Chapter 3: Coastal Environment

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Coastal Environment

3.1 Introduction

Planning, siting, design, and construction of coastal residential buildings require an understanding of the coastal environment – including a basic understanding of coastal geology, coastal processes, regional variations in coastline characteristics, and coastal sediment budgets. Each of these topics will be discussed briefly.

Coastal Geology refers to the origin, structure, and characteristics of the sediments that make up the coastal region, from the uplands to the nearshore region (see Figure 3-1). The sediments can vary from small particles of silt or sand (a few thousandths or hundredths of an inch across), to larger particles of gravel and cobble (up to several inches across), to formations of consolidated sediments and rock. The sediments can be easily erodible and transportable by water and wind, as in the case of silts and sands, or can be highly resistant to erosion. The sediments and geology that compose a particular coastline will be the product of physical and chemical processes that take place over thousands of years.

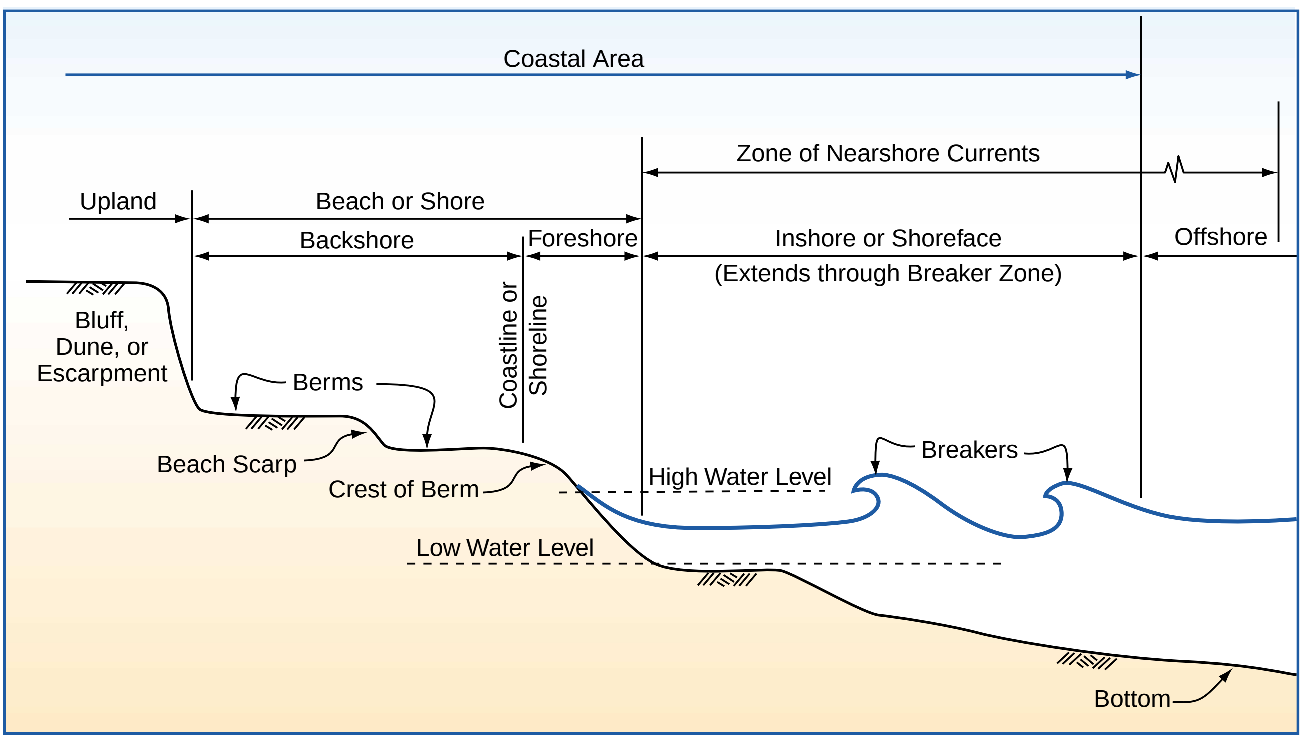


Figure 3-1 Coastal region terminology (USACE 1984).

Coastal Processes refers to those physical processes that act upon and shape the coastline. These processes, which influence the configuration, orientation, and movement of the coast, include the following:

- tides and fluctuating water levels
- waves
- currents (usually generated by tides or waves)
- winds

Coastal processes interact with the local coastal geology and sediment supply to form and modify the physical features that will be referred to frequently in this manual: beaches, dunes, bluffs, and upland areas. Water levels, waves, currents, and winds will vary with time at a given location (sometimes according to short-term, seasonal, or longer-term patterns) and will vary geographically at any point in time. A good analogy is weather: weather conditions at a given location undergo significant variability over time, but tend to follow seasonal and other patterns. Further, weather conditions can differ substantially from one location to another at the same point in time.

NOTE

The premise behind a *coastal sediment budget* is simple: if more sediment is transported by coastal processes or man's actions into a given area than is transported out, shoreline accretion results; if more sediment is transported out of an area than is transported in, shoreline erosion results.

Regional Variations in Coastlines will be the product of variations in coastal processes and coastal geology. These variations can be quite substantial, as will be seen in the following sections of this chapter. Thus, shoreline siting and design practices appropriate to one area of the coastline may not be suitable for another.

Coastal Sediment Budget refers to the identification of sediment sources and sinks, and the quantification of the amounts and rates of sediment transport, erosion, and deposition within a defined region. Sediment budgets are used by coastal engineers and geologists to analyze and explain shoreline changes and to project future shoreline behavior. While the calculation of sediment budgets is beyond the scope of typical planning and design studies for coastal residential structures, it is useful to consider the basic concept and to review the principal components that make up a sediment budget. Moreover, sediment budgets may have been calculated by others for the shoreline segment containing a proposed building site.

Figures 3-2 and 3-3 illustrate the principal components of sediment budgets for the majority of U.S. coastline types. Note that there may be other locally important sediment sources and sinks that are not shown in the figures. For example, the addition of sand to a beach through beach nourishment could be considered a significant source in some communities; the loss of sediment through storm-generated overwash (see Section 7.5.2.6) could represent an important loss in some areas.

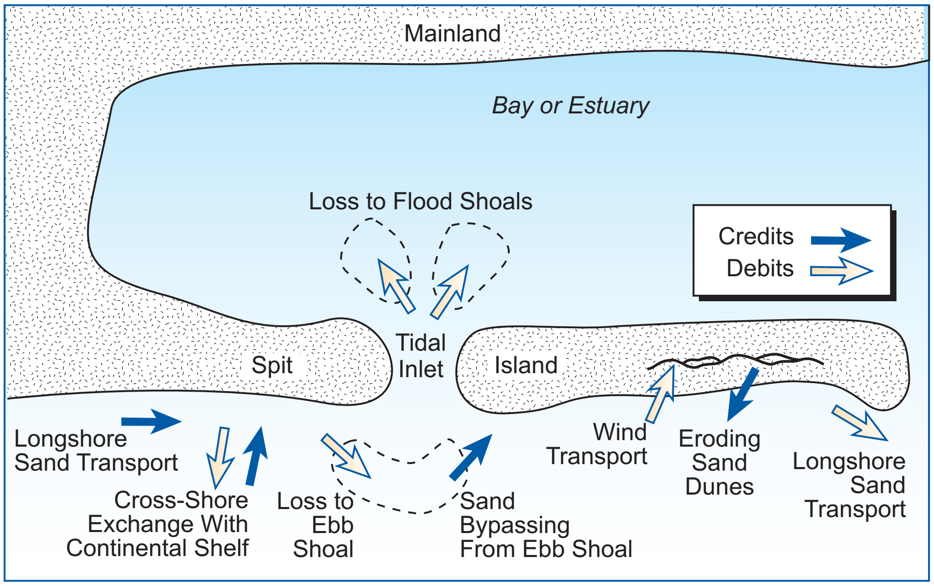


Figure 3-2
Principal components of a typical sediment budget for a barrier island and barrier spit shoreline.

DEFINITION

Flood shoals are sediment deposits formed just inside a tidal inlet by flood tidal currents (also called flood tidal delta).

Ebb shoals are sediment deposits formed by ebb tidal currents just offshore of a tidal inlet (also called ebb tidal delta).

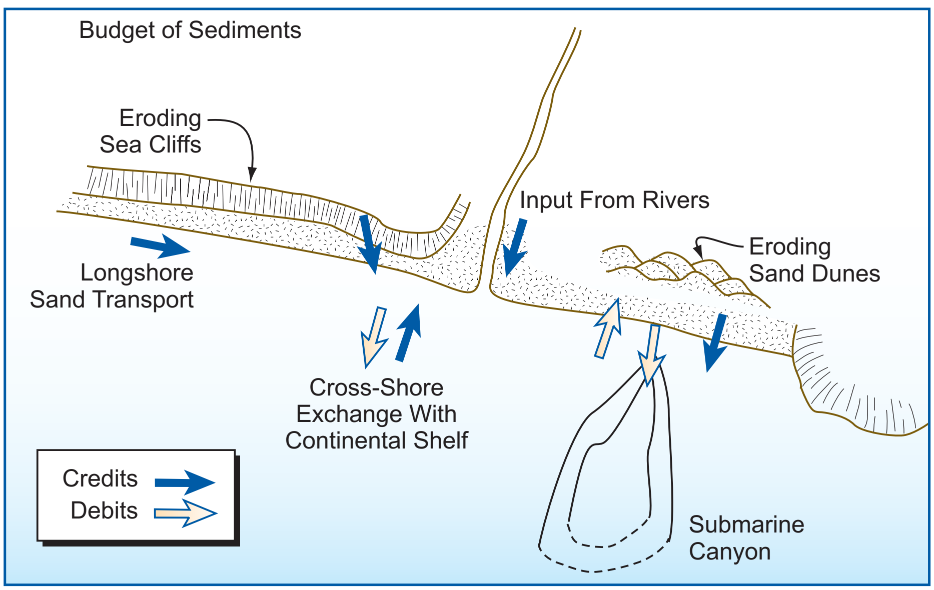


Figure 3-3
Principal components of a typical sediment budget for a mainland shoreline backed by bluffs and dunes. Modified from Komar 1996.

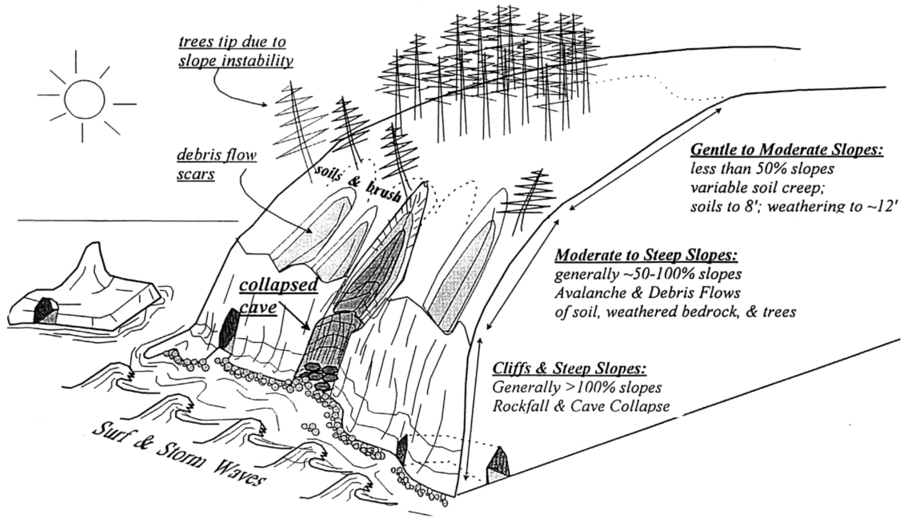
DEFINITION

Longshore sand transport is wave- and/or tide-generated movement of shallow-water coastal sediments parallel to the shoreline.

Cross-shore sand transport is wave- and/or tide-generated movement of shallow-water coastal sediments toward or away from the shoreline.

It should be noted that Figures 3-2 and 3-3 do not characterize all coastlines, particularly those rocky coastlines that are generally resistant to erosion and whose existence does not depend upon littoral sediments transport by coastal processes. Rocky coastlines typical of many Pacific, Great Lakes, New England, and Caribbean areas are better represented by Figure 3-4. The figure illustrates the slow process by which rocky coasts erode in response to elevated water levels, waves, and storms.

Figure 3-4
Generalized depiction of erosion process along a rocky coastline (from Horning Geosciences 1998).



Breakers erode base of cliff, forming caves in zones of weakness; caves eventually form arches, then stacks; some caves collapse. Weathering causes rockfall on cliff face. Debris flows and avalanches on steeper slopes are triggered by seismicity, heavy soil saturation, and loss of tree root strength.

3.2 United States Coastline Characteristics

Several sources (National Research Council 1990, Shepard and Wanless 1971, USACE 1971) were used to characterize and divide the coastline of the United States into seven major segments and smaller subsegments (see Figure 3-5). Each of the subsegments generally describes coastlines of similar origin, characteristics, and hazards.

- **The** Atlantic coast**, extending from Maine to the Florida Keys**

  The *North Atlantic* coast, extending from Maine to Long Island, New York

  The *Mid-Atlantic* coast, extending from New Jersey to Virginia

  The *South Atlantic* coast, extending from North Carolina to South Florida

  The *Florida Keys*

- **The** Gulf of Mexico coast**, extending from the Florida Keys to Texas**

  The *Eastern Gulf* coast, extending from southwest Florida to Mississippi

  The *Mississippi Delta* coast of southeast Louisiana

  The *Western Gulf* coast of Louisiana and Texas

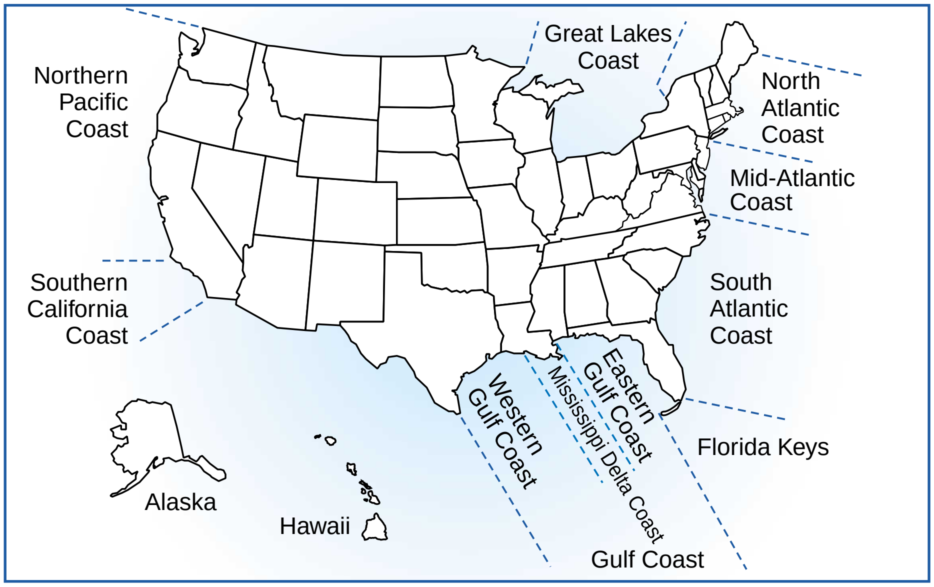


Figure 3-5
The United States coastline.

- **The** Pacific coast**, extending from California to Washington**

  The *Southern California* coast, extending from San Diego County to Point Conception (Santa Barbara County), California

  The *Northern Pacific* coast, extending from Point Conception, California, to Washington
- **The** Great Lakes coast**, extending from Minnesota to New York**
- **The coast of** Alaska
- **The coast of** Hawaii **and** Pacific Territories
- **The coast of** Puerto Rico and the U.S. Virgin Islands

The USACE (1971) estimated the total shoreline length of the continental United States, Alaska, and Hawaii at 84,240 miles, including 34,520 miles of exposed shoreline and 49,720 miles of sheltered shoreline. The shoreline length of the continental United States alone was put at 36,010 miles (13,370 miles exposed, 22,640 miles sheltered).

3.2.1 Atlantic Coast

The *North Atlantic* coast is glacial in origin. It is highly irregular, with erosion-resistant rocky headlands and pocket beaches in northern New England, and erodible bluffs and sandy barrier islands in southern New England and along Long Island, New York.

The *Mid-Atlantic* coast extends from New Jersey to Virginia, and includes two of the largest estuaries in the United States—Delaware Bay and Chesapeake Bay. The open coast shoreline is generally composed of long barrier islands separated by tidal inlets and bay entrances.

The *South Atlantic* coast consists of three regions: (1) the North Carolina and northern South Carolina shoreline, composed of long barrier and mainland beaches (including the Outer Banks and the South Carolina Grand Strand region); (2) the region extending from Charleston, South Carolina, to the St. Johns River entrance at Jacksonville, Florida (a tide-dominated coast composed of numerous short barrier islands, separated by large tidal inlets and backed by wide expanses of tidal marsh); and (3) the east coast of Florida (composed of barrier and mainland beaches backed by narrow bays and rivers).

The *Florida Keys* are a series of low-relief islands formed by limestone and reef rock, with narrow, intermittent carbonate beaches.

The entire Atlantic coast is subject to high storm surges from hurricanes and/or northeasters. Wave runup on steeply sloping beaches and shorelines in New England is also a common source of coastal flooding.

3.2.2 Gulf of Mexico Coast

The Gulf of Mexico coast can be divided into three regions: (1) the eastern Gulf coast from southwest Florida to Mississippi (composed of low-lying sandy barrier islands south of Tarpon Springs, Florida, and west of St. Marks, Florida, with a marsh-dominated coast in between in the Big Bend area of Florida); (2) the Mississippi Delta region, characterized by wide, marshy areas and a low-lying coastal plain; and (3) the western Gulf of Mexico coast, including the **cheniers** of southwest Louisiana, and the long, sandy barrier islands of Texas.

def-ə-

DEFINITION

Cheniers are Mississippi Delta sediments transported westward to form sandy ridges atop mud plains.

The entire Gulf coast is vulnerable to high storm surges from hurricanes. Some areas (e.g., the Big Bend area of Florida) are especially vulnerable because of a wide, shallow continental shelf and low-lying upland areas.

3.2.3 Pacific Coast

The Pacific coast can be divided into two regions: (1) the southern California reach (long, sandy beaches and coastal bluffs dominate this region) and (2) the northern Pacific reach (characterized by rocky cliffs, pocket beaches, and occasional long sandy barriers near river mouths).

Open coast storm surges along the Pacific shoreline are generally small (less than 2 feet) because of the narrow continental shelf and deep water close to shore. However, storm wave conditions along the Pacific shoreline are very severe, and the resulting wave runup can be very destructive. In some areas of the Pacific coast, tsunami flood elevations can be much higher than flood elevations associated with coastal storms.

3.2.4 Great Lakes Coast

The shorelines of the Great Lakes are highly variable and include wetlands, low and high cohesive bluffs, low sandy banks, and lofty sand dunes perched on bluffs (200 feet or more above lake level). Storm surges along the Great Lakes are generally less than 2 feet except in embayments (2–4 feet) and on Lake Erie (up to 8 feet). Periods of active erosion are triggered by heavy precipitation events, storm waves, rising lake levels, and changes in groundwater outflow along the coast.

3.2.5 Coast of Alaska

The coast of Alaska can be divided into two areas: (1) the southern coast, dominated by steep mountainous islands indented by deep fjords and (2) the Bering Sea and arctic coasts, backed by a coastal plain dotted with lakes and drained by numerous streams and rivers. The climate of Alaska and the action of ice along the shorelines set it apart from most other coastal areas of the United States.

3.2.6 Coast of Hawaii and Pacific Territories

The islands that make up Hawaii are submerged volcanoes; thus, the coast of Hawaii is formed by rocky cliffs and intermittent sandy beaches. Coastlines along the Pacific Territories are generally similar to those of Hawaii. Coastal flooding can be due to two sources: storm surges from hurricanes or cyclones, and wave runup from tsunamis.

3.2.7 Coast of Puerto Rico and the U.S. Virgin Islands

Like the Hawaiian Islands and Pacific Territories, the islands of Puerto Rico and the Virgin Islands are the products of ancient volcanic activity. The coastal lowlands of Puerto Rico, which occupy nearly one-third of the island's area, contain sediment eroded and transported from the steep, inland mountains by rivers and streams. Ocean currents and wave activity rework the sediments on pocket beaches around each island. Coastal flooding is usually due to hurricanes, although tsunami events are not unknown to the Caribbean.

NOTE

Base Flood Elevations (BFEs) in coastal areas will be controlled by the highest of the wave crest elevation or the wave runup elevation (see Sections 3.3.1 and 3.3.2).

3.3 Coastal Flood Hazards

Coastal flood hazards at a site will depend upon several factors:

- the elevation and topography of the site
- the erodibility of the site
- the nature and intensity of coastal flood events affecting the site

FEMA has developed procedures for estimating and mapping coastal flood hazards that take the above factors into account. Some of the underlying concepts and mapping issues are described here; more detail is provided in Chapters 6 and 7.

Coastal A

This manual will introduce the concept of the **Coastal A zone**, in order to differentiate between A zones in coastal areas from those in inland areas (see Section 1.4). Coastal A zones are not currently mapped or regulated by FEMA any differently than inland A zones; however, post-disaster damage inspections consistently show the need for such a distinction. Flood hazards in coastal A zones, like those in V zones, can include the effects of waves, velocity flow, and erosion (although the magnitude of these effects will be less in coastal A zones than in V zones).

NOTE

Several factors can contribute to the 100-year stillwater elevation in a coastal area. The most important factors include offshore bathymetry, astronomical tide, wind setup (rise in water surface as strong winds blow water toward the shore), pressure setup (rise in water surface due to low atmospheric pressure), wave setup (rise in water surface inside the surf zone due to the presence of breaking waves), and, in the case of the Great Lakes, seiches and long-term changes in lake levels.

Figure 3-6 shows a typical Flood Insurance Rate Map (FIRM) that a designer is likely to encounter for a coastal area. Three flood hazard zones have been mapped: V zones, A zones, and X zones. The V zone (also known as the velocity zone or the Coastal High Hazard Area) is the most hazardous of the three areas because structures there will be exposed to the most severe flood and wind forces, including wave action, high-velocity flow, and erosion. *The A zone shown on the map should be thought of as a coastal A zone*. FEMA's flood mapping procedures show the area designated as Zone X on the map has less than a 1-percent probability of flooding in any year.

A FIRM is the product of a **Flood Insurance Study** (FIS) conducted for a community under FEMA's National Flood Insurance Program. A coastal FIS is completed with specified techniques and procedures (FEMA 1995a, FEMA 1995b) to determine stillwater and wave elevations along transects drawn perpendicular to the shoreline (see Figures 3-6 and 3-7). The determination of the 100-year stillwater elevation (and stillwater elevations associated with other return periods) is usually accomplished through the statistical analysis of historical tide and water level data, or by the use of a numerical storm surge model. Wave heights and elevations are computed from stillwater and topographic data with established procedures and models that account for wave dissipation by obstructions (e.g., sand dunes, buildings, vegetation) and wave regeneration across overland fetches.

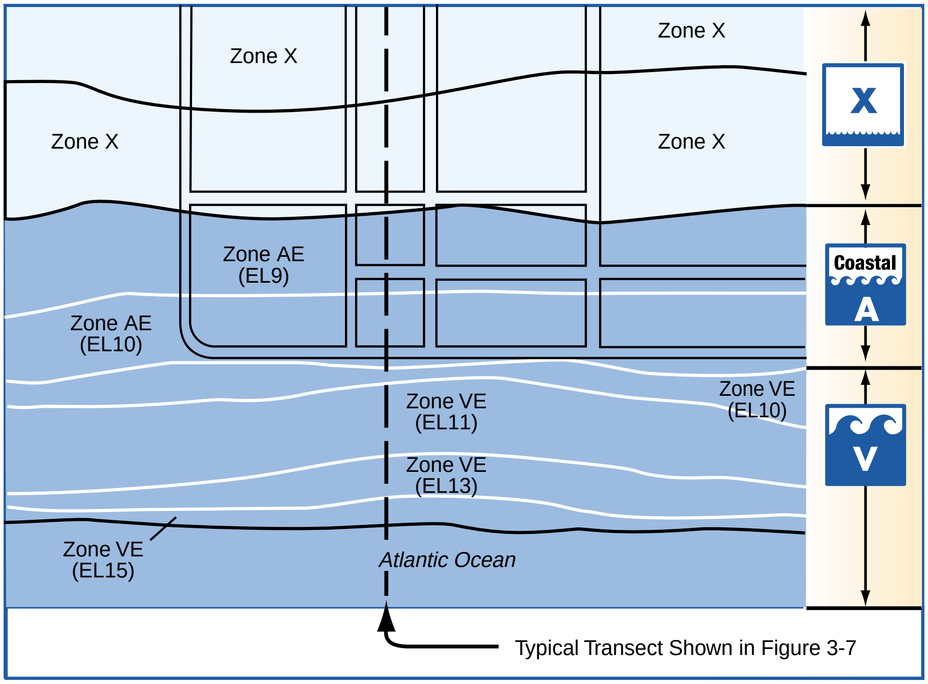
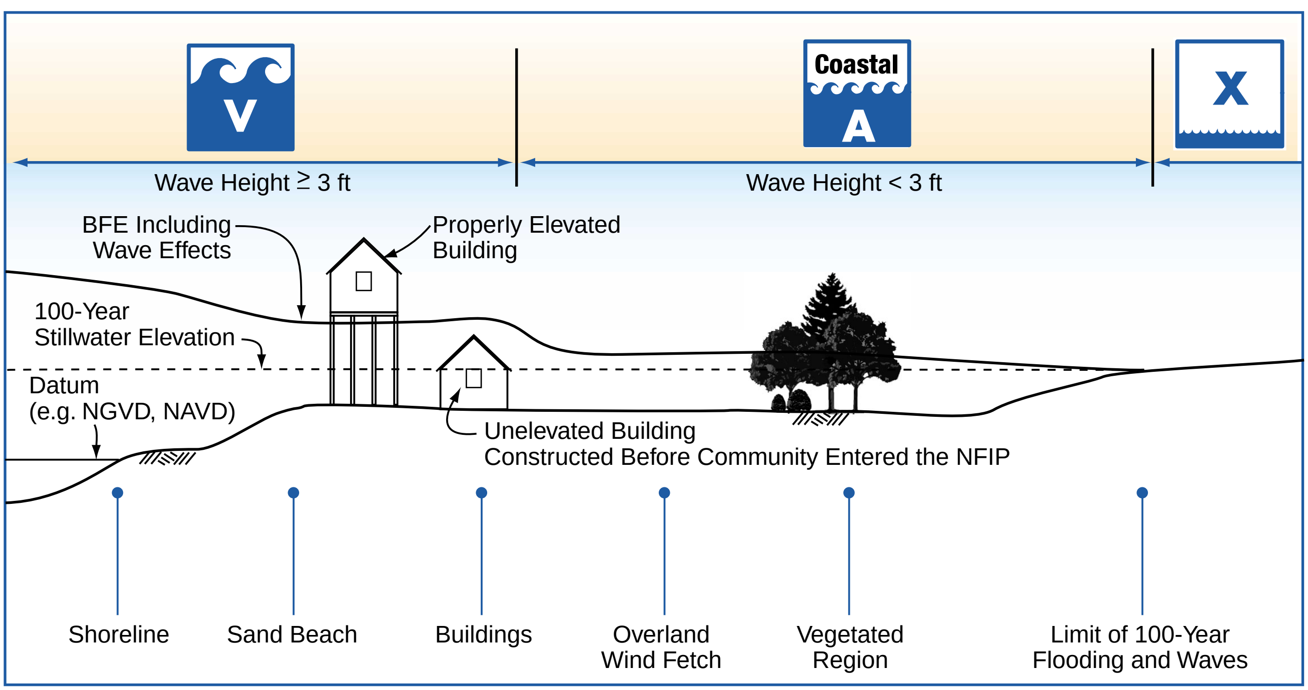


Figure 3-6
This portion of a FIRM shows a coastal Special Flood Hazard Area (SFHA) (dark gray), the 500-year flood hazard area (light gray), coastal Base Flood Elevations (BFEs) (numbers in parentheses), and flood insurance rate zones (AE and VE = SFHA, VE = Coastal High Hazard Area, X = areas outside the SFHA).

NOTE

Additional information about FIRMs is available in FEMA's 1994 booklet *How to Use a Flood Map to Protect Your Property*, FEMA 258 (FEMA 1994).

Figure 3-7
Typical shoreline-perpendicular transect used in the analysis of stillwater and wave crest elevations.



DEFINITION

Wave height is the vertical distance between the wave crest and wave trough (see Figure 3-8).

Wave crest elevation is the elevation of the crest of a wave, referenced to the National Geodetic Vertical Datum of 1929 (NGVD) or other datum.

3.3.1 Wave Heights and Wave Crest Elevations

FEMA's primary means of establishing Base Flood Elevations (BFEs) and distinguishing between V zones, (coastal) A zones, and X zones is the *wave height*. The wave height is simply the vertical distance between the crest and trough of a wave propagating over the water surface. BFEs in coastal areas are usually set at the crest of the wave as it propagates inland.

The maximum wave crest elevation (used to establish the BFE) is determined by the maximum wave height, which depends largely on the 100-year stillwater depth (d_{100}). This depth is the difference between the 100-year stillwater elevation (E_{100}) and the ground elevation (GS). Note that, as explained in Chapter 11, GS is **not** the existing ground elevation; it is the ground elevation that will result from the amount of erosion expected to occur during the 100-year flood.

CROSS-REFERENCE

Designers are referred to Chapter 11 for a discussion of eroded ground elevations and impacts on flood elevations.

In relatively shallow waters, such as those in the coastal areas of the United States, the maximum height of a breaking wave (H_b) is determined by the equation $H_b = 0.78d_{sw}$, where d_{sw} is the stillwater depth. The maximum height of a breaking wave above the stillwater elevation is equal to $0.55d_{sw}$. Thus, in the case of the 100-year (base) flood, $H_b = 0.78d_{100}$ and the maximum height of a breaking wave above the 100-year stillwater elevation = $0.55d_{100}$ (see Figure 3-8). Note that for wind-driven waves, water depth is only one of three parameters that determine the actual wave height at a particular site (wind speed and fetch length are the other two). In some instances, actual wave heights may be below the computed maximum height.

CROSS-REFERENCE

For situations in which the design flood is greater than the 100-year flood refer to Section 11.6.1, in Chapter 11.

For a coastal flood hazard area where the ground is gently sloping, the BFE shown on the FIRM is equal to the ground elevation (referenced to the National Geodetic Vertical Datum of 1929 [NGVD] or other datum) plus the 100-year stillwater depth (d_{100}) plus $0.55d_{100}$. For example, where the ground elevation is 4 feet NGVD and d_{100} is 6 feet, the BFE is equal to 4 feet plus 6 feet plus 3.3 feet, or 13.3 feet NGVD.

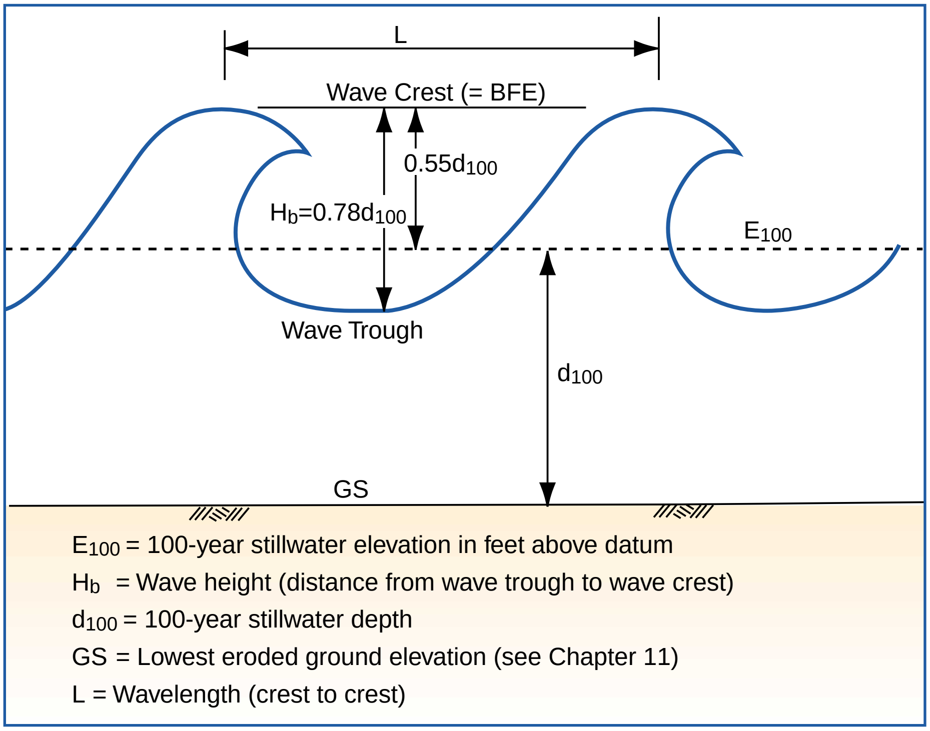
DEFINITION

Wave runup is the rush of water up a slope or structure.

3.3.2 Wave Runup

On steeply sloped shorelines, the rush of water up the surface of the natural beach, including dunes and bluffs, or the surface of a manmade structure, such as a revetment or vertical wall, can result in flood elevations higher than those of the crests of wind-driven waves. For a coastal flood hazard area where this situation occurs, the BFE shown on the FIRM is equal to the highest elevation reached by the water (see Figure 3-9). The methodology adopted by FEMA for the computation of wave runup elevations includes the determination of wave heights. Where the wave runup elevations are lower than the wave height elevations, the BFE equals the wave height elevation.

Figure 3-8
Determination of BFE in coastal flood hazard areas where wave crest elevations exceed wave runup elevations (Zones A and V). Note that the BFE = E_{100} + $0.55d_{100}$



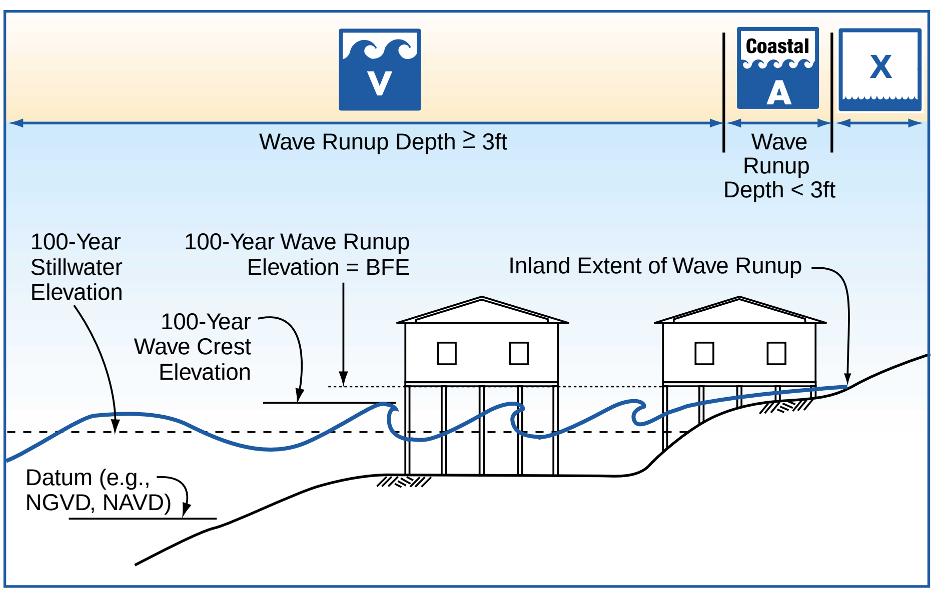
CROSS-REFERENCE

See Section 11.6.4, in Chapter 11, for a discussion of wave setup and its contribution to flood depth.

DEFINITION

Wave setup is an increase in the stillwater surface near the shoreline, due to the presence of breaking waves. Wave setup typically adds 1.5 – 2.5 feet to the 100-year stillwater flood elevation.

Figure 3-9
Where wave runup elevations exceed wave crest elevations, the BFE is equal to the runup elevation.



DEFINITION

Wave runup elevation is the elevation reached by wave runup, referenced to the National Geodetic Vertical Datum of 1929 (NGVD) or other datum.

Wave runup depth at any point is equal to the maximum wave runup elevation minus the lowest eroded ground elevation at that point.

3.3.3 Erosion Considerations and Flood Hazard Mapping

Current FIS procedures account for the potential loss of protective dunes during the 100-year flood. However, this factor was not considered in the preparation of many older coastal FIRMs, which delineated V zones without any consideration for storm-induced erosion. V-zone boundaries were often drawn at the crest of the dune solely on the basis of the elevation of the ground and without regard for the erosion that would occur during a storm.

CROSS-REFERENCE

Chapter 7 of this manual discusses the identification of coastal hazards and their effects.

Designers, property owners, and floodplain managers should be careful not to assume that flood hazard zones shown on FIRMs accurately reflect current flood hazards. For example, flood hazard restudies completed after hurricane Opal (1995 – Florida Panhandle) and Fran (1996 – Topsail Island, North Carolina) have produced FIRMs that are dramatically different from the FIRMs in effect prior to the storms.

Figure 3-10 compares pre-and post-storm FIRMs for Surf City, North Carolina. The map changes are attributable to two factors: (1) pre-storm FIRMs did not show the effects of erosion that had occurred since the FIRMs were published and did not meet technical standards currently in place, and (2) Hurricane Fran caused significant changes to the topography of the

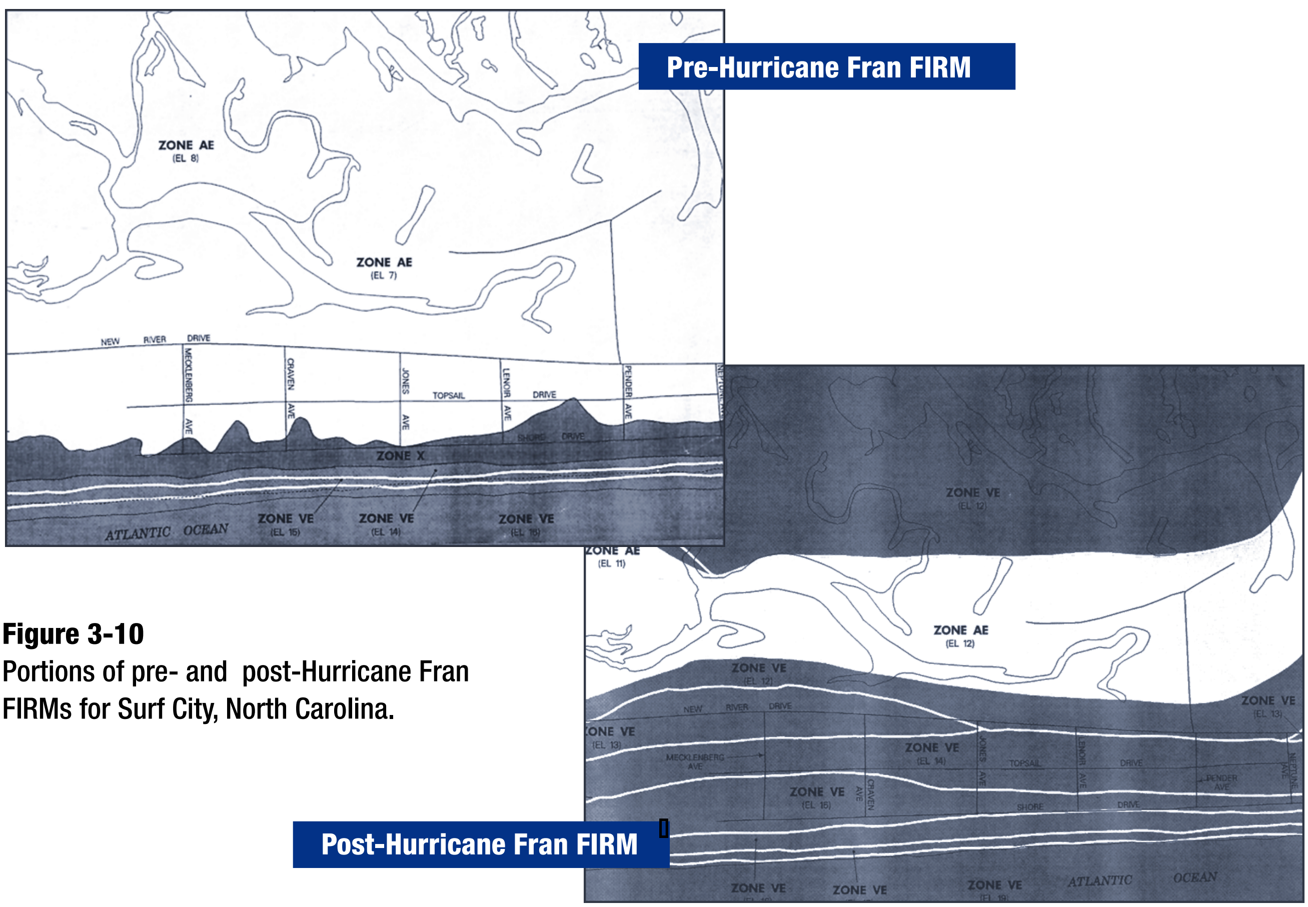


Figure 3-10
Portions of pre- and post-Hurricane Fran FIRMs for Surf City, North Carolina.

barrier island. Not all coastal FIRMs would be expected to undergo such drastic revisions after a flood restudy; however, many FIRMs may be in need of updating, and designers should be aware that FIRMs may not reflect present flood hazards at a site.

3.4 References

Federal Emergency Management Agency. 1994. *How to Use a Flood Map to Protect Your Property*. FEMA 258.

Federal Emergency Management Agency. 1995a. *Flood Insurance Study Guidelines and Specifications for Study Contractors*. FEMA 37.

Federal Emergency Management Agency. 1995b. *Guidelines and Specifications for Wave Elevation Determination and V Zone Mapping* – Final Draft.

Horning Geosciences. 1998. Illustration showing principal geologic hazards acting along typical sea cliff in Oregon.

Komar, P. D. 1996. "The Budget of Littoral Sediments – Concepts and Applications." *Shore and Beach*, Vol. 64, No. 3, July 1996. pp. 18-25.

National Research Council. 1990. *Managing Coastal Erosion*. National Academy Press.

Shepard, F. P.; H. L. Wanless. 1971. *Our Changing Coastlines*. McGraw-Hill, Inc.

U.S. Army Corps of Engineers. 1971. *Report on the National Shoreline Study*.

U.S. Army Corps of Engineers. 1984. *Shore Protection Manual*.