Chapter 7: Indentifying Hazards

Table of Contents

Page

Figures

Tables

Identifying Hazards

7.1 Introduction

In coastal areas, proper siting and design require an accurate assessment of the vulnerability of any proposed structure, including the nature and extent of coastal hazards. Failure to properly identify and design against coastal hazards can lead to severe consequences, most often building damage or destruction.

Therefore, this chapter discusses the following topics:

- hazard identification and risk assessment for natural hazards that can affect coastal construction
- hazard mapping procedures used by the National Flood Insurance Program (NFIP) and by various states and communities

Additional details on hazard identification and risk assessment issues can be found in a number of references. One of the most comprehensive is a recent report, *Multi-Hazard Identification and Risk Assessment*, produced by FEMA (1997b).

7.2 Natural Hazards Affecting Coastal Areas

The most significant natural hazards that affect the coastlines of the United States and its territories can be divided into five general categories:

WARNING

Unlike inland flood events, coastal flooding is usually accompanied by high winds, waves, and erosion

- coastal flooding
- high winds
- erosion
- earthquakes
- other hazards

This chapter provides an overview of each of these hazards, describes their effects on residential buildings and building sites, and explains where along the U.S. coastline each hazard is likely to occur.

This chapter also provides general guidance on identifying hazards that may affect a coastal building site; however, given the wide geographic variations in hazard types and effects, this chapter cannot provide specific hazard information for a particular site. Designers should consult the sources of information listed in Chapter 5 of this manual and in Appendix F.

7.2.1 Tropical Cyclones and Coastal Storms

Tropical cyclones and coastal storms include all storms associated with circulation around an area of atmospheric low pressure. When the storm origin is tropical in nature and when the circulation is closed, tropical storms, hurricanes, or typhoons result.

Tropical cyclones and coastal storms are capable of generating high winds, coastal flooding, high-velocity flows, damaging waves, significant erosion, and intense rainfall (see Figure 7-1). Like all flood events, they are also capable of generating and moving large quantities of waterborne sediments and floating debris. Consequently, the risk to improperly sited, designed, or constructed coastal buildings can be great.

Figure 7-1
Hurricane Frederic (1979). Storm surge and waves overtopping a coastal barrier island in Alabama.

CROSS-REFERENCE

Sec Section 7.3.5 for a discussion of high water levels and sea-level rise.

It should also be noted that one parameter not taken into account mentioned in storm classifications described in the following sections—*storm coincidence with spring tides or higher than normal water levels*—also plays a major role in determining storm impacts and property damage. If a tropical cyclone or other coastal storm coincides with abnormally high water levels or with the highest monthly, seasonal, or annual tides, the flooding and erosion impacts of the storm are magnified by the higher water levels upon which the storm surge and wave effects are added.

7.2.1.1 Tropical Cyclones

Tropical Storms have sustained winds averaging 39 to 74 miles per hour (mph). When sustained winds intensify to greater than 74 mph, the resulting storms are called ***hurricanes*** (in the North Atlantic basin or in the Central or South Pacific basins east of the International Date Line) or ***typhoons*** (in the western North Pacific basin).

Hurricanes are divided into five classes according to the Saffir-Simpson hurricane scale, which uses wind speed and central pressure as the principal parameters to categorize storm damage potential (see Table 7.1). Typhoons are divided into two categories – those with sustained winds less than 150 mph are referred to as typhoons, while those with sustained winds equal to or greater than 150 mph are known as ***super typhoons***.

NOTE

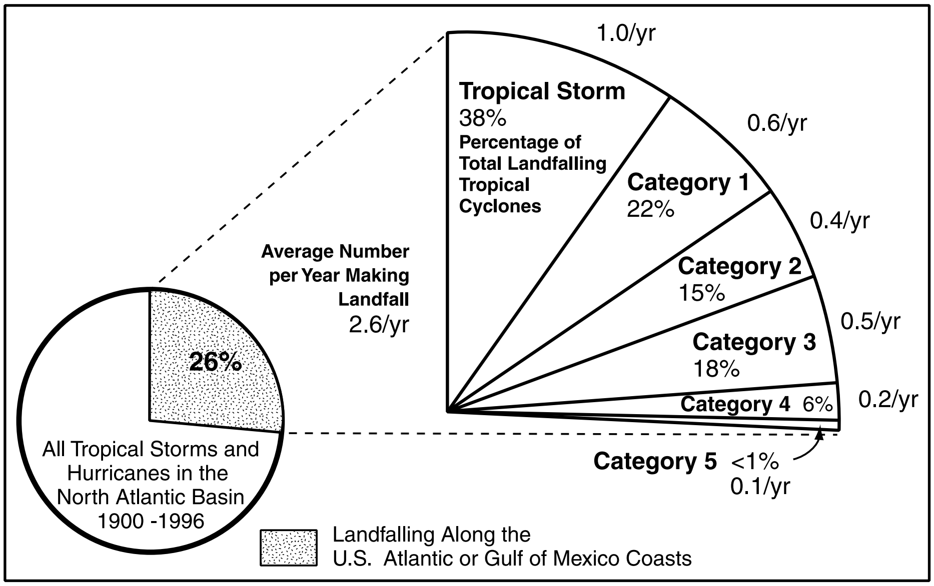
The Saffir-Simpson scale is a generalization, and classification of actual storms may be inconsistent. For example, the classification of a hurricane based on wind speed may differ from the classification based on storm surge or central pressure.

Table 7.1 Saffir-Simpson Hurricane Scale

Scale Number (Category)	Central Pressure (in) [mb]	Wind Speed Miles/Hour Sustained & (3-sec Gust)	Surge Height (ft)	Property Damage	Recent Examples
1	≥ 28.94 [≥ 980]	74 – 95 (93-119)	4 - 5	**Minimal**	**Agnes** (1972 – Florida, Northeast U.S.) **Juan** (1985 – Louisiana) **Earl** (1998 – Florida)
2	28.49 – 28.93 [965 – 979]	96 – 110 (120-138)	6 - 8	**Moderate**	**Bob** (1991 – Massachusetts) **Marilyn** (1995 – U.S. Virgin Islands)
3	27.90 – 28.48 [945 – 964]	111 – 130 (139-163)	9 - 12	**Extensive**	**Frederic** (1979 – Alabama) **Alicia** (1983 – Texas) **Fran** (1996 – North Carolina)
4	27.17 – 27.89 [920 – 944]	131 – 155 (164-194)	13 – 18	**Extreme**	**Hugo** (1989 – South Carolina) **Andrew** (1992 – Florida)
5	< 27.17 [< 920]	> 155 (> 194)	>18	**Catastrophic**	**Florida Keys** (1935) **Camille** (1969 – Mississippi)

Tropical cyclone records for the period 1900-1996 show that approximately one in four named storms (tropical storms and hurricanes) in the North Atlantic basin will make landfall along the Atlantic or Gulf of Mexico coast of the United States (approximately 2.6 landfalling storms per year). Figure 7-2 shows the annual average numbers and percentages of landfalling tropical cyclones in the United States.

Figure 7-2
Classification (by Saffir-Simpson scale) of landfalling tropical cyclones along the U.S. Atlantic and Gulf of Mexico coasts, 1900–1996.



WARNING

Statistics in Figure 7-2 show average landfall frequencies and characteristics. Actual numbers and classes of landfalling storms can vary considerably: actual data show as few as 0 and as many as 5 landfalling storms in any given year.

Tropical cyclone landfalls are not evenly distributed on a geographic basis. In fact, there is a wide variation in the incidence of landfalls. Figure 7-3 illustrates this point for the Atlantic and Gulf of Mexico coasts. The figure shows the total number of direct and indirect impacts of landfalling hurricanes between 1900 and 1994 (generally speaking, a direct impact occurs when the eye makes landfall in the county of interest, and an indirect impact occurs when the eye makes landfall in an adjacent county).

Another method of analyzing tropical cyclone incidence data is to compute the *mean return period*, or the average time (in years) between landfall or nearby passage of a tropical storm or hurricane. Table 7.2 includes the results of these computations. Note that over short periods of time, the actual number and timing of tropical cyclone passage/landfall may deviate substantially from the long-term statistics. Some years see little tropical cyclone activity with no landfalling storms; other years see many storms with several landfalls. A given area may not feel the effects of a tropical cyclone for years or decades, and then be affected by several storms in a single year.

Figure 7-3 Total number of direct and indirect impacts by landfalling hurricanes for coastal counties from Texas to Maine, 1900–1994. Adapted from FEMA (1997b).

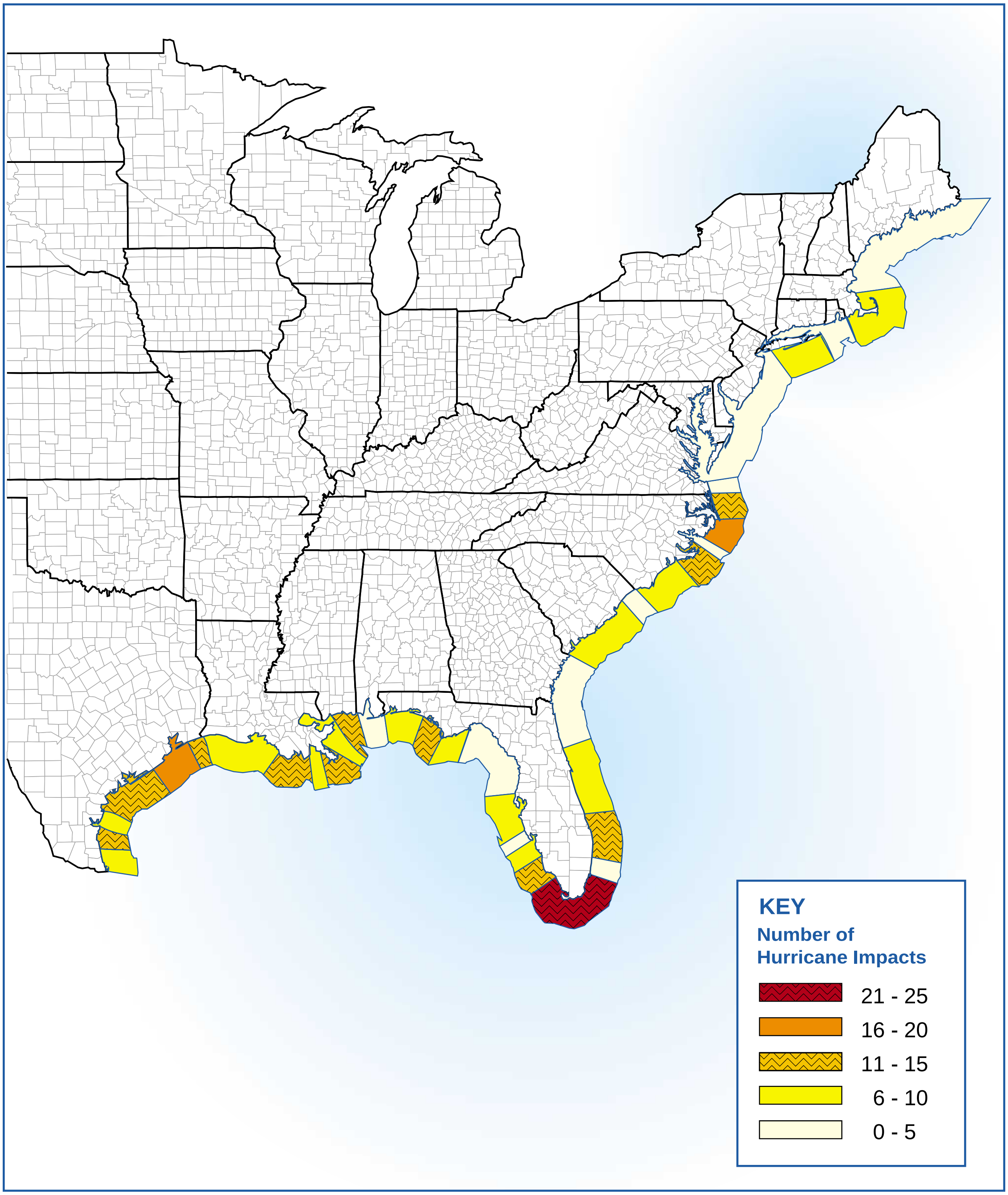


Table 7.2
Mean Return Periods (in Years) for Landfall or Nearby Passage of Tropical Cyclones

	Mean Return Period (years)		
Area	**Passage of All Tropical Cyclones Within 50 Miles[a]**	**Landfall of All Hurricanes (Category 1-5)[b]**	**Landfall of All Major Hurricanes (Category 3-5)[b]**
U.S. (Texas to Maine)	-	0.6	1.5
Texas	1.4	2.7	6.5
South	-	7.5	16
Central	-	16	49
North	-	5.7	14
Louisiana	1.6	3.9	8.1
Mississippi	2.7	12	16
Alabama	2.7	9.7	19
Florida	0.8	1.7	4.0
Northwest	-	4.0	14
Southwest	-	5.4	11
Southeast	-	3.7	8.8
Northeast	-	11	#
Georgia	2.0	19	#
South Carolina	2.3	6.9	24
North Carolina	1.7	3.9	8.8
Virginia	4.0	24	97
Maryland	4.2	97	#
Delaware	4.7	#	#
New Jersey	4.7	97	#
New York	3.7	11	19
Connecticut	4.2	19	32
Rhode Island	4.2	19	32
Massachusetts	3.7	16	49
New Hampshire	7.8	49	#
Maine	7.2	19	#
Virgin Islands [a]	2.0	~	~
Puerto Rico [a]	2.4	8	~
Hawaii [a]	7.1	~	~
Guam [a]	1.0	~	~

a based on National Weather Service (NWS) data for period 1899-1992, from FEMA Hurricane Program, 1994

b for period 1900-1996, from National Oceanic Atmospheric and Administration (NOAA) Technical Memorandum NWS TPC-1, February 1997

– no intrastate breakdown by FEMA Hurricane Program

number not computed (no storms of specified intensity made landfall during 1900-1996)

~ island; landfall statistics alone may understate hazard

NOTE

Mean return periods for tropical cyclones are based on over 90 years of data and are useful for identifying the relative likelihood of storm incidence. For any given area, the actual period between storm strikes can be much less or much more than average.

7.2.1.2 Other Coastal Storms

Other coastal storms include storms lacking closed circulation, but capable of producing strong winds. These storms usually occur during winter months and can affect the Pacific coast, the Great Lakes coast, the Gulf of Mexico coast, or the Atlantic coast. Along the Atlantic coast, these storms are known as extratropical storms or northeasters.

Classification systems for northeasters have been proposed by Halsey (1986) and Dolan and Davis (1992). These classifications—both based on storm characteristics and typical damage to beaches and dunes along the mid-Atlantic coast—have not been widely accepted, but do provide a preliminary framework for considering the hazards associated with northeasters. Table 7.3 presents a modified northeaster classification scheme, constructed by combining elements from the Halsey and Dolan/Davis classifications, and supplementing those elements with more detailed descriptions of typical property damage.

Table 7.3 Modified Classification for Northeasters*

Storm Class	Storm Description	Storm Duration	Storm Impacts on Beaches and Dunes	Property Damage
1	Weak	I tidal cycle	Minor beach erosion	Little or none
2	Moderate	2 to 3 tidal cycles	Moderate beach erosion; dune scarping begins; minor flooding and shallow overwash in low areas, especially street ends	Undermining of seaward ends of dune walkovers; undermining of slab foundations on or near the active beach; some damage to erosion control structures
3	Significant	3 to 4 tidal cycles	Significant beach erosion; dune scarping with complete loss of small dunes; increased depth of flooding and overwash in low areas	Widespread damage to dune walkovers and boardwalks; increased damage to erosion control structures; undermining of beachfront slab foundations and shallow post or pile foundations; burial of roads and inland property by overwash
4	Severe	4 to 5 tidal cycles	Severe beach erosion and dune scarping; widespread dune breaching in vulnerable areas; coalescing of overwash fans; occasional inlet formation	Damage to poorly sited, elevated, or constructed coastal buildings is common; frequent damage to erosion control structures; floodborne debris loads increase; overwash burial depths increase
5	Extreme	> 5 tidal cycles	Widespread and severe beach erosion and dune loss; widespread flooding of low-lying areas; massive overwash; inlet formation is common	Widespread damage to buildings with inadequate elevations or foundations, and to buildings with inadequate setbacks from the shoreline or inlets; widespread damage to low-lying roads and infrastructure

* modified from Halsey (1986) and Dolan and Davis (1992)

CROSS-REFERENCE

See Section 2.2.1, in Chapter 2, for a description of the 1962 and 1991 northeasters.

Dolan and Davis (1992) reviewed weather records for the period 1942 to 1984 and found 1,347 northeasters that produced deepwater significant wave heights in excess of 5 feet near Cape Hatteras, North Carolina (31 storms per year). Figure 7-4 shows how these storms were classified. Note that of the 1,347 identified northeasters, only 7 were Class 5 storms, including the March 5-7, 1962 storm (see Figure 7-5) and the October 28–November 3, 1991 storm.

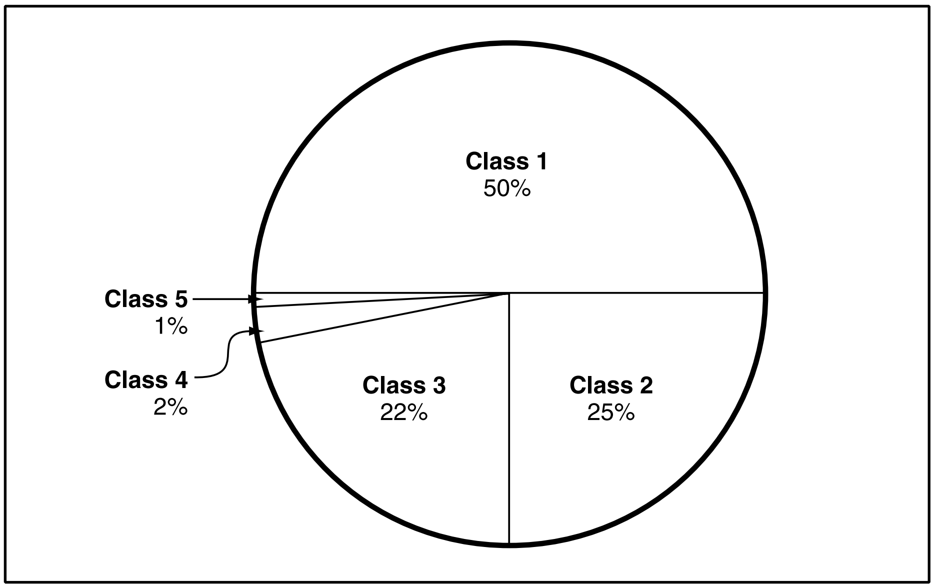


Figure 7-4
Classification (by Dolan-Davis scale) of northeasters at Cape Hatteras, North Carolina, 1942–1984.

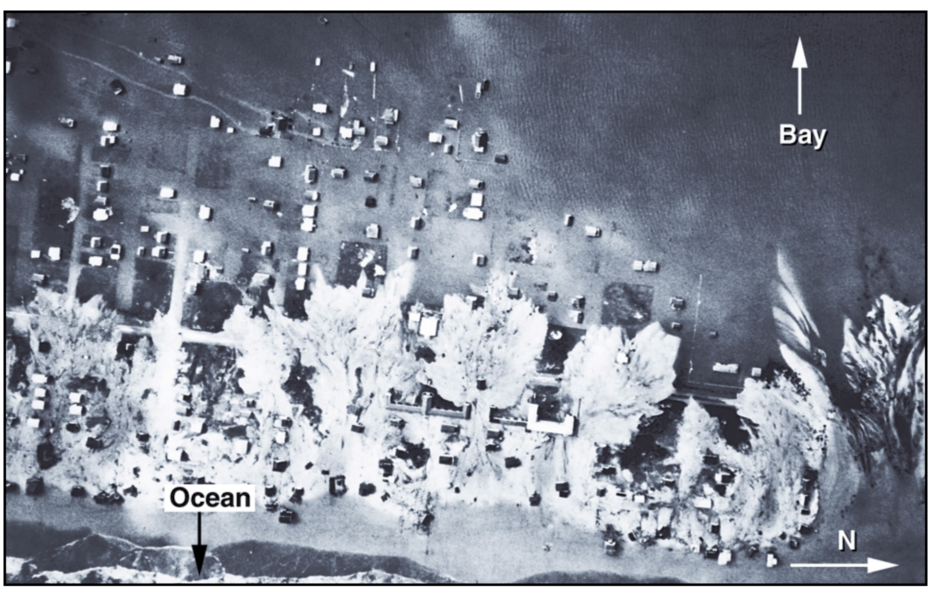


Figure 7-5
March 1962 northeaster. Flooding, erosion, and overwash at Fenwick Island, Delaware.

Coastal storms along the Pacific coast of the United States are usually associated with the passage of weather fronts during the winter months. These storms produce little or no storm surge (generally 2 feet or less) along the ocean shoreline, but they are capable of generating hurricane-force winds and large, damaging waves.

Storm characteristics and patterns along the Pacific coast are strongly influenced by the occurrence of the El Niño Southern Oscillation (ENSO) – a climatic anomaly resulting in above-normal ocean temperatures and elevated sea levels along the U.S. Pacific coast. During El Niño years, sea levels along the Pacific shoreline tend to rise as much as 12 to 18 inches above normal, the incidence of coastal storms increases, and the typical storm track shifts from the Pacific Northwest to southern and central California. The net result of these effects is increased storm-induced erosion, changes in longshore sediment transport (due to changes in the direction of wave approach—and resulting in changes in erosion/deposition patterns along the shoreline), and increased incidence of rainfall and landslides in coastal regions.

Storms on the Great Lakes are usually associated with the passage of low-pressure systems or cold fronts. Storm effects (high winds, storm surge, and wave runup) may last a few hours or a few days. Storm surges and damaging wave conditions on the Great Lakes will be a function of wind speed, direction, duration, and fetch—if high winds occur over a long fetch for more than an hour or so, the potential for flooding and erosion exists. However, because of the sizes and depths of the Great Lakes, storm surges will usually be limited to less than 2 feet, except in embayments (2–4 feet) and on Lake Erie, where storm surges can reach 8 feet near the east and west ends of the lake.

7.2.2 Tsunamis

Tsunamis are long-period water waves generated by undersea shallow-focus earthquakes or by undersea crustal displacements (subduction of tectonic plates), landslides, or volcanic activity. Tsunamis can travel great distances, undetected in deep water, but shoaling rapidly in coastal waters and producing a series of large waves capable of destroying harbor facilities, shore protection structures, and upland buildings (see Figure 7-6). Tsunamis have been known to damage some structures hundreds of feet inland and over 50 feet above sea level.

Coastal construction in tsunami hazard zones must consider the effects of tsunami runup, flooding, erosion, and debris loads. Designers should also be aware that the “rundown” or return of water to the sea can also damage the landward sides of structures that withstood the initial runup.

Figure 7-6
Hilo, Hawaii. Damage from the 1960 Tsunami (from Camfield 1994). Courtesy of *Journal of Coastal Research*.

Tsunami effects at a particular site will be determined by four basic factors:

- the magnitude of the earthquake or triggering event
- the location of the triggering event
- the configuration of the continental shelf and shoreline
- the upland topography

NOTE
Information about tsunamis and their effects is available from the National Tsunami Hazard Mitigation Program (website http://www.pmel.noaa.gov/tsunami-hazard/).

The *magnitude* of the triggering event determines the period of the resulting waves, and generally (but not always) the tsunami magnitude and damage potential. Unlike typical wind-generated water waves with periods between 5 and 20 sec, tsunamis can have wave periods ranging from a few minutes to over 1 hour (Camfield 1980). As wave periods increase, the potential for coastal inundation and damage also increases. Wave period is also important because of the potential for resonance and wave amplification within bays, harbors, estuaries, and other semi-enclosed bodies of coastal water.

The *location* of the triggering event has two important consequences. First, the distance between the point of tsunami generation and the shoreline determines the maximum available warning time. Tsunamis generated at a *remote source* will take longer to reach a given shoreline than *locally generated* tsunamis. Second, the point of generation will determine the direction from which a tsunami approaches a given site. Direction of approach can affect tsunami characteristics at the shoreline, because of the sheltering or amplification effects of other land masses and offshore bathymetry.

The *configuration* of the continental shelf and shoreline affect tsunami impacts at the shoreline through wave reflection, refraction, and shoaling. Variations in offshore bathymetry and shoreline irregularities can focus or disperse tsunami wave energy along certain shoreline reaches, increasing or decreasing tsunami impacts.

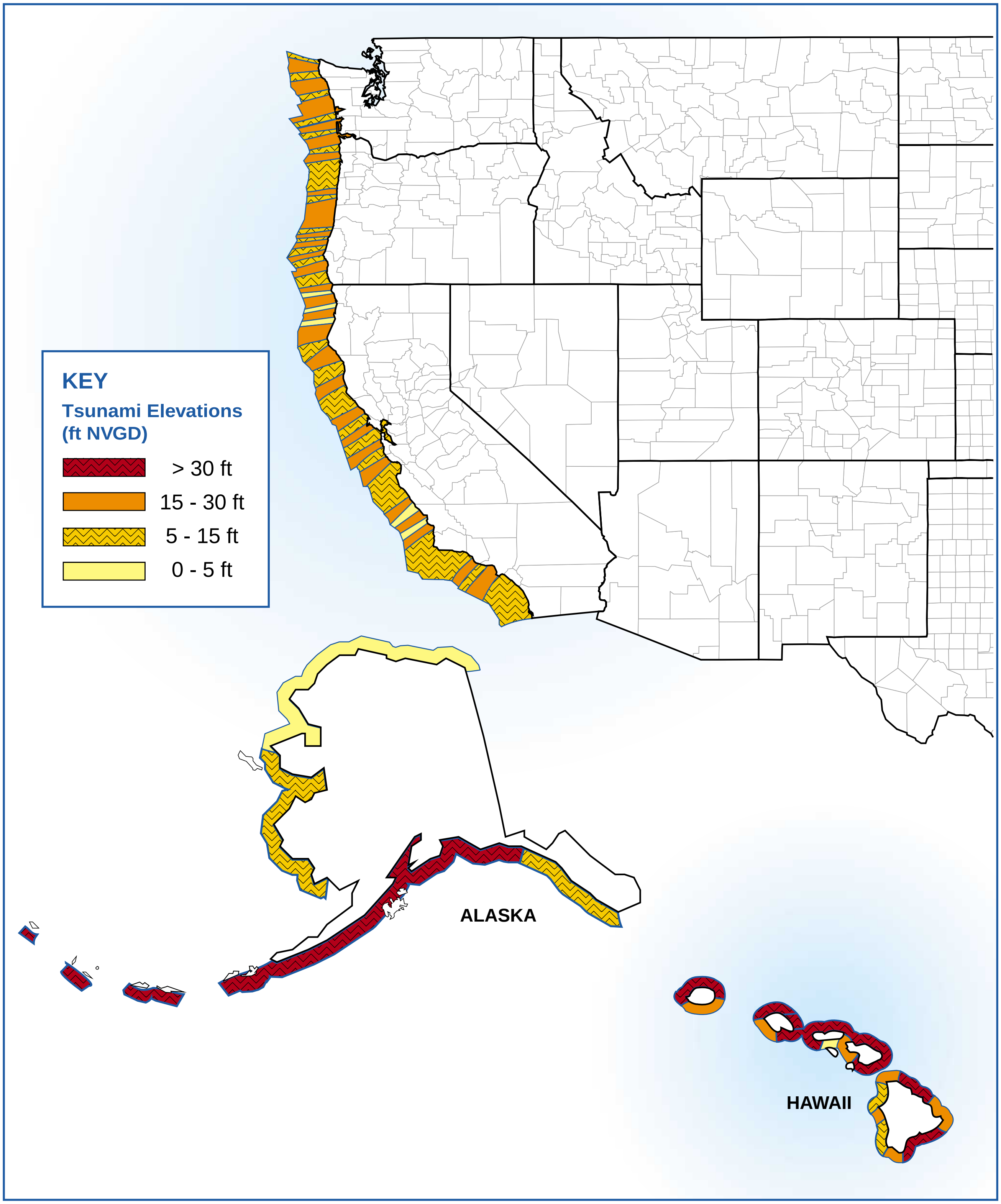
Upland elevations and topography will also determine tsunami impacts at a site. Low-lying tsunami-prone coastal sites will be more susceptible to inundation, tsunami runup, and damage than sites at higher elevations.

Table 7.4 lists areas that are subject to tsunami events, and the sources of those events. Figure 7-7 shows tsunami elevations with a 90-percent probability of being exceeded in 50 years.

Table 7.4
Areas Subject to Tsunami Events

Area	Principal Source of Tsunamis
Alaska	
North Pacific coast	locally generated events (landslides, subduction, submarine landslides, volcanic activity)
Aleutian Islands	locally generated events and remote-source earthquakes
Gulf of Alaska coast	locally generated events and remote-source earthquakes
Bering Sea coast	not considered threatened by tsunamis
Hawaii	remote source earthquakes
American Samoa	remote source earthquakes
Oregon	locally generated events, remote source earthquakes
Washington	locally generated events, remote source earthquakes
California	locally generated events, remote source earthquakes
Puerto Rico	locally generated events
U.S. Virgin Islands	locally generated events

Figure 7-7 Tsunami elevations with a 90-percent probability of not being exceeded in 50 years – western United States, Alaska, and Hawaii. Adapted from FEMA (1997b).



7.3 Coastal Flooding

Coastal flooding can originate from a number of sources. Tropical cyclones, other coastal storms, and tsunamis generate the most significant coastal flood hazards, which usually take the form of hydrostatic forces, hydrodynamic forces, wave effects, and floodborne debris effects. Regardless of the source of coastal flooding, a number of flood parameters must be investigated at a coastal site to correctly characterize potential flood hazards:

- origin of flooding
- flood frequency
- flood depth
- flood velocity
- flood direction
- flood duration
- wave effects
- erosion and scour
- sediment overwash
- floodborne debris

7.3.1 Hydrostatic Forces

Standing water or slowly moving water can induce horizontal *hydrostatic forces* against a structure, especially when floodwater levels on different sides of the structure are not equal. Also, flooding can cause vertical hydrostatic forces, or *flotation* (see Figure 7-8).

CROSS-REFERENCE

Sec Chapter 11 for procedures used to calculate flood loads.

Figure 7-8
Hurricane Hugo (1989), Garden City, South Carolina. Intact houses were floated off their foundations and carried inland.

CROSS-REFERENCE

Designers should be aware that predicting the speed and direction of high-velocity flows is difficult. The design of coastal residential buildings should be based on the guidance contained in Section 11.6.5 and the assumption that the flow can originate from any direction.

7.3.2 Hydrodynamic Forces

Hydrodynamic forces on buildings are created when coastal floodwaters move at high velocities. These high-velocity flows are capable of destroying solid walls and dislodging buildings with inadequate foundations. High-velocity flows can also move large quantities of sediment and debris that can cause additional damage.

High-velocity flows in coastal areas are usually associated with one or more of the following:

- storm surge and wave runup flowing landward, through breaks in sand dunes or across low-lying areas (see Figure 7-9)
- tsunamis
- outflow (flow in the seaward direction) of floodwaters driven into bay or upland areas
- strong currents parallel to the shoreline, driven by the obliquely incident storm waves

High-velocity flows can be created or exacerbated by the presence of manmade or natural obstructions along the shoreline and by "weak points" formed by shore-normal roads and access paths that cross dunes, bridges or shore-normal canals, channels, or drainage features. For example, anecdotal evidence after Hurricane Opal struck Navarre Beach, Florida, in 1995 suggests that large engineered buildings channeled flow between them (see Figure 7-10). The channelized flow caused deep scour channels across the island, undermining a pile supported house between the large buildings (see Figure 7-11), and washing out roads and houses (see Figure 7-12) situated farther landward.

Figure 7-9
Storm surge and wave runup across boardwalk at South Mission Beach, California, during January 1988 storm. Photograph by Dana Fisher, courtesy of *Shore and Beach*.

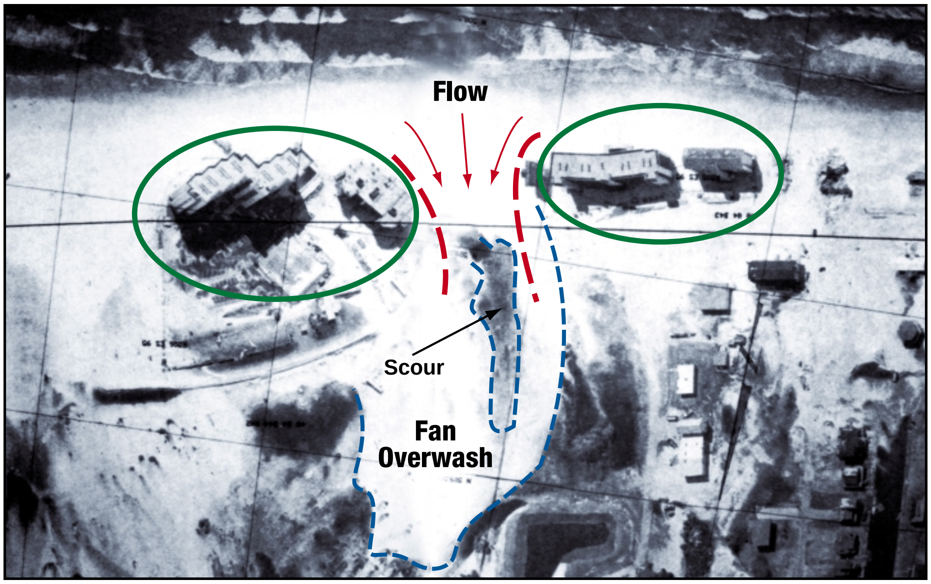


Figure 7-10
Hurricane Opal (1995). Flow channeled between large engineered buildings (circled) at Navarre Beach, Florida, scoured a deep channel across the island and damaged infrastructure and houses. Aerial photograph from Florida Department of Environmental Protection.

Figure 7-11
Pile-supported house in the area of channeled flow shown in Figure 7-10. The building foundation and elevation successfully prevented high-velocity flow, erosion, and scour from destroying this building.

Figure 7-12
This house was also in an area of channeled flow during Hurricane Opal. The house was undermined and washed into the bay behind the barrier island; as a result, the house is now a total loss and a threat to navigation.

7.3.3 Waves

Waves can affect coastal buildings in a number of ways. The most severe damage is caused by *breaking waves* (see Figure 7-13). The force created by waves breaking against a vertical surface is often 10 or more times higher than the force created by high winds during a storm event.

Figure 7-13
Storm waves breaking against a seawall in front of a coastal residence at Stinson Beach, California. Photograph by Lesley Ewing.

Wave runup occurs as waves break and run up beaches, sloping surfaces, and vertical surfaces. Wave runup (see Figure 7-14) can drive large volumes of water against or around coastal buildings, inducing fluid impact forces (albeit smaller than breaking wave forces), current drag forces, and localized erosion and scour. Wave runup against a vertical wall will generally extend to a higher elevation than runup on a sloping surface and will be capable of destroying overhanging decks and porches. Figure 7-15 shows the effects of wave runup and breaking against a vertical wall and adjacent building. *Wave reflection or deflection* from adjacent structures or objects can produce forces on a building similar to those caused by wave runup.

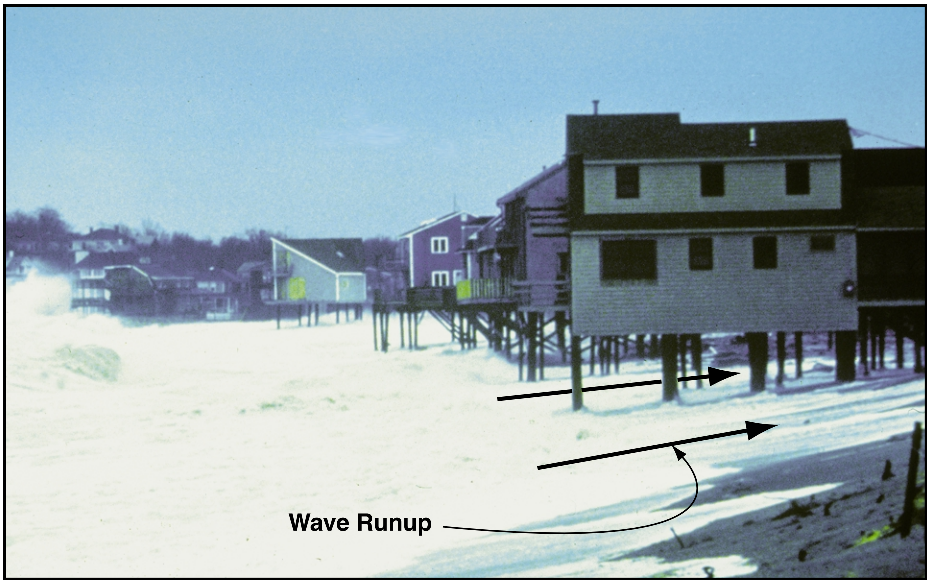


Figure 7-14
Wave runup beneath elevated buildings at Scituate, Massachusetts, during the December 1992 northeast storm. Nine homes in the area were purchased with public funds and demolished following the storm. Photograph by Jim O'Connell.

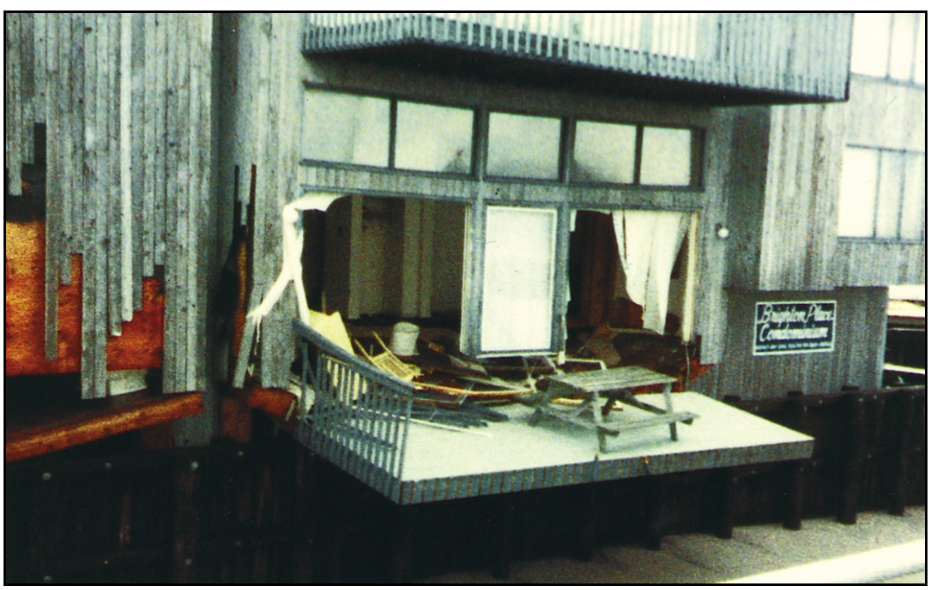


Figure 7-15
Damage to oceanfront condominium in Ocean City, New Jersey, caused by wave runup on a timber bulkhead. April 1984 photograph by Mark Mauriello.

Shoaling waves beneath elevated buildings can lead to *wave uplift* forces. The most common example of wave uplift damage occurs at fishing piers, where pier decks are commonly lost close to shore, when shoaling storm waves lift the pier deck from the pilings and beams. The same type of damage can sometimes be observed at the lowest floor of insufficiently elevated but well-founded residential buildings and underneath slabs-on-grade below elevated buildings (see Figure 7-16).

Figure 7-16
Hurricane Fran (1996). Concrete slab-on-grade flipped up by wave action came to rest against two foundation members, generating large unanticipated loads on the foundation.

7.3.4 Floodborne Debris

Floodborne debris produced by coastal flood events and storms typically includes decks, steps, ramps, breakaway wall panels, portions of or entire houses (see Figure 7-17), heating oil and propane tanks, vehicles, boats, decks and pilings from piers (see Figure 7-18), fences, destroyed erosion control structures, and a variety of smaller objects. Floodborne debris is often capable of destroying unreinforced masonry walls (see Figure 7-19), light wood-frame construction, and small-diameter posts and piles (and the components of structures they support). Debris trapped by cross bracing, closely spaced pilings, grade beams, or other components or obstructions below the Base Flood Elevation (BFE) is also capable of transferring flood and wave loads to the foundation of an elevated structure. Parts of the country are exposed to more massive debris, such as the drift logs shown in Figure 7-20.

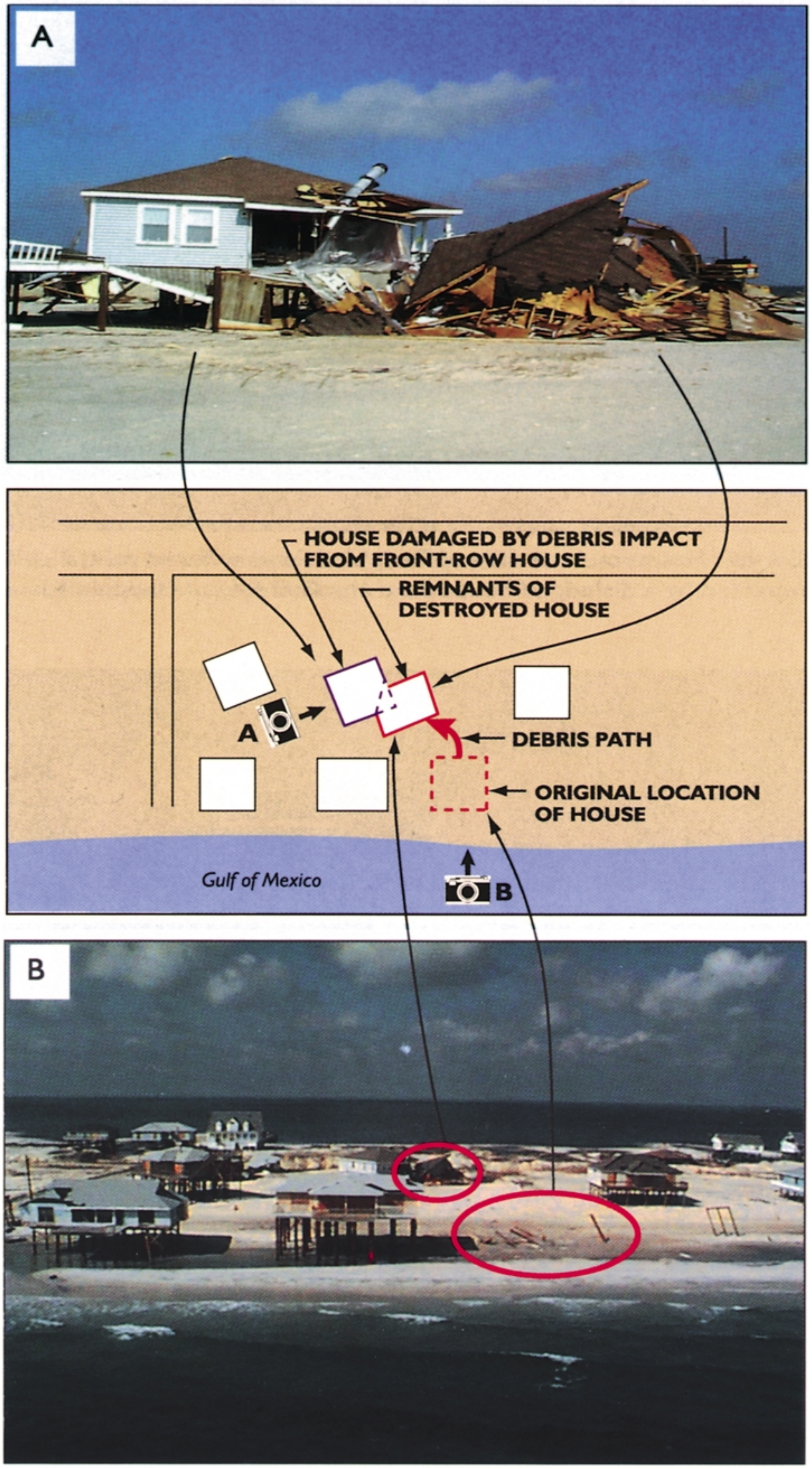


Figure 7-17
Hurricane Georges (1998). A pile-supported house at Dauphin Island, Alabama, was toppled and washed into another house, which suffered extensive damage.

Figure 7-18
Hurricane Opal (1995). Pier pilings were carried over 2 miles by storm surge and waves before they came to rest against this elevated house in Pensacola Beach, Florida.

Figure 7-19
Hurricane Fran (1996). Debris lodged beneath a Topsail Island, North Carolina, house elevated on unreinforced masonry walls. The wall damage could have resulted from flood and wave forces, debris loads, or both.

Figure 7-20
March 1975 storm. Drift logs driven into coastal houses at Sandy Point, Washington (from Knowles and Terich [1977]). Courtesy of *Shore and Beach.*

7.3.5 Sea-Level Rise and Lake-Level Rise

The coastal flood effects described above typically occur over a period of hours or days. However, longer-term water level changes also occur. Sea level tends to rise or fall over centuries or thousands of years, in response to long-term global climate changes. Great Lakes water levels fluctuate over decades, in response to regional climate changes. In either case, long-term increases in water levels increase the damage-causing potential of coastal flood and storm events and often cause a permanent horizontal recession of the shoreline.

Tide gauge records for the U.S. Atlantic and Gulf of Mexico coasts show that relative sea level has been rising at long-term rates averaging 2 to 4 mm annually, with higher rates along the Louisiana and Texas coasts (Hicks et al. 1983). Records for the U.S. Pacific coast stations show that some areas have experienced rises in relative sea levels of approximately 2 mm annually, while other areas have seen relative sea levels fall. Relative sea level has fallen at rates as much as 2 mm annually in northern California and as much as 13 mm annually in Alaska (see Figure 7-21).

Great Lakes water-level records—dating from 1860—are maintained by the U.S. Army Corps of Engineers, Detroit District. The records show seasonal water levels typically fluctuate between 1 and 2 feet. The records also show that long-term water levels in Lakes Michigan, Huron, Erie, and Ontario have fluctuated approximately 6 feet, and water levels in Lake Superior have fluctuated approximately 4 feet. Figure 7-22 shows a typical plot of actual and projected lake levels for Lakes Michigan and Huron. The web site for the Detroit District (http://sparky.nce.usace.army.mil/hmpghh.html) contains detailed data on measured and projected water levels.

NOTE

Because coastal land masses can move up (uplift) or down (subsidence) independent of water levels, discussions related to long-term water-level change must be expressed in terms of relative sea level or relative lake level.

Figure 7-21
Estimates of relative sea level rise along the continental United States in millimeters per year. Negative values indicate falling relative sea levels (from National Research Council 1987).

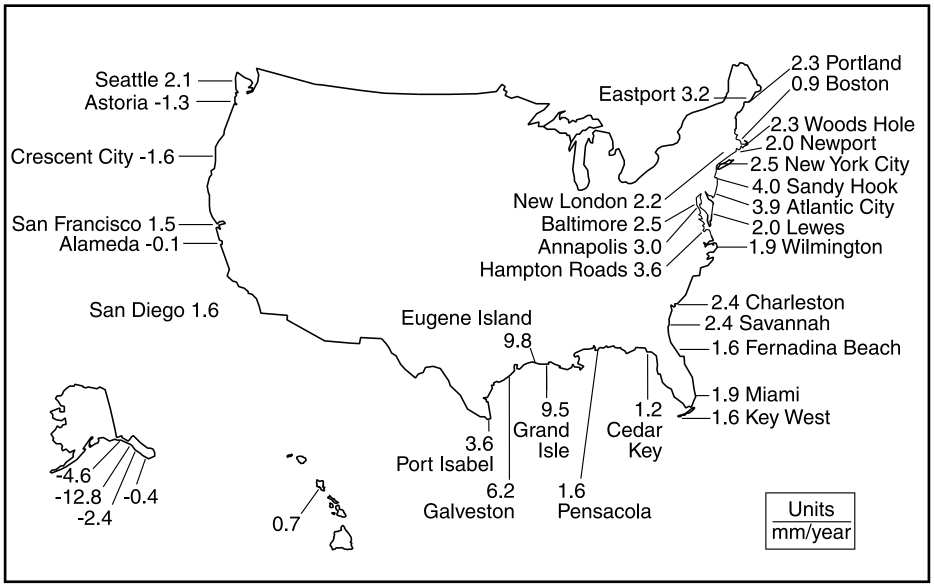
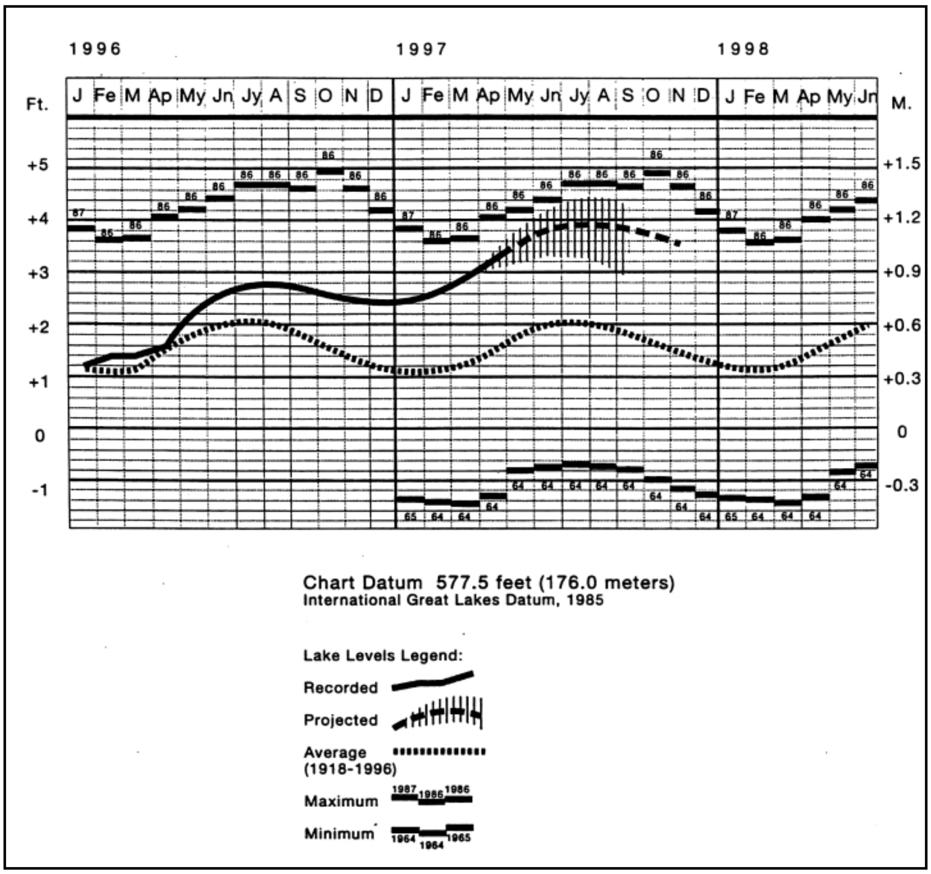


Figure 7-22
Monthly bulletin of lake levels for Lakes Michigan and Huron. Courtesy of USACE, Detroit District.



Keillor (1998) discusses the implications of both high and low lake levels on Great Lakes shorelines. In general, beach and bluff erosion rates tend to increase as long-term water levels rise. As water levels fall, erosion rates diminish. Low lake levels lead to generally stable shorelines and bluffs, but make navigation through harbor entrances difficult.

7.4 High Winds

High winds can originate from a number of events—tropical cyclones, other coastal storms, and tornadoes generate the most significant coastal wind hazards.

The most current design wind speeds are given by the national load standard, ASCE 7-98 (ASCE 1998). Figure 7-23, taken from ASCE 7-98, shows the geographic distribution of design wind speeds for the continental United States and Alaska, and lists design wind speeds for Hawaii, Puerto Rico, Guam, American Samoa, and the Virgin Islands.

High winds are capable of imposing large lateral (horizontal) and uplift (vertical) forces on buildings. Residential buildings can suffer extensive wind damage when they are improperly designed and constructed and when wind speeds exceed design levels (see Figures 7-24 and 7-25). The effects of high winds on a building will depend on several factors:

- wind speed (sustained and gusts) and duration of high winds
- height of building above ground
- exposure or shielding of the building (by topography, vegetation, or other buildings) relative to wind direction
- strength of the structural frame, connections, and envelope (walls and roof)
- shape of building and building components
- number, size, location, and strength of openings (e.g., windows, doors, vents)
- presence and strength of shutters or opening protection
- type, quantity, and velocity of windborne debris

Proper design and construction of residential structures, particularly those close to open water or near the coast, demand that every factor mentioned above be investigated and addressed carefully. Failure to do so may ultimately result in building damage or destruction by wind.

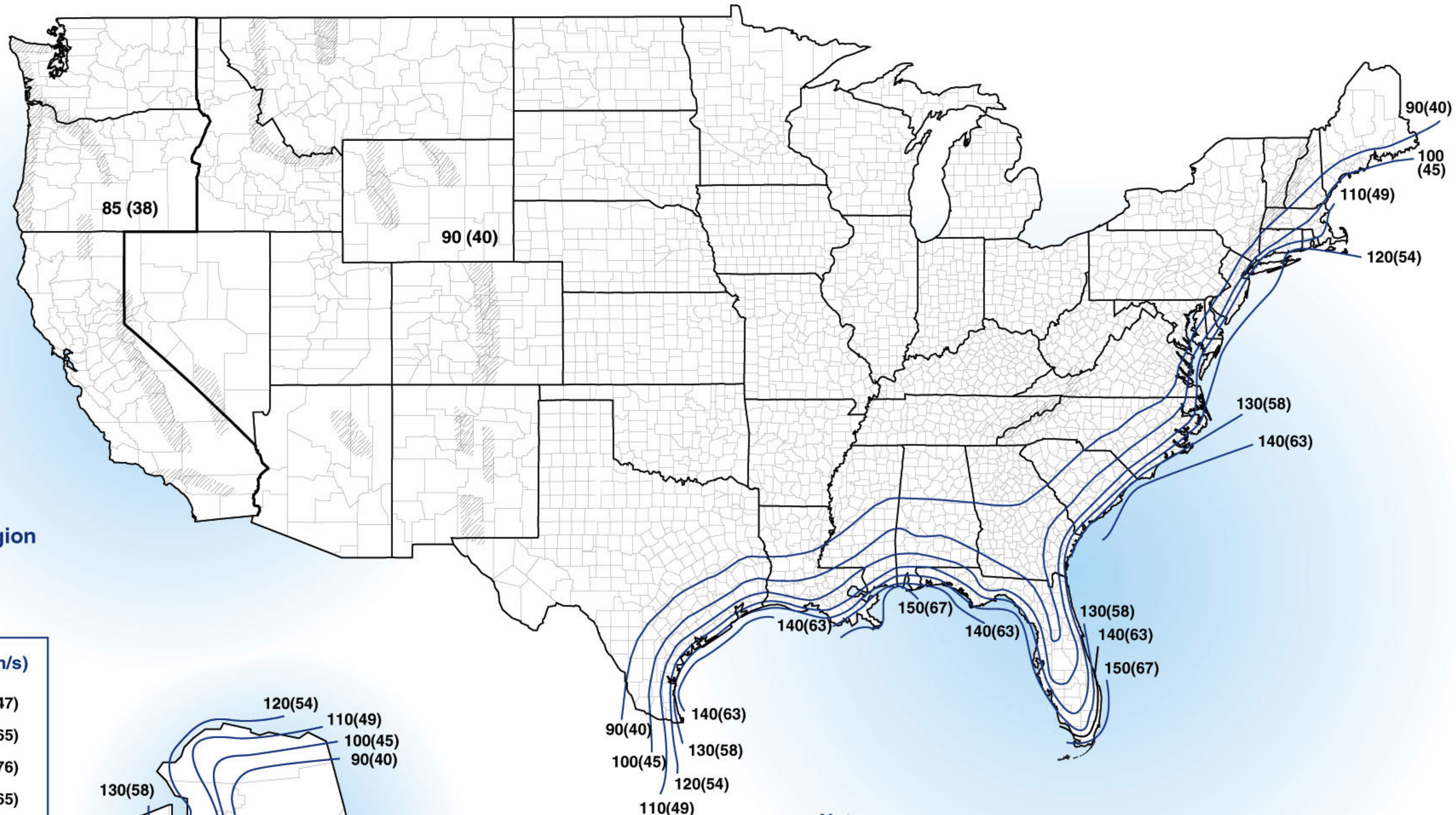
NOTE

Basic wind speeds given by ASCE 7-98, shown here in Figure 7-23, correspond to (1) a wind with a recurrence interval between 50 and 100 years in hurricane-prone regions (Atlantic and Gulf of Mexico coasts with a basic wind speed greater than 90 mph, and Hawaii, Puerto Rico, Guam, the U.S. Virgin Islands, and American Samoa), and (2) a recurrence interval of 50 years in non-hurricane-prone areas.

NOTE

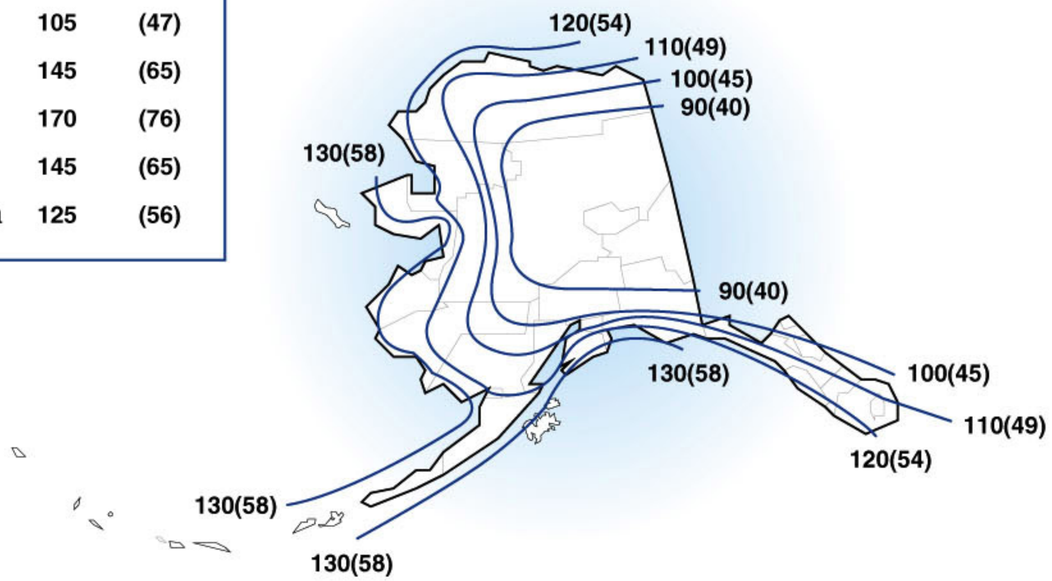
It is generally beyond the scope of most building designs to account for a direct strike by a tornado (the ASCE 7-98 wind map in Figure 7-23 excludes tornado effects). However, use of wind-resistant design techniques will reduce damage caused by a tornado passing nearby.

Figure 7-23 ASCE 7-98 wind speed map (ASCE 1998).



Special Wind Region

Location	V mph	(m/s)
Hawaii	105	(47)
Puerto Rico	145	(65)
Guam	170	(76)
Virgin Islands	145	(65)
American Samoa	125	(56)



Notes:

1. Values are nominal design 3-sec gust wind speeds in miles per hour (mph) at 33 ft (10 m) above ground for Exposure Category C.
2. Linear interpolation between contours is permitted.
3. Islands and coastal areas outside the last contour shall use the last wind speed contour of the coastal area.
4. Mountainous terrain, gorges, ocean promontories, and special wind regions shall be examined for unusual wind conditions.

Source: *Minimum Design Loads for Buildings and Other Structures*, ASCE 7-98 (ASCE 1998b)

Figure 7-24
Hurricane Andrew (1992). End-wall failure of typical first-floor masonry/second-floor wood-frame building in Dade County, Florida.

Figure 7-25
Hurricane Iniki (1992), Kauai County, Hawaii. Loss of roof sheathing due to improper nailing design and schedule.

7.4.1 Speedup of Winds Due to Topographic Effects

Speedup of winds due to topographic effects can occur wherever mountainous areas, gorges, and ocean promontories exist. Thus, the potential for increased wind speeds should be investigated for any construction on or near the crests of high coastal bluffs, cliffs, or dunes, or in gorges and canyons. ASCE 7-98 provides guidance on calculating increased wind speeds in such situations.

Designers should also consider the effects of long-term erosion on the wind speeds a building may experience over its lifetime. For example, a building sited atop a tall bluff, but away from the bluff edge, will not be prone to wind speedup initially, but long-term erosion may move the bluff edge closer to the building and expose the building to increased wind speeds due to topographic effects.

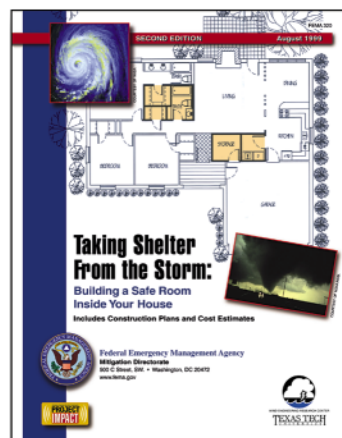
COST CONSIDERATIONS

Even minor damage to the building envelope can lead to large economic losses.

7.4.2 Windborne Debris and Rainfall Penetration

Wind loads and windborne debris are both capable of causing damage to a building envelope. Even small failures in the building envelope will, at best, lead to interior damage by rainfall penetration and winds and, at worst, lead to internal pressurization of the building, roof loss, and complete structural disintegration. Sparks et al. (1994) investigated the dollar value of insured wind losses following Hurricanes Hugo and Andrew and found the following:

- Most wind damage to houses is restricted to the building envelope.
- Rainfall entering a building through envelope failures causes the dollar value of direct building damage to be magnified by a factor of two (at lower wind speeds) to nine (at higher wind speeds).
- Lower levels of damage magnification are associated with interior damage by water seeping through exposed roof sheathing (e.g., following loss of shingles or roof tiles).
- Higher levels of damage magnification are associated with interior damage by rain pouring through areas of lost roof sheathing and through broken windows and doors.



7.4.3 Tornadoes

A *tornado* is a rapidly rotating vortex or funnel of air extending groundward from a cumulonimbus cloud. Tornadoes are spawned by severe thunderstorms and by hurricanes. Tornadoes often form in the right forward quadrant of a hurricane, far from the hurricane eye. The strength and number of tornadoes are not related to the strength of the hurricane that generates them. In fact, the weakest hurricanes often produce the most tornadoes (FEMA 1997b). Tornadoes can lift and move huge objects, move or destroy houses, and siphon large volumes from bodies of water. Tornadoes also generate large amounts of debris, which then become windborne shrapnel that causes additional damage.

NOTE

Additional information about tornadoes and tornado hazards is presented in *Taking Shelter From the Storm: Building a Safe Room Inside Your House*, FEMA 320 (FEMA 1999).

WARNING

This section reviews basic concepts related to coastal erosion, but cannot provide a comprehensive treatment of the many aspects of erosion that should be considered in planning, siting, and designing coastal residential buildings.

NOTE

Erosion is one of the most complex hazards faced by designers. However, assessing erosion can be reduced to three basic steps:

1. Define the most landward shoreline location expected during the life of the building.

2. Define the lowest expected ground elevation during the life of the building.

3. Define the highest expected BFE during the life of the building.

7.5 Erosion

Erosion refers to the wearing or washing away of coastal lands. Although the concept of erosion is simple, erosion is one of the most complex hazards to understand and predict at a given site. Therefore, it is recommended that designers develop an understanding of erosion fundamentals, but rely upon coastal erosion experts (at Federal, state and local agencies; universities; and private firms) for specific guidance regarding erosion potential at a site.

The term "erosion" is commonly used to refer to the horizontal recession of the shoreline (i.e., *shoreline erosion*), but can apply to other types of erosion. For example, *seabed or lakebed erosion* (also called *downcutting*) occurs when fine-grained sediments in the nearshore zone are eroded and carried into deep water. These sediments are lost permanently, thereby resulting in a lowering of the seabed or lakebed. This process has several important consequences: increased local water depths, increased wave heights reaching the shoreline, increased shoreline erosion, and undermining of erosion control structures. Downcutting has been documented along some ocean-facing shorelines, but also along much of the Great Lakes shoreline (which is largely composed of fine-grained glacial deposits). Designers are referred to Keillor (1998) for more information on this topic.

Erosion is capable of threatening coastal residential buildings in a number of ways:

- destroying dunes or other natural protective features, (see Figure 7-26)
- destroying erosion control devices (see Figures 7-27 and 7-28)
- lowering ground elevations, undermining shallow foundations, and reducing penetration of deep foundations such as piles (see Figures 7-29 and 7-30)
- supplying overwash sediments that can bury structures farther landward (see Figure 7-31) (Note that overwash can permanently reduce the width and elevation of beaches and dunes by transporting sediments landward into marsh areas, where its recovery is difficult, if not impossible—see Figure 7-32.)
- breaching low-lying coastal barrier islands, destroying structures at the site of the breach (see Figure 7-33), and sometimes exposing structures on the mainland to increased flood and wave effects (see Figures 7-34 and 7-35)
- washing away low-lying coastal landforms (see Figures 7-36 and 7-37)
- eroding coastal bluffs that provide support to buildings outside the floodplain itself (see Figure 7-38 and 7-39)

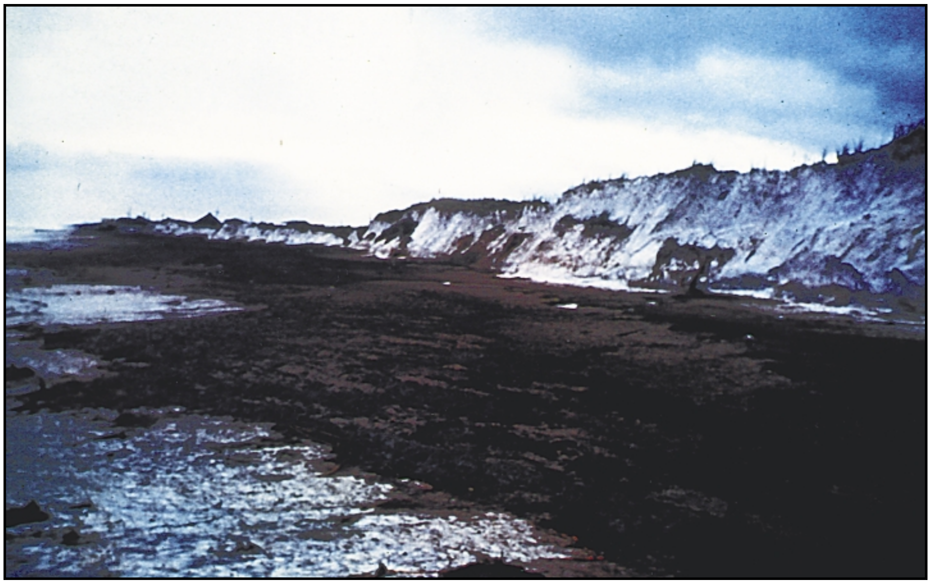


Figure 7-26
Dune erosion in Walton County, Florida, caused by Hurricane Eloise, 1975.

Figure 7-27
Erosion and revetment damage in St. Johns County, Florida, caused by the November 1984 northeast storm.

Figure 7-28
Hurricane Opal (1995). Failure of seawall in Bay County, Florida, led to undermining and collapse of the building behind the wall.

Figure 7-29
Long-term erosion at South Bethany Beach, Delaware, has lowered ground elevations beneath buildings and left them more vulnerable to storm damage. 1992 photograph.

Figure 7-30
Erosion undermining a coastal residence at Cape Shoalwater, Washington. 1992 photograph by Washington Department of Ecology.

Figure 7-31
Removal of Hurricane Opal overwash from road at Pensacola Beach, Florida. Sand washed landward from the beach buried the road, adjacent lots, and some at-grade buildings to a depth of 3–4 feet.

Figure 7-32
Hurricane Bonnie (1998). Overwash on Topsail Island, North Carolina. Photograph by Jamie Moncrief, *Wilmington Morning Star*. Copyright 1998, Wilmington Star-News, Inc.

Figure 7-33
Hurricane Fran (1996). Breach and building damage at North Topsail Beach, North Carolina.

Figure 7-34
A breach was cut across Nauset Spit on Cape Cod, Massachusetts, by a January 1987 northeaster. The breach grew from an initial width of approximately 20 feet to over a mile within 2 years, exposing the previously sheltered shoreline of Chatham to ocean waves and erosion. Photograph by Jim O'Connell.

Figure 7-35
1988 photograph of undermined house at Chatham, Massachusetts. Nine houses were lost as a result of the formation of the new tidal inlet shown in Figure 7-34. Photograph by Jim O'Connell.

Figure 7-36
Cape San Blas, Gulf County, Florida, in November 1984, before Hurricane Elena.

Figure 7-37
Cape San Blas, Gulf County, Florida, in November 1985, after Hurricane Elena.

Figure 7-38
Long-term erosion along the Lake Michigan shoreline in Ozaukee County, Wisconsin, increases the threat to residential buildings outside the floodplain. 1996 photograph.

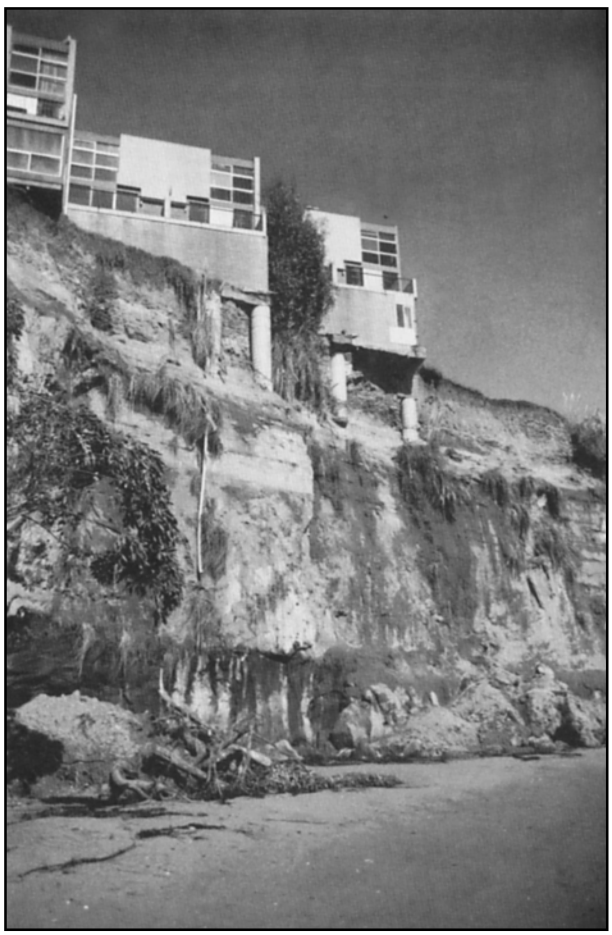


Figure 7-39
Bluff failure by a combination of marine, terrestrial, and seismic processes led to progressive undercutting of blufftop apartments at Capitola, California. Six of the units were demolished after the 1989 Loma Prieta earthquake. 1989 photograph from Griggs (1994), courtesy of Journal of Coastal Resources.

WARNING

Proper planning, siting, and design of coastal residential buildings require:

1) a basic understanding of shoreline erosion processes,

2) erosion rate information from the community, state, or other sources,

3) appreciation for the uncertainty associated with the prediction of future shoreline positions, and

4) knowledge that siting a building immediately landward of a regulatory coastal setback line does not guarantee the building will be safe from erosion.

7.5.1 Describing and Measuring Erosion

Erosion should be considered part of the larger process of shoreline change. When more sediment leaves a shoreline segment than moves into it, *erosion* results; when more sediment moves into a shoreline segment than leaves it, *accretion* results; when the amounts of sediment moving into and leaving a shoreline segment balance, the shoreline is said to be *stable*.

Care must be exercised in classifying a particular shoreline as erosional, stable, or accretional. A shoreline classified as "erosional" may experience periods of stability or accretion. Likewise, a shoreline classified as "stable" or "accretional" may be subject to periods of erosion. Actual shoreline behavior will depend on the time period of analysis and on prevailing and extreme coastal processes during that period.

It is for these reasons that we classify shoreline changes as "short-term" changes and "long-term" changes. Short-term changes occur over periods ranging from a few days to a few years and can be highly variable in direction and magnitude. Long-term changes occur over a period of decades, over which short-term changes tend to average out to the underlying erosion or accretion trend. Both short-term and long-term shoreline changes should be considered in siting and design of coastal residential construction.

Erosion is usually expressed as a rate, in terms of:

- linear retreat (e.g., feet of shoreline recession per year) or
- volumetric loss (e.g., cubic yards of eroded sediment per foot of shoreline frontage per year).

The convention that will be used in this manual will be to cite erosion rates as positive numbers, with corresponding shoreline change rates as negative numbers (e.g., an erosion rate of 2 feet/year is equivalent to a shoreline change rate of -2 feet/year). Likewise, accretion rates will be listed as positive numbers, with corresponding shoreline change rates as positive numbers (e.g., an accretion rate of 2 feet/year is equivalent to a shoreline change rate of 2 feet/year).

Shoreline erosion rates are usually computed and cited as long-term, average annual rates. However, erosion rates are *not* uniform in time or space. Erosion rates can vary substantially from one location along the shoreline to another, even when the two locations are only a short distance apart. Figure 7-40 (Douglas et al. 1998) illustrates this point for the Delaware coastline: long-term, average annual shoreline change rates for the period 1845-1993 vary from approximately -1 foot/year to -10 feet/year, over a distance of less than 5 miles.

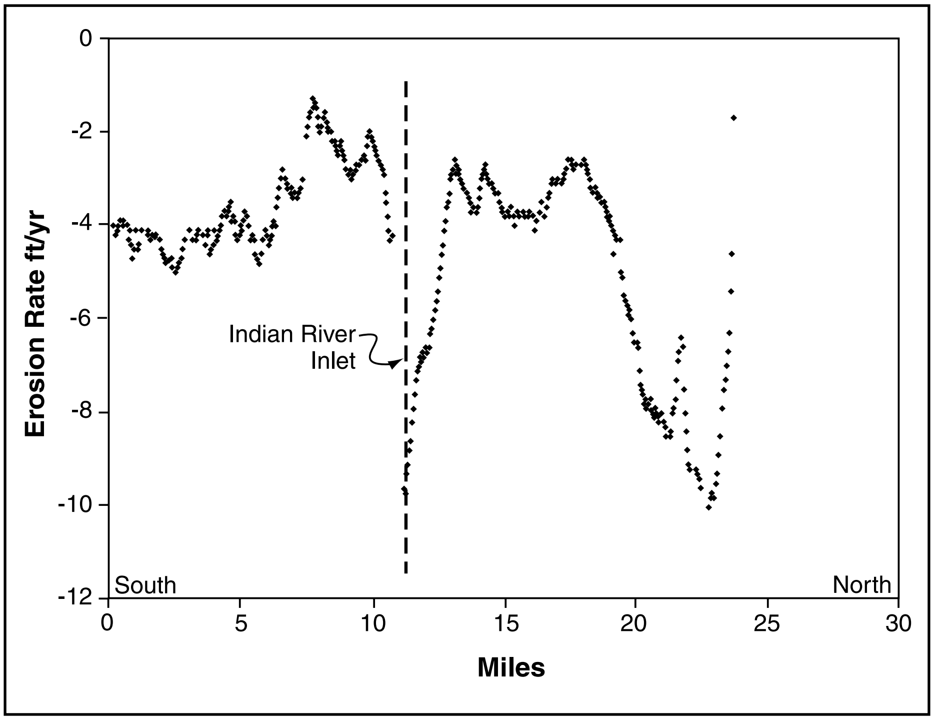


Figure 7-40
Longshore variation in long-term erosion rates, Delaware Atlantic shoreline (from Douglas et al. 1998).

Studies in other areas show similar results. For example, a study by Zhang (1998) examined long-term erosion rates along the east coast of the United States. Results showed the dominant trend along the east coast of the United States is one of erosion (72 percent of the stations examined experienced long-term erosion), with shoreline change rates averaging -3.0 feet/year (i.e., 3.0 feet/year of erosion). However, there is considerable variability along the shoreline, with a few locations experiencing more than 20 feet/year of erosion, and over one-fourth of the stations experiencing accretion. A study of the Pacific County, Washington, coastline found erosion rates as high as 150 feet/year, and accretion rates as high as 18 feet/year (Kaminsky et al. 1999).

Erosion rates can also vary over time at a single location. For example, Figure 7-41 illustrates the shoreline history for the region approximately 1.5 miles south of Indian River Inlet, Delaware. Although the long-term, average annual shoreline change rate is approximately -2 feet/year, short-term shoreline change rates vary from -27 feet/year (erosion resulting from severe storms) to +6 feet/year (accretion associated with post-storm recovery of the shoreline).

NOTE

It is not uncommon for short-term erosion rates to exceed long-term rates by a factor of 10 or more.

Designers should also be aware that some shorelines experience large seasonal fluctuations in beach width and elevation (see Figure 7-42). These changes are a result of seasonal variations in wave conditions and water levels, and should not be taken as indicators of long-term shoreline changes. For this reason, shoreline change calculations at beaches subject to large seasonal fluctuations should be based on shoreline measurements taken at approximately the same time of year.

Figure 7-41
Shoreline changes through time at a location approximately 1.5 miles south of Indian River Inlet, Delaware.

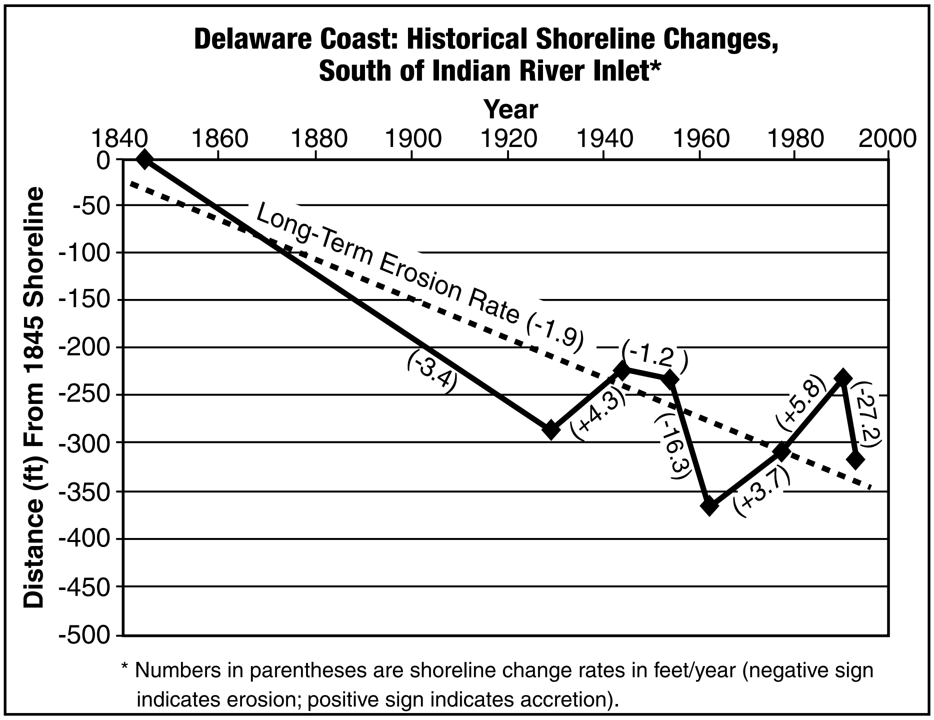
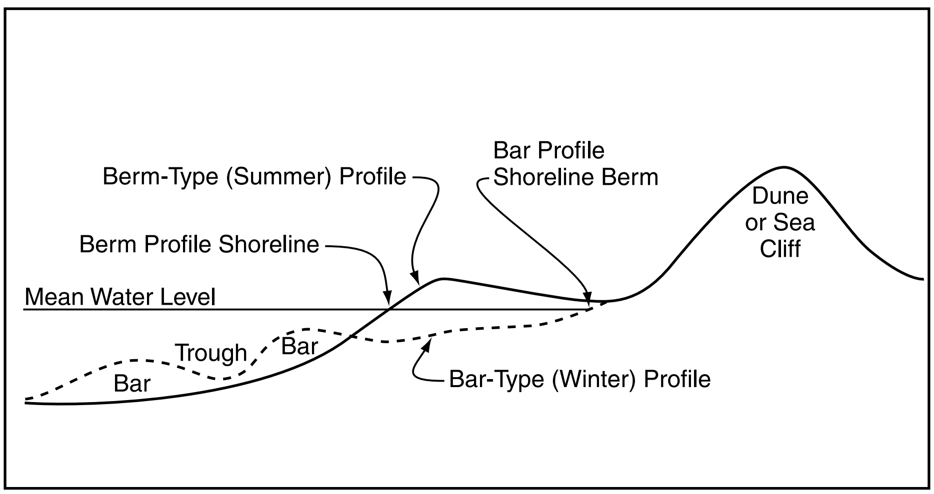


Figure 7-42
Seasonal fluctuations in beach width and elevation.



NOTE

Apparent erosion or accretion resulting from seasonal fluctuations of the shoreline is **not** an indication of true shoreline change.

Erosion rates have been calculated by many states and communities for the establishment of regulatory construction setback lines. These rates are typically calculated from measurements made with aerial photographs, historical charts, or beach profiles. However, a number of potential errors are associated with measurements and calculations using each of the data sources, particularly the older data. Some studies have estimated that errors in most computed erosion rates are at least 1 foot/year. Therefore, **it is recommended that the siting of coastal residential structures not be based on smaller erosion rates (unless there is compelling evidence to support small erosion rates or to support accretion) and be based upon erosion rates greater than or equal to 1 foot/year**.

7.5.2 Causes of Erosion

Erosion can be due to a variety of natural or manmade causes, and can include the following:

- erosion caused by *storms and coastal flood events*, usually rapid and dramatic (also called *storm-induced* erosion)
- erosion caused by natural changes associated with *tidal inlets, river outlets, and entrances to bays* (e.g., interruption of littoral transport by jetties and channels, migration or fluctuation of channels and shoals, formation of new inlets)
- erosion induced by *manmade structures and human activities* (e.g., certain shore protection structures; damming of rivers; dredging; mining sand from beaches and dunes; alteration of vegetation, surface drainage, or groundwater at coastal bluffs)
- *long-term erosion* – gradual erosion that occurs over a period of decades, due to the cumulative effects of many factors, including changes in sea/lake level, sediment supply, and those factors mentioned above
- *local scour* around structural elements, including piles and foundation elements

Erosion can affect all coastal landforms except highly resistant geologic formations. Low-lying beaches and dunes are vulnerable to erosion, as are most coastal bluffs, banks, and cliffs. Improperly sited buildings – even those situated atop coastal bluffs and outside the floodplain – and buildings with inadequate foundation support are especially vulnerable to the effects of erosion.

7.5.2.1 Erosion During Storms

Erosion during storms can be dramatic and damaging. Although storm-induced erosion is usually short-lived (usually occurring over a few hours in the case of hurricanes and typhoons, or over a few tidal cycles or days in the case of northeasters and other coastal storms), the resulting erosion can be equivalent to decades of long-term erosion. During severe storms or coastal flood events, it is not uncommon for large dunes to be eroded 25–75 feet or more (see Figure 7-26) and for small dunes to be completely destroyed.

NOTE

Some beaches and dunes will take decades to recover after a severe storm, while others may never recover.

The amount of erosion during a storm determines the level of protection that a dune or similar coastal landform will provide to buildings. Designers should be aware that the mere presence of a dune does not guarantee protection during a storm. Figure 7-43 illustrates this point: areas experiencing dune or bluff retreat will form an effective barrier to storm effects (Figure 7-43, profile A). Areas experiencing wave overtopping and overwash may be subject to shallow flooding (Figure 7-43, profile B). Areas experiencing dune disintegration will transmit, but attenuate, storm waves landward of the former dune location (Figure 7-43, profile C). Areas experiencing dune flooding or submergence will not attenuate storm waves appreciably and will allow inland penetration of storm waves (Figure 7-43, profile D).

CROSS REFERENCE

Newer FIRMs incorporate the effects of dune and bluff erosion during storms (see Section 7.8.1.3).

The parameters that control the volume of sediment eroded during a storm include the following:

- storm tide elevation relative to upland elevation
- storm duration
- storm wave characteristics

The volume of sediment eroded also depends on beach width and condition, and whether or not an area has been left vulnerable by the effects of other recent storms. In fact, the cumulative effects of two or more closely spaced minor storms can often exceed the effects of a single, more powerful storm.

Erosion during storms sometimes occurs despite the presence of erosion control devices such as seawalls, revetments, and toe protection. Storm waves frequently overtop, damage, or destroy poorly designed, constructed, or maintained erosion control devices. Lands and buildings situated behind an erosion control device are not necessarily safe from coastal flood forces and storm-induced erosion.

Storms also exploit weaknesses in dune systems: a dune that is not covered by well-established vegetation (i.e., vegetation that has been in place for two or more growing seasons) will be more vulnerable to wind and flood damage than one with well-established vegetation; a dune crossed by a road or pedestrian path will offer a weak point that storm waves and flooding will exploit. Post-storm damage inspections frequently show that dunes are breached at these weak points and that structures landward of them are more vulnerable to erosion and flood damage (see Figure 7-44).

Narrow sand spits and low-lying coastal lands can be breached by tidal channels and inlets—often originating from the buildup of water on the back side (see Figure 7-33)—or washed away entirely (see Figures 7-36 and 7-37). Storm-induced erosion damage to unconsolidated cliffs and bluffs typically takes the form of large-scale collapse, slumping, and landslides, with concurrent recession of the top of the bluff (see Figure 2-23, in Chapter 2).

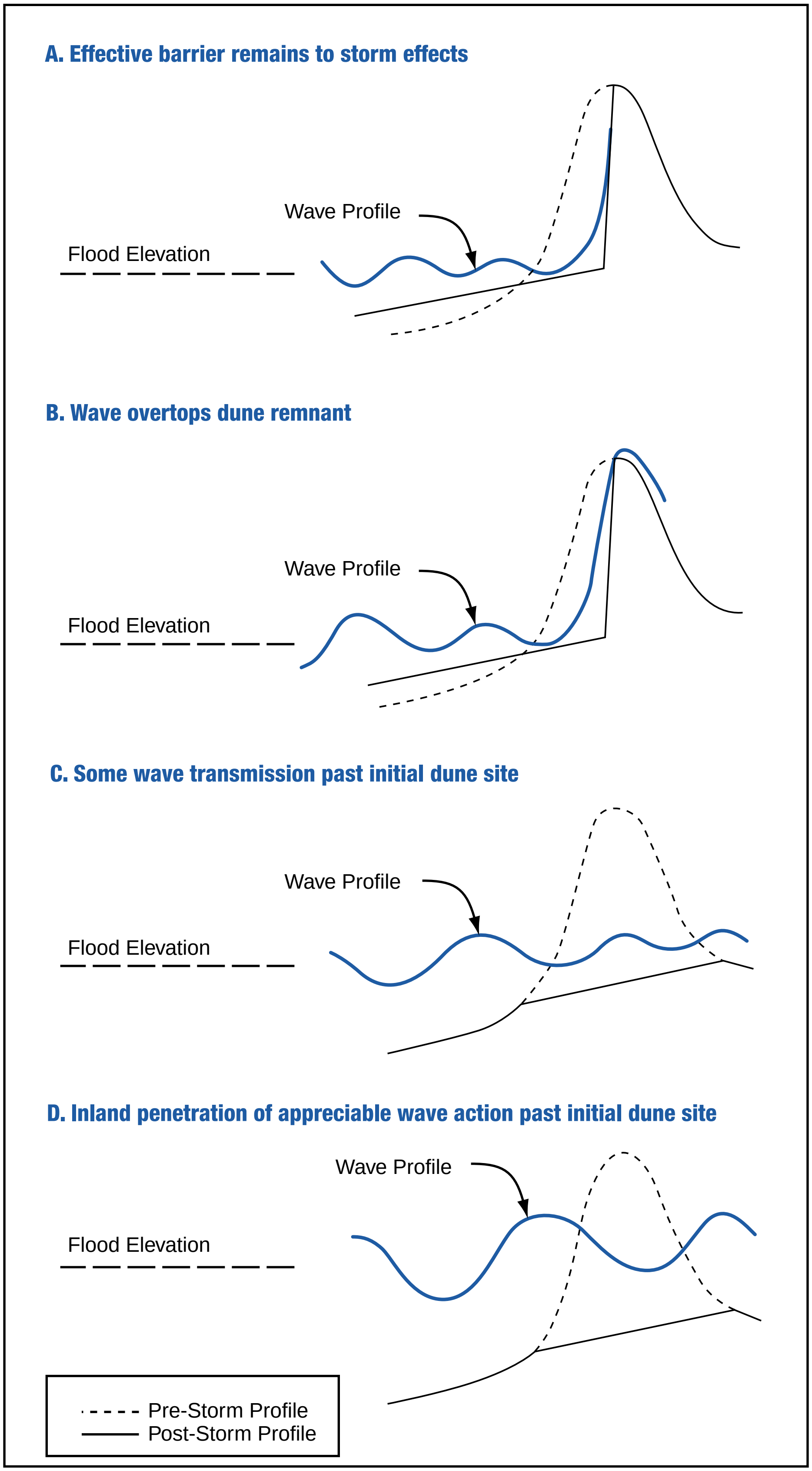
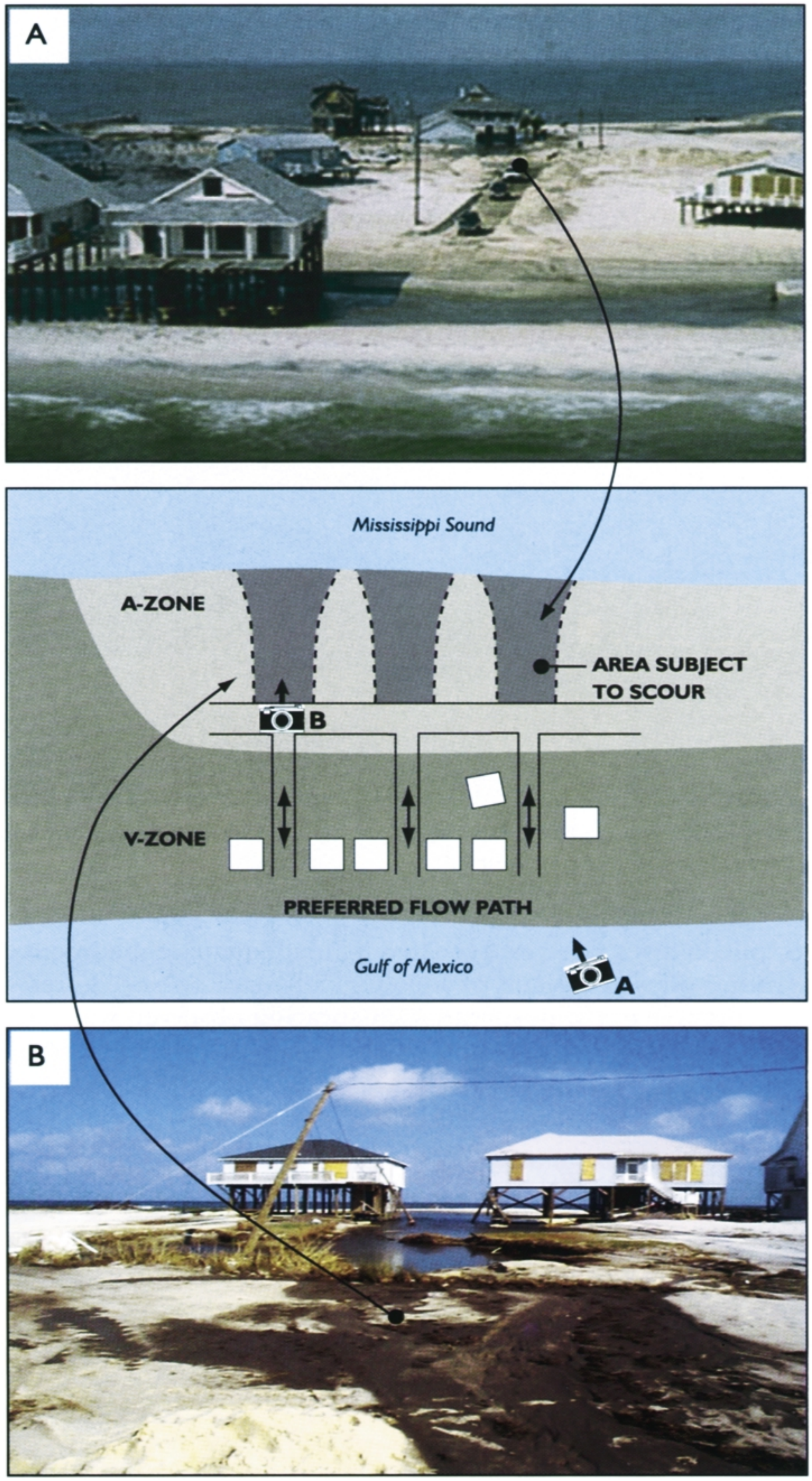


Figure 7-43
Flood protection offered by eroded dunes (from Dewberry & Davis 1989).

Figure 7-44
Hurricane Georges (1998). Damage to buildings landward of dune crossed by vehicle paths.



Siting and design of any structures to be built on coastal dunes, spits, or bluffs – or any other area subject to storm-induced erosion – should consider the potential for significant loss of supporting soil during storms:

- Buildings in low-lying coastal areas must have a deep, well-designed, and well-constructed pile or column foundation.
- Buildings constructed atop dunes and bluffs, and outside the floodplain, can still be subject to erosion, and therefore must account for the possibility of loss of supporting soil. This loss can be accounted for with one or more of the following methods:
    - setbacks from the dune or bluff edge sufficient to offer protection over the expected life of the building
    - dune or bluff toe protection designed to withstand the base flood event (designers are cautioned, however, that many states and communities restrict or prohibit the construction of dune toe protection and erosion control structures)
    - design of a moveable building, which can be lifted off its foundation and moved landward onto a new foundation
    - construction of a deep foundation (note that this method could result in a building standing high above the beach following a storm – it would probably be uninhabitable and require landward relocation)
    - a combination of these methods

CROSS REFERENCE

Chapters 12 and 13 provide information about designing and constructing sound pile and column foundations.

WARNING

Ground elevations in some V zones lie above the BFE (as a result of mapping procedures that account for storm erosion). V-zone requirements for a pile or column foundation capable of resisting flotation, collapse, and lateral movement still apply, even if the current ground level lies above the BFE.

Storm-induced erosion can take place along open-coast shorelines (Atlantic, Pacific, Gulf of Mexico, and Great Lakes shorelines) and along shorelines of smaller enclosed or semi-enclosed bodies of water. If a body of water is subject to increases in water levels and generation of damaging wave action during storms, storm-induced erosion can occur.

7.5.2.2 Erosion Due to Tidal Inlets, Harbor, Bay, and River Entrances

Many miles of coastal shoreline are situated on or adjacent to connections between two bodies of water. These connections can take the form of tidal inlets (short, narrow hydraulic connections between oceans and inland waters), harbor entrances, bay entrances, and river entrances. The size, location, and adjacent shoreline stability of these connections are usually governed by five factors:

- tidal and freshwater flows through the connection
- wave climate
- sediment supply
- local geology
- jetties or stabilization structures

WARNING

The location of a tidal inlet, harbor entrance, bay entrance, or river entrance can be stabilized by jetties or other structures, but the shorelines in the vicinity can still fluctuate in response to storms, waves, and other factors.

Temporary or permanent changes in any of these governing factors can cause the connections to migrate, change size, or change configuration, and can cause sediment transport patterns in the vicinity of the inlet to change, thereby altering flood hazards in nearby areas.

Construction of jetties or similar structures at a tidal inlet or a bay, harbor, or river entrance often results in accretion on one side and erosion on the other, with a substantial shoreline offset. This offset results from the jetties trapping the *littoral drift* (wave-driven sediment moving along the shoreline) and preventing it from moving to the downdrift side. Figure 7-45 shows such a situation at Ocean City Inlet, Maryland, where formation of the inlet in 1933 by a hurricane and construction of inlet jetties in 1934-1935 have led to approximately 800 feet of accretion against the north jetty at Ocean City and approximately 1,700 feet of erosion on the south side of the inlet along Assateague Island (Dean and Perlin 1977). The downdrift erosion is ongoing. Stauble and Cialone (1966) report that post-inlet shoreline change rates on Assateague Island have been documented between -30 feet/year and -40 feet/year (pre-inlet shoreline change rates were approximately -4 feet/year).

Figure 7-45
Ocean City Inlet, Maryland, was opened by a hurricane in 1933 and stabilized by jetties in 1934–35. Note extreme shoreline offset and downdrift erosion resulting from inlet stabilization. 1992 photograph.

It should be noted that erosion and accretion patterns at stabilized inlets and entrances sometimes differ from the classic pattern occurring at Ocean City Inlet. In some instances, accretion occurs immediately adjacent to both jetties, with erosion beyond. In some instances, erosion and accretion patterns near a stabilized inlet change over time. Figure 7-46 shows recently constructed buildings at Ocean Shores, Washington, now threatened by shoreline erosion, despite the fact that the buildings were located near an inlet jetty on a beach that was historically viewed as accretional.

Figure 7-46
Buildings threatened by erosion at Ocean Shores, Washington. The rock revetments were built in response to shoreline erosion along an area adjacent to a jetty and thought to be accretional. 1998 photograph.

NOTE

Cursory characterizations of shoreline behavior in the vicinity of a stabilized inlet, harbor, or bay entrance should be rejected in favor of a more detailed evaluation of shoreline changes and trends.

Development in the vicinity of a tidal inlet or bay, harbor, or river entrance is often affected by lateral migration of the channel and associated changes in sand bars (which may focus waves and erosion on particular shoreline areas). Often, these changes are cyclic in nature and can be identified and forecast through a review of historical aerial photographs and bathymetric data. Those considering a building site near a tidal inlet or a bay, harbor, or river entrance should investigate the history of the connection, associated shoreline fluctuations, migration trends, and impacts of any stabilization structures. Failure to do so could result in increased building vulnerability or building loss to future shoreline changes.

Shoreline changes in the vicinity of one of the more notable regulatory takings cases illustrate this point. Figure 7-47 is a 1989 photograph of one of the two vacant lots owned by David Lucas, which became the subject of the case *Lucas vs. South Carolina Coastal Council* (Lucas challenged the state's prohibition of construction on the lots – the state law has since been changed to allow residential construction in similar circumstances). By December 1997, the case had been decided in favor of Lucas, the State of South Carolina had purchased the lots from Lucas, the State had resold the lots, and a home had been constructed on one of the lots (Jones et al. 1998). Figure 7-48 shows a December 1997 photograph of the same area, with erosion undermining the home built on the former Lucas lot (left side of photo) and an adjacent house (also present in 1989 in Figure 7-47). Comparison of historical shorelines in the vicinity (see Figure 7-49) indicates such an occurrence should not be surprising – changes in inlet sand bars and channels at a nearby unstabilized inlet have caused the shoreline throughout the area to advance and recede approximately 300 feet to 400 feet in just a few years.

WARNING

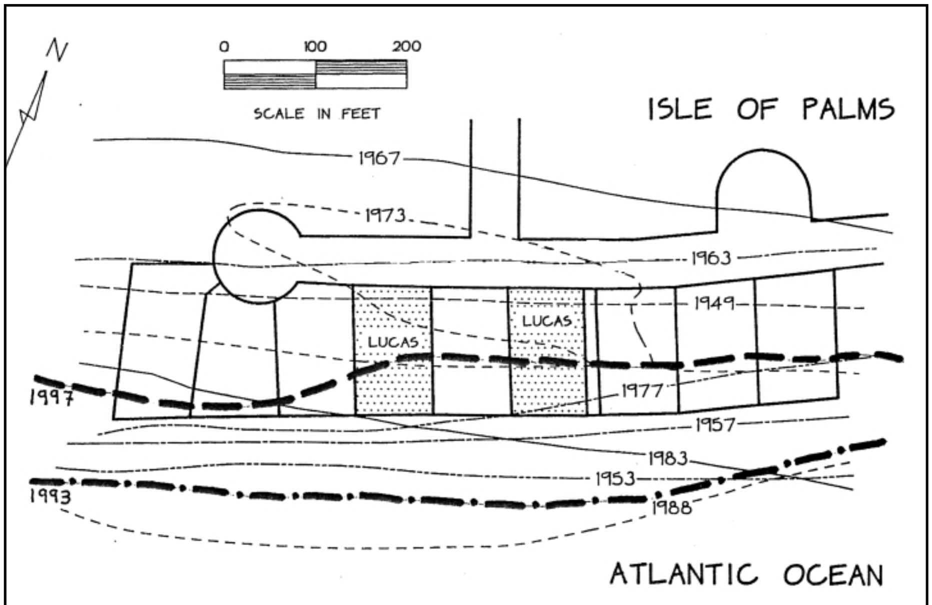
Many state and local siting regulations allow residential development in areas where erosion is likely to occur. Designers should not assume that a building sited in compliance with minimum state and local requirements will be safe from future erosion. See Chapter 8.

Figure 7-47
July 1989 photograph of vacant lot owned by Lucas, Isle of Palms, South Carolina.

Figure 7-48
December 1997 photograph taken in the same area as Figure 7-47. Erosion and undermining of the houses is a result of shoreline changes associated with changes in inlet sand bars and wave patterns. Note that this area is approximately 0.5 mile from the houses shown in Figure 4-2.

7.5.2.3 Erosion Due to Manmade Structures and Human Activities

Man's actions along the shoreline can both reduce and increase flood hazards. In some instances, structures built or actions taken to facilitate navigation will cause erosion elsewhere. In some cases, structures built or actions taken to halt erosion and reduce flood hazards at one site will increase erosion and flood hazards at nearby sites. For this reason, evaluation of a potential coastal building site requires consideration of natural and man-induced shoreline changes



Historical Vegetation Lines Superimposed on Lucas Lots

Figure 7-49
Historical shoreline changes in the vicinity of Lucas lots.

7.5.2.3.1 Effects of Shore Protection Structures

In performing their intended function, shore protection structures can lead to or increase erosion on nearby properties. This statement should not be taken as an indictment of all erosion control structures, because many provide protection against erosion and flood hazards. Rather, it simply recognizes the potential for adverse impacts. These potential impacts will vary from site to site and structure to structure and can sometimes be mitigated by *beach nourishment*—the placement of additional sediment on the beach—in the vicinity of the erosion control structure. This manual points out the potential impacts of these structures on nearby properties and offers some siting guidance for residential buildings relative to erosion control structures (see Chapter 8), where permitted by states and communities.

Groins (such as those shown in Figure 5-3, in Chapter 5) are short, shore-perpendicular structures designed to trap available littoral sediments. They can cause erosion to downdrift beaches if the groin compartments are not filled with sand and maintained in a full condition.

Likewise, *offshore breakwaters* (see Figure 7-50) can trap available littoral sediments and reduce the sediment supply to nearby beaches. This adverse effect should be mitigated by combining breakwater construction with beach nourishment – in fact, current design guidance for offshore breakwater projects calls for the inclusion of beach nourishment (Chasten et al. 1993).

NOTE

This manual does not endorse or reject the use of erosion control structures. That is a decision to be made by states and communities, based on their specific shoreline conditions and experience.

This manual merely points out the potential benefits and damage caused by erosion control structures.

Figure 7-50
Trapping of littoral sediments behind offshore breakwaters, Presque Isle, Pennsylvania. Photograph courtesy of USACE.

CROSS-REFERENCE

Adverse impacts of erosion control structures can sometimes be mitigated through beach nourishment. See Section 8.5, in Chapter 8.

Seawalls, *bulkheads*, and *revetments* are shore-parallel structures built, usually along the shoreline or at the base of a bluff, to act as retaining walls and to provide some degree of protection against high water levels, waves, and erosion (the degree of protection they afford depends on their design, construction, and maintenance). They do not prevent erosion of the beach, and in fact, can exacerbate ongoing erosion of the beach. The structures can impound upland sediments that would otherwise erode and nourish the beach, lead to *passive erosion* (eventual loss of the beach as a structure prevents landward migration of the beach profile), and lead to *active erosion* (localized scour waterward of the structure and on unprotected property at the ends of the structure).

It should also be noted that post-storm inspections show that the vast majority of privately financed seawalls, revetments, and erosion control devices fail during 100-year, or lesser, events (i.e., are heavily damaged or destroyed, or withstand the storm, but fail to prevent flood damage to lands and buildings they are intended to protect—see Figures 7-27 and 7-28). Reliance on these devices to protect upland sites and residential buildings is not a good substitute for proper siting and foundation design. Guidance on evaluating the ability of existing seawalls and similar structures to withstand a 100-year coastal flood event can be found in Walton et al. (1989).

Finally, some communities distinguish between erosion control structures constructed to protect existing development and those constructed to create a buildable area on an otherwise unbuildable site. Designers should investigate any local or state regulations and requirements pertaining to erosion control structures before building site selection and design are undertaken.

7.5.2.3.2 Effects of Dredging Navigation Channels

Dredging navigation channels can interrupt the natural bypassing of littoral sediments across tidal inlets and bay entrances, altering natural sediment transport and erosion/accretion patterns. Disposal of beach-compatible dredged sediments into deepwater will result in a permanent loss to the littoral system and may ultimately lead to shoreline erosion. The effects of these two activities can be significant; one study estimated that the two activities accounted for approximately three-fourths of the beach erosion along the east coast of Florida.

WARNING

NFIP regulations require that communities protect mangrove stands in V zones from any man-made alteration that would increase potential flood damage.

Dredging across inlet shoals, protective reefs, sand bars, nearshore shoals, or similar natural barriers can also modify wave and current patterns, and cause shoreline changes nearby. This activity has been cited as a cause of shoreline erosion in Hawaii and in many other locations.

7.5.2.3.3 Effects of Sand Mining from Beaches

Sand mining from beaches and dune areas is not permitted in most states and communities, because it causes an immediate and direct loss of littoral sediments. However, the practice is allowed in some situations where shoreline trends are accretional.

7.5.2.3.4 Effects of Alteration of Vegetation, Drainage or Groundwater

Alteration of vegetation, drainage, or groundwater can sometimes make a site more vulnerable to coastal storm or flood events. For example, removal of vegetation (grasses, ground covers, and trees) at a site can render the soil more prone to erosion by wind, rain, and flood forces. Alteration of natural drainage patterns and groundwater flow can lead to increased erosion potential, especially on steep slopes and coastal bluffs. Irrigation and septic systems often contribute to bluff instability problems.

WARNING

Drainage from septic and irrigation systems can cause coastal bluff erosion by elevating groundwater levels and decreasing soil strength.

7.5.2.3.5 Effects of Damming Rivers

Damming of rivers can reduce natural sediment loads transported to open coast shorelines. Most rivers carry predominantly fine sediments (silts and clays), but some rivers may carry higher percentages of sand, and some large rivers may yield significant quantities of sand. Although the exact shoreline impacts from damming rivers may be difficult to discern, the reduced sediment input may ultimately translate into shoreline erosion in some areas. It has been postulated that damming rivers and reduced sediment loads are responsible for the shift from long-term accretion to recent erosion along the portion of the Washington coast shown in Figure 7-46.

7.5.2.4 Long-Term Erosion

Observed long-term erosion at a site represents the net effect of a combination of factors. The factors that contribute to long-term erosion can include:

- rising sea levels (or subsidence of uplands)
- in the case of the Great Lakes, rising lake levels or lakebed erosion
- reduced sediment supply to the coast
- construction of jetties, other structures, or dredged channels that impede littoral transport of sediments along the shoreline
- increased incidence or intensity of storms
- alteration of upland vegetation, drainage, or groundwater flows (especially in coastal bluff areas)

Regardless of the cause, long-term shoreline erosion can increase the vulnerability of coastal construction in a number of ways, depending on local shoreline characteristics, construction setbacks, and structure design.

WARNING

Coastal FIRMs (even recently published coastal FIRMs) do not incorporate the effects of long-term erosion. Users are cautioned that mapped V zones and A zones in areas subject to long-term erosion will underestimate the extent and magnitude of actual flood hazards that a coastal building may experience over its lifetime.

In essence, **long-term erosion acts to shift flood hazard zones landward**. For example, a site that was at one time mapped accurately as an A zone will become exposed to V zone conditions, a site that was at one time accurately mapped as outside the 100-year floodplain may become exposed to A zone or V zone conditions.

FEMA has undertaken a series of studies mandated by Congress, under Section 577 of the National Flood Insurance Reform Act of 1994, to determine whether and how long-term erosion can be incorporated into coastal floodplain mapping (Crowell et al. 1999). The studies are divided into two phases. Phase I studies (completed winter 1997) mapped erosion in 27 coastal counties in 18 states (see Table 7.5). Phase II studies (for 18 of the 27 counties, to be completed in early 2000) will inventory structures within the erosion hazard areas mapped in Phase I, will estimate future erosion and flood damage as part of economic impact and cost/benefit analyses, and will determine whether it is economically and technically justified for FEMA to map and insure against erosion hazards through the NFIP.

Despite the fact that Flood Insurance Rate Maps (FIRMs) do not incorporate long-term erosion, there are other sources of long-term erosion data available for much of the country's shorelines. These data usually take the form of historical shoreline maps or erosion rates published by individual states or specific reports (from Federal or state agencies, universities, or consultants) pertaining to counties or other small shoreline reaches. The list of erosion-related publications in Appendix G provides examples of the types of information available.

Table 7.5
FEMA Coastal Erosion Study Areas

State	Counties*
Massachusetts	Plymouth
New York	**Suffolk**, Monroe
New Jersey	Ocean
Delaware	**Sussex**
Virginia	City of Virginia Beach
North Carolina	**Dare, Brunswick**
South Carolina	**Georgetown**
Georgia	**Glynn**
Florida	Brevard, **Lee,** Escambia
Alabama	Baldwin
Texas	**Brazoria, Galveston**
California	**San Diego, Santa Cruz**
Oregon	**Lincoln**
Washington	Pacific
Hawaii	Honolulu
Michigan	**Sanilac, Berrien**
Ohio	Lake
Wisconsin	**Racine, Ozaukee, Manitowoc** (10-mile sections of each county)

* Phase I studies were completed for all counties listed, Phase II studies will be completed for counties in bold.)

Designers should be aware that there may be more than one source of long-term erosion rate data available for a given site and that the different sources may report different erosion rates. Differences in rates may be a result of different study periods, different data sources (e.g., aerial photographs vs. maps vs. ground surveys), or different study methods. In cases where multiple sources and long-term erosion rates exist for a given site, designers should use the highest long-term erosion rate in their siting decisions, unless they conduct a detailed review of the erosion rate studies and conclude that a lower erosion rate is more appropriate for forecasting future shoreline positions.

7.5.2.5 Localized Scour

Localized scour can occur when water flows at high velocities past an object embedded in or resting on erodible soil (localized scour can also be caused or exacerbated by waves interacting with the object). The scour is not caused by the flood or storm event, per se, but by the distortion of the flow field by the object; localized scour occurs only around the object itself and is in addition to storm- or flood-induced erosion that occurs in the general area.

Flow moving past a fixed object must accelerate, often forming eddies or vortices and scouring loose sediment from the immediate vicinity of the object. Localized scour around piles and similar objects (see Figure 7-51) is generally limited to small, cone-shaped depressions (less than 2 feet deep and several feet in diameter). Localized scour is capable of undermining slabs and grade-supported structures. In severe cases, the depth and lateral extent of localized scour can lead to structural failure (see Figure 7-52). Designers should consider potential effects of localized scour when calculating foundation size, depth, or embedment requirements.

Figure 7-51
Hurricane Fran (1996). Determination of localized scour from changes in sand color, texture, and bedding.

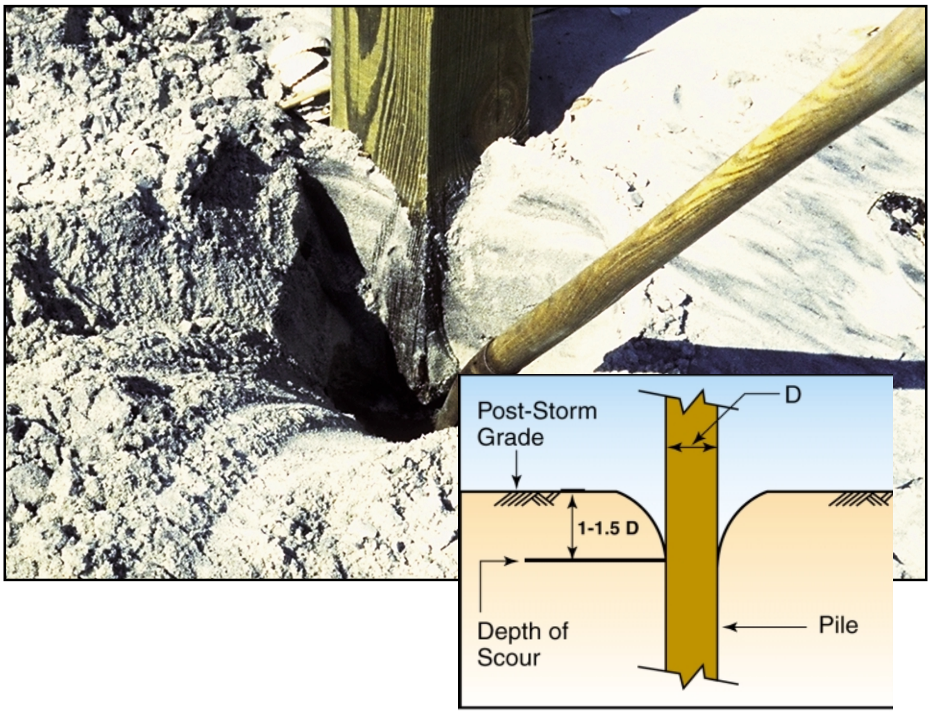


Figure 7-52
Hurricane Fran (1996). Extreme case of localized scour undermining a slab-on-grade house on Topsail Island, North Carolina. The lot was several hundred feet from the shoreline and mapped as an A zone on the FIRM prior to the storm. This case provides one argument for the treatment of these areas as coastal A zones.

7.5.2.6 Overwash and Sediment Burial

Sediment eroded during a coastal storm event must travel to one of the following locations: offshore to deeper water, along the shoreline, or inland. Overwash occurs when low-lying coastal lands are overtopped and eroded by storm surge and waves, such that the eroded sediments are carried landward by floodwaters, burying uplands, roads, and at-grade structures (see Figures 7-5 and 7-31). Depths of overwash deposits can reach 3–5 feet, or more, near the shoreline, but they gradually decrease with increasing distance from the shoreline. It is not uncommon to see overwash deposits extending several hundred feet inland following a severe storm, especially in the vicinity of shore-perpendicular roads.

NOTE

Most owners and designers worry only about erosion. However, sediment deposition and burial can also be a problem.

Post-storm aerial photographs and/or videos can be used to identify likely future overwash locations. This approach was used in a coastal vulnerability study for Delaware (Dewberry & Davis 1997a), where overwash resulting from the March 1962 northeaster was taken from post-storm aerial photographs and mapped onto recent aerial photographs. Another study (USGS 1997) mapped overwash resulting from Hurricane Fran in North Carolina, and related overwash to dune morphology, storm surge elevations, and offshore bathymetry.

The physical processes required to create significant overwash deposits (i.e., waves capable of suspending sediments in the water column and flow velocities generally in excess of 3 feet/sec) are also capable of damaging buildings. Thus, existing coastal buildings located in A zones (particularly the seaward portions of A zones) and built on slab or crawlspace foundations should be considered vulnerable to damage from overwash, high-velocity flows, and waves.

Some coastal areas suffer from an excess of sand rather than from erosion. The excess usually translates into accretion of the shoreline and/or significant quantities of windblown sand. Unless this windblown sediment is stabilized by vegetation or other means, it will likely be blown inland by coastal winds, where it can bury non-elevated coastal residential buildings and at-grade infrastructure—such as drainage structures and ground-mounted electrical and telephone equipment—and drift across roads (see Figure 7-53).

Figure 7-53
Windblown sand drifting against coastal residences in Pacific City, Oregon. Photograph by Jim Good.

7.6 Earthquakes

Earthquakes can affect coastal areas just as they can affect inland areas – through ground shaking, liquefaction, surface fault ruptures, and other ground failures. Therefore, coastal construction in seismic hazard areas must take potential earthquake hazards into account. Proper design in seismic hazard areas must strike a balance between

1. the need to elevate buildings above flood hazards and minimize obstructions to flow and waves beneath a structure, and
2. the need to stabilize or brace the building against potentially violent accelerations and shaking due to earthquakes.

Earthquakes are classified according to two parameters: magnitude and intensity. Magnitude refers to the total energy released by the event. Intensity refers to the effects at a particular site. Thus, an earthquake has a single magnitude, but the intensity varies with location. The Richter Scale is used to report earthquake magnitude, while the Modified Mercalli Intensity (MMI) Scale is used to report felt intensity. The MMI Scale (see Table 7.6) ranges from I (imperceptible) to XII (catastrophic).

The ground motion produced by earthquakes can shake buildings (both lateral and vertical building movements are common) and cause structural failure by excessive deflection. Earthquakes can cause building failures by rapid, permanent displacement of underlying soils and strata (e.g., uplift, subsidence, ground rupture, soil liquefaction, consolidation). In coastal areas, the structural effects of ground shaking can be magnified when buildings are elevated (on piles, piers, posts, or columns in V zones or by fill in A zones) above the natural ground elevation in conformance with NFIP-compliant state and local floodplain management regulations.

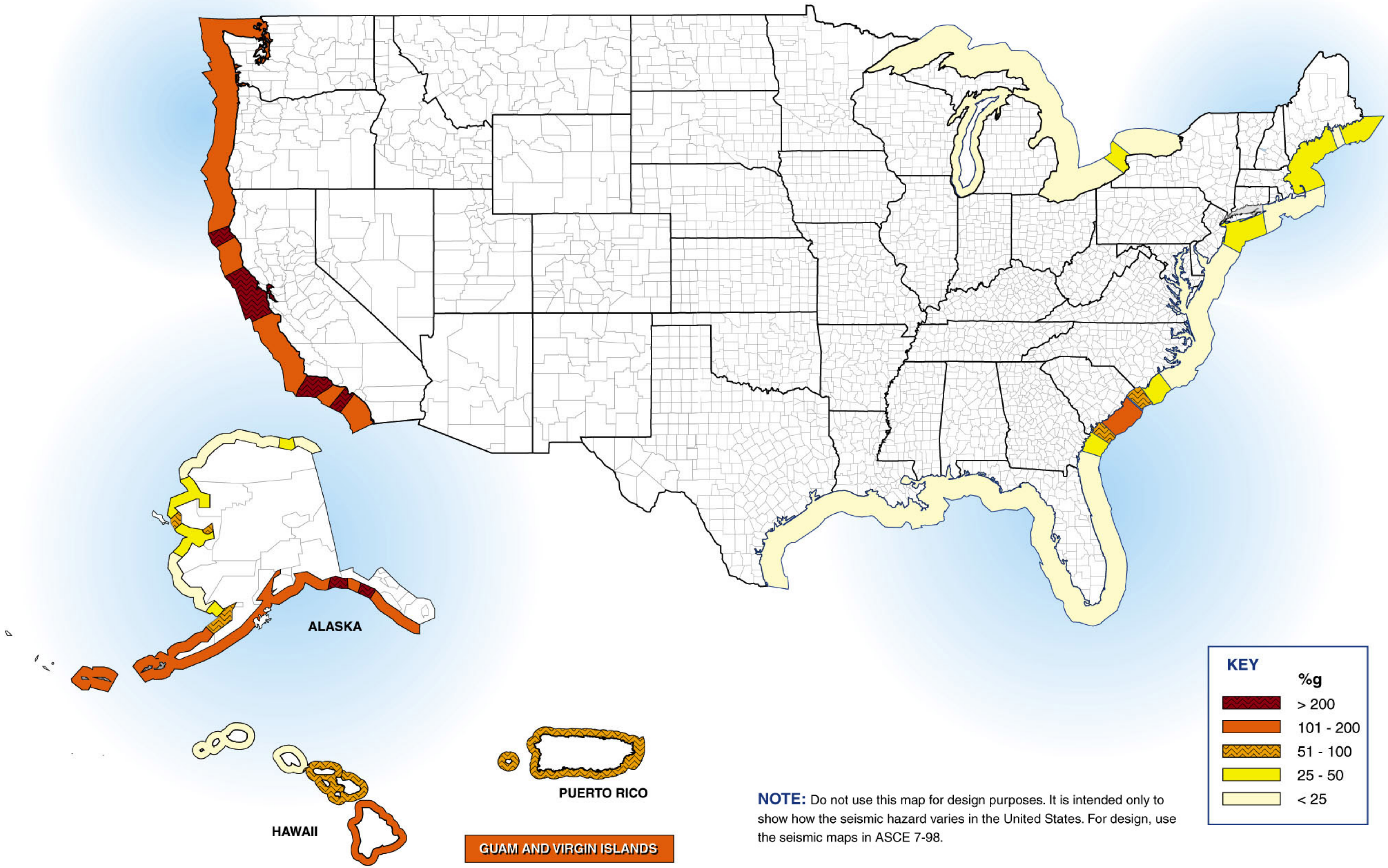
Table 7.6
Modified Mercalli Earthquake Intensity Scale (FEMA 1997b)

MMI Level	Felt Intensity
I	Not felt except by a very few people under special conditions. Detected mostly by instruments.
II	Felt by a few people, especially those on upper floors of buildings. Suspended objects may swing.
III	Felt noticeably indoors. Standing automobiles may rock slightly.
IV	Felt by many people indoors, by a few outdoors. At night, some people are awakened. Dishes, windows, and doors rattle.
V	Felt by nearly everyone. Many people are awakened. Some dishes and windows are broken. Unstable objects are overturned.
VI	Felt by nearly everyone. Many people become frightened and run outdoors. Some heavy furniture is moved. Some plaster falls.
VII	Most people are alarmed and run outside. Damage is negligible in buildings of good construction, considerable in buildings of poor construction.
VIII	Damage is slight in specially designed structures, considerable in ordinary buildings, great in poorly built structures. Heavy furniture is overturned.
IX	Damage is considerable in specially designed buildings. Buildings shift from their foundations and partly collapse. Underground pipes are broken.
X	Some well-built wooden structures are destroyed. Most masonry structures are destroyed. The ground is badly cracked. Considerable landslides occur on steep slopes.
XI	Few, if any, masonry structures remain standing. Rails are bent. Broad fissures appear in the ground.
XII	Virtually total destruction. Waves are seen on the ground surface. Objects are thrown in the air.

Source: FEMA 1997b

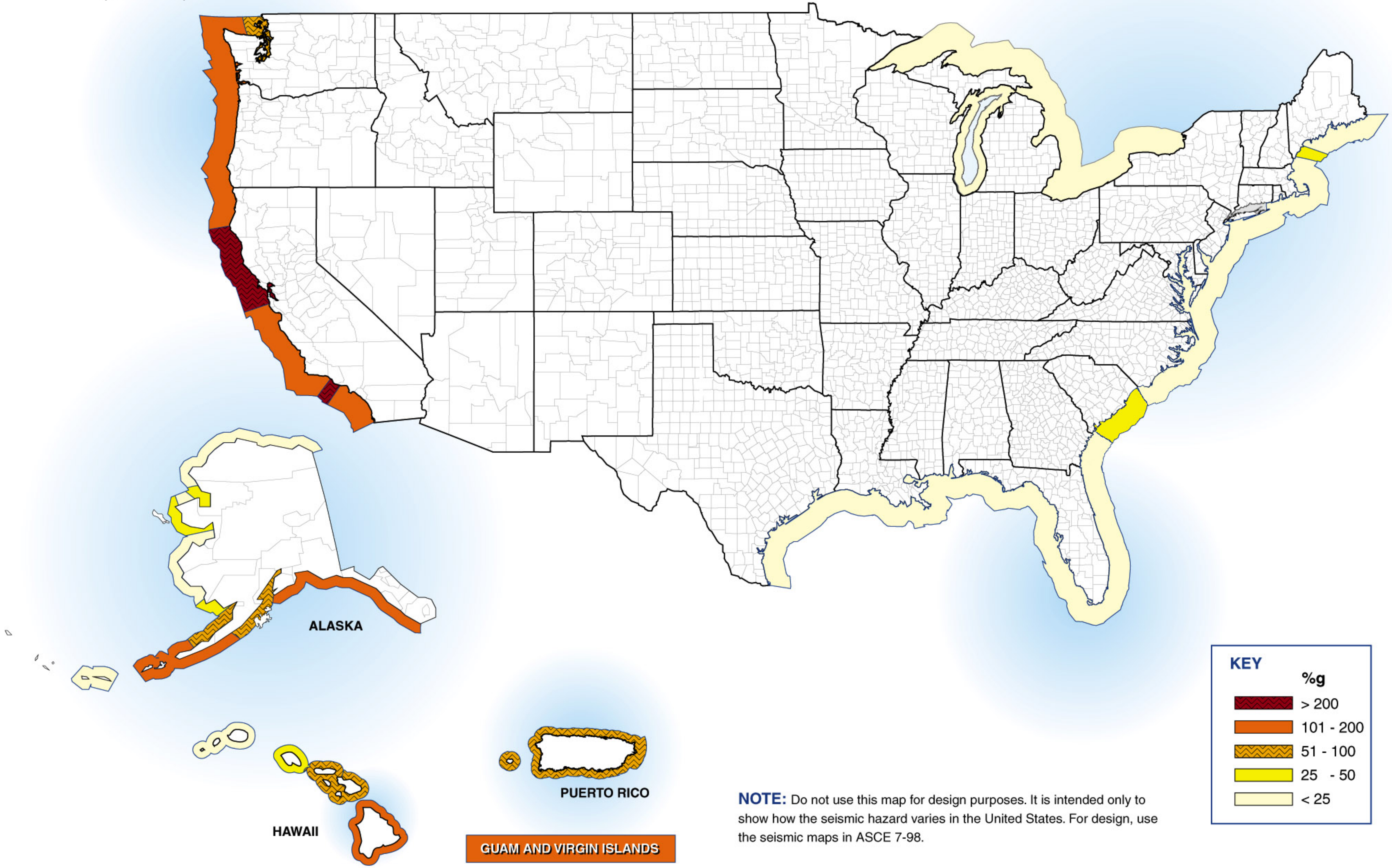
One of the site parameters controlling seismic-resistant design of buildings is the *maximum considered earthquake ground motion*, which has been mapped by the U.S. Geological Survey for the National Earthquake Hazard Reduction Program (NEHRP) at the 0.2-sec spectral response acceleration and the 1.0-sec spectral response acceleration. Accelerations are mapped as a percent of “g,” the gravitational constant. Figures 7-54 and 7-55, respectively, show 0.2-sec and 1.0-sec spectral response acceleration maps for the United States coastline extracted from the NEHRP maps (FEMA 1997a).

Figure 7-54 0.2-sec spectral response acceleration – maximum earthquake ground motion (%g) (FEMA 1997a).



NOTE: Do not use this map for design purposes. It is intended only to show how the seismic hazard varies in the United States. For design, use the seismic maps in ASCE 7-98.

Figure 7-55 1.0-sec spectral response acceleration – maximum earthquake ground motion (%g) (FEMA 1997a).



NOTE: Do not use this map for design purposes. It is intended only to show how the seismic hazard varies in the United States. For design, use the seismic maps in ASCE 7-98.

Inasmuch as the structural effects of earthquakes are a function of many factors (e.g., soil characteristics; local geology; building weight, shape, height, structural system, and foundation type), design of earthquake-resistant buildings requires careful consideration of both site and structure.

In many cases, elevating a building 8–10 feet above grade on a pile or column foundation—a common practice in low-lying V zones and A coastal zones—can result in what earthquake engineers term a “soft story” or “inverted pendulum,” a condition that requires the building be designed for a larger earthquake force. Thus, designs for pile- or column-supported residential buildings should be verified for necessary strength and rigidity below the first-floor level (see Chapter 12), to account for increased stresses in the foundation members when the building starts to move and deflect during an earthquake. For buildings elevated on fill, earthquake ground motions can be exacerbated if the fill and underlying soils are not properly compacted and stabilized.

Liquefaction of the supporting soil can be another damaging consequence of ground shaking. In granular soils with high water tables (like those found in many coastal areas), the ground motion will cause an increase in the pore water pressure, which overcomes soil cohesion and can create a semi-liquid state. The soil then can temporarily lose its bearing capacity, and settlement and differential movement of buildings can result.

Seismic effects on buildings vary with structural configuration, stiffness, ductility, and strength. Properly designed and built wood-frame buildings are quite ductile, meaning that they can withstand large deformations without losing strength. Failures, when they occur in wood-frame buildings, are usually at connections. Properly designed and built steel construction is also inherently ductile, but can fail at non-ductile connections. Modern concrete construction can be dimensioned and reinforced to provide sufficient strength and ductility to resist earthquakes; older concrete structures typically are more vulnerable. Failures in concrete masonry structures are likely to occur if reinforcing and cell grouting do not meet seismic-resistant requirements.

7.7 Other Hazards and Environmental Effects

Other hazards to which coastal construction may be exposed include a wide variety of hazards whose incidence and severity may be highly variable and localized. Examples include subsidence and uplift, landslides and ground failures, salt spray and moisture, rain, hail, wood decay and termites, wildfires, floating ice, snow, and atmospheric ice. These hazards do not always come to mind when coastal hazards are mentioned, but like the other hazards described earlier in this chapter, they can impact coastal construction and should be considered in siting, design, and construction decisions.

7.7.1 Subsidence and Uplift

Subsidence is a hazard that typically affects areas where (1) withdrawal of groundwater or petroleum has occurred on a large scale, (2) organic soils are drained and settlement results, (3) younger sediments deposit over older sediments and cause those older sediments to compact (e.g., river delta areas), or (4) surface sediments collapse into underground voids. The last of these four is most commonly associated with mining and will rarely affect coastal areas (coastal limestone substrates would be an exception because these areas could be affected by collapse). The remaining three causes (groundwater or petroleum withdrawal, organic soil drainage, and sediment compaction) have all affected coastal areas in the past (FEMA 1997b). One consequence of coastal subsidence, even when small in magnitude, is an increase in coastal flood hazards due to an increase in flood depth.

Although few people would regard *uplift* as a coastal hazard, Larsen (1994) has shown that *differential uplift* in the vicinity of the Great Lakes can lead to increased water levels and flooding. As the ground rises in response to the removal of the great ice sheet, it does so in a non-uniform fashion. On Lake Superior, the outlet at the eastern end of the lake is rising at a rate of nearly 10 inches per century, relative to the city of Duluth-Superior at the western end of the lake. This causes a corresponding water level rise at Duluth-Superior. Similarly, the northern ends of Lakes Michigan and Huron are rising relative to their southern portions. On Lake Michigan, the northern outlet at the Straits of Mackinac is rising at a rate of 9 inches per century, relative to Chicago, at the southern end of the lake. The outlet of Lakes Michigan and Huron is rising only about 3 inches per century relative to the land at Chicago.

7.7.2 Landslides and Ground Failures

Landslides occur when slopes become unstable and loose material slides or flows under the influence of gravity. Often, landslides are triggered by other events such as erosion at the toe of a steep slope, earthquakes, floods, or heavy rains, but can be worsened by human actions such as destruction of vegetation or uncontrolled pedestrian access on steep slopes (see Figure 7-56). An extreme example is Hurricane Mitch in 1998, where heavy rainfall led to flash flooding, numerous landslides, and an estimated 10,000 deaths in Nicaragua.

Figure 7-56
Unstable coastal bluff at Beacon's Beach, San Diego, California. Photograph by Lesley Ewing.

Coastal areas subject to landslide hazards are generally those with high relief and steep slopes, such as much of the west coast of the United States and portions of the Great Lakes shoreline (see Figure 7-57), Alaska, Hawaii, Puerto Rico, the U.S. Virgin Islands, Guam, and American Samoa (FEMA 1997b).

NOTE
Even small ground movements can be damaging to coastal buildings.

Although less spectacular, smaller, more subtle, and gradual movements of soil under or around residential buildings can also be destructive. These movements can be due to natural or development-induced factors, and can result in ground movements of just a few inches. For example, soil *creep* is the slow, downslope movement of overburden, usually in conjunction with subsurface drainage and slippage. Development on soils subject to creep may aggravate the problem. *Settlement* is the downward vertical movement of a building foundation or soil surface as a consequence of soil compression or lateral yielding. Creep, settlement, and other ground failures can occur in granular, cohesive, and rocky soils.

The El Niño-driven storms affecting the west coast of the United States during the winter of 1997-98 have provided ample evidence of the effects of landslides and ground failures on roads, infrastructure, and coastal construction. These failures and the resulting damage have been documented in the Seattle, Washington, area in Gerstel et al. (1997) and a series of community and state publications on stormwater erosion damage (Seattle

Department of Construction and Land Use 1996), erosion mitigation (King County Washington Conservation District), and vegetation management (Washington State Department of Ecology 1993a, 1993b). The publications document causes of and ways to prevent stormwater-induced slope failures. Prevention involves managing runoff, stabilizing slopes, maintaining ditches, and immediately repairing damaged areas.

Finally, coastal bluff failures can be induced by seismic activity. Griggs and Scholar (1997) detail bluff failures and damage to residential buildings resulting from the several earthquakes, including the March 1964 Alaska earthquake and the October 1989 Loma Prieta earthquake (see Figure 7-39). Coastal bluff failures were documented as much as 50 miles from the Loma Prieta epicenter and 125 miles from the Alaska earthquake epicenter. In both instances, houses and infrastructure were damaged and destroyed as a result of these failures. Buildings at the top and base of the bluffs were vulnerable to damage.

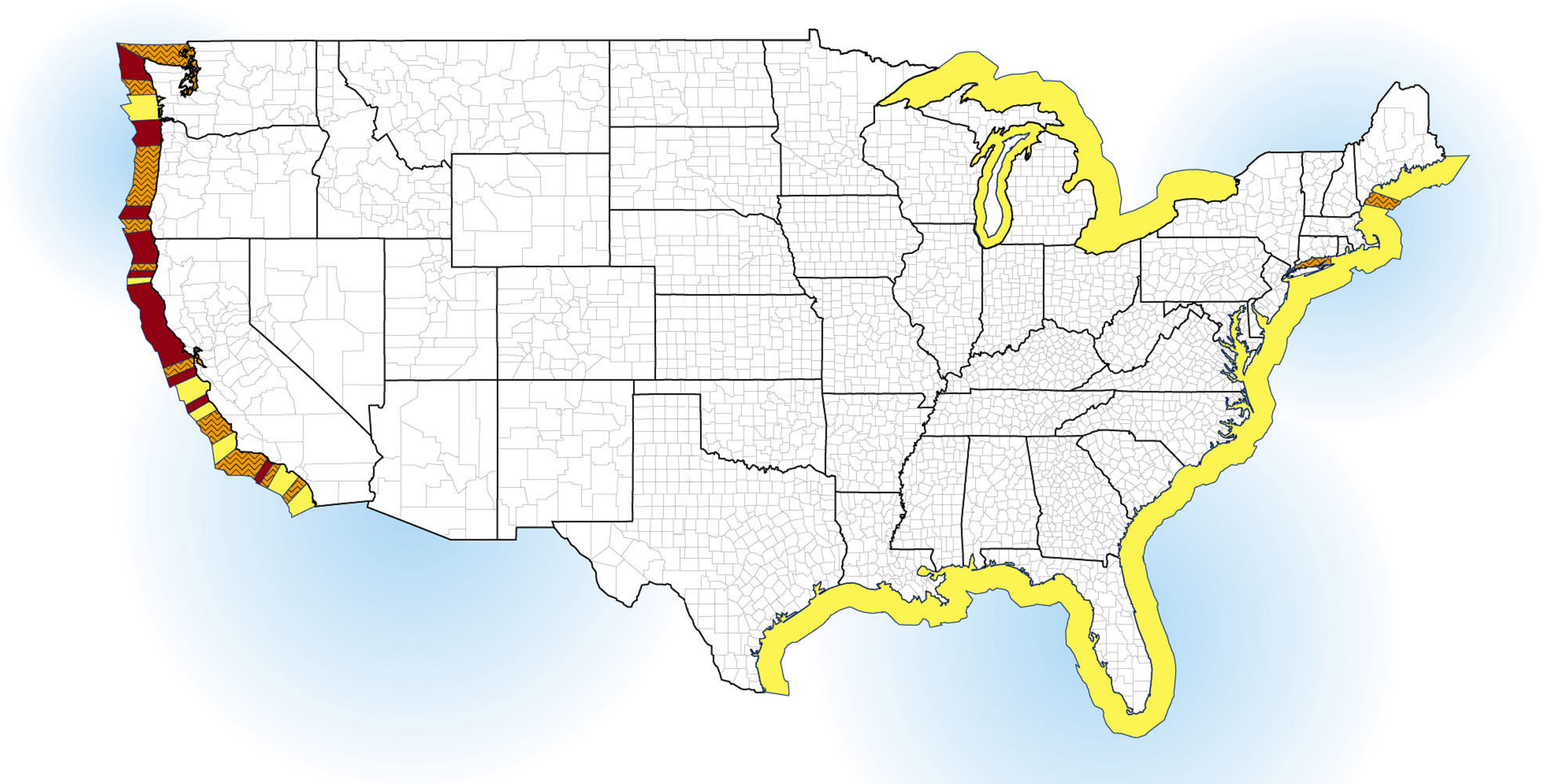
7.7.3 Salt Spray and Moisture

Salt spray and moisture effects frequently lead to corrosion and decay of building materials in the coastal environment. This is one hazard that is commonly overlooked or underestimated by designers. Any careful inspection of coastal buildings (even new or recent buildings) near a large body of water will reveal deterioration of improperly selected or installed materials.

CROSS-REFERENCE

See Section 14.2, in Chapter 14, for a discussion of salt spray and moisture effects.

Figure 7-57 Landslide incidence in the coterminous United States. Adapted from FEMA (1997b).



KEY

Landslide Incidence

- High
- Moderate
- Low

NOTE: Do not use this map for design purposes. It is intended only to show how the landslide hazard varies in the United States. For design information, consult local officials.

For example, metal connectors, straps, and clips used to improve a building's resistance to high winds and earthquakes will often show signs of corrosion (see Figure 7-58). Corrosion is affected by many factors, but the primary difference between coastal and inland areas is the presence of salt spray, tossed into the air by breaking waves and blown onto land by onshore winds. Salt spray accumulates on metal surfaces, accelerating the electrochemical processes that cause rusting and other forms of corrosion, particularly in the humid conditions common along the coast.

Figure 7-58
Example of corrosion, and resulting failure, of metal connectors. Photograph by Spencer Rogers.

CROSS-REFERENCE
See FEMA NFIP Technical Bulletin 8, in Appendix H, for more information about corrosion and corrosion-resistant connectors

Corrosion severity varies considerably from community to community along the coast, from building to building within a community, and even within an individual building. Factors affecting the rate of corrosion include humidity, wind direction and speed, seasonal wave conditions, distance from the shoreline, elevation above the ground, orientation of the building to the shoreline, rinsing by rainfall, shelter and air flow in and around the building, and the materials used to make the component. Information is available (e.g., FEMA 1996) to help designers understand the factors that influence corrosion near the shoreline.

7.7.4 Rain

Rain presents two principal hazards to coastal residential construction:

- penetration of the building envelope during high wind events (see Section 7.4.2, and
- vertical loads due to rainfall ponding on the roof

Ponding usually occurs on flat or low-slope roofs where a parapet or other building element causes rainfall to accumulate, and where the roof drainage system fails. Every inch of accumulated rainfall causes a downward-directed load of approximately 5 lb/ft^2. Excessive accumulation can lead to progressive deflection and instability of roof trusses and supports.

CROSS-REFERENCE

See Section 14.2, in Chapter 14, for a discussion of termite effects.

7.7.5 Hail

Hailstorms develop from severe thunderstorms, and generate balls or lumps of ice capable of damaging agricultural crops, buildings, and vehicles. Severe hailstorms can damage roofing shingles and tiles, metal roofs, roof sheathing, skylights, glazing, and other building components. Accumulation of hail on flat or low-slope roofs, like the accumulation of rainfall, can lead to significant vertical loads and progressive deflection of roof trusses and supports.

7.7.6 Wood Decay and Termites

Decay of wood products and infestation by *termites* are common in coastal areas subject to high humidity and frequent and heavy rains. Improper preservative treatments, improper design and construction, and even poor landscape practices, can all contribute to decay and infestation problems.

Protection against decay and termites can be accomplished by one or more of the following: use of pressure-treated wood products (including field treatment of notches, holes, and cut ends), use of naturally decay-resistant and termite-resistant wood species, chemical soil treatment, and installation of physical barriers to termites (e.g., metal or plastic termite shields).

7.7.7 Wildfire

Wildfires occur virtually everywhere in the United States and can threaten buildings constructed in coastal areas. Topography, the availability of vegetative fuel, and weather are the three principal factors that impact wildfire hazards. Reducing the wildfire hazard and the vulnerability of structures to wildfire hazards are discussed in several reports (Oregon Department of Forestry 1991; Doss 1995; and FEMA 1998).

Past experience with wildfires has shown one of the most effective ways of preventing loss of buildings to wildfire is to replace highly flammable vegetation around the buildings with minimally flammable vegetation. Clearing of vegetation around some buildings may be appropriate; however, this action can lead to slope stability and landslide failures on steeply sloping land. Siting and construction on steep slopes requires careful consideration of multiple hazards with sometimes conflicting requirements.

CROSS-REFERENCE

State Coastal Zone Management (CZM) programs (see Section 6.7, in Chapter 6) are a good source of hazard information, vulnerability analyses, mitigation plans, and other information about coastal hazards.

7.7.8 Floating Ice

Some coastal areas of the United States are vulnerable to problems caused by *floating ice.* These problems can take the form of erosion and gouging of coastal shorelines, flooding due to ice jams, and lateral and vertical ice loads on shore protection structures and coastal buildings. On the other hand, the presence of floating ice along some shorelines will reduce erosion from winter storms and wave effects. Designers should investigate potential adverse and beneficial effects of floating ice in the vicinity of their building site. Although this manual does not discuss these issues in detail, additional information can be found in the following references: Caldwell and Crissman (1983), Chen and Leidersdorf (1988), and USACE (1992).

7.7.9 Snow

The principal hazard associated with *snow* is its accumulation on roofs and the subsequent deflection and potential failure of roof trusses and supports. Calculation of snow loads is more complicated than rain loads, because snow can drift and be distributed non-uniformly across a roof. Drainage of trapped and melted snow, like the drainage of rain water, must be addressed by the designer.

7.7.10 Atmospheric Ice

Ice can sometimes form on structures as a result of certain atmospheric conditions or processes (e.g., freezing rain or drizzle or in-cloud icing—accumulation of ice as supercooled clouds or fog come into contact with a structure). The formation and accretion of this ice is termed *atmospheric ice*. Fortunately, typical coastal residential buildings are not considered ice-sensitive structures and are not subject to structural failures resulting from atmospheric ice. However, the use and occupation of coastal residential buildings may be affected by the failure of ice-sensitive structures (e.g., utility towers, utility lines, and similar structures).

7.8 Coastal Hazard Zones

Assessing risk to coastal buildings and building sites requires the identification or delineation of hazardous areas. This, in turn, requires that the following factors be considered:

- the types of hazards known to affect a region
- the geographic variations in hazard occurrence and severity
- the methods and assumptions underlying any existing hazard identification maps or products
- the concept of "acceptable level" of risk

- the consequences of employing (or not employing) certain siting, design, and construction practices

Geographic variations in coastal hazards occur, both along the coastline and relative (perpendicular) to the coastline. Hazards affecting one region of the country may not affect another; hazards affecting construction close to the shoreline will, usually, have a lesser effect (or no effect) farther inland. For example, Figure 7-59 shows how building damage caused by Hurricane Eloise in 1975 was greatest at the shoreline, but diminished rapidly in the inland direction. The damage pattern shown in Figure 7-59 is typical of storm damage patterns in most coastal areas.

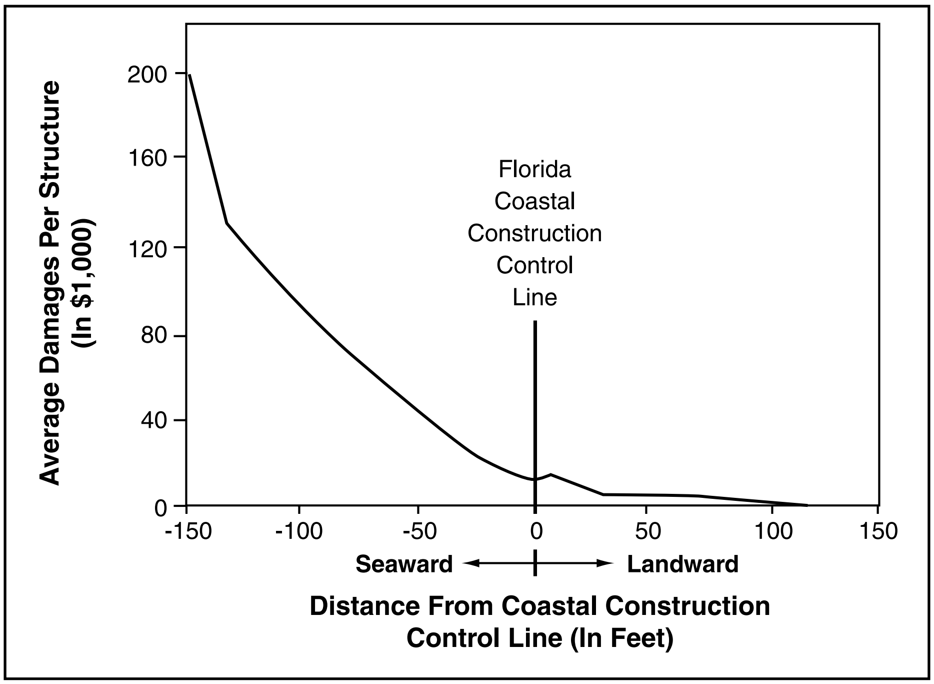


Figure 7-59
Hurricane Eloise, Bay County, Florida. Average damage per structure (in thousands of 1975 dollars) vs. distance from the Florida Coastal Construction Control Line (from Shows 1978).

FEMA, by virtue of its conducting Flood Insurance Studies (FISs) and producing FIRMs, provides reasonably detailed coastal flood hazard information (see Section 7.8.1). However, these products do not consider a number of other hazards affecting coastal areas. Other Federal agencies and some states and communities have completed additional coastal hazard studies and delineations; selected examples are described in Appendix G.

When reviewing the hazard maps and delineations in Appendix G, designers should be aware of the fact that coastal hazards are often mapped at different levels of risk. Thus, the concept of c*onsistent and acceptable level of risk* (the level of risk judged appropriate for a particular structure) should be considered early in the planning and design process (see Section 4.2, in Chapter 4).

7.8.1 NFIP Hazard Zones

Understanding the methods and assumptions underlying NFIP FISs and FIRMs will be useful to the designer, especially in the case where the effective FIRM for a site of interest is over a few years old, and where an updated flood hazard determination is desired.

FEMA relies upon four basic items in determining flood hazards at a given site:

- flood conditions (stillwater level [SWL] and wave conditions) during the base flood event
- shoreline type
- topographic and bathymetric information
- computer models to calculate flood hazard zones and BFEs

Current guidelines and standards for coastal flood hazard zone mapping along the Atlantic and Gulf of Mexico coasts are described in FEMA (1995) and summarized in Sparks et al. (1996). At the time this manual went to print, mapping procedures used for the Great Lakes coast did not call for the delineation of V zones; however, draft guidelines and standards for V-zone mapping along the Great Lakes coast had been developed, and guidelines and standards for V-zone mapping along the Pacific coast are under development.

7.8.1.1 Sources of Flooding Considered by the NFIP

FEMA currently considers five principal sources of coastal flooding to establish BFEs in coastal areas:

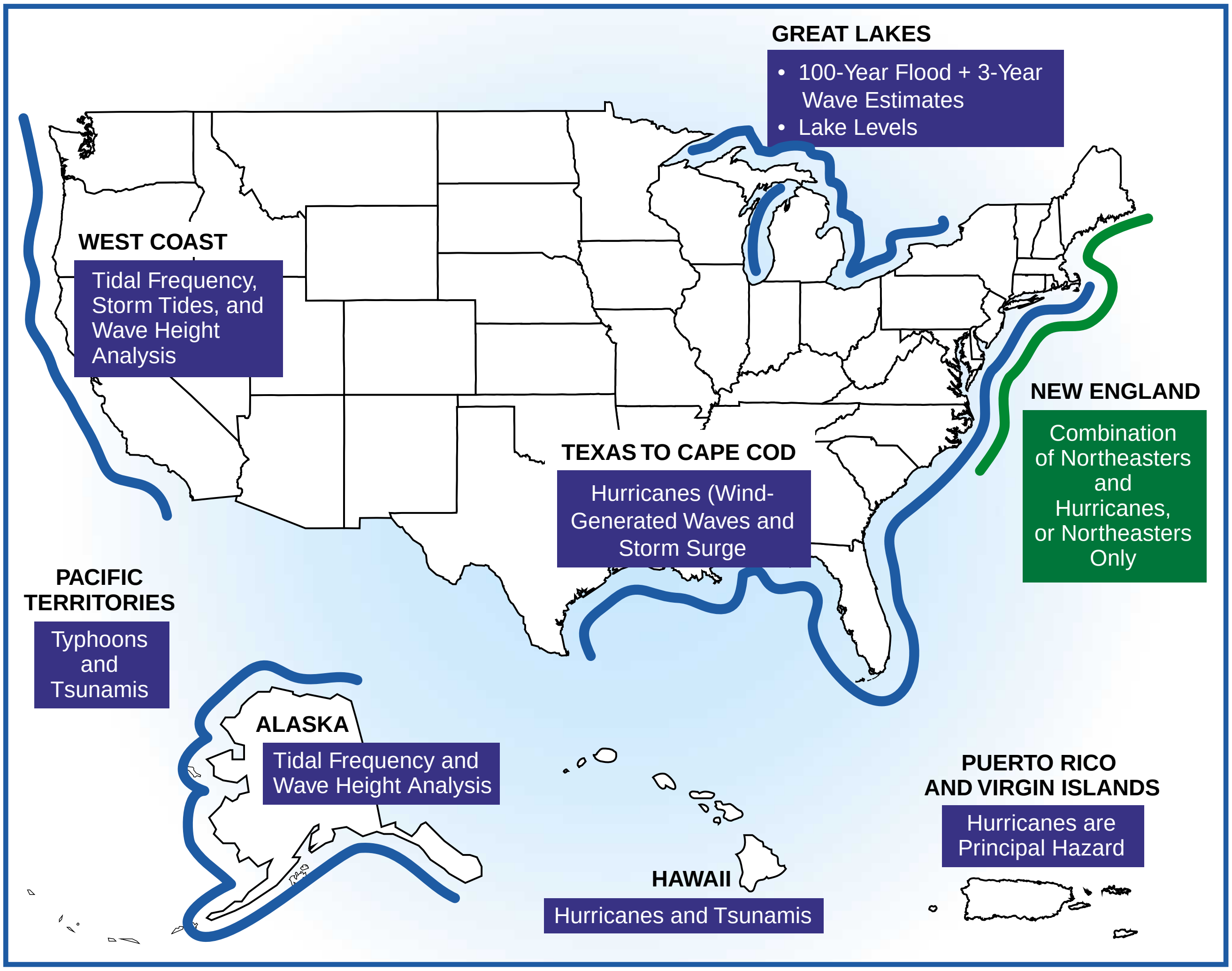
- tropical cyclones such as hurricanes and typhoons
- extratropical cyclones such as northeast storms
- tsunamis
- tidal frequency analysis
- lake levels (Great Lakes)

Figure 7-60 shows the flood sources used by FEMA to determine flood elevations along the Nation's coastline.

CROSS-REFERENCE

See Section 3.3 for a brief discussion of the determination of stillwater elevations.

Figure 7-60 BFE determination criteria for coastal hazard areas in the United States.



7.8.1.2 Models and Procedures Used by the NFIP to Establish Flood Hazard Zones

In addition to storm surge models (or other means of determining stillwater elevations), FEMA currently employs three distinct flood hazard delineation techniques in its FISs, depending on local conditions and expected flood effects: an erosion assessment procedure, a wave runup model, and a wave height transformation model (WHAFIS). Note that the erosion assessment used by FEMA accounts for storm-induced erosion and does *not* take long-term erosion into account. Table 7.7 shows which techniques are applied by FEMA to different shoreline types.

Table 7.7
FIS Model/Procedure Selection by Shoreline Type – Atlantic and Gulf of Mexico Coasts (modified from FEMA 1995)

Type of Shoreline	Model/Procedure To Be Applied		
	Erosion*	Runup*	WHAFIS*
Rocky bluffs		▲	▲
Sandy bluffs, little beach	▲	▲	▲
Sandy beach, small dunes	▲		▲
Sandy beach, large dunes	▲	▲	▲
Open wetlands			▲
Protected by rigid structure		▲	▲

* Variations of these models and procedures may be used for Great Lakes, New England, and Pacific Coasts.

NOTE

Information presented here regarding the applicability and use of FEMA models is provided as background. Designers should seek the assistance of qualified coastal engineers if a detailed or updated flood hazard analysis is needed at a site.

WARNING

Many FIRMs (especially those produced before approximately 1989) may understate present-day flood hazards. Before a FIRM is used for siting and design purposes, the accompanying FIS report should be reviewed to determine whether the study procedures used to produce the FIRM are consistent with the latest study procedures.

FEMA's application of the techniques follows the procedure illustrated in Figure 7-61 and summarized below:

1. Draw analysis transect(s) perpendicular to the shoreline at the site or region of interest.

2. Determine type of shoreline (e.g., rocky bluff, sandy beach, rigid structure—see Table 7.7) at each transect.

3. Along each transect, determine profile bathymetry (ground elevations below the waterline) and topography (ground elevations above the waterline).

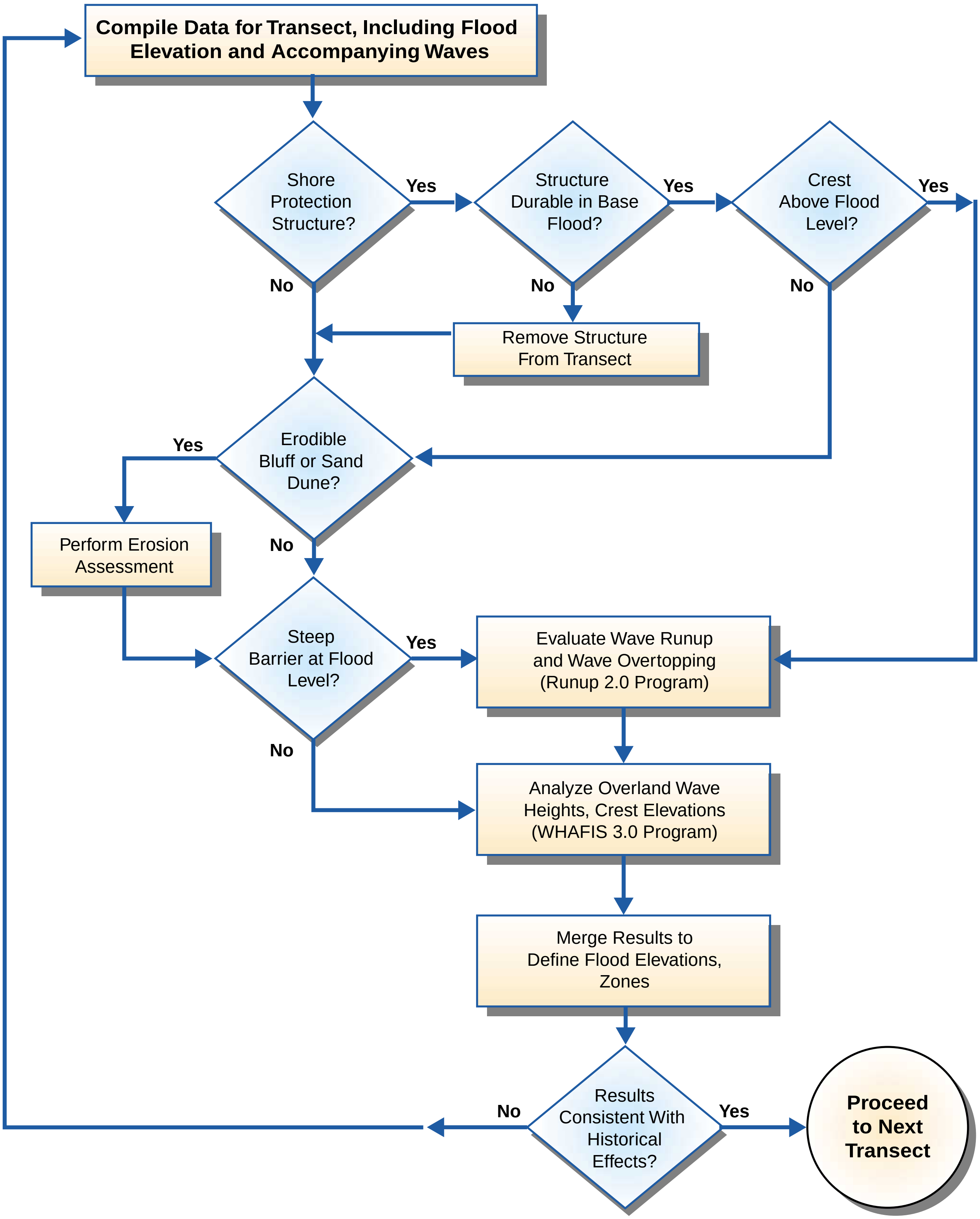
4. Determine the flood stillwater elevation and incident wave conditions during the base flood event.

5. If a shore protection structure is present on a transect, determine whether it has the structural capacity to survive the base flood event, and whether its crest elevation lies above the flood level (see Walton et al. 1989). If not, neglect the structure in further analyses. If so, apply the runup and WHAFIS models.

6. If no shore protection structure exists on the transect, or if the structure fails the tests described in step 5, determine whether the shoreline type is erodible. If not erodible, apply the Runup and WHAFIS models. If erodible, apply the erosion assessment procedure (see Section 7.8.1.4), then apply the runup and WHAFIS models on the eroded profile.

7. Determine BFEs along the transect(s) using the higher of the flood elevations calculated by the runup and WHAFIS models. Merge the results between transects to define flood hazard zones over the area of interest.

Figure 7-61 Procedural flowchart for defining coastal flood hazards (FEMA 1995).



7.8.1.3 Comments on FEMA's Coastal Flood Hazard Mapping Procedures and FIRMs

Designers are reminded that FEMA's flood hazard mapping procedures have evolved over the years. Thus, a FIRM produced today might differ from an earlier FIRM, not only because of physical changes at the site, but also because of changes in FEMA hazard zone definitions, revised models, and updated storm data. Major milestones in the evolution of FEMA flood hazard mapping procedures, which can render early FIRMs obsolete, are as follows:

- *Revised coastal water level and storm data*
  - In approximately 1979, a FEMA storm surge model replaced NOAA tide frequency data as the source of storm tide stillwater elevations for the Atlantic and Gulf of Mexico coasts.
  - In approximately 1988, coastal tide frequency data from the New England District of the USACE replaced earlier estimates of storm tide elevations for New England.
  - In approximately 1988, return periods for Great Lakes water levels from the Detroit District of the USACE replaced earlier estimates of lake level return periods.
  - Localized changes in flood elevations have been made as well. For example, following Hurricane Opal (1995), a revised analysis of historical storm tide data in the Florida panhandle raised 100-year stillwater flood elevations and BFEs several feet (Dewberry & Davis 1997b).
- *Changes in the BFE definition*
  - Prior to Hurricane Frederic in 1979, BFEs in coastal areas were set at the storm surge stillwater elevation, not at the wave crest elevation. Beginning in the early 1980s, FIRMs have been produced with V zones, using the WHAFIS model and the 3-foot wave height as the landward limit of V zones.
- *Changes in coastal flood hazard zone mapping procedures*
  - Beginning in approximately 1980, tsunami hazard zones on the Pacific coast have been mapped using procedures developed by the USACE. These procedures were revised in approximately 1995 for areas subject to both tsunami and hurricane effects.
  - Prior to May 1988, flood hazard mapping for the Atlantic and Gulf of Mexico coasts resulted in V-zone boundaries being drawn near the crest of the primary frontal dune, based solely on ground elevations and without regard for erosion that would occur during the base flood event. Changes in mapping procedures in May 1988 have accounted for storm-induced

dune erosion and have shifted many V-zone boundaries to the landward limit of primary frontal dune.

- FIRMs produced after approximately 1989 have used a revised WHAFIS model, a runup model, and wave setup considerations to map flood hazard zones.
- Beginning in approximately 1989, a Great Lakes wave runup methodology (developed by the Detroit District of the USACE and modified by FEMA) has been employed.
- Beginning in approximately 1989, a standardized procedure for evaluating coastal flood protection structures (Walton et al. 1989) has been employed.

NOTE

The storm erosion calculation procedures recommended in this manual differ from FEMA's current procedures in two important ways: by (1) increasing the dune reservoir volume required to prevent dune removal and (2) accounting for future shoreline erosion.

7.8.1.4 Comments on FEMA's Erosion Assessment Procedure

FEMA's dune erosion assessment procedure is based in large part on studies by Hallermeier and Rhodes (1986) and Dewberry & Davis (1989). These studies found that the volume of sediment contained in the dune or bluff above the 100-year storm tide SWL is a key parameter in predicting the degree of storm-induced erosion. In the case of dunes, this volume of sediment is termed the "frontal dune reservoir" (see Figure 7-62).

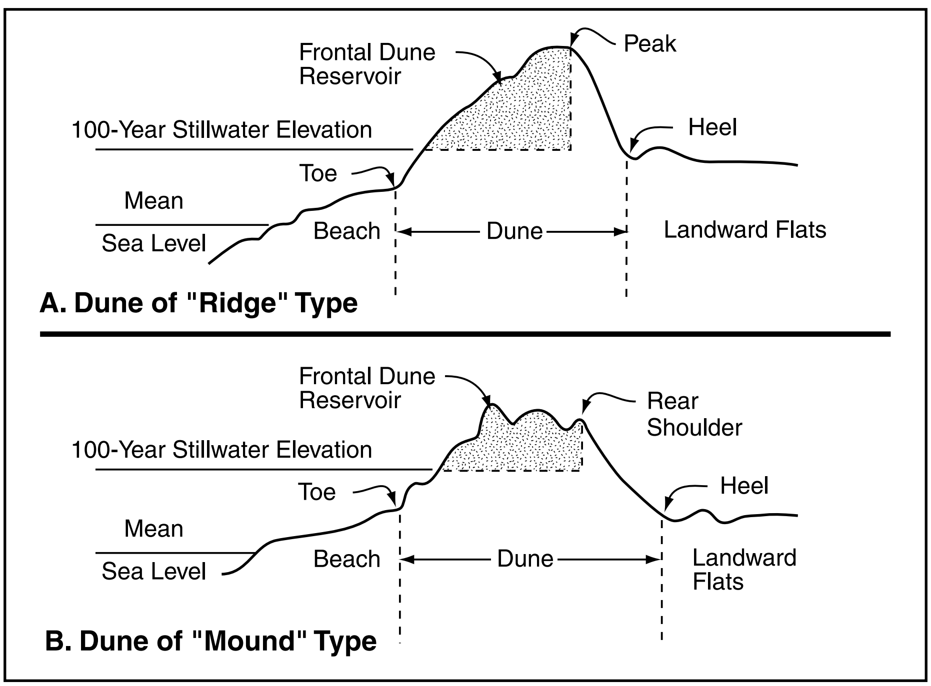


Figure 7-62
Definition sketch for frontal dune reservoir (from FEMA 1995)

NOTE

For beach/dune areas, this manual considers **frontal dune reservoir volume** the single most important parameter used to estimate post-storm eroded profile shapes and elevations.

The studies found the *median* dune erosion volume above the 100-year SWL was 540 ft^2 per linear foot of dune, with significant variability about the median value. Other investigators (Chiu 1977, USACE 1984, Savage and Birkemeier 1987, and Birkemeier et al. 1988) also found wide variability in above-SWL erosion volumes from one location to another—generally, the maximum erosion volume was found to range from 1.5 to 6.6 times the median volume.

DEFINITION

Current NFIP regulations define the **Coastal High Hazard Area (V zone)** as an area of special flood hazard extending from offshore to the inland limit of a primary frontal dune along an open coast and any other area subject to high-velocity wave action from storms or seismic sources.

FEMA's current V-zone mapping procedures (FEMA 1995) require that a dune have a minimum **frontal dune reservoir** of 540 ft^2 (i.e., the *median* erosion volume discussed above) in order to be considered substantial enough to withstand erosion during a base flood event. According to FEMA's procedures, a frontal dune reservoir less than 540 ft^2 will result in dune removal (dune disintegration), while a frontal dune reservoir greater than or equal to 540 ft^2 will result in dune retreat (see Figure 7-63). Note that FEMA also considers the **dune origin and condition** in its assessment. If the dune being evaluated was artificially constructed and does not have a well-established and long-standing vegetative cover, dune removal will be assumed even in cases where the frontal dune reservoir exceeds 540 ft^2.

FEMA's current procedure for calculating the post-storm profile in the case of dune removal is relatively simple: a straight line is drawn from the pre-storm dune toe landward at an upward slope of 1 on 50 (vertical to horizontal) until it intersects the pre-storm topography landward of the dune (see Figure 7-63). Any sediment above the line is assumed to be eroded.

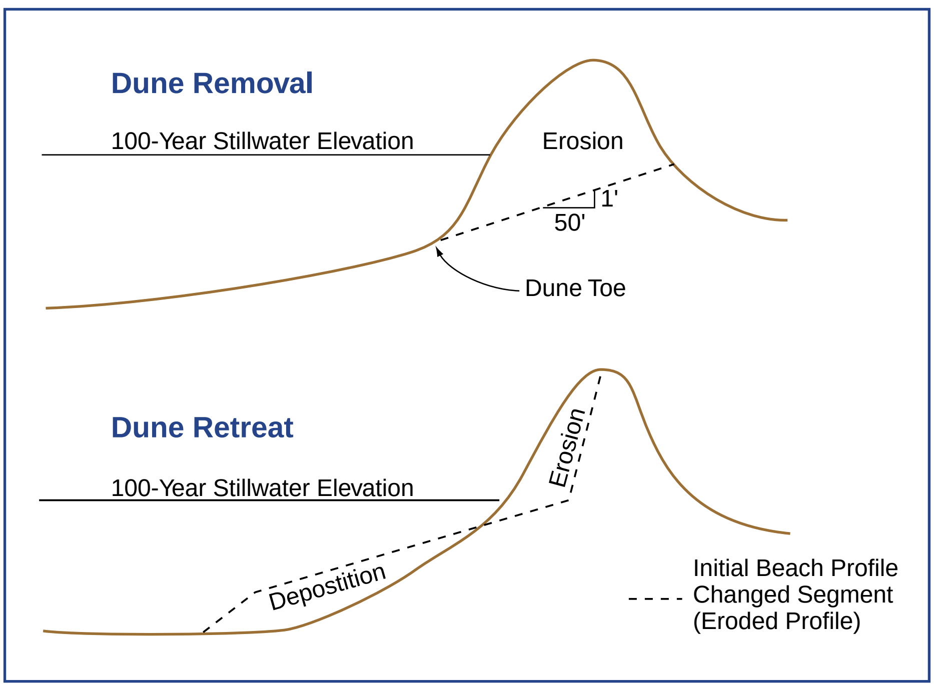


Figure 7-63
Current FEMA treatment of dune retreat and dune removal (from FEMA 1995).

This manual recommends that the size of the frontal dune reservoir used by designers to prevent dune removal during a 100-year storm be increased to 1,100 ft^2 (see Figure 7-64). This recommendation is made for three reasons: (1) FEMA's 540 ft^2 rule reflects dune size at the time of mapping and does not account for future conditions, when beaches and dunes may be compromised by long-term erosion, (2) FEMA's 540 ft^2 rule does not account for the cumulative effects of multiple storms that may occur within short periods of time, such as occurred in 1996, when Hurricanes Bertha and Fran struck the North Carolina coast within 2 months of each other (see Figure 5-5 in Chapter 5), and (3) even absent long-term erosion and multiple storms, use of the median frontal dune reservoir will underestimate dune erosion 50 percent of the time.

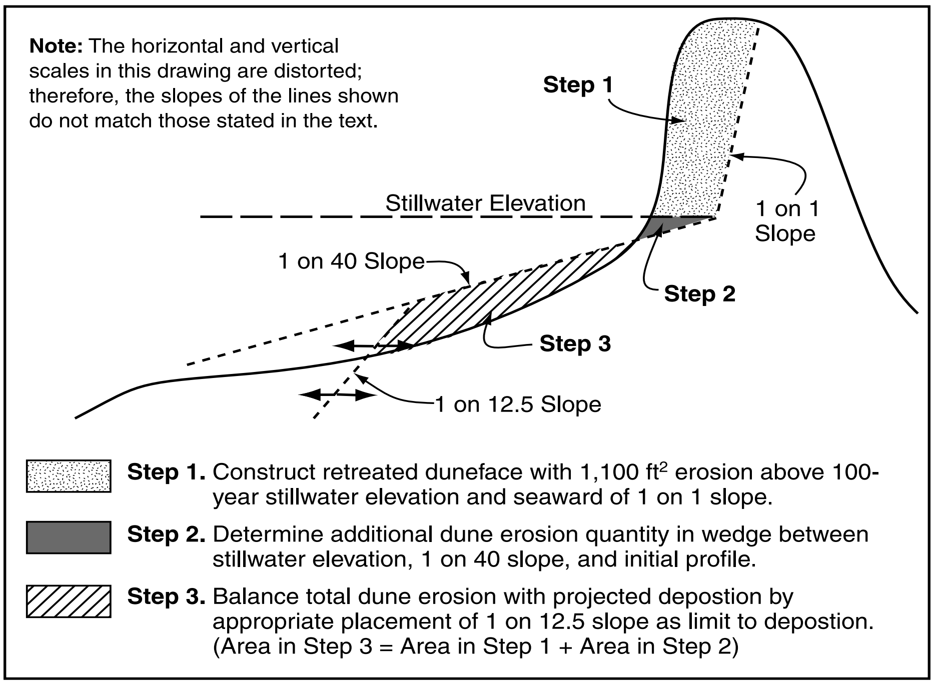


Figure 7-64
Procedure recommended by this manual for calculating dune retreat profile (modified from FEMA 1995).

Moreover, present day beach and dune topography alone should not be used to determine whether dune retreat or dune removal will occur at a site. **The most landward shoreline and beach/dune profile expected over the lifetime of a building or development should be calculated and used as the basis for dune retreat/dune removal determinations**. The most landward shoreline should be based on long-term erosion and observed shoreline fluctuations at the site (see Sections 7.5.2.2 through 7.5.2.4).

Finally, dune erosion calculations at a site should also take ***dune condition*** into account. A dune that is not covered by well-established vegetation (i.e., vegetation that has been in place for two or more growing seasons) will be more vulnerable to wind and flood damage than one with well-established vegetation. A dune crossed by a road or pedestrian path will offer a weak point that storm waves and flooding will exploit. Post-storm damage inspections frequently show that dunes are breached at these weak points and that structures landward of them are more vulnerable to erosion and flood damage (see Figure 7-44).

7.8.2 Examples of State and Community Coastal Hazard Zone Delineation

Appendix G provides introductory information concerning over 25 hazard zone delineations developed by or for individual communities or states. Some, but not all, of these delineations have been incorporated into mandatory siting and/or construction requirements.

7.8.3 Other Risk Assessment Approaches

Chapter 25 of the *Multi-Hazard Identification and Risk Assessment* report (FEMA 1997b) describes a number of other approaches to identifying and evaluating natural hazards, including the following:

- Risk Matrix Approach
- Composite Exposure Indicator Approach
- Multiple Coastal Hazard Assessment Approach
- Multiple Hazard (Seismic-Hydrologic) Approach

7.9 Translating Hazard Information into Practice

This chapter has presented a wide variety of hazard information. The question to be answered then, is ***how can a designer put it to use?***

- At a minimum, the most up-to-date published hazard data should be collected and used to assess the vulnerability of a site, following the steps outlined in Section 5.4.
- In instances where there is reason to believe that physical site conditions have changed significantly over time, or that published hazard data are obsolete or not representative of a site, an updated or more detailed a hazard assessment should be conducted.
- In instances where there is reason to believe that physical site conditions *will* change significantly over the expected life of a structure or development at the site, a revised hazard assessment should be conducted.
- After a suitable hazard assessment is completed, the designer should review siting and design options available to address and mitigate those hazards.

The remainder of this section focuses on procedures by which updated or more detailed flood hazard assessments (which may include erosion hazards) can be completed and applied. Similar procedures could be employed for other hazards.

7.9.1 Is an Updated or a More Detailed Flood Hazard Assessment Needed?

Two initial questions will drive the decision to update or complete a more detailed flood hazard massessment:

1. *Does the FIRM accurately depict present flood hazards at the site of interest?*
2. *Will expected shoreline erosion render the flood hazard zones shown on the FIRM obsolete during the projected life of the building or development at the site?*

The first question can be answered with a brief review of the FIRM, the accompanying FIS report, and site conditions. The answer to the second question depends upon whether or not the site is experiencing long-term shoreline erosion. If the shoreline at the site is stable and does not experience long-term erosion, then the FIRM will not require revision for erosion considerations. However, because FIRMs are currently produced without regard to long-term erosion, if a shoreline fluctuates or experiences long-term erosion, the FIRM will cease to provide the best available data at some point in the future (if it has not already) and a revised flood hazard assessment will be required.

It should be noted that updated and revised flood hazard assessments are discussed with siting and design purposes in mind, not in the context of official changes to FIRMs that have been adopted by local communities. The official map change process is a separate issue that will not be addressed by this manual. Moreover, some siting and design recommendations contained in this manual exceed minimum NFIP requirements, and are not tied to a community's adopted FIRM.

7.9.1.1 Does the FIRM Accurately Depict Present Flood Hazards?

In order to determine whether a FIRM represents current flood hazards, and whether an updated or more detailed flood hazard assessment is required, the following steps should be carried out:

- Obtain copies of the latest FIRM and FIS report for a site of interest. If the effective date precedes the milestones listed in Section 7.8.1.3, an updated flood hazard assessment may be required.
- Review the Legend on the FIRM to determine the history of the panel (and revisions to it), and review the study methods described in the

WARNING

Some sites lie outside flood hazard areas shown on FIRMs, but may be subject to current or future flood and erosion hazards. These sites, like those within mapped flood hazard areas, should be evaluated carefully.

FIS. If the revisions and study methods are not consistent with current study methods, an updated flood hazard assessment may be required.

- If the FIS calculated dune erosion using the 540 ft^2 criterion (see Section 7.8.1.4) and placed the V zone boundary on top of the dune, check the dune cross-section to see if it has a frontal dune reservoir of at least 1,100 ft^2 above the 100-year SWL. If not, consider shifting the V zone boundary to the landward limit of the dune and revising other flood hazard zones, as needed.
- Review the description in the FIS report of the storm, water level, and flood source data used in the FIS to generate the 100-year stillwater elevation and BFEs. If significant storms or flood events have affected the area since the FIS report and FIRM were completed, the source data may need to be revised and an updated flood hazard assessment may be required.
- Determine whether there have been significant physical changes to the site since the FIS and FIRM were completed (e.g., erosion of dunes, bluffs, or other features; modifications to drainage, groundwater, or vegetation on coastal bluffs; construction or removal of shore protection structures; filling or excavation of the site). If there has been significant change in the physical configuration and condition since the FIS and FIRM were completed, an updated and more detailed flood hazard assessment may be required.
- Determine whether there has been significant alteration of adjacent properties since the FIS and FIRM were completed (e.g., development, construction, excavation, etc. that could affect, concentrate, or redirect flood hazards on the site of interest). If so, an updated and more detailed flood hazard assessment may be required.

NOTE

Designers can easily determine the date of the effective (i.e., newest) FIRM for a community. The list is presented on FEMA's website under the heading "Community Status Book," at http://www.FEMA.gov/FEMA/CSB.htm.

NOTE

Where a new FIRM exists (i.e., one based upon the most recent FEMA study procedures and topographic data), long-term erosion considerations can be approximated by shifting all flood hazard zones landward a distance equal to the long-term annual erosion rate multiplied the life of the building or development (use 50 years as the minimum life). The shift in the flood hazard zones results from a landward shift of the profile (see Figure 7-67).

7.9.1.2 Will Long-Term Erosion Render a FIRM Obsolete?

In order to determine whether a FIRM is likely to become obsolete as a result of long-term erosion considerations, and whether a revised flood hazard assessment is required, the following steps should be carried out:

- Check with local or state coastal zone management agencies for any information on long-term erosion rates or construction setback lines. If such rates have been calculated, or if construction setback lines have been established from historical shoreline changes, long-term erosion considerations may require a revised flood hazard assessment.
- In cases where no long-term erosion rates have been published, and where no construction setback lines have been established based on historical shoreline movements, determine whether the current shoreline has remained in the same approximate location as that shown

on the FIRM (e.g., has there been any significant shoreline erosion, accretion, or fluctuation?—See Sections 7.5.2.2 to 7.5.2.4). If there has been significant change in the shoreline location or orientation since the FIS and FIRM were completed, the local floodplain administrator should require a revised flood hazard assessment.

7.9.2 Updated or Revised Flood Hazard Assessments

Updating or revising an existing flood hazard assessment—for siting and design purposes—can be fairly simple or highly complex, depending upon the particular situation. A simple change may involve shifting an A zone or X zone boundary, based upon topographic data better than those used to generate the FIRM. A complex change may involve a detailed erosion assessment and significant changes to mapped flood hazard zones.

Remember, the analyses should be directed at defining three important parameters:

- the most landward shoreline location expected during the life of a building or development
- the lowest expected ground elevation at the base of a building during its life
- the highest expected BFE at the building during its life, and associated flood forces

If an assessment requires recalculation of local flood depths and wave conditions on a site, the FEMA models (Erosion, Runup, and WHAFIS) can be run at the site (bearing in mind the recommended change to the required dune reservoir to prevent dune loss—see Section 7.8.1.4).

If an assessment requires careful consideration of shoreline erosion, the checklist, flowchart, and diagram shown in Figures 7-65, 7-66, and 7-67 can serve as a guide, but a qualified coastal professional should be consulted. It should be pointed out that much of the information and analyses described in the checklist and flowchart has probably been developed and carried out previously by others, and should be available in reports about the area—check with the community. Cases where information is unavailable and where at least basic analyses have not been completed will be rare.

The final result should be a determination of the greatest flood hazards, resulting from a 100-year coastal flood event, that the site will be exposed to over the anticipated life of a building or development. The determination should account for short- and long-term erosion, bluff stability, shoreline fluctuations, and storm-induced erosion; in other words, both chronic and catastrophic flood and erosion hazards should be considered.

NOTE

Models used by FEMA's FIS contractors (Erosion, Runup, WHAFIS) are available for use by others. However, those persons completing updated or revised flood hazard assessments are advised to obtain the assistance of an experienced coastal professional. FEMA has also issued its Coastal Hazard Modeling Program (CHAMP) to facilitate the use of standard FEMA models for flood hazard mapping.

NOTE

Additional guidance for flood and erosion hazard assessments for Great Lakes shorelines can be obtained from the web site of the University of Wisconsin Sea Grant Program (http://www.seagrant.wisc.edu/advisory/Coastal_engr/).

Figure 7-65 Erosion hazard checklist. (See Appendix F for sources of information.)

General Information

- property location and dimensions
- land use at site and adjacent properties
- historical flood and erosion damage descriptions at site and nearby

Coastal Flood Conditions – Observed and Predicted

- flood elevations due to tides, storm surge, tsunami, or seiche
- wave conditions at shoreline (height, period, direction)
- erosion of beach, dune, and/or bluff
- sediment overwash
- breaching or inlet formation

Local Soils and Geology

- soils, geology, and vegetation – site and region
- site drainage – potential for erosion from surface water or groundwater
- coastal morphology and coastal processes
- wave climate
- presence and influence of nearby inlets, harbors, coastal structures
- littoral sediment supply and sediment budget
- topography of nearshore, beach, dune, bluff, uplands
- relative sea-level changes or lake-level changes – land subsidence or uplift

Shoreline History

- shoreline change maps and historical aerial photographs
- published erosion rates – long-term and short-term
- spatial variability in erosion rates
- temporal variability in erosion rates (seasonal, annual, long-term)
- erosion/accretion cycles – magnitude and periodicity
- most landward historical shoreline (most landward shoreline in past 50-70 years)
- errors and uncertainties associated with erosion rates

Harbor/Inlet Navigation Projects; Erosion Control Projects

- navigation projects (jetties, dredged channels) affecting site
- shore protection structures, on property or nearby
- dune/bluff stabilization projects, on property or nearby
- beach/dune nourishment projects – completed or planned

Other Erosion/Sediment Considerations

- erosion by wind
- erosion by ice
- burial by storm overwash or windborne sand
- erosion due to channeling of flow between buildings or obstructions
- local scour potential and presence of terminating strata

Determine the Most Landward Expected Shoreline Location Over the Anticipated Life of the Building or Development

- Use published or calculated long-term erosion rate (ft/yr), increasing the rate to account for errors and uncertainty. It is recommended that a minimum rate of 1.0 ft/yr be used unless durable shore protection or erosion-resistant soil is present.
- Multiply the resulting erosion rate by the building or development lifetime (years) to compute the long-term erosion distance (ft). Use a minimum lifetime of 50 years.
- Measure landward (from the most landward historical shoreline) a distance equal to the long-term erosion distance – this will define the most landward expected shoreline.

↓

Determine the Lowest Expected Ground Elevation at the Base of the Building or Structure

- Beginning with the most landward expected shoreline location:
  - calculate an eroded dune profile using a storm erosion model, or
  - calculate a stable bluff profile using available guidance and data

↓

Determine the Highest Expected BFE at the Base of the Building or Structure

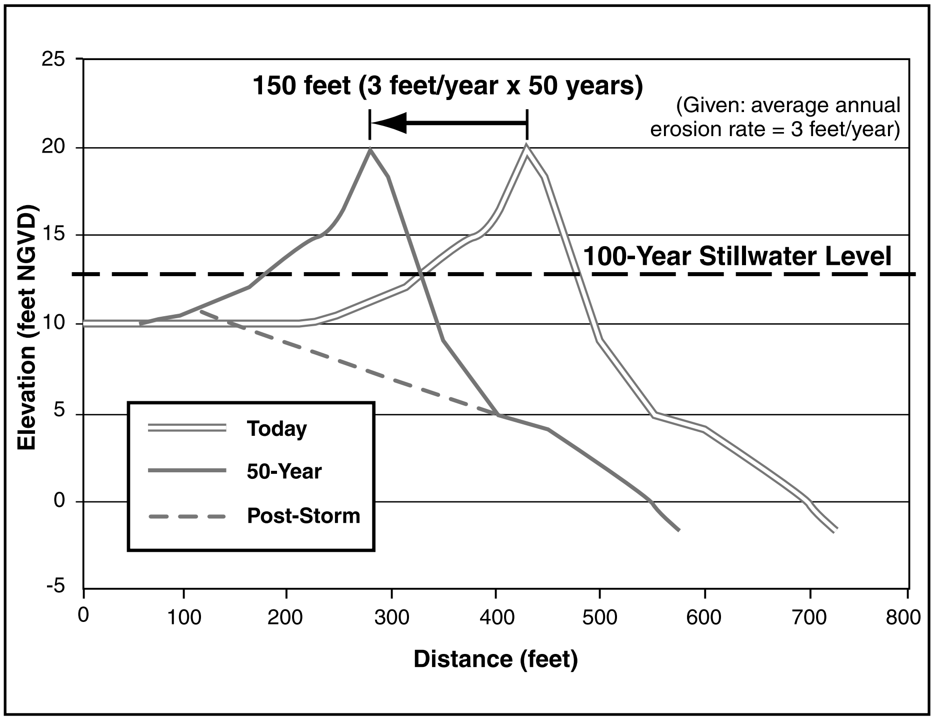
- Beginning with the eroded dune or stable bluff profile, apply Runup and WHAFIS to determine BFEs
- Calculate water depths, and compute anticipated flood forces using the methods in Section 11.6

Figure 7-66
Flowchart for estimating maximum likely flood hazards at a site over the life of a building or development.

CROSS-REFERENCE

See Figure 7-67 for an example of how an erosion assessment can incorporate the effects of long-term erosion and storm-induced erosion to determine the lowest expected ground elevation at a site.

Figure 7-67
Accounting for future shoreline erosion: shift the present-day profile landward (to account for long-term or inlet erosion), then apply the Primary Frontal Dune erosion assessment to estimate the lowest expected ground elevation at a site. This procedure also results in a landward translation of flood hazard zones.



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