (Figure 3), with S defined as the summation of the astronomical high tide and the storm-induced water level relative to mean sea level (msl). This hydrograph is characterized by its height and short duration, and is similar to that produced by tropical storms along the coast of the United States. A procedure recommended by Vellinga (1983) for modifying the results for longer duration storm surges is discussed in paragraph 14. Ideally, both S and the wave height should be measured outside the breaker zone and the corresponding deepwater wave height, H_{os} , should be computed. Estimates of H_{os} and S could also be obtained from historical data, statistical analysis (Van de Graaff 1983), or numerical modeling of the storm conditions.

For convenience, symbols and unusual abbreviations are listed and defined in the Notation (Appendix B).







Figure 3. Typical time history of North Sea storm surge, with a return period of 10,000 years (Vellinga 1983)

6. Once H_{os} , S, and w have been determined, the shape of the poststorm profile can be obtained using the following equation:

$$y = \frac{2.0 - 0.47 \left[x \left(\frac{7.6}{H_{os}} \right)^{1.28} \left(\frac{w}{0.0268} \right)^{0.56} + 18 \right]^{0.5}}{\left(\frac{7.6}{H_{os}} \right)}$$
(1)

where x , y , and H are in meters and w is in m/sec. The profile defined by Equation 1 terminates offshore at

$$x = 250 \left(\frac{H_{os}}{7.6}\right)^{1.28} \left(\frac{0.0268}{w}\right)^{0.56}$$
(2)

which, substituting into Equation 1, yields

$$y = 0.75 H_{0.05}$$
 (3)

Constant slopes are used to terminate the profile at the shoreward end $(m_1 \text{ at } x = y = 0)$ and seaward end (m_2) of Equation 1 and are defined as

$$m_1 = -1:1$$
 (4)

$$m_{2} = -1:12.5$$
 (5)

Use of this steep poststorm dune face m_1 is consistent with field observations, and m_2 is arbitrarily fixed in agreement with model tests.

7. Once the poststorm profile is obtained, its position relative to the prestorm profile is determined by horizontally shifting the origin (x = 0, y = 0) along S until the erosion area A_e equals the deposition area. Then A_e , the gross area change A_g (equal to $2A_e$ since erosion is equal to deposition), the erosion area above the surge level A_s , and the horizontal dune recession R can be found using either the graphical or computational means described in Part VI.

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PART VIII: SUMMARY

22. An empirical model, developed using data from the field and from an extensive series of two-dimensional large- and small-scale movable bed model tests, has been proposed by the Dutch to estimate dune erosion for large storm surges. The model has been evaluated using less extreme field data from the United States Atlantic and Gulf coasts and should provide useful estimates of storm erosion. However, the user should be aware of the method's inherent limitations (Part V) and assumptions (Part I) when applying the model to site-specific conditions.

Since this is less than the maximum recommended change of 50 percent, A $_{\rm S}$ can be computed as

$$A_s = 1.4 \times 87.2 = 122.1 \text{ m}^3/\text{m}$$

which would be the required quantity of material above 3 m. Assuming the additional material (34.9 m^3/m) has a constant elevation of +6 m, the additional dune recession is equal to

$$34.9/(6 - 3) = 11.7 \text{ m}$$

which places the dune crest at

$$-75.8 - 11.7 \text{ m} = -87.5 \text{ m}$$

a result identical to the one for the hurricane. Consequently, a dune crest width greater than 27.5 m is adequate for either the hurricane or storm conditions.

b. Given for northeaster:

$$S = 3.0 m$$

 $H_{os} = 8.0 m$
 $D_{50} = 0.35 mm$
 $t = 2°C$

duration = 9 hours

Solution: Since the width of the dune crest is unknown, extend it in the shoreward direction at a constant elevation of 6 m. From the computer program (or graphically), we find for the hurricane that $A_e = -155.5 \text{ m}^3/\text{m}$, $A_s =$ the erosion quantity above 4 m as -79.4, and R = -85.5 m, where R is defined as the poststorm position of the profile/surge level intercept. Then assuming the 1:1 slope of the dune face, the position of the dune crest (y = +6 m) can be determined as

$$-85.5 - (6 - 4) = -87.5 m$$

Since the prestorm dune crest position is at -50 m, a crest width of 27.5 m is required. Note that the value of A_s for the hurricane did not have be duration adjusted since the storm duration (time the surge is within 1 m of peak surge, S) is equal to the North Sea storm duration of 5 hours.

21. For the northeaster, the following erosion estimates are $A_e = -145.6 \text{ m}^3/\text{m}$, $A_s =$ the erosion quantity above 3 m = 87.2 m $^3/\text{m}$, and R = -72.8 m. In following a treatment similar to that for the hurricane, we find the dune crest position to be

$$-72.8 - (6 - 3) = -75.8 \text{ m}$$

In order to adjust the volume and R to account for the 9-hour storm duration of the northeaster, use the procedure outlined in paragraph 14. Assuming (conservatively) a 10 percent additional change in volume per additional hour, then

$$10(9 - 5) = 40$$
 percent



Figure 8. Equilibrium profile at Duck, N. C., with the predicted profile computed from the storm conditions listed

Example 2

20. Using the prestorm profile of example 1 and the computer program in Appendix A, find the maximum A_s and the width of the dune crest required to prevent dune failure for the following conditions (this could also be solved graphically):

a. Given for hurricane:

$$S = 4.0 m$$

 $H_{os} = 9.0 m$
 $D_{50} = 0.35 mm$
 $t = 27°C$

duration = 5 hours

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PART VII: EXAMPLE PROBLEMS

Example 1

19. Figure 8 shows the predicted erosion caused by a simulated storm passing CERC's Field Research Facility in Duck, N. C. The storm produced 7-m deepwater waves and a 2.5-m surge. Using the graphical technique, compute the erosion which will occur if the surge had been 2.7 m. (The computational solution to the problem shown in Figure 8 is included in Appendix A.)

Given:	$H_{os} = 7.$	0 m								
	S = 2.	7 m								
	$D_{50} = 0.$	35 mm								
	t = 25	°C								
	<u></u>		Pr	estorm	Profile	(m)				
i	1	2	3	4	5	6	7	8	9	10
×i	-500	-110	-80	-60	-50	-40	0	40	200	1200
У _і	3	3.5	4	6	6	3	0	-2	-5	-10

Solution:

- <u>a</u>. Given $D_{50} = 0.35 \text{ mm}$, $t = 25^{\circ}\text{C}$, use Figure 2 to determine w = 0.0474 m/s.
- b. Plot the prestorm profile on graph paper. Compute the poststorm profile using Equations 1-5 and plot on tracing paper. (Or, since w and H os are the same as in Figure 8, both profiles can be traced, as poststorm shape is independent of S.)
- <u>c</u>. Position poststorm profile at 2.7 m on the prestorm profile and slide it horizontally until the erosion and accretion areas between the two profiles balance.
- <u>d</u>. Once the areas balance, compute $A_e = -78 \text{ m}^3/\text{m}$ and $A_s = -44 \text{ m}^3/\text{m}$ by planimeter or by counting graph paper squares.
- e. Once plotted, the shift of the surge level contour can also be determined as -19.9 m.

PART VI: GRAPHICAL AND COMPUTATIONAL PROCEDURES

17. The simplicity of the model permits a graphical solution of the method. An example is given in Part VII. The procedure consists of

- <u>a</u>. For given values of H_{OS} and w (obtained from Figure 2), construct a template of the predicted poststorm profile using Equations 1-5.
- <u>b</u>. Position the predicted dune toe (x = y = 0) of the template at the surge level intercept of the prestorm profile. Slide the template horizontally shoreward until the erosion area appears to equal the accretion area.
- <u>c</u>. Using a planimeter (or other method), find the erosion (-) and accretion (+) areas. Repeat the procedure, sliding the template right or left until the areas balance within acceptable limits (e.g. erosion area = accretion area ± 5 percent).

18. An interactive computer program written in FORTRAN 77 is included in Appendix A along with instructions and a sample run. The computer program has several features to aid the interactive user including

- <u>a</u>. Computation of w , when the user supplies D_{50} and t (Figure 2).
- b. Use of English or metric system of measurement.
- c. Multiple interactive runs on the same profile, changing S , H_{os} , and w as desired.
- d. Output of erosion quantities to the user's terminal for immediate use.
- e. Error detection of input data, failure of convergence on a solution, or computation of nonvalid solution.

model solution will be valid if the elevation behind the dune is significantly higher (1 to 2 m) than the surge elevation, causing little or no overwash. Determination of the dune failure point for existing dune cross sections and design dune cross sections under various storm intensities can also be useful in designing protective dunes.

16. Another possible limitation which must be considered is the shape of the natural and predicted profiles. The method should work best for profiles that are similar to the Dutch ones used to develop the model (Figure 1). It may not work on profiles which deviate significantly from the typical Dutch profile. This problem was encountered first on a beach with a very flat offshore zone which covered a layer of peat. For this particular locality, the profile shape predicted by Equation 1 was too steep and always fell below the actual profile in the offshore region where deposition (not erosion) was expected. Similar problems may occur when the procedure is applied to a design beach, berm, or dune cross section which may be significantly different from the natural profile shape.

PART V: LIMITATIONS OF THE METHOD

13. The method assumes that all transport is in an offshore direction, that there is sufficient material to erode, and that the poststorm shape is in equilibrium. While these assumptions are probably acceptable for a single large event, over the long term (or where there are gradients in longshore transport) they may not be valid. For instance, as a result of the equilibrium assumption, for any additional erosion to occur following a storm, a larger storm must occur. In reality, a minor storm or several minor storms may cause the same amount of change as predicted for the larger event. Therefore, the engineer should he aware of long-term erosion trends and use the method with care in areas with known gradients in long-shore transport (near inlets, rivers, man-made or natural barriers, etc.). Similarly, the method should not be applied to beaches without dunes or beaches with seawalls.

14. Another assumption of the model is that the storm surge hydrograph should be similar to that shown in Figure 3. Although there is reasonable agreement between the model data and the United States data (Figure 5), the model appears to work best for large surge events (i.e., large A_{c} , Figure 4) since it was derived from experimental and field data with S greater than 3 m. The assumed duration of the surge peak (Figure 3) is similar to that of hurricanes occurring along the United States coast, but can be significantly shorter than that produced by a "northeaster." Based on large scale laboratory tests, Vellinga (1983) suggests increasing the erosion quantity A_s 5 to 10 percent for each additional hour of storm duration (maximum additional change not to exceed 50 percent of A_{c}). Storm duration is defined as the amount of time the surge level is within 1 m of S , minus the duration of the North Sea hydrograph (Figure 3) under the same criteria (5 hours). Note that this adjustment should be used as an upper estimate for erosional losses and may, in fact, be reduced by other factors such as offshore formations (paragraph 12). For example, although some of the data shown in Figure 5 should have been duration adjusted, a better agreement was obtained using adjusted values.

15. Model results may become questionable at the point of "dune failure," when the poststorm profile slope m_1 intercepts the prestorm profile landward of the dune crest. The possibility of overwash and shoreward movement of sand is not taken into account in the present model. Of course, the



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Figure 6. Erosion above surge level A as compared to the median sediment size D_{50} and the significant "deepwater" wave height H for the conditions shown



Figure 7. Erosion above surge level as compared to A_s surge level S and the significant deepwater wave height H_{os} , for the conditions shown

PART IV: SENSITIVITY OF THE METHOD

11. The explicit termination of the poststorm profile (m_1, m_2) and the arbitrary nature of the prestorm profile (dune shape, barred profile, etc.) make it difficult to quantitatively demonstrate how A_{p} (or A_{s}) changes with changes in H_{os} , S , or w . Vellinga (1983) presents a set of experiments showing the effect of several factors on A_s . He found that A_s was proportional to H_{OS} , S, and the dune height, and that the trends predicted by the model agreed with the experimental data. Using several profile shapes and varying H_{os} , S , and w , qualitative estimates on the model's variability were obtained using the FORTRAN program given in Appendix A. In general, A_{e} and A_{s} vary directly with H_{os} and S, and are inversely proportional to w. These trends are shown in Figures 6 and 7 for a representative profile shape. Depending on the profile shape, small changes (10 percent) in H_{oS} , S, or w can result in either large (greater than 30 percent) or small changes in A_e (and A_s). This points to the equal importance of H_{os} S , and w in the modeling of dune erosion (although H and S are implicitly coupled). The water temperature t, required in determining w, can be very important in determining A_{ρ} , particularly from summer to winter when a change in t from 25°C to 5°C can cause A_e to increase by 70 percent.

12. Vellinga (1983) also indicated that the method is sensitive to the presence of an offshore bar and trough. He found from a series of model tests that when offshore bars were present, the model overpredicted A_s by 28 percent compared with 9 percent overprediction for similar experiments without offshore formations. This discrepancy may result from dissipation of incident wave energy by the bar. Because of the model's sensitivity to offshore features, knowledge of the typical bar and trough formations in a particular study area may help in interpreting the dune erosion estimates.

of the prestorm and poststorm offshore profile shape, wave height, storm surge and sediment size.

10. Since above surge level changes (A_s) were small and similar in magnitude to the models' accuracy (σ_{A_s}) , values of A_{msl} [the change above mean sea level (msl)] have been plotted. Values of A_{msl} have not been adjusted for duration (see paragraph 14). Even for these relatively low quantities, the model produces reasonable estimates of erosion which are within the accuracy given in Equation 6. Predicted poststorm profile shapes were not usually in good agreement with actual poststorm profile shapes. Possible reasons for this could be the low magnitude of the surge levels, the use of assumed off-shore data for some points, and the timing of the surveys (some of the data, particularly data from Westhampton, showed evidence of poststorm recovery). The data in Figure 3 suggest lower bounds for the storm surge and wave height of S = 1.5 m and $H_{os} = 3.5$ m. At values higher than these, there is better agreement between predicted and actual changes. At lower values, erosion is not necessarily universal, and some profiles on a given beach experience accretion.

The method also reasonably predicted changes (S = 2.4 m) in Florida (Hughes and Chiu 1981) caused by Hurricane Eloise.*

9. To further confirm the method, historic CERC data from United States' beaches for three storms were analyzed and are presented for a number of profile lines in Figure 5, along with the Hurricane Eloise data of Hughes



Figure 5. Comparison of predicted erosion A_{msl} and measured erosion for US Atlantic and Gulf coast data

and Chiu (1981). Profile data for the two February 1972 storms at Westhampton, N. Y., were from DeWall (1979) using hindcasted wave data and a fitted offshore slope. The storm surge was measured by a tide gage at Sandy Hook, N. J. Data from Long Beach Island, N. J., including surge data from Atlantic City, N. J. and wave gage data from near Sandy Hook, N. J., were reported by Birkemeier (1979). The offshore portion of the profiles were fitted using data from Everts (1978) and Dean (1977). Data from Duck, N. C., were collected near CERC's Field Research Facility and include detailed measurements

 ^{*} Personal communication from Pier Vellinga, Subject: "Verification of Predictive Computational Model for Beach and Dune Erosion During Storm Surges -Verification for Field Data of Dune Erosion Caused by Hurricane Eloise at Walton County in Florida, September 1975," February 1983.

PART III: MODEL EVALUATION

8. Because of the general lack of extreme event profile data, the model is primarily based on an extensive series of small- and large-scale model tests. Results from these experiments compared with results from the predictive model are reported in Vellinga (1978, 1982, 1983) and are shown in Figure 4 for A_c . Figure 4 also includes field data from a storm surge event



Figure 4. Comparison of predicted dune erosion A and measured dune erosion (Vellinga 1983)

(S = 3.0 m) that occurred on the coast of the Netherlands in 1976. The field and experimental data are in good agreement with the predicted erosion quantities, and poststorm surveys following a 1953 Dutch storm surge (S = 3.9 m) confirm the shape of the predicted poststorm profile. Using statistical analysis of the data, Vellinga (1983) specifies the standard deviation of the prediction (shown as dashed lines in Figure 4) as

$$\sigma_{A_{s}} = (0.10 A_{s} + 20) m^{3}/m$$
 (6)

APPENDIX A: FORTRAN DUNE EROSION PROGRAM

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Explanation of Program

1. A listing of "DUNE," the FORTRAN 77 dune erosion program, is included here, preceded by an interactive example run. This 700-line program has been adequately documented throughout with comment cards to aid users in modifying and understanding the program. The program first requests interactive input of the prestorm profile shape, sediment characteristics, and storm conditions. It also asks for the entry of two datums: one to define the surge height and one for use in volume computations. Once all required inputs have been entered, the program determines the poststorm profile shape, computes the location of the poststorm profile using a modified secant method, and computes the area changes (Ae, As). If the duration of the storm surge exceeds 5 hours, the program computes an adjusted estimate of the erosion using the procedure described in paragraph 14 of the main text. Program output is returned to both the user's terminal and a local file (FORTRAN Unit 14) for later printing.

2. All interactive input is from the user's terminal (FORTRAN Unit 5). User input in the example follows the input prompt "?". This may differ (or be a blank) on different computer systems. Required input data are entered in free format with multiple entries separated by blanks (as in the example) or by commas. "Yes" or "no" questions require either a Y or an N response. Program execution may be terminated at any time by entering a carriage return after the input prompt (signaling an End-of-File on input).

- 3. The user is first asked to label his data with the following:
 - a. Locality code: 2-character beach identifier
 - b. Profile number: range or line number
 - c. Survey number: repetitive survey number
 - d. Date: the date of the survey (YYMMDD)

The user is then asked if the computations and data entry are to be done in English units (a Y response) or metric (an N response). Units must be consistent throughout with the exception of the sediment size which must be entered in millimeters.

4. The user must next enter the survey data which define the prestorm profile shape. The points are entered, one per line, with distance (X_i) followed by elevation (Y_i) . Up to 110 points may be entered and they should be entered in ascending order (the program checks for this). Data should be

A2

entered accurately since the program has no provision to interactively list or correct entered data. Enter a carriage return to terminate survey data entry.

5. The following information is requested to begin the computation (a similar listing is also available interactively):

- a. Surge datum: Vertical datum, relative to the profile datum used to define the relative positioning of the surge height in m (or ft).
- b. Surge height: Height of the storm surge above the surge datum in m (or ft).
- <u>c</u>. Wave height: Significant wave height H_{OS} in m (or ft).
- <u>d</u>. Change datum: Vertical datum, relative to the profile data, above which the erosion quantity, A_s , will be computed.
- e. Storm duration: The duration in hours that the surge level is within 1 m (3.3 ft) of the peak surge height. This is optional. Enter a zero if the duration is unknown.

6. The use of two datums in the calculations allows considerable flexibility in the input data. The surge datum allows the surge height to be entered relative to a datum other than the datum of the profile data. For example, profile data are often measured relative to mean sea level (msl = 0) while tide data may be measured relative to mean low water (mlw = 0). In this case, using for surge height the actual tide data, enter for the surge datum the difference between msl and mlw (which should be a negative value). The change datum defines the lower boundary for the computation of A_s . Normally, A_s is computed relative to the surge level. (To do so, enter the height of the surge, relative to the profile datum.) It is also possible to compute a modified value of A_s relative to any elevation. For instance, to compute the change above msl, enter a zero for the change datum (if the profile data are relative to msl).

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7. The sediment fall velocity may be entered directly or computed for a given sediment size and water temperature. The fall velocity should be entered in m/sec (or ft/sec), the median sediment size in mm, and the temperature in degrees C (or degrees F).

8. Following data entry, the program computes and displays at the terminal:

<u>a</u>. The total erosion area (A_e) - the volume of the total eroded area, regardless of datum.

A3

- <u>b</u>. The above datum change (A_s) the volume change above the change datum.
- c. The horizontal shift of the change datum intercept.

- <u>d</u>. The position, relative to the profile data, of the poststorm surge level intercept.
- e. An adjusted value of A which accounts for storm duration (if the duration exceeded 5 hours).

Note that in determining the adjusted value of A_s , the program does not check to see if sufficient additional material actually exists. Use the adjusted amount only as an indicator of the possible erosion. In addition to the terminal output, a more complete summary of the run is written to FORTRAN Unit 14 for later routing to a printer. The Unit 14 output includes a listing of all input and output data and a listing of the coordinates which define the predicted poststorm profile shape (unadjusted for the storm duration).

9. Following each run, the user is asked if another run is desired. Since the profile data need not be re-entered, multiple runs can be used to determine the effect of varying any of the parameters.

10. There are instances when the program will be unable to compute a solution. These include the following:

- <u>a</u>. Input errors resulting from incorrect entry of the input data or use of illegal values.
- b. A surge height that is higher than the highest point on the profile.
- c. A change datum that is higher or lower than the data defined by the predicted profile.
- d. A predicted profile shape that falls either above or below the prestorm shape in a zone where the opposite should occur. For example, the predicted profile should fall above the prestorm profile in the offshore zone and below the prestorm on the beach. If this does not occur, the procedure will not work.
- e. If the prestorm profile has insufficient beach or dune width for the procedure, the predicted profile will fall landward of all the prestorm data points and an incorrect solution will result.

The program prints an error message when each of these (or variations of them) are encountered. When possible, the program will still compute results but the user should use them with care. The best way to identify the effect of an error is to plot the prestorm and predicted profile data to see if a reasonable solution was obtained. 11. Should the program fail to converge on a solution, it may be useful to examine the sequence of iterations which occurred. These are printed out in reverse order (from the most recent iteration) on Unit 14 after each run. The top line is the iterations required to determine the horizontal shift of the profile (relative to the datum of the profile data) and the second line is the difference between the erosion and accretion volumes (which should be nearly equal to zero for the most recent iteration).

12. As written, the three subroutines to program DUNE are compatible with the Interactive Survey Reduction Program (ISRP) developed by Birkemeier (1984).* With minor modifications to the ISRP calling and plotting routines (which has been done), it is possible to interactively generate and plot the actual and pre- and poststorm profiles, together with the program's predicted profile (Figure 8). In addition, ISRP has much more powerful survey data entry, modification, and correction capability than program DUNE. Corps of Engineers users interested in either DUNE or ISRP should contact the Coastal Engineering Research Center.

^{*} References are located at the end of the main text.

INTERACTIVE PROGRAM EXAMPLE

DUNE - A PROGRAM TO ESTIMATE STORM INDUCED DUNE EROSION. WRITTEN BY FRANCIS SARGENT, CERC, 1983. THIS PROGRAM USES A PROCEDURE DEVELOPED BY VELLINGA OF THE DELFT HYDRAULICS LABORATORY, THE NETHERLANDS. NOTE - A CARRIAGE RETURN AT ANY TIME HILL TERMINATE PROGRAM EXECUTION ENTER 2 CHARACTER LOCATION CODE OF PRE-STORM PROFILE ? NB ENTER PROFILE AND SURVEY NUMBERS ? 100 34 ENTER SURVEY DATE (YYMMDD) ? 840425 LENGTH SCALE IN FEET (ELSE METERS)? - Y OR N ENTER SURVEY DATA - DISTANCE THEN ELEVATION ONE POINT PER LINE, ASCENDING BY DISTANCE TERMINATE DATA ENTRY WITH A CARRIAGE RETURN ? -500 3 ? -110 3.5 ? -80 4 ? -300 4 LAST POINT NOT ASCENDING, PLEASE RE-ENTER ERROR MESSAGE FOR ? -60 6 POINT ENTERED OUT OF ORDER ? -40 3 ? -40 3 ? 0 0 ? 40 -2 ? 200 -5 ? 1200 -10 ? - CARRIAGE RETURN ENTERED TERMINATING DATA ENTRY DO YOU WANT TO SEE A DESCRIPTION OF THE INPUT AND OUTPUT VARIABLES? 2 N ENTER A 'Y" TO GET A DESCRIPTION OF VARIABLES ENTER - SURGE DATUM, SURGE HEIGHT, WAVE HEIGHT, AND CHANGE DATUM (IN M) ? 0 2.5 7.0 2.5 ENTER HOURS STORM SURGE EXCEEDED 1.50 M (OR ENTER 0) 2.8 COMPUTE PARTICLE FALL VELOCITY GIVEN DIAMETER? - Y OR N 5 ·۷ ENTER - MEDIAN SAND SIZE (MM) AND WATER TEMP. (DEG C) ? .40.10 FALL VELOCITY = .0474 N /SEC ADDIAL ENUSION (AE) - -67.7 M3/ M ADDVE DATUM CHANGE (AS) = -36.1 M3/ M HORIZONTAL SKIFT OF CHANGE DATUM = -18. POSITION OF SURGE LEVEL = -52.4 M -18.2 M ESTIMATED EROSION ADJUSTED FOR DURATION (IF SUFFICIENT MATERIAL EXISTS) ERDSION ABOVE CHANGE DATUM (AS) = FROM -41.56 TO -46.98 M3/M

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OUTPUT PRINTED TO UNIT 14

DUTCH STORM EROSION PREDICTION

LOCATION	NB	PROFILE NO.	100
SURVEY NO.	34	DATE (YYNMDD)	840425
SURVEY NU.	39	NATE (LINUNNI	040465

*** INPUT ***

PRE-STORN PROFILE

PO INT Number	DISTANCE M	ELEVATION M
12 34 5678910	-500.0 -110.0 -80.0 -40.0 -50.0 -40.0 0.0 40.0 200.0 1200.0	3.00 3.50 4.00 6.00 3.00 -2.00 -5.00 -10.00
CHOCE	истоит =	2.50 N

SURGE BELCHI = 2.00 n	
SURGE DURATION = 8.00 HRS	
SIGNIFICANT WAVE HEIGHT =	7.00 1
MEDIAN SEDIMENT DIAMETER =	.40 ЛП
WATER TEMPERATURE = 10.0	DEG C
COMPUTED FALL VELOCITY =	.0474 N /SEL
SURGE DATUM = 0.00 M	
CHANGE DATUM = 2.50 M	

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*** RESULTS ***

TOTAL EROSION (AE) = -67.7 N3/ M ABOVE DATUM CHANGE (AS) = -36.1 M3/ M HORIZONTAL SHIFT OF CHANGE DATUM = -13.2 M POSITION OF SURGE LEVEL = -52.4 M

ESTIMATED EROSION ADJUSTED FOR DURATION (IF SUFFICIENT MATERIAL EXISTS)

ERDSIDN ADOVE CHANGE DATUM (AS) = FROM -41.56 TO -46.98 N3/M

POST-STORM PROFILE

DISTANCE N	ELEVATION N	
$\begin{array}{c} -55.7\\ -52.4\\ -50.0\\ -40.0\\ -30.9\\ -20.0\\ -10.0\\ 0.0\\ 10.0\\ 20.0\\ 30.0\\ 40.0\\ 50.0\\ 40.0\\ 50.0\\ 40.0\\ 50.0\\ 40.0\\ 50.0\\ 100.0\\ 100.0\\ 110.0\\ 111.0\\ 120.2\end{array}$	6.00 2.50 2.32 1.70 1.20 .77 .39 .04 28 59 87 -1.14 -1.40 -1.44 -1.98 -2.33 -2.54 -2.75 -2.77 -3.50	- THIS IS X-COORDINATE OF POSISTORM DUNE CREST

SURGE POSITION AND NET AREA ITERATIONS IN REVERSE ORDER (FROM LAST TO FIRST).

-52,433	-52.438	-53.761	-49.676
.000	.045	12.603	-26.298

PROGRAM DUNE

PROGRAM DUNE (INPUT. JUTPUT. TAPE5= INPUT. TAPE6=DUTPUT. TAPE14) 0000 PROGRAM 'PMAIN' USED TO ENTER PROFILE DATA AND CALL SUBROUTINE 'PREDICT' WHEN USED AS A STAND-ALONE PROGRAM. INTEGER IP, IDATEP, IPROP.NINC. IP1 CHARACTER*1 ANSHER REPLY REAL P COMMON /DATA/X(110),Y(110),Z(110),NP0INTS,PORT(110),CONSL(110),IU COMMON /BLK/IDATE,ITIME,IPROF.ILOC,ISUR,DIST,IUNIT COMMON /PRDCT/P(110,3),IP,IDATEP,IPROP.NINC,IPI COMMON /FALVEL/PDIA,CTEMP.FALLVEL,SURGE,NAVEHT,TEMP.BAREA DATA M, F/2HM , 2HFT/ С č Ĉ FIRST WRITE PROGRAM INTRO WRITE(6,900) WRITE(6.900) FORMAT(//.1X."DUNE - A PROGRAM TO ESTIMATE STORM INDUCED". \$1X."DUNE EROSION.",/.1X." WRITTEN BY FRANCIS SARGENT.", \$"CERC. 1983.",// \$1X."THIS PROGRAM USES A PROCEDURE DEVELOPED BY VELLINGA",/ \$1X."THIS PROGRAM USES A PROCEDURE DEVELOPED BY VELLINGA", \$1X. 900 <u>'</u>И. WRITE(4,1010) READ(5,1110,ERR=100,END=220)ILOC 100 10=0 C SET MAXIMUM NUMBER OF SURVEY POINTS ALLOWED. THIS MUST BE EQUAL OR LESS THAN THE ARRAY SIZE OF X AND Y ARRAYS Č Ĉ NPDINTS=110 WRITE(6,1020) 110 READ(5.*.ERR=110,END=220) IPROF, ISUR 115 WRITE(6,1025) READ(5.4.ERR=115,END=220) IDATE WRITE(6,1050) READ(5,1100,ERR=120,END=220)ANSWER 120 IF (ANSWER, EQ. 'Y') THEN IUNIT=2HF1 ELSE IF (ANSHER.ED. 'N') THEN IUNIT=2HM ELSE GOT0120 END IF WRITE(6,1040) 140 D0 170 1=1.NPOINTS READ(5. * ERR=160 END=180)Y(1).Z(1) IF(1.E0.1)CO TO 170 145 Č CHECK TO BE SURE DISTANCES ARE ASCENDING IF(Y(I).GE.Y(I i))GD TO 170 WRITE(6,130) FORMAT("LAST POINT NOT ASCENDING, PLEASE RE-ENTER") 150GO TO 145 WRITE(6.165) FORMAT("INPUT ERROR.PLEASE RE-ENTER") 160 165 GO TO 145 170 CONTINUE CLEAR END-OF-FILE FLAG BEFORE CONTINUING. C ſ 130 X7=E0F(5) NPOINTS=I-1 Ĩ90 CALL PREDICT 200 WRITE(6.1030) READ (5,1100, ERR=200, END=220) ANSHER

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IF (ANSHER.EQ. 'Y') THEN HRITE(6,1060) READ(5,1100,ERR=210,END=220)ANSWER IF(ANSWER.E0.'Y')GDT0100 250 IF (ANSWER.E0. 'N')GOT0190 G0T0210 ELSE IF (ANSWER.NE. 'N')GOTD200 IF (ANSWER.NE. N.) GUID200 END (F FORMAT("ENTER 2 CHARACTER LOCATION CODE OF PRE-STORM PROFILE") FORMAT("ENTER PROFILE AND SURVEY NUMBERS") FORMAT("ENTER SURVEY DATE (YYMMDD)") FORMAT("DO YOU MANT ANOTHER RUN? - Y OR N") FORMAT("ENTER SURVEY DATA - DISTANCE THEN ELEVATION",/, \$ "ONE POINT PER LINE, ASCENDING BY DISTANCE", \$ //. "TERMINATE DATA ENTRY WITH A CARRIAGE RETURN",//) FORMAT("LENGTH SCALE IN FEET (ELSE METERS)? - Y OR N") FORMAT("NEW PROFILE? - Y OR N") FORMAT("NEW PROFILE? - Y OR N") 1010 1020 1025 1030 1040 1050 1060 1100 1110 FORMAT(A2) 220 STOP END С С SUBROUTINE PREDICT С PREDICT - CERCFRF - DCS:FTN5 - F. E. SARGENT - B30609 PROFILE GIVEN A 'PRESTORM' PROFILE AND SEVERAL BULK PARAMETERS OF THE STORM AND BEACH. THE PROGRAM FOLLOWS A METHOD PRESENTED BY VELLINGA (1983). THE POSITIVE Y-DIRECTION IS OUTHARD NORMAL AND THE POSITIVE Z-DIRECTION IS UPHARD. 'PREDICT' CAN BE USED AS A STAND-ALONE PROGRAM WITH ITS CALLING PROGRAM 'PMAIN' OR AS A SUBROUTINE TO PROGRAM 'ISRP' DEVELOPED BY BILL BIRKEMEIER AT THE CERC FIELD RESEARCH FACILITY. PROGRAM CODING IS IN FORTRAN77. C C Ć Ĉ Ĉ C Ē REAL DZ1, DZ2, DY, SAREA, CW, CY, CZ, ZACT1, ZACT2, YACT1(13), YACT2, BAREA REAL M1, M2, TAREAI, TAREA2, DAREA(13), T1, SURGE, WAVEHT, FALLVEL, DATUM REAL P, YIT, ZEND, YEND, CAREA, SLOPEI, YC1, YC2, ZC1, ZC2, YI, ZI, AREA(3), PR REAL DY2, EAREA, C, C1, C2, C3, DATUM2, K1, K2, PDIA, TEMP, CTEMP, POS(2), T2 REAL SHIN, MHIN, FMIN, PMIN INTEGER JUNEY, UNEXY, INTEGER IN A MIN, TAN, A MIN, MIN, CAREA, C, C1, C2, C3, DATUM2, K1, K2, PDIA, TEMP, CTEMP, POS(2), T2 REAL SHIN, MHIN, FMIN, PMIN INTEGER INDEX. INDEX1. INDEX2. IP. IDATEP.FLAG.NINC, IP1.I.J.K.L.H.N.ML INTEGER ZSIGN1,ZSIGN2,IY,YS1,YS2,YE1,YE2,IRODE.ASIGN1,ASIGN2,IPROP INTEGER FRMT.OPOUT,U CHARACTER*2 U2. U4. REPLY*1. ANSHER*1 C Č LABELED COMMON DLOCKS USED WITH PROGRAM 'ISRP'. COMMON /DATA/X(110),Y(110),Z(110),NPOINTS,PORT(110),CONSL(110),IU COMMON /BLK/IDATE,ITIME,IPROF,ILOC.ISUR.DIST,IUNIT COMMON /PRDCT/P(110.3),IP,IDATEP,IPROP.NINC,IP1 COMMON /FALVEL/PDIA.CTEMP,FALLVEL,SURGE,WAVEHT,TEMP.BAREA £ GLOBAL CONSTANTS (NOT CHANGED ON SUBSEQUENT CALLS TO 'PREDICT') NINC (OR = DIMENSION OF PROFILE ARRAYS IN LABELED COMMON 'DATA' MAY OTHERWISE BE DEFINED IN A 'BLOCK DATA' STATEMENT. Ũ Ĉ DATA X1.K2, M1, M2.T1.T2, ML/.471405..752266.-1..-.08..01..01.13/ DATA SMIN, WHIN, PMIN, FMIN, OPOUT/3+.01,.001.0/ NINC=110 N=NINC-1 С Č SET FLAGS FOR 'ISRP' PLOTTING ROUTINE 'IPLOT'. IP=1 IDATEP = IDATE IPROP = IPROF U= IUNIT Č C USE APPROPRIATE UNITS (FEET OR METERS) FOR ANALYSIS.

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IF (IUNIT.EQ.2HM) THEN C=1. C1=1. C2=0. C3=2. U2=' M UA=' C' ELSE C=.3048 C1 = . 5556 C2=32. C3=54. U2='YD' U4=' F' END IF CONTINUE 100 IF (IPD2.E0.1)GO TO 102 C DETERMINE IF AN EXPLANATION OF THE VARIABLES IS DESIRED? Ū C C C C HRITE(6.1011) 1011 FORMAT(/.1X,"DO YOU WANT TO SEE A DESCRIPTION OF THE"./, \$1X, "INPUT AND OUTPUT VARIABLES?") READ(5.1030_END=410.ERR=100)IREPLY IF (IREPLY.EO. 1HY) CALL EXPLAIN IPD2=3 CONTINUE 102 REQUEST ENTRY OF SURGE AND HAVE HEIGHT PARAMETERS Ē 105 WRITE(6.1000) U READ(5, *, ERR=105, END=410) DATUM, SURGE, WAVEHT, DATUM2 0000 REQUEST STORM DURATION IN HOURS FOR LATER ADJUSTMENT OF THE EROSION AMOUNTS (IF DURATION GT 5 HRS) S=SURGE-1./C WRITE(6,107)S.U FORMAT(1X,"ENTER HOURS STORM SURGE EXCEEDED", \$F6.2.1X.A2." (OR ENTER 0)") \$F6.2.1X.A2." (OR ENTER 0)") 106 107 READ(5,*,ERR=106,END=410)DUR £ Ć C SUBTRACT DURATION OF NORTH SEA STORM DUR=DUR-5. IF (DUR.LT.O.)DUR=0. ۵ COMPUTE FALL VELOCITY GIVEN MEDIAN PARTICLE DIAMETER (IN MH) AND WATER TEMPERATURE, OTHERWISE INPUT FALL VELOCITY. 0000 WRITE(6.1020) READ(5.1030.ERR=100.END=410)REPLY IF(REPLY.EG.'Y')THEN WRITE(6.1010)U4 110 READ(5.*,ERR=110,END=410)PDIA.TEMP C CONVERT TEMPERATURE TO DEG C (IF REQUIRED) C Ĉ CTEMP=C1+(TEMP-C2) IF (CTEMP.GE.O.. AND. CTEMP.LE.40. AND.PDIA.GT.PNIN)GOTO120 WRITE(6,1250) HRY12(6,1230) GDT0110 CALL SPEED FALLVEL=FALLVEL/C HRITE(S,123)FALLVEL.U FORMAT(" FALL VELOCITY =",F7.4,1%,A2,"/SEC") ELSE IF(REPLY.E0.'N')THEN PD1A=0. HDYTE(4,101=) 120 123 WRITE(6,1015) 130

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READ(5. *. ERR=130_END=410)FALLVEL ELSE **GDT0100** END IF IF (FALLVEL.GT.FMIN.AND.WAVEHT.GT.WHIN.AND.SURGE.GT.SMIN)GOTO140 WRITE(6,1240) G0T0100 000 INITIALIZE CONSTANTS AND FLAGS. 140 ASIGN1=-1 ASIUM1=-1 ASIGN2=-1 CH=(FALLVEL*C/0.0268)**.56 CZ=7.6/(WAVEHT*C) CY=CZ**1.28*CH ZACT1=DATUM+SURGE 24CT1=DATUM+SURGE IF (Z(NPOINTS).LT.ZACT1)GOT0150 WRITE(6, 1060) ASSIGN 1060 TO FRMT FLAG=2 GOTO340 C C C INITIALIZE FIRST THO 'GUESSES' OF POST-STORM PROFILE POSITION. DC 160 I=NPOINTS.1.-1 IF(Z(I).LT.ZACTI)GOTO160 150 INDEX-I GOT0170 CONT INUE 160 WRITE(5.1070) ASSIGN 1070 TO FRMT FLAG=2 **GDT0340** SLOPE=(Y(I)-Y(I+1))/(Z(I)-Z(I+1)) YIT=(ZACT1-Z(I+1))*SLOPE+Y(I+1) YEND=250./(CY*C) YACT1(1)=YIT-YEND/10. 170 YACTI(1)=YI-YEND/0. YACTI(2)=YIT-YEND/8. ZEND=K2*WAVEHT ZACT2=ZACT1-ZEND CAREA=YEND*ZACT1+2.*YEND/(CZ*C)+(72.-2.*K1*(CY*C*YEND+18.)**1.5)/ \$ (3.*C*C*CZ*CY) ¢ 0000 LOOP INTERATION STARTS HERE, USING A SECANT METHOD TECHNIQUE. DB 270 J=1.ML FLAG=0 YACT2=YACT1(J)+YEND 0000 LOCATE LOWER INDEX OF THE PRESTORM PROFILE AT THE LEFT END OF CURVED PORTION OF PREDICTED PROFILE. D0 i90 I=INDEX+1.1.-i IF(Y(1).GT.YACT1(J))GOT0(90 SLOPEI=(Z(I)-Z(I+1))/(Y(I)-Y(I+1)) IF(SLOPEI.LE.M1)GOT0190 YEI=(MI*YACT1(J)-SLOPEI*Y(I+1)+Z(I+1)-ZACT1)/(M1-SLOPEI) IF(YCI.LT.Y(I))GOT0190 JNDEY1-T41 INDEX1=I+1 IF (YC1.LE.YACT1(J))GOT0180 YC1=YACT1(J) FLAG=1 ZC1=SLRPEI*(YC1-Y(I+1))+Z(I+1) G0T0200 180 CONTINUE WRITE(5,1080) ASSIGN 1080 TO FRMT FLAG=2 190 G0T0340 C C LOCATE UPPER INDEX OF THE PRESTORM PROFILE AT THE RIGHT END

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OF CURVED PORTION OF PREDICTED PROFILE.
C
         DO 220 I= INDEX, NPOINTS_1
200
         IF(Y(1).LT.YACT2)G0T0220
SLOPEI=(Z(I)-Z(I~1))/(Y(I)-Y(I-1))
IF(SLOPEI.LE.M2)G0T0220
         YC2=(M2*YACT2-SLOPEI*Y(I-1)>Z(I-1)-Z(CT2)/(M2-SLOPEI)
          IF (YC2.GT.Y(1))GOT0220
          INDEX2=I-1
          IF (YC2.GE.YACT2)GOT0210
          YC2=YACT2
         FLAG=1
         ZC2=SLOPEI*(YC2-Y(I-1))+Z(I-1)
GOT0230
210
220
         CONTINUE
         WRITE(6,1090)
         ASSIGN 1090 TO FRMT
         FLAG=2
         GOT0340
2
2
         COMPUTE AREAS RELATIVE TO ZERO DATUM - PREDICTED AREA.
TAREA1=((ZC1+ZACT1)+(YACT1(J)-YC1)+(ZC2+ZACT2)+(YC2-YACT2))/2.
         PROFILE AREA.
         TAREA1=TAREA1+CAREA
         IF(INDEX2.GE.INDEX1)THEN
TAREA2=(ZC1+Z(INDEX1))*(Y(INDEX1)-YC1)
         TAREA2-(20172(TADEX1))CT(TADEX1)-(21)

TF(INDEX2.EG,INDEX1)GOTO250

DO 240 I=JNDEX1,INDEX2-1

TAREA2=TAREA2+(2(I)+2(I+1))*(Y(I+1)-Y(I))

TAREA2=(TAREA2+(2(INDEX2)+ZC2)*(YC2-Y(INDEX2)))/2.
240
250
          EL SE
         TAREA2=(ZC1+ZC2)*(YC2-YC1)/2.
END IF
0000
         CHECK IF AREAS LESS THAN TOLERANCE (OR FLAG IS EXECUTED)
         CHECK IF AREAS LESS THAN TOLLRANCE (UR FLAG IS EXECUTED).
EXIT IF SO. OTHERHISE COMPUTE NEW GUESS AND RECOMPUTE AREAS.
ITERATION PROCEDURE BASED ON STANDARD SECANT EXTRAPOLATION
TECHNIQUE WHEN NET AREAS (DAREA) ARE OF THE SAME SIGN.
WHEN NET AREAS ARE OF OPPOSITE SIGN PROGRAM SELECTS TWO
BOUNDING VALUES TO INTERPOLATE NEW PROFILE POSITION.
C
C
C
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         DAREA(J)=TAREA2-TAREA1
         IF (ADS(DAREA(J)).LE.T1)G0T0280
IF (DAREA(J).LT.0)THEN
260
          IF (ASIGN2.E0.1) THEN
IF (DAREA(J).GT.DAREA(J2)) J2=J
          ELSE
         ASIGNZ=1
          J2=J
         END IF
          ELSE
          IF (ASIGN1.E0.1) THEN
          IF(DAREA(J).LT.DAREA(J1))J1=J
         ELSE
ASIGN1=1
          J1 = J
         END IF
          IF (ASIGN1.E0.1.AND.ASIGN2.E0.1) THEN
          JN=J1
J0=J2
          ELSE
          JN=J
          JO=J-1
         END IF
IF(J.ER.1.OR.J.EO.ML)GOTO270
          SLOPE=(YACT1(JN)-YACT1(JO))/(DAREA(JN)-DAREA(JO))
          YACT1(J+1)=YACT1(JN)=DAREA(JN)*SLOPE
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270 CONT INUE FLAG=3 j=NL С COMPUTE ADSOLUTE AREA CHANGE AND CHANGE ABOVE AREA CHANGE DATUM. ADDITIONAL CONVERGENCE CHECK BASED ON NET AREA CHANGE. DISCRITIZE PRE/POST PROFILES BETWEEN THEIR INTERCEPTS. P(1,1)=YC1 P(1,2)=ZC1 P(1,3)=ZC1 IF(ABS(YACT1(J)-YC1).LT..0001)P(1,3)=ZACT1 P(NINC.1)=YC2 P(NINC.2)=ZC2 P(NINC.3)=ZC2 IF(ABS(YACT2-YC2).LT..0001)P(NINC.3)=ZACT2 С Č C COMPUTE DISTANCES AND PRE/POST STORM ELEVATIONS. L=INDEX1 DY-YC2-YC1 DQ 300 I=2.N P(I.1)=YC1+DY#(I-1)/N IF(P(I,1).LT.YACT1(J))THEN P(I,3)=ZC1+H1+(P(I,1)-YC1) ELSE IF(P(I,1).LT.YACT2)THEN P(I_3)=ZACT1-(K1*SORT(CY*C*(P(I,1)-YACT1(J))+18.)-2.)/(CZ*C) ELSE P(1.3)=ZACT2+M2+(P(1.1)-YACT2) 290 IF(Y(L).GE.P(I.1))G0T0300 L=L+1 G0T0290 <u>3</u>00 P(I,2)=Z(L-1)+(P(I,1)-Y(L-1))*(Z(L)-Z(L-1))/(Y(L)-Y(L-1)) C C C SUM ABSOLUTE, NET AREAS. AREA(1)=0. DY=DY/N DZ2=P(1.2)-P(1.3) Z3IGN2=1 IF(DZ2.LT.0.)ZSIGN2=-1 С č ABSOLUTE AREA. DD 310 I=2.NINC DZ1=D72 ZSIGNI=ZSIGN2 DZ2=F(I,2)-P(I,3) ZSIGN2=1 IF(DZ2,LT.0.)7SIGN2=-1 IF(ZSIGN2.EG.ZSIGNI)THEN AREA(1)=AREA(1)+ABS((DZ2+DZ1)*DY) ELSE ELSE AREA(1)=AREA())+(DZ2++2+DZ1++2)+ABS(DY/(DZ2-DZ1)) END (F CONTINUE 310 SAREA=AREA(1)/(2.*C3) K=SAREA*10.+.5 BAREA=K/10. PR=ABS(DAREA(J)/SAREA) 0 0 0 IF CHANGE DATUM IS OUTSIDE POST STORM PROFILE, REQUEST A NEW DATUM2 C 311 IF (DATUM2.GE.ZC2.AND.DATUM2.LE.ZC1)GO TO 319 NRITE(6.315) FORMAT(" CHANGE DATUM IS OUTSIDE THE 'IMITS"./. \$" OF THE POST STORM PROFILE."./. \$" ENTER NEW CHANGE DATUM") STORY & FOR SHORE DATUM") 312 315 READ(5.*.ERR=312.END=410)DATUN2

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GO TO 311 DD 320 II=2,3 AREA(II)=0. 319 POS(II-1)=0. DZ2=?(1,II)-DATUM2 ZSIGN2=1 IF (DZ2.LT.O.)ZSIGN2=-1 IRODE=0 DD 320 J=2,NINC DZ1=DZ2 ZSIGN1=ZSIGN2 ZSIGN1=ZSIGN2 DZ2=F(I.II)-DATUM2 ZSIGN2=1 IF(DZ2.LT.0.)ZSIGN2=-1 IF(ZSIGN2E0.ZSIGN1)THEN IF(ZSIGN1.E0.1)AREA(II)=AREA(II)+(DZ2+DZ1)+DY ELSE IF(ZSIGN1.E0.1)THEN AREA(II)=AREA(II)+DZ1+2+DY/(DZ1-DZ2) IF(IRODE.E0.0)THEN PDS(II=1)=P(I=1.1)+DY+DZ1/(DZ1-DZ2) POS(IJ-1)=P(I-1,1)+DY*DZ1/(DZ1-DZ2) IRODE=1 ELSE END IF ELSE AREA(II)=AREA(II)+DZ2*+2+DY/(DZ2-DZ1) END IF CONTINUE 320 EAREA=(AREA(3)-AREA(2))/C3 DP=POS(2)-POS(1) С ŭ C TOLERANCE. LOOP CHECK. IF(J.EB.ML)GOT0330 IF(PR.LE.T2)GOT0330 G0T0260 330 12=2 SAREA=-1.*SAREA 0000 COMPUTE ADDITIONAL EROSION BASED ON STORM DURATION SKIP COMPUTATION IF DUR = 0 IF(DUR.EG.O.)G0 TO 335 ADJ3=EAREA*DUR*.05+EAREA ADJ4=EAREA*DUR*.1+EAREA IF(ADJ3.GT.EAREA/2.)ADJ3=EAREA/2. IF(ADJ4.GT.EAREA/2.)ADJ4=EAREA/2. C 335 IF (FLAG.EQ.1)WRITE(6,1150) WRITE(5,1140)SAREA.U2.U.EAREA.U2.U.DP.U.YACT1(J),U IF (DUR.GT.O.)WRITE(6,1270)ADJ3,ADJ4,U2,U IF(FLAG.EQ.3)WRITE(6,1130) IF (DPOUT.EQ.0)GOT0360 340 WRITE(6,1260) WRITE(6,1260) READ(5,1030,ERR=350,END=410)ANSWER IF(ANSWER.E0.'N')RETURN IF(ANSWER.E0.'Y')GOT0360 COT0356 350 GOT0350 С ē HRITE DATA INPUT/OUTPUT TO UNIT 14. HRITE(14,1160) HRITE(14,1040)ILOC, IPROF, ISUR, IDATE HRITE(14,1190)U,U 360 DO 370 I=1, NPOINTS WRITE(14,1230)I,Y(I),Z(I) IF(REPLY.EG.'Y')THEN 370 WRITE(14,1110)SURGE, U. DUR+5, , WAVEHT, U. PDIA, TEMP, U4, FALLVEL, U, \$DATUM, U, DATUM2, U ELSE HRJTE(14,1100)SURGE, U. DUR+5., HAVEHT, U. FALLVEL, U. DATUM, U.

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$DATUH2_U
        END IF
         IF (FLAG.NE.2) GOT0380
        WRITE(14.1120)
WRITE(14.FRMT)
         RETURN
        WRITE(14,1170)
WRITE(14,1140)SAREA.UZ,U,EAREA,UZ,U,DP,U,YACT1(J),U
 380
         IF(DUR.GT.0)WRITE(14,1270)ADJ3.ADJ4.U2.U
 Ĉ
        COMPUTE AND WRITE PREDICTED PROFILE AT 10 FOOT/METER INTERVALS.
 Ĉ
         YS1=YACT1(J)/10.
         YE1=YACT2/10.
         IF (YS1.E0.0.AND.YC1.LT.0.)G0T0390
IF(YS1.GE.0)YS1=YS1+1
 390
        YS2=YS1+10
         YEZ=YE1+10
         WRITE(14,1180)U,U
        WRITE(14.1210)YC1.ZC1
WRITE(14.1210)YACT1(J).ZACT1
DO 400 IY=YS2.YE2.10
         YI=IY
        11-17

ZJ=ZACT1-(K1*SQRT(CY*C*(YI-YACT1(J))+18.)·2.)/(CZ*C)

HRITE(14.1210)YI.ZI

HRITE(14.1210)YACT2.ZACT2

HRITE(14.1210)YC2.ZC2

IF(FLAG.CO.1)HRITE(14.1150)

HOVIE(14.1200)
 400
$A2 ")")
1015 FORMAT("ENTER - FALL VELOCITY")
1020 FORMAT("COMPUTE PARTICLE FALL VELOCITY GIVEN DIAMETER?".
$ ______ Y OR N")
$
1030 FORMAT(A1)
1040 FORMAT(" LOCATION ",A4," PROFILE NO.", 19,/,
$
"SURVEY NO.", 15," DATE (YYMMDD) ", 16,//)

$1X.A2./.
$ "HORIZONTAL SHIFT OF CHANGE DATUM = ",FB.1,1X,A2./.
```

\$ "POSITION OF SURGE LEVEL = ".F8.1.1X.A2.//)
1150 FORMAT(" HARNING - PORTION OF PREDICTED PROFILE ABOVE/BELOW"./,
\$ "PRESTORM PROFILE WHERE REVERSE TREND SHOULD OCCUR")
1160 FORMAT(//,5X,"DUTCH STORM EROSION PREDICTION".//)
1170 FORMAT(///.16X."*** RESULTS \$**".///)
1180 FORMAT(" POST-STORM PROFILE ".//.
\$ "DISTANCE ELEVATION"./.7X,A2.9X.A2./)
1190 FORMAT(//.10X."*** INPUT ***".///.
\$ "POE-STORM PROFILE ".//.
\$ "REVERSE ORDER (FROM LAST TO FIRST).".//.
\$ "REVERSE ORDER (FROM LAST TO FIRST).".//. 1210 FORMAT(1X, F9.1, 2X, F10.2) 1220 1230 FORMAT(////) 1230 FORMAT(14.2X,F9.1.2X,F10.2) 1240 FORMAT("SURGE, WAVE HEIGHT OR FALL VELOCITY BELOW"./. * "NINIHUM ACCEPTABLE, RE-ENTER DATA") 1250 FORMAT("TEMPERATURE NOT ACCEPTABLE, RE-ENTER DATA") 1260 FORMAT("OUTPUT RESULTS TO FILE OR LINE PRINTER? - Y OR N") 1270 FORMAT(//,1X,"ESTIMATED EROSION ADJUSTED FOR". * DURATION"./.5X."(IF SUFFICIENT MATERIAL EXISTS)"./, */,1X."EROSION ABOVE CHANGE DATUM (AS) = FROM",FG.2. * TO ".F3.2,1X.A2."3/",A2.//) PETIDEN FORMAT(14,2X,F9.1,2X,F10.2) RETURN CLOSE(5) OPEN(5,FILE='INPUT') 410 RETURN END £ Ĉ SUBROUTINE SPEED REAL PDIA.CTENP.FALLVEL.RHOSED.RHOSEA.KVCSEA.MU.RHO.KVC.GRNBUDY.R COMMON /FALVEL/PDIA.CTENP.FALLVEL.SURGE.WAVEHT.TEMP,BAREA DATA RHOSED.RHOSEA.KVCSEA/2.70.1.027.1.048/ GIVEN MEDIAN PARTICLE DIAMETER (IN MN) AND HATER TEMPERATURE (IN DEG. C) 'SPEED' COMPUTES THE PARTICLE FALL VELOCITY (IN METERS/SECOND). PROGRAM ASSUMES SEDIMENT DENSITY ĉ C (RHOSED = 2.70 GH/CU. CM), ANBIENT WATER DENSITY RATIO (SALTWATER, 33 PPT - RHOSEA = 1.027) AND AMBIENT WATER VISCOSITY RATIO (KVCSEA = 1.048). REFER TO CETN-II-4 Ĉ Č FOR FURTHER INFORMATION. Ĉ MU=.0020319+.015883/EXP(CTEMP**.9/22.) RH0=R:035A*(1-.000019549*ADS(CTEMP'4.)**1.68) KVC=KVCSEA*MU/R:M0 GRNBUOY = . 9806 * (RHOSED-RHO) *PDIA**3/ (RHO*KVC**2) R=KVC/PDIA IF(GRNDUDY.LT.39.)THEN FALLVEL=GRNDUDY*R/180. ELSE IF(GRNDUDY.LE.10009.)THEN FALLVEL=GRNBUOY **.7#R/60. ELSE FALLVEL=SORT(GRNDUOY)*R/7.54 END IF RETURN END С SUBROUTINE EXPLAIN THIS SUBROUTINE EXPLAINS THE VARIABLES USED BY THE PREDICT С C PROCEDURE. Č COMMON/BLK/IDATE.ITIME.IPROF.ILOC.ISUR.DIST.IUNIT C Ē DETERMINE IF WATER TEMP TO BE INPUT IN DEGREES C. OR F. ITEMP-1HF

IF (IUNIT.EQ.2HM) ITEMP=1HC

С WRITE(5,100) IUNIT, IUNIT, IUNIT FORMAT(1X,/.5X,"THE PROCEDURE REQUIRES THE". \$__FOLLOWING INPUT",/. 100 \$5X. С WRITE(6,110) IUNIT, ITEMP, IUNIT 110 FORMAT \$2X, "CHANGE DATUM - VERTICAL DATUM, (IN ".A2. \$" RELATIVE TO THE PROFILE DATA)",/. \$RX." ABOVE WHICH THE ERODED AREA WILL BE COMPUTED".//. \$2X."MEDIAN SAND SIZE - ALWAYS IN MM.".//. \$2X."MATER TEMPERATURE - IN DEGREES ".A1.//. \$2X."FALL VELOCITY - IN ".A2."/SEC. (OPTIONAL. " \$."PROGRAM WILL COMPUTE THIS)",/) WOITE(.115). WRITE(5.115) FORMAT(2X,"STORM DURATION - HOURS SURGE EXCEEDED A LEVEL"/. \$8X,"3.3 FT (1 M) LESS THAN THE PEAK SURGE."./) 115 С WRITE(6,117) FORMAT("CONTINUE?") READ(5,118,END=135,ERR=135)IREPLY FORMAT(1A1) 117 118 IF (IREPLY.NE.1HY)GOT0140 С WRITE(6,120) FORMAT(/.5X."THE PROGRAM OUTFOLS THE VOLUME OF THE"./ \$5X." TOTAL EROSION (AE)- THIS IS THE VOLUME OF THE"./ \$2X." TOTAL ERODED AREA. REGARDLESS OF DATUM".//, 42X."ABOVE DATUM CHANGE (AS) - THIS IS THE VOLUME",/, \$2X." CHANGE ABOVE THE CHANGE DATUM.",//, \$2X."HORIZONTAL SHIFT - THIS IS THE HORIZONTAL"./. \$2X." SHIFT OF THE CHANGE DATUM", \$2X." SHIFT OF THE CHANGE DATUM", \$2X." POSITION OF THE SURGE INTERCEPT THE POSITION.",/, \$2X." RELATIVE TO THE SURVEY DATA. OF THE",/. \$2X." POST-STORM SURGE LEVEL INTERCEPT.",/} 120 FORMAT(7.5%, "THE PROGRAM OUTPUTS THE FOLLOWING". /, С WRITE(6,130) FORMAT(2X, ADJUSTED EROSION AMOUNTS THIS IS THE RANGE OF // \$8X, "-AS- ADJUSTED FOR THE DURATION OF THE STORM (AS DEFINED // 8X, \$"ABOVE). MAXIMUM ALLOWED ADJUSTMENT IS 50 PERCENT OF -AS-.",//) 130 140 135 RETURN

135 K7=EDF(5) RETURN

END

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APPENDIX B: NOTATION

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Ae	Volume of erosion and accretion zones computed between prestorm and poststorm profiles $(1/2 A_g)$
Ag	Gross change between prestorm and poststorm profiles
A msl	Volume of material eroded above mean sea level (msl)
A _s	Volume of material removed above the surge level
^D 50	Median sediment size
Hos	Significant deepwater wave height
Lo	Significant deepwater wave length
m ₁	Predicted poststorm dune slope
^m 2	Seaward slope of the poststorm profile
R	Maximum shoreward extent of poststorm profile/surge level intercept
S	Peak surge level relative to mean sea level
t	Water temperature during storm event
w	Fall velocity of median sediment size, D ₅₀
x	Horizontal position, positive in seaward direction
у	Vertical position, positive with increasing elevation
σ _A	Standard deviation of prediction of A

END

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