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Chapter 1: Introduction

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Introduction

1.1 Background

The Federal Emergency Management Agency (FEMA) first published the *Coastal Construction Manual* (FEMA-55) in 1981. The manual was updated in 1986 and has provided guidance to public officials, designers, architects, engineers, and contractors for over a decade. In that time, however, construction practices and materials have changed, and more information on hazards and building performance has been developed. There has also been an explosion in coastal development, leading to greater numbers of structures at risk. Many of the residential buildings being constructed today are larger and more valuable than those of the past, leading to the potential for larger economic losses when disasters strike. The increase in coastal development has also brought about greater use of sites located in areas where the risk is higher, such as lots closer to the ocean, lots on high bluffs subject to erosion, or lots artificially created on fill deposits.

Regulatory requirements have also expanded over the past decade. More communities require compliance with model building codes. More states and communities, in implementing the Coastal Zone Management Act, have instituted construction setbacks and coastal resource protection programs. More jurisdictions require geotechnical studies and certifications from design professionals for construction along the coastline. Finally, more communities participate in the **National Flood Insurance Program** (NFIP), which requires, among other things, that plans for new buildings constructed in a **Coastal High Hazard Area** be certified by a design professional.

CROSS-REFERENCE

The **National Flood Insurance Program** is discussed in Chapter 6, Section 6.4. **Coastal High Hazard Area** (or V zone) is explained on page 1-6 of this Chapter. Both terms are also defined in Appendix B, in Volume III of this manual.

Investigations conducted by FEMA and other organizations after major coastal disasters have consistently shown that properly sited, well-designed, and well-constructed coastal residential buildings generally perform well. This updated *Coastal Construction Manual*—prepared by FEMA with assistance from other agencies, organizations, and professionals involved in coastal construction and regulation—is intended to help the designer, contractor, and community official identify and evaluate practices that will improve the quality of construction and reduce the economic losses associated with coastal disasters.

1.2 Purpose

This manual provides guidance for the design and construction of coastal residential buildings that will be more resistant to the damaging effects of natural hazards. The focus is on new residential buildings—principally detached single-family, attached single-family (townhouses), and low-rise (three-story or less) multi-family buildings. Discussions, examples, and example problems are provided for buildings located in or near coastal flood hazard areas, in a variety of coastal environments and subject to high winds, flooding, seismic activity, erosion, and other hazards.

This manual will be of assistance to all persons involved in the design and construction of one- to three-story residential buildings in coastal areas of the United States and its territories. Contractors, designers, architects, engineers, and building officials can apply the information presented in this manual as they strive to site and construct disaster-resistant housing.

One objective of this manual is to highlight the many tasks and decisions that must be made before actual construction begins. These tasks include, but may not be limited to, the following:

- evaluating the suitability of coastal lands for residential construction
- planning for development of raw land, and for infill or redevelopment of previously developed land
- identifying regulatory, environmental, and other constraints on construction or development
- evaluating site-specific hazards and loads at a building site
- evaluating techniques to mitigate hazards and reduce loads
- identifying risk, insurance, and financial implications of siting, design, and construction decisions

A second objective of this manual is to identify the best design and construction practices that can be used to build disaster-resistant structures. As a result, the manual will at times recommend and advocate techniques that exceed the minimum requirements of model building codes, design and construction standards, or Federal, state, and local regulations. However, the authors of the manual are aware of the implications of such recommendations, and make them on the basis of a careful review of building practices and subsequent building performance.

The construction and design techniques included in this manual are based on a comprehensive evaluation of:

- coastal residential buildings, both existing and under construction,
- siting, design, and construction practices employed along the U.S. coastlines,
- various building, floodplain management, and other codes and standards applicable to coastal construction, and
- the performance of coastal buildings, based on post-disaster field investigations.

The manual first provides a history of coastal disasters in the United States, an overview of the U.S. coastal environment, and fundamental considerations for constructing a building in a coastal region. The manual provides information on every step in the process of constructing a home, from evaluating potential sites, to selecting a site, to locating, designing, and constructing the building, to insuring and maintaining the building (see Figure 1-1). Flowcharts, checklists, maps, formulas, and details are provided throughout the manual to help the reader understand the entire process. In addition, example problems are presented to demonstrate decisions and calculations designers must make to reduce the potential for damage to the building from natural hazard events.

The manual also includes numerous examples of siting, design, and construction practices—both good and bad—to illustrate the results and ramifications of those practices. The intent is twofold: (1) to highlight the benefits of practices that have been employed successfully by communities, designers, or contractors, and (2) to warn against practices that have resulted in otherwise avoidable damage or loss of coastal residential buildings.

1.3 Organization

Because of its size, the manual is divided into three volumes, with 14 chapters and appendixes as follows:

Volume I

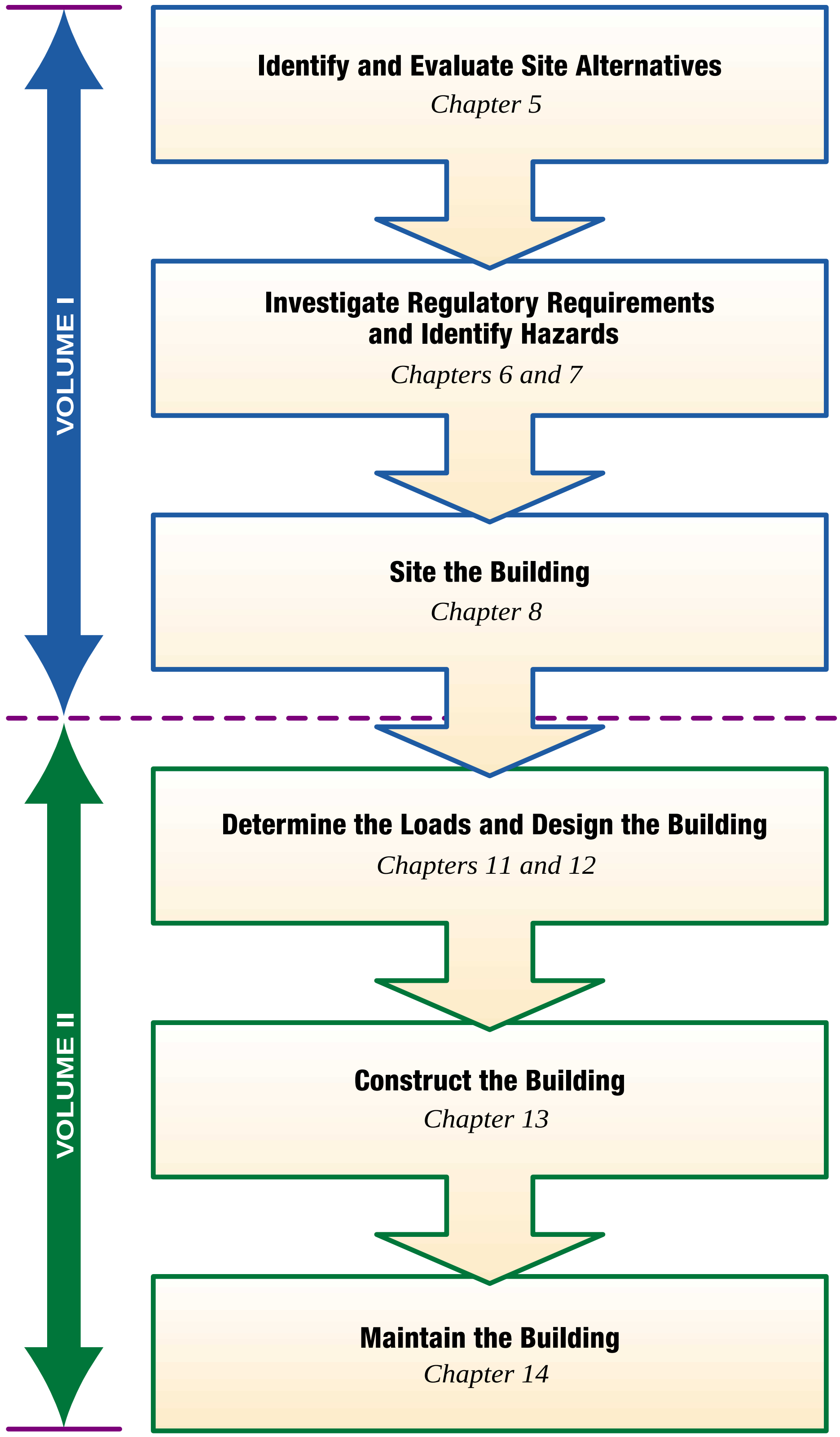
Chapter 1– Introduction. This chapter describes the purpose of the manual, provides an overview of the manual's contents and organization, and explains how icons and summary tables are used throughout the manual to guide and advise the reader.

Chapter 2 – Historical Perspective. This chapter provides short summaries of selected coastal flood events, including findings of post-event evaluations, and it documents the causes and types of damage associated with storms and tsunamis ranging from the 1900 hurricane that struck Galveston, Texas, to Hurricane Georges, which struck Puerto Rico and the U.S. Gulf coast in September 1998.

Chapter 3 – Coastal Environment. This chapter provides an introduction to coastal processes, coastal geomorphology, and coastal hazards. Regional variations for the Great Lakes, north Atlantic, middle Atlantic, south Atlantic, Gulf of Mexico, Pacific, Alaska, Hawaii, and U.S. territories are discussed.

Chapter 4 – Fundamentals. This chapter provides an overview of acceptable levels of risk; tradeoffs in decisions concerning siting, design, construction, and maintenance; and cost and insurance implications that need to be considered in coastal construction.

Figure 1-1
General process flowchart for coastal construction.



NOTE

The chapters not listed in Figure 1-1 provide general information that supports the process illustrated in the figure. See pages 1-3, 1-5, and 1-6 for descriptions of all chapters in the manual.

Chapter 5 – Identifying and Evaluating Site Alternatives. Detailed discussions of the coastal construction process begin in this chapter, which presents information on which to base the selection of a site for a coastal residential building.

Chapter 6 – Investigating Regulatory Requirements. This chapter presents an overview of building codes and Federal, state, and local regulations, including the NFIP, Coastal Barrier Resources Act, and Coastal Zone Management programs, which may affect construction on a coastal building site.

Chapter 7 – Identifying Hazards. This chapter provides information about hazards that will influence the design and construction of a coastal building, including coastal storms, erosion, tsunamis, and earthquakes, and their effects.

Chapter 8 – Siting. This chapter describes the factors that should be considered in the selection of building sites, including small parcels within already developed areas, large parcels of undeveloped land, and redevelopment sites. Also provided is guidance that will assist designers and contractors in determining how a building should be placed on a site.

Chapter 9 – Financial and Insurance Implications. This chapter includes explanations of short-term and lifecycle costs associated with alternative decisions regarding siting, design, and construction. Included is a discussion of different types of hazard insurance and the effects that decisions regarding where and how to build have on insurance purchase requirements and rates, including premium discounts.

Volume II

Chapter 10 – Introduction to Volume II.

Chapter 11 – Determining Site-Specific Loads. This chapter provides information on calculating site-specific loads, including loads from high winds, flooding, seismic events, and tsunamis, as well as combinations of more than one load.

Chapter 12 – Designing the Building. This chapter provides designers and builders with information needed to design each part of a building to withstand the expected loads. Topics covered include structural failure modes, load paths, building systems, application of loads, structural connections, the building envelope, utilities, and appurtenant structures.

Chapter 13 – Constructing the Building. This chapter provides information needed to properly construct a building in a coastal area. Information is provided on ways to avoid common construction mistakes that may lessen the ability of a building to withstand a natural disaster.

Chapter 14 – Maintaining the Building. This chapter explains special maintenance concerns for new and existing buildings in coastal areas. Methods to reduce damage from corrosion, rot, fatigue, and weathering are provided along with descriptions of building elements that require frequent maintenance.

Volume III

Volume III contains the appendixes referred to in Volumes I and II.

1.4 Using the Manual

As discussed in Chapter 3 of this manual, the NFIP flood insurance zone designations shown on **Flood Insurance Rate Maps** (FIRMs) issued by FEMA indicate the nature and magnitude of the flood hazard in a given area. As explained in Chapter 6, communities who participate in the NFIP use these insurance zone designations to regulate construction in identified **Special Flood Hazard Areas** (SFHAs) – areas subject to inundation by a flood that has a 1-percent probability of being equaled or exceeded in any given year (also referred to as the base flood). The flood elevation associated with the SFHA is termed the **Base Flood Elevation** (BFE).

CROSS-REFERENCE

Flood Insurance Rate Maps (FIRMs) are discussed in Chapters 3 and 6 of this manual.

This manual uses the term BFE when it discusses NFIP elevation requirements, but introduces the term **Design Flood Elevation** (DFE) to account for situations where communities choose to enforce floodplain management requirements more stringent than those of the NFIP. For example, many communities require **freeboard** above the BFE, and some regulate to more severe flood conditions. Where a community chooses to exceed NFIP minimum requirements, the DFE will be higher than the BFE. Where a community's requirements are the same as the NFIP requirements, the DFE and BFE will be identical.

DEFINITION

Under the NFIP, **freeboard** is a factor of safety, usually expressed in feet above flood level, that is applied for the purposes of floodplain management. Freeboard tends to compensate for the many unknown factors that could contribute to flood heights greater than those calculated for a selected flood, such as the base flood.

Currently, the NFIP uses two categories of zones to differentiate between flood hazards in SFHAs: **V zones** and **A zones**. These zones are described below (and in greater detail in Chapter 6). Also described below is a third zone defined specifically for this manual: **Coastal A zone**.

V zone – The portion of the SFHA that extends 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. The V zone is also referred to as the **Coastal High Hazard Area**. As explained in Chapter 6, the minimum NFIP regulatory requirements regarding construction in V zones are more stringent than those regarding A-zone construction. V-zone requirements account for the additional hazards associated with high-velocity wave action, such as the impact of waves and waterborne debris and the effects of severe scour and erosion.

Coastal A zone – The portion of the SFHA landward of a V zone or landward of an open coast without mapped V zones (e.g., the shorelines of the Great Lakes), in which the principal sources of flooding are astronomical tides, storm surges, seiches, or tsunamis, not riverine sources. Like the flood forces in V zones, those in coastal A zones are highly correlated with coastal winds or coastal seismic activity. Coastal A zones may therefore be subject to wave effects, velocity flows, erosion, scour, or combinations of these forces. The forces in coastal A zones are not as severe as those in V zones but are still capable of damaging or destroying buildings on inadequate foundations.

Non-Coastal A zone – Portions of the SFHA in which the principal source of flooding is runoff from rainfall, snowmelt, or a combination of both. In (non-coastal) A zones, flood waters may move slowly or rapidly, but waves are usually not a significant threat to buildings. However, in extreme cases (e.g., 1993 Midwest floods), long fetches and high winds have generated damaging waves in non-coastal A zones. Designers in non-coastal A zones subject to waves may wish to employ some of the methods described in this manual.

X zone – Areas where the flood hazard is less than that in the SFHA. Shaded X zones shown on recent FIRMs (B zones on older FIRMs) designate areas subject to inundation by the flood with a 0.2-percent annual probability of being equaled or exceeded (the 500-year flood). Unshaded X zones (C zones on older FIRMs) designate areas where the annual exceedance probability of flooding is less than 0.2 percent.

The flood hazard zone icons shown above are used as visual guides throughout this manual to help readers find information specific to their needs. To use the icons effectively, readers must determine whether the property or building site in question is in a V zone, coastal A zone, or non-coastal A zone. Chapter 3 of this manual provides information readers will need to make such a determination.

NOTE

The coastal A zone classification is used by ASCE 7-98 (*Minimum Design Loads for Buildings and Other Structures*), in the determination of both flood loads and design load combinations.

NOTE

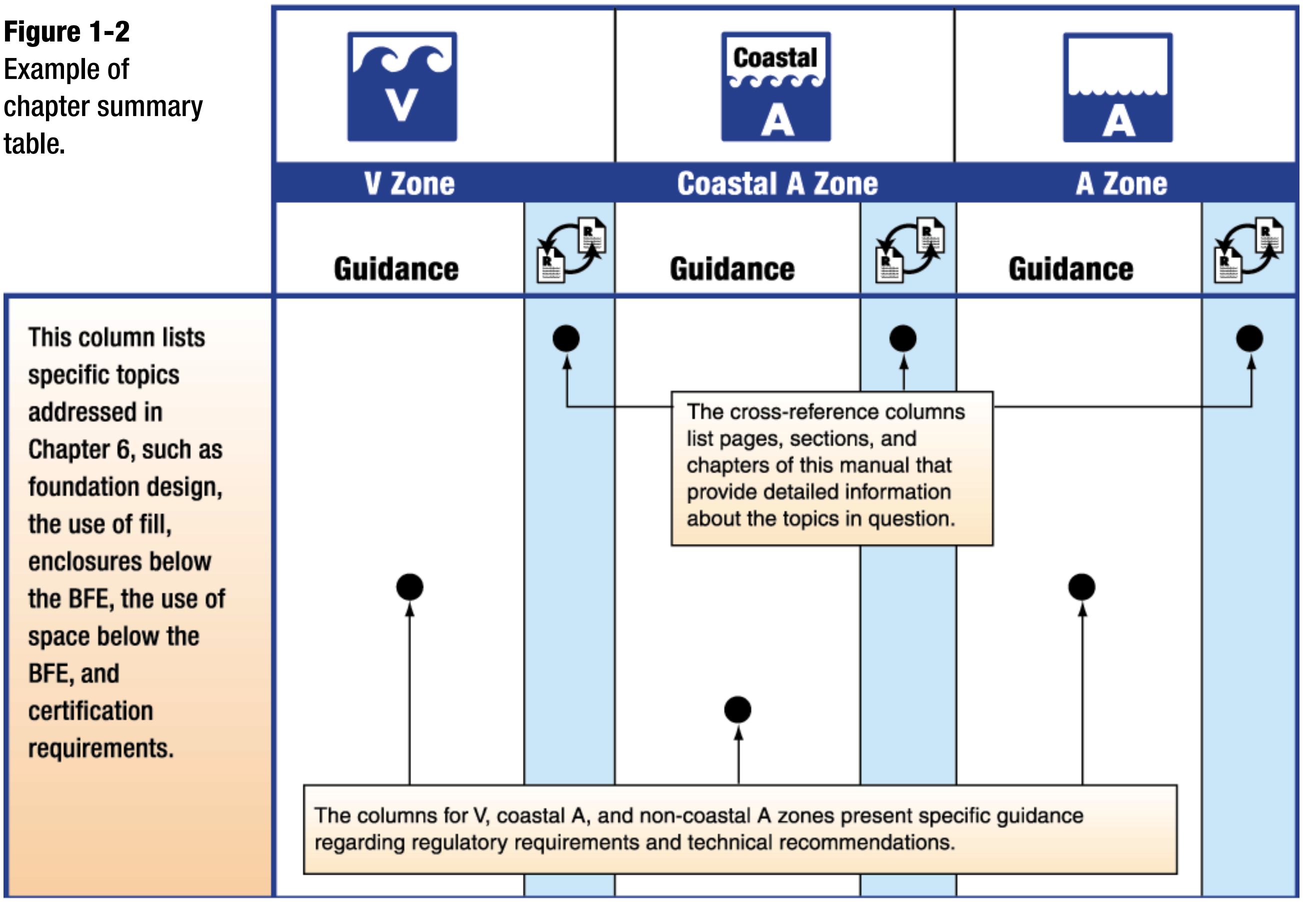
Although the NFIP regulations do not differentiate between coastal and non-coastal A zones, this manual recommends that buildings in coastal A zones be designed and constructed to be more resistant to flood forces—including wave effects, velocity flows, erosion, and scour—than buildings in non-coastal A zones (see Section 6.5 in Chapter 6).

WARNING

Areas outside the SFHA can still be subject to flooding and erosion. Designers should not ignore potential flooding and erosion hazards in areas labeled Zone X, Zone B, or Zone C.

These icons also appear in the summary table (see Figure 1-2) presented in Chapter 6. As shown by the example in Figure 1-2, the table summarizes zone-based differences among regulatory requirements and technical recommendations for buildings in V, coastal A, and non-coastal A zones. The table also provides cross-references that enable readers to quickly find more detailed information in the body of the text.

Figure 1-2
Example of chapter summary table.



Additional icons appear in the margins of pages throughout the manual. These icons call out notes, warnings, definitions, cross-references, cost considerations, formulas, and example problems:

Note – Notes contain supplemental information that readers may find helpful, including things to consider when undertaking a coastal construction project, suggestions that can expedite the project, and the titles and sources of other publications related to coastal construction. Full references for publications are presented at the end of each chapter of the manual.

Warning – Warnings present critical information that will help readers avoid mistakes that could result in dangerous conditions, violations of community ordinances or laws, and, possibly, delays and higher costs in a coastal construction project. All readers should be sure to heed these warnings. Any questions about the meanings of warnings in this manual should be directed to the appropriate state or local officials.

Definition – The meanings of selected technical and other special terms are presented in the page margins where appropriate. Definitions are also provided in Appendix B, in Volume III.

NOTE

Many technical and regulatory terms used in this manual may not be familiar to some readers. Definitions of those terms are presented in the margins of pages and in Appendix B, in Volume III.

Cross-Reference – Cross-references point the reader to related information—including technical discussions, regulatory information, formulas, tables, and figures—that supplements or further explains issues of interest.

Cost Considerations – Cost consideration notes discuss issues that can affect short-term and lifecycle costs associated with a coastal residential construction project**.**

Formula – Chapter 11 includes formulas for calculating loads imposed by forces associated with natural hazard events. Chapter 12 presents formulas used in the design of building components intended to withstand the loads imposed by design events. Each formula is presented in a box that separates it from the body of the text.

Example Problem – In Chapter 11, Example Problems demonstrate the calculation of flood, wind, and seismic loads on a coastal residential building.

Every effort has been made to make this manual as comprehensive as possible. However, no single manual can anticipate every situation or need that may arise in a coastal construction project. Readers who have questions that are not addressed herein should consult local officials. Information is also available from the Mitigation Division of the appropriate FEMA Regional Office (see Appendix C, in Volume III), the State NFIP Coordinating Agency (see Appendix D, in Volume III), and the State Coastal Zone Management Agency (see Appendix E, in Volume III).

Chapter 2: Historial Perspective

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Historical Perspective

2.1 Introduction

Through the years, FEMA and other agencies have documented and evaluated the effects of coastal flood events and the performance of coastal buildings during those events. These evaluations are useful because they provide a historical perspective on matters related to the siting, design, and construction of buildings along the Atlantic, Pacific, Gulf of Mexico, and Great Lakes coasts. They are useful also because they provide a baseline against which the impacts of later coastal flood events can be measured.

NOTE

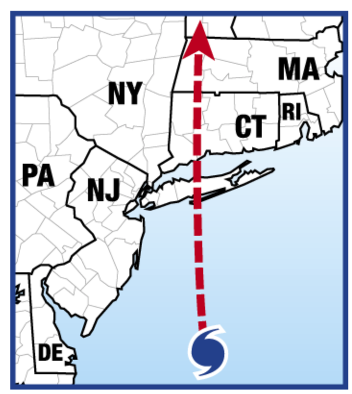
Hurricane categories reported in this manual should be interpreted cautiously. Storm categorization based on wind speed may differ from that based on barometric pressure or storm surge. Also, storm effects vary geographically—only the area near the point of landfall will experience effects associated with the reported storm category.

Within this context, several hurricanes, coastal storms, and other coastal flood events stand out as being especially important, either because of the nature and extent of the damage they caused or because of particular flaws they exposed in hazard identification, siting, design, construction, or maintenance practices. Many of these events—particularly the more recent ones—have been documented by FEMA in Flood Damage Assessment Reports and Building Performance Assessment Team (BPAT) reports.

This chapter describes coastal flood and wind events that have affected the continental United States, Alaska, Hawaii, and U.S. Territories since the beginning of this century. Findings of post-event building performance and damage assessments are summarized, as are the lessons learned regarding factors that contribute to flood and wind damage.

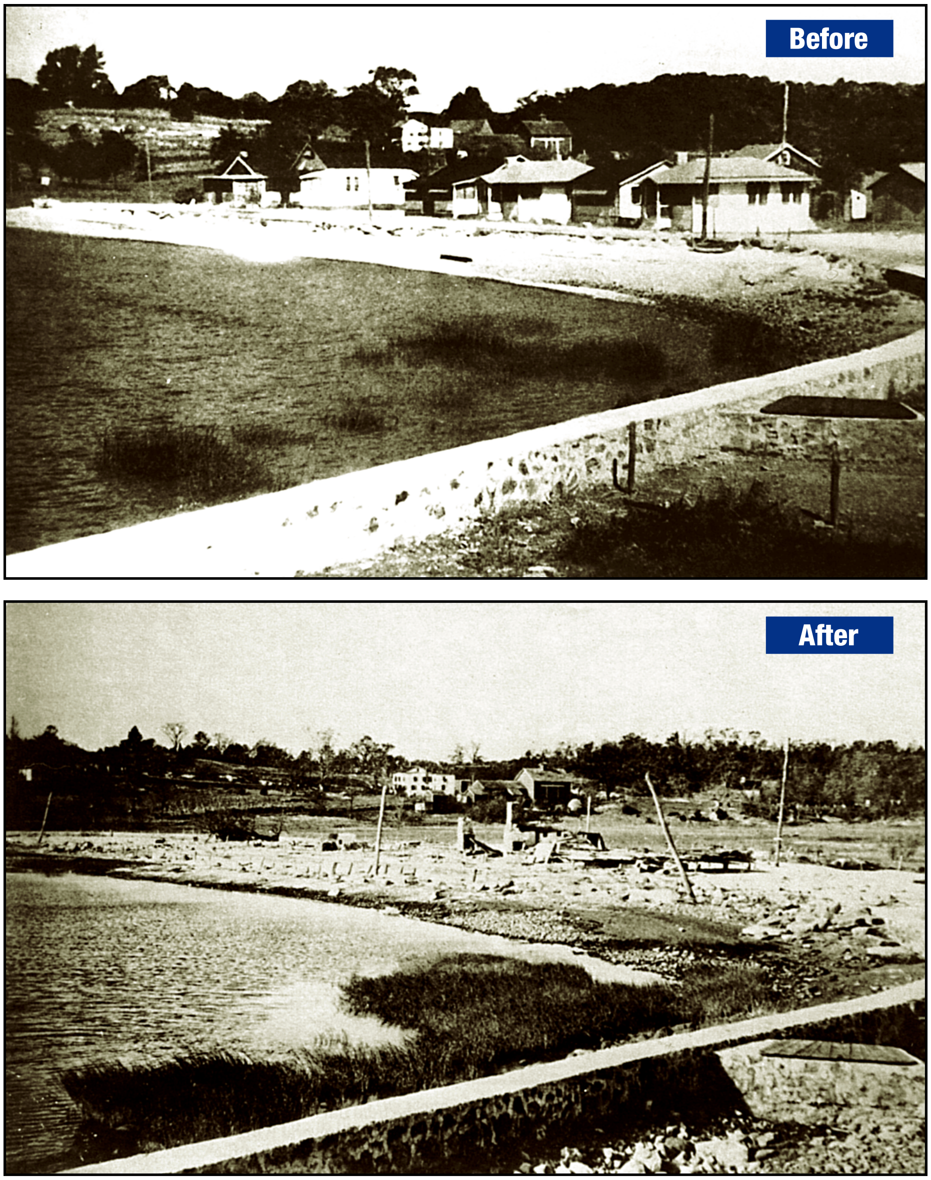
2.2 Coastal Flood and Wind Events

2.2.1 Northeast Atlantic Coast



1938, September 21 – New England Hurricane. The 1938 hurricane was one of the strongest ever to strike New York and New England. Although the maximum sustained wind speed at the storm's peak was estimated at 140 mph, by landfall the wind speeds had diminished substantially (NOAA 1996). The storm, like most other hurricanes striking the area (e.g., Hurricane Gloria in 1985), had a forward speed in excess of 30 mph at the time of landfall, and it moved through the area rapidly. Despite its high forward speed, the storm caused widespread and significant damage to buildings close to the shoreline (see Figure 2-1) (surge and wave damage) and to buildings away from the coast (wind and tree-fall damage). Minsinger (1988) provides documentation of the storm and the damage it caused, which, according to NOAA (1997), rank this storm as the eighth most costly hurricane to strike the United States this century.

Figure 2-1
1938 Hurricane. Schell Beach, Guilford, Connecticut, before and after the storm. Unelevated houses at the shoreline were destroyed. WPA photograph, from Minsinger (1988).

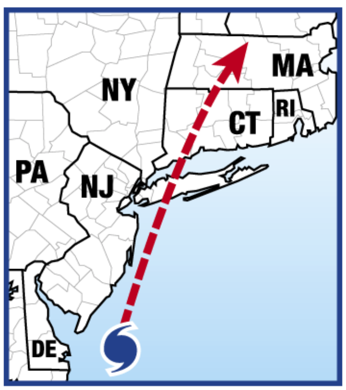


1962, March 5-8 – Mid-Atlantic Northeaster. One of the most damaging storms on record, this northeaster affected almost the entire eastern seaboard of the United States and caused extreme damage in the mid-Atlantic region. As documented by Wood (1976), the high winds associated with this slow-moving storm included peak gusts of up to 84 mph and continued for 65 hours, through five successive high tides. The combination of sustained high winds with spring tides resulted in extensive flooding along the coast from the Outer Banks of North Carolina to Long Island, New York (see Figure 2-2). In many locations, waves 20 to 30 feet high were reported. The flooding caused severe beachfront erosion, inundated subdivisions and coastal industrial facilities, toppled beachfront houses and swept them out to sea, required the evacuation of coastal areas, destroyed large sections of coastal roads, and interrupted rail transportation in many areas. In all, property damage was estimated at half a billion dollars (in 1962 dollars).

Figure 2-2
1962 Mid-Atlantic storm. Extreme damage to homes along the beach at Point-o-Woods, Fire Island, New York. UPI/Corbis-Bettmann photograph.

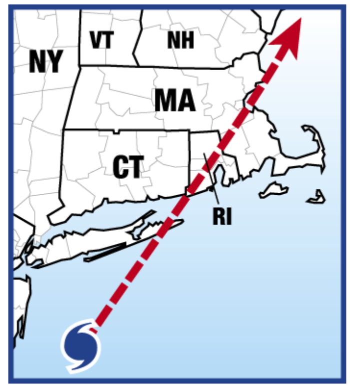
1984, March 29 – Northeaster, New Jersey. On March 28, 1984, a large low-pressure system developed in the southeastern United States and strengthened dramatically as it moved across Tennessee, Kentucky, and Virginia. In the early morning hours of March 29, the storm system moved northeastward past the Delmarva Peninsula, gaining additional strength from the Atlantic Ocean. The storm continued tracking to the northeast with near hurricane-force winds (sustained winds ranged from 40 to 60 mph). The barometric pressure dropped from a normal of 29.92 inches to 28.5 inches, and it was estimated that tides along the New Jersey coast ranged from 4 to 7 feet above normal at high tide (USDC, NOAA 1984). Measurements of local tidal flooding indicate that this storm had a recurrence interval of approximately 10–20 years (NJDEP 1986).

In its 1986 Hazard Mitigation Plan, the New Jersey Department of Environmental Protection reported the following regarding damage from the 1984 storm (NJDEP 1986): "In general, damage along the oceanfront from this storm varied depending on whether beaches and dunes were present or absent. In more structurally fortified areas with seawalls, bulkheads, and revetments, areas usually with little or no beach, there was more structural and wave damage. In areas of moderate beaches with little or no dune protection, particularly at street ends, there was significant overwash of sand into streets and property, in addition to severe beach erosion. There was also significant amounts of sand blown down streets and onto adjacent properties in areas where there were unvegetated dunes. In areas with wider beaches and cultivated dunes, damage was limited to the ubiquitous beach erosion and scarping (or cliffing) of dunes. Because of the short duration of the storm, there was remarkably little structural damage to private homes. Undoubtedly, better building practices and better dunes instituted since the 1962 storm contributed to this fairly low loss. In more inland areas, along the baysides behind the barriers, there was significant flooding from the elevated tidal waters. Although evacuations were called for in many areas, low causeways and highways, particularly in Atlantic County, made evacuations impossible."



1985, September 27 – Hurricane Gloria, New York. This fast-moving hurricane crossed Long Island near the time of low tide, causing minor storm surge and erosion damage, but substantial wind damage. Storm impacts were documented in the first of many FEMA Post-Flood Disaster Assessment Reports. The report (URS 1986) concluded the following:

- Wind speeds on Long Island may have exceeded the code-specified 75 mph (fastest-mile) wind speed.
- Tree damage, which was widespread and substantial, led to loss of overhead utility lines and damage to buildings.
- Common causes of failures in residential construction included poor roof-to-wall connections, lack of hurricane clips, flat roofs, eaves greater than 18 inches, and large plate glass windows facing seaward.
- The density of development, combined with high incidence of first-row roof failures, led to significant debris and projectile damage to second- and third-row buildings.
- Oceanfront areas had been left vulnerable to flood, erosion, and wave damage by previous northeast storms. Accordingly, damage from Gloria included settlement of inadequately embedded pilings, loss of poorly connected beams and joists, failure of septic systems due to erosion, and water and overwash damage to non-elevated buildings.



1991, August 19 – Hurricane Bob, Buzzards Bay Area, Massachusetts. Hurricane Bob, a Category 2 hurricane, followed a track similar to that of the 1938 New England hurricane. Although undistinguished by its intensity (not even ranking in the 65 most intense hurricanes to strike the United States during the 20th century), it caused $1.75 billion in damage (1996 dollars) (see Figure 2-3), ranking 18th in terms of damage (NOAA 1997). A FEMA Flood Damage Assessment Report (URS 1991c) documented damage in the Buzzards Bay area. The wind speeds during Hurricane Bob were below the design wind speed and the storm tide (corresponding to a 15-year tide) was at least 5 feet below the Base Flood Elevation (BFE). Nevertheless the results of the storm allowed an evaluation of the performance of different foundation types.

- Many buildings in the area had been elevated on a variety of foundations, either in response to Hurricane Carol (1954) or the 1978 northeaster, or as a result of community-enforced NFIP requirements.
- Buildings constructed before the date of the Flood Insurance Rate Map (FIRM) for each community—referred to as *pre-FIRM* buildings—that had not been elevated, or that had not been elevated sufficiently, suffered major damage or complete destruction; some destroyed buildings appeared to have had insufficient foundation embedment.
- Post-FIRM buildings (i.e., built after the date of the FIRM) and pre-FIRM buildings with sufficient elevation performed well during the storm. Where water was able to pass below buildings unobstructed by enclosed foundations, damage was limited to loss of decks and stairs.

Figure 2-3
Hurricane Bob (1991) destroyed 29 homes along this reach of Mattapoisett, Massachusetts. Photograph by Jim O’Connell.

- Foundation types that appeared to survive the storm without structural damage included the following:
  a) cast-in-place concrete columns, at least 10 inches in diameter
  b) masonry block columns with adequate embedment depth
  c) 10-inch-thick shear walls with a flow-through configuration (open ends) or modified to include garage doors at each end of the building (intended to be open during a storm)

1991, October 31 – Northeaster, Long Island, New York, and Boston, Massachusetts. This storm, which followed closely on the heels of Hurricane Bob, was one of the most powerful northeasters on record and is described in papers by Dolan and Davis (1992) and Davis and Dolan (1991). A FEMA Flood Damage Assessment Report (URS 1992) documented damage to buildings along the south shore of Long Island and in the Boston area, and noted the following:

- Pre-FIRM at-grade buildings were generally subject to erosion and collapse; however, at least one was partially buried by several feet of sand overwash.
- Some buildings were damaged by floodborne debris from other damaged structures.
- Some pile-supported buildings sustained damage as a result of inadequate pile embedment; some settled unevenly into the ground as a result of loss of bearing capacity; some were damaged as a result of collapse of the *landward* portion of the foundation (the seaward portion had been repaired after recent storms, while the landward portion was probably original and less deeply embedded).
- In areas subject to long-term erosion, buildings became increasingly vulnerable to damage or collapse with each successive storm.
- Although erosion control structures provided protection to many buildings, some buildings landward of revetments or bulkheads were damaged as a result of wave overtopping and erosion behind the erosion control structures.
- Buildings atop continuous masonry block foundations (such as those permitted in A zones) commonly were damaged or destroyed when exposed to flooding, wave action, erosion, and/or localized scour (see Figure 2-4).
- Buildings atop continuous cast-in-place concrete foundations performed better than those atop continuous masonry block foundations, and were generally more resistant to wave and flood damage; however, some continuous cast-in-place concrete foundations were damaged as a result of the footing being undermined by erosion and localized scour.

Figure 2-4
October 1991 northeaster damage to homes at Scituate, Massachusetts. Photograph by Jim O'Connell.

1992, January 4 – Northeaster, Delaware and Maryland. This northeaster was the most intense and damaging in coastal Delaware and Maryland since the Ash Wednesday1962 northeaster. A FEMA Building Performance Assessment Team (BPAT) inspected damage in six Delaware and Maryland communities (see Figure 2-5). In its report (FEMA 1992), the BPAT concluded the following:

- Damage was principally due to storm surge, wave action, and erosion. Beaches affected by the January storm had not fully recovered from the Halloween 1991 storm, which left coastal areas vulnerable to further damage.

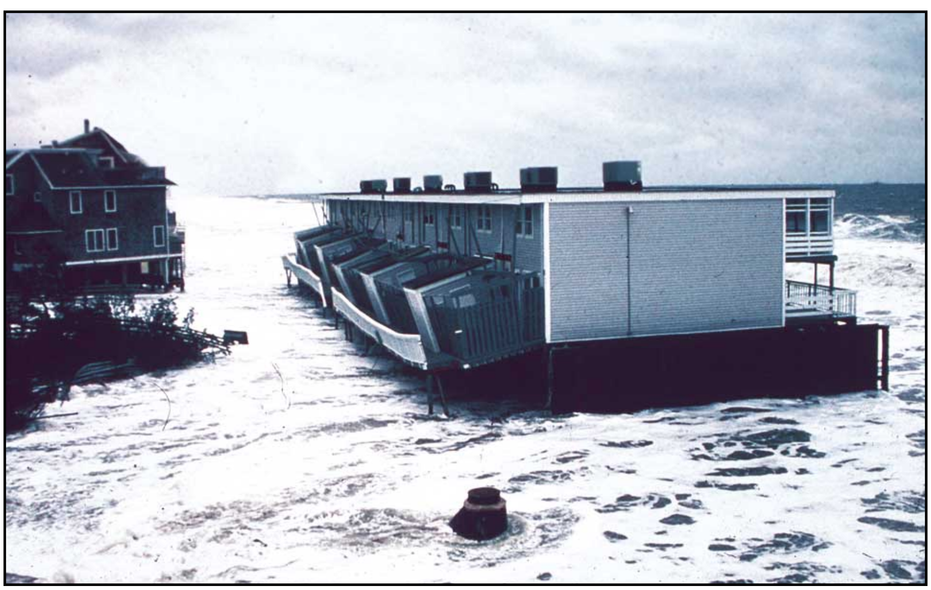


Figure 2-5
1992 storm impacts at Dewey Beach, Delaware. Note collapse of deck on landward side of building. Photograph by Anthony Pratt.

- Those buildings constructed to NFIP requirements fared well during the storm. For those buildings damaged, a combination of ineffective construction techniques and insufficient building elevation appeared to be the major causes of damage.
- For some pile-supported buildings, inadequate connection of floor joists to beams led to building damage or failure. Obliquely incident waves are believed to have produced non-uniform loads and deflections on pile foundations, causing non-uniform beam deflections and failure of inadequate joist-to-beam connections. The report provides three possible techniques to address this problem.
- Some buildings had poorly located or fastened utility lines. For example, some sewer stacks and sewer laterals failed as a result of erosion and flood forces. The report provides guidance on location and fastening of sewer connections to minimize vulnerability.
- Many pile-supported buildings were observed to have sustained damage to at-grade or inadequately elevated mechanical equipment, including air conditioning compressors, heat pumps, furnaces, ductwork, and hot water heaters. The report provides guidance on proper elevation of these units.

2.2.2 Southeast Atlantic Coast and Caribbean

1926, September 18 – Hurricane, Miami, Florida. Those who believe we have only recently come to understand storm-resistant design and construction will be surprised by the insight and conclusions contained in a 1927 article by Theodore Efting, a south Florida engineer, 1 year after the 1926 hurricane (see Figure 2-6) struck Miami, Florida (Eefting 1927). The article points out many weaknesses in buildings and construction that we still discuss today:

- light wooden truss roof systems and truss-to-wall connections
- faults and weaknesses in windows and doors, and their attachment to the main structure
- poor quality materials
- poor workmanship, supervision, and inspection
- underequipped and undermanned building departments

Eefting makes specific comments on several issues that are still relevant:

Buildings under three stories in height – "… the most pertinent conclusion that may be reached is that the fault lies in the actual construction in the field, such as lack of attention to small detail, anchors, ties, bracing, reinforcing, carpentry, and masonry work."

The role of the designer – "Engineers and architects are too prone to write specifications in which everything is covered to the minutest detail, and to draw plans on which requirements are shown with hair splitting accuracy, and then allow the contractor to build the building, sewer, pavement or structure in general with little or no supervision."

Building codes – "In the repeated emphasis on inspection and the importance of good workmanship we should not lose sight of the value of good building codes. . . Every city in the state whether damaged by the storm or not would do well to carefully analyze the existing codes and strengthen them where weak."

Figure 2-6
Building damage from 1926 hurricane, Miami, Florida.

1988, April 13 – Northeaster, Sandbridge Beach, Virginia, and Nags Head, North Carolina. This storm, although not major, resulted in damage to several piling-supported oceanfront houses in North Carolina and Virginia. Long-term shoreline erosion coupled with the effects of previous coastal storms (January 1987, February 1987, April 8, 1988) left these areas vulnerable to the erosion caused by the April 13 storm. The Flood Damage Assessment Report completed after the storm (URS 1989) concluded the following:

- The storm produced sustained winds in excess of 30 mph for over 40 hours; storm tide stillwater levels were approximately 3 feet above normal; the dune face retreated landward 20 to 60 feet in places.
- Several pile-supported single-family houses sustained damage to decks and main structures as a result of insufficient pile penetration; in North Carolina, the affected houses appeared to predate 1986 North Carolina Building Code pile embedment requirements.
- Post-storm inspections revealed that foundations of many of the affected houses had been repaired previously (by jetting of new piles and splicing/bolting to old piles; addition of cross-bracing; addition of timber grade beams). Previous repairs were only partially effective in preventing structural damage during the storm.

- Followup examinations of some of the houses in August 1988 showed the same types of foundation repairs used previously.
- Standard metal hurricane clips and joist hangers were observed to have suffered significant to severe corrosion damage. Alternative connectors – such as heavier gauge connectors, wooden anchors, or noncorrosive connectors – should be used in oceanfront areas.

1989, March 6-10 – Northeaster, Nags Head, North Carolina, Kill Devil Hills, North Carolina, and Sandbridge Beach, Virginia. Damage from the March 1989 northeaster was much greater than that caused by the April 1988 storm, despite lower peak wind speeds and storm surge during the latter event. The increased damage was caused by a longer storm duration (sustained winds of 33 mph for over 59 hours) coincident with spring tides. The storm reportedly destroyed or damaged over 100 cottages and motels.

In addition to reaffirming the conclusions of the FEMA report of the April 1988 storm (URS 1989), the March 1989 FEMA Flood Damage Assessment Report (URS 1990) concluded the following:

- Once undermined, plain concrete slabs, and grade beams cast monolithically with them, failed under their own weight or as a result of wave and debris loads (see Figure 2-7).
- Failure of the pile-to-beam connection was observed where a bolt head lacked a washer and pulled through the beam.
- Cracks in, or failed connections to, piles and deck posts were, in some cases, attributed to cross-bracing oriented parallel to the shore or the attachment of closely spaced horizontal planks.
- Construction in areas subject to high rates of long-term erosion is problematic. Buildings become increasingly vulnerable to the effects of even minor storms (see Figure 2-8). This process eventually necessitates their removal or results in their destruction.
- Many of the buildings affected during the April 1988 storm were further damaged during the March 1989 storm, because of either additional erosion and undermining or debris damage to cross-bracing and foundation piles (see Figures 2-9 and 2-10).

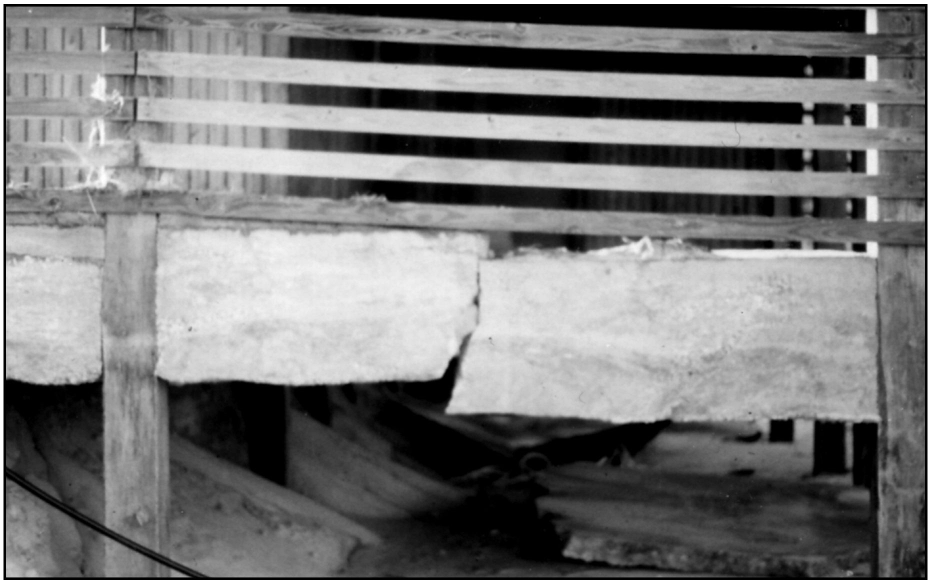


Figure 2-7
March 1989 northeaster. This plain concrete perimeter grade beam cracked in several places.

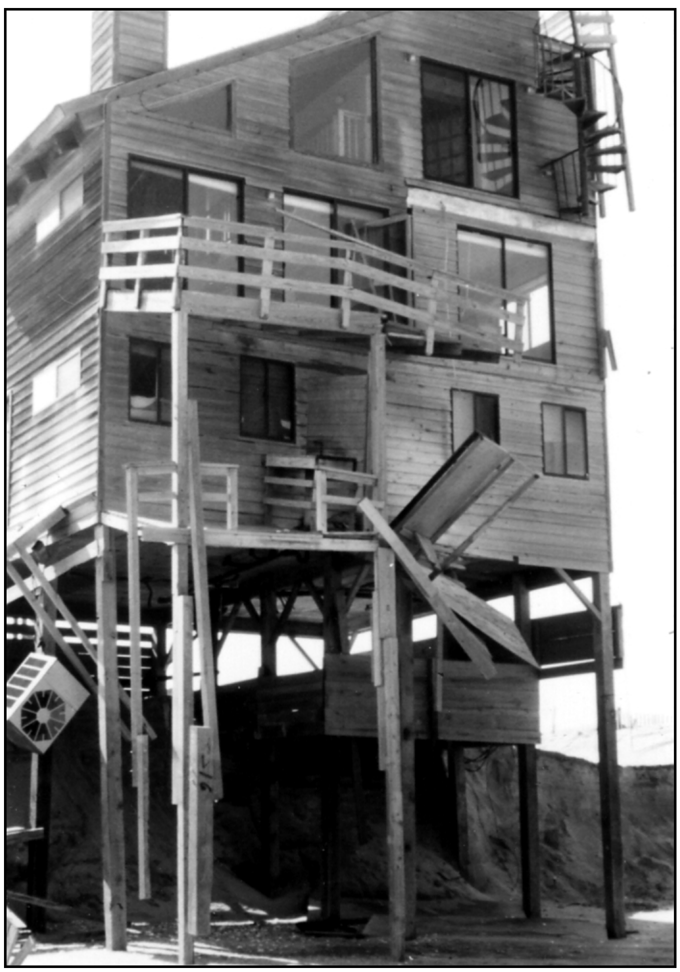


Figure 2-8
March 1989 northeaster. Although this house seems to have lost only several decks and a porch, the loss of supporting soil leaves its structural integrity in question.

Figure 2-9
March 1989 northeaster. Failure of cross-bracing.

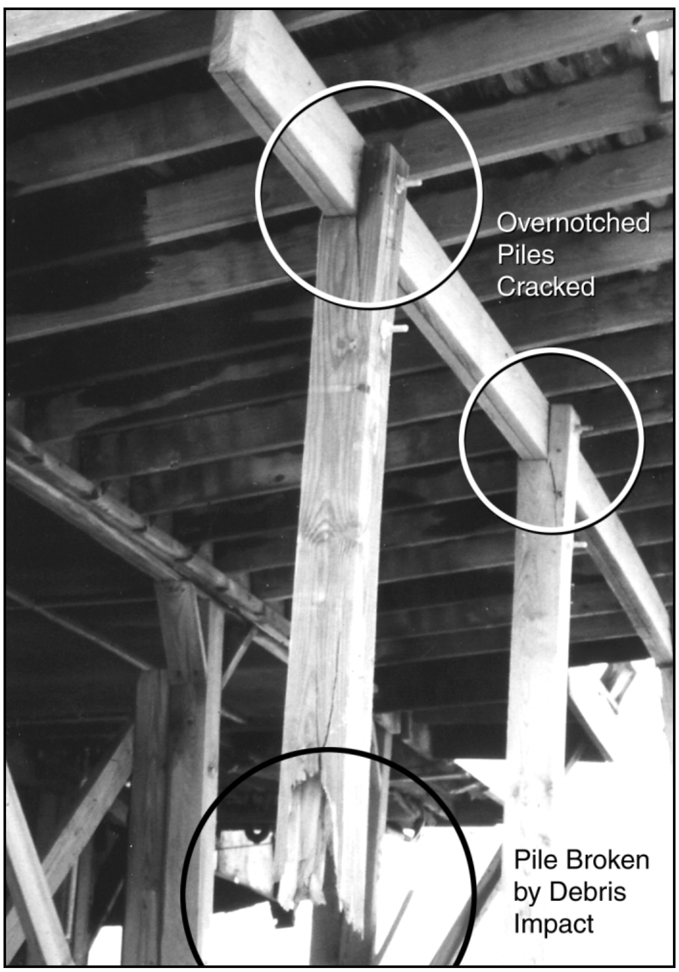


Figure 2-10
March 1989 northeaster. Deck pile broken by debris impact. Flood forces also caused piles to crack at overnotched connections to floor beam.

1989, September 21-22 – Hurricane Hugo, South Carolina. Hurricane Hugo was one of the strongest hurricanes known to have struck South Carolina. Widespread damage was due to a number of factors: flooding, waves, erosion, debris, and wind. In addition, building and contents damage caused by rainfall penetration into damaged buildings, several days after the hurricane itself, often exceeded the value of direct hurricane damage.

Damage from, and repairs following, Hugo were documented in a FEMA Flood Damage Assessment Report (URS 1991a) and a Follow-Up Investigation Report (URS 1991b). The reports concluded the following:

- Post-FIRM buildings that were both properly constructed and elevated survived the storm (see Figure 2-11). These buildings stood out in sharp contrast to pre-FIRM buildings and to post-FIRM buildings that were poorly designed or constructed.

Figure 2-11
Hurricane Hugo (1989), Garden City Beach, South Carolina. House on pilings survived while others did not.

- Many buildings elevated on masonry or reinforced concrete columns supported by shallow footings failed. In some instances, the columns were undermined; in others, the columns failed as a result of poor construction (see Figure 2-12).
- Several pile-supported buildings not elevated entirely above the wave crest showed damage or destruction of floor beams, floor joists, floors, and exterior walls.
- Some of the most severely damaged buildings were in the second, third, and fourth rows back from the shoreline. These areas were mapped as A zones on the FIRMs for the affected communities. Consideration should be given to more stringent design standards for coastal A zones.

- The storm exposed many deficiencies in residential roofing practices: improper flashing, lack of weather-resistant ridge vents, improper shingle attachment, and failure to replace aging roofing materials.

Figure 2-12
Hurricane Hugo (1989), South Carolina. Failure of reinforced masonry column.

1992, August 24 – Hurricane Andrew, Dade County, Florida. Hurricane Andrew was a strong Category 4 hurricane when it made landfall in southern Dade County and caused over $26 billion in damage (NOAA 1997). The storm is the third most intense hurricane to strike the United States in the 20th century and remains the most costly natural disaster to date. The storm surge and wave effects of Andrew were localized and minor when compared with the damage due to wind. A FEMA Building Performance Assessment Team evaluated damage to one- to two-story wood-frame and/or masonry residential construction in Dade County. In its report (FEMA 1993a), the team concluded the following:

- Buildings designed and constructed with components and connections that transferred loads from the envelope to the foundation performed well. When these critical "load transfer paths" were not in evidence, damage ranged from considerable to total, depending on the type of architecture and construction.

- Catastrophic failures of light wood-frame buildings were observed more frequently than catastrophic failures of other types of buildings constructed on site. Catastrophic failures were due to a number of factors:

  a) lack of bracing and load path continuity at wood-frame gable ends

  b) poor fastening and subsequent separation of roof sheathing from roof trusses

c) inadequate roof truss bracing or bridging (see Figure 2-13)

d) improper sillplate-to-foundation or sillplate-to-masonry connections

Figure 2-13
Hurricane Andrew (1992). Roof structure failure due to inadequate bracing.

- Failures in masonry wall buildings were usually attributable to one or more of the following:

  a) lack of or inadequate vertical wall reinforcing

  b) poor mortar joints between masonry walls and monolithic slab pours

  c) lack of or inadequate tie beams, horizontal reinforcement, tie columns, and tie anchors

  d) missing or misplaced hurricane straps between the walls and roof structure

- Composite shingle and tile (extruded concrete and clay) roofing systems sustained major damage during the storm. Failures were usually due to improper attachment, impacts of windborne debris, or mechanical failure of the roof covering itself.

- Loss of roof sheathing and consequent rainfall penetration through the roof magnified damage by a factor of five over that suffered by buildings whose roofs remained intact or suffered only minor damage (Sparks, et al. 1994).

- Exterior wall opening failures (particularly garage doors, sliding glass doors, French doors, and double doors) frequently led to internal pressurization and structural damage. Storm shutters and the covering of windows and other openings reduced such failures significantly.

- Quality of workmanship played a major role in building performance. Many well-constructed buildings survived the storm intact, even though they were adjacent to or near other buildings that were totally destroyed by wind effects.

1995, September 15-16 – Hurricane Marilyn, U.S. Virgin Islands and Puerto Rico. Hurricane Marilyn struck the U.S. Virgin Islands on September 15-16, 1995. With sustained wind speeds of 120 to 130 mph, Marilyn was classified a Category 3 hurricane. The primary damage from this storm was caused by wind; little damage was caused by waves or storm surge.

As documented by the National Roofing Contractors Association (NRCA 1996), most of the wind damage consisted of either the loss of roof sections (see Figure 2-14)—usually metal decking installed on purlins attached to roof beams spaced up to 48 inches on center—or failures of gable ends. In addition, airborne debris penetrated roofs (see Figure 2-15) and unprotected door and window openings. This damage allowed wind to enter buildings and cause structural failures in roofs and under-reinforced walls. Near the tops of high bluffs, wind speedup effects resulted in damage that better represented 140-mph sustained winds.

Figure 2-14
Hurricane Marilyn (1995). This house lost most of the metal roof covering. Neighbors stated that the house also lost its roof covering during Hurricane Hugo, in 1989.

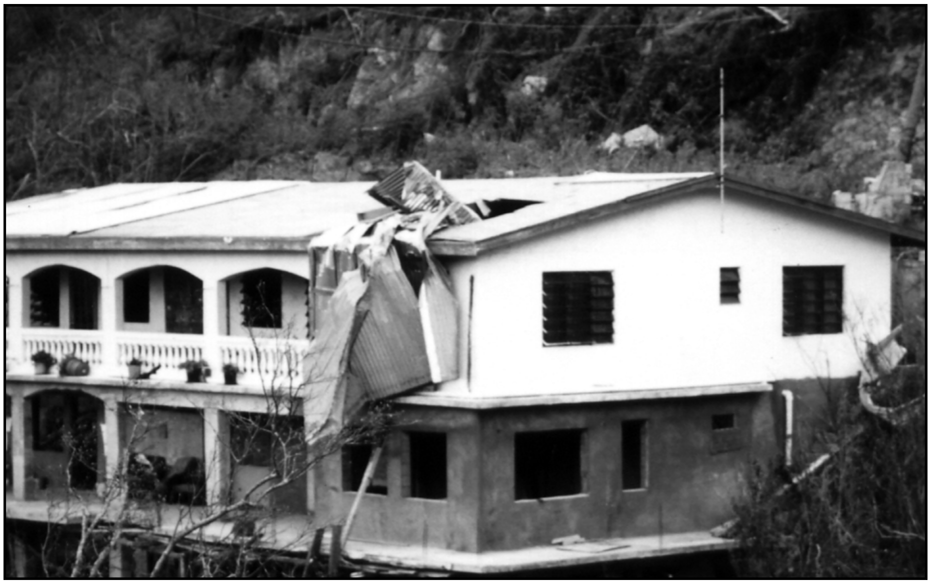


Figure 2-15
Hurricane Marilyn (1995). The roof of this house was penetrated by a large wind-driven missile (metal roof covering).

1996, September 5 – Hurricane Fran, Southeastern North Carolina. Hurricane Fran, a Category 3 hurricane, made landfall near Cape Fear, North Carolina. Erosion and surge damage to coastal construction were exacerbated by the previous effects of a weaker storm, Hurricane Bertha, which struck 2 months earlier. A FEMA Building Performance Assessment Team (BPAT) reviewed building failures and successes and concluded the following (FEMA 1997):

- Many buildings in mapped A zones were exposed to conditions associated with V zones, which resulted in building damage and failure from the effects of erosion, high-velocity flow, and waves. Remapping of flood hazard zones after the storm, based on analyses that accounted for wave runup, wave setup, and dune erosion, resulted in a significant landward expansion of V zones.
- Hundreds of oceanfront houses were destroyed by the storm, mostly as a result of insufficient pile embedment (see Figure 2-16) and wave effects. Most of the destroyed buildings had been constructed under an older building code provision that required that piling foundations extend only 8 feet below the original ground elevation. Erosion around the destroyed oceanfront foundations was typically 5–8 feet. In contrast, foundation failures were rare in similar, piling-supported buildings located farther from the ocean and not subject to erosion.
- A significant reduction in building losses was observed in similarly sized oceanfront buildings constructed after the North Carolina Building Code was amended in 1986 to require a minimum embedment to –5.0 feet National Geodetic Vertical Datum (NGVD) or 16 feet below the original ground elevation, whichever is shallower, for

CROSS-REFERENCE

Figure 3-10, in Chapter 3, shows how a restudy of coastal hazards after a severe storm such as Hurricane Fran can result in significantly different flood hazard mapping. The more extensive V zone on the post-Fran FIRM shown in Figure 3-10 is due in part to the topographic changes caused by storm-induced erosion.

pilings near the ocean. A study of Topsail Island found that 98 percent of post-1986 oceanfront houses (200 of 205) remained after the hurricane. Ninety-two percent of the total displayed no significant damage to the integrity of the piling foundation. However, 5 percent (11) were found to have leaning foundations (see Figure 2-16). A non-destructive test used to measure piling length in a partial sample of the leaning buildings revealed that none of the leaning pilings tested met the required piling embedment standard. Many were much shorter. However, given the uncertainty of predicting future erosion, the BPAT recommended that consideration be given to a piling embedment standard of –10.0 feet NGVD.

Figure 2-16
Hurricane Fran (1996). Many oceanfront houses built before the enactment of the 1986 North Carolina State Code were found to be leaning or destroyed.

- The BPAT noted a prevalence of multi-story decks and roofs supported by posts resting on elevated decks; these decks, in turn, were often supported by posts or piles with only 2–6 feet of embedment. Buildings with such deck and roof structures often sustained extensive damage when flood forces caused the deck to separate from the main structure or caused the loss of posts or piles and left roofs unsupported.

- Design or construction flaws were often found in breakaway walls. These flaws included the following:
    a) excessive connections between breakaway panels and the building foundation (however, the panels were observed generally to have failed as intended)
    b) placement of breakaway wall sections immediately seaward of foundation cross-bracing
    c) attachment of utility lines to breakaway wall panels
- Wind damage to poorly connected porch roofs and large roof overhangs was frequently observed.
- Corrosion of galvanized metal connectors (e.g., hurricane straps and clips) may have contributed to the observed wind damage to elevated buildings.
- As has been observed time and time again following coastal storms, properly designed and constructed coastal residential buildings generally perform well. Damage to well-designed, well-constructed buildings usually results from the effects of long-term erosion, multiple storms, large debris loads (e.g., parts of damaged adjacent houses), or storm-induced inlet formation/modification.

1998, September 21-22 – Hurricane Georges, Puerto Rico. On the evening of September 21, 1998, Hurricane Georges made landfall on Puerto Rico's east coast as a strong Category 2 hurricane. Wind speeds for Georges reported by the National Weather Service (NWS) varied from 109 mph to 133 mph (3-sec peak gust at a height of 33 feet). Traveling directly over the interior of the island in an east-to-west direction, George caused extensive damage. Over 30,000 homes were destroyed, and 50,000 more suffered minor to major damage.

A Building Performance Assessment Team deployed by FEMA conducted aerial and ground investigations of residential and commercial building performance. The team evaluated concrete and masonry buildings, including those with concrete roof decks and wood-frame roof systems, combination concrete/masonry and wood-frame buildings, and wood-frame buildings. The team's observations and conclusions include the following (FEMA 1999b):

- Many houses suffered structural damage from high winds, even though recorded wind data revealed that the wind speeds associated with Hurricane Georges did not exceed the basic design wind speed of the Puerto Rico building code in effect at the time the hurricane struck.
- Wind-induced structural damage in the observed buildings was attributable primarily to the lack of a continuous load path from the roof structure to the foundation.

- Concrete and masonry buildings, especially those with concrete roof decks, generally performed better than wood-frame buildings; however, the roofs of concrete and masonry buildings with wood-frame roof systems were damaged when a continuous load path was lacking.
- Coastal and riverine flood damage occurred primarily to buildings that had not been elevated to or above the BFE (see Figure 2-17).
- Flood damage to concrete and masonry structures was usually limited to foundation damage caused by erosion, scour, and the impact of waterborne debris.
- Although some examples of successful mitigation were observed, such as the use of reinforced concrete and masonry exterior walls, too little attention had been paid to mitigation in the construction of the observed houses.
- While not all of the damage caused by Hurricane Georges could have been prevented, a significant amount could have been avoided if more buildings had been constructed to meet the requirements of the Puerto Rico building code and floodplain management regulations in effect at the time the hurricane struck the island.

As a result of recommendations made by the FEMA Building Performance Assessment Team, the Government of Puerto Rico passed emergency, and subsequently final, regulations that repealed the existing building code and adopted the 1997 Uniform Building Code (UBC) as an interim step toward adopting the International Building Code (IBC) when it becomes available in early 2000.

Figure 2-17
Hurricane Georges (1998). Coastal building in Puerto Rico damaged by storm surge and waves.

2.2.3 Gulf of Mexico Coast

1900, September 8 – Galveston, Texas. This Category 4 hurricane was responsible for over 8,000 deaths—it is the most deadly natural disaster to affect the United States. The storm caused widespread destruction of much of the development on Galveston Island and pointed out the benefits of siting construction away from the shoreline. As a result, the city completed the first, large-scale retrofitting project (see Figure 2-18): roads and hundreds of buildings were elevated, ground levels in the city were raised several feet with sand fill, and the Galveston seawall was built (Walden 1990).

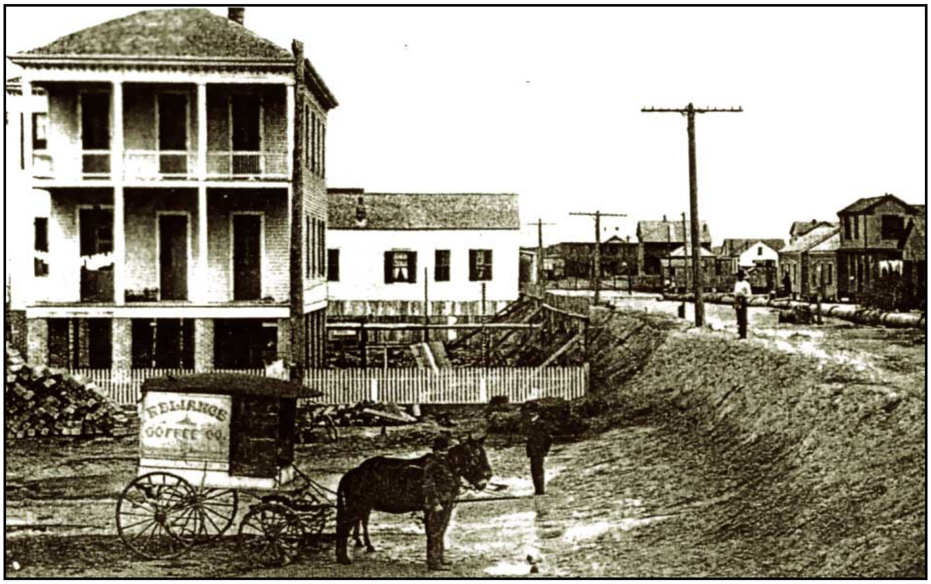


Figure 2-18
Galveston on two levels—the area at the right has already been raised; on the left, houses have been lifted, but the land is still low. Photograph courtesy of the Rosenberg Library, Galveston, Texas.

1961, September 7 – Hurricane Carla, Texas. Hurricane Carla was one of the 10 most intense hurricanes to strike the United States this century. This large, slow-moving Category 4 hurricane caused widespread erosion along the barrier islands of the central Texas coast. Storm surges reached 12 feet on the open coast and 15–20 feet in the bays. Hayes (1967) provides an excellent description of the physical effects of the storm on the barrier islands, where dunes receded as much as 100 feet, where barrier island breaching and inlet formation were commonplace, and where overwash deposits were extensive. The storm and its effects highlight the need for proper siting and construction in coastal areas.

1969, August 17 – Hurricane Camille, Mississippi and Alabama. Hurricane Camille was the second Category 5 hurricane to strike the United States and the most intense storm to strike the Gulf Coast during the 20th century. According to Thom and Marshall (1971), the storm produced winds with a recurrence interval of close to 200 years and storm tides that exceeded 200-year elevations in the vicinity of Pass Christian and Gulfport, Mississippi.

Thom and Marshall characterize observed wind damage as "near total destruction" in some sections of Pass Christian and Bay St. Louis, but "surprisingly light" in areas well back from the beach – this may have been due to the relatively small size of Camille and its rapid loss of strength as it moved inland. The aerial reconnaissance performed by Thom and Richardson indicated an extremely high incidence of damage to low, flat-roofed buildings. With few exceptions, they also found that residential buildings near the beach were totally destroyed by waves or storm surge; wave damage to commercial and other buildings with structural frames was generally limited to first-floor windows, and spandrel walls and partitions.

Several publications produced after Hurricane Camille documented typical wind damage to buildings (e.g., Zornig and Sherwood 1969, Southern Forest Products Association [undated], Saffir 1971, Sherwood 1972). The publications also documented design and construction practices that resulted in buildings capable of resisting high winds from Camille. Pertinent conclusions from these reports include the following:

- The structural integrity of wood buildings depends largely on good connections between components.
- Wood can readily absorb short-duration loads considerably above working stresses.
- Six galvanized roofing nails should be used for each three-tab strip on asphalt and composition roof shingles.
- Block walls with a u-block tie beam at the top do not sufficiently resist lateral loads imposed by high hurricane winds.
- Adding a list of shape factors for roof shape and pitch would strengthen the wind provisions of the building code.
- Many homes built with no apparent special hurricane-resistant construction techniques exhibited little damage, because the openings were covered with plywood "shutters."
- The shape of the roof and size of the overhang seem to have had a major effect on the extent of damage.

1979, September 12 – Hurricane Frederic, Alabama. Hurricane Frederic was a Category 3 hurricane that made landfall at Dauphin Island. Storm surge, wave, erosion, and wind effects of the storm caused widespread damage to non-elevated and elevated buildings (see Figure 2-19) (USACE 1981). For example, a post-storm assessment of coastal building damage (FEMA 1980) found that over 500 homes were destroyed along the 22-mile reach from Fort Morgan through Gulf Shores.

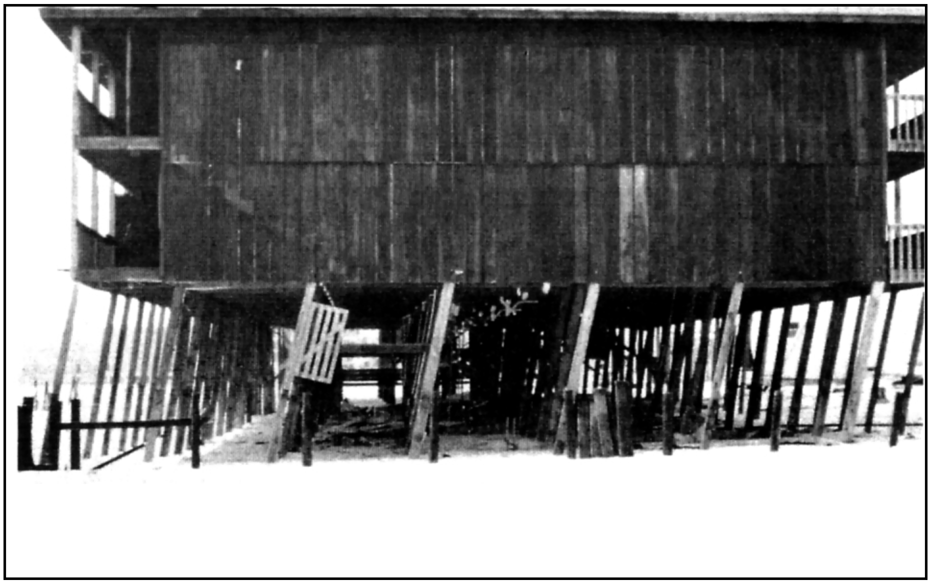


Figure 2-19
Hurricane Frederic (1979). Effects of wind and water forces on unbraced pile foundation.

Approximately 73 percent of front-row buildings were destroyed, while only 34 percent of second- and third-row buildings were destroyed. The destruction of non-elevated buildings was predictable; however, large numbers of elevated houses built to the BFE enforced at that time were also destroyed. Analyses confirmed that much of the damage to houses elevated to the BFE occurred because the BFE was based on the stillwater level only. It was after Hurricane Frederic that FEMA began to include wave heights in its determination of BFEs in coastal flood hazard areas.

CROSS-REFERENCE

Section 3.3.1, in Chapter 3 of this manual, explains how wave heights are considered in FEMA's determination of BFEs in coastal areas.

The conclusion of the 1980 FEMA study was supported by studies by Rogers (1990, 1991), which assessed damage to buildings constructed in Gulf Shores before and after 1972, when the community adopted minimum floor elevation standards based on its first NFIP flood hazard map. In addition to showing that the adoption of the 1972 standards helped reduce damage, the 1991 study showed the value of incorporating wave heights into BFEs and noted the further need to account for the effects of erosion and overwash.

1983, August 17–18 – Hurricane Alicia, Galveston and Houston, Texas. Hurricane Alicia came ashore near Galveston, Texas, during the night of August 17-18, 1983. It was the first tropical cyclone of the 1983 Atlantic hurricane season and the first hurricane to strike the continental United States since Hurricane Allen made landfall in August 1980. After Hurricane Agnes, which caused inland flooding over a large part of the U.S. east coast, Alicia was the second most costly storm to strike the United States at that time. A study by the National Academy of Sciences (NAS 1984) states that property damage resulting from Alicia was exceeded only by that of Hurricane Frederic. Wind damage was extensive throughout the Galveston–Houston area, and rain and storm surge caused flood damage in areas along the Gulf of Mexico and Galveston Bay.

The NAS report (1984) states that most of the property damage resulting from Alicia was caused by high winds. Overall, more than 2,000 homes and apartments were destroyed and over 16,000 other homes and apartments were damaged. The report noted the following concerning damage to residential buildings:

- Single-family and multi-family dwellings, and other small buildings that are usually not engineered, experienced the heaviest overall damage.
- Most of the damage to wood-frame houses could easily be traced to inadequate fastening of roof components, poor anchorage of roof systems to wall frames, poor connections of wall studs to the plates, and poor connections of sill plates to foundations. In houses that were destroyed, hurricane clips were usually either installed improperly or not used at all.
- Single-family dwellings near the water were extensively damaged by a combination of wind, surge, and wave action. Some were washed off their foundations and transported inland by the storm surge and waves.
- The performance of elevated wood-frame buildings along the coast can be significantly improved through the following actions:
    a) ensuring that pilings are properly embedded
    b) providing a continuous load path with the least possible number of weak links
    c) constructing any grade-level enclosures with breakaway walls
    d) protecting openings in the building envelope with storm shutters
    e) adequately elevating air-conditioning compressors

1995, October 4 – Hurricane Opal, Florida Panhandle. Hurricane Opal was one of the more damaging hurricanes to ever affect Florida. In fact, the state concluded that more coastal buildings were damaged or destroyed by the effects of flooding and erosion during Opal than in all other coastal storms affecting Florida in the previous 20 years combined. Erosion and structural damage were exacerbated by the previous effects of Hurricane Erin, which hit the same area just 1 month earlier.

The Florida Bureau of Beaches and Coastal Systems (FBBCS) conducted a post-storm survey to assess structural damage to major residential and commercial buildings constructed seaward of the Florida Coastal Construction Control Line (CCCL). The survey revealed that out of 1,942 existing buildings, 651 had sustained some amount of structural damage.

None of these damaged buildings had been permitted by FBBCS (all pre-dated CCCL permit requirements). Among the 576 buildings for which FBBCS had issued permits, only 2 sustained structural damage as a result of Opal (FBBCS 1996), and those 2 did not meet the state's currently implemented standards.

A FEMA Building Performance Assessment Team evaluated damage (FEMA 1996) in the affected area and concluded the following:

- Damaged buildings generally fell into one of the following four categories:
  - a) pre-FIRM buildings founded on slabs or shallow footings and located in mapped V zones
  - b) post-FIRM buildings outside mapped V zones and on slab or shallow footing foundations, but subject to high-velocity wave action, high-velocity flows, erosion, impact by floodborne debris, and/or overwash
  - c) poorly designed or constructed post-FIRM elevated buildings
  - d) pre-FIRM and post-FIRM buildings dependent on failed seawalls or bulkheads for protection and foundation support
- Oceanfront foundations were exposed to 3–7 feet of vertical erosion in many locations (see Figure 2-20). Lack of foundation embedment, especially in the case of older elevated buildings, was a significant contributor to building loss.

Figure 2-20
Hurricane Opal (1995), Bay County, Florida. Building damage from erosion and undermining.

- Two communities enforced freeboard and V zone foundation requirements in coastal A zones. In these communities, the performance of buildings subject to these requirements was excellent.
- State-mandated elevation, foundation, and construction requirements seaward of the Coastal Construction Control Line exceeded minimum NFIP requirements and undoubtedly reduced storm damage.

The National Association of Home Builders (NAHB) Research Center also conducted a survey of damaged houses (1996). In general, the survey revealed that newer wood-frame construction built to varying degrees of compliance with the requirements of the *Standard for Hurricane Resistant Residential Construction SSTD 10-93* (SBCCI 1993), or similar construction requirements, performed very well overall, with virtually no wind damage. In addition, the Research Center found that even older houses not on the immediate coastline performed well, partly because the generally wooded terrain helped shield these houses from the wind.

1998, September 28 – Hurricane Georges, Mississippi, Alabama, and Florida. Hurricane Georges made landfall in the Ocean Springs/Biloxi, Mississippi, area. Over the next 30 hours, the storm moved slowly north and east, causing heavy damage along the Gulf of Mexico coast. According to data from NWS reports, the maximum sustained winds ranged from 46 mph at Pensacola, Florida, to as high as 91 mph, with peak gusts up to 107 mph at Sombrero Key in the Florida Keys. Storm surges over the area ranged from more than 5 feet in Pensacola to 9 feet in Pascagoula, Mississippi. The total rainfall in the affected area ranged from 8 to 38 inches.

A Building Performance Assessment Team (BPAT) deployed by FEMA conducted aerial and ground investigations of building performance in Gulf coast areas from Pensacola Beach, Florida, to Gulfport, Mississippi, and inland areas flooded by major rivers and streams. In coastal areas, the BPAT evaluated primarily one- and two-family, one- to three-story wood-frame buildings elevated on pilings, although a few slab-on-grade buildings were also inspected.

The findings of the BPAT (FEMA 1999a) are summarized below:

- Engineered buildings performed well when constructed in accordance with current building codes, such as the Standard Building Code (SBC), local floodplain management requirements compliant with the NFIP regulations, and additional state and local standards.
- Communities that recognized and required that buildings be designed and constructed for the actual hazards present in the area suffered less damage.

- Specialized building materials such as siding and roof shingles designed for higher wind speeds performed well.
- Publicly financed flood mitigation programs and planning activities clearly had a positive effect on the communities in which they were implemented.

The BPAT concluded that several factors contributed to the building damage observed in the Gulf coast area, including the following:

- inadequate pile embedment depths on coastal structures (see Figure 2-21)
- inadequately elevated and inadequately protected utility systems
- inadequate designs for frangible concrete slabs below elevated buildings in coastal areas subject to wave action
- impacts from waterborne debris on coastal buildings
- lack of consideration of erosion and scour in the siting of coastal buildings
- corrosion of metal fasteners (e.g., hurricane straps) on coastal buildings

Figure 2-21
Hurricane Georges (1998), Dauphin Island, Alabama. As a result of erosion, scour, and inadequate pile embedment, the house on the right was washed off its foundation and into the house on the left.

2.2.4 Pacific Coast

1964, March 27 – Alaska Tsunami. This tsunami, generated by the 1964 Good Friday earthquake, affected parts of Washington, Oregon, California, and Hawaii; however, the most severe effects were near the earthquake epicenter in Prince William Sound, southeast of Anchorage, Alaska (Wilson and Tørum 1968). The tsunami flooded entire towns and caused extensive damage to waterfront and upland buildings (see Figure 2-22). Tsunami runup reached approximately 20 feet above sea level in places, despite the fact that the main tsunami struck near the time of low tide. Also, liquefaction of coastal bluffs in Anchorage resulted in the loss of buildings.

Figure 2-22
1964 Good Friday earthquake. Damage in Kodiak City, Alaska, caused by the tsunami of the 1964 Alaskan earthquake (from Wilson and Tørum 1968).

The 1968 report (p. 379) provides recommendations for land and waterfront buildings, including the following:

- Buildings on exposed land should have deep foundations of reinforced concrete or of the beam and raft type, to resist scour and undermining.
- Buildings should be oriented, if possible, to expose their shorter sides to potential wave inundation.
- Reinforced concrete or steel-frame buildings with shear walls are desirable.
- Wood-frame buildings should be located in the lee of more substantial buildings.
- Wood-frame buildings should be well-secured to their foundations, and have corner bracing at ceiling level.
- Wood-frame buildings in very exposed, low-lying areas should be designed so that the ground floor area may be considered expendable, because wetting damage would be inevitable. Elevated "stilt" designs of aesthetic quality should be considered.
- Tree screening should be considered as a buffer zone against the sea and for its aesthetic value.

1982-83 – Winter Coastal Storms, California, Oregon, and Washington. A series of El Niño-driven coastal storms caused widespread and significant damage to beaches, cliffs, and buildings along the coast between Baja California and Washington. These storms were responsible for more coastal erosion and property damage from wave action than had occurred since the winter of 1940-41 (Kuhn and Shepard 1991). One assessment of winter storm damage in the Malibu, California, area (Denison and Robertson 1985) found the following storm effects:

- Many beaches were stripped of their sand, resulting in 8–12 feet of vertical erosion.
- Bulkheads failed when scour exceeded the depth of embedment and backfill was lost.
- Many oceanfront houses were damaged or destroyed, particularly older houses.
- Sewage disposal systems that relied on sand for effluent filtration were damaged or destroyed.
- Battering by floating and wave-driven debris (pilings and timbers from damaged piers, bulkheads, and houses) caused further damage to coastal development.

CROSS-REFERENCE

Chapter 7 and Appendix G discuss the identification of hazard zones in coastal areas.

A 1985 conference on coastal erosion, storm effects, siting, and construction practices was organized largely as a result of the 1982-83 storms. The proceedings (McGrath 1985) highlights many of the issues and problems associated with construction along California's coast:

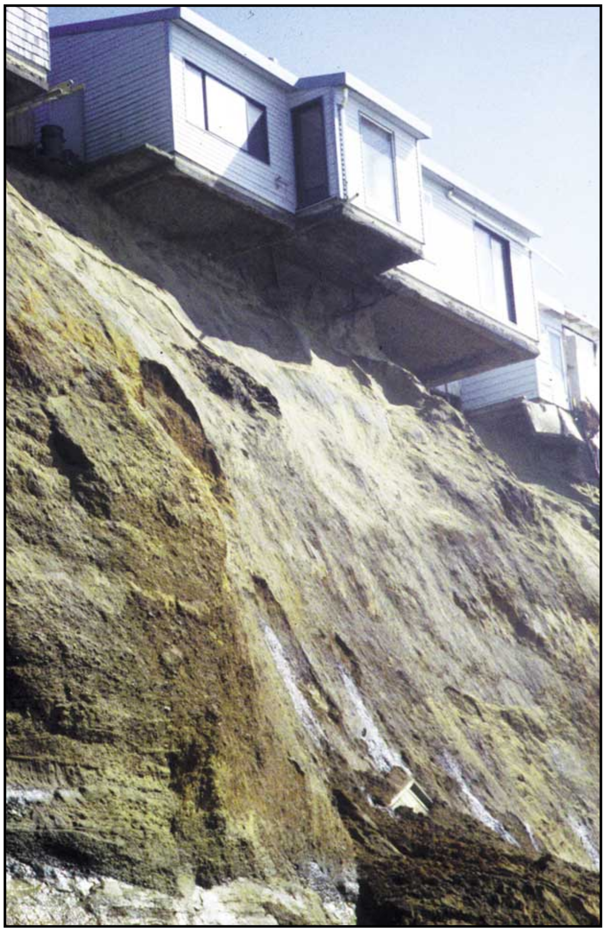
- the need for high-quality data on coastal erosion and storm effects
- the vulnerability of houses constructed atop coastal bluffs, out of mapped floodplains, but subject to destruction by erosion or collapse of the bluffs
- the benefits, adverse impacts, and costs associated with various forms of bluff stabilization, erosion control, and beach nourishment
- the need for rational siting standards in coastal areas subject to erosion, wave effects, or bluff collapse

January 1988 – Winter Coastal Storm, Southern California. This storm was unusual because of its rapid development, small size, intensity, and track. While most winter storms on the Pacific coast are regional in scale and affect several states, damage from this storm was largely confined to southern California. Damage to harbor breakwaters, shore protection structures, oceanfront buildings, and infrastructure were severe, as a result of the extreme waves associated with this storm. One study (Seymour 1989) concluded that wave heights for the January 1988 storm were the highest recorded and would have a recurrence interval of at least 100-200 years.

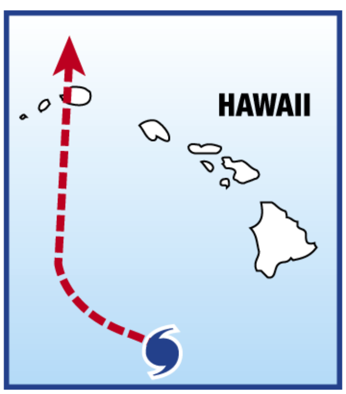
1997-98 – Winter Coastal Storms, California and Oregon. Another series of severe El Niño-driven coastal storms battered the Pacific coast. The distinguishing feature of the 1997-98 event was rainfall. The California

Coastal Commission (1998) reported widespread soil saturation, which resulted in thousands of incidents of debris flows, landslides, and bluff collapse (see Figure 2-23).

Figure 2-23
Winter coastal storms, California and Oregon (1997–1998). House in Pacifica, California, undermined by bluff erosion. Photograph by Lesley Ewing, courtesy of the California Coastal Commission.



2.2.5 Hawaii and U. S. Pacific Territories



1992, September 11 – Hurricane Iniki, Kauai County, Hawaii. Hurricane Iniki was the strongest hurricane to affect the Hawaiian Islands in recent memory—it was stronger than Hurricane Iwa (1992) and Hurricane Dot (1959) and caused significant flood and wave damage to buildings near the shoreline. Before Iniki, BFEs in Kauai County had been established based on tsunami effects only; following the storm, BFEs were reset based on both tsunami and hurricane flood effects. FEMA's Building Performance Assessment Team (BPAT) for Hurricane Iniki, in its report (FEMA 1993b), concluded that the following factors contributed to flood damage :

- buildings constructed at-grade
- inadequately elevated buildings
- inadequate structural connections

- inadequate connections between buildings and their pier or column foundations, which allowed flood waters to literally "float" buildings off their foundations (see Figure 2-24)
- embedment of foundations in unconsolidated sediments (see Figure 2-25)
- improper connection of foundations to underlying shallow rock
- impact of floodborne debris, including lava rock and parts of destroyed structures (Most of the lava rock debris originated from rock landscaping and privacy walls, which were common in the area.)

Figure 2-24
Hurricane Iniki (1992). Non-elevated house at Poipu Beach that floated off its foundation and was pinned against another house and destroyed by waves.

Figure 2-25
Hurricane Iniki (1992). Undermining of shallow footings supporting columns at Poipu Beach due to lack of sufficient embedment below erosion level.

The BPAT concluded that the following factors contributed to the observed wind damage:

- inadequately attached roof sheathing and roof coverings
- roof overhangs greater than 3 feet
- inadequately designed roofs and roof-to-wall connections
- unprotected windows and doors
- poor quality of construction
- deterioration of building components, principally due to wood rot and corrosion of metals
- wind speedup effects due to changes in topography

The BPAT concluded that properly elevated and constructed buildings sustained far less damage than buildings that were inadequately elevated or constructed.

1997, December 16 – Typhoon Paka, Guam. In January 1998, FEMA deployed a Hazard Mitigation Technical Assistance Program (HMTAP) team to Guam to evaluate building performance and damage to electric power distribution systems. In its report (FEMA 1998), the team noted that damage to wood-frame buildings was substantial, but that many buildings were built with reinforced masonry or reinforced concrete and survived the storm with minimal damage (see Figure 2-26). Many of the roof systems were flat and many were covered with a "painted-on" coating that also survived the storm with almost no damage. At the time of the storm, Guam used the 1994 Uniform Building Code (ICBO 1994) but has adopted a local amendment specifying a design wind speed of 155 mph (fastest-mile basis).

Figure 2-26
Typhoon Paka (1997). Although damaged by the storm, the concrete house in the upper part of the photograph survived, while the wood-frame house next to it was destroyed.

2.2.6 Great Lakes

1940, November 11 – Armistice Day Storm, Lake Michigan. On the afternoon of November 11, high winds moved quickly from the southwest into the area around Ludington, Michigan, on the eastern shoreline of Lake Michigan. Heavy rains accompanied the winds and later changed to snow. The winds, which reached speeds as high as 75 mph, overturned small buildings, tore the roofs from others, toppled brick walls, uprooted trees, and downed hundreds of telephone and power lines throughout the surrounding areas of Mason County.

1951, November 7 – Storm on Lake Michigan. After 20 years of lower-than-average levels, the water level on Lake Michigan in November 1951 was slightly above average. The November 7 storm caused extensive erosion along the southeast shore of the lake, undermining houses and roads (see Figure 2-27). Damage observed as a result of this storm is consistent with the concept of Great Lakes shoreline erosion as a slow, cumulative process, driven by lakebed erosion, high water levels, and storms.

Figure 2-27
House on southeastern shoreline of Lake Michigan undermined by erosion during storm of November 1951. Photograph courtesy of USACE, Chicago District.

1973, April 9 – Northeaster, Lake Michigan. This storm caused flooding 4 feet deep in downtown Green Bay, Wisconsin. Flood waters reached the elevation of the 500-year flood as strong winds blowing the length of the bay piled up a storm surge on already high lake levels. Erosion damage occurred on the open coast of the lake.

1975, November 9 and 10 – Storm on the western Great Lakes. This storm, one of the worst to occur on Lake Superior since the 1940's, caused the sinking of the 729-foot-long ore carrier *Edmund Fitzgerald* in eastern Lake Superior, with the loss of all 29 of its crew. The storm severely undermined the harbor breakwater at Bayfield, Wisconsin, requiring its replacement the following year. Bayfield is relatively sheltered by several of the Apostle Islands. A portion of the Superior Entry rubblemound jetty was destroyed at Duluth-Superior in the eastern end of Lake Superior and had to be repaired. Storm waves on the open lake were estimated by mariners to range from 20 to 40 feet in height.

1985, March – Storms on the Great Lakes. As lake levels were rising toward the new record levels that would be set in 1986, the Town of Hamburg, New York, south of Buffalo, New York, was flooded by a damaging 8-foot storm surge from Lake Erie, which was driven by strong westerly winds. In this same month, properties along the lower sand bank portions of Wisconsin's Lake Michigan shore experienced 10–50 feet of rapid shoreline recession in each of several weekend storms, which suddenly placed lakeside homes in peril. Some houses had to be quickly relocated.

1987, February. This storm occurred during a period of record high lake levels. Sustained northerly wind speeds were estimated to be in excess of 50 mph, and significant deepwater wave heights in the southern portion of the lake were estimated to be greater than 21 feet (USACE 1989).

1986, 1996, 1997 – Sometimes, stalled storm systems bring extremely heavy precipitation to local coastal areas, where massive property damage results from flooding, bluff and ravine slope erosion from storm runoff, and bluff destabilization from elevated groundwater. The southeastern Wisconsin coast of Lake Michigan had three rainfall events in excess of the 500-year precipitation event within 11 recent years: August 6, 1986 (Milwaukee, Wisconsin); June 16-18, 1996 (Port Washington, Wisconsin); and June 20-21, 1997 (northern Milwaukee County, including the City of Milwaukee) (SWRPC 1997). Massive property damage from flooding was reported in all three events, and Port Washington suffered severe coastal and ravine erosion during the 1996 event.

The Chicago District of the U. S. Army Corps of Engineers, using its Great Lakes Storm Damage Reporting System (GLSDRS), has estimated the total damage for storm-affected shoreline areas of the Great Lakes in 1996 and 1997 to be $1,341,000 and $2,900,000, respectively (USACE 1997, 1998). These amounts include damage to buildings, contents, vehicles, landscaping, shore protection, docks, and boats.

Figure 2-28
August 1988. Erosion along the Lake Michigan shoreline at Holland, Michigan, resulting from high lake levels and storm activity (photo courtesy of Mark Crowell).

2.3 Lessons Learned

Although flood events and physiographic features vary throughout the coastal areas of the United States, post-event damage reports show that the nature and extent of damage caused by coastal flood events are remarkably similar. Moreover, review of these reports shows that the types of damage experienced today are, in many ways, similar to those experienced decades ago. It is clear that although we have improved many aspects of coastal construction over the years, we make many of the same mistakes over and over.

The conclusions of post-event assessments can be classified according to those factors that contribute to both building damage and successful building performance: hazard identification, siting, design, construction, and maintenance. Reduction of building damages in coastal areas will require attention to these conclusions and coordination between owners, designers, builders, and local officials.

NOTE
Although there is no statistical basis for the conclusions presented in this section, they are based on numerous post-event damage assessments, which serve as a valuable source of information on building performance and coastal development practices.

2.3.1 Hazard Identification

- Flood damage can result from the effects of **short- and long-term increases in water levels** (storm surge, tsunami, seiche, sea-level rise); wave action; high-velocity flows; erosion; and debris. Addressing all potential flood hazards at a site will help reduce the likelihood of building damage or loss.

CROSS-REFERENCE
Chapter 7 of this manual discusses the identification of coastal hazards and their effects on coastal buildings.

CROSS-REFERENCE

See Figure 5-5, in Chapter 5, for an example of the effects of multiple storms.

WARNING

FIRMs do not account for future effects of long-term erosion. Users are cautioned that all mapped flood hazard zones (V, A, and X) in areas subject to long-term erosion will likely underestimate the extent and magnitude of actual flood hazards that a coastal building will experience over its lifetime.

CROSS-REFERENCE

Sections 1.4 and 3.3 of this manual explain the concept of a coastal A zone.

- Failure to consider the **effects of multiple storms or flood events** may lead to an underestimation of flood hazards in coastal areas; coastal buildings left intact by one storm may be vulnerable to damage or destruction by a second storm.
- **Long-term erosion** can increase coastal flood hazards through time, causing loss of protective beaches, dunes, and bluffs, and soils supporting building foundations. Failure to account for long-term erosion is one of the more common errors made by those siting and designing coastal residential buildings.
- Flood hazards in areas mapped as A zones on coastal FIRMs can be much greater than flood hazards in riverine A zones. There are two reasons for this situation:

    1. Waves 2–3 feet high (i.e., too small for an area to be classified as a V zone, but still capable of causing structural damage and erosion) will occur during base flood conditions in many coastal A zones.
    2. Aging FIRMs may fail to keep pace with changing site conditions (e.g., long-term erosion, loss of dunes during previous storms) and revised flood hazard mapping procedures.

  Therefore, minimum A-zone foundation and elevation requirements should not be assumed adequate to resist coastal flood forces without a review of actual flood hazards. The concept of a "**coastal A Zone**" with elevation and foundation requirements closer to those of V zones should be considered.

- Failure to consider the **effects of topography** (and changes in topography, e.g., bluff erosion) on **wind speeds** can lead to underestimation of wind speeds that will be experienced during the design event. Siting buildings on high bluffs or near high-relief topography requires special attention by the designer.
- In coastal bluff areas, consideration of the potential effects of surface and subsurface drainage, removal of vegetation, and site development activities can help reduce the likelihood of problems resulting from **slope stability hazards and landslides**.
- **Drainage from septic systems** on coastal land can destabilize coastal bluffs and banks, accelerate erosion, and increase the risk of damage and loss to coastal buildings.
- Vertical cracks in the soils of some cohesive bluffs cause a rapid rise of **groundwater in the bluffs** during extremely heavy and prolonged precipitation events and rapidly decrease the stability of such bluffs.

- Some coastal areas are also susceptible to seismic hazards; although the likelihood of flood and seismic hazards acting simultaneously is small, each hazard should be identified carefully and factored into siting, design, and construction practices.

2.3.2 Siting

- **Building close to the shoreline** is a common, but possibly poor, siting practice: it may render a building more vulnerable to wave, flood, and erosion effects; may remove any margin of safety against multiple storms or erosion events; and may require moving, protecting, or demolishing the building if flood hazards increase over time.
- In coastal areas subject to long-term or episodic erosion, poor siting often results in otherwise well-built **elevated buildings standing on the active beach**. While a structural success, such buildings are generally uninhabitable (because of the loss of utilities and access). This situation can also lead to conflicts over beach use and increase pressure to armor or renourish beaches (controversial and expensive measures).
- **Building close to other structures** may increase the potential for damage from flood, wind, debris, and erosion hazards. Of particular concern is the siting of homes or other small buildings adjacent to large, engineered high-rise structures—the larger structures can redirect and concentrate flood, wave, and wind forces, and have been observed to increase flood and wind forces as well as scour and erosion.
- Depending on erosion or flood protection structures often leads to building damage or destruction. Seawalls, revetments, berms, and other structures may not afford the required protection during a design event and may themselves be vulnerable as a result of erosion and scour or other prior storm impacts. **Siting too close to protective structures** may preclude or make difficult any maintenance of the protective structure.
- **Siting buildings on the tops of erodible dunes and bluffs** renders those buildings vulnerable to damage caused by the undermining of foundations and the loss of supporting soil around vertical foundation members.
- **Siting buildings on the downdrift shoreline** of a stabilized tidal inlet (an inlet whose location has been fixed by jetties) often places the buildings in an area subject to increased erosion rates.
- **Siting buildings near unstabilized tidal inlets** or in areas subject to large-scale shoreline fluctuations may result in increased vulnerability to even minor storms or erosion events.

CROSS-REFERENCE

Chapter 8 of this manual discusses siting considerations, siting practices to avoid, and recommended alternatives.

CROSS-REFERENCE

Figures 4-1, 4-2, and 7-28, in Chapters 4 and 7 of this manual, show the consequences of poor siting.

CROSS-REFERENCE

Figures 7-38 and 7-39, in Chapter 7 of this manual, show the consequences of siting buildings on the tops of erodible bluffs.

- Siting along shorelines protected against wave attack by barrier islands or other land masses does not guarantee protection against flooding. In fact, **storm surge elevations along low-lying shorelines in embayments** are often higher than storm surge elevations on open coast shorelines.

CROSS-REFERENCE

Chapter 12 of this manual covers the design of coastal buildings.

2.3.3 Design

- Use of **shallow spread footing and slab foundations** in areas subject to wave impact and/or erosion can result in building collapse, even during minor flood or erosion events. Because of the potential for undermining by erosion and scour, shallow spread footing and slab foundations may not be appropriate for some coastal A zones and some coastal bluff areas outside the mapped floodplain.
- In areas subject to wave impact and/or erosion, the use of **continuous perimeter wall foundations**, such as crawlspace foundations, (especially those constructed of unreinforced masonry) may result in building damage, collapse, or total loss.
- Inadequate depth of foundation members (e.g., pilings not embedded deeply enough, shallow footings supporting masonry and concrete walls and columns) is a common cause of failure in elevated 1- to 4-family residential buildings.
- Elevating a building sufficiently will help protect the superstructure from damaging wave forces. **Designs should incorporate freeboard** above the required elevation of the lowest floor or bottom of lowest horizontal member.
- Failure to **use corrosion-resistant structural connectors** (e.g., wooden connectors, galvanized connectors made of heavier gauge metal or with thicker galvanizing, stainless steel connectors) can compromise structural integrity and may lead to building failures under less than design conditions.
- **Corrosion of metal building components** is accelerated by salt spray and breaking waves. Nails, screws, sheet-metal connector straps, and truss plates are the most likely to be threatened by corrosion.
- Failure to provide a **continuous load path** using adequate connections between all parts of the building, from the roof to the foundation, may lead to structural failure.
- **Multi-story decks/roofs** supported by inadequately embedded vertical members can lead to major structural damage, even during minor flood and erosion events. Either roof overhangs should be designed to remain intact without vertical supports, or supports

should be designed to the same standards as the main foundation. Decks must be designed to withstand all design loads or should be designed so that they do not cause damage to the main building when they fail.

- Failure to adequately connect **porch roofs** and to limit the size of **roof overhangs** can lead to extensive damage to the building envelope.
- Many coastal communities have building height restrictions that, when coupled with building owner's desires to maximize building size and area, encourage the use of **low-slope roofs**. These roofs can be more susceptible to wind damage and water penetration problems.
- Roof designs that incorporate gable ends (especially **unbraced gable ends**) and **wide overhangs** are susceptible to failure unless adequately designed and constructed for the expected loads. Alternative designs that are more resistant to wind effects should be used in coastal areas.
- Many commonly used residential roofing techniques, systems, and materials are susceptible to damage from wind and windborne debris. Designs should pay special attention to the **selection and attachment of roof sheathing and roof coverings** in coastal areas.
- **Protection of the entire building envelope** is necessary in high-wind areas. Therefore, proper specification of windows, doors, and their attachment to the structural frame is essential.
- **Protecting openings** with temporary or permanent storm shutters and the use of impact-resistant (e.g., laminated) glass will help protect the building envelope and reduce damage caused by wind, windborne debris, and rainfall penetration.
- Designs should **maximize the use of lattice and screening** below the BFE and minimize the use of breakaway wall enclosures in V zones and solid wall enclosures in A zones. Post-construction conversion of enclosures to habitable space remains a common violation of floodplain management requirements and is difficult for communities and states to control.
- The **design and placement of swimming pools** can affect the performance of adjacent buildings. Pools should not be structurally attached to buildings, because an attached pool can transfer flood loads to the building. Building foundation designs should also account for increased flow velocities, wave ramping, wave deflection, and scour that can result from the redirection of flow by an adjacent pool.

CROSS-REFERENCE

Chapter 13 of this manual covers the construction of coastal buildings.

2.3.4 Construction

- **Poorly made structural connections**, particularly in wood-frame and masonry structures, (e.g., pile/pier/column to beam, joist to beam) have been observed to cause the failure of residential structures throughout the coastal areas of the United States.
- **Connections must be made with the appropriate fastener** for the design structural capacity to be attained. For example, post-event investigations have revealed many inadequate connections (e.g., made with the wrong size nails) that either failed during the event or could have failed if the design loads had been realized at the connection.
- **Nail and staple guns**, which are frequently used to speed construction, have disadvantages that can lead to connections with reduced capacity. These guns can easily overdrive nails or staples, or drive them at an angle. In addition, it is often difficult for the nail gun operator to determine whether a nail has penetrated an unexposed wood member as intended, such as a rafter or truss below roof sheathing.
- Failure to achieve the **pile or foundation embedment** specified by building plans or local/state requirements will render an otherwise properly-constructed building vulnerable to flood, erosion, and scour damage.
- **Improperly constructed breakaway walls** (e.g., improperly fastened wall panels, panels constructed immediately seaward of foundation cross-bracing) can cause preventable damage to the main structure. Lack of knowledge or inattention by contractors can cause unnecessary damage.
- **Improperly installed utility system components** (e.g., plumbing and electrical components attached to breakaway walls or on the waterward side of vertical foundation members, unelevated or insufficiently elevated heat pumps/air conditioning compressors and ductwork) will not only fail during a flood event, they can also cause damage to the main structure that otherwise might not have occurred.
- **Bracing and fastening roofs and walls** can help prevent building envelope failures in high-wind events.
- Lack of, or inadequate, connections between shingles and roof sheathing and between sheathing and roof framing (e.g., nails that fail to penetrate roof truss members or rafters) can cause **roof failures** and subsequent building failures.

- Communities often have **insufficient resources to inspect buildings** frequently during construction. Although contractors are responsible for following plans and satisfying code requirements, infrequent inspections may result in failure to find and remedy construction deficiencies.

2.3.5 Maintenance

- **Repairing and replacing structural elements**, connectors, and building envelope components that have deteriorated over time, because of decay or corrosion, will help maintain the building's resistance to natural hazards. Maintenance of building components in coastal areas should be a constant and ongoing process. The ultimate costs of deferred maintenance in coastal areas can be high when natural disasters strike.
- **Failure to inspect and repair damage** caused by a wind, flood, erosion, or other event will make the building even more vulnerable during the next event.
- **Failure to maintain erosion control or coastal flood protection structures** will lead to increased vulnerability of those structures and the buildings behind them.

CROSS-REFERENCE

Chapter 14 of this manual covers the maintenance of coastal buildings.

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Chapter 3: Coastal Environment

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Coastal Environment

3.1 Introduction

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

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

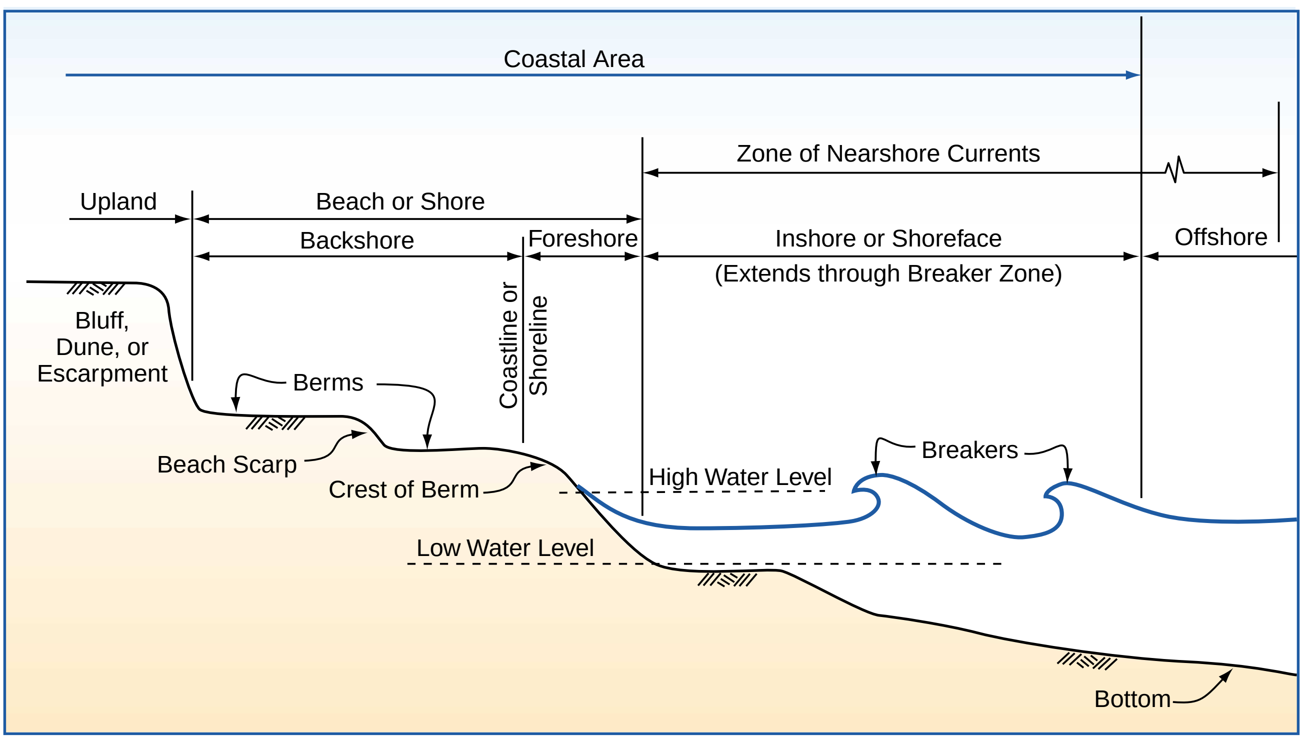


Figure 3-1 Coastal region terminology (USACE 1984).

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

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

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

NOTE

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

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

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

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

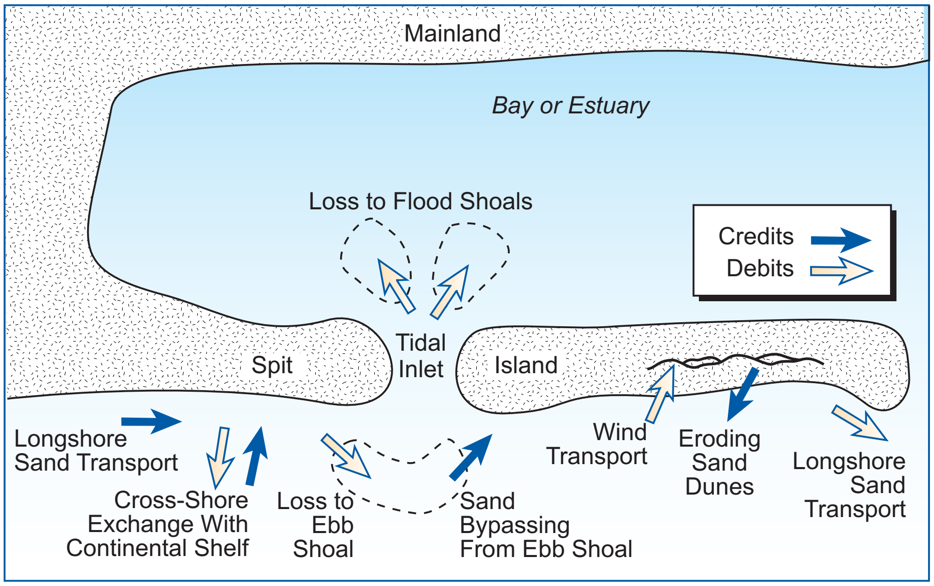


Figure 3-2
Principal components of a typical sediment budget for a barrier island and barrier spit shoreline.

DEFINITION

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

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

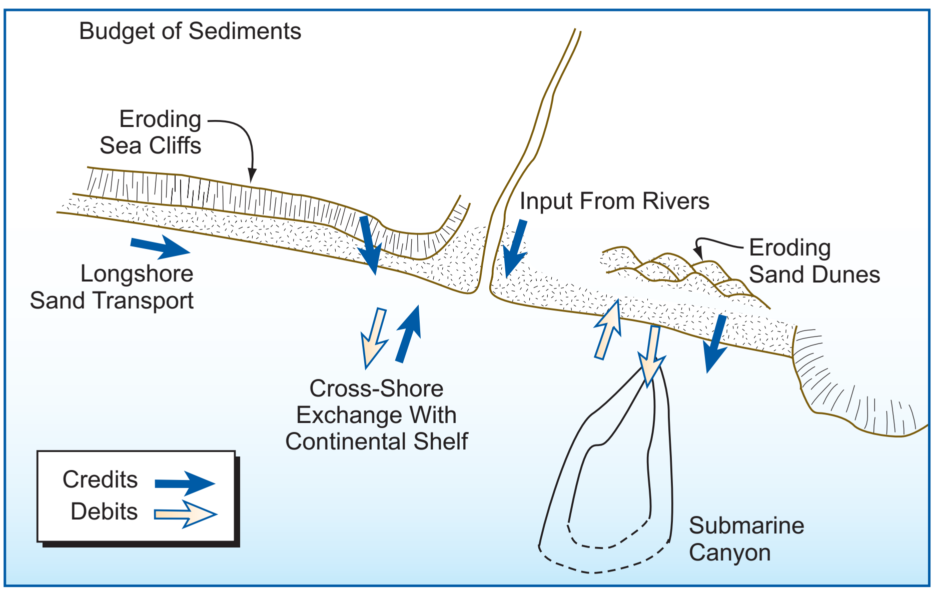


Figure 3-3
Principal components of a typical sediment budget for a mainland shoreline backed by bluffs and dunes. Modified from Komar 1996.

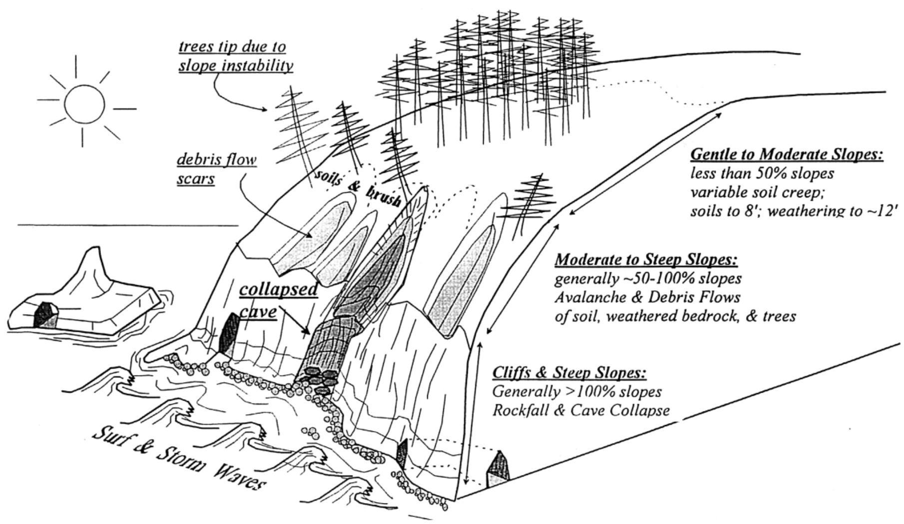
DEFINITION

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

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

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

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



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

3.2 United States Coastline Characteristics

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

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

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

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

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

  The *Florida Keys*

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

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

  The *Mississippi Delta* coast of southeast Louisiana

  The *Western Gulf* coast of Louisiana and Texas

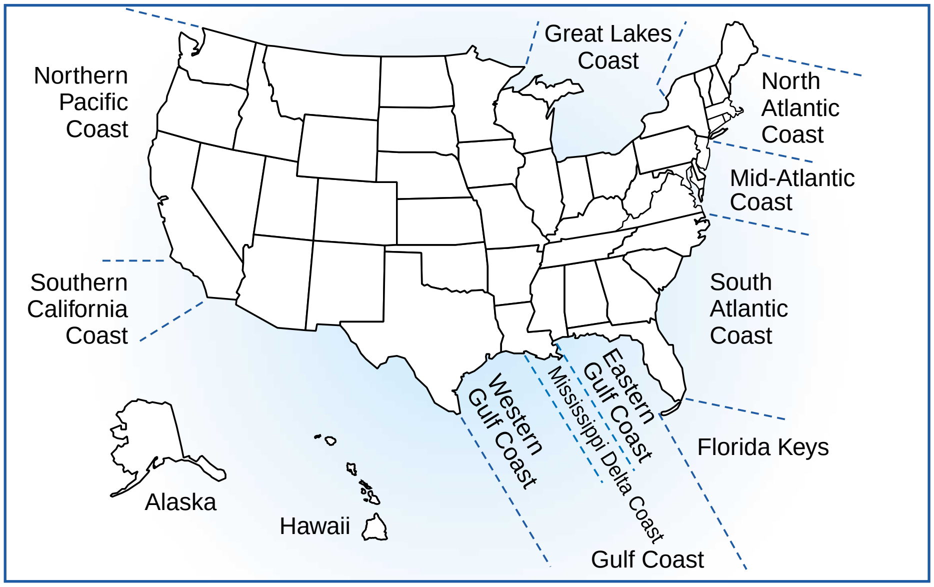


Figure 3-5
The United States coastline.

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

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

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

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

3.2.1 Atlantic Coast

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

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

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

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

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

3.2.2 Gulf of Mexico Coast

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

def-ə-

DEFINITION

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

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

3.2.3 Pacific Coast

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

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

3.2.4 Great Lakes Coast

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

3.2.5 Coast of Alaska

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

3.2.6 Coast of Hawaii and Pacific Territories

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

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

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

3.3 Coastal Flood Hazards

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

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

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

NOTE

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

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

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

NOTE

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

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

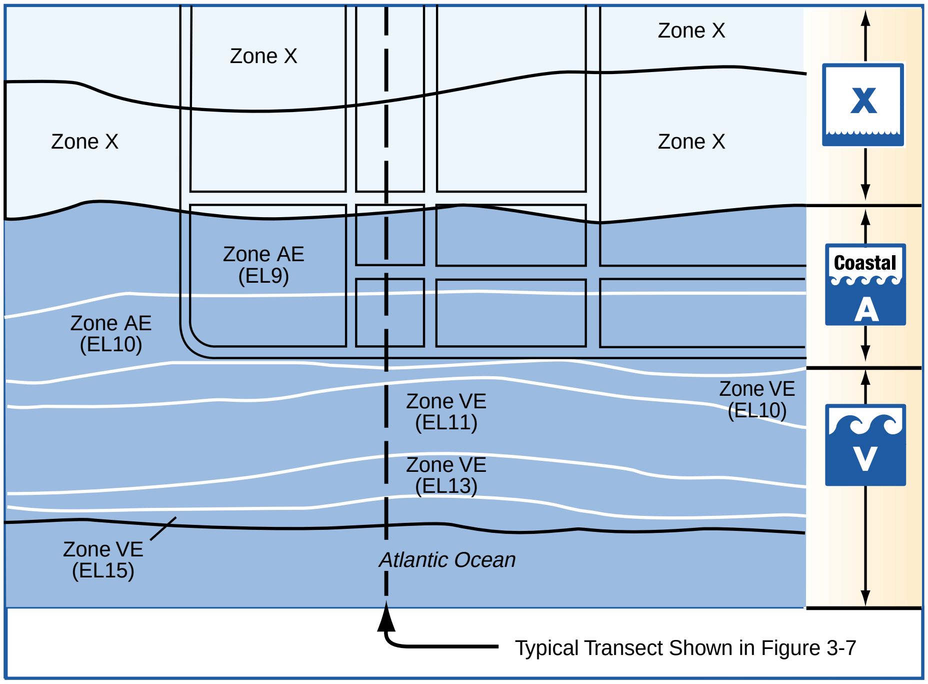
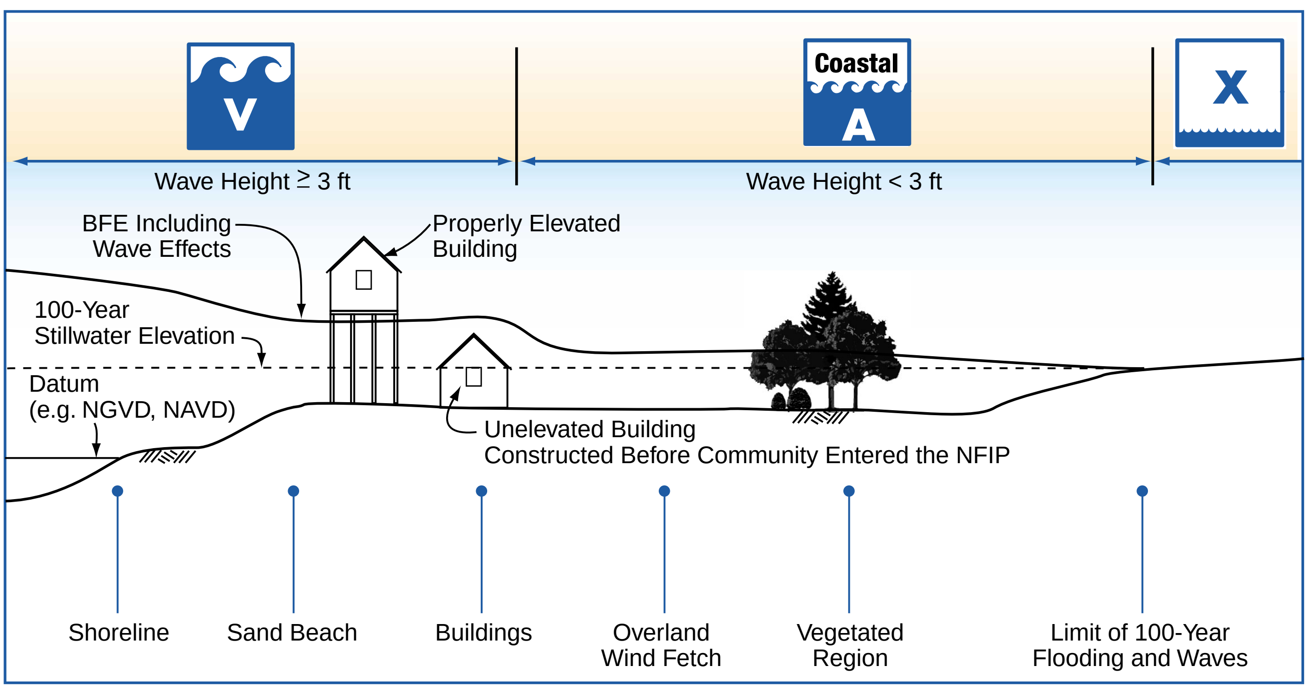


Figure 3-6
This portion of a FIRM shows a coastal Special Flood Hazard Area (SFHA) (dark gray), the 500-year flood hazard area (light gray), coastal Base Flood Elevations (BFEs) (numbers in parentheses), and flood insurance rate zones (AE and VE = SFHA, VE = Coastal High Hazard Area, X = areas outside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

NOTE

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

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



DEFINITION

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

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

CROSS-REFERENCE

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

CROSS-REFERENCE

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

DEFINITION

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

3.3.1 Wave Heights and Wave Crest Elevations

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

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

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

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

3.3.2 Wave Runup

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

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

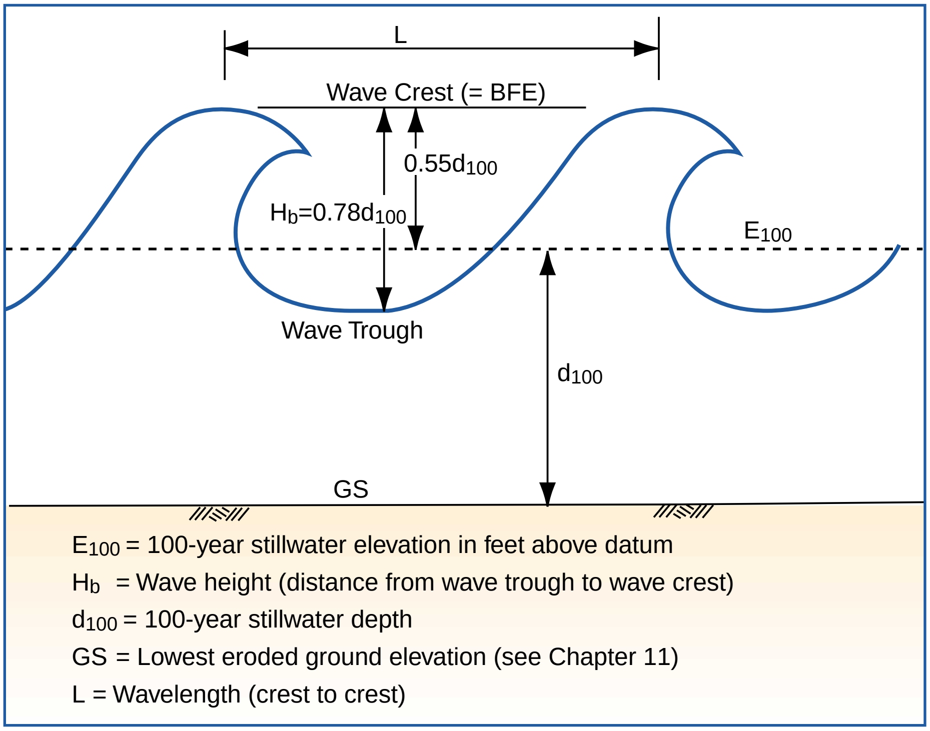
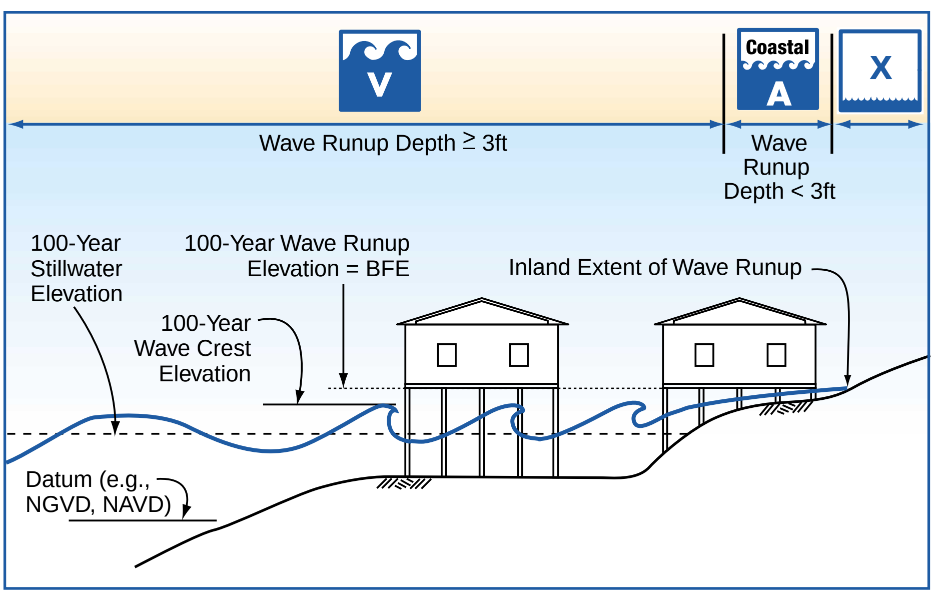


Figure 3-9
Where wave runup elevations exceed wave crest elevations, the BFE is equal to the runup elevation.



CROSS-REFERENCE

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

DEFINITION

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

DEFINITION

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

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

3.3.3 Erosion Considerations and Flood Hazard Mapping

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

CROSS-REFERENCE

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

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

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

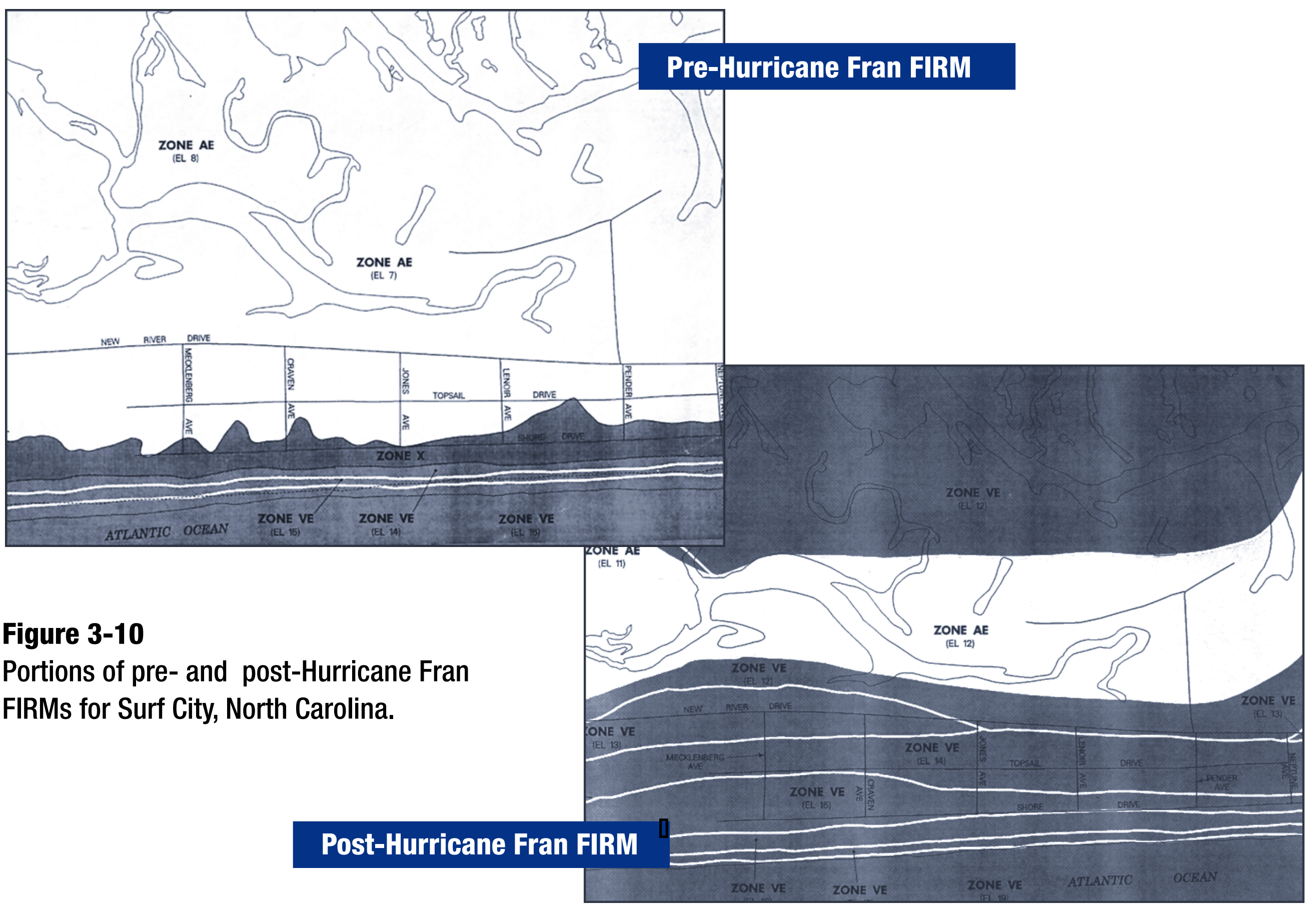


Figure 3-10
Portions of pre- and post-Hurricane Fran FIRMs for Surf City, North Carolina.

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

3.4 References

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Chapter 4: Fundamentals

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Fundamentals

4.1 Introduction

In coastal areas, a building can be considered a ***success*** only if it is capable of resisting damage from coastal hazards and coastal processes over a period of decades. This statement does not imply that a coastal residential building must remain undamaged over its intended lifetime. It implies that the impacts of a design level flood, storm, wind, or erosion event (or series of lesser events with combined impacts equivalent to a design event) will be limited to the following:

- The building foundation should remain intact and functional.
- The envelope (lowest floor, walls, openings and roof) should remain structurally sound and capable of minimizing penetration by wind, rain, and debris.
- The lowest floor elevation must be sufficient to prevent floodwaters from entering the elevated building envelope during the design event.
- The utility connections (e.g., electricity, water, sewer, natural gas) should remain intact or be restored easily.
- The building should be accessible and usable following a design-level event.
- Any damage to **enclosures** below the design flood elevation (DFE) should not result in damage to the foundation, the utility connections, or the elevated portion of the building.

Note that success during a design seismic event is defined differently than in flood, storm, wind, and erosion events:

- The building should protect life and provide safety, even though the structure itself may sustain significant damage.

The above definitions of "building success" can be met through various methods, but they all have one thing in common—careful consideration and use of siting, design, construction, and maintenance practices. Failure to address even one of these four concerns can lead to building damage, destruction, or loss of use. Hence:

- A design and construction success can be negated by a failure to site the building properly (see Figures 4-1, 4-2, and 4-3). The house shown in Figure 4-1 appears to be a structural success, but long-term erosion has left it standing permanently in the water. As a result, it is now uninhabitable. The three houses in Figure 4-2 were built between January 1995 and January 1996, approximately 2 years before the

NOTE

Design of a "successful" coastal building must consider the effects of coastal hazards and coastal processes over a period of decades.

DEFINITION

For the purposes of this manual, an **enclosure** is that portion of an elevated building below the design flood elevation (DFE) that is partially or fully surrounded by solid (including breakaway) walls. See the warning on page 4-12 of this chapter, and Sections 6.4.3.3 and 9.3.1.1, in Chapters 6 and 9, respectively, for more information about enclosures and the use of space below elevated buildings.

NOTE

A conservative approach to siting and design of coastal residential buildings is recommended—even expert opinion can underestimate the hazards to which a building will be exposed over its lifetime.

photograph was taken (July 1997). They were built 100 or more feet landward of the vegetation line, but rapid erosion associated with a nearby tidal inlet has left the houses standing on the beach. The shoreline will probably return to its former location, taking several years to do so. Although the buildings are structurally intact, their siting can be considered a failure. The townhouses shown in Figure 4-3 were built as little as 10 feet landward of a 170-foot-high bluff in 1991–92. By late 1997, storm- and inlet-related erosion at the base of the bluff destabilized the bluff face and threatened some of the buildings. Although experts assured the local government that the site was safe, it was not.

Figure 4-1
Although this North Carolina house appears to be a structural success, long-term erosion has left it standing on the beach.

Figure 4-2
These three South Carolina houses were built at least 100 feet landward of the vegetation line, but rapid erosion associated with a nearby tidal inlet has left the houses standing on the beach. Although these buildings are structurally intact, their siting can be considered a failure. (July 1997 photograph)

Figure 4-3
These Oregon townhouses were built as little as 10 feet landward of a 170-foot-high bluff, after an expert assured the local government that the site was suitable. Storm- and inlet-related erosion at the base of the bluff has destabilized the bluff and threatened some of the buildings. (April 1998 photograph)

- A siting success can be overshadowed by poor design, construction, or maintenance. The house shown in Figure 4-4 was set back from the shoreline, and safe from long-term erosion. However, it could not resist wind from Hurricane Fran.

Figure 4-4
Hurricane Fran (1996). This North Carolina house was set back from the shoreline, and safe from long-term and storm-induced erosion. However, high winds from the storm caused heavy damage to the porch walls and roof. (September 1996 photograph)

It must be recognized that lack of building damage during a high-probability (low-intensity) storm, flood, or other event cannot be construed as a building success – success can only be measured against a design event or against a series of lesser events with the cumulative effect of a design event.

Finally, before focusing on siting, design, construction, and maintenance issues, this manual must address more fundamental issues, such as those associated with hazard identification, hazard vulnerability, risk assessment, and risk management.

4.2 Hazards, Risk Assessment, and Risk Management

The coastal construction process described in this manual is intended to reduce damage caused by natural hazards in coastal areas. These hazards include not only those associated with widely recognized, discrete events that recur over time, such as hurricanes, coastal storms, earthquakes, and earthquake-induced landslides and tsunamis, but also continuous and less-obvious coastal phenomena such as long-term erosion, shoreline migration, and the corrosion and decay of building materials. The effects of hazards associated with recurring events are often immediate, severe, and readily apparent, while those associated with long-term processes are more likely to become apparent only after having accumulated over time.

Sound coastal construction, therefore, depends upon an understanding of the natural hazards that affect coastal areas, an accurate characterization of the variety of risks to which coastal construction is exposed, and an understanding of various risk management techniques. For the purposes of this discussion, several key terms will be defined (a more detailed discussion of these terms and related terms may be found in *Multi-Hazard Identification and Risk Assessment, A Cornerstone of the National Mitigation Strategy* [FEMA 1997]).

Hazard Identification means the process of defining and describing a hazard (including its physical characteristics, magnitude, severity, frequency, and causative factors) and the locations or areas it affects.

Risk means the potential losses associated with a hazard, defined in terms of expected probability and frequency, exposure, and consequences.

Risk Assessment means a process or method for evaluating risk that is associated with a specific hazard and defined in terms of probability and frequency of occurrence, magnitude and severity, exposure, and consequences.

Risk Management means measures taken to reduce, modify, offset, or share risks associated with development in areas subject to coastal hazards. In the context of coastal residential construction, risk management is usually accomplished through mitigation (see below) or insurance.

Mitigation means sustained action taken to reduce or eliminate long-term risk to people and property from hazards and their effects. In the context of coastal residential construction, mitigation usually takes the form of siting, design, construction, and maintenance of the building itself, and (sometimes) the form of protective works (e.g., dune or bluff stabilization, erosion control structures, beach nourishment). Mitigation distinguishes actions that have a long-term impact from those that are more closely associated with preparedness for, immediate response to, and short-term recovery from a specific event.

4.2.1 Risk Assessment

For the purposes of this manual, *risk assessment* is the process of quantifying the total risk to a coastal building (i.e., the risk associated with all the significant natural hazards that may act on the building.) The *risk* associated with any one hazard is defined by the combination of two factors:

1. the probability that an event of a given recurrence interval will affect the building within a specified period
2. both the short-term and long-term consequences of that event for the building

NOTE

Risk Assessment must consider the occurrence and effects of multiple events, not just a single event. For example, it is not uncommon for an area to be struck by several minor storms in a short period of time, and for those storms to cause more damage than a major storm.

4.2.1.1 Probability and Recurrence Interval

In most coastal areas of the United States, buildings must meet minimum regulatory and code requirements intended to provide protection from natural hazard events of specified magnitudes. These events are usually identified according to their recurrence intervals. Examples are the 100-year flood (the flood that has a 1-percent probability of being equaled or exceeded in any given year) and the 50-year wind (the wind that has a 2-percent probability of being equaled or exceeded in any given year).

To determine the probability that a building will be affected by a specific natural hazard event, the designer must know not only the recurrence interval of the event, but also the period during which the building will be exposed to the hazard. The length of this period is determined by the designer, but it should not be arbitrary; it should be based on some amount of time relevant to the building, such as the assumed useful life of the building.

NOTE

While designers may assume a "useful life" for coastal buildings, owners typically view the habitation of the site as permanent (although the building itself may be renovated or replaced several times). Thus, designers may wish to consider two useful lives, one for the building itself and a longer lifetime for siting and setback purposes.

When the recurrence interval of a natural hazard event is known, the designer can determine the probability of one or more occurrences of that event or a larger event during the specified period. Table 4.1 illustrates this concept for natural hazard events with recurrence intervals of 10, 25, 50, 100, and 500 years. Of particular interest in this example is the 100-year event, because the 100-year flood serves as the basis for the floodplain management and insurance requirements of the National Flood Insurance Program (NFIP) regulations.

As noted above and shown in Table 4.1, the 100-year flood has a 1-percent probability of being equaled or exceeded during a 1-year period. As the length of the period increases, so does the probability that a flood of this magnitude or greater will occur. For example, during a 30-year period (equivalent to the length of a standard mortgage), the probability increases to 26 percent. And during a 70-year period, which may be assumed to be the useful life of many buildings, the probability increases to 50 percent. The same principle applies to other natural hazard events with other recurrence intervals.

Table 4.1 Natural Hazard Probabilities During Periods of Various Lengths*

LENGTH OF PERIOD (YEARS)	FREQUENCY – RECURRENCE INTERVAL: 10- YEAR EVENT	25- YEAR EVENT	50- YEAR EVENT	100- YEAR EVENT	500- YEAR EVENT
1	10 %	4 %	2 %	1 %	0.2 %
10	65 %	34 %	18 %	10 %	2 %
20	88 %	56 %	33 %	18 %	5 %
25	93 %	64 %	40%	22 %	5 %
30	96 %	71 %	45 %	26 %	6 %
50	99+ %	87 %	64%	39 %	10 %
70	99.94+ %	94 %	76 %	50 %	13 %
100	99.99+ %	98 %	87 %	63 %	18 %

*The percentages shown represent the probabilities of one or more occurrences of an event of a given magnitude or larger within the specified period. The formula for determining these probabilities is $P_n = 1-(1-P_a)^n$, where P_a = the annual probability and n = the length of the period.

WARNING

Designers along Great Lakes shorelines should be aware that flood probabilities shown in Table 4.1 may underestimate actual probabilities during periods of high lake levels. For example, Potter (1992) calculated that during rising lake levels in 1985, Lake Erie had a 10-percent probability of experiencing a 100-year flood event in the next 12 months (vs. 1-percent as shown in Table 4.1)

4.2.1.2 Consequences of the Hazards

The nature and severity of an event's consequences for a given building will depend on the hazard forces associated with the event, over which the designer has no control, and on the siting, design, construction, and maintenance of the building, which are largely within the control of the designer.

Because most coastal areas of the United States are subject to multiple hazards, the designer must identify all significant hazards at the construction site and determine the vulnerability of the building to those hazards. The risk assessment must account for the short-term and long-term effects of each hazard, including the potential for cumulative effects, and the combination of effects from different hazards. Overlooking a hazard or underestimating its long-term effects can have disastrous consequences for the building and its owner.

4.2.1.3 Safety Factors and the Consequences of Exceeding a Design Condition

The selection of specific design conditions for an individual building should consider the safety factors inherent in the design, construction, and regulatory process and the consequences of a hazard exceeding the design condition. A good example is the difference in return frequencies used nationally for minimum wind and flood standards.

Minimum wind regulations are generally based on a 50-year return frequency. For a house in use for 70 years, it is likely (a 76-percent probability from Table 4.1) that a faster wind will occur. However, the design process for wind applies safety factors in the estimation of both the force of the wind on the structure and the strength of the materials intended to resist the wind force. If a house is properly designed and constructed, a net safety factor of at least 1.5 in the wind-resisting strength of the building can be expected. The safety factors for a house designed for 120-mph winds should mean that there will be no damage at 121 mph or even considerably faster. The consequences of a wind speed somewhat higher than design wind is very small—a relatively low risk of additional damage.

In comparison, flood regulations include no safety factors but partially compensate by using a longer return frequency of 100 years. From Table 4.1, the 70-year-old house is at lower risk to flood than wind, only a 50-percent chance of experiencing a worse flood, versus 76 percent for wind. However, the consequences of flooding slightly above the standard are severe. A water level a few inches above a minimum floor elevation can result in damaged walls, flooded carpets, warped flooring, and the loss of floor insulation, wiring, and ductwork. **Safety factors for flood resistance are not inherent in the design process but must be specified by the designer or owner.**

Wind and flood standards are based on reducing building damage. In contrast, fire safety regulations are based on life safety issues. The protection of human life is held to much higher standard than the risk of property damage. Similarly, high-occupancy publicly used buildings are held to even higher standards (e.g., the requirement for sprinkler systems) because more many lives are at risk.

Safety factors are not only used for wind, flood, seismic, and other design loads, but are also used by geotechnical engineers to determine the risk of slope failures to blufftop buildings. The ratio of soil strength to soil stresses is commonly used as the safety factor in such cases. The choice of a safety factor depends on the type and importance of blufftop development, the bluff height and the nature of the bluff failure (e.g., deep rotational failure vs. translational failure), and the acceptable level of risk associated with a bluff failure. Studies in the Great Lakes (Valejo and Edil 1979, Chapman et al. 1996, and Terraprobe 1994) provide guidance for the selection of appropriate safety factors.

NOTE

Safety factors are critical when bluff stability and setback distances are calculated.

Risk assessment for siting and design conditions should consider the return frequency of the hazard and any safety factors inherent in the design process, or safety factors should be explicitly added. In addition, the design should consider the severity of the consequences that would result if the design conditions are exceeded

4.2.2 Risk Management

Risk management refers to the process of reducing or offsetting risks. Therefore, risk management for coastal construction requires an understanding of the following:

- the ways in which siting, design, construction, and maintenance decisions can mitigate or exacerbate the consequences of individual hazard events
- the role of hazard insurance
- the acceptable level of residual risk (i.e., risk not offset through siting, design, construction, maintenance, and insurance)

COST CONSIDERATION

There are costs associated with all decisions made regarding coastal construction. Some costs are readily apparent, while others are not.

Risks can be managed physically—through the protection provided by siting, design, construction, and maintenance—and financially through the protection provided by insurance. Some risks can also be managed through protective works (where permitted by local and state jurisdictions). But eliminating all risk is impossible; therefore, inherent to residual risk management is the concept of an *acceptable level of residual risk*—that is, the level of risk that is not offset and that must be accepted by the property owner. The principle of residual risk management, including the acceptable level of residual risk, underlies the entire coastal construction process.

4.2.2.1 Risk Management Through Hazard Mitigation

NOTE

Meeting only minimum code and regulatory requirements may result in designs based on different levels of risk for different hazards. The hazard levels addressed by such requirements should therefore be carefully considered during the design process.

Building codes and Federal, state, and local regulations establish minimum requirements for siting, design, and construction. Among these are requirements that buildings be constructed to withstand the effects of natural hazards with specified recurrence intervals (e.g., 100-year flood, 50-year wind, 500-year earthquake). Therefore, when building code and regulatory requirements are met, they can help reduce the vulnerability of a building to natural hazards and, in a sense, provide a baseline level of risk management. It should be noted, however, that **meeting minimum regulatory requirements for the siting, design, and construction of a building does not guarantee that the building will be "safe."**

Property owners, developers, and builders have the ability to further manage risks by providing an increased level of hazard mitigation. For example:

- A building can be sited further landward than the minimum distance specified by state or local setback requirements.
- A building can be elevated above the level required by NFIP, state, and local requirements.
- Supporting piles can be embedded deeper than required by state or local regulations.
- Structural members or connections can be used that exceed code requirements for gravity, uplift, and/or lateral forces.
- Improved roofing systems can be used that provide greater resistance to wind than that required by code.
- Building and roof shapes (e.g., hip roofs) can be selected that reduce wind loads.
- Openings (e.g., windows, doors) can be protected with permanent or temporary shutters or covers, whether or not such protection is required by code
- Construction of enclosures below an elevated building can be eliminated or minimized. Enclosures will be vulnerable to flood damage (even during minor flood events), are not covered by the Standard Flood Insurance Policy, and will increase flood insurance premiums for the building.

Consider the following example of how just one decision left to the designer, builder, or homeowner can affect risk. Local floodplain management requirements that comply with the NFIP regulations require that any building constructed in the V zone be elevated so that the bottom of the lowest horizontal structural member is at or above the Base Flood Elevation (BFE) (100-year flood elevation, including wave effects). Meeting this requirement should protect the elevated portion of the building from the 100-year and lesser floods. However, the elevated part of the building is still vulnerable to floods of greater magnitude. As shown in Table 4.1, the probability that the building will be subjected to a flood **greater** than the 100-year flood during an assumed useful life of 70 years is 50 percent. But during the same 70-year period, the probability of a 500-year or greater flood is only 13 percent. Therefore, raising the lowest horizontal structural member to the elevation of the 500-year flood would significantly reduce the risk for that building. If elevating to the level of the 500-year flood is not possible, because of cost or other considerations, elevating by some lesser amount above the BFE will still reduce the risk.

WARNING

Regulations require a minimum standard, but do not imply that any building that meets the standard is "safe." For example, a 30-year erosion setback does not imply that a building will be safe from erosion at that location. In fact, it is an estimation of future erosion based on historical erosion rates. A building located at the 30-year setback may be threatened long before 30 years pass.

CROSS-REFERENCE

BFEs and the elevations of floods with other recurrence intervals (e.g., 500-year flood) are shown in FEMA Flood Insurance Study (FIS) reports (see Chapters 3 and 6) .

COST CONSIDERATION

In some areas, mortgage lenders may require that borrowers obtain specific types of hazard insurance.

NOTE

In the past, homeowners have relied on insurance for replacement costs when a natural hazard occurred, without regard to the inconvenience and disruption of their daily lives. Little thought was given to mitigation. Taking a mitigation approach can reduce these disruptions and inconveniences.

COST CONSIDERATION

Unless large numbers of buildings perform reasonably well, insurance availability or affordability can be jeopardized; therefore, enhancing performance through mitigation is important.

Like the decision described above, decisions made concerning the placement and orientation of the building, its size and shape, and the materials and methods used in its construction can decrease (or increase) potential damage from natural hazard events. However, these decisions can also affect initial and long-term costs (see Section 4.3), aesthetic qualities (e.g., the appearance of the finished building, views from within), and convenience for the homeowner (e.g., accessibility). The tradeoffs among these factors involve objective and subjective considerations that are often difficult to quantify and are likely to be assessed differently by developers, builders, homeowners, and community officials. Ultimately, however, a balance must be struck between cost, siting, and design decisions on the one hand and the amount of protection provided on the other.

4.2.2.2 Risk Management Through Insurance

Insurance provides a property owner with a financial tool for managing risk. For houses in coastal areas, the risks associated with flooding, high winds, and, in some areas, earthquakes are of particular concern. These risks can be addressed through a variety of insurance mechanisms, including the NFIP, homeowners insurance, insurance pools, and self-insurance plans.

Flood Insurance

Federally backed flood insurance is available for both existing and newly constructed buildings in communities that participate in the NFIP. To be insurable under the NFIP, a building must have a roof, have at least two walls, and be at least 50 percent above grade. Like homeowner's insurance, flood insurance is obtained from private insurance companies. But an important distinction is that insurance companies that issue homeowner's policies occasionally deny wind and earthquake coverage to buildings in areas where the risks from these hazards are high. Flood insurance, because it is federally backed, is available for buildings in all coastal areas of participating communities, with the following exceptions:

- buildings constructed entirely over water or seaward of mean high tide after October 1, 1982
- buildings newly constructed, substantially improved, or substantially damaged on designated undeveloped coastal barriers included in the Coastal Barrier Resources System after October 1, 1983 (see Section 6.6 in Chapter 6 of this manual)
- portions of boat houses located partially over water (e.g., the ceiling and roof over the area where boats are moored)

As discussed in Chapter 9, the flood insurance rates for buildings in participating communities vary according to the physical characteristics of the building, the date the building was constructed, and the magnitude of the flood hazard at the site of the building. The flood insurance premium for a building is based on the rate, standard per-policy fees, the amount of the deductible, applicable NFIP surcharges and discounts, and the amount of coverage obtained.

Wind Insurance

Homeowner's insurance policies normally include coverage for wind. However, as noted previously, wind coverage is not always available, especially in coastal areas subject to a significant hurricane or typhoon risk, where wind hazards are usually high. At the time this manual was prepared, underwriting associations, or "pools," were a last resort for homeowners who need wind coverage, but could not obtain it from private companies. Eight states have established windstorm insurance plans: Alabama, Florida, Louisiana, Mississippi, New York, North Carolina, South Carolina, and Texas. In addition, New Jersey operates the Windstorm Market Assistance Program (Wind-MAP) to help residents in coastal communities find homeowner's insurance in the voluntary market. When Wind-MAP does not identify an insurance carrier for a homeowner, the New Jersey FAIR Plan may provide a policy for perils only.

Earthquake Insurance

A standard homeowner's insurance policy can often be modified through an endorsement to include earthquake coverage. However, like wind coverage, earthquake coverage may not be available in areas where the earthquake risk is high. Moreover, deductibles and rates for earthquake coverage (of typical coastal residential buildings) are usually much higher than those for flood, wind, and other hazard insurance.

Self-Insurance

Where wind and earthquake insurance coverage is not available from private companies or insurance pools—or where property owners choose to forego available insurance—owners with sufficient financial reserves may be able to insure themselves (i.e., assume complete financial responsibility for the risks not offset through siting, design, construction, and maintenance). It is imperative, however, that property owners who contemplate self-insurance understand the true level of risk they are assuming.

4.3 Cost Considerations

Coastal residential buildings, like all buildings, have initial, long-term, and operational costs.

Initial costs include property evaluation and acquisition costs, and the costs of permitting, design, and construction.

Long-term costs include costs for preventive maintenance and for repair and replacement of deteriorated or damaged building components.

Operational costs include costs associated with the use of the building, such as the costs of utilities and insurance.

In general, the decision to build in any area subject to significant natural hazards—especially coastal areas—increases the initial, long-term, and operational costs of building ownership. Initial costs increase because the natural hazards must be identified, the associated risks assessed, and the building designed and constructed to resist damage from the natural hazard forces. Long-term costs are likely to be greater because a building constructed in a natural hazard area will usually require more frequent and more extensive maintenance and repairs than a building sited elsewhere. Operational costs can increase for buildings in hazard areas because of higher insurance costs and, in some instances, higher utility costs.

Once a site has been selected, decisions must be made concerning the placement and orientation (siting or location) of the building and its design. These decisions are driven primarily by the following:

- owner, designer, and contractor awareness of natural hazards
- risk tolerance of the owner
- aesthetic considerations (e.g., the appearance of the building, its proximity to the water, views from within the building, sizes and numbers of windows)
- building use (e.g., full-time residence, part-time residence, rental property)
- requirements of Federal, state, and local regulations and codes
- initial costs and long-term costs

The interrelationships among aesthetics, building use, regulatory and code requirements, and initial cost become apparent during siting and design, and decisions are made according to the individual needs or goals of the property owner, designer, or builder. What is often lacking in this process is an understanding of the effect of these decisions on long-term and operational costs. The consequences can range from increased maintenance and utility

WARNING

Improper construction of enclosures below elevated V-zone residential buildings and post-construction conversion of enclosed space to habitable use (in A zones and V zones) are the biggest compliance problems faced by the NFIP. Designers and owners should realize that (1) enclosures and items within them are subject to flood damage (even during minor flood events), (2) enclosures—and most items with them—are *not covered* by flood insurance and can result in significant costs to the building owner, and (3) even the presence of properly constructed enclosures will increase flood insurance premiums for the entire building (the premium rate will increase as the enclosed area increases). Including enclosures in a building design can have significant cost implications.

This manual recommends the use of insect screening or open wood lattice instead of solid enclosures beneath elevated residential buildings. Note that some designers have incorporated open lattice with layers of translucent, reinforced plastic to overcome the most common objection by property owners—passage of salt spray and blowing sand through open lattice.

costs to the ultimate loss of the building. The following examples illustrate some of the effects that siting and design decisions can have on long-term and operational costs.

Cost Implications of Siting Decisions

- The closer buildings are sited to the water the more likely they are to be affected by flooding, wave action, erosion, scour, debris impact, overwash, and corrosion. In addition, wind speeds are typically higher along coastlines, particularly within the first several hundred feet inland. **Repeated exposure to these hazards, even when buildings are designed to resist their effects, can lead to increased long-term costs for maintenance and damage repair.**
- Erosion—especially long-term erosion—poses an especially serious threat to buildings near the water, even those situated on high bluffs above the floodplain. Storm-induced erosion can lower ground elevations around coastal buildings, exposing V-zone buildings to higher than anticipated forces, and exposing A-zone buildings to V-zone flood hazards. **Maintenance and repair costs will be high for buildings in erosion hazard areas, not only because of damage to the building, but also because of the need for remedial measures (e.g., building relocation or erosion protection projects, such as seawalls, revetments, or beach nourishment, where permitted).** Note that the average annual maintenance cost for shore protection can equal 5 to 10 percent of construction cost or the cost of building relocation.
- Sites nearest the water are more likely to be in a V zone, where building foundations, access stairs, parking slabs, and other components below the building are especially vulnerable to flood, erosion, and scour effects. As a result, **the potential for repeated damage and repair costs is greater for V-zone buildings, and the buildings have higher flood insurance rates and increased operational costs.** In addition, although elevating a building can protect the superstructure from flood damage, it may make the entire building more vulnerable to earthquake and wind damage.

Cost Implications of Design Decisions

- For aesthetic reasons, the walls of coastal buildings often include a large number of openings for windows and doors, especially the walls that face the water. **Designs of this type lead to greater initial costs for strengthening the walls and for protecting the windows and doors from wind and windborne debris (missiles)**. If adequate protection in the form of shutter systems or impact-resistant glazing is not provided, long-term costs will increase because of (1) the need to repair damage to glazing and secondary damage to the building caused

CROSS-REFERENCE

See Sections 6.4.3.3 and 9.3.1.1, in Chapters 6 and 9, respectively, for additional information about enclosures, the use of space below elevated buildings, and flood insurance.

CROSS-REFERENCE

Chapter 8 of this manual discusses the siting of coastal residential buildings.

COST CONSIDERATION

Designers and homeowners should recognize that erosion control measures can be expensive, both initially and over the lifetime of a building. In some instances, erosion control costs can equal or exceed the cost of the property or building being protected.

CROSS-REFERENCE

Chapter 12 of this manual discusses the design of coastal residential buildings.

by the entry of wind-driven rain and sea spray and/or (2) the need to install retrofit protection devices at a late date.

- As explained in Chapter 6 of this manual, NFIP regulations allow buildings in coastal A zones to be constructed on perimeter wall (e.g., crawlspace) foundations or on earth fill. Open (pile, pier, or column) foundations are required only for V-zone buildings. Although a coastal A-zone building on a perimeter wall foundation or fill may have a lower initial construction cost than a similar building on an open foundation, it may well be subject to damaging waves, velocity flows, and/or erosion scour over its useful life. As a result, **the long- term costs for a building on a perimeter wall foundation or fill may actually be higher because of the increased potential for damage**.
- Designers, in an effort to reduce initial construction costs, may select building materials that require high levels of maintenance. Unfortunately, two things tend to counteract any initial savings: (1) coastal buildings, particularly those near bodies of salt water, are especially prone to the effects of corrosion, and (2) owners of coastal buildings frequently fail to sustain the continuing and time-consuming levels of maintenance required. **The net effect is often increased building deterioration and, sometimes, a reduced capacity of structural and non-structural components to resist the effects of future natural hazard events**.

4.4 References

Chapman, J. A.; T. B. Edil; and D. M. Mickelson. 1996. *Effectiveness of Analysis Methods for Predicting Long Term Slope Stability on the Lake Michigan Shoreline*. Final report of the Lake Michigan, Wisconsin, Shoreline Erosion and Bluff Stability Study. December.

Federal Emergency Management Agency. 1997. *Multi-Hazard Identification and Risk Assessment, A Cornerstone of the National Mitigation Strategy*.

Potter, K. W. 1992. "Estimating the Probability Distribution of Annual Maximum Levels on the Great Lakes." *Journal of Great Lakes Research, International Association of Great Lakes Research*. (18)1, pp. 229-235.

Terraprobe. 1994. *Geotechnical Principles for Stable Slopes. Great Lakes-St. Lawrence River Shoreline Policy*. Prepared for the Ontario Ministry of Natural Resources. Terraprobe, Ltd., Brampton, Ontario. March.

Valejo, L. E.; T. B. Edil. 1979. "Design Charts for Development and Stability of Evolving Slopes." *Journal of Civil Engineering Design*. Marcel Dekker, Inc., publisher, 1(3), pp. 232-252.

Chapter 5: Identifying and Evaluating Site Alternatives

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Identifying and Evaluating Site Alternatives

5.1 Introduction

Informed decisions regarding siting, design, and construction begin with a complete and detailed understanding of the advantages and disadvantages of potential sites for coastal residential construction. It is hoped that this knowledge will be gained *prior* to the purchase of coastal property and the initiation of development.

NOTE

One of the principal objectives of this manual is to improve site selection for coastal residential buildings.

Experience has shown that not all coastal lands are suitable for development, or at least not the type and intensity of development that has occurred on coastal lands in the past. Figures 4-1, 4-2, and 4-3 in the preceding chapter show some of the results of inappropriate site selection and development. Unfortunately, many similar siting and development decisions are made every day based on site conditions at the time of purchase or on an incomplete or inaccurate assessment of future conditions. Too often these decisions leave property owners and local governments struggling in the future with a number of *avoidable* problems:

- damage to or loss of buildings
- damage to attendant infrastructure
- encroachment of buildings onto public beaches
- the need to provide emergency or permanent measures to protect vulnerable buildings and infrastructure
- the need to relocate buildings
- emergency evacuation
- injuries and loss of life

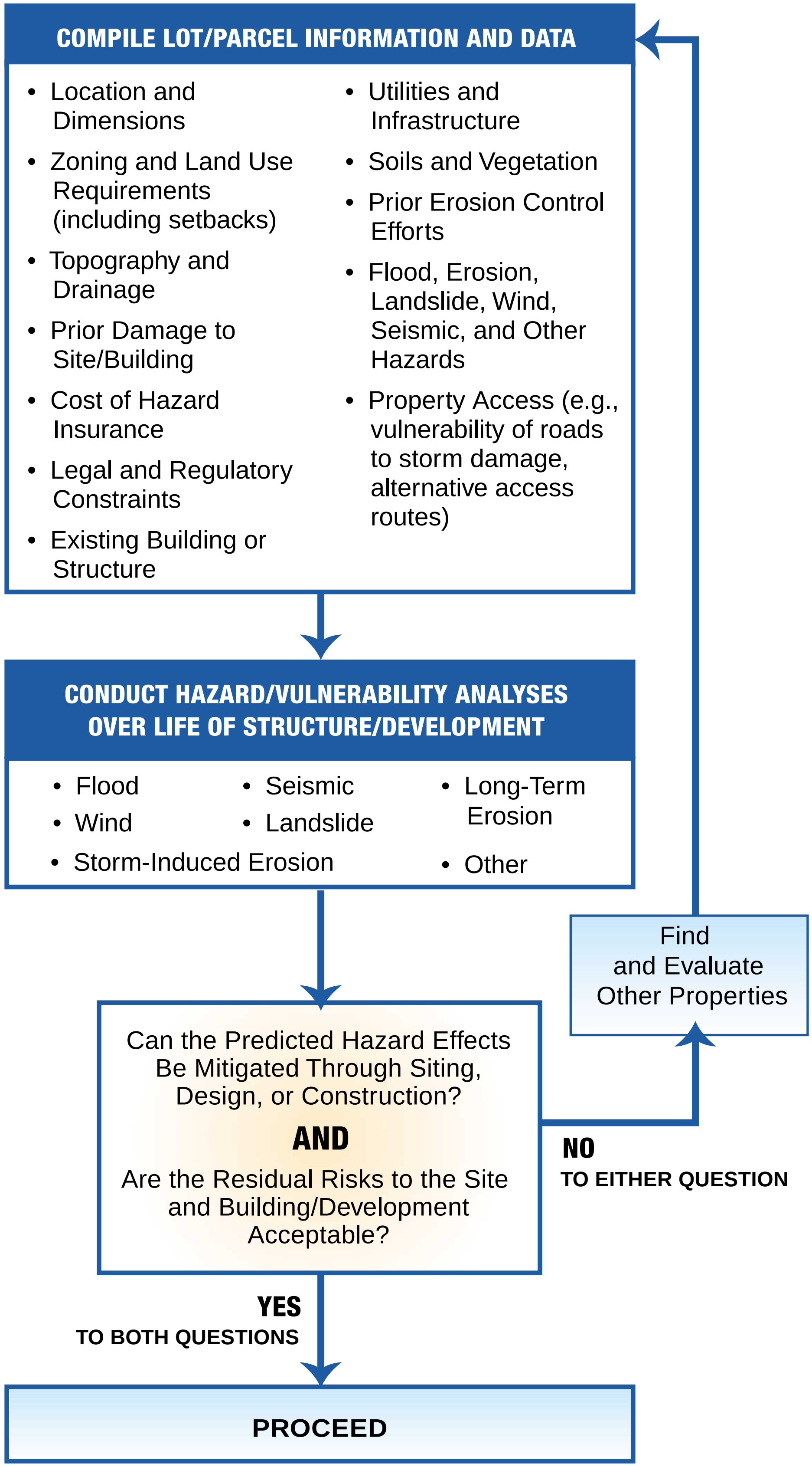
A thorough evaluation of coastal property for development purposes involves four steps (see Figure 5-1):

1. Compile lot/parcel information for one or more candidate properties, and, for each property follow steps 2 through 4:
2. Conduct a hazards analysis and risk assessment.
3. Determine whether the hazards can be mitigated through siting, design, or construction and whether the residual risks to the site and the building are acceptable.
4. Either proceed with the purchase or development of a property, or reject the candidate properties, and find and evaluate other properties.

WARNING

Many coastal property buyers fail to investigate potential hazards to their land and buildings. Designers should work with owners to identify and mitigate those hazards.

Figure 5-1
Evaluation of coastal property.



A building or development site need not be vacant or undeveloped land; indeed, much of the coastal construction occurring today involves redevelopment or replacement of existing buildings. Therefore, this chapter will discuss property evaluation broadly and will apply to the following:

- *Infill development* – development on previously subdivided or platted vacant lots or small parcels, with roads and utilities in place, surrounded by or adjacent to residential structures
- *Redevelopment* – development on previously developed lots or small parcels on which a building currently exists (see Figure 5-2)
- *Development of raw land* – development on large, vacant parcels, usually without on-site access roads and utilities

Figure 5-2
Coastal development sometimes involves development of subdivisions or large residential projects from raw land. However, coastal development increasingly involves infill development between adjacent buildings or redevelopment of previously developed property, such as this post-Hurricane Fran elevation and reconstruction project on Figure Eight Island, North Carolina.

5.2 Identifying Suitable Property for Coastal Residential Structures

The first step in the coastal development or construction process involves the purchase of a vacant or previously developed lot or parcel. It is this step that, in many ways, constrains subsequent siting, design, and construction decisions and determines the long-term vulnerability of coastal residential buildings. **Prospective property buyers who fail to fully investigate properties before acquiring them may subsequently be faced with a variety of problems that are difficult, costly, or essentially impossible to solve.**

Although this manual will not address the initial identification of candidate properties in detail, property buyers and design professionals who are assisting them in property evaluations should keep the following in mind as they narrow their search for a building/development site:

- Before any purchase, each property buyer should, **in consultation with experts**, determine the acceptable level of residual risk and decide how to manage the actual risks expected over the life of the building or development. Note that risk assessment, risk tolerance, and risk management issues are not simple — **property acquisition and development decisions must often be made with inadequate or imprecise information**.
- The geographic region or area a purchaser is interested in will determine the **types of hazards** to which the property will be exposed.
- In the absence of better information, **historical records** can be used to predict future hazard conditions, impacts, and frequencies. However, natural and manmade changes at a site may render simple extrapolation of historical patterns inaccurate.
- Any given lot or parcel may or may not be suitable for the purchaser's **intended use** of the property.
- Land use, zoning, setbacks, health, floodplain management, building code, and related requirements will, in large part, determine development densities, building size and location limitations, minimum design and construction practices, and allowable responses to erosion hazards; however, **compliance with these requirements does not ensure the future safety of the building or development**.
- Likewise, development **practices that perpetuate or duplicate historical siting, design, or construction practices will not ensure the future safety** of a new building or development. Many historical practices are inadequate by today's standards; further, **changing shoreline conditions** may render inadequate historical practices that were at one time adequate.

- An **existing erosion control structure** on a lot or parcel is an indication of prior erosion, but the structure **may or may not be adequate to protect** a building or development in the future; moreover, many states and communities limit or prohibit construction or reconstruction of erosion control devices (see Figure 5-3).
- The **vulnerability of a coastal building will probably increase with time**, as a result of one or more of the following: a gradual weakening or deterioration of the building itself, sea-level or lake-level rise, or erosion-induced shoreline recession, which affects the majority of coastal areas.
- **Future development activities** and patterns on adjacent and nearby properties may affect the vulnerability of buildings or development on any given property.
- **Property selection, along with subsequent siting, design, construction, and maintenance decisions**, will determine the actual vulnerability of and risk to any building or improvements.

Figure 5-3
Narrowing the search for coastal property suitable for development or redevelopment requires careful consideration of a variety of property and area characteristics, including the nature and success of previous erosion control efforts (e.g., groins and revetments at this Massachusetts community). Note that some communities and states restrict or prohibit the construction or reconstruction of revetment, seawall, and groin structures such as those shown in the photograph.

5.3 Compiling Information on Coastal Property

After candidate properties are identified, the next step is to compile a wide range of information for each property. This is no trivial matter; completing this step may require considerable time and effort. The box at the top of Figure 5-1 lists the types of information that should be compiled. Table 5.1 is a checklist of general information that should be compiled. More detail is provided in Chapter 7 in the form of checklists for hazard and vulnerability evaluations.

NOTE

Owners or prospective buyers property of coastal property should contact their community or state officials for publications that will help them evaluate the property.

CROSS-REFERENCE

Chapter 6 of this manual provides more information about regulatory requirements that should be considered in the evaluation of potential building or development sites.

Many states and communities have produced brochures or publications that will help property owners and prospective buyers evaluate coastal property. The publications listed below are offered as examples of the types of information available.

Purchasing Paradise: Things to know and questions to ask when buying coastal property in Florida (Florida Coastal Management Program 1997). This brochure briefly summarizes coastal ecosystems, coastal processes, the impacts humans have on coastal environments, and important considerations regarding the purchase of coastal property.

Coastal Processes Manual: How to Estimate the Conditions of Risk to Coastal Property from Extreme Lake Levels, Storms, and Erosion in the Great Lakes Basin, 2nd edition (Keillor 1998). Although this manual contains information specific to the Great Lakes shorelines of Wisconsin, it also provides a technical framework for evaluating coastal processes and erosion control measures in other areas. A videotape was produced in conjunction with the first edition (1987) of the manual. The following web site complements, supplements, and updates the current manual: http://www.seagrant.wisc.edu/advisory/coastal_engr/index.html (see Appendix F).

A Manual for Researching Historical Coastal Erosion (Fulton 1981). This manual describes in detail how one might use historical weather data, local government records, and historical maps and photos to understand and quantify shoreline, sea bluff, and cliff retreat. Two communities in San Diego County, California, are used as case studies to illustrate the research methods presented.

Questions and Answers on Purchasing Coastal Real Estate in North Carolina (North Carolina Real Estate Commission 1996). This brochure provides prospective property owners with basic information on a variety of topics: shoreline erosion, erosion control, siting, storm-resistant construction techniques, flood and wind insurance, and building repair regulations.

Table 5.1 General Information Checklist*

PROPERTY LOCATION

- Municipal, township, county, or other local jurisdiction
- Street address
- Parcel designation (e.g., tax map ID)
- Subdivision information
- Special zoning or land use districts
- Other hazard area designation
- Natural resource protection area designation

PROPERTY DIMENSIONS

- Total acreage
- Seaward or waterward property boundary (platted or fixed line; moving line [e.g., Mean High Water line, Mean Low Water line, or other datum, elevation, feature])
- Property shape
- Property elevations and topography
- Location relative to adjacent properties; configuration of adjacent properties
- Shoreline frontage (i.e., dimension parallel to shoreline)
- Property depth (i.e., dimension perpendicular to shoreline)
- Acreage landward/outside of natural, physical, or regulatory construction or development limits (i.e., usable acreage)

LEGAL AND REGULATORY INFORMATION

- Land use designation at property and adjacent properties
- Zoning classification and resulting restrictions on use
- Building code and local amendments
- Flood hazard area: elevation and construction requirements
- Erosion hazard area: construction setbacks and regulations
- Natural resource protection area: siting, construction, or use restrictions
- Easements and rights-of-way on property (including beach access locations for nearby properties or the general public)
- Local/state siting and construction regulations
- Regulatory front, back, and side setbacks
- Local/state permitting procedures and requirements
- Local/state regulations regarding use, construction, and repair of erosion control measures
- Riparian rights
- Local/state restrictions on cumulative repairs or improvements
- Conditions or other requirements attached to building or zoning permits
- Subdivision plat covenants and other restrictions imposed by developers and homeowner's associations
- Hazard disclosure requirements for property transfer, including geologic hazard reports

* This checklist outlines the types of information that should be obtained in order to evaluate coastal property. Information listed in this table is usually available from local, regional, state, or Federal governments, from universities, or from knowledgeable professionals. However, the availability and quality of the information will vary by state and community.

Table 5.1 General Information Checklist (continued)*

PHYSICAL AND NATURAL CHARACTERISTICS

- Soils, geology, and vegetation – site and region
- Topography of nearshore (including nearshore slope), beach, dune, bluff, uplands
- Site drainage – surface water and groundwater
- Littoral sediment supply and sediment budget
- Storm, erosion, and hazard history of property
- Erodibility of the nearshore bottom
- Erosion control structure on site: type, age, condition, and history
- Proximity to inlets and navigation structures
- Previous or planned community/regional beach/dune restoration projects
- Relative sea-level/water-level changes – land subsidence or uplift

INFRASTRUCTURE AND SUPPORTING DEVELOPMENT

- Access road(s)
- Emergency evacuation route(s)
- Electric, gas, water, telephone, and other utilities – onsite or offsite lines and hookups
- Sewer or septic
- Limitations imposed by utility/infrastructure locations on property use

FINANCIAL CONSIDERATIONS

- Intended use: owner-occupied or rental property
- Real estate taxes
- Development impact fees
- Permit fees
- Hazard insurance: availability, premiums, deductibles, and exclusions
- Property management fees
- Special assessments for community/association projects (e.g., private roads and facilities, dune preservation)
- Maintenance and repair of private erosion control structures
- Increased building maintenance and repairs in areas subject to high winds, wind-driven rain, and/or salt spray
- Building damage costs (insured and uninsured) from previous storms

* This checklist outlines the types of information that should be obtained in order to evaluate coastal property. Information listed in this table is usually available from local, regional, state, or Federal governments, from universities, or from knowledgeable professionals. However, the availability and quality of the information will vary by state and community.

The Citizen's Guide to North Carolina's Shifting Inlets (Baker 1977). This publication illustrates the dynamic nature of tidal inlets by superimposing historical shorelines onto more recent aerial photographs (see Figure 5-4). This method of presentation is excellent and could serve as a model for other states to follow.

A Pictorial Atlas of North Carolina Inlets (Cleary and Marden 1999). This is North Carolina Sea Grant's replacement for *The Citizen's Guide to North Carolina's Shifting Inlets* (see above).

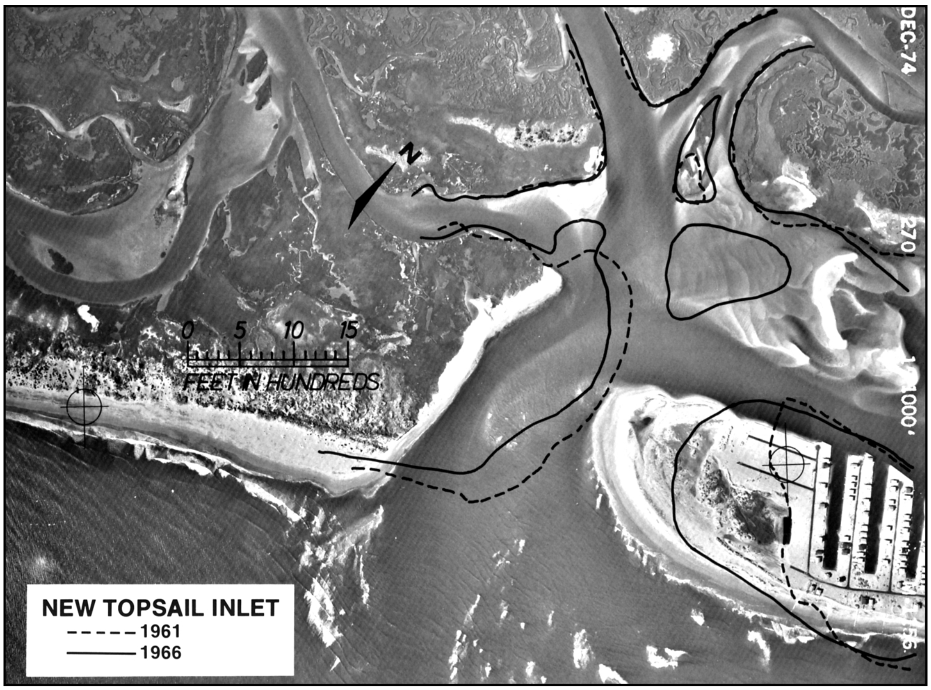


Figure 5-4
Development near tidal inlets requires special attention, as evidenced by earlier shorelines superimposed on this 1974 photograph (Baker 1977). Photograph courtesy of North Carolina Sea Grant.

CROSS-REFERENCE

Appendix F, in Volume III of this manual, lists additional sources of information.

5.3.1 Sources of Information

Prospective property buyers and designers can contact agencies and organizations listed in Table 5.2. These sources may be able to provide information that will support an evaluation of the suitability of coastal property for residential construction or development. (See Appendix F for other sources of information.)

Table 5.2 Potential Sources of Supporting Information for Evaluating Coastal Property

Local Regional, and State Agencies with the Following Responsibilities:		
LOCAL	• Environmental • Planning • Zoning • Floodplain Management • Land Use • Health • Building Permits	• Soils and Geology • Municipal Engineering • Utilities • Deeds and Property Records • Assessments and Taxes • Emergency Management
REGIONAL	• Health • Planning • Utilities • Water/Waste Management • Soils and Geology • Beach or Shore Management/ Erosion Control	• Navigation and Ports • Natural Resource Conservation and Management • Geographic Information Systems • Photogrammetry and Remote Sensing
STATE	• Coastal Zone Management • Planning • Building Codes and Standards • Soils and Geology • Floodplain Management • Natural Resource Management • Beach or Shore Management / Erosion Control	• Department of Insurance • Navigation and Ports • Emergency Management • Transportation • Natural Resource Conservation and Management • Geographic Information Systems • Photogrammetry and Remote Sensing

Table 5.2 Potential Sources of Supporting Information for Evaluating Coastal Property (continued)

Federal Agencies, Including the Following:

- Federal Emergency Management Agency (FEMA)
- U.S. Army Corps of Engineers (USACE)
- U.S. Geological Survey (USGS)
- National Ocean Service, Office of Ocean and Coastal Resource Management (OCRM)
- U.S. Natural Resources Conservation Service (NRCS)
- National Weather Service (NWS)
- International Joint Commission (Great Lakes)

University Departments, Including the Following:

- Coastal or Ocean Engineering
- Geology, Civil Engineering, or Soils
- Architecture and Building Construction
- Planning
- Atmospheric Sciences
- Botany, Biology, or Marine Biology
- Coastal or Ocean Law
- Sea Grant Programs (Research and Advisory Components)

Professional Organizations, Including the Following:

- American Society of Civil Engineers (ASCE)
- National Society of Professional Engineers (NSPE)
- American Institute of Architects (AIA)
- American Planning Association (APA)
- Model Building Code Organizations
  - Building Officials & Code Administrators International, Inc. (BOCA)
  - International Conference of Building Officials (ICBO)
  - Southern Building Code Congress International, Inc. (SBCCI)
- American Society of Landscape Architects (ASLA)
- Geological Society of America (GSA)
- Association of State Flood Plain Managers (ASFPM)
- National Association of Home Builders (NAHB)

WARNING

Even in states that require hazard disclosures in residential real estate transactions, property buyers should conduct their own investigations of prospective sites rather than rely solely on information provided by sellers and real estate agents.

5.3.2 Property Disclosure Requirements

A number of states require that residential real estate transactions be accompanied by a disclosure of information pertaining to flood hazards and/or other hazards (if the seller or agent knows of such hazards). However, the requirements concerning the form and timing of disclosures differ from state to state. Therefore, the type and amount of information that must be disclosed varies widely. Table 5.3 summarizes disclosure requirements for selected states. The list in Table 5.3 is based on information presented in *Coastal Hazard Mitigation 309 State Enhancement Grants, Assessment & Strategy Summary*, by the National Ocean Survey, Office of Ocean and Coastal Resource Management (OCRM 1998), and a review of selected state statutes and regulations. Taken collectively, the disclosure requirements (in force and as proposed) provide a good indication of the types of information that prospective property buyers and designers should seek, whether or not their state requires such a disclosure.

Table 5.3 Selected State Disclosure Requirements and Ongoing Efforts to Require Hazard Disclosure

STATE	COMMENTS
CALIFORNIA	Section 8589.3 of the California Codes requires disclosure if a property is within a Special Flood Hazard Area (A zone or V zone). Section 1102.6c of the California Codes requires sellers or agents to complete a Natural Hazard Disclosure Statement (disclosing whether property lies within any of the following: a Special Flood Hazard Area; an Area of Potential Flooding [in the event of dam failure]; a Very High Fire Hazard Severity Zone; a Wildland Area That May Contain Substantial Forest Fire Risks and Hazards; an Earthquake Fault Zone; a Seismic Hazard Zone).
FLORIDA	Chapter 161, "Beach and Shore Preservation," and Chapter 498, "Land Sales Practices," of the Florida Statute address property disclosure statements. Section 161.57, "Coastal properties disclosure statements," sets forth specific requirements. Section 498.037 requires that any public offering statement for subdivided lands disclose fully and accurately the physical characteristics of the lands and make known to prospective buyers all unusual and material circumstances of features that affect those lands.
HAWAII	Hawaii has adopted procedures, as part of its NFIP ordinances, requiring disclosure of flood zone information.
ILLINOIS	Illinois requires that sellers sign a form that states whether they know if the property has even been flooded.

Table 5.3 Selected State Disclosure Requirements and Ongoing Efforts to Require Hazard Disclosure (continued)

STATE	COMMENTS
MAINE	The Maine Coastal Management Program is working with real estate agents to develop a mechanism for disclosing the risks of coastal hazards.
MASSACHUSETTS	Massachusetts Coastal Zone Management has generated shoreline change maps depicting long-term average annual shoreline change rates at 50-meter intervals along the shore. A Coastal Hazards Notification bill(disclosing erosion rate and flood zone information) has been submitted to the legislature
NEW JERSEY	Amendments to the Coastal Area Facility Review Act (CAFRA) include a provision that permits issued for properties in the coastal zone, and conditions that must be met to receive the permit, must be recorded with the deed to the property.
NEW YORK	A Coastal Erosion Task Force report recommended notification if a property lies within a designated State Coastal Erosion Hazard Area. Draft disclosure legislation was developed by the Department of State, but has not been enacted by the legislature.
NORTH CAROLINA	The Division of Coastal Management is working to develop disclosure mechanisms, in response to recommendations from the Governor's Task Force on Hurricane Mitigation.
OHIO	Section 1506.06(F) of the Ohio Administrative Code requires disclosure if a property is included in a Lake Erie Coastal Erosion Area. Section 5302.30(D) of the Ohio Revised Code requires completion of a disclosure form developed by the Director of Commerce.
OREGON	A Coastal Natural Hazards Policy working group (Oregon Sea Grant 1994) concluded that Oregon law requires only minimal disclosure of natural hazards information. The Working Group recommended creation of a new category of information (Geotechnical) to be included in the disclosure form required under Oregon Revised Statute 696. The legislature has not yet acted on the recommendation.

Table 5.3 Selected State Disclosure Requirements and Ongoing Efforts to Require Hazard Disclosure (continued)

STATE	COMMENTS
SOUTH CAROLINA	Section 48-39-330 of the Code of Laws of South Carolina requires a disclosure statement for the transfer of property extending seaward of the 40-year setback line. The statement must include language that states the property is or may be affected by setback requirements, must include the local erosion rate, and must include the state plane coordinates of the seaward corners of habitable structures.
TEXAS	Section 61.025 of the Texas Statutes, Natural Resources Code, requires disclosure of the following to purchasers of property in close proximity to Gulf of Mexico beaches: that the public has acquired a right of use or easement over the area seaward of the vegetation line; that state law prohibits any obstruction of, barrier to, restraint of, or interference with use of the public easement; and that structures erected seaward of the vegetation line, or that become seaward of the vegetation line as a result of natural processes, are subject to a lawsuit by the state seeking removal.
WASHINGTON	Section 64.06.020 of the Revised Code of Washington requires, among other things, that sellers complete a disclosure form that lists the following information (if known by the seller): if the property is in a designated floodplain; if the property or structure is damaged as a result of fire, wind, flood, beach movements, earthquake, expansive soils, or landslides; if rights-of-way, easements, and access limitations affect the property; or if settling, slippage, or sliding of the house or improvements has occurred.

5.4 Evaluating Hazards and Potential Vulnerability

This step is perhaps the most crucial in evaluating the suitability of coastal lands for development or redevelopment. Basing hazard and vulnerability analyses solely on building code requirements, the demarcation of hazard zones or construction setback lines, and the location and design of nearby buildings is clearly an inadequate approach. A recommended procedure is outlined below.

5.4.1 Define Coastal Hazards Affecting the Property

1. Use all available information to characterize the type, severity, and frequency of hazards (e.g., flood, storm-induced and long-term erosion, accretion or burial, wind, seismic, tsunami, landslide, wildfire, and other natural hazards) that have affected or could affect the property

2. Examine the record for long-term trends (> 50-100 years), short-term trends (< 10-20 years), and periodic or cyclic variations (both spatial and temporal) in hazard events. Determine whether particularly severe storms are included in the short-term or long-term records and what effects those storms had on the overall trends. If cyclic variations are observed, determine the periods and magnitudes of the variations.

3. Determine whether or not extrapolation of historical trends and hazard occurrences is reasonable. Examine the record for significant changes to the coastal system or upland areas that will reduce, intensify, or modify the type, severity, and frequency of hazard occurrence at the property.

   The following are examples of events or processes that will preclude simple extrapolation of historical trends:

   - Loss of a historically present protective dune or bluff feature may lead to increased incidence and severity of flood or erosion damage.

   - Significant increases in sea, bay, or lake levels will probably increase vulnerability to flooding and coastal storm events.

   - Erosion or storms may create weak points along the shoreline that will be predisposed to future breaching, inlet formation, and accelerated erosion, or may expose geologic formations that are more resistant to future erosion.

   - Recent or historical modifications to an inlet (e.g., construction or modification of jetties, creation or deepening of a dredged channel) may alter the supply of littoral sediments and modify historic shoreline change trends.

   - Formation or closure of an inlet during a storm will alter local tide, wave, current, and sediment transport patterns and may expose previously sheltered areas to damaging waves (see Figures 7-34 and 7-45, in Chapter 7).

NOTE

This manual is intended primarily for design professionals, coastal specialists, and others with the expertise to evaluate coastal hazards and the vulnerability of sites and buildings to those hazards. Readers who are not familiar with hazard and vulnerability evaluations are encouraged to seek the services of qualified professionals.

CROSS-REFERENCE

Chapter 7 of this manual presents additional information about natural hazards in coastal areas and the effects of those hazards.

- Widespread construction of erosion control devices may reduce the input of sediments to the littoral system and cause or increase local erosion.
- Recent seismic events may have caused uplift, settlement, submergence, or fracturing of a region, altering its hazard vulnerability to flood and other hazards.
- Changes in surface water flows, drainage patterns, or groundwater movements, and reduction in vegetative cover may increase an area's susceptibility to landslides.
- Topographic changes resulting from the retreat of a sea cliff or coastal bluff may increase wind speeds at a site.

4. Forecast the type, severity, and frequency of future hazard events likely to affect the property over a suitably long period of time, say over at least 50-70 years.

   This forecast should be based on either (1) extrapolation of observed historical trends, modified to take into account those factors that will cause deviations from historical trends, or (2) detailed statistical and modeling studies calibrated to reflect basic physical and meteorological processes, and local conditions. The first procedure should be attainable for most any coastal site and project. The second procedure will be beyond the scope and capabilities of all but a few coastal development projects.

5.4.2 Evaluate Hazard Effects on the Property

Once the type, severity, and frequency of future hazard events have been forecast, designers should use past events as an indication of the nature and severity of effects likely to occur during those forecast events. Information about past events at the site of interest and at similar sites should be considered. This historical information should be combined with knowledge about the site and local conditions to estimate future hazard effects on the site and any improvements.

Designers should consider the effects of low-frequency, rare events (e.g., major storms, extreme water levels, tsunamis, earthquakes) and multiple, closely spaced lesser events (see Figure 5-5). For example, many of the post-storm damage assessments summarized in Chapter 2 show that the cumulative erosion and damage caused by of a series of minor coastal storms can be as severe as the effects of a single, major storm.

Figure 5-5
Siting and design should include consideration of multiple storms or hazards within a short period, whose cumulative effects can exceed those of a design-level event. Photograph by John Althouse, Jacksonville, North Carolina.

5.5 Decision Time

The final step in evaluating a lot or parcel for potential development or redevelopment is to answer two questions:

Can the Predicted Hazard Effects Be Mitigated Through Siting, Design, or Construction?

AND

Are the Residual Risks to the Site and Building/Development Acceptable?

WARNING

Remember, buildings near the shoreline are at a far greater risk of being damaged by natural causes than buildings farther inland.

Unless both questions can be answered affirmatively, the property should be rejected (at least for its intended use) and other properties should be identified and evaluated. Alternatively, the intended use of the property might be modified so that it is consistent with predicted hazard effects and other constraints. Ultimately, however, reducing the long-term risks to coastal residential buildings requires an approach to site evaluation such as that described in this chapter.

5.6 References

Baker, S. 1977. *The Citizen's Guide to North Carolina's Shifting Inlets*. UNC-SG-77-008. North Carolina Sea Grant, NC State University, Raleigh, NC.

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Chapter 6: Investigating Regulatory Requirements

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Investigating Regulatory Requirements

6.1 Introduction

States and communities throughout the United States enforce regulatory requirements that determine where and how buildings may be sited, designed, and constructed. These requirements include those associated with regulatory programs established by Federal and state statutes, building codes and standards, and locally adopted floodplain management and land use ordinances and laws. Applicable regulatory programs include the National Flood Insurance Program (NFIP), which is intended to reduce the loss of life and damage caused by natural hazards, and programs established to protect wetlands and other wildlife habitat, which seek to minimize degradation of the environment. In addition, states and communities enforce requirements aimed specifically at the regulation of construction along the shorelines of oceans, bays, and lakes .

Federal, state, and local regulatory requirements can have a significant effect on the siting, design, construction, and cost of buildings. Therefore, designers, property owners, and builders engaged in residential construction projects in the coastal environment should conduct a thorough investigation to identify all regulations that may affect their properties and projects.

CROSS-REFERENCE

Appendix G, in Volume III of this manual, presents selected examples of how states and communities identify coastal hazard areas and regulate development in those areas.

6.2 Land Use Regulations

State and local governments establish regulations for governing the development and use of land within their jurisdictions. The goal of these land use regulations is generally to promote sound physical, social, and economic development. The regulations take many forms – including zoning and floodplain management ordinances, subdivision regulations, utility codes, impact fees, historic preservation requirements, and environmental regulations – and they are often incorporated into and implemented under comprehensive or master plans developed by local jurisdictions in coordination with their state governments.

With land use regulations, communities can prohibit or restrict development in specified areas; they can also establish requirements for lot size, clearing and grading, and drainage, as well as the siting of buildings, floodplain management, construction of access roads, installation of utility lines, planting of vegetative cover, and other aspects of the land development and building construction processes. The land use regulations enacted and enforced by state and local governments across the country vary in content and complexity according to the needs and concerns of individual jurisdictions; therefore, it is beyond the scope of this manual to list or describe specific regulations. Clearly, however, such regulations can have a significant impact on the construction and improvement of residential and other type of buildings in both coastal and non-coastal areas. Therefore, it is important that designers, builders, and property owners be aware of the regulations that apply to their projects.

The best sources of information about land use regulations are state and local planning, land management, economic development, building code, floodplain management, and community affairs officials. Professional organizations such as the American Planning Association (APA) and its state chapters are also excellent sources of information. Community officials may be interested in several recent APA projects and publications (described on the APA web site, http://www.planning.org):

- *Subdivision Design in Flood Hazard Areas* (Morris 1997), APA Planning Advisory Service Report Number 473. This report provides information and guidance on subdivision design appropriate for floodplain areas and includes several examples of state and local subdivision requirements in coastal floodplains. The report was prepared under a cooperative agreement with FEMA.

- *Modernizing State Planning Statutes: the Growing Smart^{sm} Working Papers* (APA 1996), American Planning Advisory Service Report Number 462/463, and *Growing Smart^{sm} Legislative Guidebook* (APA 1998). Growing Smart^{sm} is a major initiative launched by the APA in 1994. The Project will result in a national planning statute clearinghouse and database of state legislative materials, and in model planning legislation and commentary. Chapter 7 of the document includes a model Natural Hazards Element for incorporation into local government comprehensive plans.

- *Planning for Post-Disaster Recovery and Redevelopment* (Schwab et al. 1998), APA Planning Advisory Service Report Number 483/484. This report provides all-hazards guidance for local planners. It includes a model ordinance for regulating hazard areas and includes case studies for five hazard scenarios (flood, hurricane, wildfire, earthquake, and tornado). The report includes a model Natural Hazards Element (taken from the *Growing Smart^{sm} Legislative Guidebook*) for incorporation into local comprehensive plans. The report was prepared under a cooperative agreement with FEMA.

WARNING

Designers and floodplain management officials are cautioned that hazard area identifications (including those on FIRMs) and associated development regulations can be rendered obsolete by a natural hazard event. Extreme care should be taken in siting and designing residential buildings in post-disaster situations.

6.3 Building Codes and Standards

Many states and communities regulate the construction of buildings by adopting and enforcing building codes and standards that affect how buildings are designed and constructed. Building codes set forth requirements for structural design, materials, fire safety, exits, natural hazard mitigation, sanitary facilities, light and ventilation, environmental control, fire protection, and energy conservation. The purpose of a code is to establish the minimum acceptable requirements necessary for protecting the public health, safety, and welfare in the built environment. Building codes apply primarily to new construction, but may also apply to existing buildings that are being rebuilt, rehabilitated, or modified. Codes may also apply when a building is undergoing a change of occupancy as defined by the code.

WARNING

The adoption and enforcement of building codes and standards is not consistent across the United States. Codes and standards in some states and communities may be more restrictive than those in others. In addition, some states and communities have not adopted any building codes or standards.

A standard is "a prescribed set of rules, conditions, or requirements concerned with the definition of terms; classification of components; delineation of procedures; specification of dimensions, materials, performance, design, or operations; descriptions of fit and measurement of size; or measurement of quality and quantity in describing materials, products, systems, services, or practices" (CABO 1997). There are hundreds of standards related to design and construction practices, and thousands of standards related to construction materials. When a standard is developed according to definitive rules of procedure and consensus, it may be incorporated into a building code by reference rather than by inclusion of all of the text of the standard in the code.

Most building codes in the United States are based on model building codes. Model building codes are the result of an effort begun early in the 20th century to produce a model law or guide document that could be adopted by a legislative body to reduce losses caused by fire and other hazards. Six model building codes are now used in the United States:

- *International Building Code* (IBC), published by the International Code Council (ICC) (ICC 2000a)
- *International Residential Code for One- and Two-Family Dwellings* (ICC), published by the International Code Council (ICC) (ICC 2000b)
- *Uniform Building Code* (UBC), published by the International Conference of Building Officials (ICBO) (ICBO 1997)
- *The BOCA National Building Code*, published by Building Officials & Code Administrators International (BOCA) (BOCA 1996)
- *Standard Building Code* (SBC), published by the Southern Building Code Congress International (SBCCI) (SBCCI 1997)
- *International One-and Two-Family Dwelling Code*, published by the Council of American Building Officials (CABO) (CABO 1998)

NOTE

For additional information about building codes and standards, refer to *An Introduction to Model Codes* (CABO 1997), published by the Council of American Building Officials, now the International Code Council (ICC).

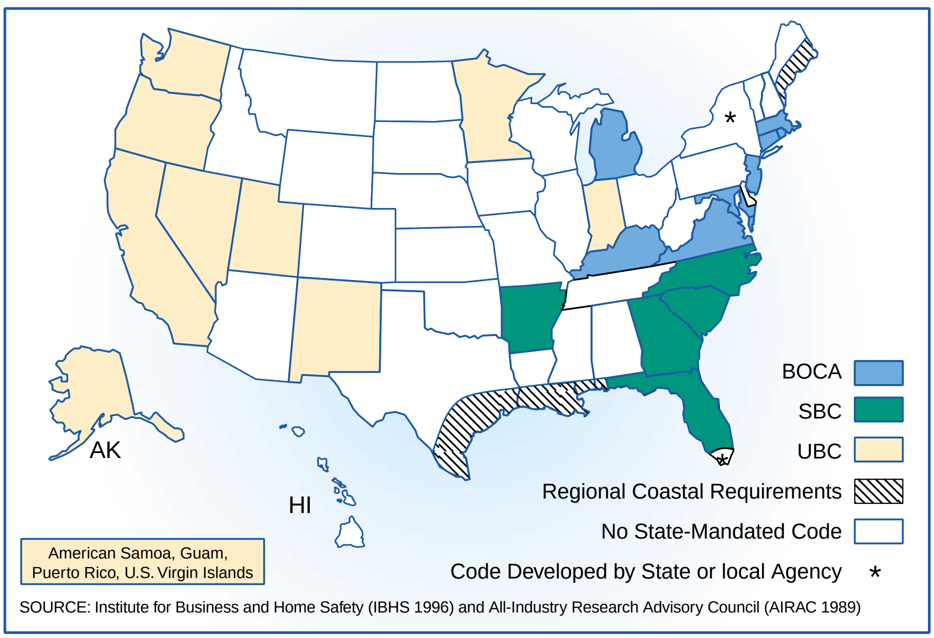
NOTE

In areas where a model building code has not been adopted or where the existing code is not applied to one- and two-family residential buildings, design professionals, contractors, and others engaged in the design and construction of coastal residential buildings are encouraged to follow the requirements of a model building code and the recommendations presented in this manual.

States and local jurisdictions may adopt a model code, unaltered or with amendments and revisions, and they may adopt and enforce other codes and standards to meet specific needs, such as providing additional resistance to damage in areas subject to flood, wind, and earthquake hazards. A few examples of these State and local codes and standards are the South Florida Building Code, the Massachusetts State Building Code, and the Texas Department of Insurance Windstorm Resistant Construction Guide (1998). Other codes and standards in use include the American Society of Civil Engineers (ASCE) *Minimum Design Loads for Buildings and Other Structures*, ASCE 7-98 (ASCE 1998), and the SBCCI *Standard for Hurricane Resistant Residential Construction*, SSTD 10-99 (SBCCI 1999). In addition, trade organizations publish design documents; an example is the High Wind Edition of the *Wood Frame Construction Manual for One- and Two-Family Dwellings* by the American Forest & Paper Association (AFPA 1996).

It is important to note that not every state has adopted a model building code, and some of those that have do not require that the code be applied to the construction of one- and two-family residential buildings. The map in Figure 6-1 shows the states that have adopted a mandatory state building code, based on one of the model codes, that applies to some or all types of construction within the state. The figure also shows areas of the United States that have adopted regional requirements governing coastal construction.

Figure 6-1
States that have a mandatory building code based on one of the model building codes (IBHS 1996, AIRAC 1989).



Note that, in general, most coastal states have adopted a model building code and/or specific requirements concerning the construction of buildings in coastal flood and wind hazard areas. It should be noted that in states where no mandated codes exist, it is common for relatively populous political jurisdictions, towns, and cities to have some form of regulatory control on the construction of housing. In the entire United States, about 4,400 political jurisdictions have adopted some type of building code.

The International Code Council (ICC) was formed to bring together the three model code groups—ICBO, BOCA, and SBCCI—under a unifying code body in support of common code development. Among the new codes developed by the ICC are the ***International Building Code 2000*** (ICC 2000a) (hereafter referred to as the IBC 2000), the ***International Residential Code for One- and Two-Family Dwellings 2000*** (ICC 2000b) (hereafter referred to as the IRC 2000). The IBC 2000 and the IRC 2000 both meet the minimum building science requirements of the NFIP regulations. Together, the IBC 2000 (with its Appendix G) and the IRC 2000 meet the minimum requirements of the NFIP regulations. Note that communities must adopt both codes to be compliant with the regulatory requirements of the NFIP. Also, the IRC 2000 and the IBC 2000 are both substantially equivalent to the National Earthquake Hazards Reduction Program 1997 *NEHRP Recommended Provisions for Seismic Regulations for New Buildings* (FEMA 1997).

At the time this manual went to print, many states and communities were considering adoption of the IBC 2000 and the IRC 2000. Thus many state and local building code requirements may change as a result. Variations from one state or jurisdiction to the next, coupled with potential code revisions, make it imperative that the designer work with local officials to identify the current codes, standards, and other construction requirements that apply. Even in states and communities that have not adopted the IBC 2000 and IRC 2000, designers may elect to use the new codes.

NOTE

The ICC has also developed mechanical, plumbing, and private sewage disposal codes, all of which are compliant with the applicable provisions of the NFIP regulations.

NOTE

Under the NFIP, **substantially damaged** and **substantially improved** buildings must meet the floodplain management requirements for new buildings. Damage to a building (regardless of the cause) is considered substantial damage if the cost of restoring the building to its before-damage condition would equal or exceed 50 percent of the market value of the structure before the damage occurred. Similarly, an improvement of a building (such as reconstruction, rehabilitation, or addition) is considered a substantial improvement if its cost equals or exceeds 50 percent of the market value of the building before the start of construction of the improvement.

For more information, consult your local floodplain management officials or refer to *Answers to Questions About Substantially Damaged Buildings*, FEMA 213 (FEMA 1991).

6.4 National Flood Insurance Program

6.4.1 Background

Congress created the NFIP in 1968 when it passed the National Flood Insurance Act. The NFIP, which is administered by FEMA, is a voluntary program whose goal is to reduce the loss of life and the damage caused by flooding, to help victims recover from floods, and to promote an equitable distribution of costs among those who are protected by flood insurance and the general public. It does this by:

- conducting flood hazard studies and providing each community with a Flood Insurance Rate Map (FIRM) and Flood Insurance Study (FIS) report, which present flood hazard information, including the boundaries of the Special Flood Hazard Area (SFHA) — the area subject to inundation by the flood that has a 1-percent probability of being equaled or exceeded in any given year — base flood elevations (BFEs), and flood insurance zones,

- providing state and local agencies with technical assistance and funding in support of flood hazard mitigation,
- requiring participating communities to control construction so that new buildings, substantially improved buildings, and repaired substantially damaged buildings in the SFHA are in compliance with floodplain management ordinances and laws intended to eliminate or reduce flood damage,
- providing residents in participating communities with flood insurance so that the need for disaster relief is reduced,
- requiring the purchase of flood insurance as a condition of receiving Federal or federally related financial assistance for the acquisition and/or construction of buildings in SFHAs, and
- providing the means by which disaster assistance agencies and Federal lending regulatory agencies can fulfill their obligation to require that flood insurance be purchased for property in the SFHA that is securing a Federal or federally regulated loan or that has been the recipient of Federal disaster assistance.

The NFIP operates through a partnership between the Federal Government, the states, and individual communities such as counties, parishes, and incorporated cities, towns, townships, boroughs, and villages. Participation in the NFIP is voluntary. In participating communities, affordable, federally backed flood insurance is made available to property owners and renters. In return, each community adopts and enforces a floodplain management ordinance or law, which it uses to define regulatory floodplains and control floodplain development, including new construction, substantial improvement of existing buildings, and repairs of substantially damaged buildings.

NOTE

In 1999, nearly 900 communities throughout the United States were receiving flood insurance premium discounts through the Community Rating System (CRS) as a result of implementing local mitigation, outreach, and educational activities that go beyond minimum NFIP requirements. For more information about the CRS, contact the NFIP Coordinating Agency for your state (see Appendix D) or the appropriate FEMA Regional Office (see Appendix C).

A participating community's floodplain management ordinance or law must, at a minimum, meet the requirements of the NFIP regulations, but FEMA encourages communities to establish additional or more stringent requirements as they see fit. In 1990, to provide incentives for communities to adopt more stringent requirements, FEMA established the NFIP Community Rating System (CRS), a program through which FEMA encourages and recognizes community floodplain management activities that exceed the minimum NFIP requirements. Under the CRS, flood insurance premium rates within participating communities are adjusted to reflect the reduced flood risk resulting from community activities that meet the three goals of the CRS: (1) reducing flood losses, (2) facilitating accurate insurance rating, and (3) promoting the awareness of flood insurance.

Through the CRS, communities are awarded credit points for carrying out floodplain management activities in the areas of public information, mapping and regulations, flood damage reduction, and flood preparedness. The number of points awarded determines a community's CRS class (from 1 to 10), which, in turn, determines the amount of reduction in the flood insurance premium rates for structures within and outside the SFHA. Participation in the CRS is voluntary; any community compliant with the rules and regulations of the NFIP may apply for a CRS classification. In addition to helping communities obtain insurance premium discounts, the CRS promotes floodplain management activities that help save lives, reduce property damage, and promote sustainable, more livable communities.

As noted above, the regulatory requirements of the NFIP are based on the flood that has a 1-percent probability of being equaled or exceeded in any given year. The NFIP regulations refer to this flood as the "base flood." To provide communities with the information they need to enact and enforce floodplain management ordinances or laws compliant with the requirements of the NFIP, FEMA conducts flood hazard studies for communities throughout the United States and publishes the results in the form of FIRMs and FIS reports (see Section 3.3, in Chapter 3).

The information provided by FIS reports and FIRMs includes the names and locations of flooding sources; the sizes and frequencies of past floods; the limits of the SFHA in areas subject to riverine, lacustrine, and coastal flooding; flood insurance zone designations; and BFEs throughout the SFHA. With this information, communities can manage floodplain development and FEMA can establish insurance rates for houses and other buildings. Of particular importance for a coastal construction project are the BFE and the flood insurance zone designation at the building site. The following sections explain how BFEs and zone designations are determined for coastal flood hazard areas and how they affect coastal construction.

NOTE

A FIRM consists of one or more numbered panels that cover the geographic area of a community such as a city, town, or county. FIRMs that consist of two or more panels are accompanied by an index map that shows the layout of the panels. For more information about FIRMs, refer to FEMA's *Guide to Flood Maps*, FEMA 258 (FEMA 1995b).

6.4.2 Determination of BFEs and Flood Insurance Zones in Coastal Flood Hazard Areas

6.4.2.1 Base Flood Elevations

To determine BFEs for areas affected by coastal flooding, FEMA computes 100-year stillwater elevations and then determines the maximum 100-year wave heights and, in some areas, the maximum 100-year wave runup, associated with those stillwater elevations (see Chapter 3). Stillwater elevations are the elevations of the water surface resulting solely from storm surge (i.e., the rise in the surface of the ocean due to the action of wind and the drop in atmospheric pressure associated with hurricanes and other storms.) Wave heights are the heights, above the wave trough, of the crests of wind-driven waves. Wave runup is the rush of wave water up a slope or structure.

NOTE

A detailed discussion of the methodology for computing stillwater elevations, wave heights, and wave runup is beyond the scope of this manual. Refer to *Guidelines and Specifications for Wave Elevation Determination and V Zone Mapping* (FEMA 1995c) for more information.

NOTE

Zones AE, VE, and X appear on FIRMs produced since the mid-1980's. On older FIRMs, the corresponding zones are A1-A30, V1-V30, and B or C, respectively.

The BFEs shown for coastal flood hazard areas on FIRMs are established not at the stillwater elevation, but at the maximum elevation of either the wave crest or the wave runup, whichever is greater. Whether the wave crest elevation or the wave runup elevation is greater depends primarily on upland topography. In general, wave crest elevations are greater where the upland topography is gentle, such as along most of the Gulf, southern Atlantic, and middle-Atlantic Coasts, and wave runup elevations are greater where the topography is steeper, such as along portions of the Great Lakes, northern Atlantic, and Pacific Coasts.

6.4.2.2 Flood Insurance Zones

The insurance zone designations shown on FIRMs (see Chapter 3) indicate the magnitude and severity of flood hazards. The zone designations that apply to coastal flood hazard areas are listed below, in decreasing order of magnitude and severity.

NOTE

As explained in Chapters 1 and 3, this manual defines an additional hazard zone—coastal A zone—which is not established by the NFIP regulations. As further explained in those chapters, the hazards in coastal A zones are greater than those in non-coastal A zones but less severe than those in V zones.

Zones VE, V1–V30, and V – These zones, collectively referred to as V zones, identify the Coastal High Hazard Area, which is the portion of the SFHA that extends from offshore to the inland limit of a primary frontal dune along an open coast and any other portion of the SFHA that is subject to high-velocity wave action from storms or seismic sources. V zones are generally based on wave heights (3 feet or greater) or wave runup depths (3 feet or greater).

Zones AE, A1–A30, AO, and A – These zones, collectively referred to as A zones, identify portions of the SFHA that are not within the Coastal High Hazard Area. Although both A zones and V zones designate areas at risk from a flood of the same magnitude, the hazard in V zones is greater because of the presence of breaking waves with heights equal to or greater than 3 feet. It is important to note that FIRMs use Zones AE, A1-A30, AO, and A to designate both coastal and non-coastal SFHAs, and that the regulatory requirements of the NFIP are the same for buildings in coastal and non-coastal A zones. However, buildings in coastal A zones may be subject to breaking waves with heights less than 3 feet and wave runup with depths less than 3 feet.

NOTE

For more information about the NFIP and its minimum requirements, check with the appropriate NFIP State Coordinating Agency (see Appendix D) or FEMA Regional Office (see Appendix C).

Zones X, B, and C– These zones identify areas outside the SFHA. Zone B and shaded Zone X identify areas subject to inundation by the flood that has a 0.2-percent probability of being equaled or exceeded during any given year. This flood is often referred to as the 500-year flood. Zones C and unshaded Zone X identify areas above the level of the 500-year flood.

6.4.3 Minimum Regulatory Requirements Imposed by Communities Participating in the NFIP

The floodplain management ordinances or laws adopted by communities that participate in the NFIP are based, in part, on the minimum NFIP regulatory requirements set forth at Title 44, Chapter 1, Section 60.3 of the U.S. Code of

Federal Regulations (44 CFR 60.3). Community floodplain management ordinances and laws include requirements concerning the following types of buildings in the SFHA, including those in both A zones and V zones: newly constructed buildings, substantially damaged buildings (see NOTE on page 6-5), and substantially improved buildings (see NOTE on page 6-5). Additional requirements apply to new subdivisions and other development in the SFHA.

The **minimum** NFIP regulatory requirements regarding newly constructed, substantially damaged, and substantially improved buildings affect primarily the **type of foundation** allowed, the required **height of the lowest floor**, the **installation of building utility systems**, the **use of flood-resistant materials**, and the **use of the area below the lowest floor**. In recognition of the greater hazard posed by breaking waves 3 feet high or higher, FEMA has established minimum NFIP regulatory requirements for V-zone buildings that are more stringent than the minimum requirements for A-zone buildings. Therefore, the location of a building in relation to the A-zone/V-zone boundary on a FIRM can affect the design of the building. In that regard, it is important to note that **a building or other structure that has any portion of its foundation in a V zone must be built to comply with V-zone requirements**. The following sections summarize the minimum NFIP regulatory requirements. (For the exact wording of the regulations, refer to Title 44, Chapter I, of the CFR.) Section 6.4.3.1 describes the minimum requirements that apply throughout the SFHA. Sections 6.4.3.2 and 6.4.3.3 describe requirements specific to A zones and V zones, respectively.

6.4.3.1 Minimum Requirements for All Buildings in All SFHAs

The **minimum** floodplain management requirements applied in **all** SFHAs by communities participating in the NFIP affect buildings, subdivisions and other new development, new and replacement water supply systems, and new and replacement sanitary sewage systems. These requirements, set forth at 44 CFR 60.3(a) and (b), can be summarized as follows:

Newly Constructed , Substantially Damaged, and Substantially Improved Buildings in the SFHA

- Building sites must be reasonably safe from flooding.
- Buildings must be:
  - designed (or modified) and anchored to prevent flotation, collapse, and lateral movement of the building resulting from hydrodynamic and hydrostatic loads, including the effects of buoyancy,
  - constructed with materials resistant to damage from immersion in flood waters,
  - constructed with methods and practices that minimize flood damage, and

NOTE

Under the NFIP, the "lowest floor" of a building includes the floor of a basement. The NFIP regulations define a basement as "… any area of a building having its floor subgrade (below ground level) on all sides." For insurance rating purposes, this definition applies even when the subgrade floor is not enclosed by full-height walls, such as in a subgrade parking area under a building elevated on an open foundation. Refer to *Below-Grade Parking Requirements for Buildings Located in Special Flood Hazard Areas*, NFIP Technical Bulletin 6 (FEMA 1993a) (see Appendix H).

WARNING

Communities participating in the NFIP are encouraged to adopt and enforce floodplain management ordinances or laws that include requirements more stringent than the minimum requirements of the NFIP regulations. For example, some states and communities require that buildings be elevated **above** rather than simply to the BFE. The additional elevation required is referred to as "freeboard" (see Figure 6-4). Check with local floodplain managers and building officials concerning such requirements.

- constructed with electrical, heating, ventilation, plumbing, and air conditioning equipment and other service facilities that are designed and/or located so as to prevent water from entering or accumulating within their components during conditions of flooding.

- If FEMA has not provided BFE data on the FIRM , the community must obtain and reasonably use any BFE data available from other sources for the purpose of regulating construction in Zone A.

WARNING

This manual does not cover manufactured housing. For NFIP requirements concerning manufactured housing, refer to Section 60.3 of the NFIP regulations.

Subdivisions and Other New Development in the SFHA

- All proposals for subdivisions and other new development in the SFHA must be consistent with the need to minimize flood damage within the floodprone area.

- All public utilities and facilities, such as sewer, gas, electrical, and water systems for such subdivisions and other new developments must be located and constructed to minimize or eliminate flood damage.

- Adequate drainage must be provided for all such subdivisions and new developments in order to reduce exposure to flood hazards.

- All proposals for subdivisions and other new developments greater than 50 lots or 5 acres, whichever is less, in an SFHA for which no BFEs are shown on the effective FIRM must be accompanied by 100-year flood elevation data.

WARNING

In addition to the floodplain management requirements discussed in this manual, the NFIP regulations include requirements specific to floodplains along rivers and streams. Because this manual focuses on the construction of residential buildings in coastal areas, it does not discuss these additional requirements. For more information about these requirements, consult local floodplain management officials. Also refer to *Engineering Principles and Practices for Retrofitting Flood Prone Residential Buildings*, FEMA 259 (FEMA 1995a).

New and Replacement Water Supply Systems in the SFHA

- New and replacement water supply systems within the SFHA must be designed to minimize or eliminate infiltration of flood waters.

New and Replacement Sanitary Sewage Systems in the SFHA

- New and replacement sanitary sewage systems in the SFHA must be designed to minimize or eliminate infiltration of flood waters into the systems and discharges from the systems into flood waters.

- On-site waste disposal systems must be located to avoid impairment to them or contamination from them during flooding.

6.4.3.2 Additional Minimum Requirements for Buildings in A Zones

The additional **minimum** requirements specific to buildings in Zones AE, A1-A30, AO, and A pertain to (1) the elevation of the lowest floor, including basement, in relation to the BFE or the depth of the 100-year flood and (2) enclosed areas below the lowest floor. Note that these requirements are the same for coastal and non-coastal A zones.

Building Elevation in Zones AE and A1-A30

The top of the lowest floor, including the basement floor, of all newly constructed, substantially damaged, and substantially improved buildings must be at or above the BFE (see Figure 6-2).

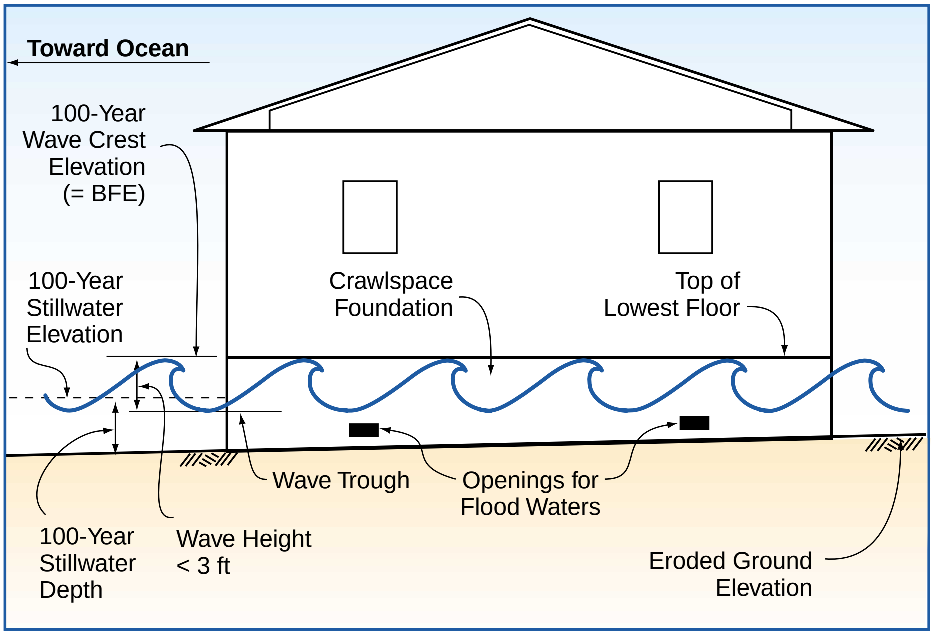


Figure 6-2
Minimum NFIP A-zone requirements: The lowest floors of buildings in Zones AE, A1-A30, and A must be at or above the BFE. Foundation walls below the BFE must be equipped with openings that allow the entry of flood waters so that interior and exterior hydrostatic pressures can equalize.

NOTE

For new, substantially damaged, and substantially improved **non-residential** buildings in A zones, the NFIP regulations allow dry-floodproofing as an alternative to elevating the lowest floor to or above the BFE or base flood depth. Dry-floodproofing refers to making the portion of a building below the BFE or base flood depth watertight, with walls substantially impermeable to the passage of water and with structural components capable of resisting hydrostatic and hydrodynamic loads and the effects of buoyancy. The design, specifications, and construction plans for all dry-floodproofing projects must be certified by a registered professional engineer or architect. Additional information is available in *Non-Residential Floodproofing — Requirements and Certification for Buildings Located in Special Flood Hazard Areas,* FEMA's NFIP Technical Bulletin 3 (FEMA 1993d).

Building Elevation in Zone A

FIRMs do not present BFEs in SFHAs designated Zone A (i.e. unnumbered A zones). The lowest floors of buildings in Zone A must be elevated to or above the BFE whenever BFE data are available from other sources. If no BFE data are available, communities must ensure that the building is constructed with methods and practices that minimize flood damage.

Building Elevation in Zone AO

Zone AO designates areas where flooding is characterized by shallow depths (averaging 1–3 feet) and/or unpredictable flow paths. In Zone AO, the top of the lowest floor, including the basement floor, of all newly constructed, substantially damaged, and substantially improved buildings must be above the highest grade adjacent to the building by at least the depth of flooding in feet shown on the FIRM. For example, if the flood depth shown on the FIRM is 3 feet, the top of the lowest floor must be at least 3 feet above the highest grade adjacent to the building. If no depth is shown on the FIRM, the minimum required height above the highest adjacent grade is 2 feet.

Note that areas adjacent to V zones—behind bulkheads or on the back sides of dunes—are sometimes designated Zone AO. For these areas, this manual encourages the use of open foundations, as required in V zones (see Section 6.4.3.3), in Zone AO.

NOTE

For more information about openings requirements for the walls of enclosures below the lowest floors of buildings in A zones, refer to *Openings in Foundation Walls for Buildings Located in Special Flood Hazard Areas*, FEMA NFIP Technical Bulletin 1 (FEMA 1993e) (see Appendix H).

WARNING

Even waves less than 3 feet high can impose large loads on foundation walls. This manual recommends that buildings in coastal A zones be designed and constructed to meet V-zone requirements (see Section 6.5.2 and Chapter 11).

Enclosures Below the Lowest Floor in Zones AE, A1-A30, AO, and A

Enclosed space below the lowest floors of newly constructed, substantially damaged, and substantially improved buildings may be used only for parking of vehicles, access to the building, or storage. The walls of such areas must be equipped with openings designed to allow the automatic entry and exit of flood waters so that interior and exterior hydrostatic pressures will equalize during flooding. Designs for openings must either meet or exceed the following minimum criteria:

1. A minimum of two openings with a total net area of not less than 1 in^2 for every 1 ft^2 of enclosed area subject to flooding must be provided.
2. The bottoms of all openings must be no higher than 1 foot above grade.
3. The openings may be equipped with screens, louvers, valves, or other coverings or devices provided that they permit the automatic entry and exit of flood waters.

An alternative to meeting criterion 1 is to provide a certification by a registered engineer or architect that states that the openings are designed to automatically equalize hydrostatic forces on exterior walls by allowing the entry and exit of flood waters. Even if such a certification is provided, however, the openings must still meet criteria 2 and 3 above.

6.4.3.3 Additional Minimum Requirements for Buildings in V Zones

The additional **minimum** requirements enforced by participating communities regarding newly constructed buildings, substantially damaged buildings, and substantially improved buildings in Zones VE, V1-V30, and V pertain to the **siting** of the building, the **elevation of the lowest floor** in relation to the BFE, the **foundation design**, **enclosures below the BFE**, and **alterations of sand dunes and mangrove stands** (refer to 44 CFR 60.3(d)).

Siting

All newly constructed buildings must be located landward of the reach of mean high tide (i.e., the mean high water line). In addition, manmade alterations of sand dunes or mangrove stands are prohibited if those alterations would increase potential flood damage. Removing sand or vegetation from, or otherwise altering, a sand dune or removing mangroves may increase potential flood damage; therefore, such actions must not be carried out without the prior approval of a local official.

Building Elevation

All newly constructed, substantially damaged, and substantially improved buildings must be **elevated on pilings, posts, piers, or columns so that the**

bottom of the lowest horizontal structural member of the lowest floor (excluding the vertical foundation members) is at or above the BFE (see Figure 6-3).

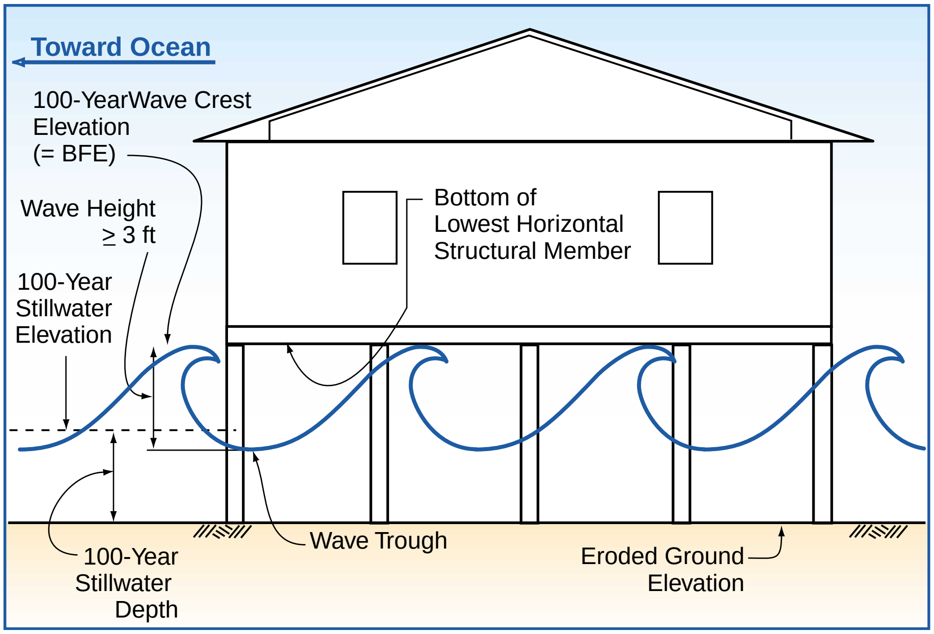


Figure 6-3
Minimum NFIP V-zone requirements: In V zones, buildings must be elevated on an open foundation (e.g., pilings, posts, piers, or columns) so that the bottom of the lowest horizontal structural member is at or above the BFE.

Foundation Design

The piling or column foundations for all newly constructed, substantially damaged, and substantially improved buildings, as well as the buildings attached to the foundations, must be anchored to resist flotation, collapse, and lateral movement due to the effects of wind and water loads acting simultaneously on all components of the building. **A registered engineer or architect must develop or review the structural design, construction specifications, and plans for construction** and **must certify that the design and methods of construction to be used are in accordance with accepted standards of practice for meeting the building elevation and foundation design standards** described above.

In addition, **erosion control structures and other structures such as bulkheads, seawalls, and retaining walls may not be attached to the building or its foundation**.

Use of Fill

Fill may not be used for the structural support of any building within Zones VE, V1-V30, and V. Fill may be used in V zones for minor landscaping and site drainage purposes (consult local officials for specific guidance or requirements).

NOTE

For more information about the use of fill in V zones, refer to *Free of Obstructions Requirements for Buildings Located in Coastal High Hazard Areas*, FEMA NFIP Technical Bulletin 5 (FEMA 1993c) (see Appendix H).

NOTE

For more information about enclosures, the use of space below elevated buildings, and breakaway walls, refer to Section 12.4.6, 12.6.2, and 12.8 of this manual and to the following FEMA NFIP Technical Bulletins (see Appendix H):

Design and Construction Guidance for Breakaway Walls for Structures Located in Coastal High Hazard Areas, NFIP Technical Bulletin 9 (FEMA 1999a)

Flood-Resistant Materials Requirements for Buildings Located in Special Flood Hazard Areas, NFIP Technical Bulletin 2 (FEMA 1993b)

Free-Of-Obstruction Requirements for Buildings Located in Coastal High Hazard Areas, NFIP Technical Bulletin 5 (FEMA 1993c).

WARNING

Although the NFIP regulations permit below-BFE enclosures that meet the criteria presented here, many communities may have adopted ordinances that prohibit all such enclosures or that establish more stringent criteria, such as an enclosure size limitation. Check with local officials about such requirements.

Space Below the BFE

The space below all newly constructed, substantially damaged, and substantially improved buildings must either be **free of obstructions** or enclosed only by non-supporting **breakaway walls**, open wood **latticework**, or **insect screening** intended to collapse under water loads without causing collapse, displacement, or other structural damage to the elevated portion of the building or the supporting foundation system. Furthermore, there are specific NFIP requirements regarding **permitted uses** below the BFE, use of **flood-damage-resistant materials** below the BFE, and placement of **mechanical/utility equipment** below the BFE. These requirements have been developed over the years, based on damage to thousands of structures during many flood events—they should not be ignored by the designer, contractor, or owner. Failure to comply with not only these requirements not only violates the local floodplain management ordinance and NFIP regulations, but can also lead to large, uninsured losses.

The current NFIP regulatory requirements regarding breakaway walls are set forth at 44CFR 60.3(e)(5). The regulations specify a design safe loading resistance for breakaway walls of not less than 10 lb/ft^2 and not more than 20 lb/ft^2. However, the regulations also provide for the use of alternative designs that do not meet the specified loading requirements. In general, breakaway walls built according to such designs are permitted if a registered professional engineer or architect certifies that the walls will collapse under a water load less than that which would occur during the base flood and that the elevated portion of the building and supporting foundation system will not be subject to collapse, displacement, or other structural damage due to the effects of wind and water loads acting simultaneously on all components of the building. Additional requirements apply to the use of an enclosed area below the BFE—it may be used only for parking, building access, or storage, and it must be constructed of flood-resistant materials.

The current NFIP regulations do not provide specifications or other detailed guidance for the design and construction of alternative types of breakaway walls. However, the results of recent research conducted for FEMA and the National Science Foundation by North Carolina State University (NCSU) and Oregon State University (OSU), including full-scale tests of breakaway wall panels, provide the basis for prescriptive criteria for the design and construction of breakaway wall panels that do not meet the requirement for a loading resistance of 10-20 lb/ft^2. These criteria are presented in *Design and Construction Guidance for Breakaway Walls Below Elevated Coastal Buildings*, FEMA NFIP Technical Bulletin 9 (FEMA 1999a). The criteria address breakaway wall construction materials, including wood framing, light-gauge steel framing, and masonry; attachment of the walls to floors and foundation members; utility lines; wall coverings such as interior and exterior sheathing, siding, and stucco; and other design and construction issues. In addition, the bulletin describes the results of the NCSU-OSU tests. The test results are described in greater detail in *Behavior or Breakaway Walls Subjected to Wave Forces: Analytical and Experimental Studies* (Tung et al. 1999).

CROSS-REFERENCE

See Section 12.4.6 for information on the construction of breakaway wall enclosures.

6.5 Recommendations for Exceeding Minimum NFIP Regulatory Requirements

Section 6.4 describes the minimum requirements of the NFIP regulations concerning buildings in A zones and V zones. This section presents recommendations for exceeding NFIP minimum requirements. These recommendations address the significant hazards present in coastal A zones and V zones and are aimed at increasing the ability of coastal residential buildings to withstand natural hazard events. Table 6.1, presented at the end of this section, summarizes the NFIP requirements and the recommendations of this manual regarding buildings in A zones, coastal A zones, and V zones.

6.5.1 Non-Coastal A Zones

Recommendations for the design and construction of buildings in non-coastal A zones are not within the scope of this manual. Designers seeking guidance regarding good practice for the design and construction of such buildings should consult local floodplain management, building, or code officials. Additional guidance can be found in *Engineering Principles and Practices for Retrofitting Flood Prone Residential Buildings*, FEMA 259 (FEMA 1995a); the IBC 2000 (ICC 2000a) and IRC 2000 (ICC 2000b); and FEMA's NFIP Technical Bulletin Series (see Appendix H for copies of Technical Bulletins).

6.5.2 Coastal A Zones and V Zones

As explained in Chapters 1 and 3 of this manual, the NFIP regulations do not differentiate between coastal and non-coastal A zones. Because coastal A zones may be subject to the types of hazards present in V zones, such as wave effects, velocity flows, erosion, scour, and high winds, **this manual recommends that buildings in coastal A zones meet the NFIP regulatory requirements for V-zone buildings** (i.e., the performance requirements concerning resistance to flotation, collapse, and lateral movement and the prescriptive requirements concerning elevation, foundation type, engineering certification of design and construction, enclosures below the BFE, and use of structural fill—see Section 6.4.3.3).

To provide a greater level of protection against the hazards in coastal A zones and V zones, this manual recommends the following as good practice for the siting, design, and construction of buildings in those zones:

- The building should be located landward of both the long-term erosion setback and the limit of 100-year storm erosion, rather than simply landward of the reach of mean high tide.
- The bottom of the lowest horizontal structural member should be elevated **above**, rather than to, the BFE (i.e., provide freeboard—see Figure 6-4).
- Open latticework or screening should be used in lieu of breakaway walls in the space below the elevated building, or, at a minimum, the use of solid breakaway wall construction should be minimized.

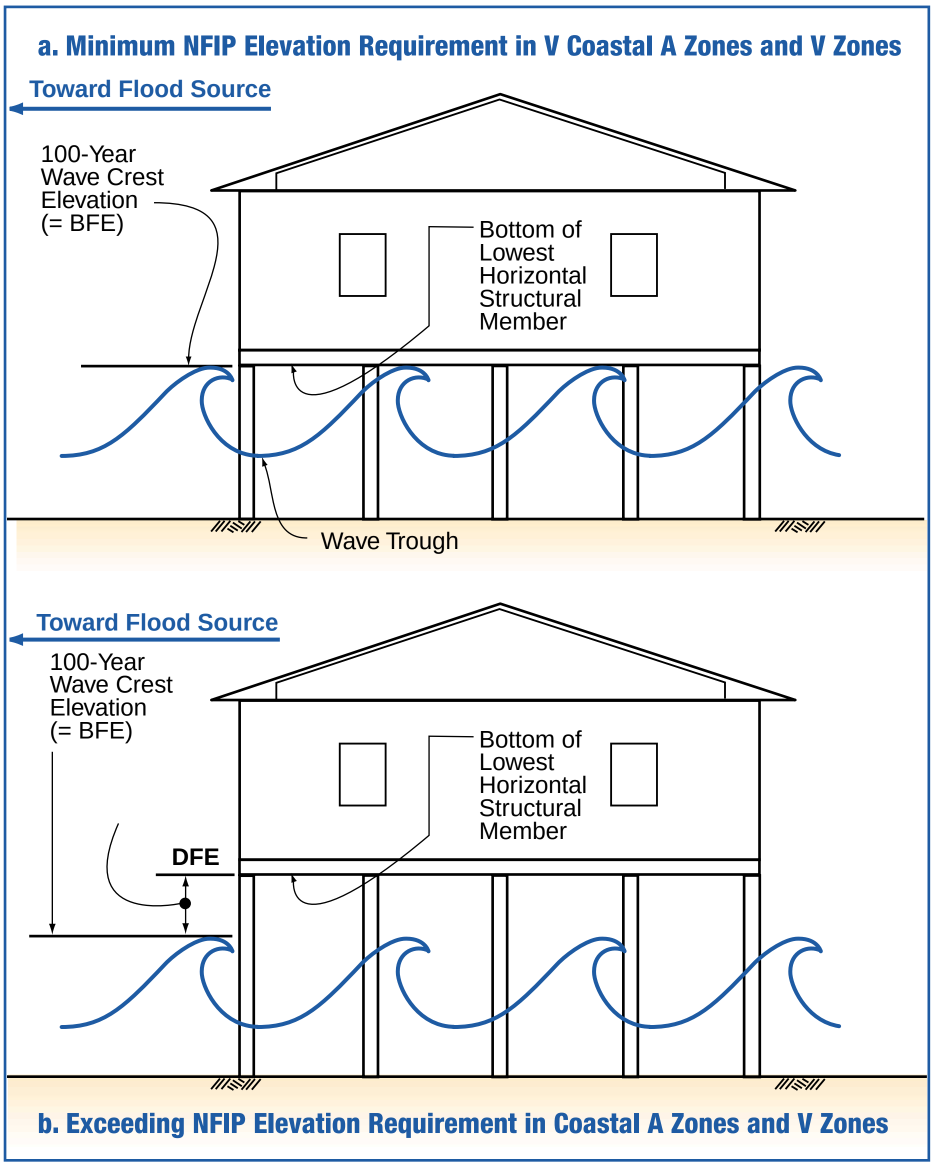


Figure 6-4
Recommended elevation for buildings in coastal A zones and V zones: The bottom of the lowest horizontal structural member should be above the BFE (rather than elevated to the BFE as shown in Figure 6-3). The additional amount of elevation above the BFE is referred to as *freeboard*. In V zones, the lowest horizontal structural members should be perpendicular to the expected wave crest.

NOTE

To determine whether state coastal zone management regulations apply to a specific property, the designer or property owner should consult community officials or the appropriate state coastal zone management agency (see Appendix E, in Volume III of this manual).

In V zones, the lowest horizontal structural members should be oriented perpendicular to the expected wave crest.

6.5.3 Summary

Table 6.1 Summarizes NFIP regulatory requirements for A, coastal A, and V zones, and recommendations for exceeding the requirements. Because the table occupies four pages, the notes are presented twice—here and at the end of the table.

Table 6.1 Summary of NFIP Regulatory Requirements and Recommendations for Exceeding the Requirements

Notes	
a	"Prohibited" and "Allowed" refer to the minimum NFIP regulatory requirements; individual states and communities may enforce more stringent requirements that supersede those summarized here. **Exceeding minimum NFIP requirements will provide increased flood protection and may result in lower flood insurance premiums.**
b	In this column, "TB" means NFIP Technical Bulletin (e.g., TB 1 = Technical Bulletin 1), and "CFR" means the U.S. Code of Federal Regulations. Refer to Appendix H for copies of the bulletins cited here.
c	Some communities may allow encroachments to cause a 1-foot rise in the flood elevation, while others may allow no rise.
d	Some coastal communities require open foundations in A zones.
e	Bottom of lowest horizontal structural member must be at or above the BFE.
f	State or community may regulate to a higher elevation (DFE).
g	Some coastal communities prohibit breakaway walls and allow only open lattice or screening.
h	If an area below the BFE in an A-zone building is fully enclosed by breakaway walls, the walls must meet the requirement for openings that allow equalization of hydrostatic pressure.
i	Placement of nonstructural fill adjacent to buildings in coastal AO zones is not recommended.
j	There are some differences between what is permitted under floodplain management regulations and what is covered by NFIP flood insurance. Building designers should be guided by floodplain management requirements, not by flood insurance policy provisions. See Section 9.3.1.1, in Chapter 9, for additional information.
k	Walls below BFE must be designed and constructed as breakaway walls that meet the minimum requirements of the NFIP regulations (see Section 6.4.3.3).

Table 6.1 Summary of NFIP Regulatory Requirements and Recommendations for Exceeding the Requirements (continued)

	V Zone Guidance[a]	V Zone X-ref[b]	Coastal A Zone Guidance[a]	Coastal A Zone X-ref[b]	A Zone Guidance[a]	A Zone X-ref[b]
General Requirements						
Design	**Requirement:** building and its foundation must be designed, constructed, and anchored to prevent flotation, collapse, and lateral movement due to **simultaneous wind and water loads**	Section 6.4.3.3	**Requirement:** building must be designed, constructed, and anchored to prevent flotation, collapse, and lateral movement resulting from hydrodynamic and hydrostatic loads, including the effects of buoyancy **Recommendation:** same a V zone	Section 6.4.3.1	**Requirement:** building must be designed, constructed, and anchored to prevent flotation, collapse, and lateral movement resulting from hydrodynamic and hydrostatic loads, including the effects of buoyancy	Section 6.4.3.1
Materials	**Requirement:** structural and nonstructural building materials at or below the BFE must be flood-resistant	Section 6.4.3.1 TB2 (see Appendix H)	**Requirement:** structural and nonstructural building materials at or below the BFE must be flood-resistant	Section 6.4.3.1 TB2 (see Appendix H)	**Requirement:** structural and nonstructural building materials at or below the BFE must be flood-resistant	Section 6.4.3.1 TB2 (see Appendix H)
Construction	**Requirement:** building must be constructed with methods and practices that minimize flood damage	Section 6.4.3.1	**Requirement:** building must be constructed with methods and practices that minimize flood damage	Section 6.4.3.1	**Requirement:** building must be constructed with methods and practices that minimize flood damage	Section 6.4.3.1
Siting	**Requirement:** all new construction shall be landward of mean high tide; alteration of sand dunes and mangrove stands that increases potential flood damage is prohibited **Recommendation:** site new construction landward of the long-term erosion setback and landward of the area subject to erosion during the 100-year coastal flood event	Section 6.4.3.3 CFR 60.3(e)(3) and 60.3(e)(7) Section 6.5.2 Section 7.5 Chapter 8	**Requirement:** encroachments into the SFHA are permitted as long as they do not increase the BFE by more than 1 foot[c]; encroachments into the floodway are prohibited **Recommendation:** same as V zone	CFR 60.3(c)(10) Section 6.5.2 Section 7.5 Chapter 8	**Requirement:** encroachments into the SFHA are permitted as long as they do not increase the BFE by more than 1 foot[c]; encroachments into the floodway are prohibited	CFR 60.3(c)(10)

Table 6.1 Summary of NFIP Regulatory Requirements and Recommendations for Exceeding the Requirements (continued)

	V Zone		Coastal A Zone		A Zone	
	Guidance[a]	X-ref[b]	Guidance[a]	X-ref[b]	Guidance[a]	X-ref[b]
Foundation						
Structural Fill	**Prohibited**	Section 6.4.3.3 TB5 (see Appendix H)	**Allowed, but not recommended;** compaction required where used; protect against scour and erosion[d]	Section 6.5.2	**Allowed;** compaction required where used; protect against scour and erosion[d]	
Solid Foundation	**Prohibited**	Section 6.4.3.3 TB5 (see Appendix H)	**Allowed, but not recommended**[d]	Section 6.5.2	**Allowed**[d]	
Open Foundation	**Required**	Section 6.4.3.3 TB5 (see Appendix H)	**Not required, but recommended**[d]	Section 6.5.2	**Allowed**[d]	
Lowest Floor Elevation	**Not Applicable**[e]		**Requirement:** top of floor must at or above BFE[f] **Recommendation:** elevate bottom of lowest horizontal structural member to or above BFE[f] (see next category below); orient member perpendicular to wave crest	Section 6.4.3.2	**Requirement:** top of floor must at or above BFE[f]	Section 6.4.3.2
Bottom of Lowest Horizontal Structural Member	**Requirement:** bottom must at or above BFE[f]	Section 6.4.3.3 TB5 (see Appendix H)	**Allowed below BFE[f], but not recommended** **Recommendation:** same as V zone	Section 6.5.2	**Allowed below BFE[f], but not recommended** **Recommendation:** same as V zone	
Orientation of Lowest Horizontal Structural Member	No requirement **Recommendation:** orient perpendicular to wave crest	Section 6.5.2	No requirement		No requirement	
Freeboard	**Not required[f], but recommended**	Section 6.5.2	**Not required[f], but recommended**	Section 6.5.2	**Not required[f], but recommended**	

Table 6.1 Summary of NFIP Regulatory Requirements and Recommendations for Exceeding the Requirements (continued)

	V Zone Guidance[a]	V Zone X-ref[b]	Coastal A Zone Guidance[a]	Coastal A Zone X-ref[b]	A Zone Guidance[a]	A Zone X-ref[b]
Enclosures Below The BFE						
(Also see CERTIFICATION)	**Prohibited,** except for breakaway walls, open lattice, and screening[g] **Recommendation:** if constructed, use open lattice or screening instead of breakaway walls	Section 6.4.3.3 TB5 & TB9 (see Appendix H)	Allowed, but **not recommended;** if an area is fully enclosed, the enclosure walls must be equipped with openings to equalize hydrostatic pressure; size, location, and covering of openings governed by regulatory requirements **Recommendation:** if enclosure is constructed, use breakaway walls, open lattice, or screening (as required in V zone)[g,h]	Section 6.5.2 Section 6.4.3.2 TB1 (see Appendix H)	**Allowed;** if an area is fully enclosed, the enclosure walls must be equipped with openings to equalize hydrostatic pressure; size, location, and covering of openings governed by regulatory requirements[g,h]	Section 6.4.3.2 TB1 (see Appendix H)
Nonstructural Fill						
	Allowed for minor landscaping and site drainage as long as the fill does not interfere with the free passage of flood waters and debris beneath the building or cause changes in flow direction during coastal storms that could result in damage to buildings	Section 6.4.3.3 TB5 (see Appendix H)	**Allowed**[i] **Recommendation:** same as V zone	Section 6.5.2	**Allowed**	
Use of Space Below BFE[j]						
	Allowed only for parking, building access, and storage	Section 6.4.3.3 TB5 (see Appendix H)	**Allowed only** for parking, building access, and storage	Section 6.4.3.2 TB1 (see Appendix H)	**Allowed only** for parking, building access, and storage	Section 6.4.3.2 TB1 (see Appendix H)
Utilities[j]						
	Requirement: must be designed, located, and elevated to prevent flood waters from entering and accumulating in components during flooding	Section 6.4.3.1 FEMA 348 (FEMA 1999b)	**Requirement:** must be designed, located, and elevated to prevent flood waters from entering and accumulating in components during flooding	Section 6.4.3.1 FEMA 348 (FEMA 1999b)	**Requirement:** must be designed, located, and elevated to prevent flood waters from entering and accumulating in components during flooding	Section 6.4.3.1 FEMA 348 (FEMA 1999b)

Table 6.1 Summary of NFIP Regulatory Requirements and Recommendations for Exceeding the Requirements (continued)

	V Zone		Coastal A Zone		A Zone	
	Guidance[a]	X-ref[b]	Guidance[a]	X-ref[b]	Guidance[a]	X-ref[b]
Certification						
Structure	**Required:** registered engineer or architect must certify that the design and methods of construction are in accordance with accepted standards of practice for meeting the design requirements described under **GENERAL REQUIREMENTS**	Section 6.4.3.3	**Recommendation:** same as V zone	Section 6.5.2	**Recommendation:** same as V zone	
Breakaway Walls (Also see ENCLOSURES BELOW THE BFE)	**Required:** either of the following: (1) walls must be designed to provide a safe loading resistance of between 10 lb/ft^2 and 20 lb/ft^2 OR (2) a registered engineer or architect must certify that the walls will collapse under a water load associated with the base flood and that the elevated portion of building and its foundation will not be subject to collapse, displacement, or lateral movement under simultaneous wind and water loads[g,h]	Section 6.4.3.3 TB 9 (see Appendix H)	Not required, but **recommended**[g,h]	Section 6.5.2	Not required[g,h]	
Openings in Below-BFE Walls (Also see ENCLOSURES BELOW THE BFE)	Not Applicable[k]		**Required:** unless number and size of openings meets regulatory requirements, registered engineer or architect must certify that openings are designed to automatically equalize hydrostatic forces on walls by allowing the automatic entry and exit of flood waters	Section 6.4.3.3 TB 1 (see Appendix H)	**Required:** unless number and size of openings meets regulatory requirements, registered engineer or architect must certify that openings are designed to automatically equalize hydrostatic forces on walls by allowing the automatic entry and exit of flood waters	Section 6.4.3.3 TB 1 (see Appendix H)

Table 6.1 Summary of NFIP Regulatory Requirements and Recommendations for Exceeding the Requirements (continued)

Notes

a "Prohibited" and "Allowed" refer to the minimum NFIP regulatory requirements; individual states and communities may enforce more stringent requirements that supersede those summarized here. **Exceeding minimum NFIP requirements will provide increased flood protection and may result in lower flood insurance premiums.**

b In this column, "TB" means NFIP Technical Bulletin (e.g., TB 1 = Technical Bulletin 1), and "CFR" means the U.S. Code of Federal Regulations. Refer to Appendix H for copies of the bulletins cited here.

c Some communities may allow encroachments to cause a 1-foot rise in the flood elevation, while others may allow no rise.

d Some coastal communities require open foundations in A zones.

e Bottom of lowest horizontal structural member must be at or above the BFE.

f State or community may regulate to a higher elevation (DFE).

g Some coastal communities prohibit breakaway walls and allow only open lattice or screening.

h If an area below the BFE in an A-zone building is fully enclosed by breakaway walls, the walls must meet the requirement for openings that allow equalization of hydrostatic pressure.

i Placement of nonstructural fill adjacent to buildings in coastal AO zones is not recommended.

j There are some differences between what is permitted under floodplain management regulations and what is covered by NFIP flood insurance. Building designers should be guided by floodplain management requirements, not by flood insurance policy provisions. See Section 9.3.1.1, in Chapter 9, for additional information.

k Walls below BFE must be designed and constructed as breakaway walls that meet the minimum requirements of the NFIP regulations (see Section 6.4.3.3).

6.6 Coastal Barrier Resources Act of 1982

The Coastal Barrier Resources Act (CBRA) of 1982 was enacted to protect vulnerable coastal barriers from development; minimize the loss of life; reduce expenditures of Federal revenues; and protect fish, wildlife, and other natural resources. This law established the Coastal Barrier Resources System (CBRS), which is managed by the U.S. Department of the Interior, Fish and Wildlife Service. The law restricts Federal expenditures and financial assistance that could encourage development of coastal barriers. The CBRA does not prohibit privately financed development; however, it does prohibit most new Federal financial assistance, **including federally offered flood insurance**, in areas within the CBRS (also referred to as CBRA areas). Flood insurance may not be sold for buildings in the CBRS that were constructed or substantially improved after October 1, 1983. The financial risk of building in these areas is transferred from Federal taxpayers directly to those who choose to live in or invest in these areas.

NOTE

Additional information about Coastal Barrier Resources System (CBRS) regulations and areas included in the CBRS is available at the U.S. Fish and Wildlife Service website at http://www.fws.gov/cep/cbrtable. html.

The Coastal Barrier Improvement Act (CBIA), passed in 1991, tripled the size of the CBRS to over 1.1 million acres. The CBIA also designated "otherwise protected areas" that include lands that are under some form of public ownership. The CBIA prohibits the issuance of flood insurance on buildings constructed or substantially improved after November 16, 1991, for the areas added to the CBRS, including these "otherwise protected areas." An exception is made to allow insurance for buildings located in "otherwise protected areas" that are used in a manner consistent with the purpose for which the area is protected. Examples include research buildings, buildings that support the operation of a wildlife refuge, and similar buildings.

CBRS boundaries are shown on a series of maps produced by the Department of the Interior (DOI). In addition, FEMA has transferred CBRS boundaries to FIRMs so that insurance agents and underwriters may determine eligibility for flood insurance coverage. Before constructing a new building, substantially improving an existing building, or repairing a substantially damaged building, the designer or property owner should review the FIRM to determine whether the property is within the CBRS. In situations where the FIRM does not allow for a definitive determination, the designer or property owner should consult local officials. In some situations, it may be necessary to request a determination from the U.S. Fish and Wildlife Service based on the DOI maps.

NOTE

Remember: Any building within a CBRS area that is constructed or substantially improved after October 1, 1983, or the date of designation for areas added to the system in 1991, is not eligible for Federal flood insurance or other Federal financial assistance. The same restriction applies to substantially damaged buildings in a CBRS area that are repaired or renovated after those dates.

6.7 Coastal Zone Management Regulations

The Coastal Zone Management (CZM) Act of 1972 encourages adoption of coastal zone policies by U.S. coastal states in partnership with the Federal Government. CZM regulations have been adopted by 27 coastal states and 5 island territories. Two of the three remaining coastal states—Indiana and Minnesota—are preparing CZM regulations for the Great Lakes for Federal approval. For current information concerning the status of state and national CZM programs, refer to the website of the National Oceanic and Atmospheric Administration, National Ocean Service, Office of Coastal Resource Management, at http://wave.nos.noaa.gov/ocrm/czm.

Each state's CZM program contains provisions to:

- protect natural resources,
- manage development in high hazard areas,
- manage development to achieve quality coastal waters,
- give development priority to coastal-dependent uses,
- have orderly processes for the siting of major facilities,
- locate new commercial and industrial development in or adjacent to existing developed areas,
- provide public access for recreation,
- redevelop urban waterfronts and ports, and preserve and restore historic, cultural, and aesthetic coastal features,

- simplify and expedite governmental decision-making actions,
- coordinate state and Federal actions,
- give adequate consideration to the views of Federal agencies,
- ensure that the public and local government have a say in coastal decision-making, and
- comprehensively plan for and manage living marine resources.

Coastal zone regulations vary greatly. Many states, such as Washington, Oregon, and Hawaii, provide guidelines for development while leaving the enactment of specific regulatory requirements up to county and local governments.

Most state coastal zone regulations control construction seaward of a defined boundary line, such as a dune or road. Many states, though not all, regulate or prohibit construction seaward of a second line based on erosion. Some of these lines are updated when new erosion mapping becomes available; lines that follow physical features such as dune lines are not fixed and "float" as the physical feature shifts over time. Examples of other types of state coastal regulations include requirements concerning the placement or prohibition of shore protection structures and the protection of dunes.

Some states not only control new construction, but also regulate renovations and repairs of substantially damaged buildings to a greater degree than required by the NFIP. These regulations help limit future damage in coastal areas by requiring that older buildings be brought up to current standards when they are renovated or repaired.

In addition to regulating the construction of buildings near the coast, many jurisdictions regulate the construction of accessory structures, roads and infrastructure, and other development-related activities.

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Chapter 7: Indentifying Hazards

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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).

WARNING

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

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:

- 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

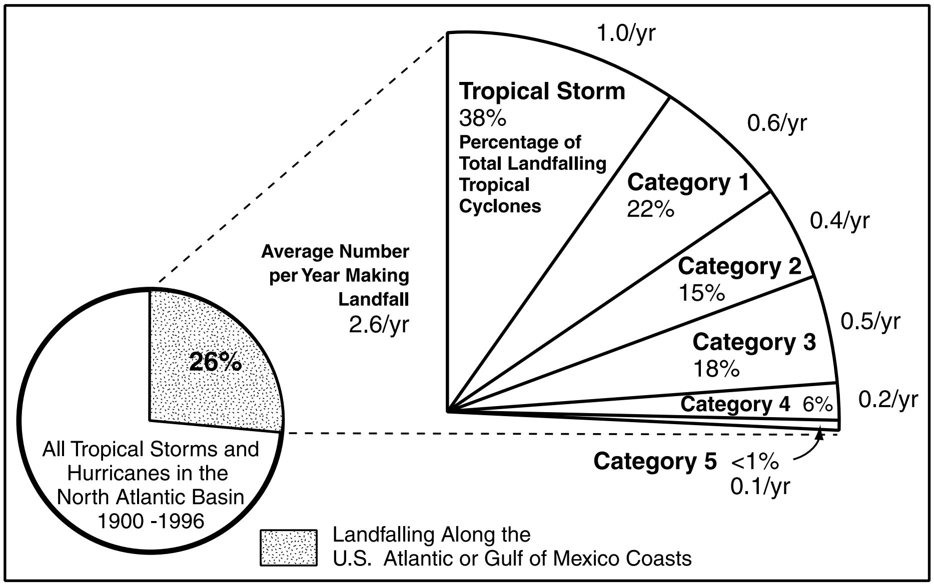
The Saffir-Simpson scale is a generalization, and classification of actual storms may be inconsistent. For example, the classification of a hurricane based on wind speed may differ from the classification based on storm surge or central pressure.

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).

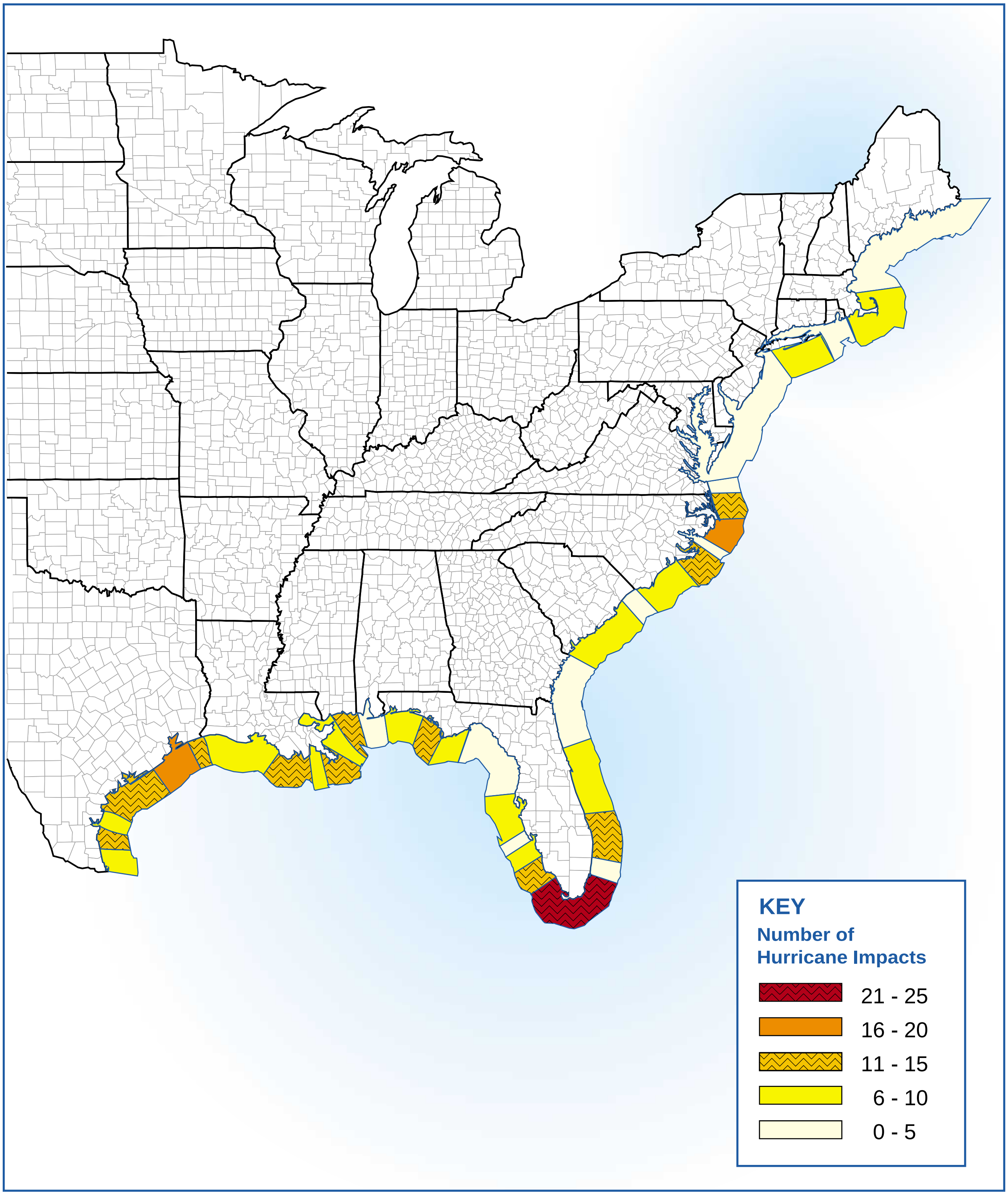


Table 7.2
Mean Return Periods (in Years) for Landfall or Nearby Passage of Tropical Cyclones

	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.

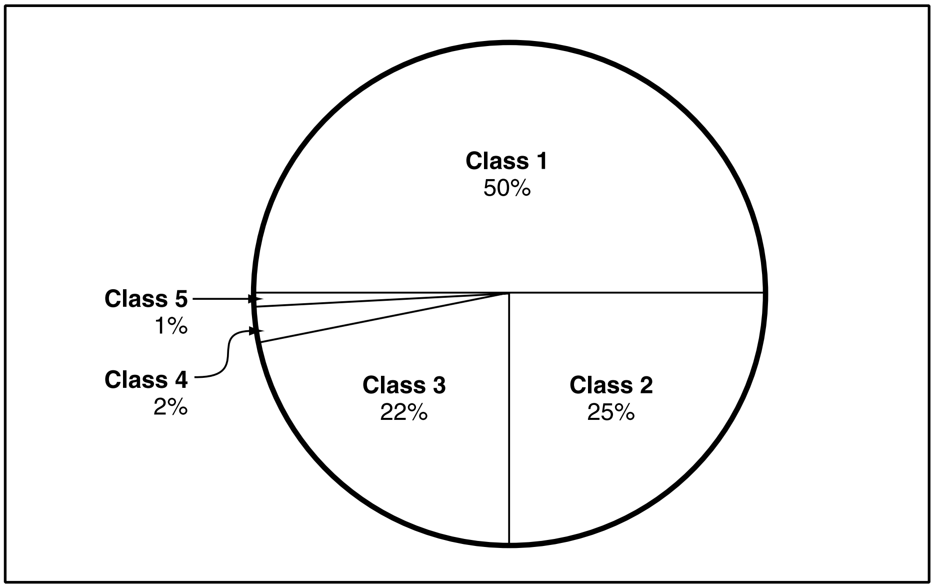


Figure 7-4
Classification (by Dolan-Davis scale) of northeasters at Cape Hatteras, North Carolina, 1942–1984.

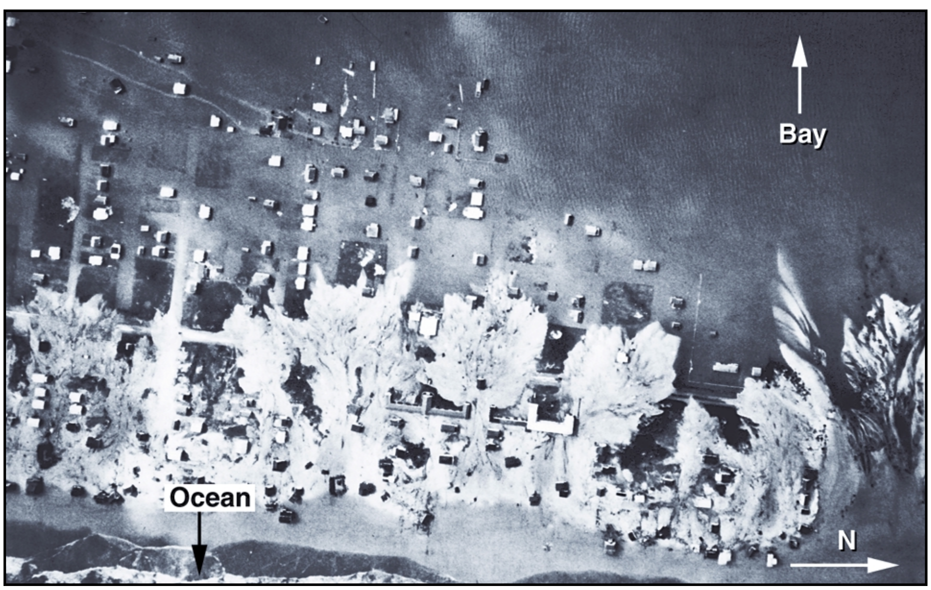


Figure 7-5
March 1962 northeaster. Flooding, erosion, and overwash at Fenwick Island, Delaware.

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.

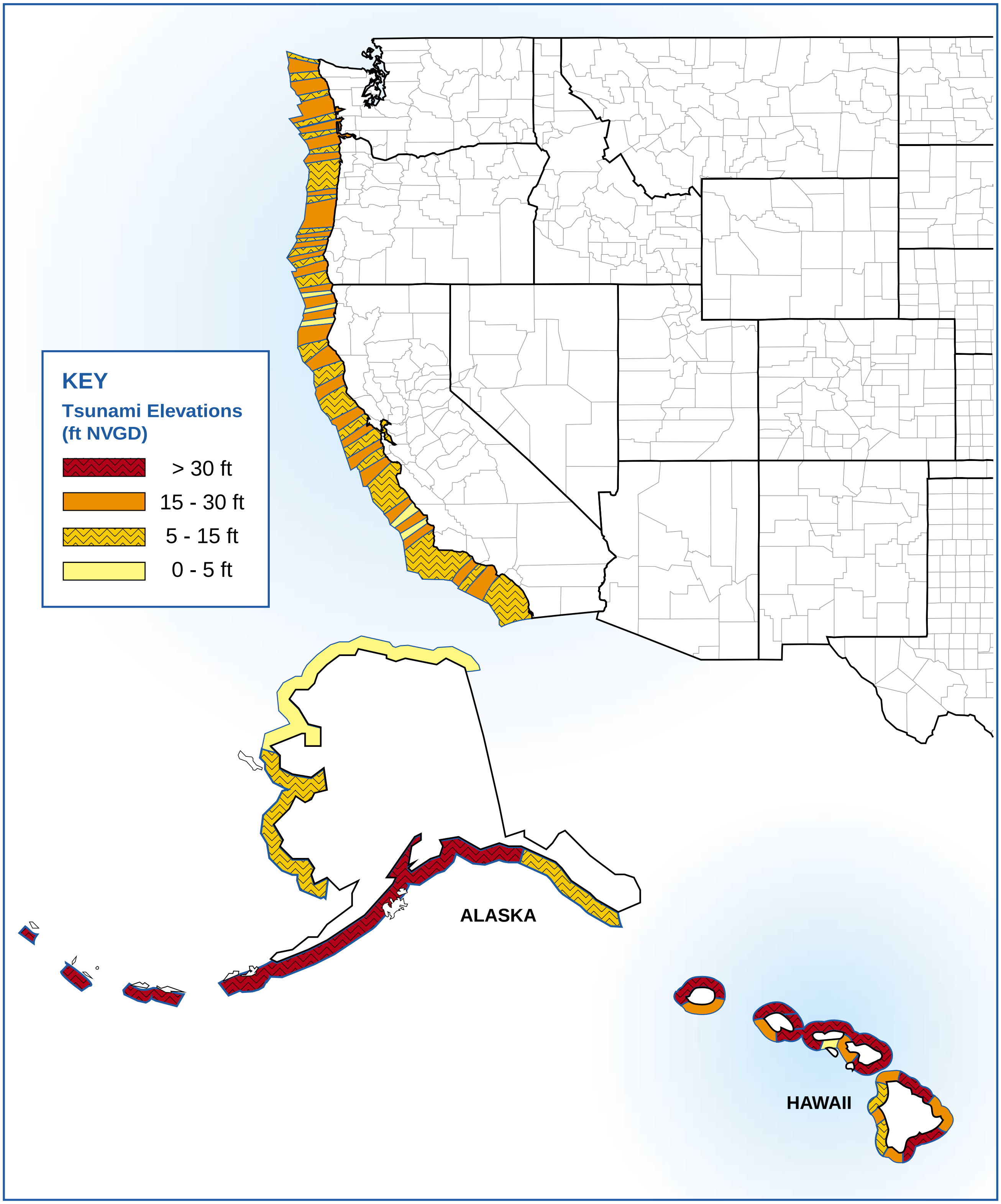
Upland elevations and topography will also determine tsunami impacts at a site. Low-lying tsunami-prone coastal sites will be more susceptible to inundation, tsunami runup, and damage than sites at higher elevations.

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

CROSS-REFERENCE

Sec Chapter 11 for procedures used to calculate flood loads.

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).

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

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.

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.

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*.

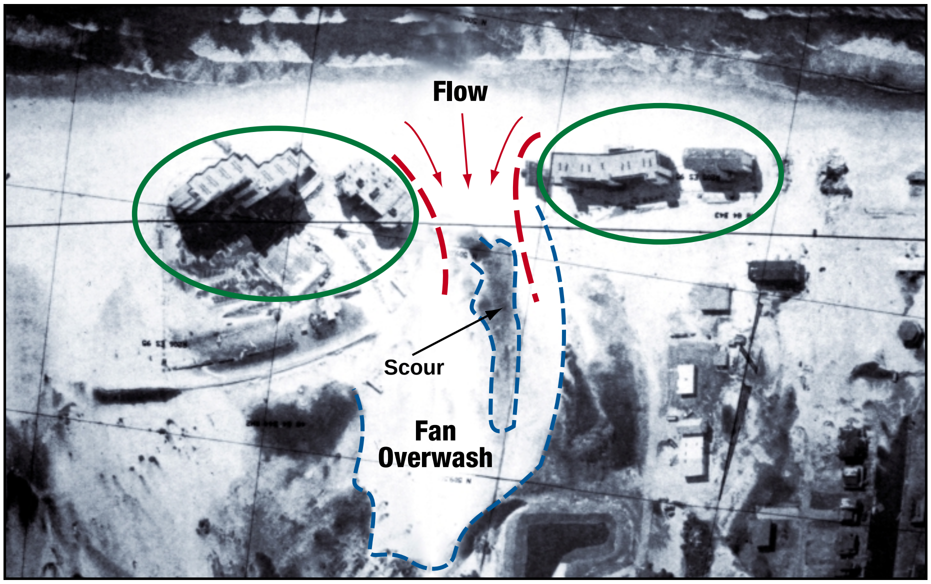


Figure 7-10
Hurricane Opal (1995). Flow channeled between large engineered buildings (circled) at Navarre Beach, Florida, scoured a deep channel across the island and damaged infrastructure and houses. Aerial photograph from Florida Department of Environmental Protection.

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.

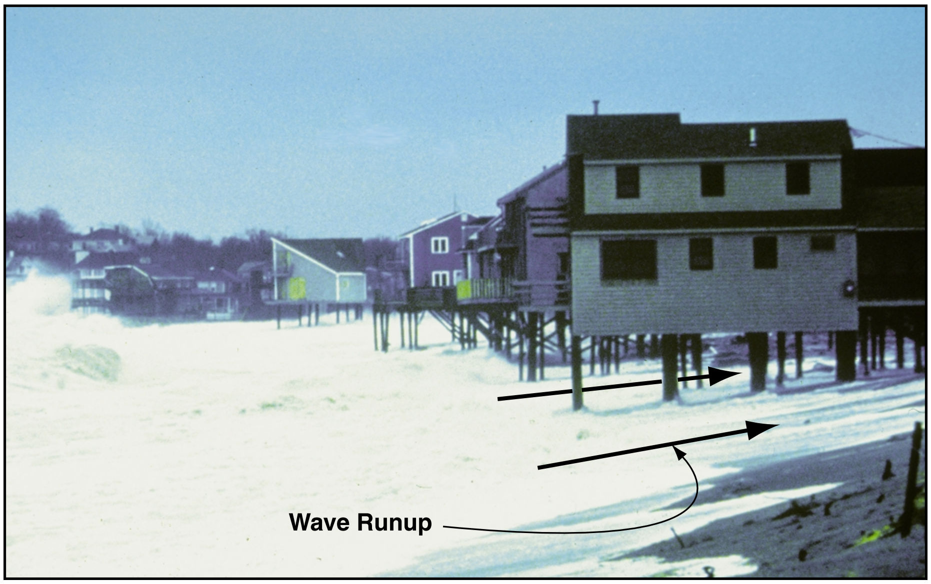


Figure 7-14
Wave runup beneath elevated buildings at Scituate, Massachusetts, during the December 1992 northeast storm. Nine homes in the area were purchased with public funds and demolished following the storm. Photograph by Jim O'Connell.

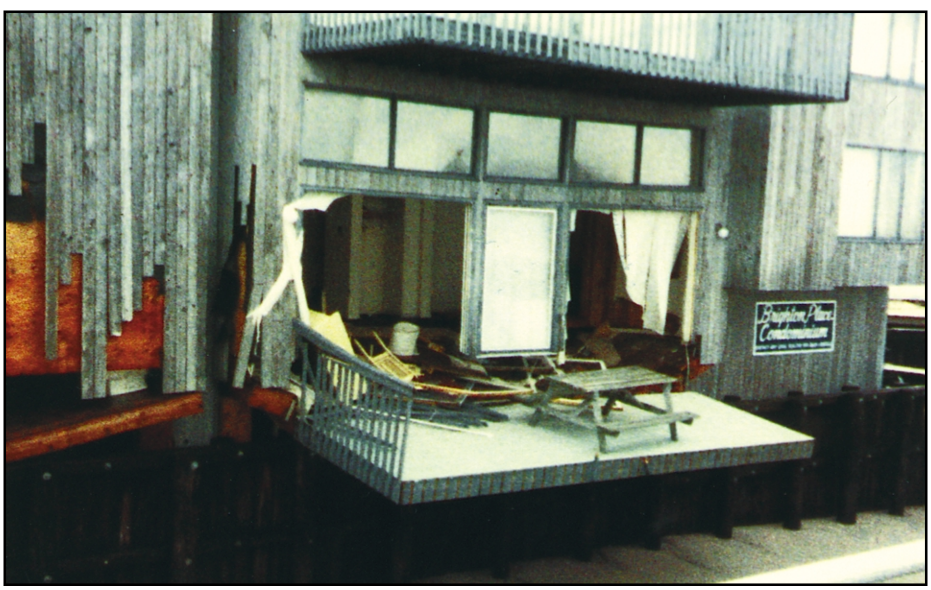


Figure 7-15
Damage to oceanfront condominium in Ocean City, New Jersey, caused by wave runup on a timber bulkhead. April 1984 photograph by Mark Mauriello.

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.

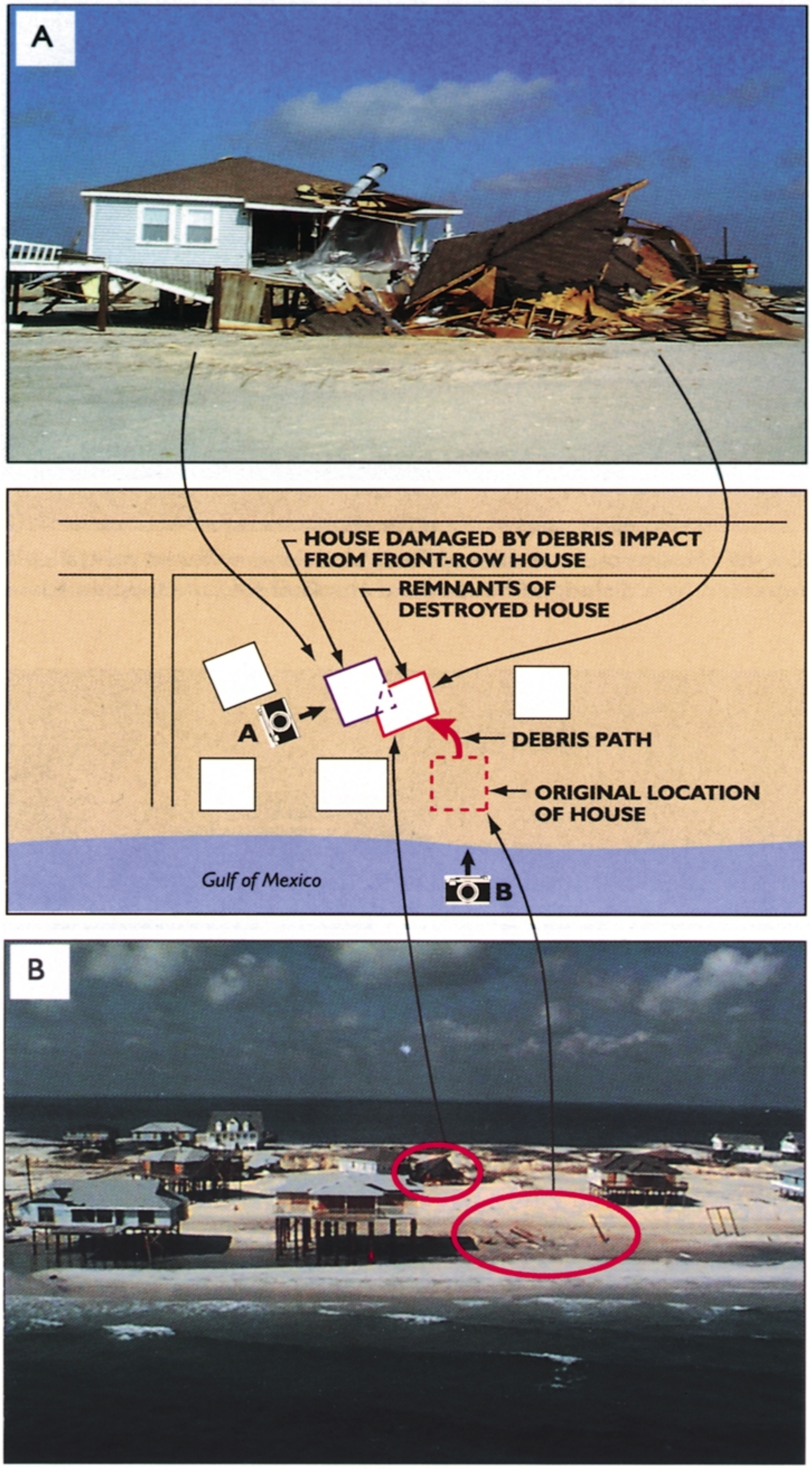


Figure 7-17
Hurricane Georges (1998). A pile-supported house at Dauphin Island, Alabama, was toppled and washed into another house, which suffered extensive damage.

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.*

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.

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.

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).

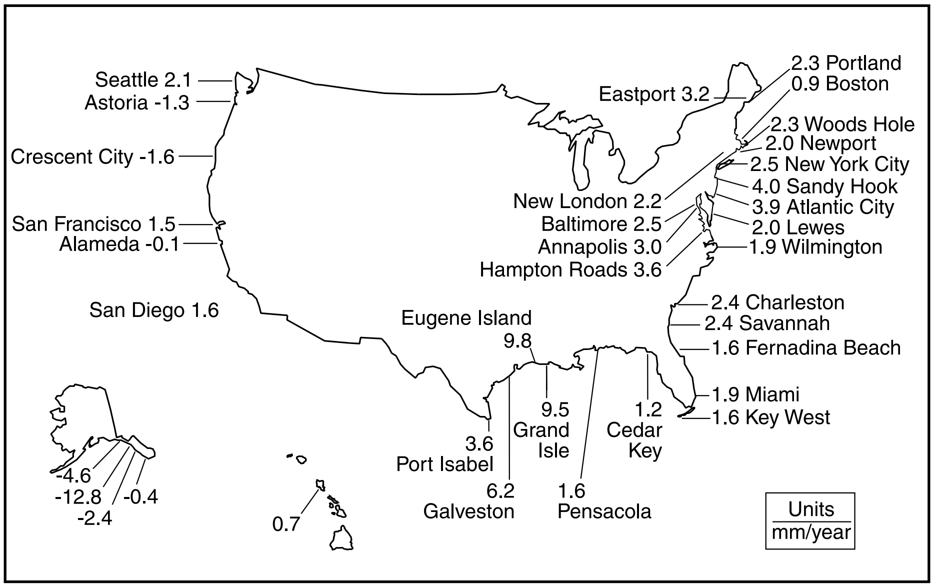
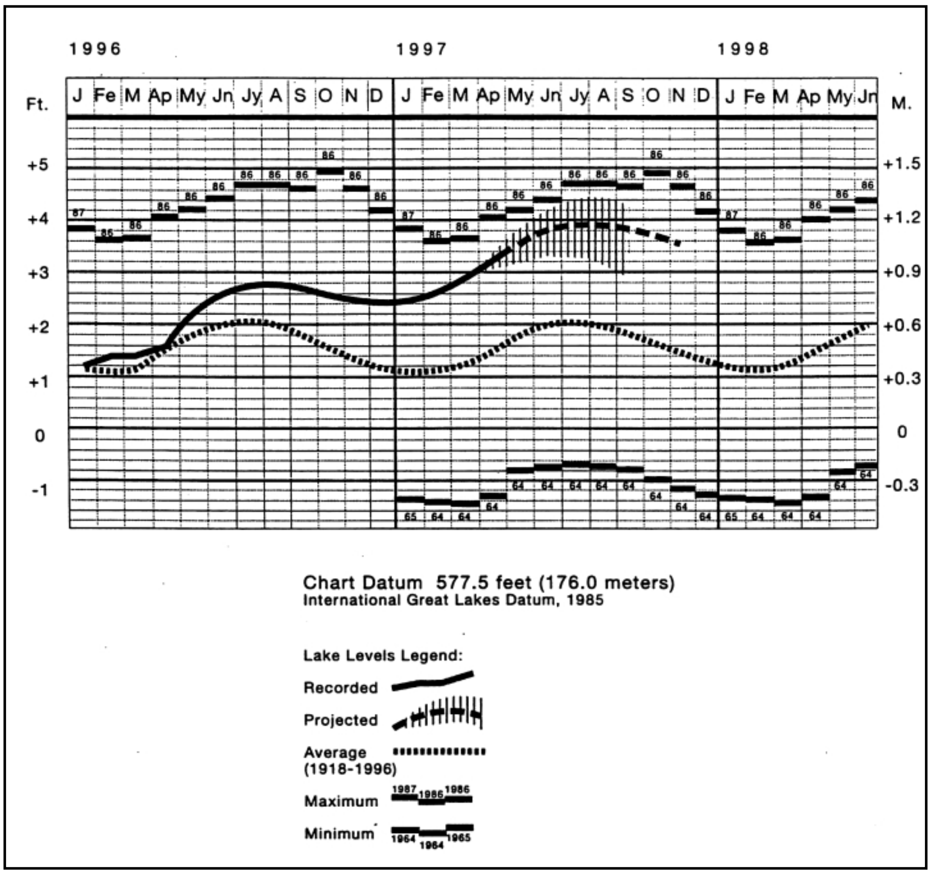


Figure 7-22
Monthly bulletin of lake levels for Lakes Michigan and Huron. Courtesy of USACE, Detroit District.



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.

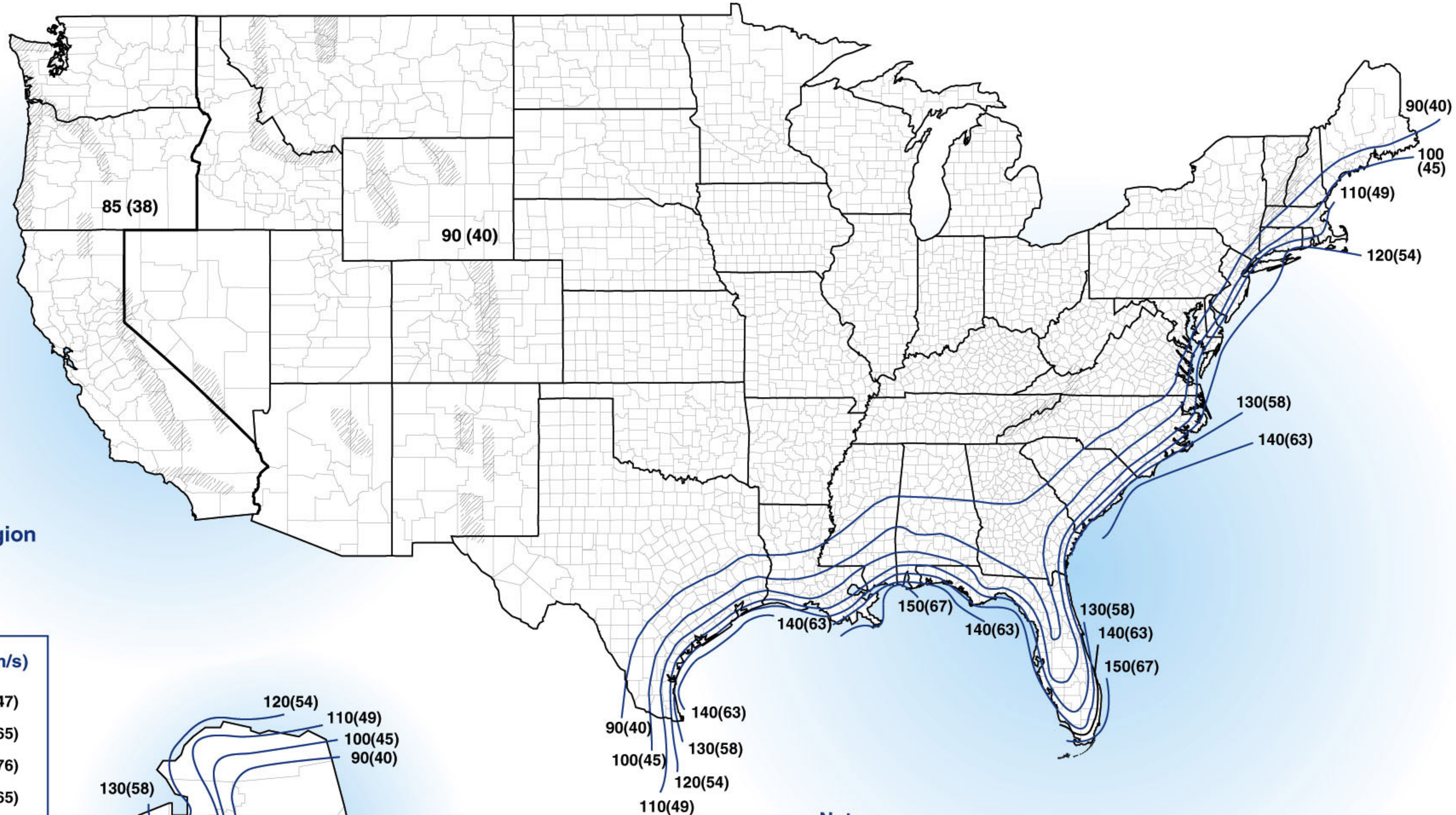
NOTE

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

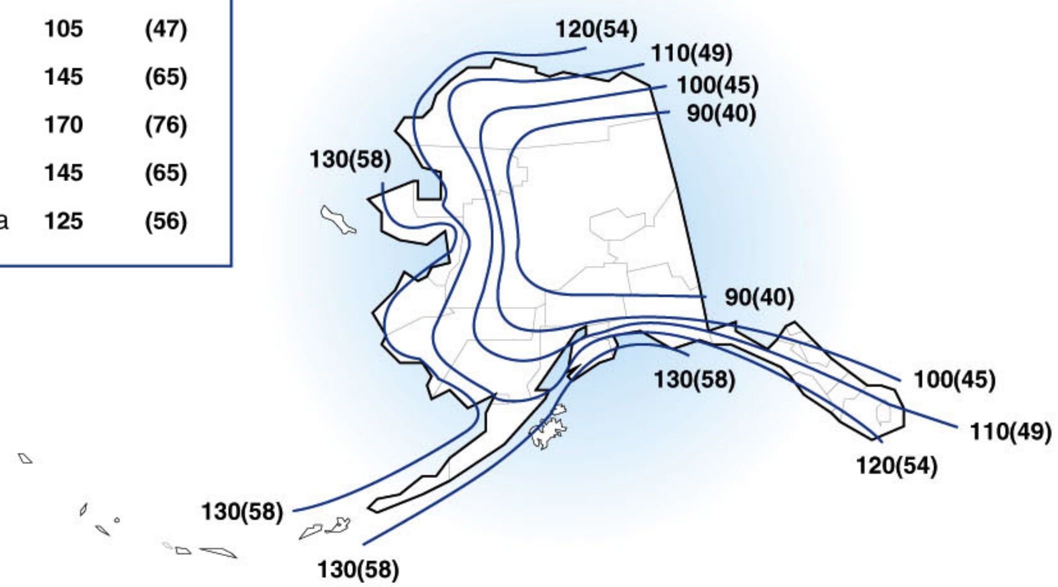
It is generally beyond the scope of most building designs to account for a direct strike by a tornado (the ASCE 7-98 wind map in Figure 7-23 excludes tornado effects). However, use of wind-resistant design techniques will reduce damage caused by a tornado passing nearby.

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.

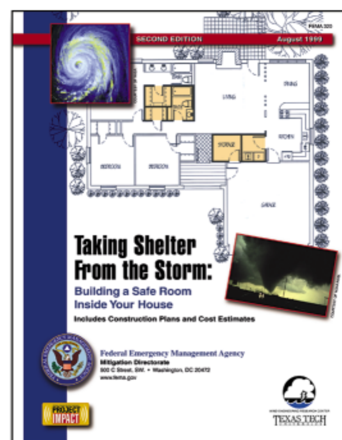
7.4.2 Windborne Debris and Rainfall Penetration

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.

COST CONSIDERATIONS

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



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).

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.

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.

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.

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.

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)

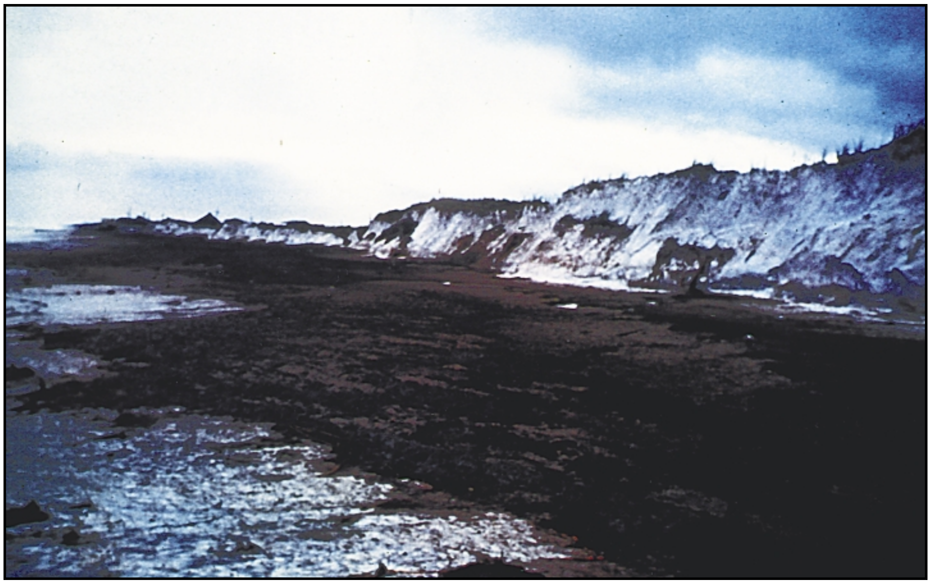


Figure 7-26
Dune erosion in Walton County, Florida, caused by Hurricane Eloise, 1975.

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.

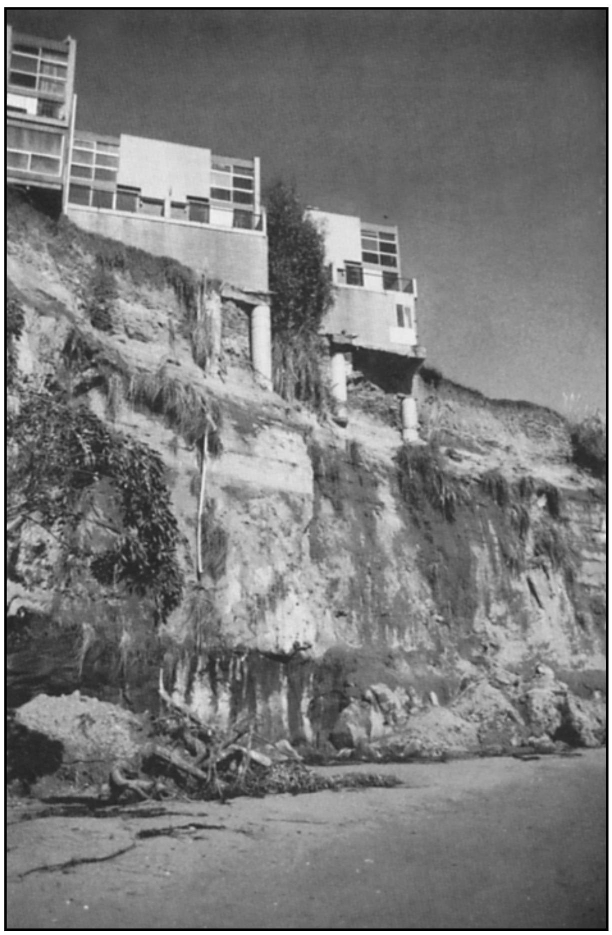


Figure 7-39
Bluff failure by a combination of marine, terrestrial, and seismic processes led to progressive undercutting of blufftop apartments at Capitola, California. Six of the units were demolished after the 1989 Loma Prieta earthquake. 1989 photograph from Griggs (1994), courtesy of Journal of Coastal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

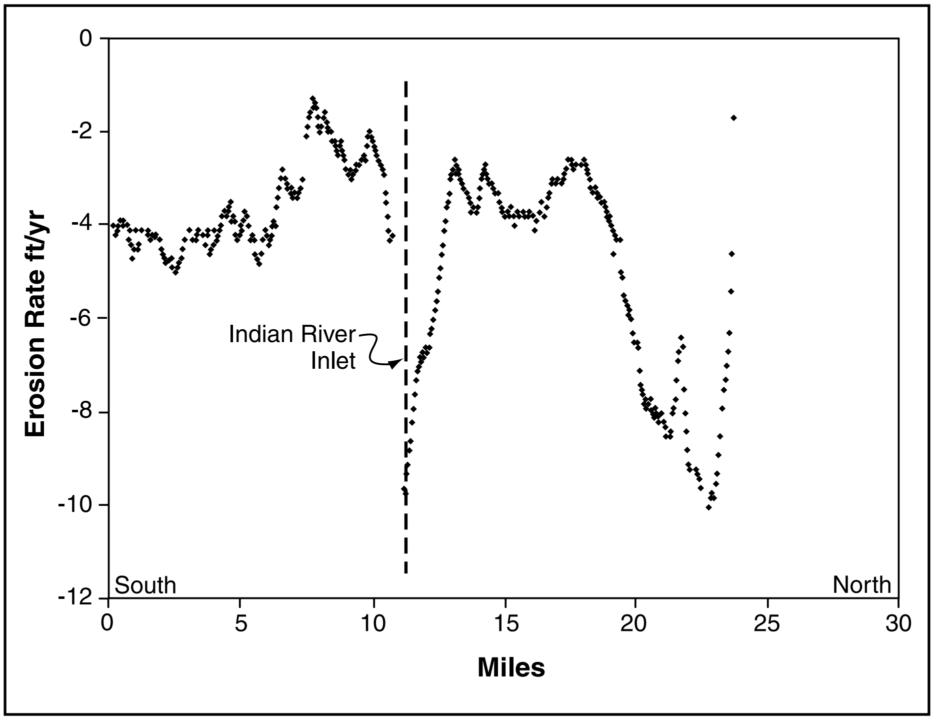


Figure 7-40
Longshore variation in long-term erosion rates, Delaware Atlantic shoreline (from Douglas et al. 1998).

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).

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

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).

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.

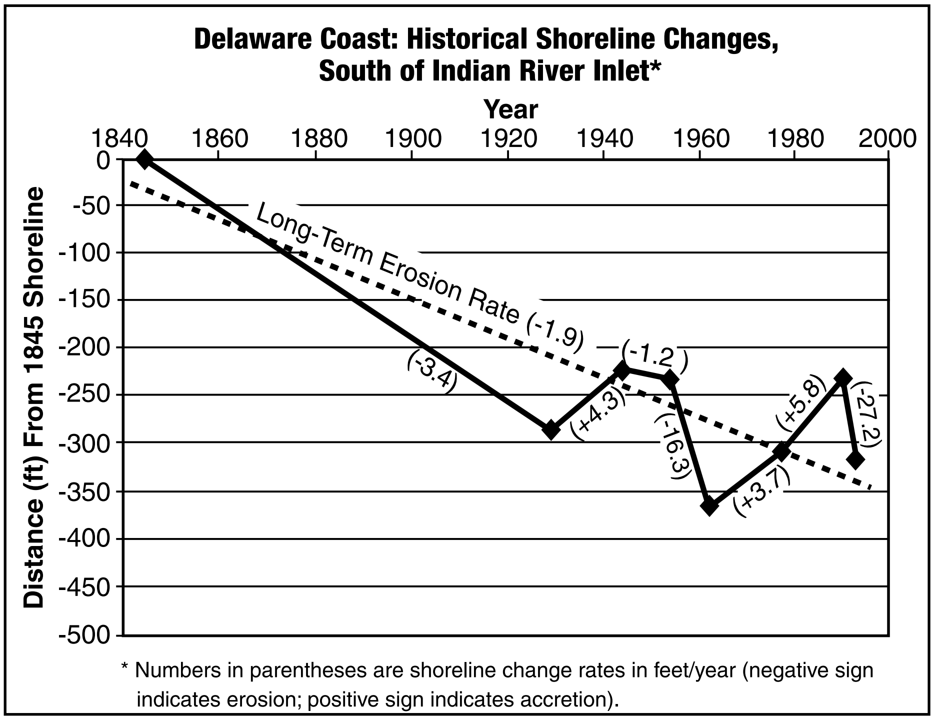
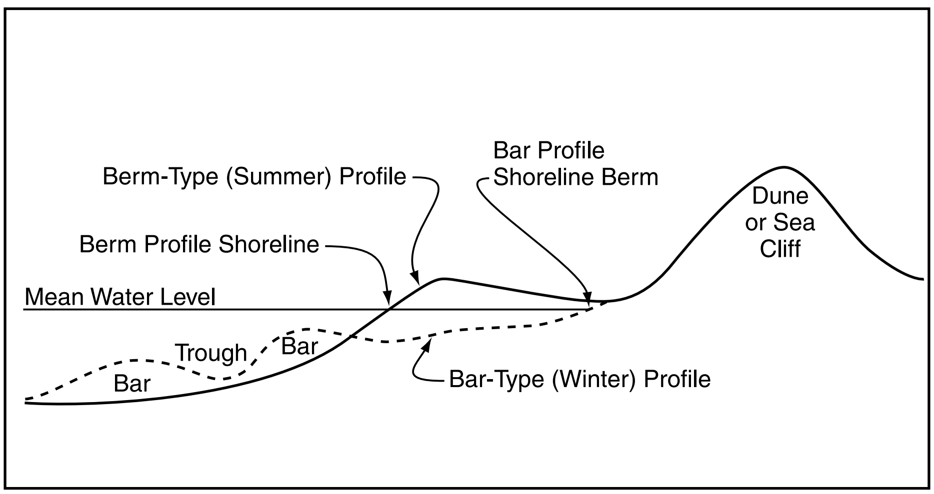


Figure 7-42
Seasonal fluctuations in beach width and elevation.



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.

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

NOTE

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

CROSS REFERENCE

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

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).

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).

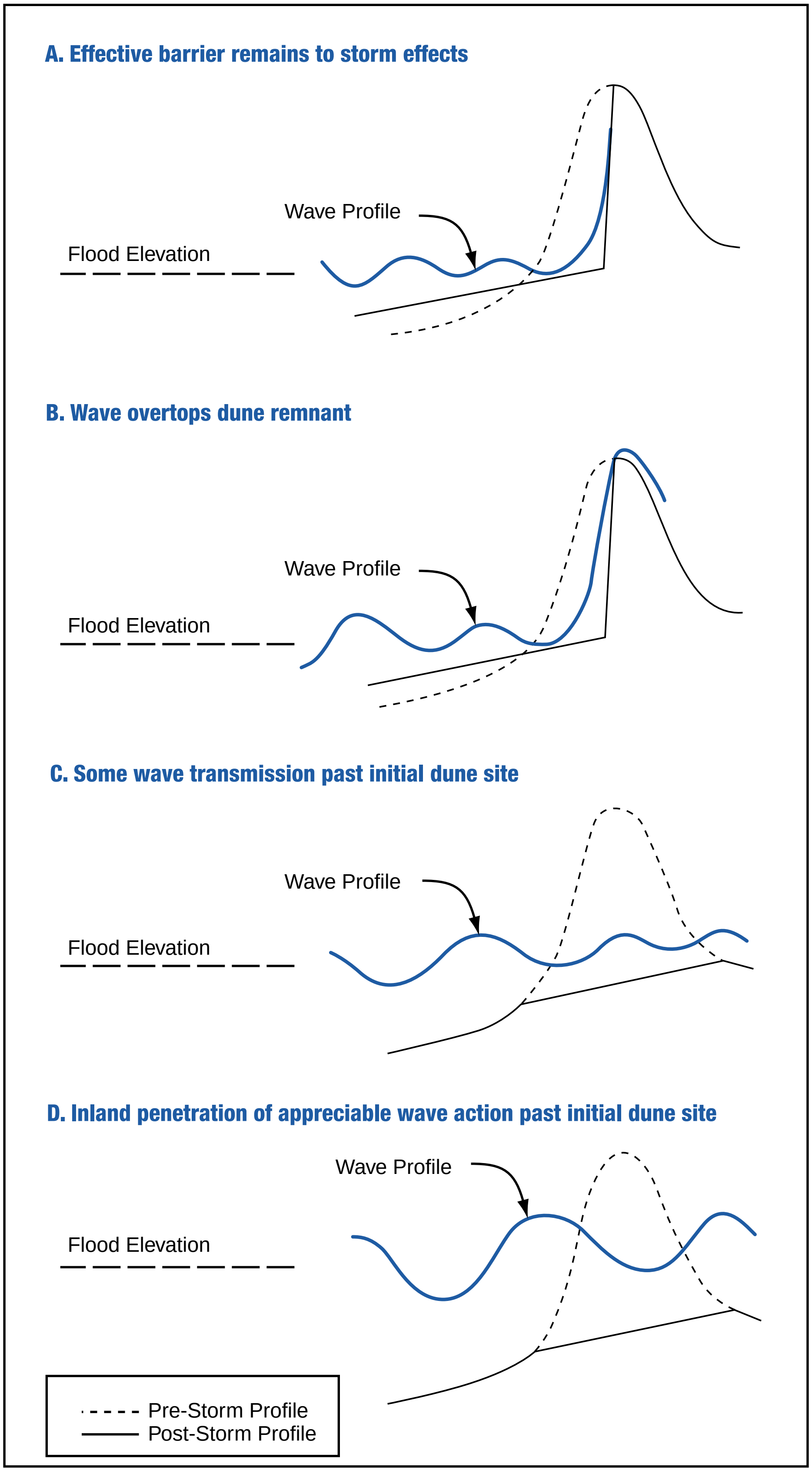
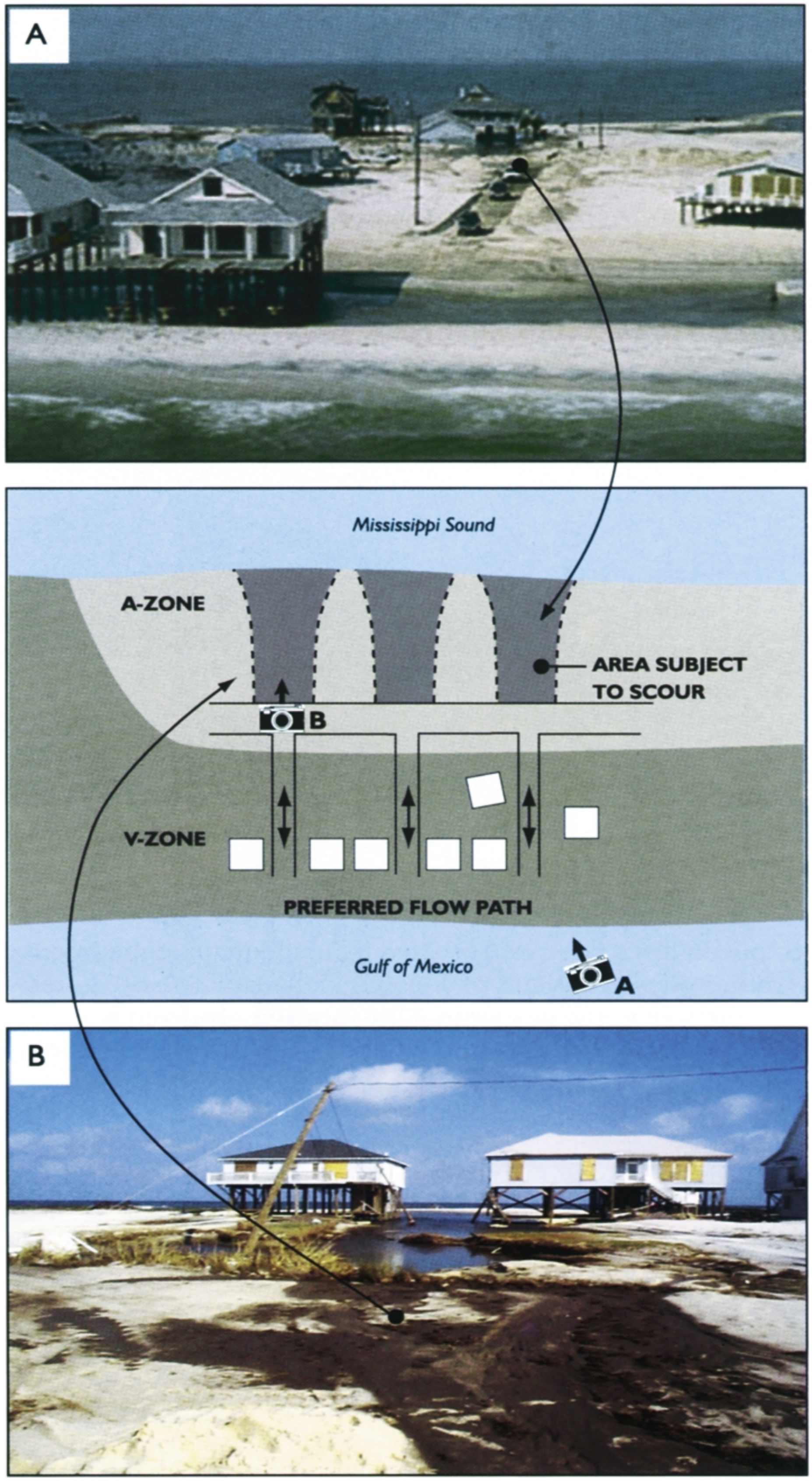


Figure 7-43
Flood protection offered by eroded dunes (from Dewberry & Davis 1989).

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

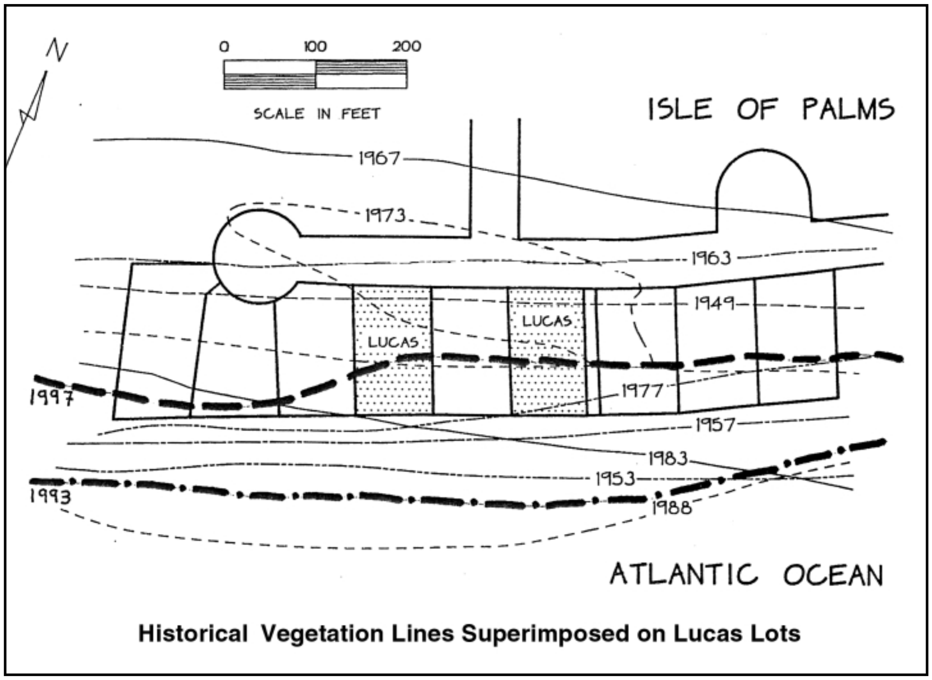


Figure 7-49
Historical shoreline changes in the vicinity of Lucas lots.

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.

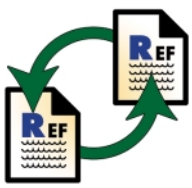
Likewise, *offshore breakwaters* (see Figure 7-50) can trap available littoral sediments and reduce the sediment supply to nearby beaches. This adverse effect should be mitigated by combining breakwater construction with beach nourishment – in fact, current design guidance for offshore breakwater projects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

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.

WARNING

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

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.

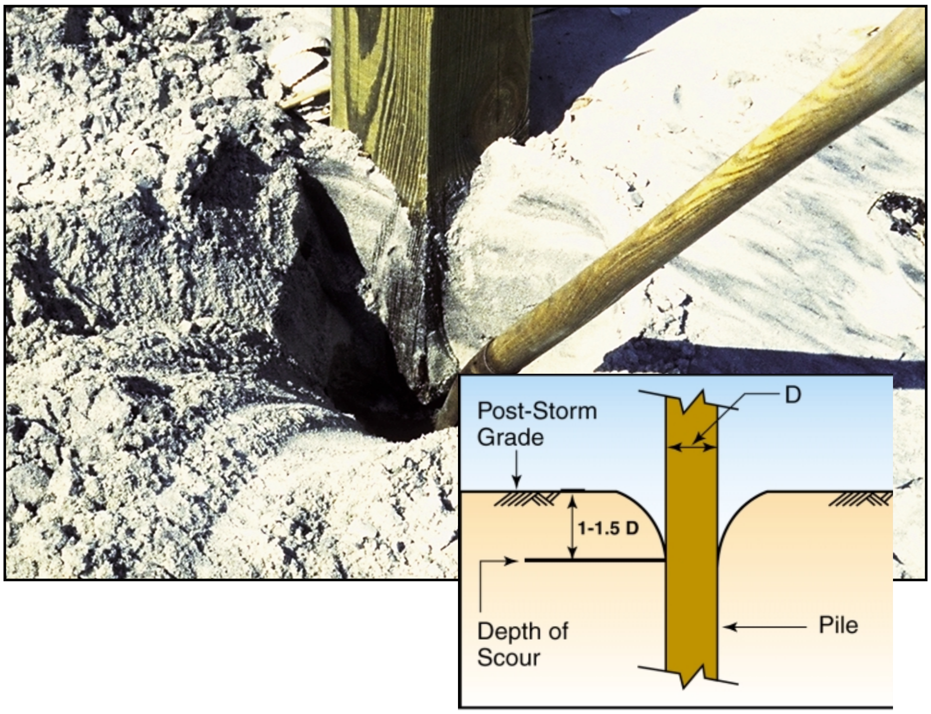


Figure 7-51
Hurricane Fran (1996). Determination of localized scour from changes in sand color, texture, and bedding.

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.

Coastal A

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).

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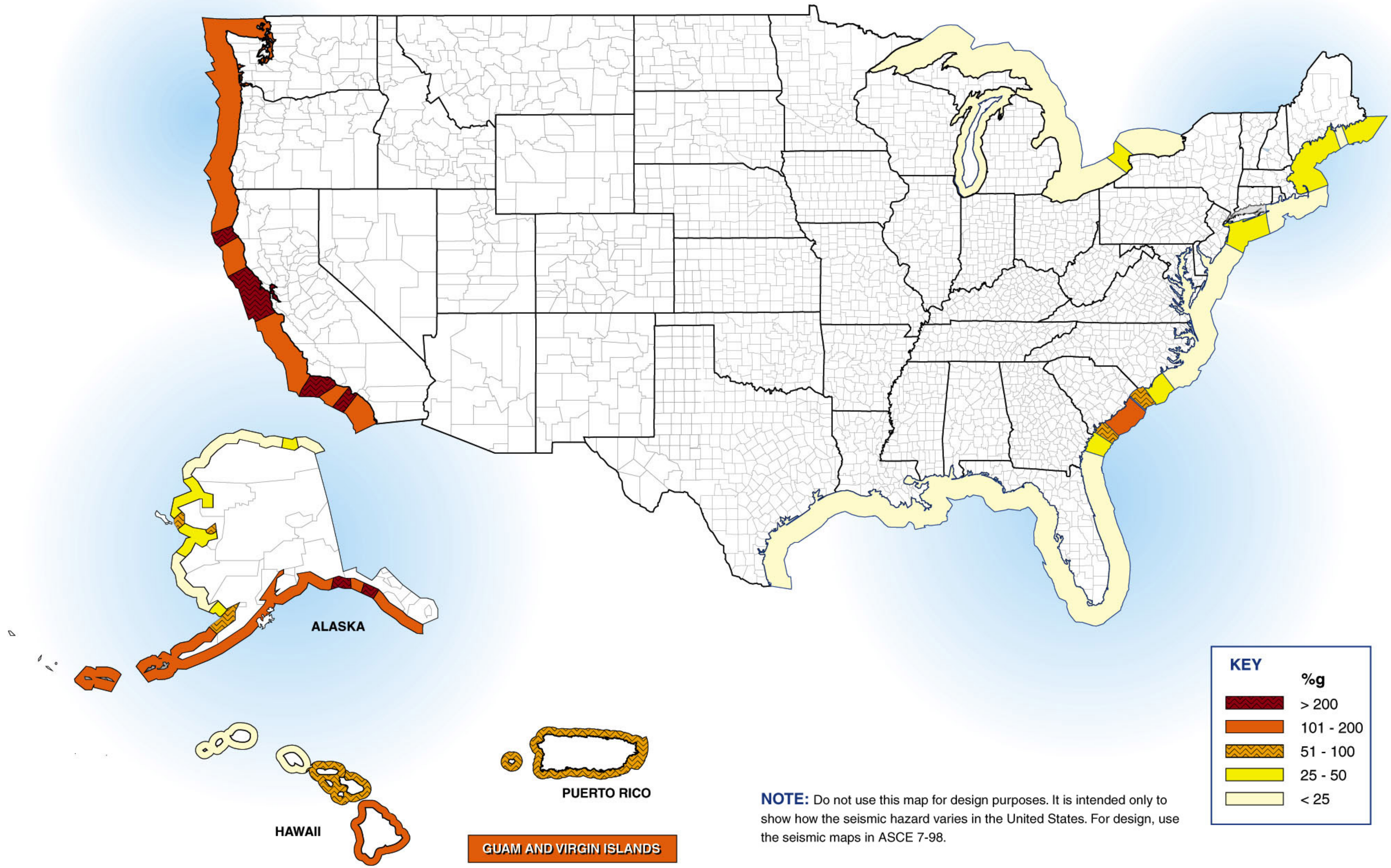
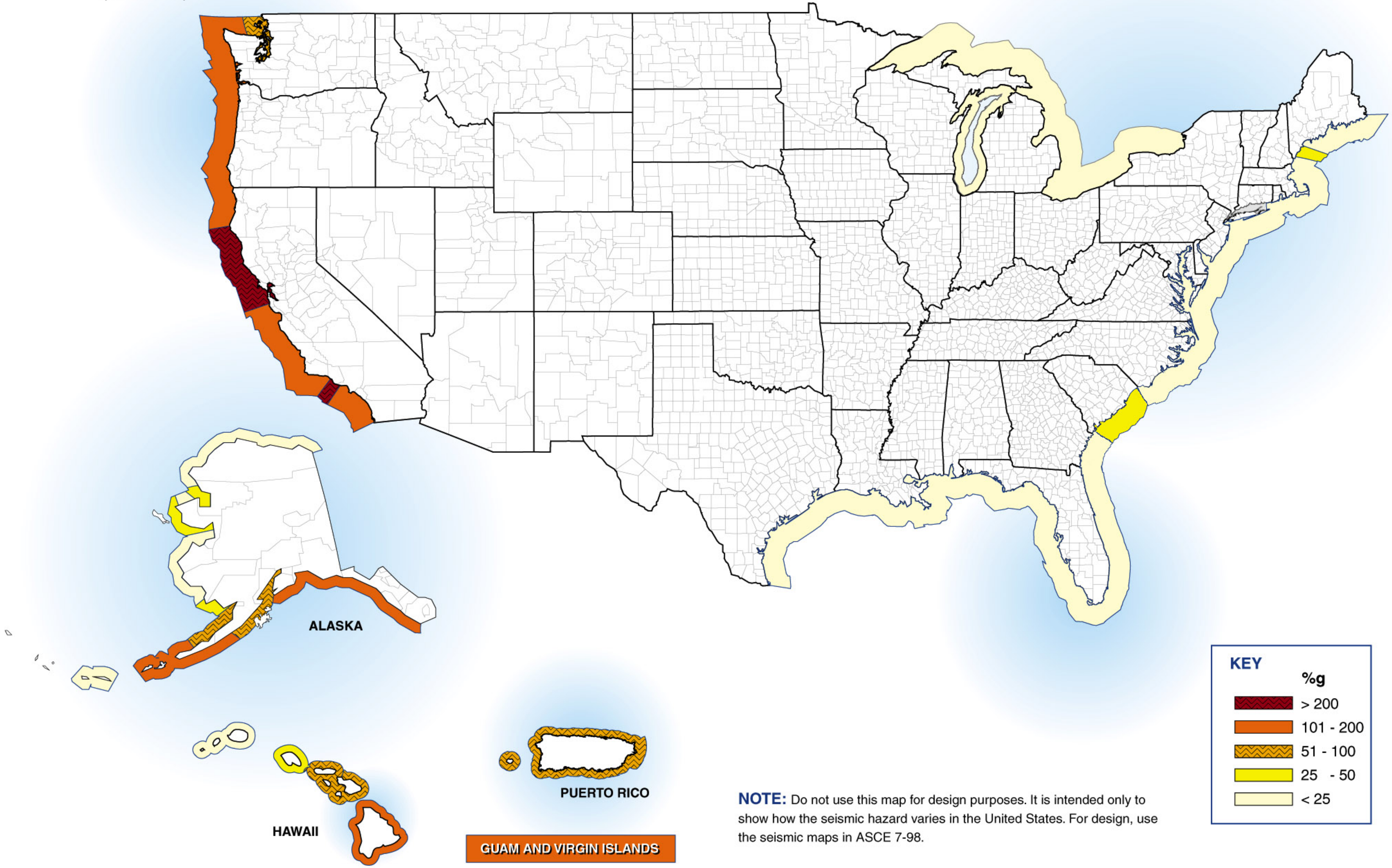
Figure 7-54 0.2-sec spectral response acceleration – maximum earthquake ground motion (%g) (FEMA 1997a).



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.

IDENTIFYING HAZARDS CHAPTER 7

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.

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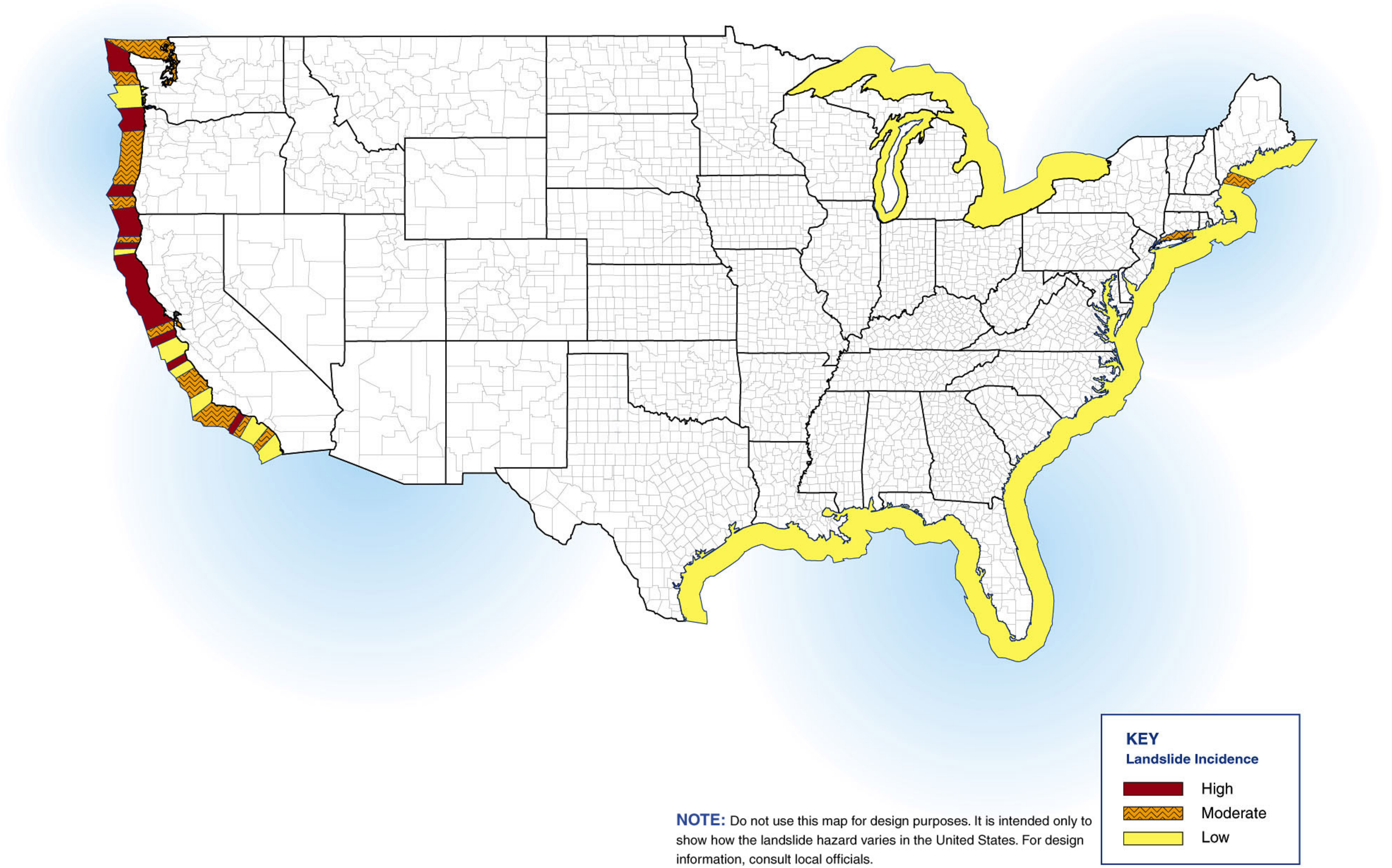
Figure 7-57 Landslide incidence in the coterminous United States. Adapted from FEMA (1997b).



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.

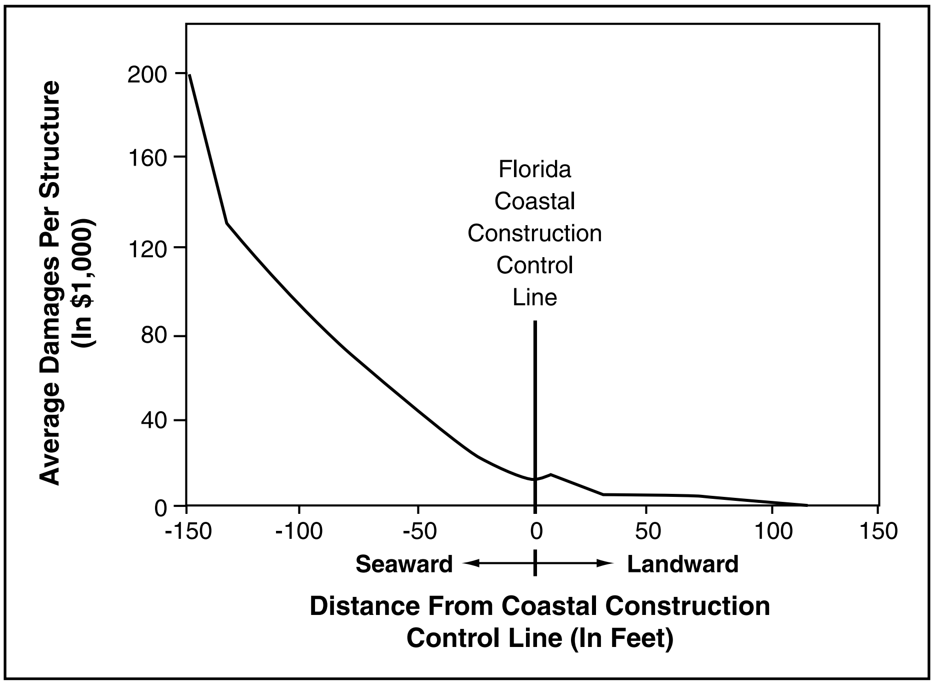


Figure 7-59
Hurricane Eloise, Bay County, Florida. Average damage per structure (in thousands of 1975 dollars) vs. distance from the Florida Coastal Construction Control Line (from Shows 1978).

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

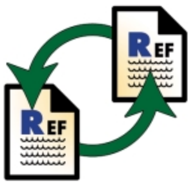
Current guidelines and standards for coastal flood hazard zone mapping along the Atlantic and Gulf of Mexico coasts are described in FEMA (1995) and summarized in Sparks et al. (1996). At the time this manual went to print, mapping procedures used for the Great Lakes coast did not call for the delineation 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)

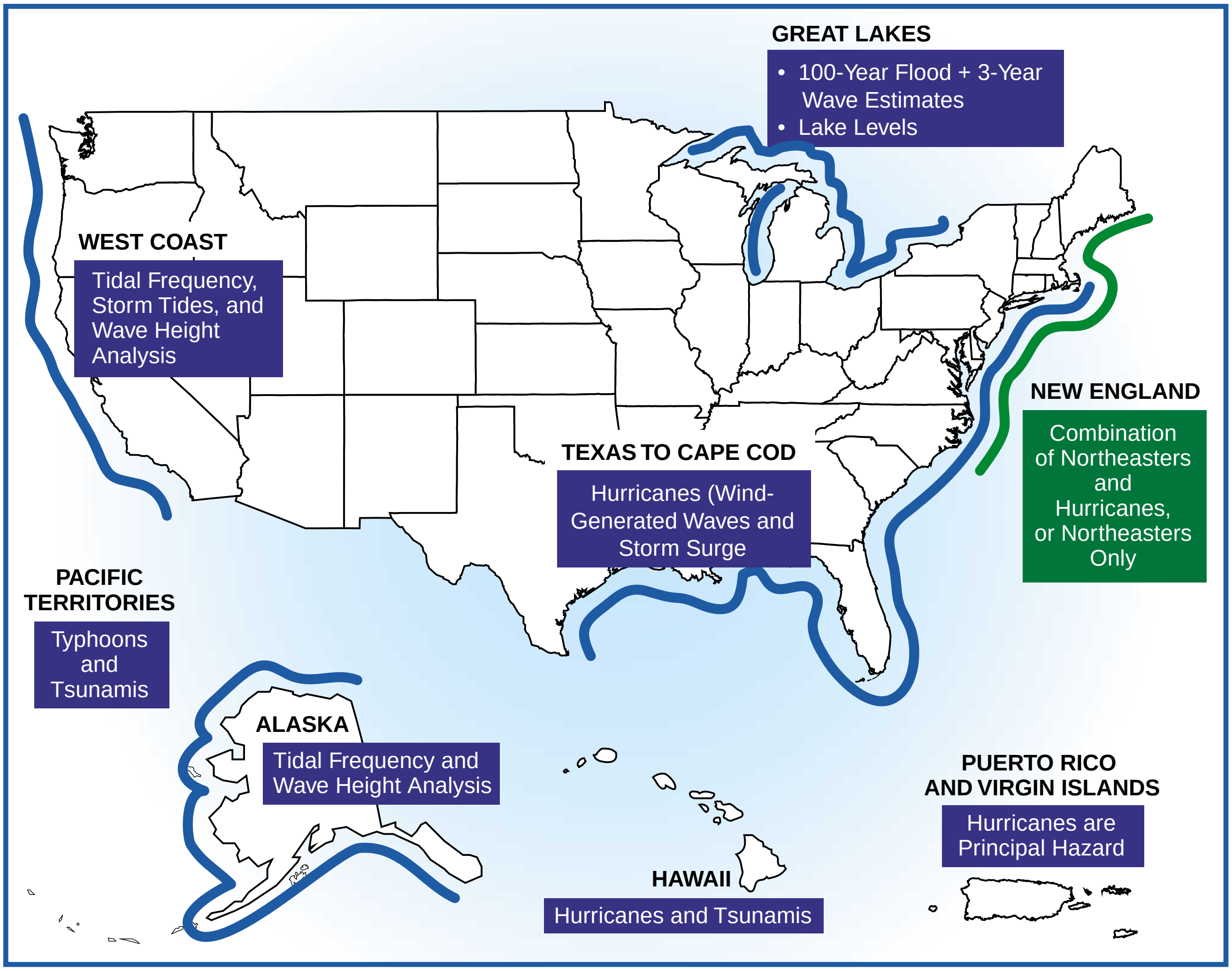
Figure 7-60 shows the flood sources used by FEMA to determine flood elevations along the Nation's coastline.



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.

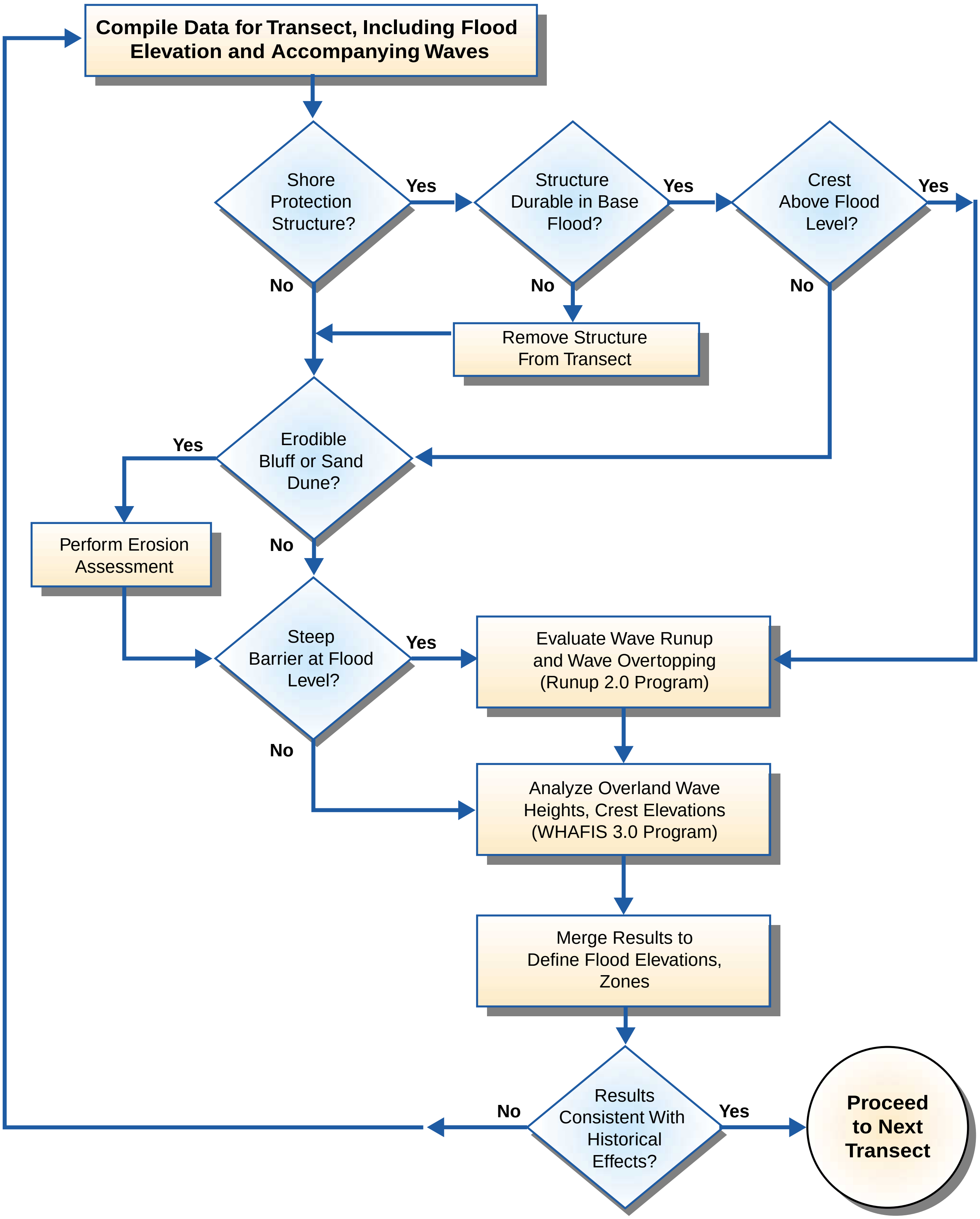
WARNING

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).

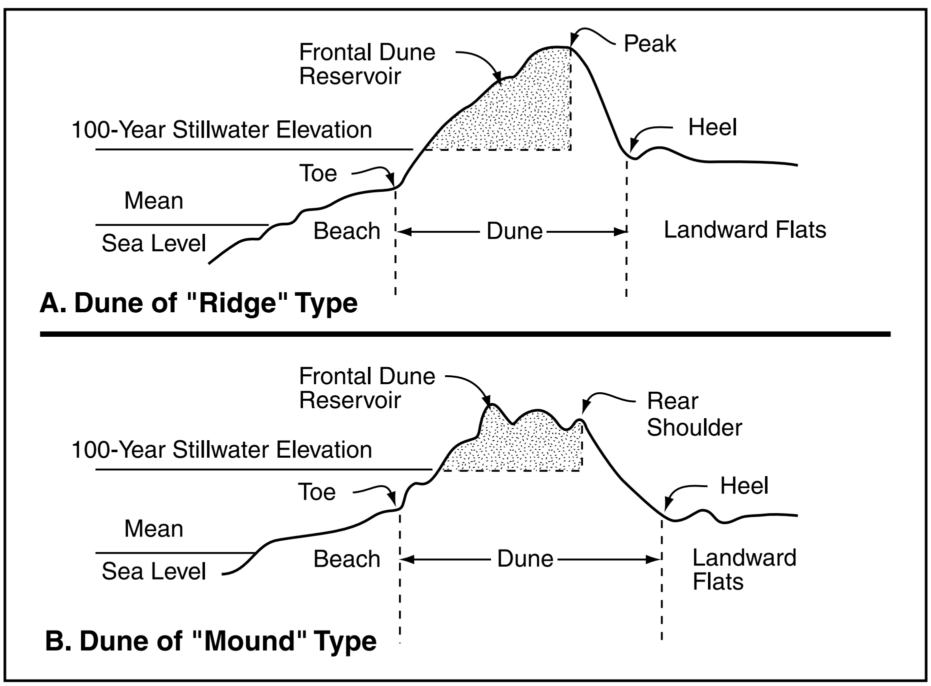


Figure 7-62
Definition sketch for frontal dune reservoir (from FEMA 1995)

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.

DEFINITION

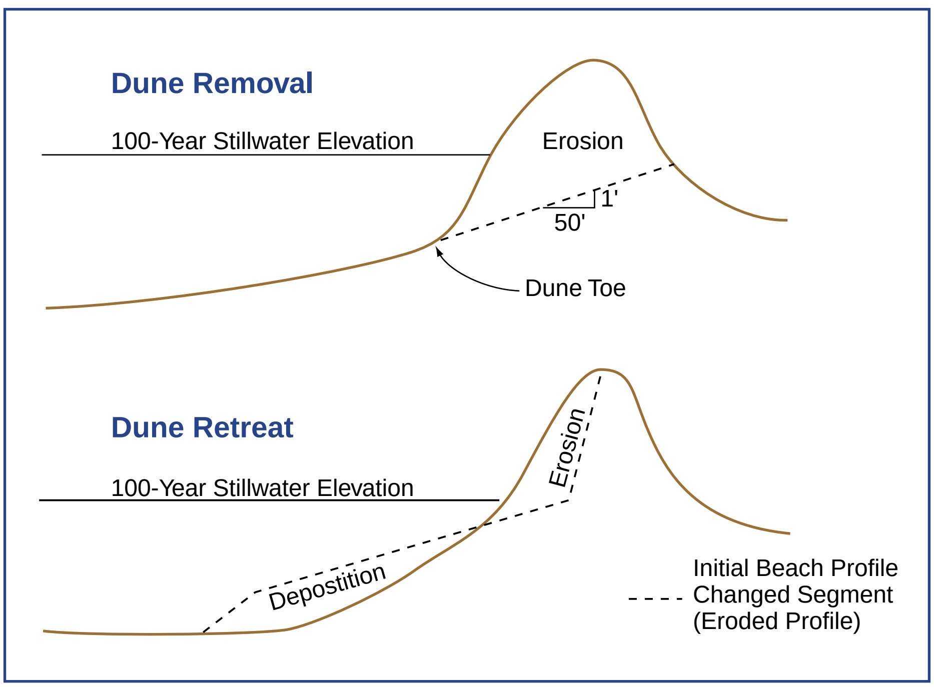
Current NFIP regulations define the **Coastal High Hazard Area (V zone)** as an area of special flood hazard extending from offshore to the inland limit of a primary frontal dune along an open coast and any other area subject to high-velocity wave action from storms or seismic sources.

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.

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.

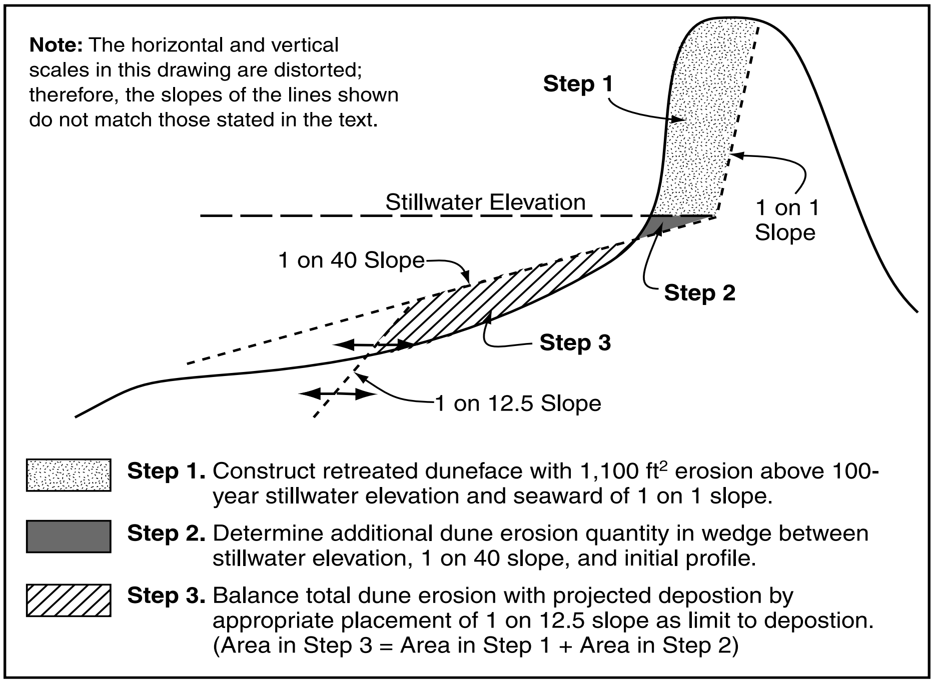


Figure 7-64
Procedure recommended by this manual for calculating dune retreat profile (modified from FEMA 1995).

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.

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

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).

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.

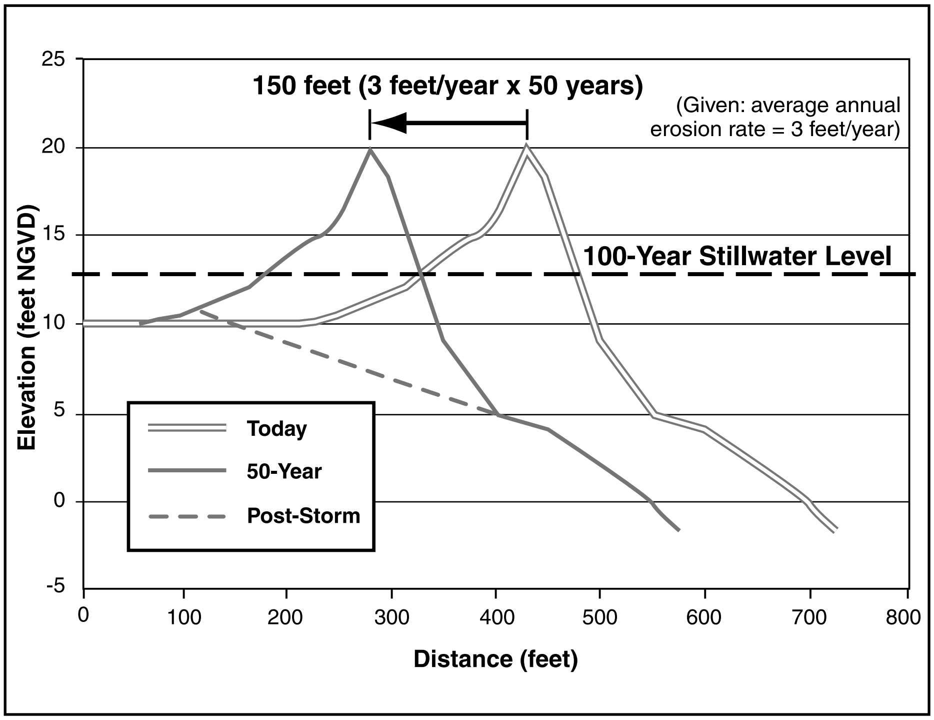


Figure 7-67
Accounting for future shoreline erosion: shift the present-day profile landward (to account for long-term or inlet erosion), then apply the Primary Frontal Dune erosion assessment to estimate the lowest expected ground elevation at a site. This procedure also results in a landward translation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

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Chapter 8: Siting

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Siting

8.1 Introduction

Siting residential buildings to minimize their vulnerability to coastal hazards is one of the most important aspects of the development (or redevelopment) process. Unfortunately, prudent siting has often been overlooked or ignored in the past as properties have been developed and buildings have been constructed close to the shoreline, near bluff edges, and atop steep coastal ridges. There are literally hundreds, if not thousands, of examples where residential buildings have been constructed with little regard for coastal hazards, only to suffer what could have been preventable damage or loss.

Today, there are few places along our shorelines where we lack sufficient information to make rational, informed siting decisions. Following the lessons and procedures described in Volume 1 of this manual will help designers, purchasers, developers, and community officials identify those locations where coastal residential development and buildings can be sited so that the risks associated with coastal hazards are minimized. Those who ignore siting and hazard identification issues, and who rely solely upon the design and construction recommendations contained in this manual, increase the likelihood that their structures will be damaged, destroyed, or left standing, but uninhabitable, by flooding, erosion, landslides, or other coastal hazards.

WARNING

Not all coastal hazards can be mitigated through design and construction. A design and construction "success" can be rendered a failure by poor siting.

8.2 Siting Considerations

A variety of factors must be considered in selecting a specific site and locating a building on that site:

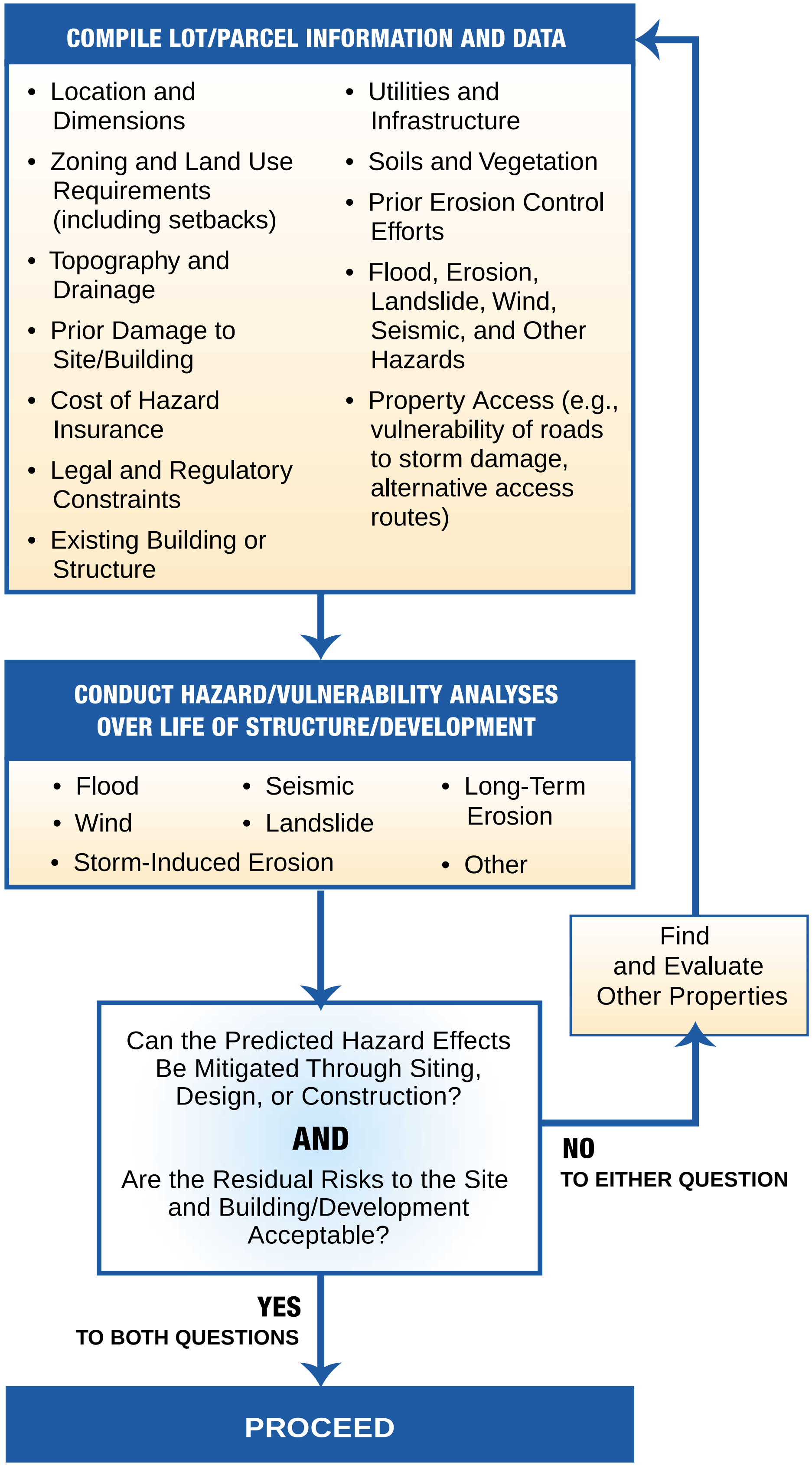
- regulatory requirements
- presence and location of infrastructure
- previous development and/or subdivision of property
- physical and natural characteristics of the property
- vulnerability of the property to coastal hazards

These factors were outlined in Figure 5-1 (repeated here as Figure 8-1) and are discussed further in this chapter.

NOTE

Proper siting and design should take into account both chronic hazards (e.g., long-term erosion) and catastrophic hazards (e.g., extreme storm events).

Figure 8-1
Evaluation of coastal property.



A thorough review of these factors will sometimes show that minimum regulatory requirements and/or previous subdivision/infrastructure decisions allow or constrain future development onto sites that will be highly vulnerable to the effects of coastal hazards. In other words, regulatory controls do not necessarily result in prudent siting of coastal buildings (see Figure 8-2). Likewise, constraints imposed by previous lot creation and infrastructure construction sometimes drive development to more hazardous locations.

Although these situations should have been discovered when the property was first evaluated for its suitability for purchase, development, or redevelopment, it is common practice for property owners to undertake detailed studies only after property has been acquired. This is especially true in the case of the development of raw land, where planning, engineering, architectural, and site development costs can be substantial.

WARNING

Compliance with minimum siting requirements imposed by local and state governments does not guarantee a building will be safe from hazard effects. To reduce risks from coastal hazards to an acceptable level, it is often necessary to exceed minimum siting requirements.

Figure 8-2
Hurricane Opal (1995). Damage to new construction in a mapped A zone. The flood and debris damage could have been avoided had the site been considered a coastal A zone and had the structure been elevated on an open foundation.

Designers should recognize situations in which poor siting is allowed or encouraged, and should work with property owners to minimize risks to coastal buildings. Depending on the scale of the project, this could involve one or more of the following:

- locating development on the least hazardous portion of the site
- rejecting the site and finding another
- transferring development rights to another parcel better able to accommodate development
- combining lots or parcels

- reducing the footprint of the proposed building, and shifting the footprint away from the hazard
- shifting the location of the building on the site by modifying or eliminating ancillary structures and development
- seeking variances to lot line setbacks along the landward and side property lines (in the case of development along a shoreline)
- moving roads and infrastructure
- modifying the building design and site development to facilitate future relocation of the building
- altering the site to reduce its vulnerability
- construction of protective structures (if allowed by the authority having jurisdiction)

8.3 Raw Land Development: Infrastructure and Lot Layout

8.3.1 Introduction

Large, undeveloped parcels available for coastal development generally fall into two classes:

- **Parcels well-suited to development**, but vacant due to the desires of a former owner, lack of access, or lack of demand for their development (see Figure 8-3)
- **Parcels that are difficult to develop**, with extensive areas of sensitive or protected resources, with topography or site conditions requiring extensive alteration, or with other special site characteristics that make development expensive relative to other nearby parcels (see Figure 8-4)

Proper development will be much easier for the former, and much harder for the latter. Nevertheless, development in both instances should satisfy the planning and site development guidelines listed in Figure 8-5, adapted from recommended subdivision review procedures for coastal development in California (California Coastal Commission 1994).

Development of raw land in coastal areas must consider the effects of all hazards known to exist and should not ignore the effects of those hazards on future property owners. Likewise, development of raw land in coastal areas should consider any local, state, or Federal policies, regulations, or plans that will affect the abilities of future property owners to protect, transfer, or redevelop their properties (e.g., those dealing with erosion control, coastal setback lines, post-disaster redevelopment, landslides, and geologic hazards).

Figure 8-3
Example of coastal development well-suited to the land: deep lots, generous setbacks, and avoidance of dune areas should afford protection against erosion and flood events for years to come.

Figure 8-4
Increasingly, coastal residential structures are being planned and constructed as part of mixed-use developments, such as this marina/townhouse development. These projects can involve a new set of environmental and regulatory issues, as well as more difficult geotechnical conditions and increased exposure to flood hazards.

Figure 8-5
Planning and site development guidelines for raw land (adapted from the California Coastal Commission 1994).

Development of Raw Land in Coastal Areas – Summary of Site Planning and Subdivision Guidelines

1. **DO** determine whether the parcel is suitable for subdivision or should remain a single parcel.
2. **DO** ensure that the proposed land use is consistent with local, regional, and state planning and zoning requirements.
3. **DO** ensure that all aspects of the proposed development consider and integrate topographic and natural features into the design and layout.
4. **DO** avoid areas that require extensive grading to ensure stability.
5. **DON'T** rely on engineering solutions to correct poor planning decisions.
6. **DO** study the parcel thoroughly for all possible resource and hazard concerns.
7. **DON'T** rely on relocation or restoration efforts to replace resources impacted by poor planning decisions.
8. **DO** identify and avoid, or set back from, all sensitive resources and prominent land features.
9. **DON'T** assume that omissions in planning can be corrected during site development.
10. **DO** consider combining subdivision elements, such as access, utilities, and drainage.
11. **DON'T** overlook the effects of infrastructure location on the hazard vulnerability of building sites and lots.
12. **DO** account for all types of erosion (e.g., long-term erosion, storm-induced erosion, erosion due to inlets) and governing erosion control policies when laying out lots and infrastructure near a shoreline.
13. **DON'T** overlook the effects to surface and groundwater hydrology from modifications to the parcel.
14. **DO** consider existing public access to shoreline and resource areas.
15. **DON'T** plan development on beaches or dunes, on ridge lines or on top of prominent topographic features, on steep slopes, or in or adjacent to streams.
16. **DO** incorporate setbacks from identified high-hazard areas.
17. **DON'T** forget to consider future site and hazard conditions on the parcel.
18. **DO** use a multi-hazard approach to planning and design.
19. **DON'T** assume that engineering and architectural practices can mitigate all hazards.
20. **DO** involve a team of experts with local knowledge, and a variety of technical expertise and backgrounds.

8.3.2 Practices To Avoid and Recommended Alternatives

A review of previous coastal development patterns and resulting damages suggests there are several subdivision and lot layout practices to avoid:

1. In the case of an eroding shoreline, placing a road close to the shoreline and creating small lots between the road and the shoreline results in buildings, roadway, and utilities being extremely vulnerable to erosion and storm damage, and can lead to future conflicts over shore protection and buildings occupying public beaches (see Figure 8-6). Figure 8-7 shows a recommended lot layout that provides sufficient space to comply with state/local setback requirements and avoid damage to dunes.

   Some communities have land development regulations that help achieve this goal. For example, the Town of Nags Head, North Carolina, modified its subdivision regulations in 1987 to require all new lots to extend from the ocean to the major shore-parallel highway (Morris 1997). Figure 8-8 compares lots permitted in Nags Head prior to 1987 with those required after 1987. The town also has policies and regulations governing the combination of nonconforming lots (Town of Nags Head 1988).

Figure 8-6
View along a washed-out, shore-parallel road in Bay County, Florida, after Hurricane Opal. Homes to the left are standing on the beach and have lost upland access; some homes to the right have also lost their roadway access.

Figure 8-7
Recommended lot layout. Sufficient space is provided to comply with state/local setback requirements and avoid dune damage.

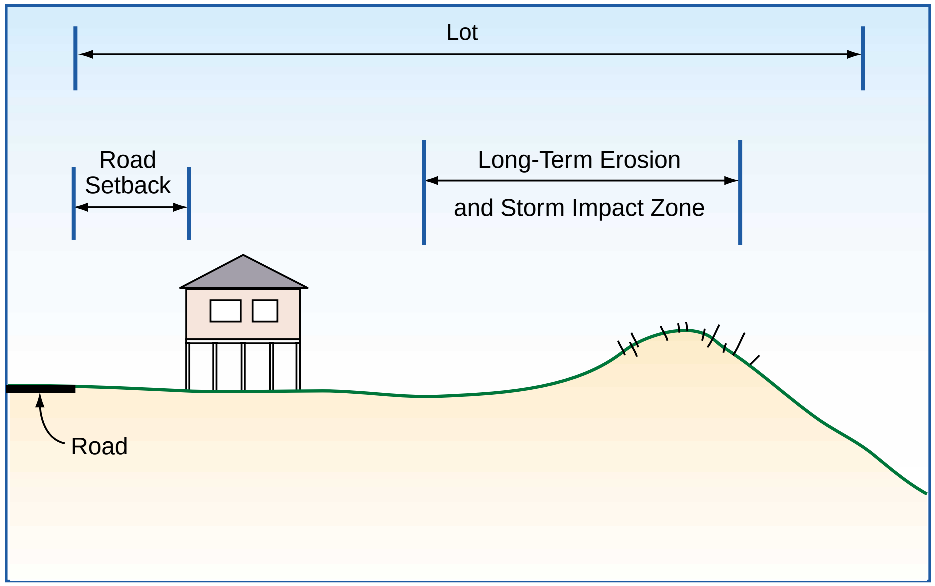
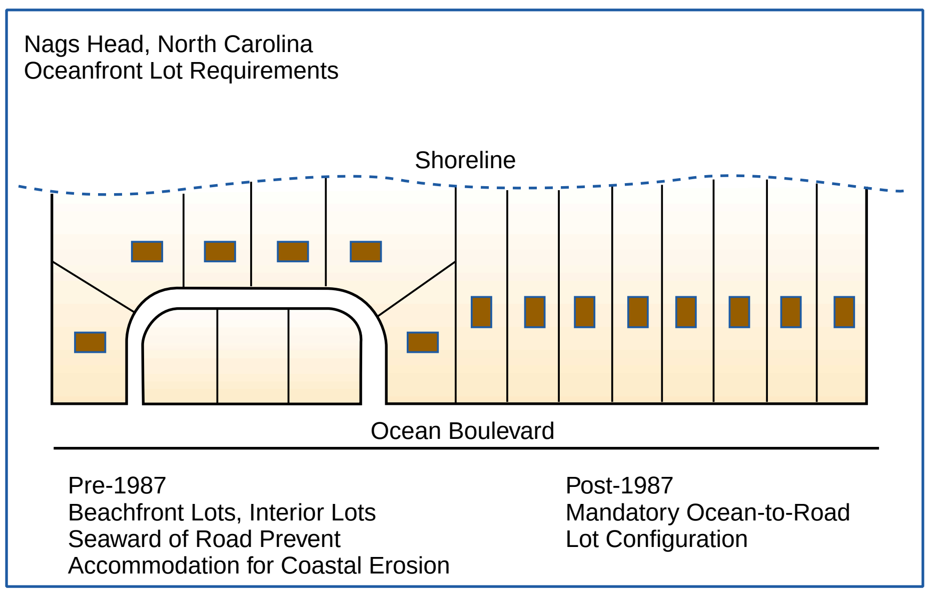


Figure 8-8
Comparison of Nags Head, North Carolina, oceanfront lot layouts permitted before 1987 and post-1987 oceanfront lot requirements (Morris 1997).



WARNING

Proper lot layout and building siting along an eroding shoreline are critical. Failure to provide deep lots and to place roads and infrastructure well away from the shoreline only ensures future conflicts over building reconstruction and shore protection.

2. A second problem associated with a shore-parallel road close to the shoreline is storm erosion damage to the road and associated utilities. Some infrastructure damage can be avoided by reconfiguring the seaward lots (so they all have access from shore-perpendicular roads), eliminating the shore-parallel road, and eliminating the shore-parallel utility lines (see Figure 8-9).

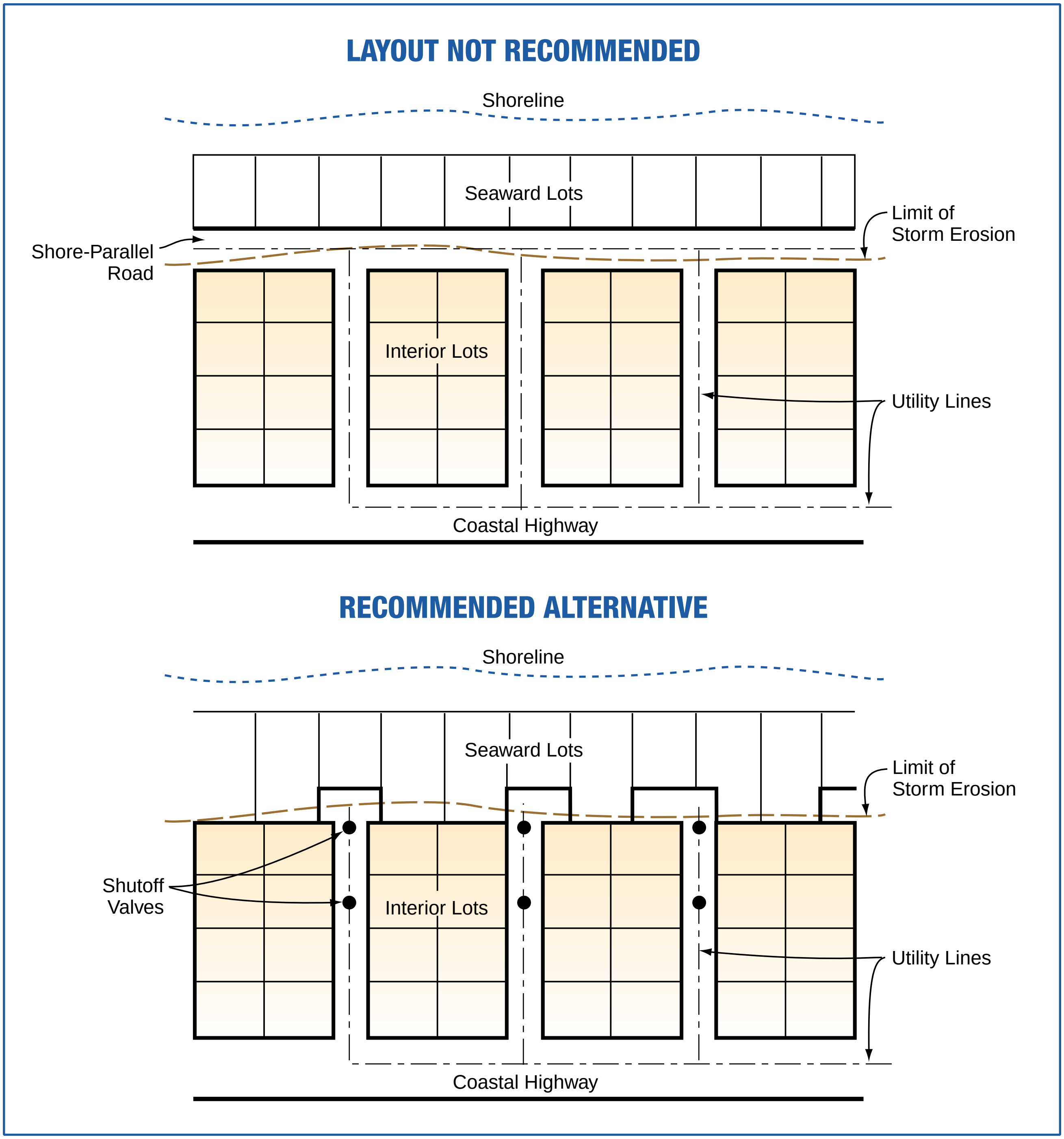


Figure 8-9
Shore-parallel roadways and associated utilities may be vulnerable to storm effects and erosion (upper). One alternative is to create lots and infrastructure without the shore-parallel road; install shutoff valves on water and sewer lines (lower).

3. Another type of lot layout not recommended for vulnerable or eroding coastal shorelines is the “flag” lot or “key” lot illustrated in Figure 8-10. This layout is used to provide more lots with direct access to the shoreline, but limits the ability of half of the property owners to respond to coastal flood hazards and erosion by constructing or relocating their buildings farther landward. Again, the recommended alternative is to locate the shore-parallel road sufficiently landward to accommodate coastal flooding and future erosion and to create all lots so that their full width extends from the shoreline to the road.

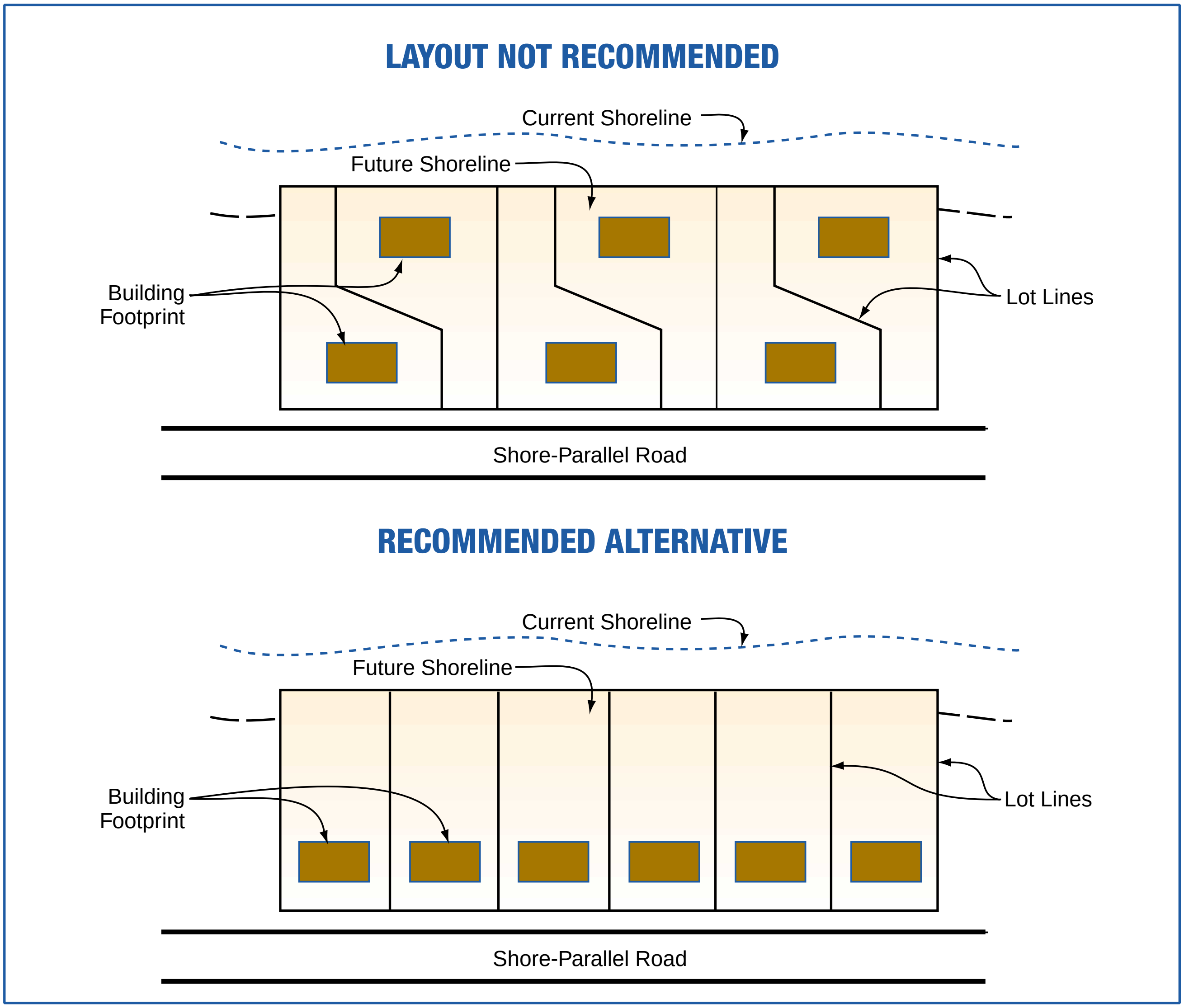


Figure 8-10
Typical layout of “flag” lots or “key” lots, which are NOT RECOMMENDED for use along eroding shorelines (upper). Suggested alternative layout (lower).

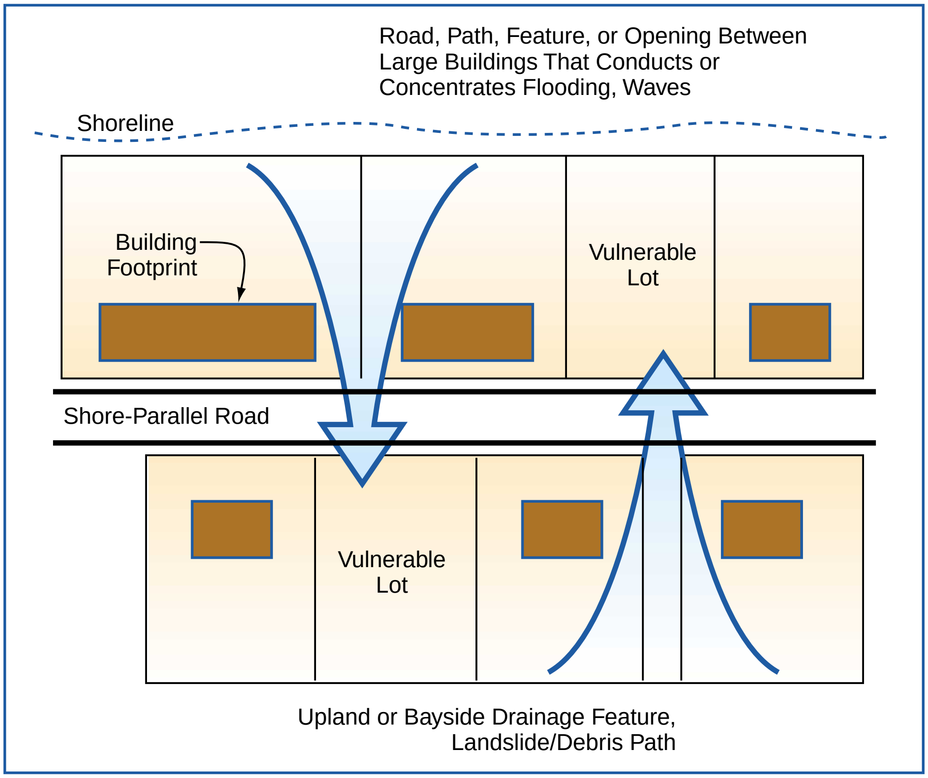
4. Creation of lots along narrow sand spits and low-lying landforms (see Figure 8-11) is not recommended, especially if the shoreline is eroding. Any buildings constructed there will be routinely subject to coastal storm effects, overwash, and other flood hazards.

Figure 8-11
Construction along this narrow, low-lying area of St. Johns County, Florida, is routinely subjected to coastal storm effects (photo following November 1984 northeast storm). The lots and buildings are landward of a previous state highway location, now abandoned.

5. Lots should not be created in line with natural or manmade features that concentrate floodwaters (see Figure 8-12). These features can include areas of historic shoreline breaching, roads or paths across dunes, drainage features or canals, and areas of historic landslides or debris flows. One alternative is to leave these vulnerable areas as open space and/or to modify them to reduce associated hazards to adjacent lots.

   Care should also be exercised when lots are created between or landward of gaps between large buildings or objects capable of channeling floodwaters and waves (see Figures 7-10, 7-11, and 7-12 in Chapter 7).

Figure 8-12
Lot landward of opening between dunes or obstructions may be more vulnerable to flooding and wave effects. Front-row lot waterward of interior drainage feature may be vulnerable to concentrated flooding from upland or bay side.



6. Lot configurations should not be created where small lots are concentrated along an eroding or otherwise hazardous shoreline. It is preferable to create deeper lots along the shoreline, locate building sites farther landward on the lots, or cluster development away from the shoreline. Figure 8-13 (Morris 1997, adapted from the California Coastal Commission 1994) illustrates this progression, from a “conventional” lot layout, to a “modified” lot layout, to a “cluster development” layout with lot line changes. The California Coastal Commission (1994) has also developed similar alternatives for a parcel on a ridge top with steep slopes and for a parcel bisected by a coastal lagoon.

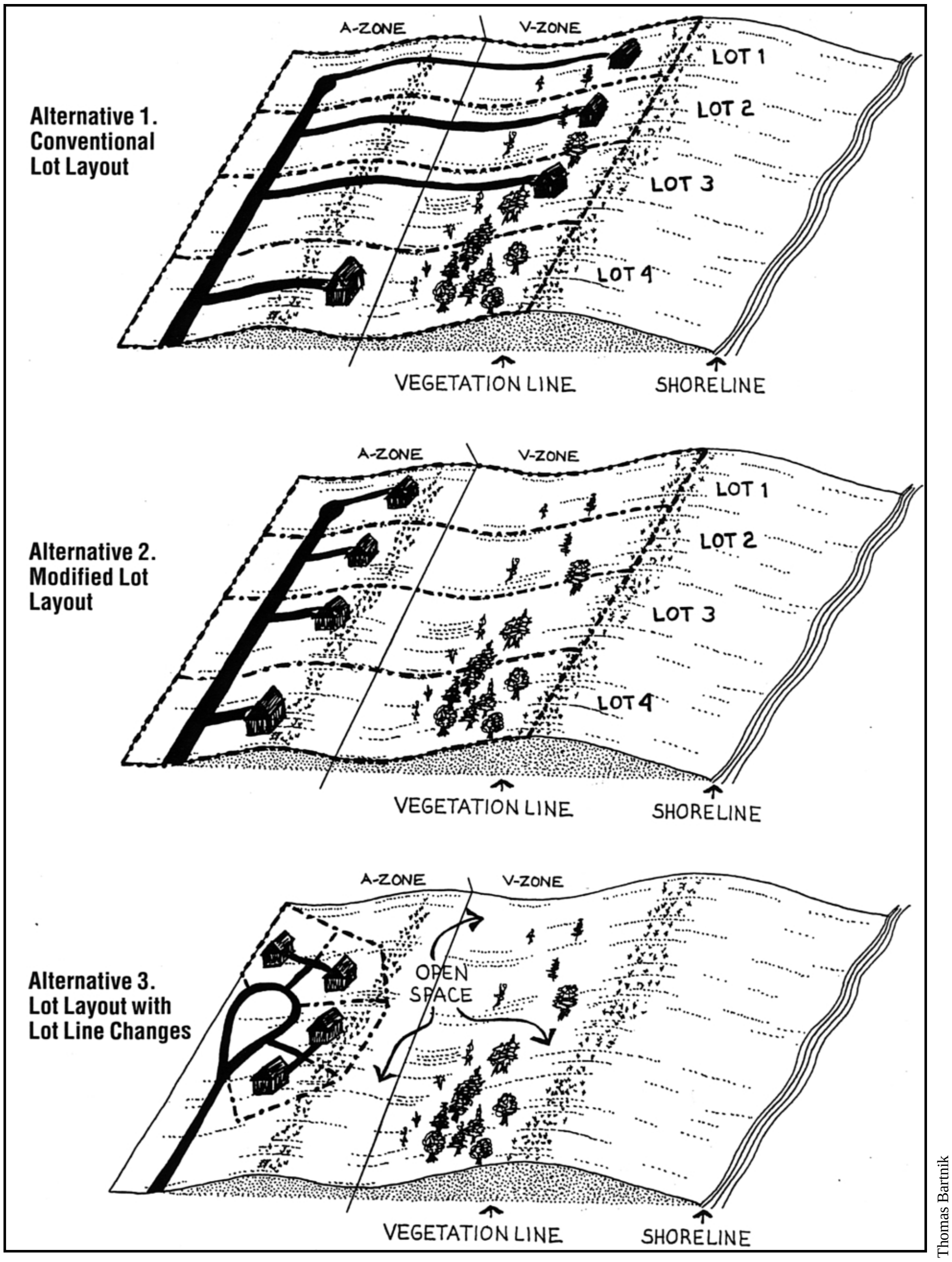


Figure 8-13
Coastal lot development scenarios (Morris 1997, adapted from California Coastal Commission 1994).

7. Another related approach is to occupy a small fraction of the total buildable parcel and to accommodate erosion by moving threatened buildings to other available sites on the parcel. A small Pacific Ocean community in Humbolt County, California, has successfully employed this approach (Tuttle 1987). Figure 8-14 shows a community of 76 recreational cabins on a 29-acre parcel, jointly owned by shareholders of a corporation. As buildings are threatened by erosion, they are relocated (at the building owner's expense) to other sites on the parcel, in accordance with a cabin relocation policy adopted by the corporation.

Figure 8-14
Humbolt County, California, parcel fronting the Pacific Ocean. As buildings are threatened by bluff erosion, they are moved to other sites on the parcel.

CROSS-REFERENCE

Some states and communities have adopted regulations requiring that buildings sited in erosional areas be movable. The State of Michigan has such a requirement; see Appendix G.

In extreme cases, entire communities have been threatened by erosion and have elected to relocate. For example, the village of Shishmaref, Alaska, voted in November 1998 to relocate their community of 600 after recent storm erosion threatened several houses and after previous shore protection efforts failed.

More information on specific examples of relocation of threatened buildings can be found in *Mitigation of Flood and Erosion Damage to Residential Buildings in Coastal Areas* (FEMA 1994). That report also presents several examples of flood and erosion mitigation through other measures (e.g., elevation, foundation alterations).

8. Layout of lots and infrastructure along shorelines near tidal inlets, bay entrances, and river mouths is especially problematic. Figures 4-2 and 4-3, in Chapter 4, and Figures 7-45, 7-46, 7-47, 7-48, and 7-49, in Chapter 7, all show instances where the recent subdivision and development of oceanfront parcels near ocean-bay connections has led to buildings being threatened by inlet-caused erosion. Infrastructure development and lot layout in similar cases should be preceded by a detailed study of historical shoreline changes, including development of (at least) a conceptual model of shoreline changes. Projections of potential future shoreline positions should be made, and development should be sited well-landward of any areas of persistent or cyclic shoreline erosion.

8.4 Infill Development: Siting a Building on an Existing Lot

8.4.1 Introduction

Many of the same principles discussed in the raw land scenario also apply to the construction or reconstruction of buildings on existing lots. Building siting on a particular lot should take site dimensions, site features (e.g., topographic, drainage, soils, vegetation, sensitive resources), coastal hazards, and regulatory factors into consideration. However, several other factors must be considered at the lot level that are not a primary concern at the subdivision level:

- buildable area limits imposed by lot line setbacks, hazard setbacks, and sensitive resource protection requirements
- impacts of coastal hazards on lot stability
- location and extent of supporting infrastructure, utility lines, septic tanks and drain fields, etc.
- impervious area requirements for the lot
- prior development of the lot
- need for future building repairs, relocation, or protection
- regulatory restrictions or requirements for on-site flood or erosion control

Although the local regulations, lot dimensions, and lot characteristics generally define the maximum allowable building footprint on a lot, the designer should not assume construction of a building occupying the entire buildable area is a prudent siting decision. The designer should consider all those factors that can affect an owner's ability to use and maintain the building and site in the future (see Figure 8-15).

Figure 8-15
Guidelines for siting buildings on existing lots.

Development or Redevelopment of Existing Lots in Coastal Areas – Summary of Guidelines for Siting Buildings

1. **DO** determine whether the lot is suitable for its intended use; if not, alter the use to better suit the site or look at alternative sites.
2. **DON'T** assume engineering and architectural practices can mitigate poor lot layout or poor building siting.
3. **DO** study the lot thoroughly for all possible resource and hazard concerns – seek out all available information on hazards affecting the area and prior coastal hazard impacts on the lot.
4. **DON'T** assume that siting a new building in a previous building footprint or in line with adjacent buildings will protect the building against coastal hazards.
5. **DO** account for all types of erosion (e.g., long-term erosion, storm-induced erosion, erosion due to inlets) and governing erosion control policies when selecting a lot and siting a building.
6. **DON'T** rely on existing (or planned) erosion or flood control structures to guarantee long-term stability of the lot.
7. **DO** avoid lots that require extensive grading to achieve a stable building footprint area.
8. **DON'T** overlook the constraints that site topography, infrastructure and ancillary structures (e.g., utility lines, septic tank drain fields, swimming pools), trees and sensitive resources, and adjacent development place on site development, and (if necessary) future landward relocation of the building.
9. **DO** ensure that the proposed siting is consistent with local, regional, and state planning and zoning requirements.
10. **DON'T** overlook the constraints that building footprint size and location place on future work to repair, relocate or protect the building – allow for future construction equipment access and room to operate on the lot.
11. **DO** identify and avoid, or set back from, all sensitive resources.
12. **DON'T** overlook the effects to surface and groundwater hydrology from development of the lot.
13. **DO** consider existing public access to shoreline and resource areas.

8.4.2 Practices To Avoid and Recommended Alternatives

Experience shows that—just as there are certain subdivision development practices to avoid in hazardous coastal areas—there are individual lot siting and development practices to avoid as well. These include the following:

1. One of the most common siting errors is placing a building as far seaward or waterward as allowed by local and state regulations. Although such siting is permitted by law, it can lead to a variety of avoidable problems, including increased building vulnerability, damage to the building, encroachment onto a beach. On an eroding shoreline, this type of siting often results in the building owner being faced with one of three options: loss of the building, relocation of the building, or (if permitted) protection of the building through an erosion control measure.

   Alternatives to this practice include siting the building farther landward than required by minimum setbacks, and designing the building so it can be easily relocated. Siting a building farther landward also allows (in some cases) for the natural episodic cycle of dune building and storm erosion to occur without jeopardizing the building itself.

2. Siting a building too close to a coastal bluff edge can result in building damage or loss (see Figure 4-3, in Chapter 4, and Figures 7-38 and 7-39, in Chapter 7). Keillor (1998) provides excellent guidance regarding selection of appropriate construction setbacks for bluffs on the Great Lakes shorelines, but the general concepts are applicable elsewhere (see Figure G-17, in Appendix G).

3. Some sites present multiple hazards, which designers and owners may not realize. For example, Figure 8-16 shows southern California homes that have been constructed along the Pacific shoreline at the mouth of a coastal stream. The homes may be subject to storm waves and erosion, stream flooding and debris flows, and earthquakes.

4. Siting a building too close to an erosion control structure, or failing to allow sufficient room for such a structure to be built, is another siting practice to avoid. Figure 8-17 shows an example of buildings that were constructed near the shoreline, only to be damaged by storm effects and erosion. Subsequent construction of a rock revetment will provide some protection to the buildings, but not as much as if there were a greater distance between the revetment and buildings. Storm waves can easily overtop the revetment and damage the buildings. An alternative to this situation is simply to plan ahead by siting the building farther landward and providing enough room between the building and the erosion control structure to dissipate the effects of wave and flood overtopping.

Figure 8-16
This site near Malibu, California, is an example of a coastal building site subject to multiple hazards—storm waves and erosion, stream flooding and debris flows, and earthquakes. Photo courtesy of *Journal of Coastal Research* (Griggs 1994, in Finkl 1994).

Figure 8-17
Hurricane Hugo (1989). Damage to buildings sited close to an eroding shoreline at Garden City Beach, South Carolina. Storm waves often overtop revetments and damage buildings.

A related siting problem (also observed along bay or lake shorelines, canals, manmade islands, and marina/townhouse developments) is the construction of buildings immediately adjacent to bulkheads (see Figure 8-18). The bulkheads are rarely designed to withstand a severe coastal flood and are easily overtopped by floodwaters and waves. During severe storms, landward buildings receive little or no protection from the bulkheads. In fact, if such a bulkhead fails, the building foundation will be undermined and the building may be sustain additional damage or be a total loss.

Figure 8-18
Damage at Bonita Beach, Florida, from June 1982 subtropical storm. Had this building not been supported by an adequate pile foundation, it would have collapsed. Buildings sited close to an erosion control structure should not rely on the structure to prevent undermining. Photograph by Judson Harvey

In both of the above cases, it may be difficult to repair the erosion control devices in the future, because of limitations on construction access and equipment operation. If erosion control devices are permitted and are employed, they should be sited far enough away from any nearby buildings so that there is room to access the site and complete any repairs.

5. Although preservation of vegetation and landscaping are an important part of the siting process, designers should avoid siting and design practices that can lead to building damage. For example, designs that "notch" buildings and rooflines for placement of large trees should be avoided (see Figure 8-19). This siting practice may lead to avoidable damage to the roof and envelope during a high-wind event. Additionally, the potential consequences of siting a building immediately adjacent to existing large trees (capable of falling and damaging structures) should be evaluated carefully.

6. Pedestrian access between a coastal building and the shoreline is often overlooked when siting decisions and plans are made. Experience shows, however, that uncontrolled access can damage coastal vegetation and landforms, providing weak points upon which storm forces to act. Dune blowouts and breaches during storms often result, and buildings landward of the weak points can be subject to increased flood, wave, erosion, or overwash effects. Several options exist for controlling pedestrian (and vehicular access) to shorelines. Guidance for the planning, layout, and construction of access structures and facilities can be found in a number of publications (California Coastal Commission 1982, California State Coastal Conservancy 1987, Florida Department of Environmental Protection 1998 [see Appendix I], Walton and Skinner 1983 [see Appendix I]).

Figure 8-19
Siting and designing buildings to accommodate large trees is important for a variety of reasons. However, notching the building and roofline to allow placement around a tree can lead to roof and envelope damage during a high-wind event and is not a recommended practice.

8.5 Influence of Beach Nourishment and Dune Restoration on Siting Decisions

Beach nourishment was discussed in Section 7.5.2.3.1, in Chapter 7, as a means of mitigating potential adverse impacts of shore protection structures. Beach nourishment and dune restoration can also be carried out alone, as a way of replacing beach/dune sediments already lost to erosion or of providing nourishment in anticipation of future erosion (National Research Council 1995).

NOTE
Beach nourishment and dune restoration projects are temporary. Although they can mitigate some storm and erosion impacts, they should not be used as a substitute for sound siting, design, and construction practices.

Beach nourishment projects typically involve dredging or excavating hundreds of thousands to millions of cubic yards of sediment, and placing it along the shoreline. Beach nourishment projects are preferred over erosion control structures by many states and communities, largely because the projects add sediment to the littoral system and provide recreational beach space.

The longevity of a beach nourishment project will depend upon several factors: project length, project volume, native beach and borrow site sediment characteristics, background erosion rate, and the incidence and severity of storms following construction. Thus, most projects are designed to include an initial beach nourishment, followed by periodic maintenance nourishment (usually at an interval of 5 to 10 years). The projects can provide protection against erosion and storms, but future protection is tied to a community's commitment to future nourishment efforts.

Beach nourishment projects are expensive and often controversial (the controversy usually arises over environmental concerns and the use of public monies to fund the projects). Although this manual will not take sides on the matter, suffice it to say planning and construction of these projects can take years to carry out, and economic considerations usually restrict their use to densely populated shorelines. Therefore, as a general practice, designers and owners should not rely upon future beach nourishment as a way of providing significant and continuous relief that can compensate for poor siting decisions.

As a practical matter, however, beach nourishment is the only viable option available to large, highly developed coastal communities, where both upland protection and preservation of the recreational beach are vital. Beach nourishment programs have been established and are ongoing in many of these communities—infill development and redevelopment will continue landward of nourished beaches. Owners and designers should realize, however, while the nourishment programs will reduce potential storm and erosion damage to upland development, they will not eliminate all damage, and sound siting, design, and construction practices must be followed.

WARNING

Although dune vegetation serves many valuable functions, it is not very resistant to coastal flood and erosion forces.

Dune restoration projects typically involve placement of hundreds to tens of thousands of cubic yards of sediment along an existing or damaged dune. The projects can be carried out in concert with beach nourishment, or alone. Smaller projects may fill in gaps or blowouts caused by pedestrian traffic or minor storms, while large projects may reconstruct entire dune systems. Dune restoration projects are often accompanied by dune revegetation efforts, where native dune grasses or ground covers are planted to stabilize the dune against windblown erosion, and to trap additional windblown sediment.

The success of dune restoration and revegetation projects depends largely on the condition of the beach waterward of the dune. Property owners and designers are cautioned that dune restoration and revegetation projects along an eroding shoreline will be short-lived—without a protective beach, high tides, high water levels, and minor storms will erode the dune and wash out most of the planted vegetation.

In some instances, new buildings are sited so that there is not sufficient space waterward to construct and maintain a viable dune. In many instances, erosion has placed existing development in the same situation. A dune restoration project waterward of these structures will not be effective; those buildings in greatest need of protection will receive the least protection. Hence, as in the case of beach nourishment, dune restoration and revegetation should not be used as a substitute for proper siting, design, and construction practices.

8.6 References

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