

D.2.9 Coastal Erosion

This subsection provides methods for Mapping Partners to define the shape and location of eroded beach profiles, upon which 1-percent-annual-chance flood conditions (waves and water levels) will act and from which flood insurance risk zones and BFEs will be mapped.

D.2.9.1 Overview

Erosion processes and consequences of erosion can either be “episodic” or “chronic.” These two descriptors assign a very important temporal component to erosion processes and their results. *Episodic erosion* is the shore and backshore adjustment that results from short duration, high intensity meteorologic and oceanic storm events. This type of event response results in shore adjustment and occurs during a single storm or during a series of closely spaced storm events within a storm season. Shore and backshore profile changes during intense storms and hurricanes can result in dramatic beach and dune erosion, retreat, breaching, or removal of backshore dunes; cause retreat and collapse of bluff and cliff formations; and culminate in greater landward encroachment of waves and flooding from the ocean. *Chronic erosion* is associated with slow, long-term processes such as gradual shoreline adjustment associated with: (1) sea-level rise, (2) land subsidence, (3) changes in sediment supply due to watershed modifications or dam building, and (4) decadal adjustments in rainfall, runoff, and wave climate associated with global warming.

Current FEMA regulations are limited to risks and losses occurring as the direct result of a storm event. The NFIP does not address long-term chronic erosion, but focuses on episodic, flood-related erosion due to coastal storm events.¹¹ FEMA does not currently map long-term erosion hazard areas as some local or State agencies do. FEMA FIRMs do not inform property owners of erosion risks. FIRMs only indicate risks from flooding hazards in the form of BFEs and flood insurance risk zones. Therefore, flood assessment guidelines in this subsection only include methods for estimating eroded shore and backshore profiles during single, large storm events; the resulting profiles are then used in runup and overtopping computations to determine flood risks associated with these events. Subsection D.2.8 discusses how results from event-based erosion assessments are to be used by Mapping Partners to determine flood risks and delineate hazard zones.

D.2.9.2 Atlantic Coast Characteristics Related to Storm-Induced Erosion

Atlantic Coast beaches undergo typical seasonal changes in profile and location from summer to winter conditions. During winter months, increased total water levels, along with high-energy, steep waves, tend to move sand offshore. Throughout the summer and early fall, during months of calm seas, the beach recovers and the berms and dunes rebuild as sand moves back onshore. Figure D.2.9-1 provides a sketch of generalized, seasonal profile changes that occur on sand beaches of the Atlantic Coast.

¹¹ Discussions of long-term erosion and the potential consequences of chronic erosion are found in materials listed in the reference section of this document and in many of the support documents referenced herein.

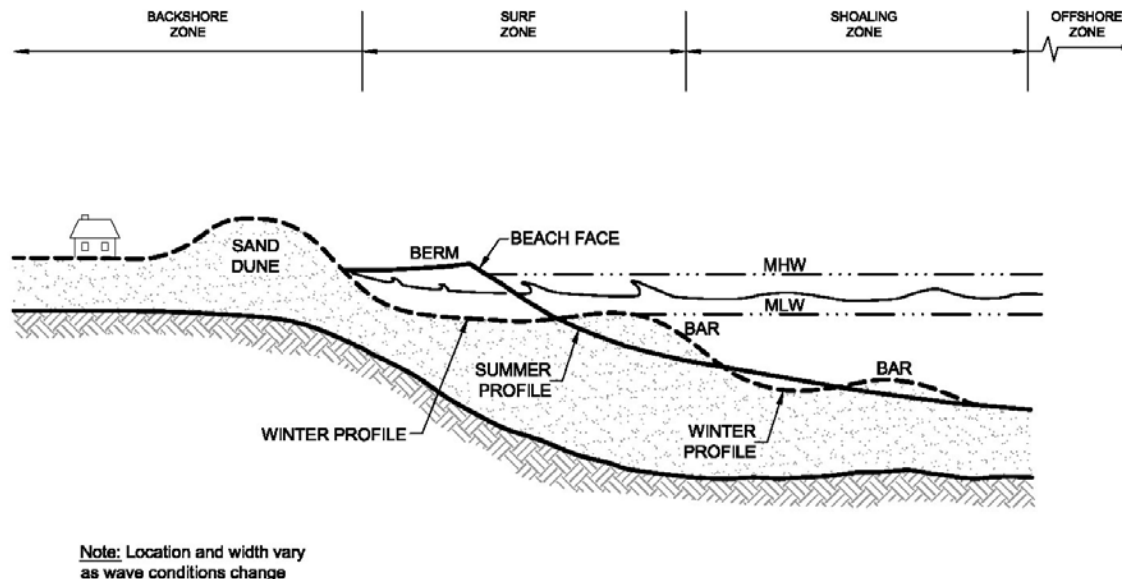


Figure D.2.9-1. Typical Atlantic Coast Summer and Winter Beach Profiles (after Bascom, 1964)

To estimate beach erosion and profile changes for a specific coastal setting, it may be important to consider during which season the potential flooding hazard event will likely occur. Many Atlantic and Gulf sandy beaches exhibit significant seasonal changes in their profiles due to seasonal differences in weather and wave climate. As a result, physical aspects such as beach width, berm height, and dune size can be reduced significantly at certain times of year. The severity of flooding associated with a given storm can be much greater if that storm strikes when the beach is in its seasonally eroded condition. To the extent practicable and where appropriate, Mapping Partners should consider the impacts of seasonal beach profile variability and the timing of severe storms when assessing flood hazards.

Northeasters can be particularly dangerous storms because they tend to occur during the time of year when beaches are in their most depleted or eroded condition. When determining the flooding and erosion hazard that a northeaster poses, it is important first to estimate the initial beach profile conditions that exist just before the occurrence of the storm (Figure D.2.9-2). Where significant storms occur during the winter, it may be appropriate for the Mapping Partner to consider use of the Most Likely Winter Profile (MLWP) approach. The concept of MLWP and how it can be used in assessing storm-induced erosion in appropriate study settings is discussed in greater detail in Subsection D.4.6.4. Mapping Partners conducting studies in areas subject to northeasters should consider estimating an MLWP prior to determining beach profile changes for a particular winter storm event. Generally, beaches south of Virginia are seldom affected by northeasters and therefore the MLWP approach is unlikely to be helpful when assessing coastal flood hazards.

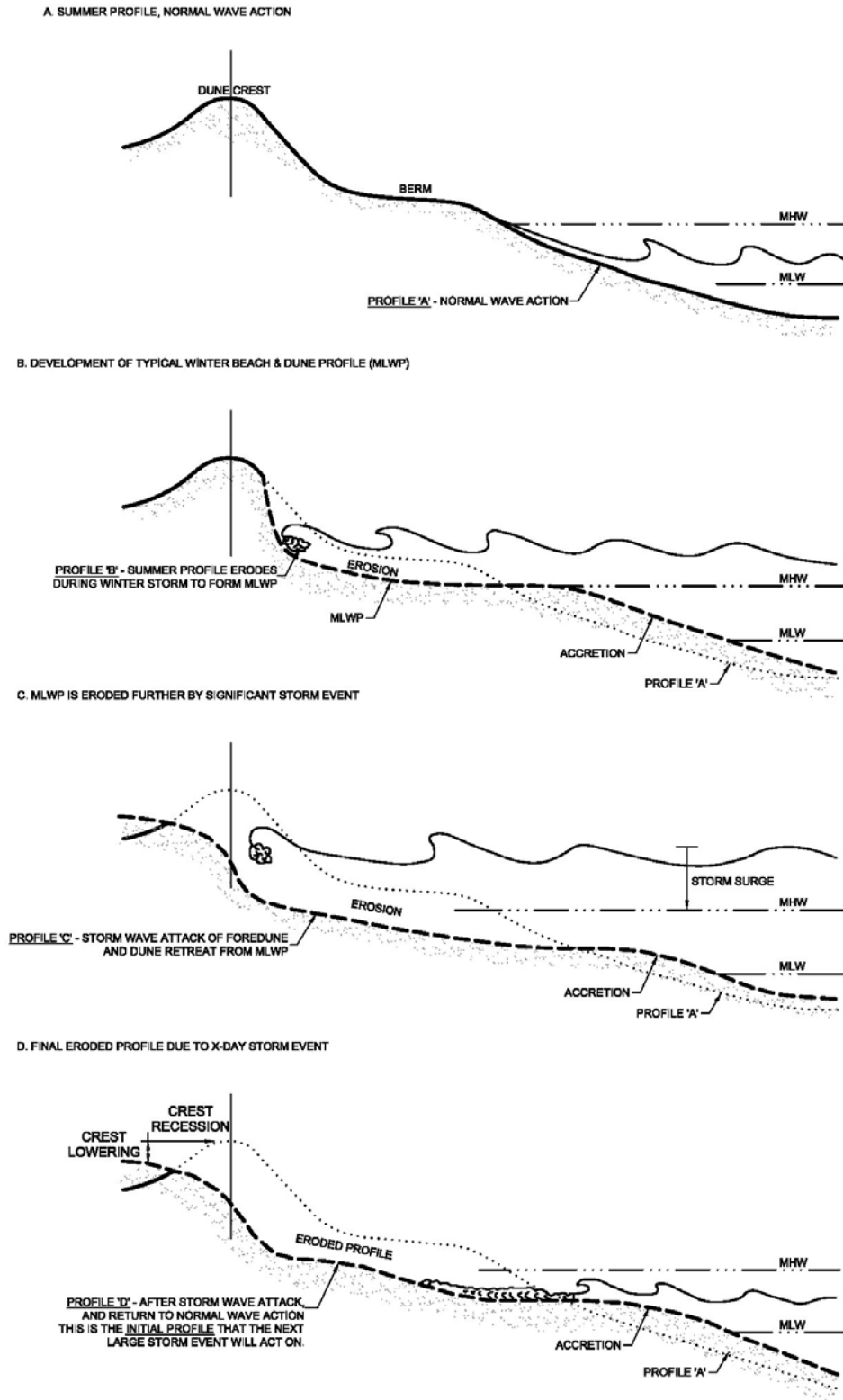


Figure D.2.9-2. Evolution of the Initial Beach Profile Before Occurrence of Large Storm Event (after SPM, 1984)

The following list provides references and websites where pertinent data may be obtained for use in event-based erosion analyses:

- Barton, C. C. 2004. U.S. National Coastal Assessment, USGS, Geologic Division, St. Petersburg, FL, website: <http://coastal.er.usgs.gov/national_assessment/>.
- Carr, E. E. 2002. Database of Federal Inlets and Entrances. U.S. Army Corps of Engineers, Coastal Inlets Research Program. <<http://cirp.wes.army.mil/cirp/inletsdb/inletsdbinfo.html>>. June 19.
- Good, J. W. (ed.). 1992. Coastal Natural Hazards, Science, Engineering and Public Policy. Oregon Sea Grant, Oregon State University, Publication No. ORESU-B-92-001, 162 pages.
- NOAA. 2000a. Tidal Datums and Their Applications. NOAA Special Publication NOS CO-OPS 1, Silver Spring, MD. June. <http://www.co-ops.nos.noaa.gov/publications/tidal_datums_and_their_applications.pdf>.
- NOAA. 2000b. Nautical Chart Symbols, Abbreviations and Terms, Chart No. 1, Eleventh Edition. Lighthouse Press, Annapolis, MD. 99 pp. NOAA Nautical Chart Users Manual. <<http://chartmaker.ncd.noaa.gov/staff/ncum/ncum.htm>>.
- NOAA. 2003. Computational Techniques for Tidal Datums Handbook, NOAA Special Publication NOS CO-OPS 2, Silver Spring, MD. September. <http://www.co-ops.nos.noaa.gov/publications/Computational_Techniques_for_Tidal_Datums_handbook.pdf>.
- Links to Other Information Sites Regarding Coastal Zone Management Topics:
 - <http://coastal.er.usgs.gov/lidar/AGU_fall98/>: Coastal Erosion (NOAA).
 - <<http://geodesy.noaa.gov/RSD/coastal/cscap.shtml>>: Remote Sensing (NOAA).
 - <<http://gis.sfsu.edu/data.htm>>: GIS Data Bases for Various Types of Data.
 - <<http://www.csc.noaa.gov/shoreline/>>: Shoreline Data (NOAA).
 - <<http://www.csc.noaa.gov/crs/tcm/missions.html>>: Topographic Data (NOAA).

D.2.9.3 Description of Beach Settings and Erosion Assessment Procedures

By their nature, coastlines are extremely complex and dynamic environments. The type and magnitude of coastal erosion are closely related to general coastal exposure and beach setting.

Coastal exposure refers to: (1) whether the coastline and beach are situated on the open coast, i.e., exposed to the undiminished waves, water levels, tides, winds, and currents associated with the open coast, or (2) whether the coastline is located within a sheltered area that is fully or

partially protected from the direct action of ocean waves, winds, tides, water levels, and currents. The latter condition is referred to as a *sheltered water area*. Beach erosion processes resulting from changes in total water level and wave action are similar along the open coast and within sheltered water areas; however, the magnitude, rate, and ultimate beach response may be quite different. Sheltered water areas typically have reduced wave energy and smaller runup. Some sheltered water areas found in confined embayments or estuaries may, however, experience higher still-water elevations as a result of the combined effects of astronomical tides and fresh water runoff from streams and rivers and modified tidal and surge conditions.

The primary differences in estimating coastal erosion for these two types of beach exposures relate to how waves and water levels are determined for the 1-percent-annual-chance storm condition. Refer to Subsection D.2.2 for guidance on how the 1-percent-annual-chance storm is determined and to Subsections D.2.4 and D.2.5 for guidance on how waves and water levels are estimated for these two coastal exposures.

Beach setting refers to localized geomorphic characteristics of the shore and backshore zone related to site-specific geology, profile shape, material composition, and material erodibility; proximity to other dominant features such as coastal inlets, storm outfalls, streams, and creeks; harbors and coastal structures; littoral sediment supply; pocket beaches; and seasonal changes in beach width due to changes in wave direction. Four common beach settings representative of those along the Gulf of Mexico and Atlantic Ocean shorelines are addressed in these guidelines:

1. Sandy beach backed by a low sand berm or high sand dune formation
2. Cobble, gravel, shingle, or mixed grain sized beach and berms
3. Erodible and non-erodible coastal bluffs or cliffs
4. Sheltered waters (e.g., tidal marsh or other reduced-energy basins)

Beach Setting No. 1 is likely to be the most important coastal setting for the Atlantic and Gulf coasts from a hazards mapping perspective. This setting tends to experience the most erosion and flooding during large storm events.

The main erosion-related factors affecting all beach profiles during storms are:

Antecedent conditions of the beach and back beach (profiles and beach-dune juncture elevation) before the occurrence of the specified storm event;

Forcing processes that include the duration and time histories of wave characteristics, water levels, and runup; and

Response elements that include the beach setting and the dune/bluff characteristics, including material erodibility.

To estimate profile changes for beaches and back-beach dunes and bluffs during storms, Mapping Partners need erosion-assessment methods that account for the unique morphologies of each beach setting and the general effects of the above processes. The following four subsections briefly describe the characteristics of each Atlantic and Gulf coast beach setting that influence

erosion assessments. The procedures for estimating storm-induced erosion for each setting are then provided in detail.

D.2.9.3.1 Sandy Dunes

Figures D.2.9-3a and D.2.9-3b provide sketches of typical beach profiles for broad sandy beaches backed by dunes or low sand berms. The primary factor controlling the basic type of dune erosion is the pre-storm cross section lying above the 1-percent-annual-chance SWEL (frontal dune reservoir). The Mapping Partner shall determine this area 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 (for example, Figure D.2.9-4), 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.

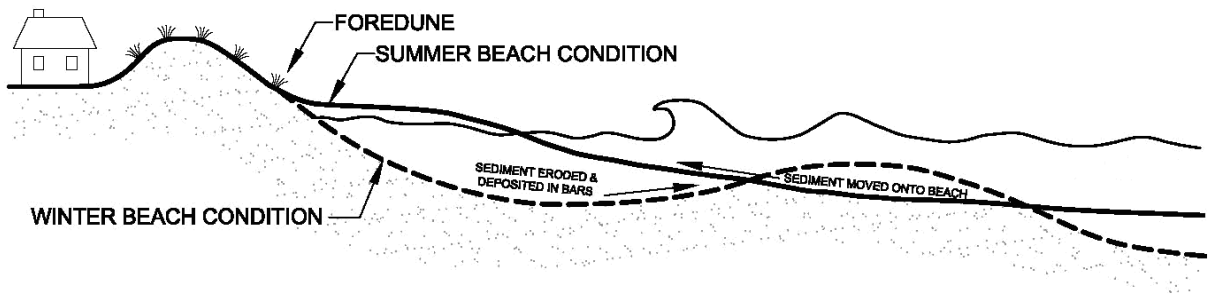


Figure D.2.9-3a. Sand Beach Backed by High Sand Dune (Beach Setting No. 1) (after Griggs, 1985)

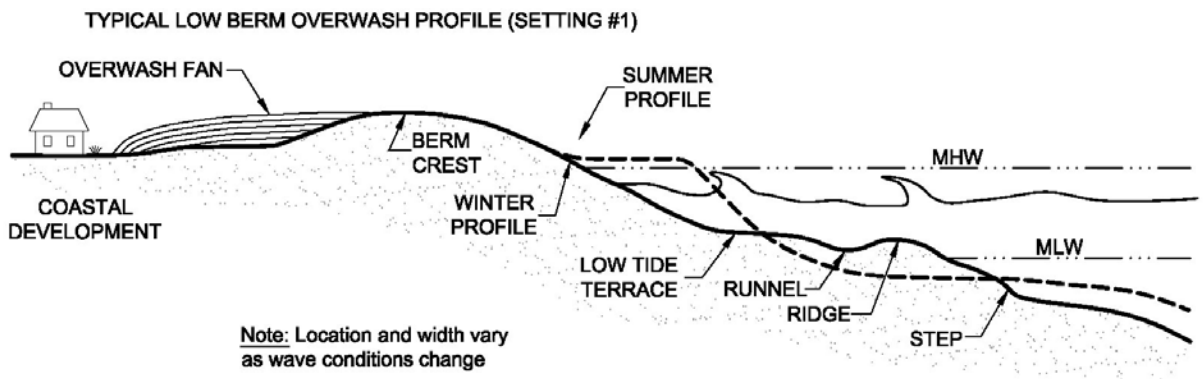


Figure D.2.9-3b. Sand Beach Backed by Low Sand Berm (Beach Setting No. 1) (after Bascom, 1964)



Figure D.2.9-4. Sandy Beach Backed by Low Dune

Figure D.2.9-5 introduces terminology for two representative dune types. A frontal dune is a ridge or mound of unconsolidated sandy soil, extending continuously along the shore 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 back beach berm on the seaward side. The dune toe is a crucial feature and can be located at the junction between gentle slope seaward and a slope of 1:10 or steeper, marking the front dune face. The rear shoulder, as shown on the mound-type dune in Figure D.2.9-5, 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 D.2.9-5 shows the location of the “frontal dune reservoir,” above the 1-percent-annual-chance SWEL and seaward of the dune peak or rear shoulder. The amount of frontal dune reservoir determines dune integrity under storm-induced erosion.

As a result of changes to the NFIP regulations, coastal flood studies undertaken since the 1990s have analyzed and mapped dune ridge systems and assessed whether these features are able to withstand storm-induced erosion and remain as barriers to coastal flooding. Those dunes meeting specific NFIP criteria are designated as PFDs. Section 59.1 of the NFIP regulations defines a PFD as, “a continuous or nearly continuous mound or ridge of sand with relatively steep seaward and landward slopes immediately landward and adjacent to the beach and subject to erosion and overtopping from high tides and waves during major coastal storms.” The regulations further state that the inland limit of the PFD, also known as the heel of the dune, “occurs at the point where there is a distinct change from a relatively steep slope to a relatively mild slope.” The inland limit of the PFD establishes the minimum landward limit of the V zone. Section 65.11 of the NFIP regulations explains the criteria by which PFDs will be evaluated to determine if they are of sufficient volume to act as barriers to storm surge and waves during the base flood.

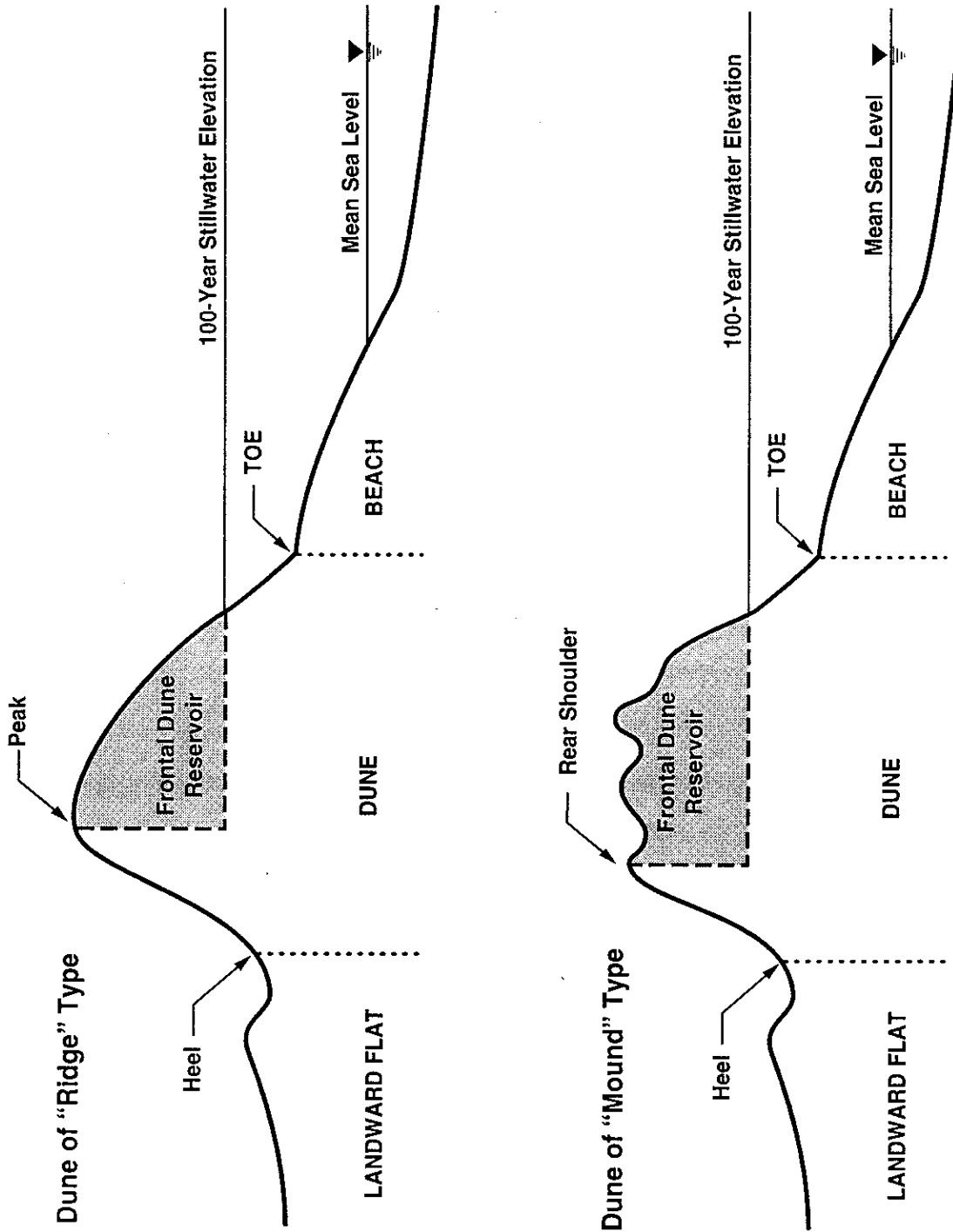


Figure D.2.9-5. Dune Features and Present Terminology

To prevent dune removal during the 1-percent-annual-chance storm, the frontal dune reservoir must typically have a cross-sectional area of at least 540 square feet (or 20 cubic yards volume per foot along the shore) above the 1-percent-annual-chance SWEL without wave setup (FEMA, September 1986; FEMA, November 1988). 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 the 1-percent-annual-chance SWEL. The simplified treatment of dune face retreat is described in Subsection D.2.9.3.1.2.

If a dune has a frontal dune reservoir less than 540 square feet in cross-sectional area, storm-induced erosion can be expected to obliterate the existing dune with sand transported both landward and seaward. The Mapping Partner shall estimate the eroded profile using procedures presented in Subsection D.2.9.3.1.1. 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 yet feasible (Birkemeier et al., 1987), so the frontal dune is simply removed.

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 D.2.9-5, the Mapping Partner shall use judgment to separate the sand reservoir expected to be effective in resisting dune removal from the landward portion of the pre-storm dune. The Mapping Partner shall complete the erosion assessment for the shoreline conditions representative of either the summertime shore profile for hurricane effects or the wintertime shore profile for northeaster storm effects, whichever is the appropriate and predominant source of coastal flooding that has been selected for use in the coastal hydraulic analyses and erosion assessment.

Figure D.2.9-6 presents a complete flowchart of necessary erosion considerations, outlining the major alternatives of duneface retreat and dune removal. Figure D.2.9-7 provides schematic sketches of the different geometries of dune erosion arising in coastal flood hazard assessments.

One additional factor complicating erosion assessment is the dissipative effect of wide sand beaches that shelter dunes from the full storm impact and retard retreat or removal. If the existing slope between mean level and the 1-percent-annual-chance SWEL is 1:50 or gentler, overestimation of erosion is possible during the 1-percent-annual-chance flood; therefore, the Mapping Partner shall examine this carefully. This effect and other variables, such as sand size, dune vegetation, and actual storm characteristics at a specific site, make thorough comparison of estimated erosion to documented historical effects in extreme storms necessary.

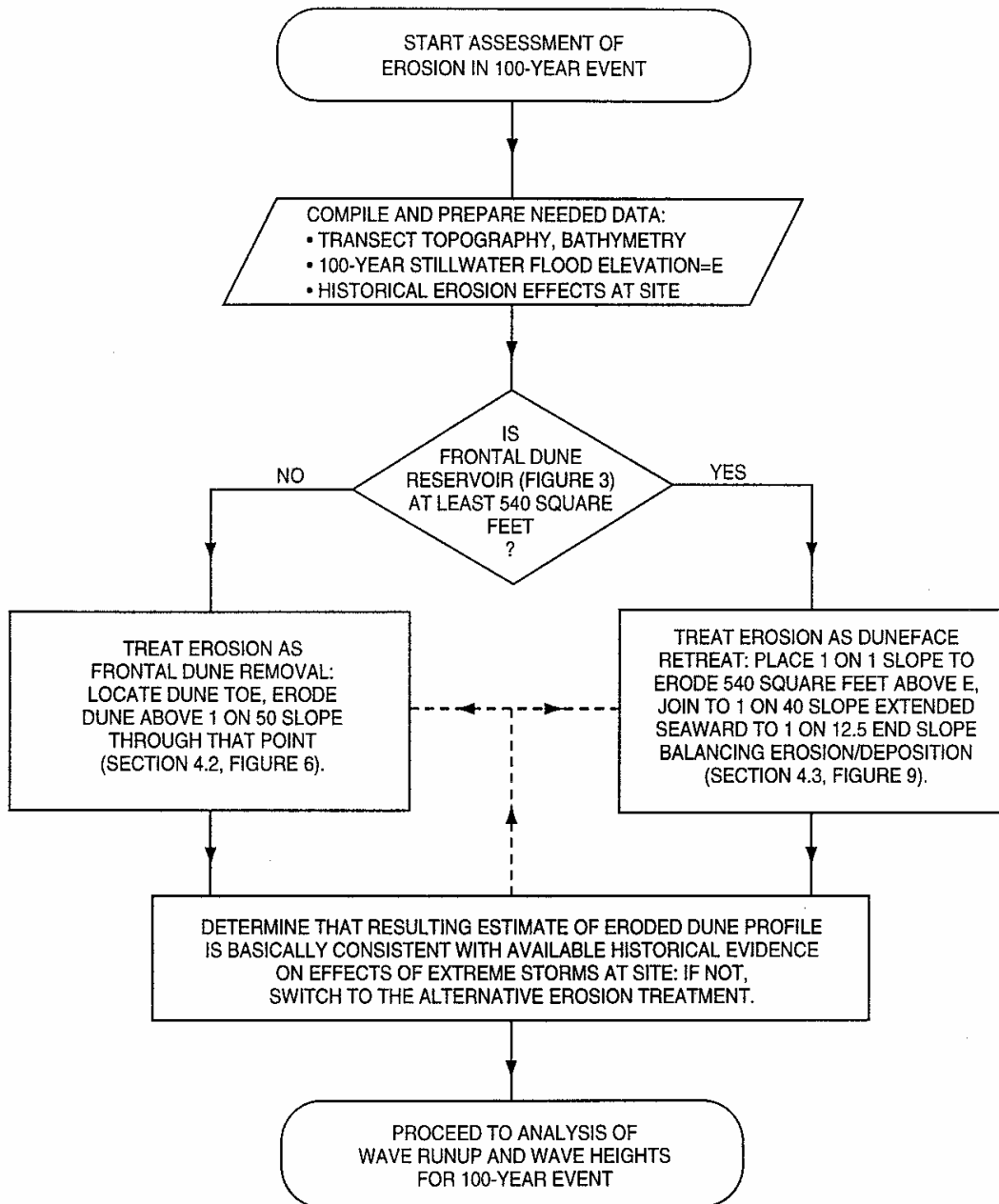


Figure D.2.9-6. Flowchart of Erosion Assessment for a Coastal Flood Map Project

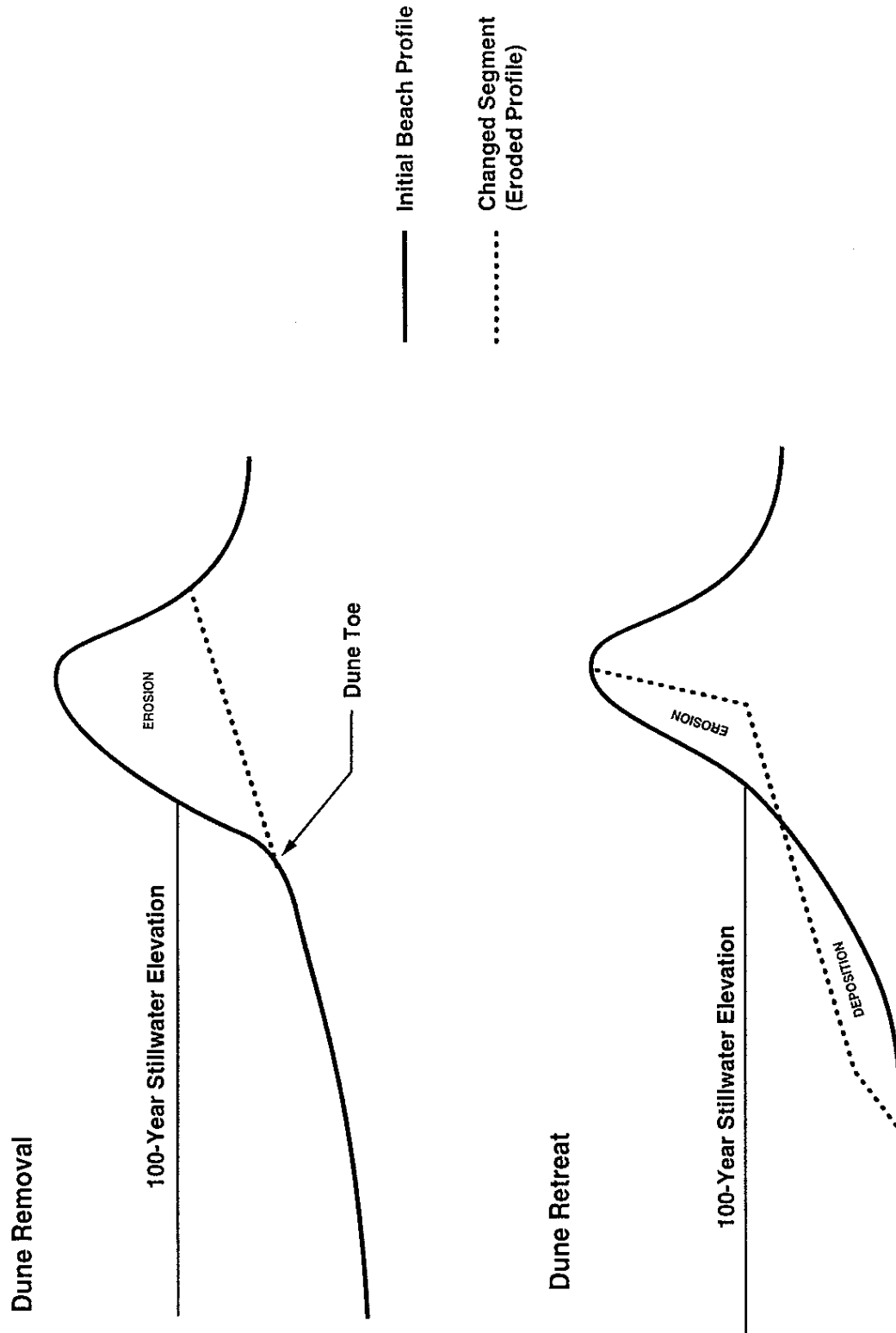


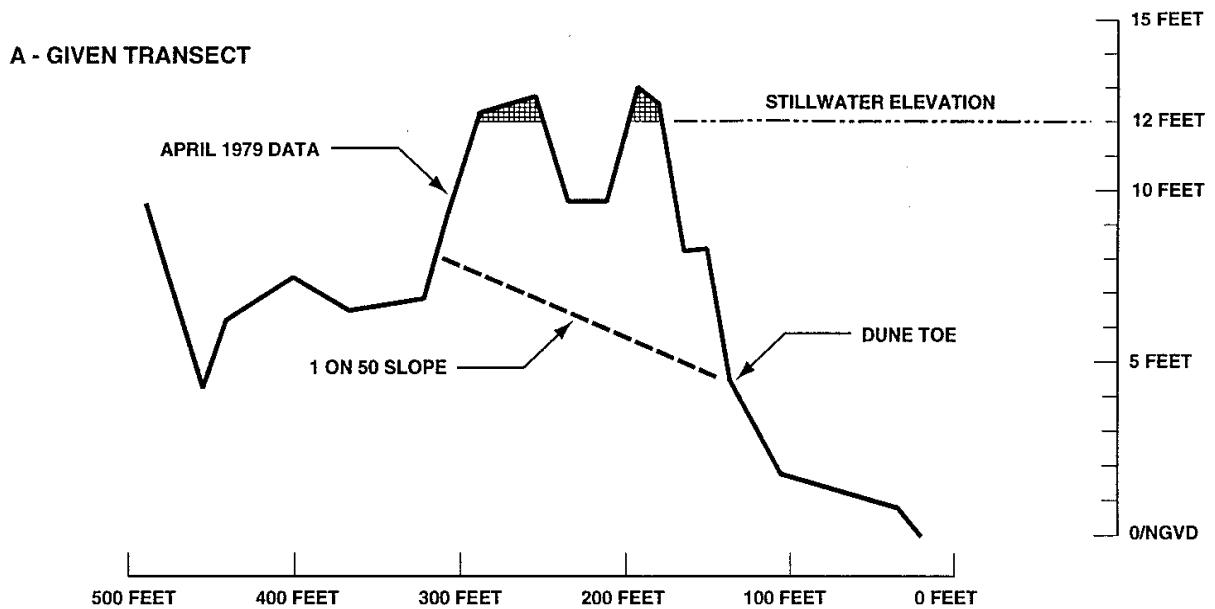
Figure D.2.9-7. Schematic Cases of Eroded Dune Geometries with Planar Slopes

D.2.9.3.1.1 Treatment of Dune Removal

Determining the dune reservoir requires an assessment of the profile area located above the 1-percent-annual-chance still-water flood level and seaward of the crest of the primary dune (see Figure D.2.9-5). 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 1:50 running through the dune toe. The eroded profile is taken to be that slope across the pre-storm dune spliced onto the flanking segments of a given transect. This gives a gentle ramp across the extended storm surf zone, which is 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 transect.

Construction of an eroded profile focuses on the usually distinct feature termed the dune toe. The 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 back-beach 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 area. Alternatively, the dune toe may be set at the local 10-percent SWEL, which has been shown to be an adequate approximation along the 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 D.2.9-8, D.2.9-9, and D.2.9-10 show examples of the dune removal method described above. These simple constructions give appropriate estimates for the limits of high ground removed during the 1-percent-annual-chance flood, but cannot provide accurate representations of eroded profiles because of the complicated processes of dune failure. One example of overly simplified results is seen when deeper scour appears to occur where the frontal dune reservoir is relatively large.



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.

C - ERODED TRANSECT

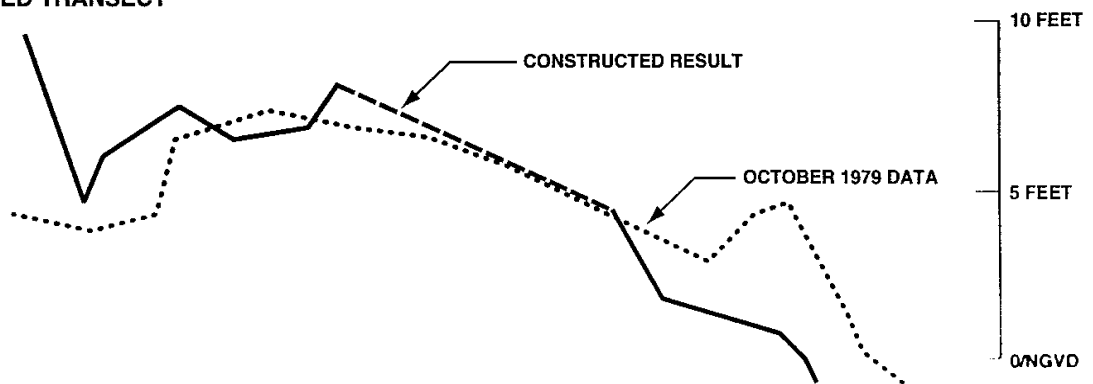


Figure D.2.9-8. Quantitative Example of Dune Removal Treatment for Alabama Profile Eroded by 1979 Hurricane Frederic. Situation Is Profile B-35 in Baldwin County, Alabama

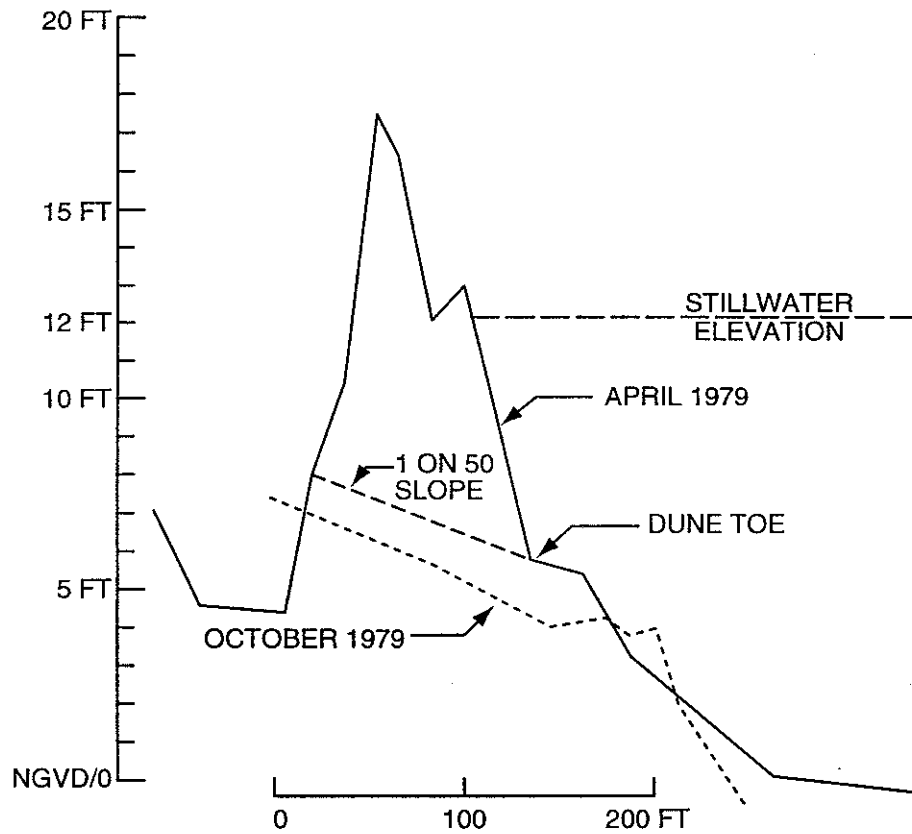


Figure D.2.9-9. Case of Relatively Large Dune Removed by 1979 Hurricane Frederic in Baldwin County, Alabama

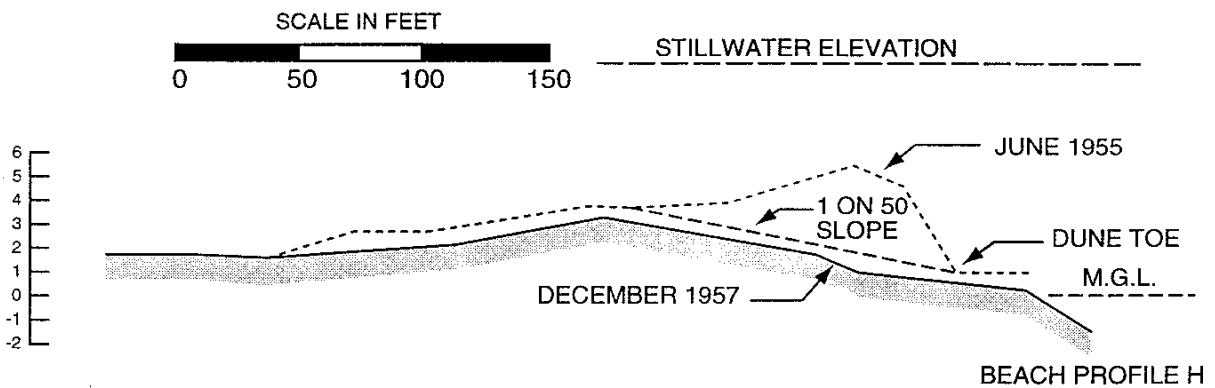


Figure D.2.9-10. Erosion of Relatively Low Profile by 1957 Hurricane Audrey in Cameron Parish, Louisiana

D.2.9.3.1.2 Treatment of Duneface Retreat

The procedure described here pertains to cases in which the frontal dune reservoir is at least 540 square feet. It yields an eroded profile for a beach impacted by duneface retreat during the 1-percent-annual-chance flood. During such retreat, the frontal dune barrier remains basically intact and eroded sand is transported in the seaward direction (Figure 2.9-11). The post-storm profile provides a balance between sand eroded from the duneface and sand deposited at lower elevations seaward of the dune.



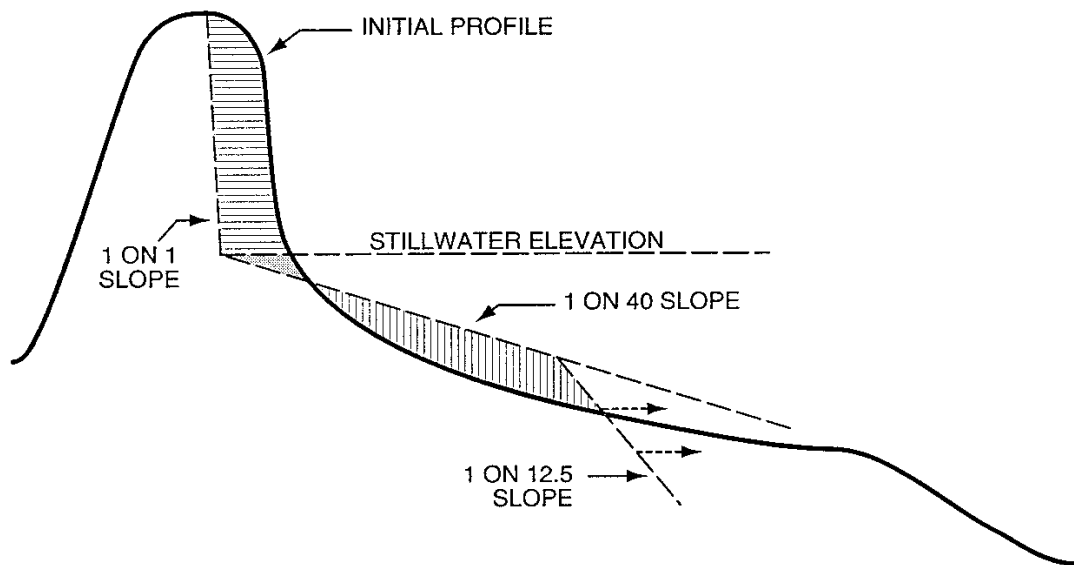
Figure D.2.9-11. Dune Retreat on the South Shore of Long Island, New York

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 (DHL, 1986). Erosion above the 1-percent-annual-chance SWEL is fixed at 540 square feet to guarantee an appropriate amount for the Atlantic and Gulf coasts (FEMA, 1986 and November 1988). (In the DHL model, erosion is determined as the variable depending on specified storm and site conditions.)

The simplification of 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 (Birkemeier et al., 1987; FEMA, November 1988). Other modifications of the model and treatment of duneface retreat have been implemented in an attempt to simplify the treatment by ignoring the variation of sand size and approximating the planar slope to the curved segment of the DHL post-storm profile.

Figure D.2.9-12 summarizes the simplified procedure adopted by FEMA to treat cases of duneface retreat. The eroded profile consists of three planar slopes: uppermost is a retreated duneface slope of 1:1, joining an extensive middle slope of 1:40, which is terminated by a brief segment with a slope of 1:12.5 at the limit to storm deposition. Upper dune erosion is specified to be 540 square feet above the 1-percent-annual-chance SWEL and in front of the 1:1 slope. Geometrical construction balances the nearshore deposition with the total dune erosion of

somewhat more than 540 square feet by an appropriate seaward extension of the 1:40 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.



PROCEDURE:



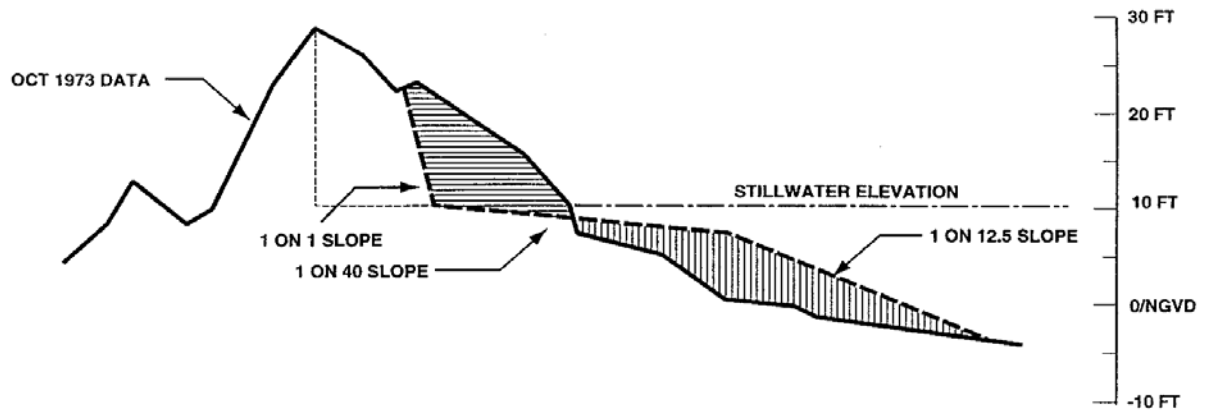
- 1 - CONSTRUCT RETREATED DUNEFACE WITH 540 FT² EROSION [] ABOVE 100-YEAR STILLWATER ELEVATION AND SEAWARD OF 1 ON 1 SLOPE.
- 2 - DETERMINE ADDITIONAL DUNE EROSION QUANTITY, SHOWN DOTTED, IN WEDGE BETWEEN STILLWATER ELEVATION, 1 ON 40 SLOPE, AND INITIAL PROFILE.
- 3 - BALANCE TOTAL DUNE EROSION WITH POSTULATED DEPOSITION [] BY APPROPRIATE PLACEMENT OF 1 ON 12.5 SLOPE AS LIMIT TO DEPOSITION.

Figure D.2.9-12. Procedure Giving Eroded Profile in Cases of Duneface Retreat, and Simplification of Dune Retreat Model Developed by Delft Hydraulics Laboratory of the Netherlands

Figure D.2.9-13A 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. 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 large variations in natural situations, and this procedure presumes a generally representative value for the 1-percent-annual-chance flood condition. For the example in D.2.9-13C taken from a study in Walton County, Florida, the estimated erosion and deposition proved greater than the observed. However, based on the reported characteristics of Hurricane Eloise, the associated flood was less severe than the 1-percent-annual-chance flood. So, while this specific profile would indicate another slope may be a better fit, the representative erosion slope proved to be valid, on average, for this reach of the coast and this storm.

A - GIVEN TRANSECT



B - ANALYSIS

- 1 - FRONTAL DUNE RESERVOIR, OUTLINED BY---, GREATLY EXCEEDS 540 FT² SO DUNEFACE WILL RETREAT.
- 2 - SPECIFYING EROSION ABOVE STILLWATER ELEVATION AS 540 FT², TOTAL DUNE EROSION ABOVE TWO UPPERMOST SLOPES IS FOUND TO BE APPROXIMATELY 620 FT².
- 3 - EROSION [Hatched] IS MADE TO EQUAL DEPOSITION [Hatched] BY EXTENDING MIDDLE (1 ON 40) SLOPE.

C - ERODED TRANSECT

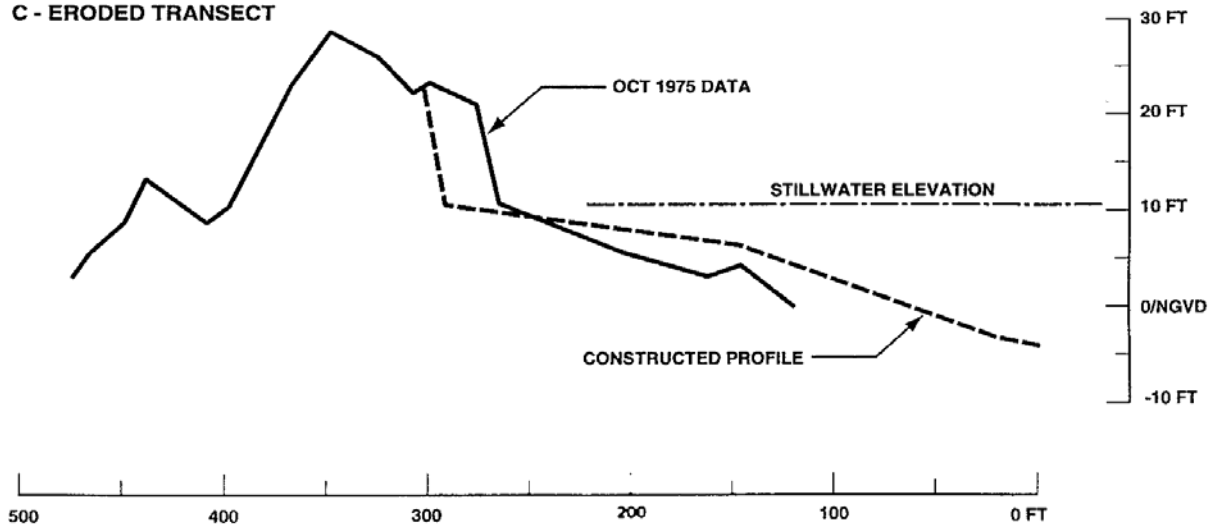


Figure D.2.9-13. Example of Duneface Retreat Treated by Simplified Version of DHL Model, with Erosion above SWEL Fixed at 540 Square Feet. Situation Is Profile R-105 in Walton County, Florida, Surveyed Before and After 1975 Hurricane Eloise

D.2.9.3.1.3 Finalizing Erosion Assessment

Based on measured erosion along the Atlantic and Gulf coasts, the demarcation between duneface retreat and dune removal in a 1-percent-annual-chance flood has been set at a frontal dune reservoir of 540 square feet (FEMA, 1986 and November 1988). 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. Validating the present erosion assessment for a specific site by means of available evidence is advisable.

At many sites, historical evidence may be available regarding the extent of flooding, erosion, and damage in an extreme event comparable to the local 1-percent-annual-chance flood. In these instances, 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 flood map projects.

D.2.9.3.1.4 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 1-percent-annual-chance flood. However, storm wave action can result in occasional extreme runup overtopping that barrier, yielding floodwater run off or ponding landward of the dune. DHL (1983) has determined the mean overtopping rate with storm waves incident on a typical duneface retreat geometry to be:

$$\bar{Q} = 5.26 \exp [-0.253 F] \quad (D.2.9-1)$$

Here the overtopping rate \bar{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 SWEL. 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 1-percent-annual-chance flood along U.S. seacoasts, although expected wave characteristics will differ between hurricanes and extratropical storms at various sites. Recorded rates of overtopping can show sizable departures from the expected mean, even with steady flood conditions (Goda, 1985; Owen, 1980).

Despite uncertainties about actual overtopping rates for a dune remnant, the equation gives a useful basis for outlining expected effects. The threshold for severe overtopping, associated with jeopardizing the structural integrity of bare soil behind steep barriers exposed to storm waves, is on the order of magnitude of 1 cfs/ft (Goda, 1985). From Equation D.2.9-1, \bar{Q} of approximately 1 cfs/ft corresponds to F of approximately 7 feet, so retreated remnants with less relief above the 1-percent-annual-chance SWEL certainly require consideration of possible flood

hazards landward of the dune. Appropriate treatments for ponding or runoff behind barriers are outlined in Subsection D.2.8.2.

D.2.9.3.2 Mixed / Coarse Sediment Systems

Beaches armored with cobbles, gravel, or other coarse sediments (Figures 2.9-14 and 2.9-15) develop in two distinct coastal environments. Often, these mixed-sediment beaches are prevalent in areas with slowly eroding bluffs that provide coarse sediment to the coastal system. Along the Atlantic Coast, these beaches are most common in New York, Massachusetts, and other New England States. In particular, mixed-sediment beaches are typically found along the shores of relatively sheltered bodies of water, where development of sandy beaches is inhibited by the absence of significant wind and wave action and by limited amounts of erodible sand. The other environment in which mixed-sediment beaches develop is one in which the coastline is exposed to high energy wave action, and, as a result, the finer sediments are winnowed away. Consideration of the wind and wave action to which the beach is exposed is necessary to determine whether the cobbles and gravel will provide a protective armoring against the 1-percent-annual-chance event, or whether wave action will exert sufficient force to erode them away.



Figure D.2.9-14. Mixed-sediment beach with materials ranging from sand to large cobbles, Peggotty Beach, Massachusetts (Photo courtesy of R. Haney, Massachusetts Coastal Zone Management)



Figure D.2.9-15. Mixed-sediment beach with well defined berm crest in Mann Hill Beach, Massachusetts (Photo courtesy of R. Haney, Massachusetts Coastal Zone Management)

Mixed-sediment beaches can vary significantly in overall morphology and sediment size distribution (i.e., size fractionation). These characteristics make it difficult to identify a “typical” mixed-sediment beach profile in either fair-weather or post-storm conditions. Figure D.2.9-16 provides one example of a mixed-sediment profile, but the composition and spatial relationships of the various sediment types can vary significantly from beach to beach. Historical profile data, therefore, are essential for the assessment of event-based erosion in mixed-sediment systems.

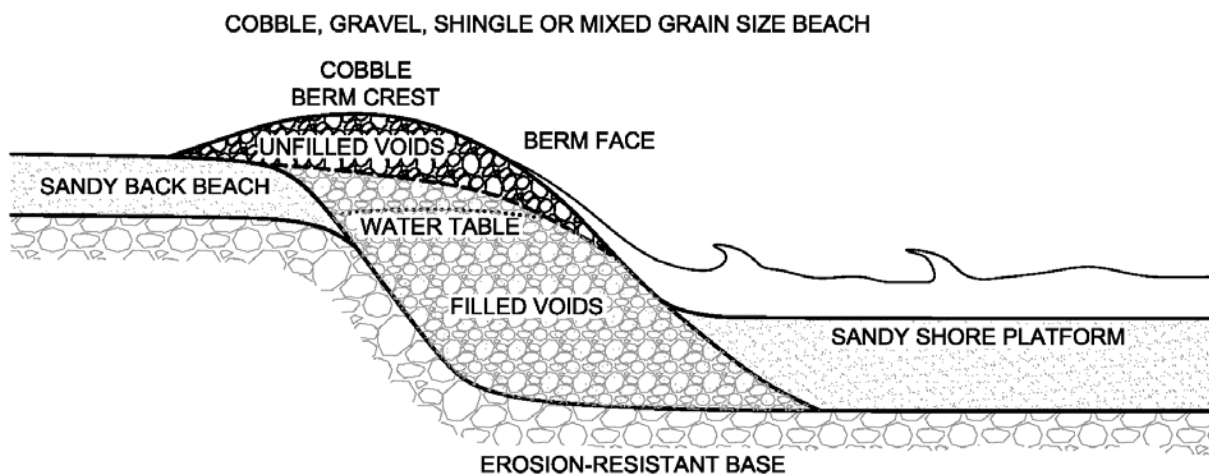


Figure D.2.9-16. Cobble, Gravel, Shingle, or Mixed Grain Sized Beach and Berms (Beach Setting No. 2)

Explicit procedures for determining beach and back beach profile changes on gravel and cobble beaches are not as well developed or documented as for sand beaches. Mixed-sediment beaches can be relatively stable in fair-weather conditions, but may behave dynamically or even breach in response to storms or other significant wave events (Figure D.2.9-17). Resorting of material, particularly between the Mean Higher High Water and Mean Lower Water elevations, is a common response to significant wave events (T. Ruthven, personal communication, 2006).



Figure D.2.9-17. Breach of mixed-sediment beach following a May 2005 northeaster, Mann Hill Beach, Massachusetts (Photo courtesy of R. Haney, Massachusetts Coastal Zone Management)

Given the lack of extensive observational data and prior coastal flood hazard analyses to date, there is currently no set of prescriptive profile geometries or erosion volumes that can be applied to all mixed-sediment beaches. Until such guidelines can be developed, Mapping Partners should use the following procedures and engineering judgment, as appropriate, to establish the typical eroded profile for Beach Setting No. 2, cobble, gravel, or shingle beaches and berms:

- Review the references listed in the support documents and literature on the design of and construction of dynamic revetments and cobble berms
- Examine photos and historical pre- and post-storm event LIDAR and beach profile data for the study area and develop a typical eroded profile from observed data, including a MLWP, if appropriate
- If a relatively broad sandy beach is located in front of the cobble berm, determine whether there is a history of significant erosion of the sand beach portion, and include that information in the beach profile data
- Survey the top-of-berm and back beach profile

- Splice the cobble berm profile, winter sand beach profile, top-of-berm, and back-beach profiles together to create a continuous beach profile that represents the complete profile for the beach, cobble berm, and back-beach areas
- Use this eroded-beach profile for subsequent runup computations during the selected storm event, unless other information indicates the profile may need further adjustment during large storm events
- Check results and try to validate them with observed information
- Document assumptions and results

D.2.9.3.3 Bluffs (Erodible and Erosion-Resistant)

Portions of the New England and U.S. island territory coasts have narrow to nonexistent beaches backed by high, steep, erodible coastal bluffs and cliffs, as illustrated in Figures D.2.9.-18 and D.2.9-19. The geomorphic evolution of this bluff-type shoreline is significantly different from that of the sandy beaches backed by either dunes or low-lying berms. A thin sand lens often overlies a rocky beach or bedrock platform fronting the bluff. These thin deposits of sand are removed during each winter storm season. If storm water levels reach sufficient elevations to intersect the toe of the bluff, storm waves can directly impinge upon the bluff face, causing bluff toe erosion (Figure 2.9-20). If enough material is eroded from the toe during a storm, the upper portion of the bluff can fail, resulting in bluff retreat. It should be noted that significant bluff failure may not occur during all storm events. However, if the bluff materials are erodible, toe erosion and bluff failure are possible during individual storm events.



Figure D.2.9-18. Erodible bluff fronted by narrow cobble beach, Scituate, Massachusetts (Photo courtesy of R. Haney, Massachusetts Coastal Zone Management)



Figure D.2.9-19. Erosion-resistant bluffs in Maine, with pocket beach of 0.5- to 1-m diameter boulders in the foreground (Photo courtesy of M. Honeycutt)

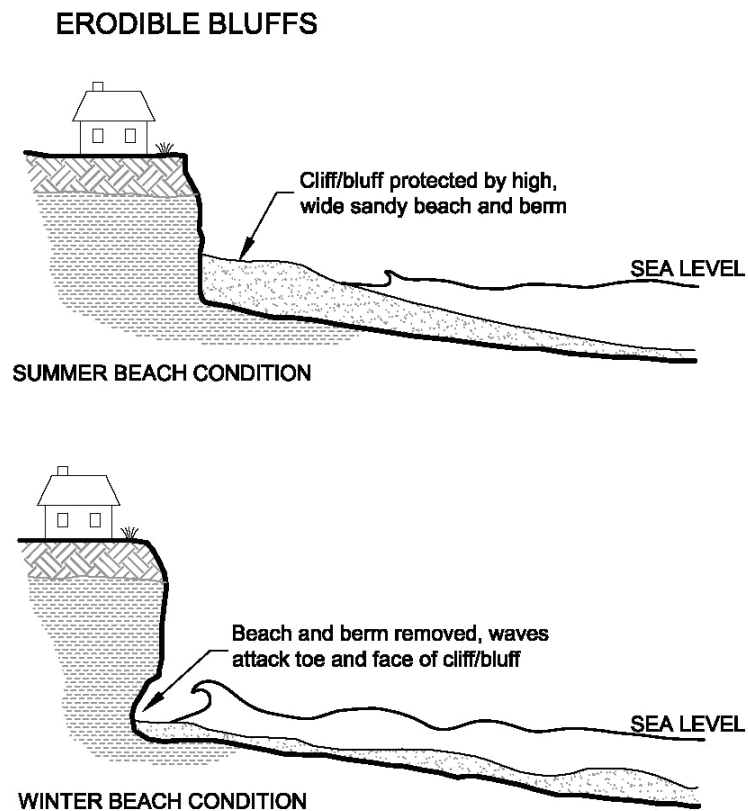


Figure D.2.9-20. Erodible coastal bluffs, showing seasonal profile variations and bluff-toe erosion (after Griggs, 1985)

The rate and extent of bluff erosion and failure depends on the site-specific bluff profile conditions at the time of the event (e.g., toe elevation and setback distance from the surf zone) and on the erodibility of the bluff materials. In some locations, it may take several storms to cause sufficient toe erosion to lead to bluff failure, or only one significant event with sufficient total water level, storm duration, and wave orientation to result in significant storm erosion.

Previous estimates of coastal bluff retreat have typically resorted in temporally averaged rates over a long period. Though the average annual rate of coastal cliff erosion is a reasonable indicator of the gradual retreat of the bluff top, it does not adequately predict the episodic nature of bluff failure that can result in 3 to 50 feet (or more) of retreat during a single storm event. The average annual retreat rate provides a misleading indication of the hazards of coastal bluff or cliff erosion because the occurrence of storms of sufficient magnitude and duration to cause significant bluff retreat are episodic. At some locations, coastal bluffs have fairly low elevations and may be overtopped by large wave events. Therefore, assessment of coastal flood and erosion hazards in coastal settings with erodible bluffs (Beach Setting No. 3) requires special methods and data.

D.2.9.3.3.1 Erodible Bluffs and Cliffs

Once the Mapping Partner has determined through reconnaissance that a bluff or cliff is susceptible to erosion, it is important to investigate the coastal setting and history of episodic and chronic bluff erosion for the study area. The Mapping Partner should then follow the steps below:

1. Obtain reliable beach and bluff profile data (surveyed cross-shore profiles or LIDAR) for existing conditions. Try to obtain data reflecting conditions near the end of the winter season (March or April).
2. Determine whether bluff erosion and failure-monitoring data are available for the study area. Obtain and examine that information to determine the magnitude of episodic toe erosion and bluff retreat.
3. Estimate top-of-bluff elevations and compare to potential significant storm, total water level (stillwater plus waves). Determine whether the bluff is subject to overtopping, frequent wave attack, or toe erosion.
4. If potential damage to structures or public safety is determined to be insignificant, the Mapping Partner shall document those results and determine whether any further analyses of potential coastal flooding are recommended.
5. If further analysis of bluff erosion or overtopping is not recommended, or the site is determined to be non-eroding, the Mapping Partner should apply methods listed below for Erosion-Resistant bluffs.
6. Perform all additional runup and overtopping analyses on the surveyed existing winter conditions beach and bluff profiles for the site.
7. Document results and summarize the data, methods used, and assumptions associated with the analyses.

If it is determined that the study site experiences significant erosion and retreat during large storm events, the Mapping Partner shall document those findings and discuss with the FEMA Study Representative whether there are sufficient data, time, and budget to perform a more detailed bluff erosion analysis. Depending on the site-specific characteristics of the setting and bluff materials, a detailed bluff erosion analysis will likely require detailed geologic sampling, bluff erosion monitoring data, and bluff erosion simulation analyses. Data requirements and procedures for conducting detailed bluff erosion analyses are presented in Subsection D.4.6.8.2 of this Appendix.

D.2.9.3.3.2 Erosion-Resistant Bluffs or Cliffs

Erosion-resistant bluffs and cliffs are often fronted by rock terraces, rocky beaches, or narrow rock platforms capped with thin layers of sand or gravel. Once the thin sand cap is eroded from the rocky beach, this beach setting is stable. Therefore, Mapping Partners shall assume the sand cap is removed from the beach profile before a significant storm event, and use the adjusted rocky beach profile, along with measured profiles, for the non-erodible bluffs or cliffs for all subsequent runup and overtopping computations. All assumptions, methods, data resources, and results should be well documented.

D.2.9.3.4 Sheltered Waters

“Sheltered waters,” for the purposes of FEMA coastal flood hazard analyses, are defined in detail in Subsection D.2.1.2.3. Generally, “sheltered waters” are water bodies or regions that experience diminished forces from wind and/or wave action relative to the open coast due to the presence of physical barriers, both natural and human, either on land or under water. Coastal reaches in this beach setting include (but are not limited to) low-energy beaches, tidal flats, and wetlands (Figure D.2.9-21).



**Figure D.2.9-21. Photograph of Tidal Flats and Wetlands Complex
(Photo by Northwest Hydraulic Consultants, Inc.)**

Tidal flats and wetlands are low-gradient coastal features, usually comprised of fine cohesive silts and clay (Figure D.2.9-22). Sedimentation processes in this beach setting are typically depositional. Over time, these coastal landforms may become capped with wetland vegetation and detrital deposits, and sand or debris from overland wave propagation during storm events (Figure D.2.9-23).

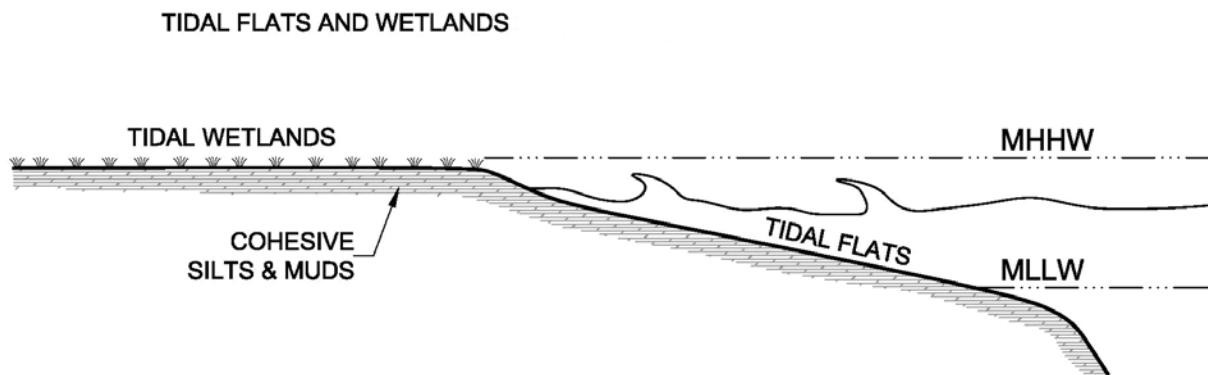


Figure D.2.9-22. Sheltered Water: Tidal Flats and Wetlands (Beach Setting No. 4)



Figure D.2.9-23. Virginia Tidal Salt Marsh, with Overwash Deposit After Hurricane Floyd

For the purposes of assessing storm-induced erosion, the classification of an area as "sheltered" suggests that shoreline or wetland response to the storm surge and wave action is expected to be minimal. Therefore, Mapping Partners may assume that tidal mudflats and wetland profiles do not erode over the time-scale of a single storm event.

Mapping Partners should compare existing tidal flat and wetland profiles with recent post-storm profiles to verify this assumption. If it is determined that no measurable erosion occurs during single storm events, then the Mapping Partner shall use the existing profile information to determine runup, overtopping, and overland propagation. However, if it is found that measurable changes can occur during a single storm, the Mapping Partner should document the observed changes experienced at the site and propose to the FEMA Study Representative a procedure for using that information to adjust the existing profiles before determining runup, overtopping, and overland propagation. The Mapping Partner shall document assumptions, data used, and methods implemented to prepare the final profiles and summarize the results.

D.2.9.3.5 Special Considerations

D.2.9.3.5.1 Beach Nourishment and Constructed Dunes

Policy and criteria for evaluating the stability and performance of coastal beach nourishment projects are not yet developed, and only basic guidance is provided in Subsection D.2.1.2.5.

The presence of constructed dunes in the study area may raise questions as to whether the material will affect flood insurance risk zones or BFEs. If the Mapping Partner determines that beach renourishment and/or dune construction have occurred in the study area, it should be brought to the attention of the FEMA Study Representative. As outlined in Subsection D.2.1.2.5, further analysis may be needed to assess the performance of the beach renourishment and/or dune construction, and what impact, if any, these actions will have on flood zones and BFEs.

For all practical purposes, the Mapping Partner shall treat constructed or reconstructed dunes (referred to as “artificial” dunes by FEMA) as natural dunes during the FIS. In the erosion assessment, this means assessing the dune reservoir and applying the dune removal (Subsection 2.6.3.1.1) or dune retreat (Subsection 2.6.3.1.2) procedures as appropriate. Note, however, that the condition of the artificial dune may alter this procedure. NFIP regulations [44 CFR 65.11(a)] do not allow an artificial dune to be considered as an effective barrier to coastal flooding, regardless of its size and cross-sectional area, unless it has well-established, longstanding vegetative cover. Pre-nourishment topography shall be used for non-vegetated artificial dunes and nourished beaches unless special consideration is granted by the FEMA Study Representative.

D.2.9.4.5.2 Erosion Assessment in the Vicinity of Coastal Structures

The erosion assessment procedures that the Mapping Partner must complete for coastal structures are dependent on whether the structure is certified or uncertified, and in the latter case, whether the structure will completely or partially fail during the 1-percent-annual-chance flood.

If a coastal structure is certified to withstand the 1-percent-annual-chance flood (see Subsection D.2.10.2), but the structure will be inundated by the 1-percent-annual-chance flood, the ground profile landward of the structure (including any PFD identified) must be evaluated for storm-induced erosion. Because the structure provides protection against the full forces associated with the base flood, application of the 540-square-foot rule for open coast settings would not be appropriate. The Mapping Partner shall, at a minimum, erode the land surface immediately landward of the structure to the crest elevation. The Mapping Partner will need to exercise professional judgment in constructing the remainder of the eroded profile, connecting the crest elevation to natural ground elevation at a point landward where erosion is likely to be negligible.

If a coastal structure cannot be certified, the Mapping Partner must determine whether the structure will completely or partially fail during the base flood. When failure will be complete, the Mapping Partner shall remove the structure entirely from the analysis transect. The remaining soil profile should be altered to achieve its likely slope immediately after structure failure. Information on slopes behind failed structures is limited. These slopes may vary from 1:100 (v:h) for unconsolidated sands to 1:1 or steeper for consolidated material landward of the failed structure. The post-failure slope for this analysis should be in the range of 1:1 to 1:1.5. Note that

the post-failure slope may not necessarily match the long-term stable slope, but will serve as the basis for subsequent site-specific, event-based, erosion wave height, wave runup, and wave overtopping analyses. If the Mapping Partner determines that the structure will partially fail, storm-induced erosion must still be evaluated both seaward and landward of the structure. Subsection D.2.7.3 of this document provides further information on how to determine an appropriate post-failure profile for use in subsequent coastal flood hazard modeling.