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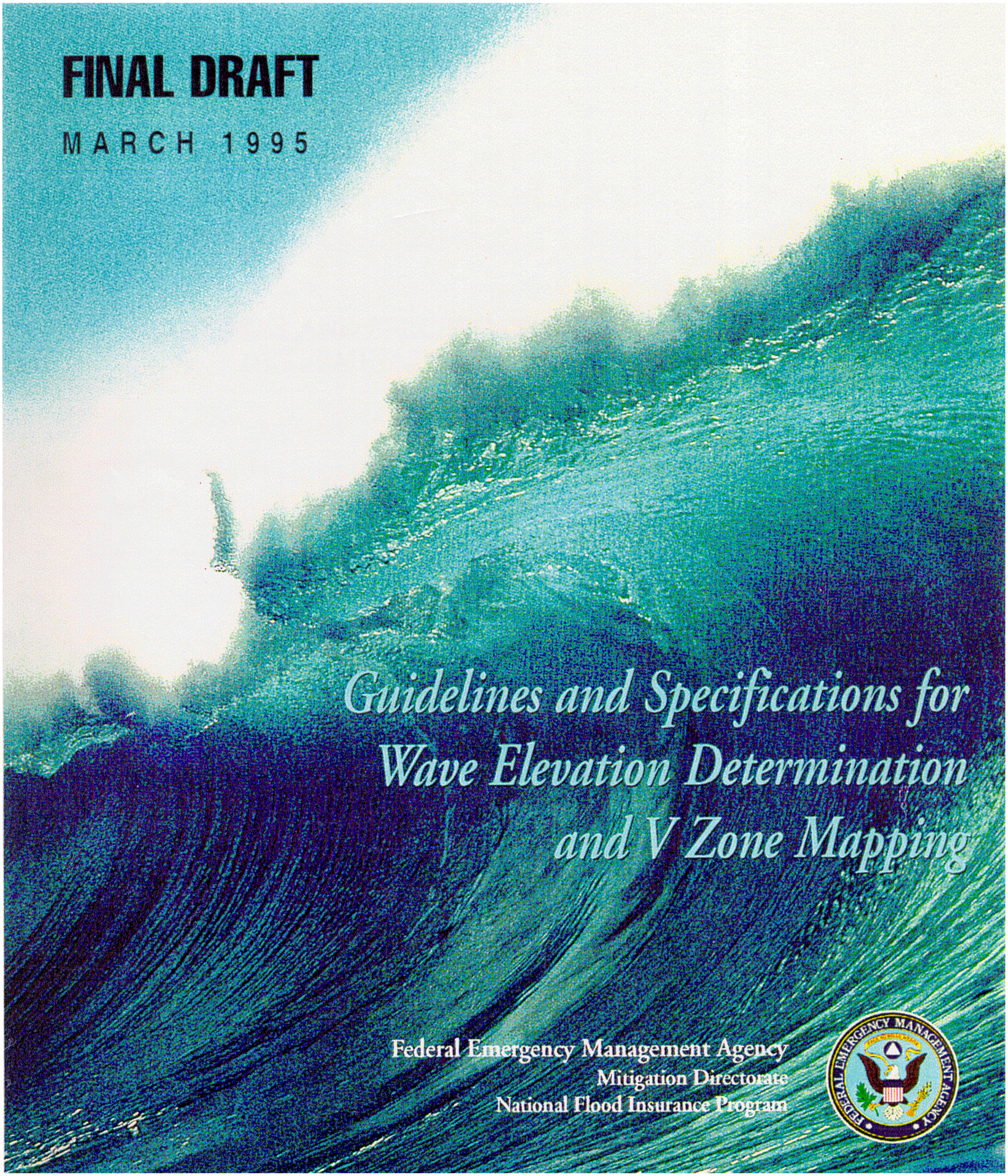

Guidelines and Specifications for Wave Elevation Determination and V Zone Mapping

Federal Emergency Management Agency
Mitigation Directorate
National Flood Insurance Program

GUIDELINES AND SPECIFICATIONS FOR WAVE ELEVATION DETERMINATION AND V ZONE MAPPING

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Federal Insurance Administration

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LIST OF NOTATION

b	horizontal spacing of rigid vegetation
C	elevation of barrier crest
C_D	drag coefficient
d	water depth
d_t	water depth at toe of barrier
D	diameter of vegetation (stem or trunk)
F	freeboard of barrier above stillwater elevation
F_{cov}	fractional coverage of plants
g	gravitational acceleration
h	height of vegetation
H	wave height (crest to trough)
H'	limited valve of incident wave height
H_c	controlling wave height
H_{mo}	zero-moment wave height
L	wavelength
m	slope (tangent)
n	Manning's coefficient describing roughness
N	numerical density of vegetation
Q	discharge rate of wave overtopping
r	roughness coefficient for barrier
R	vertical wave runup dimension above stillwater level
R'	excess runup height above bluff crest
R_a	adjusted wave runup elevation
S	wave setup at shore, above stillwater level
T	wave period
X	distance inland to runup limit

Overbar denotes mean over time
Subscript o denotes deep-water value
Subscript p denotes energy peak
Subscript s denotes significant wave description
Superscript * denotes dimensionless parameter

GUIDELINES AND SPECIFICATIONS FOR WAVE ELEVATION DETERMINATION AND V ZONE MAPPING

1.0 INTRODUCTION

1.1 Authority and Purpose

The National Flood Insurance Program (NFIP) was established by the National Flood Insurance Act of 1968 and further defined by the Flood Disaster Protection Act of 1973. The 1968 Act provided for the availability of flood insurance within communities that were willing to adopt floodplain management programs to mitigate future flood losses. The act also required the identification of all floodplain areas within the United States and the establishment of flood risk zones within those areas.

A vital step toward meeting these goals is the conduct of Flood Insurance Studies (FISs) and restudies for flood-prone communities in the United States. These studies provide communities with sufficient technical information to enable them to adopt the floodplain management measures required for participation in the NFIP. FISs also provide the necessary flood risk information to establish actuarial flood insurance premiums.

Coastal communities generally have unique flood hazards because of storm surges and wave action from large open water bodies. Defining

Coastal High Hazard Areas (V zones) requires determination of wave elevations associated with the 100-year flood. The Federal Emergency Management Agency (FEMA), Mitigation Directorate, has compiled these Guidelines and Specifications for Wave Elevation Determination and V Zone Mapping (referred to herein as these Guidelines) to specify technical policies and procedures to be employed in the preparation of coastal FISs and restudies. These Guidelines are a supplement to the Flood Insurance Study Guidelines and Specifications for Study Contractors (Reference 1), and may be superseded by future instructions that reflect updated policies and procedures. The present Guidelines are not applicable to studies on Great Lakes coasts because different analysis procedures and computer models are applied there, as described in Reference 2.

Detailed guidance is provided for the determination of wave elevations associated with the 100-year coastal flood and for the identification of resultant V zones. Methodologies and models for the determination of wave heights, wave crest elevations, wave runup, and coastal erosion have been adopted and refined by FEMA. Various available documents describing the development, basis, and application of these methodologies are referenced, but not discussed in detail. These Guidelines have been compiled to provide unified instructions on the application of these methodologies to determine the coastal flooding elevations and hazards set forth in the FIS, and on the delineation of the flood elevations and hazards on the Flood Insurance Rate Map (FIRM). The FIRM provides base flood elevations (BFEs) and divides the community into flood hazard zones that are used to establish actuarial insurance rates.

1.2 Background

The mapping of V zones under the NFIP first 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: "areas subject to high velocity waters, including but not limited to hurricane wave wash." The initial technical guidance for identifying V zones was provided in General Guidelines for Identifying Coastal High Hazard Zone, Flood Insurance Study - Texas Gulf Coast Case Study, prepared by the Galveston District, Corps of Engineers (COE) (Reference 3). This 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.

The COE issued a follow-up report, Guidelines for Identifying Coastal High Hazard Zones, which maintained the basic recommendations contained in the previous report for identifying V zones in undeveloped and developed areas (Reference 4). However, this 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 have impacted developed areas along the Atlantic and Gulf coasts.

Between 1975 and 1980, FIRMs with V zones were published for approximately 270 communities along the Atlantic and Gulf coasts using the COE guidance for V zone mapping. During this period, the procedures for the determination and delineation of V zones in developed areas lacked uniformity among studies. The regulatory BFEs, at that time, for both insurance and construction purposes, were the 100-year stillwater elevations 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. It was 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.

In 1976, FEMA contracted the National Academy of Sciences (NAS) to provide recommendations about how calculations of wave height and runup should be incorporated in FISs of coastal communities to provide an estimate of the areal extent and height of stormwater inundation having specified recurrence intervals. The NAS concluded that the prediction of wave heights should be included in FISs of coastal communities and provided a methodology for the open coast and shores of embayments and estuaries on the Atlantic and Gulf coasts. The Methodology for Calculating Wave Action Effects Associated with Storm Surges included means for taking account of varying fetch lengths, barriers to wave transmission, and the regeneration of waves likely to occur over flooded land areas (Reference 5). The extent and elevation of wave runup, amount of barrier overtopping, and coastal erosion were not addressed by the NAS.

The NAS methodology was adopted by FEMA in 1979, and a Users Manual was issued in 1980 (Reference 6). The computer program Wave Height Analyses for Flood Insurance Studies (WHAFIS) was also made available in 1980 (Reference 7). With WHAFIS, FEMA initiated a large effort to incorporate the effects of wave action on the FIRMs for coastal communities along the Atlantic Ocean and Gulf of Mexico.

Along the New England coast with its very steep shore, structures identified as being outside of the flood hazard areas using the NAS methodology had experienced considerable wave damage from recent storms, most notably the northeaster of February 1978, a near 100-year event. The need to account for the effects of wave runup was recognized, and in 1981 FEMA approved a methodology that determined the height of wave runup landward of the stillwater line (Reference 8). FEMA's computer model for runup elevations was slightly modified in 1987 to increase the convenience of preparing input conditions, and again in 1990 to improve computational procedures and application instructions to conform with the best available guidance on wave runup (Reference 9).

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. It was surmised that the motion of submerged marsh plants absorbed wave energy, reducing wave heights. 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 (Reference 10). This addition has been incorporated into WHAFIS.

The muddy bottom situation occurs only at the Mississippi 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 waves. A methodology was developed for FEMA to calculate the wave energy losses due to muddy bottoms (Reference 11). Waves in the offshore areas are tracked over the mud bottom, resulting in lower incident wave heights at the shoreline. This is a phenomenon unique to the

Mississippi Delta, so the methodology has not been incorporated into WHAFIS and is not further discussed in these Guidelines.

In 1988, FEMA upgraded WHAFIS to incorporate revised wave forecasting methodologies described in the 1984 Edition of the Shore Protection Manual (Reference 12) and to compute an appropriately gradual increase or decrease of stillwater elevations between two given values (Reference 13).

In the performance of wave height analyses and the preparation of FISs, erosion considerations were left to the judgment of the contractors. General guidance directed that coastal erosion should be assumed where there was evidence of erosion from historical storms, but objective procedures for treating erosion were not provided. 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 coastal FISs.

In response to criticisms indicating 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 presented a number of recommendations to allow for a more realistic delineation of V zones and to better meet the objectives of the NFIP for actuarial soundness and prudent floodplain development (Reference 14). One recommendation was for full consideration of storm-induced erosion and wave runup in determining base flood elevations and mapping V zones. As part of that investigation, a study was made 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 100-year storm, it was determined that on the average, to prevent dune breaching or removal, a cross-sectional area of 540 square feet (ft^2) is required above the stillwater flood elevation and seaward of the dune crest. That standard for dune cross section has a central role in erosion assessment procedures presented later in these Guidelines.

The COE, Coastal Engineering Research Center (CERC), performed a study of the available quantitative erosion models for FEMA (Reference 15). This study 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 extremely simplified procedures for objective erosion assessment (Reference 16). These procedures have a direct basis in documented effects due to extreme storms, and are judged appropriate for treating dune erosion in coastal FISs.

As the official basis for treating flood hazards near coastal sand dunes, the Federal Register published new rules and definitions having an effective date of October 1, 1988. This included a revised definition of Coastal High Hazard Area in Section 59.1:

> "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.

As additional clarification of this matter, a definition of Primary Frontal Sand Dune was added 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 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.

Also, a new section is included in Part 65 which identifies a cross-sectional area of 540 square feet as the basic criterion to be used in evaluating whether a primary frontal dune will act as an effective barrier during the base flood. Another consideration is the documented historical performance of coastal sand dunes in extreme local storms.

In 1989, the COE completed a review for the NFIP regarding coastal structures as protection against the base flood (Reference 17). Among technical topics addressed were predictions of wave forces, wave overtopping, and wave transmission for commonly occurring structures. These Guidelines incorporate procedural criteria recommended by the COE for evaluating structural stability.

1.3 Organization and Overview

Figure 1 presents a flowchart of appropriate procedures for defining coastal hazards of the base flood. Fundamental aspects of the 100-year flood are addressed in this sequence: stillwater elevation, accompanying wave conditions, stability of coastal structures, storm-induced erosion, wave runup and overtopping, and, finally, overland wave heights. Determination of stillwater elevations usually involves detailed statistical analyses, but added effects due to surface wave action are treated by simplified deterministic methodologies. This strategy avoids any potential complications due to conditional probabilities for simultaneous flooding effects. The sequence for treating these effects is entirely consistent in principle; for example, added wave effects are not resolved within

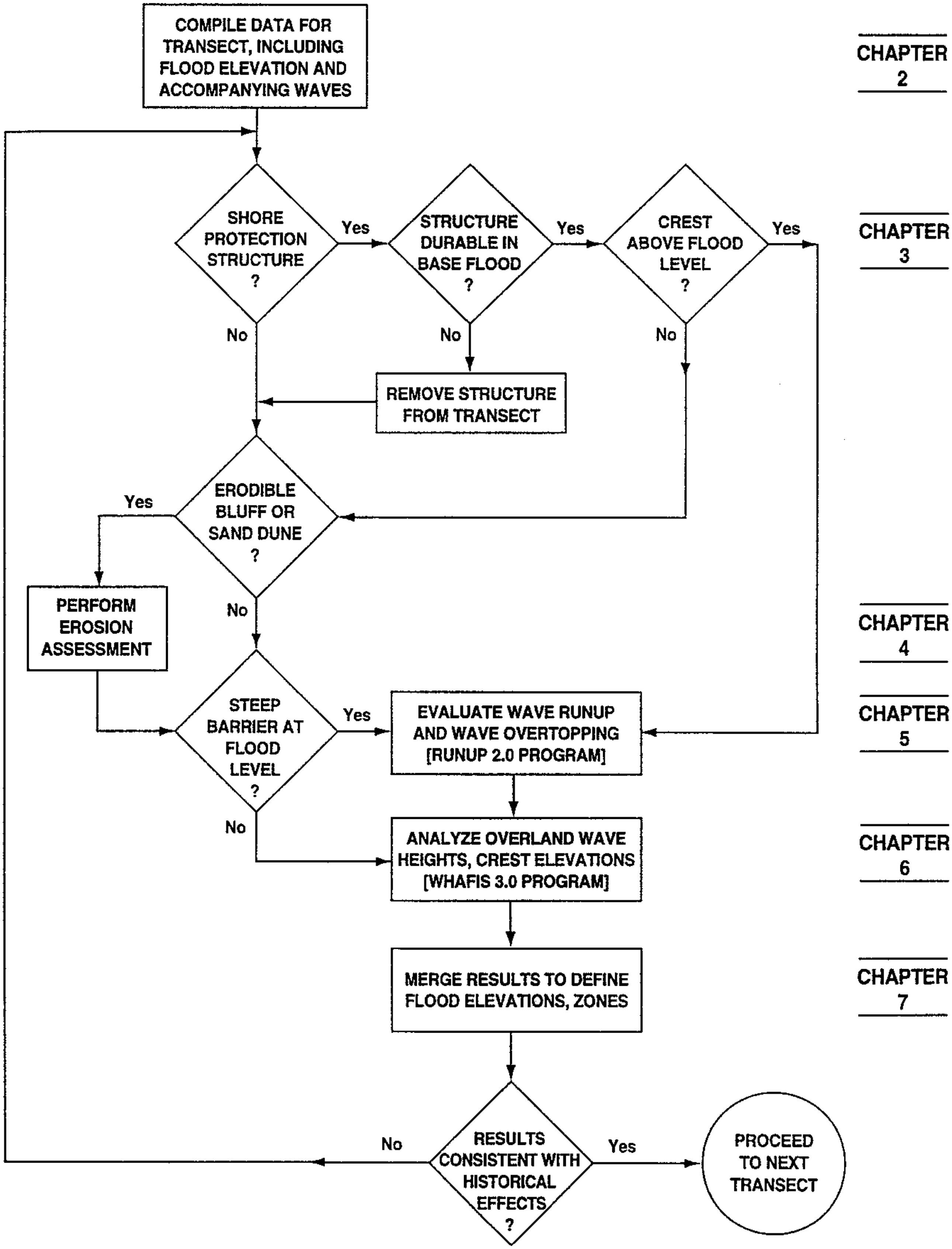

Figure 1. Procedural Flowchart for Defining Coastal Flood Hazards.

the equations commonly used to simulate coastal storm surges and establish stillwater elevation for the 100-year flood.

The order indicated in Figure 1 for activities, assessments, and analyses also outlines the appropriate organization of topics treated in these Guidelines. Chapter 2 describes general data requirements for conducting a coastal FIS, including that data needed as input to computer models. Chapter 3 discusses requisite evaluation of coastal structures potentially providing wave and/or flood protection. Chapter 4 considers the erosion assessment needed to project the configuration of a shore site during the base flood. Chapter 5 treats wave runup and overtopping occurring at shore barriers in flood conditions. Chapter 6 addresses the analysis of nearshore wave heights and wave crest elevations relevant to an FIS. All that material provides guidance on the models and procedures for treating individual transects at a study site.

FEMA has established specific models and procedures for the evaluation of shore structures, erosion, wave runup, and wave heights in the determination of coastal flood hazards. For many coastal areas, all four topics must be considered for an adequate treatment; for other coastal areas, application of only one or two of the FEMA methodologies may be required to produce reasonable results. Table 1 lists some typical shoreline types and the models that should be used for them.

Table 1

Model Selection for Typical Shorelines

Type of Shoreline	Models to be Applied		
	Erosion	Runup	WHAFIS
Rocky bluffs		x	x
Sandy bluffs, little beach	x	x	x
Sandy beach, small dunes	x		x
Sandy beach, large dunes	x	x	x
Open wetlands			x
Protected by rigid structure		x	x

The remaining material in these Guidelines adopts a more comprehensive view towards FIS completion. Chapter 7 deals with the integration of basic results into a coherent map for flood elevations and hazard zones. Chapter 8 defines required documentation of the process, decisions, and data used in determining coastal flood hazards for a community. Appendix A carries through a complete example study employing procedures and models applicable to a wide range of situations and conditions. For consistency with the NFIP and compatibility with FISs, these Guidelines use standard English units for all variables.