D.2 Coastal Flooding Analyses and Mapping: Atlantic and Gulf Coasts

This subsection of Appendix D provides guidance for coastal flood hazard analyses and mapping that is specific to the Atlantic and Gulf of Mexico (herein referred to as Gulf) Coasts of the United States, generally referred to as "guidelines." The procedures described in this subsection were developed by a Technical Working Group (TWG) assembled by the Department of Homeland Security's Federal Emergency Management Agency (FEMA) in November 2005. They are intended to provide guidance that is generally independent of other Appendix D subsections, and that is based on the specific physical processes that influence coastal flooding on the Atlantic and Gulf coasts.

This section focuses on the Atlantic coast from the Maine-Canada border to the southernmost reaches of the Florida, the Gulf coast from Florida to the Texas-Mexico border, and the Puerto Rico and US Virgin Island Coasts, as shown in Figure D.2-1. The Great Lakes and Pacific coastlines are specifically addressed in Sections D.3 and D.4, respectively. However, much of the guidance in Section D.2 may be considered applicable in those geographic areas, if it is supplemented with engineering judgment and methods to address geographically unique processes or settings.

The mapping of V zones under the National Flood Insurance Program (NFIP) began in the early 1970s. The objective was to identify hazardous coastal areas in a manner consistent with the original regulatory definition of coastal high hazard areas as an "area subject to high velocity waters, including but not limited to hurricane wave wash." The initial technical guidance for identifying V zones was provided in a June 1973 report by the U.S. Army Corps of Engineers (USACE), Galveston District, titled "General Guidelines for Identifying Coastal High Hazard Zones, Flood Insurance Study - Texas Gulf Coast Case Study" (USACE, 1973). The USACE report identified a breaking wave height of 3 feet as critical in terms of causing significant structural damage and illustrated procedures for mapping the limit of this 3-foot wave (V zone) in two distinct situations along the Texas coast: undeveloped areas and highly developed areas.

In June 1975, the USACE, Galveston District, issued a followup report entitled "Guidelines for Identifying Coastal High Hazard Zones," which maintained the basic recommendations contained in the 1973 report for identifying V zones in undeveloped and developed areas; however, the 1975 report also included guidance for determining effective fetch lengths, a technical discussion justifying the 3-foot wave height criterion for V zones, an abbreviated procedure for V-zone mapping in undeveloped areas, an expanded discussion of V-zone mapping in developed areas, and historical accounts of several severe storms that affected developed areas along the Atlantic and Gulf coasts.

Between 1975 and 1980, the Federal Government (U.S. Department of Housing and Urban Development until 1978 and FEMA thereafter) published Flood Insurance Rate Maps (FIRMs) with V zones for approximately 270 communities along the Atlantic and Gulf coasts using the USACE guidance for V-zone mapping. During this period, the procedures for determining and delineating V zones in developed areas differed among studies. At that time, the regulatory Base

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(1-percent-annual-chance) Flood Elevations (BFEs), for both insurance and construction purposes, were the 1-percent-annual-chance stillwater elevations (SWELs), which consisted of the astronomical tide and storm surge caused by low atmospheric pressure and high winds. Although V zones were identified, the increase in water-surface elevation due to wave action was not included. The Federal Government recognized that this practice did not accurately represent the flooding hazard along the open coast, but an adequate method for estimating the effects of wave action, applicable to most coastal communities, was not readily available at the time.

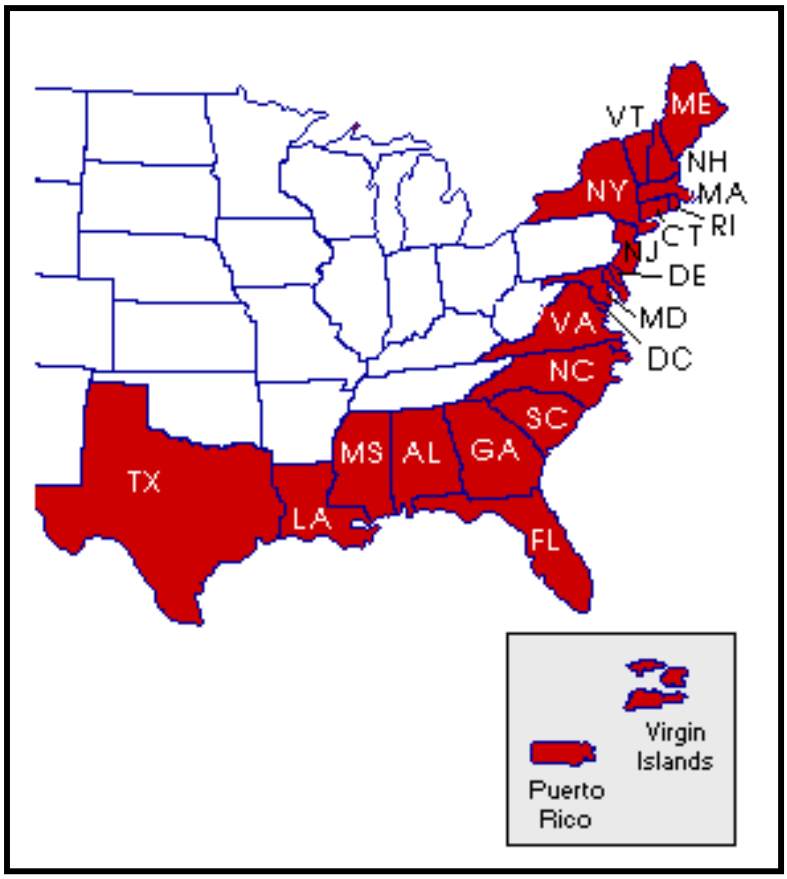

Figure D.2-1. Appendix D.2 Applicable Area – Atlantic and Gulf Coast Guidelines

In 1976, the National Academy of Sciences (NAS) was asked to provide recommendations about how calculations of wave height and runup should be incorporated in Flood Map Projects for Atlantic and Gulf coast communities to provide an estimate of the extent and height of stormwater inundation having specified recurrence intervals. The NAS concluded that the prediction of wave heights should be included in Flood Map Projects for coastal communities and provided a methodology for the open coast and shores of embayments and estuaries on the Atlantic and Gulf coasts. The report documenting the NAS findings, "Methodology for Calculating Wave Action Effects Associated with Storm Surges" (NAS, 1977), included means for taking into account varying fetch lengths, barriers to wave transmission, and regeneration of

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waves likely to occur over flooded land areas. NAS did not address the extent and elevation of wave runup, amount of barrier overtopping, and coastal erosion.

In 1979, FEMA adopted the NAS methodology. In 1980, FEMA issued "Users Manual for Wave Height Analysis," which was subsequently revised in February 1981 (FEMA, 1981). FEMA also introduced a computer program, Wave Height Analysis for Flood Insurance Studies (WHAFIS), in 1980. With WHAFIS, FEMA initiated a large effort to incorporate the effects of wave action on the FIRMs for communities along the Atlantic and Gulf coasts.

Along the coast of New England, with its very steep shore, the NAS methodology proved to be insufficient. Structures that were shown as being outside of the Special Flood Hazard Area on effective FIRMs experienced considerable wave damage from storms, most notably the northeaster of February 1978, a near 1-percent-annual-chance flood event. The need to account for the effects of wave runup was recognized. In 1981, FEMA approved a methodology that determined the height of wave runup landward of the stillwater line (Stone & Webster Engineering Corporation, 1981).

Two additions were made to the NAS methodology in 1984 to account for coastal situations involving either marsh grass or muddy bottoms. The NAS methodology did not account for flexible vegetation; in particular, marsh plants. Experts surmised that the motion of submerged marsh plants absorbed wave energy, reducing wave heights. In 1984, a FEMA task force examined this phenomenon in detail and developed a methodology that adjusted the wave height to reflect energy changes resulting from the flexure of various types of marsh plants and the wind, water, and plant interaction (FEMA, 1984). FEMA incorporated the new methodology into WHAFIS.

In 1987, FEMA modified its computer model for runup elevations slightly to increase the convenience of preparing input conditions. In 1990, FEMA modified the model again to improve computational procedures and application instructions to conform to the best available guidance on wave runup (Dewberry & Davis, 1990).

The muddy bottom situation occurs only at the Mississippi River Delta in the United States. The Mississippi River has deposited millions of tons of fine sediments into the Gulf of Mexico to form a soft mud bottom in contrast to the typical sand bottom of most coastal areas. This plastic, viscous bottom deforms under the action of surface waves. This wave-like reaction of the bottom absorbs energy from the surface waves, thus reducing the surface wave heights. A methodology was developed for FEMA to calculate the wave energy losses due to muddy bottoms (Suhayda, 1984). Waves in the nearshore areas are tracked over the mud bottom, resulting in lower incident wave heights at the shoreline. This is a phenomenon unique to the Mississippi River Delta, and FEMA has not incorporated the methodology into WHAFIS.

In 1988, FEMA upgraded WHAFIS to incorporate revised wave forecasting methodologies described in the 1984 edition of the "USACE Shore Protection Manual" (USACE, 1984) and to compute an appropriately gradual increase or decrease of SWELs between two given values (FEMA, September 1988).

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In the performance of wave height analyses and the preparation of Flood Map Projects, erosion considerations were left to the judgment of FEMA contractors. Coastal erosion was to be considered a hazard when there was historical evidence of erosion from previous storms, but before 1986 objective procedures for treating erosion were not available. Consequently, some shorefront dunes were designated as stable barriers to flooding and some were not. In 1986, FEMA initiated studies aimed at providing improved erosion assessments in Flood Map Projects for coastal communities.

In response to criticisms that indicated a significant underestimation of the extent of Coastal High Hazard Areas, FEMA undertook an investigation to reevaluate V zone identification and mapping procedures. The resulting report, titled "Assessment of Current Procedures Used for the Identification of Coastal High Hazard Areas (V Zones)" (FEMA, 1986), presented a number of recommendations that allowed a more realistic delineation of V zones and better fulfilled the NFIP objectives, namely, actuarial soundness and prudent floodplain development. One recommendation called for full consideration of storm-induced erosion and wave runup in determining BFEs and mapping V zones.

As part of its investigation, FEMA performed a study of historical cases of notable dune erosion. In this quantitative analysis, field data for 30 events (later increased to 38 events) yielded a relationship of erosion volume to storm intensity as measured by flood recurrence interval. For the 1-percent-annual-chance storm, FEMA determined that, to prevent dune breaching or removal, an average cross-sectional area of 540 square feet is required above the SWEL and seaward of the dune crest. That standard for dune cross section has a central role in erosion assessment procedures on the Atlantic and Gulf coasts.

The USACE Coastal Engineering Research Center (CERC) performed a study of the available quantitative erosion models for FEMA (CERC, 1987). CERC determined that only empirically based models produce reasonable results with a minimum of effort and input data, that each available model for simple dune retreat has certain limitations, and that dune overwash processes are poorly documented and unquantified. After further investigations, FEMA decided to employ a set of simplified procedures for objective erosion assessment (FEMA, November 1988). These procedures have a direct basis in documented effects due to extreme storms and are judged appropriate for treating dune erosion in Flood Map Projects for coastal communities.

As the official basis for treating flood hazards near coastal sand dunes, FEMA published new rules and definitions in the Federal Register that became effective on October 1, 1988. FEMA included the following revised definition in Section 59.1 of the NFIP regulations:

> *Coastal high hazard area* means an area of special flood hazard extending from offshore to the inland limit of a primary frontal dune along an open coast and any other area subject to high velocity wave action from storms or seismic sources.

FEMA also added a clarification of this matter, a definition of primary frontal sand dune, in Section 59.1:

> *Primary frontal dune* means a continuous or nearly continuous mound or ridge of sand with relatively steep seaward and landward slopes immediately landward and adjacent

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> to the beach and subject to erosion and overtopping from high tides and waves during major coastal storms. The inland limit of the primary frontal dune occurs at the point where there is a distinct change from a relatively steep slope to a relatively mild slope.

FEMA also included a new section in Part 65 of the NFIP regulations, identifying a cross-sectional area of 540 square feet as the basic criterion to be used in evaluating whether a Primary Frontal Dune (PFD) will act as an effective barrier during the 1-percent-annual-chance flood. Another consideration is the documented historical performance of coastal sand dunes in extreme local storms.

In 1989, CERC completed a review for the NFIP regarding coastal structures as protection against the 1-percent-annual-chance flood and published Technical Report CERC 89-15, "Criteria for Evaluating Coastal Flood-Protection Structures"(CERC, 1989). Predictions of wave forces, wave overtopping, and wave transmission for commonly constructed coastal protection structures were among technical topics addressed in the CERC report. FEMA summarized the CERC 89-15 report for use in the NFIP in a 1990 memorandum, Criteria for Evaluating Coastal Flood Protection Structures for NFIP Purposes. The guidelines in this Appendix incorporate procedural criteria recommended by CERC for evaluating structural stability as presented in the 1990 memorandum.

In 2003, recognizing that coastal areas are among the most densely populated and economically important areas in the nation, FEMA created a TWG of Coastal Engineers and Scientists and authorized an evaluation of the existing FEMA procedures for delineating coastal flood hazard areas in three major coastal regions of the United States: Atlantic, Gulf, and Pacific. The final products of the TWG were included in "Guidelines for Coastal Flood Hazard Analysis and Mapping for the Pacific Coast of the United States," and the subsequent FEMA Procedure Memorandum No. 37, "Protocol for Atlantic and Gulf Coast Coastal Flood Insurance Studies in FY05," issued on August 1, 2005. Procedure Memorandum No. 37 presents revisions and modifications to existing protocols in Appendix D, "Guidelines for Coastal Flooding Analyses and Mapping," of FEMA's *Guidelines and Specifications for Flood Hazard Mapping Partners* (FEMA, 2003) for performing detailed coastal hazard assessments for communities along the Atlantic and Gulf coasts.

The developments presented in Procedure Memorandum No. 37 were determined by TWG during the Pacific Coast Study Guidance project and deemed applicable to the Atlantic and Gulf coasts. Many of the recommendations of the TWG for the Atlantic and Gulf coasts still require additional development and testing. Updates and new recommendations for tide gage analyses, coastal structures, storm meteorology, wave runup, wave setup, and other aspects of coastal flood hazard identification have been incorporated into Section D.2.

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