4.0 EROSION ASSESSMENT

Coastal sand dunes usually extend above the 100-year stillwater elevation, but such barriers to flooding may not be durable due to massive shorefront erosion occurring during a 100-year flood. Storm-induced erosion will remove or significantly modify most frontal dunes on the U.S. coasts. This is particularly true on barrier islands known historically to be susceptible to storm overwash. Therefore, coastal erosion must be assessed before determining wave elevations and mapping V zones for the 100-year flood.

Available procedures for computing erosion show limited precision in documented hindcasts of recorded erosion quantities, and have questionable pertinence to the entire range of erosion effects possible on U.S. coasts. Therefore, a rather schematic treatment of expected erosion quantities and geometries has been developed as an appropriate approach for treating erosion in FISs at present. The overall rationale and level of detail in these erosion assessment procedures closely parallel the simple and effective NAS methodology for calculating wave action effects associated with storm surges (Reference 5).

The procedures described here are entirely objective, fundamentally reasonable, and empirically valid for treating dune erosion in the 100-year flood. These procedures are meant to give schematic estimates of eroded profile geometry suitable for the purposes of coastal FISs. The simplified estimates are suitable erosion approximations for extreme storms at sandy sites with typical open-coast wave and flood climate. The following erosion assessment procedures are intended for application to natural sites where there are no coastal structures such as breakwaters, groins, or revetments.

Quantitative considerations here are based on measured sand erosion accompanying extreme floods from hurricanes or extratropical storms on the U.S. Atlantic and Gulf coasts (Reference 16). For the study site, storm meteorology along with associated flood and wave characteristics may be used to assess whether such open-coast effects can be typical of anticipated local erosion for the base flood. Of course, any local historical evidence on storm erosion must also be examined in deciding applicability of the following procedures.

4.1 Basic Erosion Considerations

The primary factor controlling the basic type of dune erosion is the pre-storm cross section lying above the 100-year stillwater elevation (frontal dune reservoir). This area needs to be determined to assess the stability of the dune as a barrier. If the elevated dune cross-sectional area is very large, erosion will result in retreat of the seaward duneface with the dune remnant remaining as a surge and wave barrier. On the other hand, if the dune cross-sectional area is relatively small, erosion will remove the pre-storm dune leaving a low, gently sloping profile. Different treatments for erosion are required for these two distinct situations because no available model of dune erosion suffices for the entire range of coastal situations.

Figure 3 introduces terminology for two representative dune types. A frontal dune is a ridge or mound of unconsolidated sandy soil, extending continuously alongshore landward of the sand beach. The dune is defined by relatively steep slopes abutting markedly flatter and lower regions on each side. For example, a barrier island dune has inland flats on the landward side, and the beach or backbeach berm on the seaward side. The dune toe is a crucial feature, and can be located as the junction between gentle slope seaward and a slope of 1 on 10 or steeper marking the front duneface. The rear shoulder, as shown on the mound-type dune of Figure 3, is defined by the upper limit of the steep slope on the dune's landward side.

The rear shoulder of mound-type dunes corresponds to the peak of ridge-type dunes. Once erosion reaches those points, the remainder of the dune offers greatly lessened resistance and is highly susceptible to rapid and complete removal during a storm. Figure 3 shows the location of the "frontal dune reservoir," above 100-year stillwater elevation and seaward of the dune peak or rear shoulder. The amount of frontal dune reservoir determines dune integrity under storm-induced erosion.

To prevent dune removal in the 100-year storm, the frontal dune reservoir must typically have a cross-sectional area of at least 540

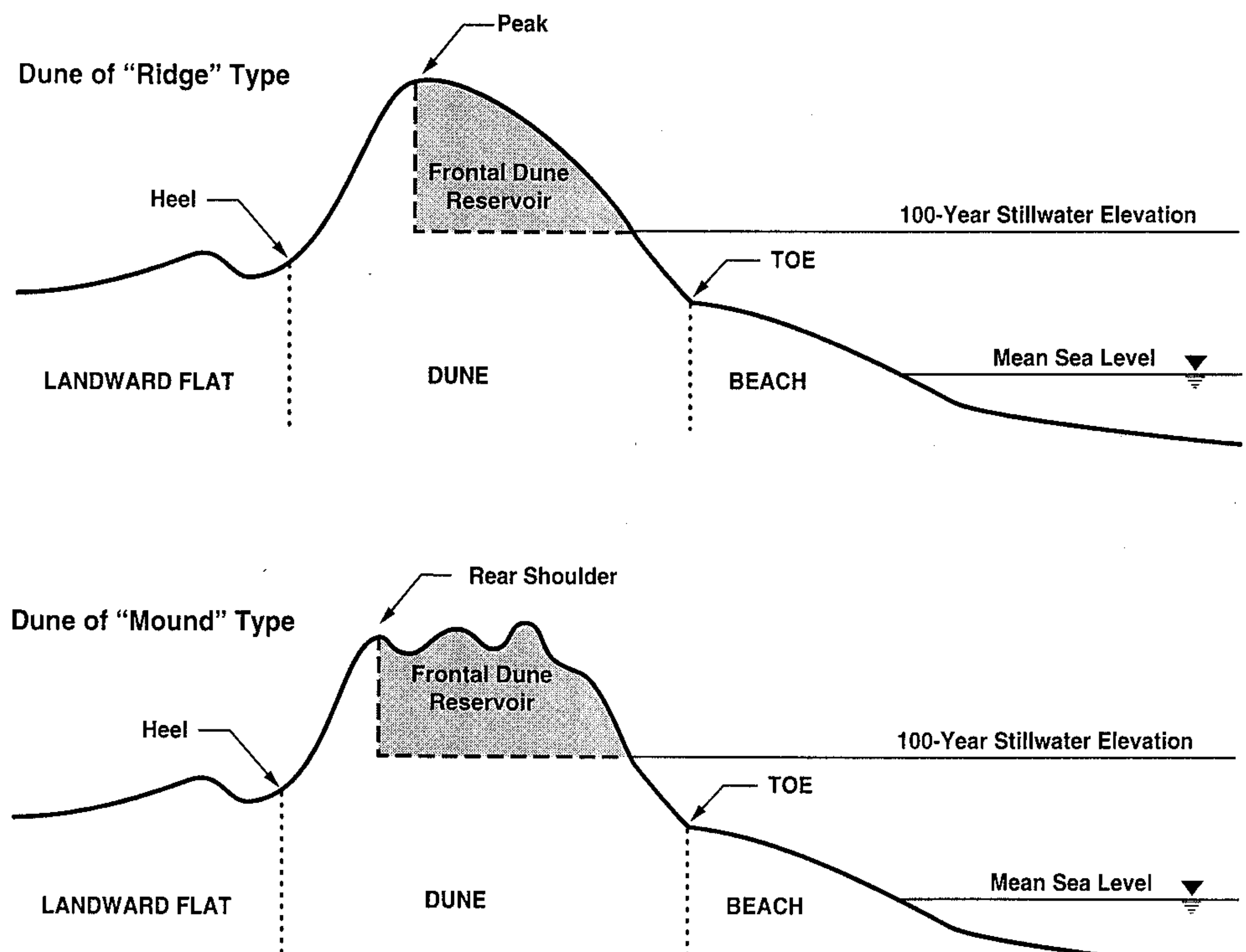


Figure 3. Dune Features and Present Terminology.

ft^2 (or 20 cubic yards volume per foot along the shore: References 14, 16). For more massive dunes, erosion will result in duneface retreat, with an escarpment formed on the seaward side of the remaining dune. To compute the eroded profile in such cases, FEMA has adopted a simplified version of the dune retreat model developed by Delft Hydraulics Laboratory of the Netherlands. This treatment is also appropriate in cases with sandy bluffs or headlands extending above 100-year stillwater elevation. The simplified treatment of duneface retreat is described in Section 4.3.

If a dune has a frontal dune reservoir less than 540 ft^2, storm-induced erosion can be expected to obliterate the existing dune with sand transported both landward and seaward. The eroded profile should be estimated using procedures presented in Section 4.2. Those procedures provide a realistic eroded profile across the original dune, but do not determine detailed sand redistribution by dune erosion, overwash, and breaching. Quantitative treatment of overwash processes is not feasible at present (Reference 15), so the frontal dune is simply removed in the present treatment.

The initial decision in treating erosion as duneface retreat or as dune removal is based entirely on the size of the frontal dune reservoir. For coastal profiles more complicated than those in Figure 3, judgment may be required to separate the sand reservoir expected to be effective in resisting dune removal from the landward portion of the pre-storm dune. The erosion assessment should usually address the summertime shore profile for hurricane impacts, and the wintertime profile for extratropical storms.

Figure 4 presents a complete flow chart of necessary erosion considerations, outlining the major alternatives of duneface retreat and dune removal. Figure 5 provides schematic sketches of the different geometries of dune erosion arising in coastal FIS assessments.

One additional factor complicating erosion assessment is the dissipative effect of wide sand beaches that shelter dunes from full storm impact and retard retreat or removal. If the existing slope between usual sea level and the 100-year stillwater elevation is 1 on 50 or gentler, careful examination of likely erosion during the 100-year flood will be required to avoid overestimation. This effect and other variables, such as sand size, dune vegetation, and actual storm characteristics at a specific site, emphasize the need for thorough comparison of estimated erosion to documented historical effects in extreme storms.

4.2 Treatment of Dune Removal

Where the frontal dune reservoir is less than 540 square feet, construction of the eroded profile is extremely simple: dune removal is effected by means of a seaward-dipping slope of 1 on 50 running through the dune toe. The eroded profile is taken to be

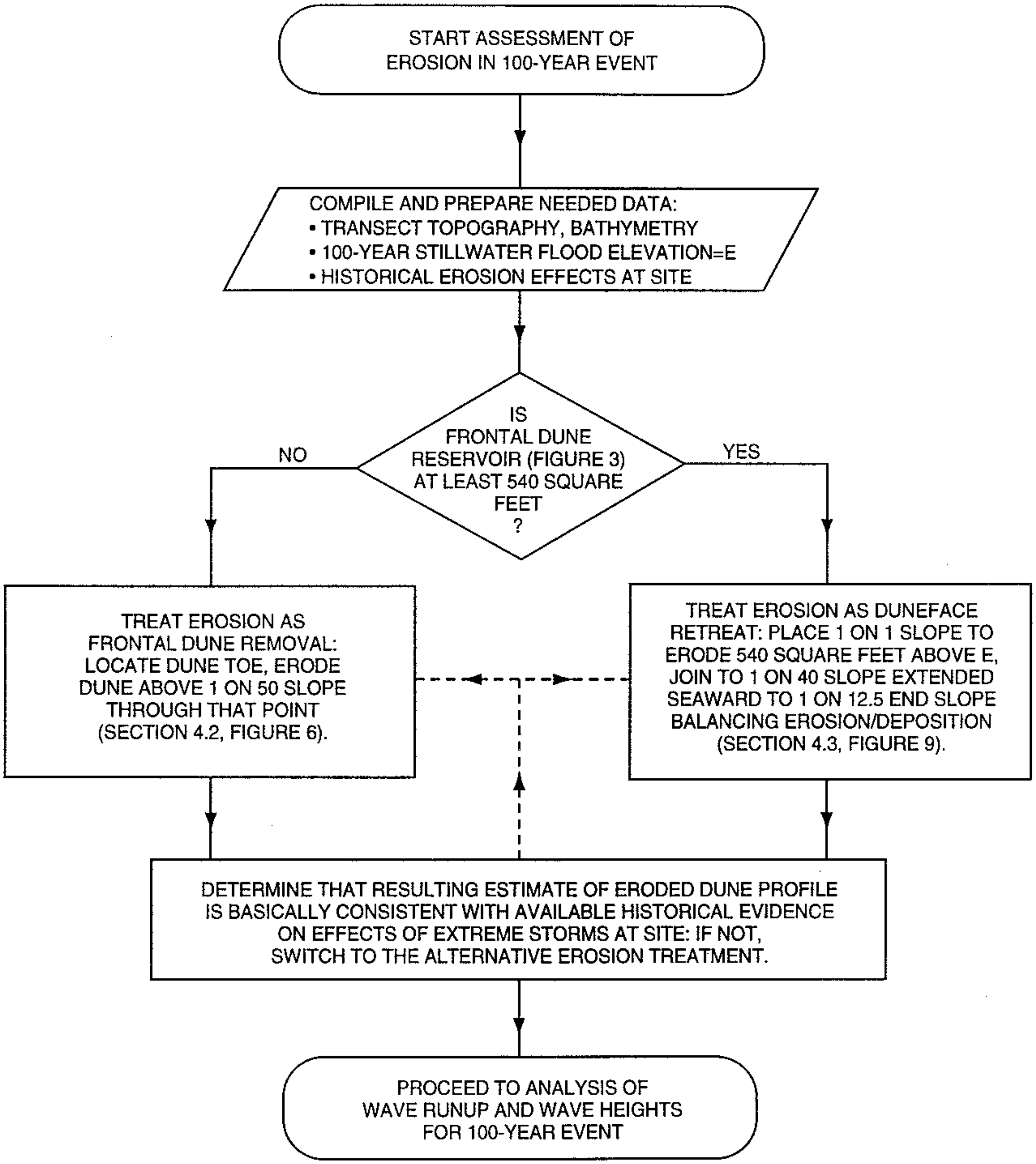


Figure 4. Flowchart of Erosion Assessment for a Coastal Flood Insurance Study.

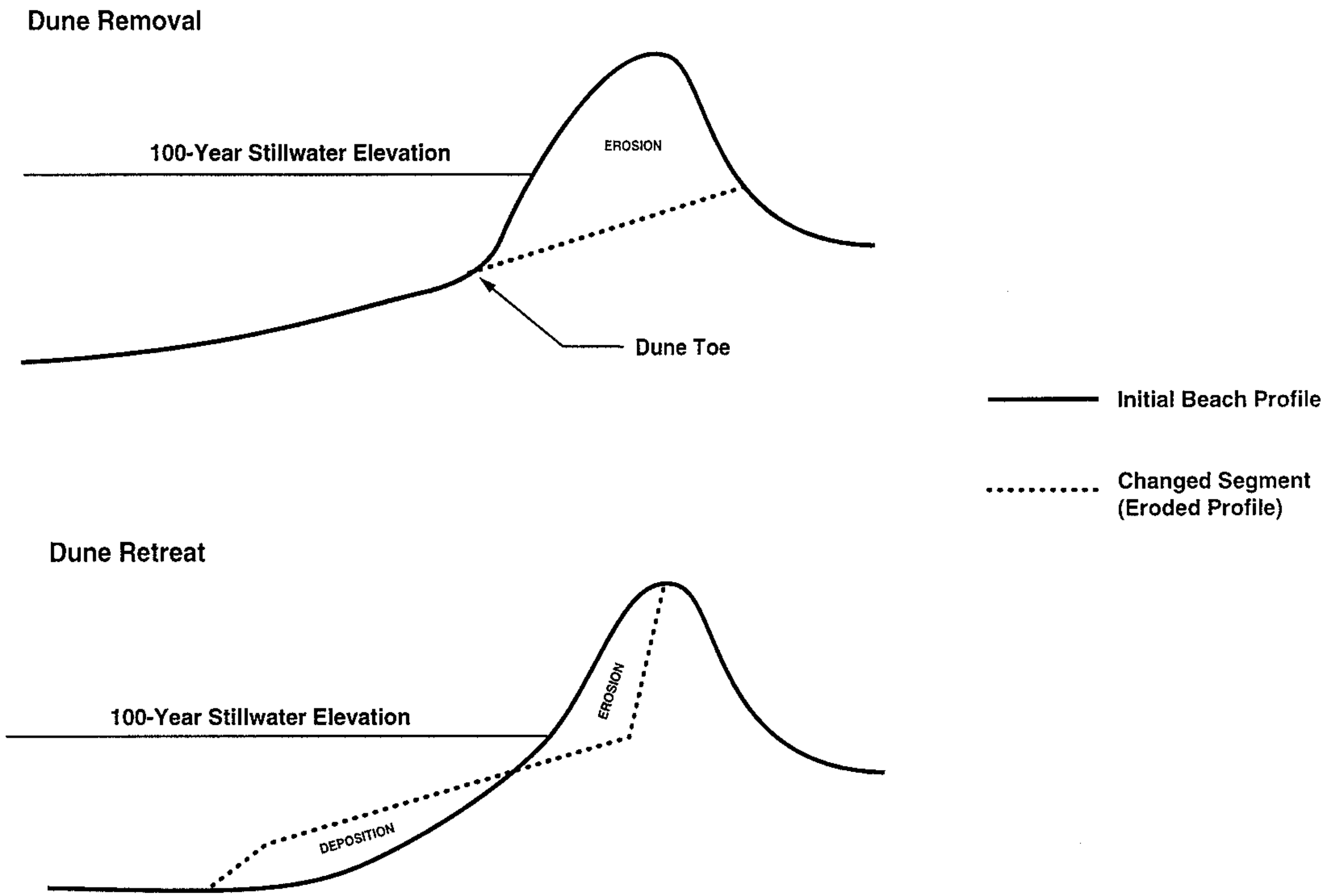
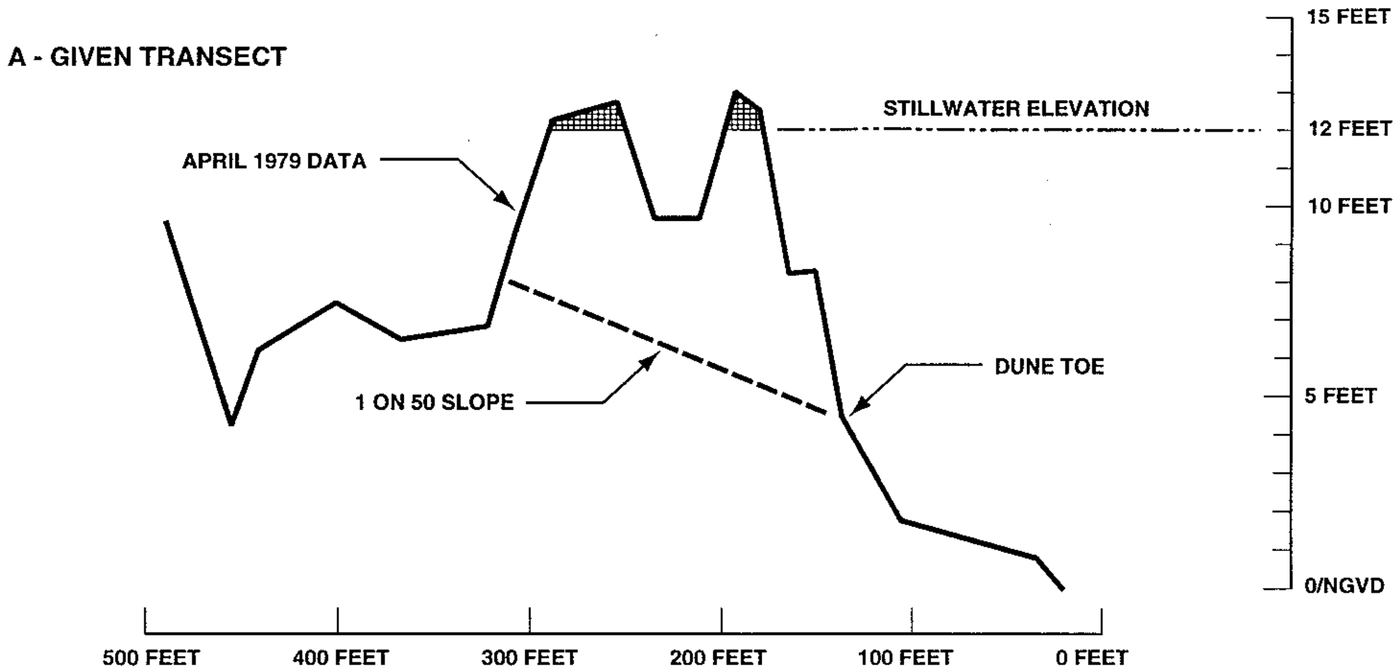


Figure 5. Schematic Cases of Eroded Dune Geometries with Planar Slopes.

that slope across the pre-storm dune, simply spliced onto the flanking segments of the given transect. This gives a gentle ramp across the extended storm surf zone adequate as a first approximation to the profile existing at the storm's peak. This treatment simply removes the major vertical projection of the frontal dune from the given transect.

Construction of an eroded profile focuses on the usually distinct feature termed the dune toe. That dune toe is taken to be the junction between the relatively steep slope of the front duneface and the notably flatter seaward region of the beach or the backbeach berm (including any minor foredunes). If a clear slope break is not apparent on a given coastal transect, its location should be taken at the typical elevation of definite dune toes on nearby transects within the study region. The alternative is to set the dune toe at the 10-year stillwater flood elevation in the vicinity: that appears to be a generally adequate approximation along U.S. Atlantic and Gulf coasts. In every case, the dune toe must be taken at an elevation above that of any beach berms on local shores.

Figures 6-8 display examples of this treatment for a removed dune. These simple constructions give appropriate estimates for the limits of high ground removed during the 100-year flood, but cannot provide accurate representations of eroded profiles due to the complicated processes of dune failure. One example of overly simplified results



B - ANALYSIS

1 - FRONTAL DUNE RESERVOIR ABOVE STILLWATER FLOOD ELEVATION (SHOWN CROSS-HATCHED) TOTALS ABOUT 35 SQUARE FEET, SO DUNE REMOVAL IS EXPECTED IN THIS 100-YEAR EVENT.
2 - DUNE TOE IS LOCATED AT JUNCTION BETWEEN 1 ON 3.8 AND 1 ON 11.5 SLOPES ON DUNEFACE.
3 - 1 ON 50 SLOPE THROUGH DUNE TOE PROVIDES APPROPRIATE ESTIMATE OF ERODED PROFILE ACROSS REMOVED DUNE.

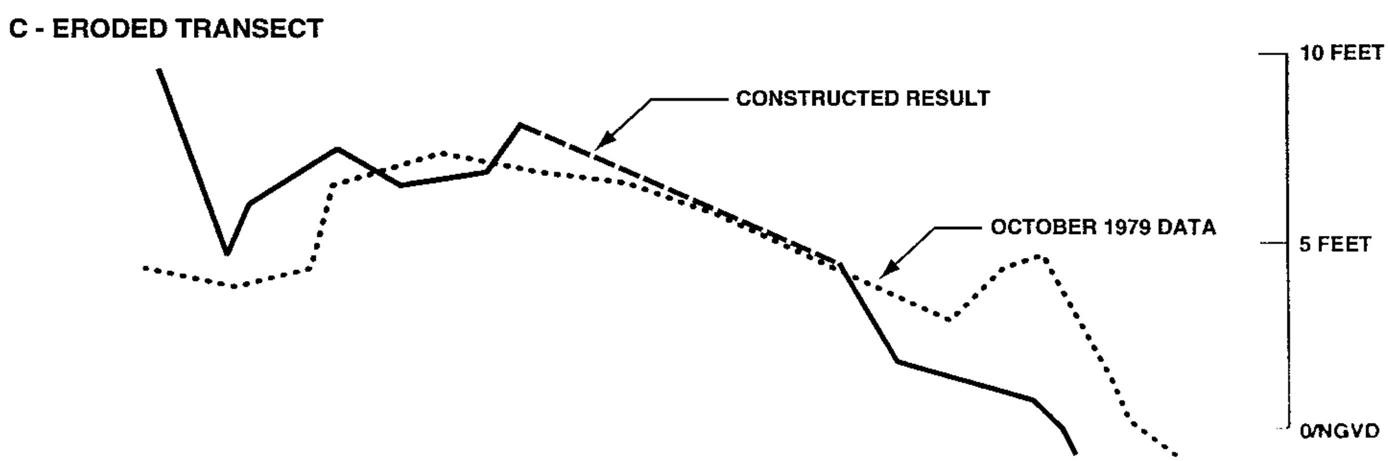


Figure 6. Quantitative example of dune removal treatment for Alabama profile eroded by the 1979 Hurricane Frederic. Situation is profile B-35 in Baldwin County, Alabama.

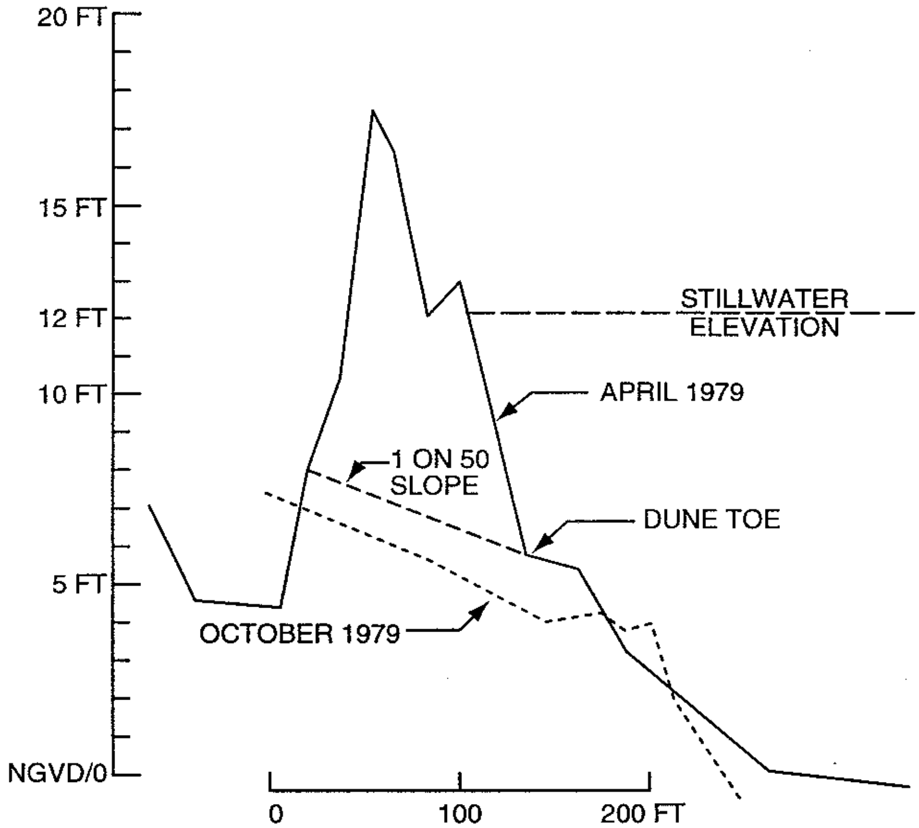


Figure 7 Case of relatively large dune removed by the 1979 Hurricane Frederic in Baldwin County, Alabama.

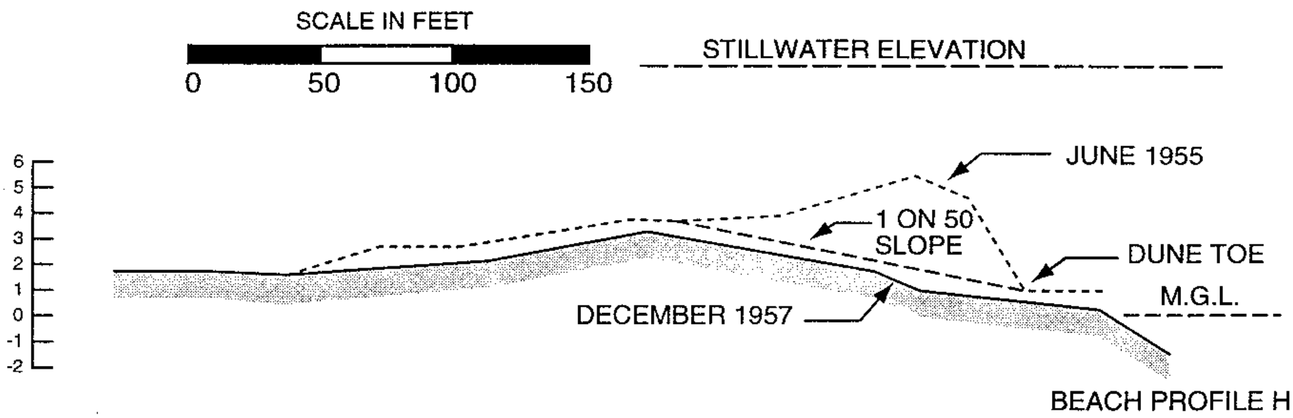


Figure 8. Erosion of relatively low profile by 1957 Hurricane Audrey in Cameron Parish, Louisiana.

is that deeper scour appears to occur where the frontal dune reservoir is relatively large.

The present viewpoint is consistent with this basic description of storm-induced erosion: greater erosion occurs where the pre-storm barrier provides more resistance, that is, has a relatively large cross section but still is removed during the 100-year flood. Net shore erosion appears to be maximum for situations where the dune barrier apparently just failed, and the eroded cross section can be much greater than in cases of duneface retreat. A slight opening to landward flow as an eroded dune becomes an overwash channel can result in much deeper scour than in cases of duneface retreat, where most shore erosion is above the stillwater elevation as duneface sand is continuously deposited in shallow water during the storm.

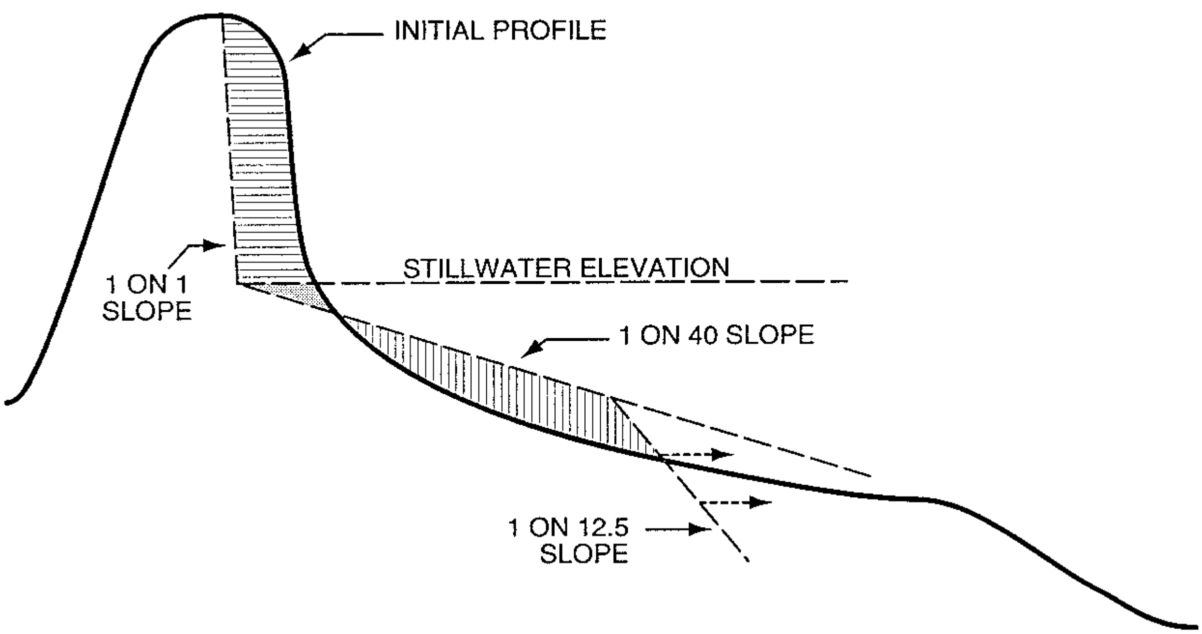
4.3 Treatment of Duneface Retreat

The procedure described here yields an eroded profile for duneface retreat in the 100-year flood, for cases where the frontal dune reservoir is at least 540 square feet. During such retreat, the frontal dune barrier remains basically intact and eroded sand is transported in the seaward direction. The post-storm profile provides a balance between sand eroded from the duneface and sand deposited at lower elevations seaward of the dune.

The following procedure for constructing the eroded profile constitutes a simplification of the dune retreat model developed by Delft Hydraulics Laboratory (DHL) of the Netherlands (Reference 29). Erosion above 100-year stillwater elevation is fixed at 540 ft^2, to guarantee an appropriate amount for the U.S. Atlantic and Gulf coasts (References 14, 16). (In the DHL model, erosion is determined as the variable depending on specified storm and site conditions.)

This modification to the DHL model eliminates potential problems associated with computation sensitivity to storm wave height and with uncertain capabilities for situations dissimilar to the Netherlands coast (References 15, 16). Other simplifications in this treatment are that the variation of sand size is ignored and that the curved segment of the DHL post-storm profile is approximated by a planar slope.

Figure 9 summarizes the simple procedure adopted to treat cases of duneface retreat. The eroded profile consists of three planar slopes: uppermost is a retreated duneface slope of 1 on 1, joining an extensive middle slope of 1 on 40, which is terminated by a brief segment with a slope of 1 on 12.5 at the limit to storm deposition. Upper dune erosion is specified to be 540 ft^2 above the 100-year stillwater elevation and in front of the 1 on 1 slope. Geometrical construction balances the nearshore deposition with the total dune erosion of somewhat more than 540 ft^2 by an appropriate seaward



PROCEDURE:

1 - CONSTRUCT RETREATED DUNEFACE WITH 540 FT^2 EROSION [☰] ABOVE 100-YEAR STILLWATER ELEVATION AND SEAWARD OF 1 ON 1 SLOPE.

2 - DETERMINE ADDITIONAL DUNE EROSION QUANTITY, SHOWN DOTTED, IN WEDGE BETWEEN STILLWATER ELEVATION, 1 ON 40 SLOPE, AND INITIAL PROFILE.

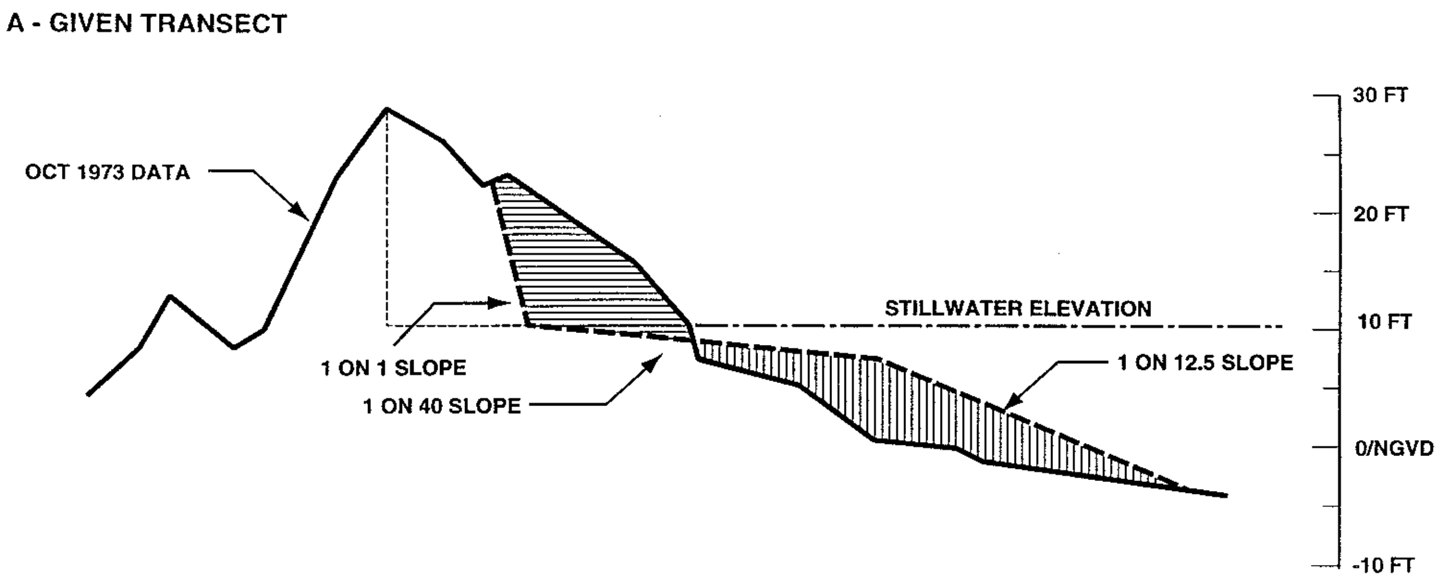
3 - BALANCE TOTAL DUNE EROSION WITH POSTULATED DEPOSITION [|||||||] BY APPROPRIATE PLACEMENT OF 1 ON 12.5 SLOPE AS LIMIT TO DEPOSITION.

Figure 9. Procedure giving eroded profile in cases of duneface retreat. This is simplification of dune retreat model developed by Delft Hydraulics Laboratory of the Netherlands.

extension of the 1 on 40 slope. The resulting eroded profile is spliced onto the unchanged landward and seaward portions of the pre-storm profile. This procedure gives a complete profile suitable for use with the Wave Runup Model in assessing an appropriate flood elevation on the dune remnant.

Figure 10 presents an example of duneface retreat according to the present procedure. This simple construction of a retreated dune profile gives appropriate eroded slopes important to the wave runup analysis of the remaining barrier. For this example, estimated erosion and deposition do not match well with those recorded, because there is a net sand loss shown on this profile and the event appears somewhat less extreme than a 100-year flood (judging from reported characteristics of Hurricane Eloise). Where historical data on duneface retreat are available for comparison, agreement of estimated erosion slopes with those recorded should be considered of primary importance in verifying the present treatment. Actual quantities of dune erosion are subject to very large variations in natural situations, and this procedure presumes a generally representative value for 100-year flood conditions.

The basic procedure outlined in Figure 9 should also be applied in estimating erosion of high open-coast headlands or bluffs of sandy material. In such cases, parallel retreat of the existing face slope should be presumed, rather than using the typical 1 on 1 slope for the escarpment on an eroded sand dune, because that existing



B - ANALYSIS

1 - FRONTAL DUNE RESERVOIR, OUTLINED BY--- , GREATLY EXCEEDS 540 FT^2 SO DUNEFACE WILL RETREAT.
2 - SPECIFYING EROSION ABOVE STILLWATER ELEVATION AS 540 FT^2, TOTAL DUNE EROSION ABOVE TWO UPPERMOST SLOPES IS FOUND TO BE APPROXIMATELY 620 FT^2.
3 - EROSION [☰] IS MADE TO EQUAL DEPOSITION [|||||||] BY EXTENDING MIDDLE (1 ON 40) SLOPE.

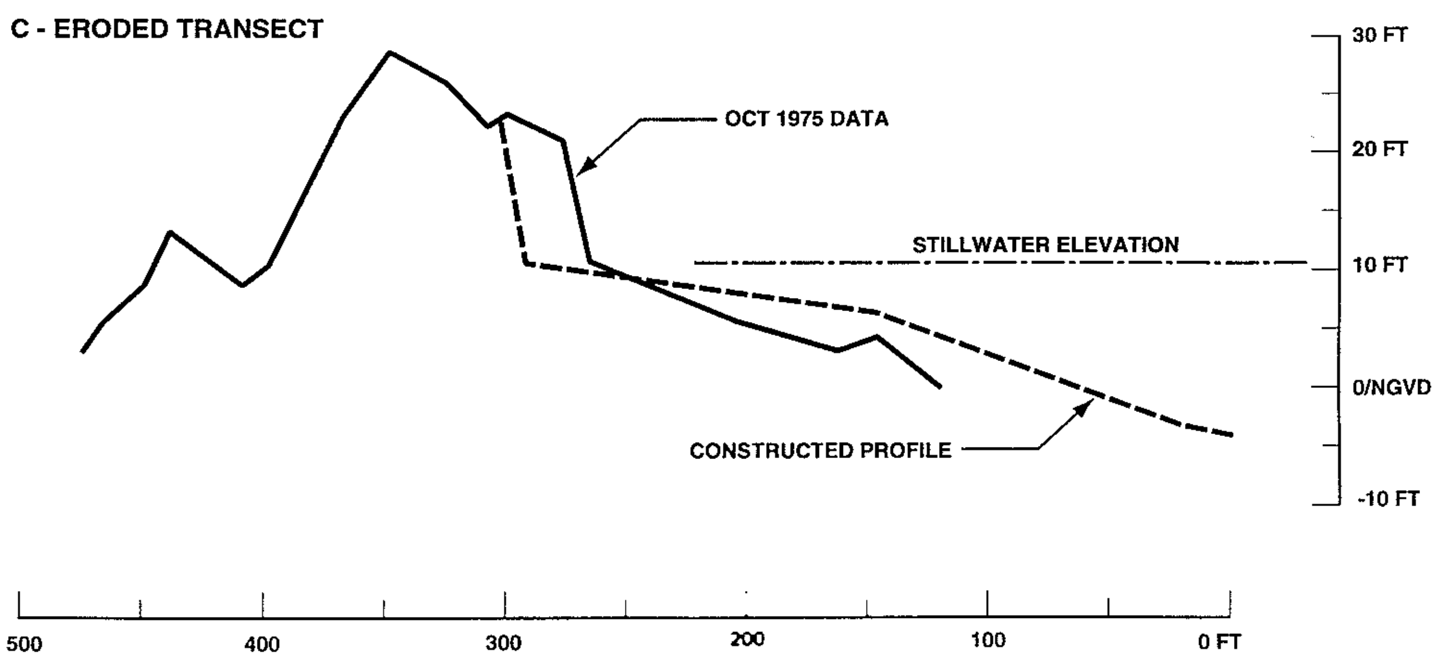


Figure 10. Example for duneface retreat treated by simplified version of D.H.L model, with erosion above stillwater elevation fixed at 540 ft^2. Situation is profile R-105 in Walton County, Florida, surveyed before and after 1975 Hurricane Eloise.

slope reflects actual consolidation properties of the headland or bluff material.

4.4 Finalizing Erosion Assessment

Based on measured erosion along the U.S. Atlantic and Gulf coasts, the demarcation between duneface retreat and dune removal in a 100-year flood has been set at a frontal dune reservoir of 540 square feet (References 14, 16). This quantitative criterion might appear too precisely stated, in view of potential inaccuracies in available dune topography, possible complications in delineating the effective frontal dune reservoir, and documented variability of dune erosion during extreme storms. In fact, the likelihood of duneface retreat or dune removal cannot be assessed with full certainty, so that validating the present erosion assessment by means of available evidence for a specific site is advisable.

At many sites, some historical evidence may be available regarding the extent of flooding, erosion, and damage in an extreme event comparable to the local 100-year flood. Then the erosion treatment giving results more consistent with historical records must be selected as appropriate. That choice may be relatively clear-cut, given potential differences in expected erosion and inland flood penetration for duneface retreat versus dune removal. Where available historical evidence is not definitive, the decision between retreat and removal on a given transect should be based solely on size of the frontal dune reservoir. Present procedures for erosion assessment are highly simplified, but provide an unbiased estimation and a level of detail appropriate to coastal FISs.

4.5 Wave Overtopping for Cases of Duneface Retreat

Where the erosion assessment indicates duneface retreat, an eroded dune remnant persists as an appreciable barrier to the base flood. However, storm wave action can result in occasional extreme runups overtopping that barrier, yielding floodwaters running off or ponding landward of the dune. The mean overtopping rate with storm waves incident on a typical duneface retreat geometry has been determined to be (Reference 30).

$$\overline{Q} = 5.26 \exp\left[-0.253\, F\right] \qquad (1)$$

Here the overtopping rate $\overline{Q}$ has units of cubic feet per second, per foot alongshore (cfs/ft), and F is maximum height (in feet) of the dune remnant above stillwater elevation. This result was measured in DHL tests scaled to reproduce a specific extratropical storm on the Dutch seacoast, with a significant deep-water wave height of 25 feet and a peak wave period of 12 seconds. Those wave conditions seem roughly representative for the base flood along U.S. seacoasts, although expected wave characteristics will differ between hurricanes and extratropical storms at various sites. Note that recorded rates of overtopping can show sizable departures from the expected mean even with steady flood conditions (References 26, 31).

Despite uncertainties about actual overtopping rates for a dune remnant, Equation 1 gives a useful basis for outlining expected effects. The order of magnitude for severe overtopping may be taken as 1 cfs/ft, past allowable thresholds for structural integrity with bare soil behind steep barriers exposed to storm waves (Reference 26). From Equation 1, $\overline{Q}$ of about 1 cfs/ft corresponds to F of about 7 feet, so retreated remnants with less relief above the 100-year stillwater elevation certainly require consideration of possible flood hazards landward of the dune. Appropriate treatments for ponding or runoff behind barriers are outlined in the next chapter.