D.3 Wave Elevation Determination and V Zone Mapping: Great Lakes

Methodologies for determining coastal flood elevations and flood insurance risk zones have been adopted and refined over a period of time, as recounted in Section D.2 and in FEMA's *Guidelines and Specifications for Wave Elevation Determination and V Zone Mapping* (1995). Standard treatments for U.S. seacoast sites address wave heights, wave crest elevations, wave runup, and coastal erosion accompanying the 1-percent-annual-chance flood (FEMA, 1995). The effects of such waves determine flood elevations and the extent of Coastal High Hazard Areas (V Zones).

Until recently, wave effects were not taken into account along Great Lakes shores, but storms during the high water levels from 1985 to 1987 prompted reconsideration of this omission. A USACE study in 1989 concluded that recent significant storm damage at New York, Michigan, and Illinois sites confirmed the importance of wave runup contributions to actual coastal flooding on the Great Lakes. That finding led to specific calculation procedures to determine runup elevations appropriate to Great Lakes coasts with barriers to wave propagation (FEMA, 1991). Later, the standard NFIP seacoast model for wave height analysis was modified to apply to the lower wind speeds typical of Great Lakes events, and a detailed review addressed wave conditions and coastal erosion processes and quantities accompanying extreme floods at various U.S. lake sites (Dewberry & Davis, 1995). All necessary guidance has now been developed for treating wave effects in communities located along the Great Lakes

This subsection unifies the technical policies, procedures, and methodologies relevant to conducting a flood hazard study for a Great Lakes coastal community. In addressing coastal studies for specific geographical regions, these Guidelines and FEMA's *Guidelines and Specifications for Wave Elevation Determination and V Zone Mapping* (1995) serve as user guides. Appropriate application of this guidance, along with an understanding of coastal engineering principles, will assist Mapping Partners in determining coastal flooding elevations and hazards and presenting this information on the FIRM.

[February 2002]

D.3.1 Appropriate Treatments

The methodologies that shall be used to treat all the wave hazards possibly associated with a 1-percent-annual-chance flood are summarized in Table D-14. However, Mapping Partners must recognize that not every wave effect that occurs on the Great Lakes must be addressed for every flood hazard study or for every lakeshore community. To minimize unnecessary effort, it is useful early in the study process to identify those wave effects that can contribute noticeably to the BFEs and thus should be analyzed. Whether or not a wave treatment is appropriate depends primarily on the basic type of coastal topography, as outlined in Table D-14.

Table D-14. Important Wave Treatments for Typical Coastal Topographies

COASTAL TOPOGRAPHY	IMPORTANT WAVE TREATMENTS		
	EROSION	RUNUP	WHAFIS
Rocky bluff		x	x
Sediment bank or bluff	x	x	x
Sandy beach, small dunes	x		x
Sandy beach, large dunes	x	x	x
Open wetlands			x
Shore protection structure		x	x

The objective of a coastal study is to provide legible and accurate flood hazard maps with appropriate BFEs including wave contributions. Although procedures to define V Zones are fully documented in these Guidelines, mapping V Zones may not be appropriate in some Great Lakes areas. Both engineering and practical judgment are required for a proper decision on this matter. The typical study finding is a narrow V Zone, making its usefulness uncertain on maps at usual scales. Also, relatively small numbers of existing coastal buildings are likely to be affected by possible V-Zone designations along some Great Lakes.

V Zones are to be mapped only when the Regional Project Officer (RPO) approves such action. Some common exceptions to required approval might include coastal areas lakeward of sizable bluffs or designated as primary frontal dunes, so that the V Zone can be clearly delineated.

A flowchart with the basic study procedures for defining flood hazards in the Great Lakes region is presented in Figure D-35.

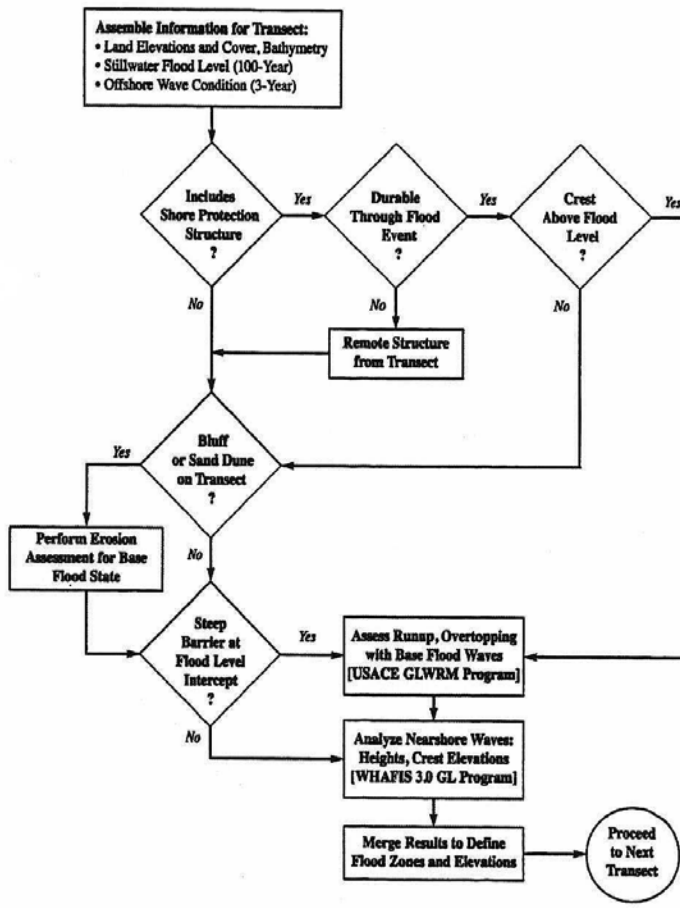

Figure D-35. Procedure for Defining Flood Hazards on Great Lakes Shores

[February 2002]

D.3.2 Data Requirements for Coastal Flood Hazard Analyses

A coastal flood hazard analysis begins with collecting the data and information required for the ensuing analyses, including the input needed for the computer models. The coastal models discussed here are executed along transects, which, as discussed earlier in this Appendix, are cross sections taken perpendicular to the mean shoreline to represent a segment of coast with similar characteristics. Thus, collected data are compiled primarily for use in developing transects and for locating and detailing the results on work maps. Work maps are to show the topography and land cover at a scale with sufficient detail to properly delineate the results of the analyses and interpolate between transects.

Data collection is to start at the community level and proceed with inquiries to appropriate county, State, and Federal agencies. To pursue any suggestions provided by government agencies, private firms specializing in topographic mapping or aerial photography may also be contacted.

This subsection describes the data requirements for coastal flood hazard analyses.

[February 2002]

D.3.2.1 Stillwater Elevations

The USACE's *Revised Report on Great Lakes Open-Coast Flood Levels* (1988) is FEMA's source for SWELs on the Great Lakes, at recurrence intervals of 10, 50, 100, and 500 years (reflecting 10-, 2-, 1-, and 0.2-percent-annual-chance flood elevations, respectively). Documented flood elevations pertain to specific U.S. reaches of open coast, defined as "lake shoreline which is unprotected by the presence of islands and which is uninterrupted by bays." These elevations are based on a standardized analysis of maximum annual water levels from long-term gage records (1900 to 1986) and are referenced to NGVD.

The USACE report on Great Lakes flood levels is divided into Phase I and Phase II reports. The Phase I report provides SWELs for most of the U.S. shoreline of Lake Superior (divided into five separate reaches), Lake Michigan (nine reaches), Lake Huron (eight reaches), Lake St. Clair (one reach), Lake Erie (24 reaches), and Lake Ontario (five reaches). In Subsection D.3.9, charts identifying separate reaches and the flood elevations on each lake are reproduced; except on Lake Erie, flood elevations usually remain constant over tens of miles along the shore. The Phase II report provides the flood levels for connecting channels and addresses general methods for developing flood levels in other areas, such as bays, inlets, and sheltered shorelines. For some of these areas, separate reports such as the "Saginaw Bay Flood Levels Report" for Lake Huron, have been prepared to document the SWELs (USACE, September 1989).

[February 2002]

D.3.2.2 Transect Locations

Transects for coastal flood hazard analyses are to be located with careful consideration given to the physical and cultural characteristics of the land so that they will closely represent conditions in the vicinity of the transect. If they are carefully placed, excessive mapping interpolation of the BFEs between transects, as well as unnecessary study effort, can be avoided. The transects are to be placed more closely together in areas of complex topography, dense development, and unique flooding, and where computed wave heights and runup may be expected to vary significantly. Wider spacing may be appropriate in areas having more uniform characteristics. For example, a stretch of developed shoreline with various building densities, protective structures, and vegetation may require a transect every 1,000 feet or so, whereas a long stretch of undeveloped shoreline with a continuous dune or bluff of fairly constant height and shape, and similar landward features may require a transect only every 1 to 2 miles.

In areas where runup is significant, the location of transects is governed by variations in shore slope or steepness. In other areas where dissipation of wave heights is significant to the computation of flood hazards, transect location is based on variations in land cover, such as buildings and vegetation. Often, areas with similar characteristics may be scattered throughout a community, and the results from one transect are also representative of other locations and can be delineated accordingly.

The Mapping Partner performing the coastal flood hazard study shall locate transects on the work map to be submitted with the analysis, and shall compile the input data and displayed the data on individual profiles for each transect. The Mapping Partner shall take the data (e.g., topography, development, vegetation) not only at the transect site, but for the entire area or length of shoreline represented by the transect so that the input data depict average characteristics of the area. The Mapping Partner may divide the work map into transect areas to help in compiling the data.

[February 2002]

D.3.2.3 Topographic Data

Topographic data must have a contour interval of equal or greater detail than that used for the effective FIS, and a minimum interval of 5 feet or 1.5 meters. While more detailed information, such as spot elevations or a smaller contour interval, can be useful in defining the dune or bluff profile and in delineating floodplain boundaries, it is required only when a map revision request with new coastal analyses is based on new detailed topographic data. As discussed in Volume 2, the data, usually in the form of maps, shall be certified and shall reflect current conditions in the area of the analysis or, at a minimum, conditions at a time more recent than the topographic data used in the effective FIS.

Topography must extend lakeward at least to the Low Water Datum defined for each Great Lake, as listed in Table D-14. The Low Water Datum corresponds to extremely low annual means of lake level during the 1900s and is described in terms of the International Great Lakes Datum of

1985 (IGLD85). The relation of NGVD29 to IGLD85 needs to be defined for each coastal flood hazard analysis site. NGVD29 is required as the datum for the topographic map.

If possible, the Mapping Partner shall check the shore topography to note any changes caused by construction, erosion, or other causes and document any significant erosion by location with descriptions, drawings, and/or photographs. The Mapping Partner is not required to field survey transects unless available topographic data are unsuitable or incomplete.

The community, county, and state are usually the best sources for topographic data. The Mapping Partner shall examine USGS 7.5-minute series topographic maps. The USGS maps may have a 5-foot contour interval, and if not, they are still often useful as a reference for planimetric features in the study area.

Table D-14. Elevations of Low Water Datum on the Great Lakes

LOCATION	LOW WATER DATUM ELEVATION:	
	FEET ABOVE IGLD85	FEET ABOVE NGVD29 (APPROXIMATE)
Lake Superior	601.1	601
Lake Michigan	577.5	578
Lake Huron	577.5	578
Lake St. Clair	572.3	573
Lake Erie	569.2	570
Lake Ontario	243.3	244

[February 2002]

D.3.2.4 Land-Cover Data

The land-cover data include information on structures and vegetation. Stereoscopic aerial photographs can provide the required data on structures and some of the data on vegetation. The aerial photographs must not be more than 5 years old unless they are updated by surveys. A local, county, or State agency may have the coastline photographed on a periodic basis. That agency may provide the photographs or give permission to obtain them from its contractor. Because topographic maps are often developed from aerial photographs, the Mapping Partner also shall contact the mapping contractor for the topographic maps for data.

Aerial photographs can provide the required data on tree- and bush-type vegetation and can be used to identify areas although not the specific type of grass-like vegetation. National Wetland Inventory maps from the U.S. Fish and Wildlife Service and color infrared aerial photographs can provide more specific data required for marsh plants. Ground-level photographs and surveys also are useful in providing information on the plants (e.g., density, species). State offices of coastal zone management, park and wildlife management, and/or natural resources should be able to provide information on significant vegetation types. Also, the Mapping Partner shall contact local universities with coastal studies and/or Sea Grant programs. The Mapping Partner may conduct field surveys in lieu of the above sources, but these are more cost effective when used only to verify some of the data obtained from these sources.

[February 2002]

D.3.2.5 Bathymetric Data

It is not possible to provide precise guidance on the extent of bathymetry needed for a Great Lakes FIS. In some cases, only typical water depths in the vicinity of shore structures will be required in the analysis of wave effects. For sand beaches, bathymetry out to water depths of approximately 30 feet is required for wave treatments. Bathymetry further offshore may be useful for interpreting likely differences between nearshore and offshore wave conditions. (See Subsection D.3.2.6). An advisable procedure for studies of Great Lakes sites is to gather any readily available bathymetric data, but to defer all data reduction or analysis until the need is firmly established. Bathymetric data can be acquired from National Ocean Survey nautical charts, although any reliable source can be used.

[February 2002]

D.3.2.6 Offshore Wave Characteristics

One basic assumption in conducting coastal wave analyses is that wave direction must have some onshore component, so wave hazards occur coincidentally with the 1-percent-annual-chance flood. That assumption appears generally appropriate on open coasts and bay shores of the Great Lakes, where the 1-percent-annual-chance SWEL must include some contribution from storm surge and usually requires an onshore wind component. However, the assumption of onshore waves along the shores of connecting channels, near inlets, and behind protective islands may require detailed examination.

Once the Mapping Partner has confirmed that sizable waves travel onshore during the 1-percent-annual-chance flood, the most important specification is wave period rather than wave height. This is because wave heights are severely limited by shallow water at sites where the models described in Subsections D.3.5 and D.3.6 are applied. Wave treatments within those models provide depth-limited wave heights controlled by the wave period, so that the specified period influences the results of coastal wave analyses. The specified wave period can pertain to offshore storm waves in deep water, because dominant or spectral peak period is commonly unchanged during complex wave transformations near the shore. The most notable sources of suitable storm-wave information along Great Lakes coasts are the USACE Coastal Engineering Research Center (CERC) Wave Information Studies (WIS) Nos. 22, 23, 24, 25, and 26, with one report for each Great Lake on computed wave conditions in deep water from 1956 to 1987 (Driver, Reinhard, & Hubertz, 1991 and 1992; Hubertz, Driver, & Reinhard, 1991; Reinhard, Driver, & Hubertz, 1991). Maps locating approximately 300 sites for which computed wave information is available, one map for each lake, are included in Subsection D.3.9.

The draft of "Basic Analyses of Wave Action and Erosion with Extreme Floods on Great Lakes Shores" (Dewberry & Davis, 1995) concluded from historical evidence that extreme floods were usually accompanied by the local 1/2-year wave condition on Lake Ontario, or by the 3-year wave condition on Lakes Erie, Huron, Michigan, and Superior. Those wave heights can be determined using the simple treatment illustrated by Figure D-36. Tabulated significant wave heights in the CERC WIS reports include the extremes for each month/year at every calculation site, and the median of each set of results gives the 2-month/2-year wave height. Extreme wave heights at various recurrence intervals usually are well approximated by an exponential distribution, so those two known values on a semi-logarithmic graph define other significant wave conditions of interest, as demonstrated in Figure D-36.

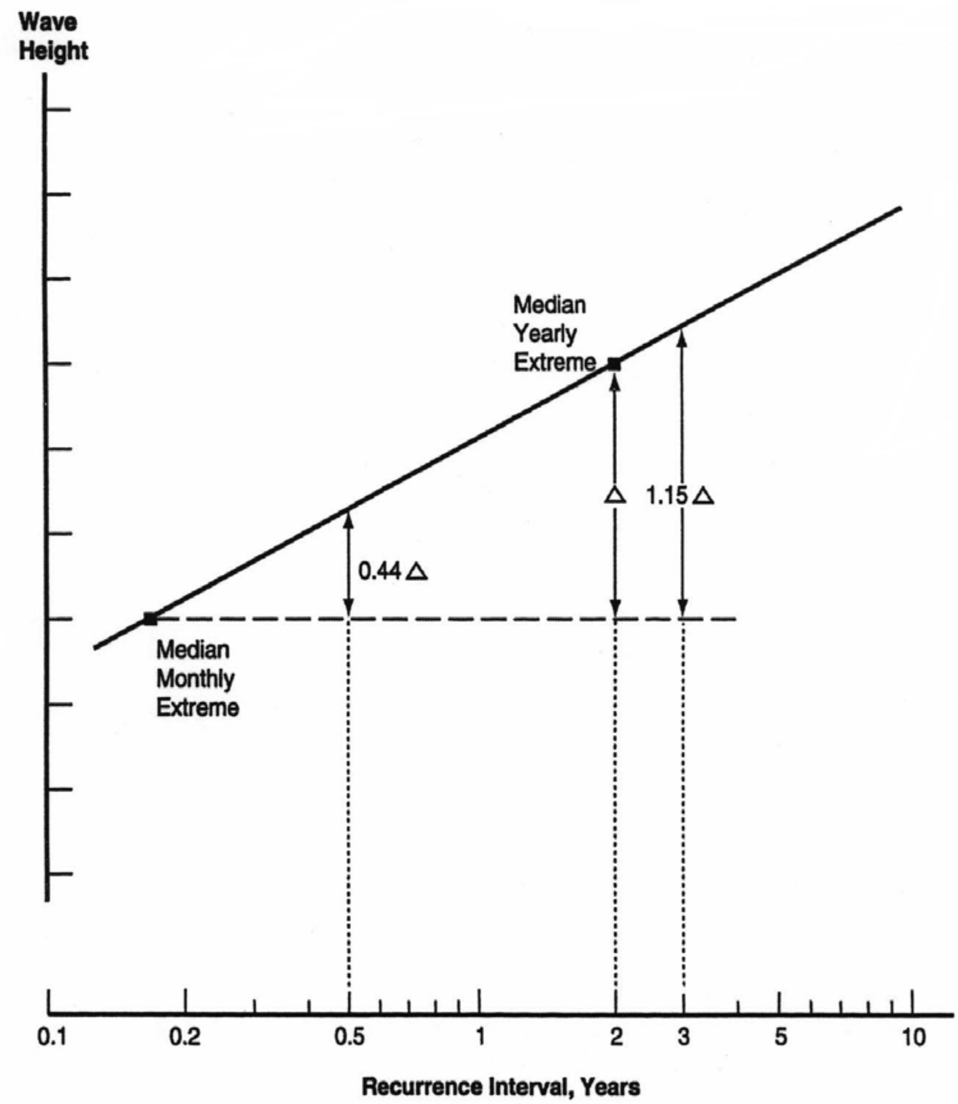

Figure D-36. Defining ½ Year or 3-Year Wave Height in an Exponential Distribution Using a Semi-Logarithmic Graph.

Once a suitable offshore wave height is specified from the CERC WIS reports, the Mapping Partner shall determine the wave period crucial to coastal analyses in one of two ways. The more rigorous determination examines the electronic file of calculated conditions for 1956 to 1987, extracting cases with the specified wave height and with wave direction toward shore; prevalent wave period in those cases should be appropriate to the flood. Section D.3.9 includes examples of appropriate wave conditions derived for several sites on each of the Great Lakes. An alternative procedure considers wave steepness, or ratio of wave height to wavelength, with these typical values for storm waves: 0.035 for Lake Ontario or Lake Erie, 0.04 for Lake Huron or Lake Michigan, and 0.045 for Lake Superior. In deep water, the wavelength is 0.16 times the gravitational acceleration times the wave period squared, so specified wave steepness and wave height imply a suitable wave period for the site.

The hindcast wave study of the CERC WIS reports provides no information for Lake St. Clair, or within major embayments and connecting channels of the Great Lakes. Such sites require an independent assessment to define likely wave characteristics associated with the 1-percent-annual-chance flood. Fundamental information for such an assessment includes the water basin geometry at a site and the meteorology of storms potentially yielding the 1-percent-annual-chance SWEL, i.e., capable of generating the surge magnitude needed in addition to a high mean lake level.

Major factors in wave generation are windspeed and duration, local water depth, and fetch length. Fetch length is the over-water distance along which waves arise (USACE, 1984). In the Great Lakes vicinity, a windspeed of 40 mph sustained for several hours is usually appropriate to the 1-percent-annual-chance flood. For some cases, fetch length might be estimated as straight-line distance in the wind direction, but current guidance specified in the USACE ACES manual (USACE, 1992) pertinent to many Great Lakes sites indicates that a more involved analysis of restricted fetches must be performed for water basins of relatively complex geometry. The effective fetch length is derived as a weighted average of available distance with angle from the wind direction, as outlined in Figure D-37. A PC-compatible computer program included with the ACES manual is convenient for evaluating restricted fetch geometries and provides estimates of representative wave height and wave period based upon recommendations by CERC on wave generation.

[February 2002]

D.3.2.7 Coastal Structures

Documentation gathered for each coastal structure that may provide protection from 1-percent-annual-chance flood hazards should include the following:

- Type and basic layout of structure;
- Dominant site particulars (e.g., local water depth, structure freeboard, ice climate); etc.
- Construction materials and present integrity;

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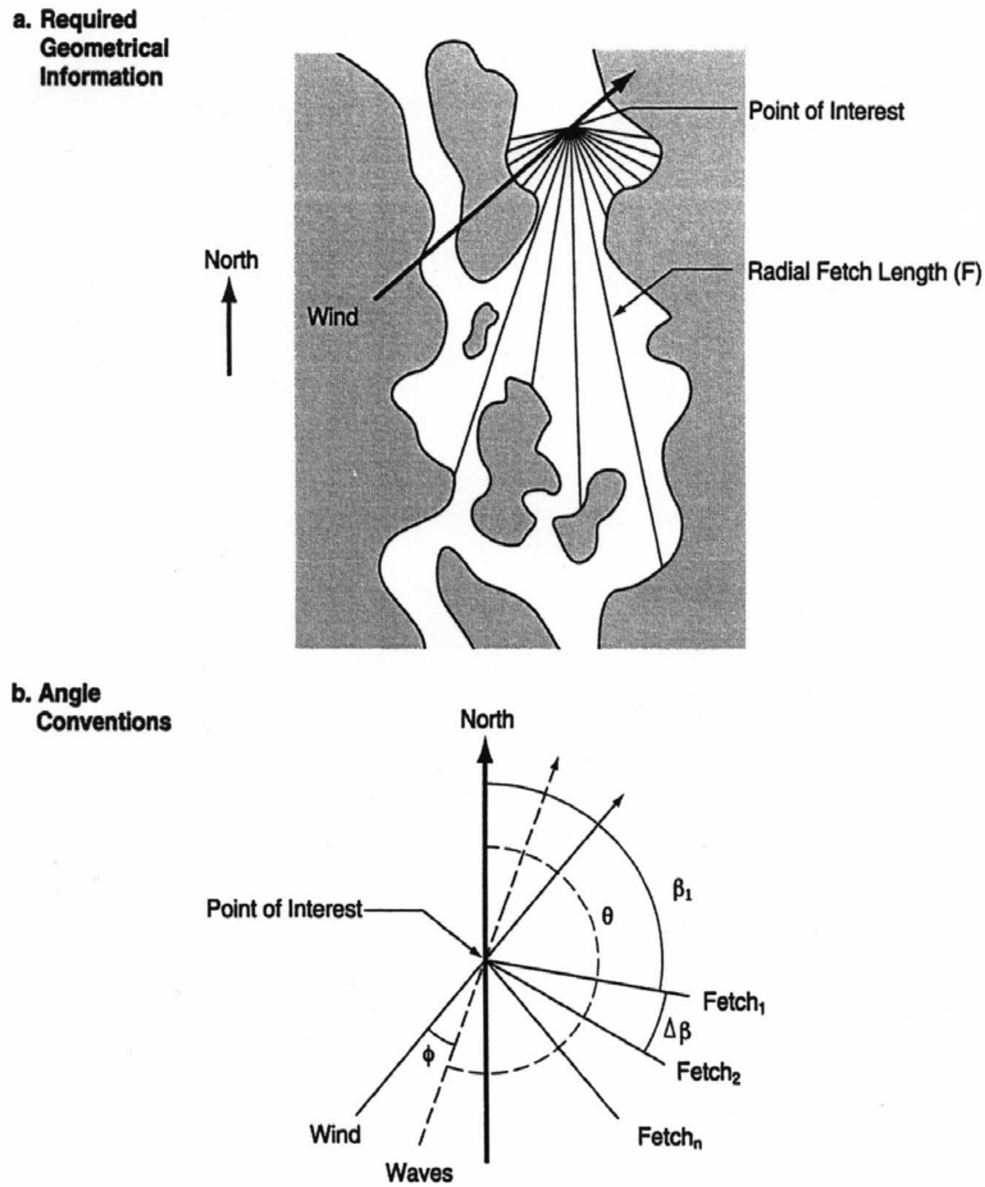

Figure D-37. Outline of Geometry for Wave Development on Restricted Fetches, from ACES Direction of Wave Development (θ) is Defined by Maximizing the Product $[(F_{\phi})^{0.25}\cdot(\cos\phi)^{0.44}\}$.

- Historical record for structure, including construction date, maintenance plan, responsible party, and repairs after storm episodes; and

- Clear indications of effectiveness/ineffectiveness.

The Mapping Partner may develop much of this information through office activity, including a careful review of aerial photographs. In some cases of major coastal structures, site inspection could be advisable to confirm preliminary judgments.

[February 2002]

D.3.2.8 Historical Erosion Accounts

Coastal erosion can occur during any major storm; however, the most significant erosion events for the purpose of a coastal FIS are those that occur with major storms during historical periods of high lake levels. Ideal information documenting storm-eroded cross sections will seldom be available because studies including repetitively surveyed profiles appear rare, except at some Lake Michigan sites. Although quantitative data may not be available, qualitative information can be valuable in confirming that reasonable results are obtained from the erosion assessment. The Mapping Partner shall conduct a search for erosion descriptions in newspaper articles or other publications, focusing on recent intervals of high mean lake levels. In addition, State agencies may be able to provide long-term recession rates over the study area. These are helpful in demonstrating local susceptibilities to storm-induced erosion.

[February 2002]

D.3.2.9 Historical Flood Information

Information from previous storms and floods can be valuable in developing proper assessments of coastal flood hazards. This is particularly true on the Great Lakes, because many notably extreme events occurred on the four western lakes during 1985, 1986, and 1987 and ample information should be readily available for many study sites.

General descriptions of flooding are useful in determining what areas are subject to flooding and in obtaining an understanding of flooding patterns. More specific information, such as erosion associated with the event or the location of buildings damaged by wave action, can be used to verify the results of the coastal analyses. When quantitative data on the effects, recorded water elevations, and offshore wave conditions are available, the Mapping Partner shall check those data for proximity to the coastal site and impact on the evaluation. Those data can be used to estimate recurrence intervals for SWEL and wave action during the event and assist in the appropriate comparison to the 1-percent-annual-chance flood conditions and SWELs established by the USACE for the specific recurrence intervals (1988).

Local, county, and State agencies are usually good sources for historical data, especially during the more recent events. It is becoming common practice for these agencies to record significant flooding with photographs, maps, and/or surveys. Federal agencies such as the USACE, USGS, and NRC prepare post-storm reports for the more severe storms. Local libraries, newspapers, and historical societies may also be able to provide some useful data.

Additional criteria and submittal requirements for historical information are identified in the certification forms package for Study Contractors (SC-1) and the application/certification forms package (MT-2) for map revision requests.

[February 2002]

D.3.3 Evaluation of Coastal Structures

The crucial first consideration in evaluating a coastal structure is whether it was properly designed and has been maintained to provide protection during the 1-percent-annual-chance flood. If it can be expected to survive the 1-percent-annual-chance flood, the structure should figure in all ensuing analyses of wave effects (erosion, runup, and wave height). Otherwise, it should be considered destroyed before the 1-percent-annual-chance flood and removed from subsequent transect representations.

The USACE technical report entitled *Criteria for Evaluating Coastal Flood-Protection Structures* (Walton, Ahrens, Truitt, & Dean, 1989) recommends specific criteria for evaluating coastal flood-protection structures in regard to the 1-percent-annual-chance flood. A FEMA memorandum dated April 23, 1990, entitled "Criteria for Evaluating Coastal Flood Protection Structures for National Flood Insurance Program Purposes," based on the USACE report, provides a self-contained account of the evaluation process. The criteria in the memorandum have been adopted as the basis for NFIP accreditation of new or proposed coastal structures to reduce the flood hazard areas and elevations designated on the current NFIP maps. Ideally, these evaluation criteria could be applied to existing coastal structures, but for older structures, design and construction information sufficient to complete the formal evaluation is typically unavailable. For these structures, engineering judgment based on visual inspection and any historical evidence should be used.

In general, for evaluation of coastal structures on the Great Lakes the Mapping Partner shall rely on engineering judgment firmly based on experience regarding structural stability at sites with similar flood and wave climate. Because extreme floods have been relatively common over the past decade on the Great Lakes, the Mapping Partner shall consider historical information about a particular structure in its evaluation. Construction date and damage history of a structure permit a performance record to be accumulated for events potentially comparable to the 1-percent-annual-chance flood.

Analysis based on historical information and past performance may be complicated by one unique aspect of Great Lakes design considerations. The 1990 FEMA memorandum specifies that representative analyses be carried out at a range of water levels, usually from the Low Water Datum to the 1-percent-annual-chance SWEL for Great Lakes sites. However, incident wave conditions associated with the 1-percent-annual-chance flood may be markedly less extreme than those expected for lower but more persistent water levels near long-term Mean Lake Level.

Nevertheless, even where water depth at the structure site strongly limits local wave heights, the most severe conditions for design could still occur during the 1-percent-annual-chance flood; therefore, the Mapping Partner must consider these conditions.

The USACE technical report identifies the four primary functional types of coastal flood protection structures: gravity seawalls, pile-supported seawalls, anchored bulkheads, and dikes or levees. The report recommends as a general policy that "FEMA not consider anchored bulkheads for flood-protection credit because of extensive failures of anchored bulkheads during large storms" (p. 100). However, the report provides no examples for the Great Lakes. Seacoast storm conditions are possibly quite different from the 1-percent-annual-chance flood on the Great Lakes; therefore, this structure type cannot be completely discredited.

The FEMA memorandum focuses on structures designed for flood protection. Such structures can have a significant impact on the information shown on a FIRM, perhaps directly justifying the removal of sizable areas from the Coastal High Hazard Area. However, structures in other categories also are to be considered. Although a breakwater may act primarily to limit wave action, and a revetment primarily to control shore erosion, these structures also can provide 1-percent-annual-chance flood protection. The FEMA memorandum places the responsibility on local interests to certify new structures; however, it is crucial that the Mapping Partner evaluate the structure accurately and consider its effects. For example, a structure might decrease flood impacts in one area, yet increase erosion or wave hazards at adjacent sites. Of course, the greater the potential effects of a coastal structure, the more detailed the evaluation process should be.

As discussed in Volume 2, additional requirements regarding coastal structures are included on Form 10 of the Application/Certification forms package (MT-2) for map revision requesters.

[February 2002]

D.3.4 Erosion Assessment

Along many Great Lakes shores, erosion accompanying the 1-percent-annual-chance flood may change the location and alter the form of an existing sedimentary barrier extending above the local 1-percent-annual-chance SWEL. Mapping Partners must assess the likely erosion before proceeding to determination of additional flood effects dependent on topography, such as wave runup or overtopping, or overland wave heights. Procedures described here are meant to give schematic estimates of eroded transect geometry suitable for the purposes of a coastal FIS or map revision request on the Great Lakes.

In an erosion assessment relating to the 1-percent-annual-chance flood, Great Lakes coasts may be separated into three basic site categories:

1. Sandy shores with backing dunes or banks;

2. Backshore bluffs of cohesive material; and

3. Other shore situations more resistant to erosion during extreme floods, with bedrock, wetlands, shore protection, and other conditions.

For the third category, erosion is usually not too important a consideration, so the major distinction for present purposes is between sand dunes and cohesive bluffs. Besides up-to-date coastal topography, information about the basic shore type is crucial for an appropriate erosion assessment pertaining to the 1-percent-annual-chance flood. Also, documented erosion effects during a historical flood at the study site can be useful in a valid assessment of 1-percent-annual-chance flood effects, but such evidence requires careful interpretation, as discussed below.

Detailed examination of recent record episodes of lake levels (Dewberry & Davis, 1995) provides several notable findings:

- Extreme Great Lakes floods usually involve rather moderate storms during relatively brief intervals when mean lake level is significantly higher than the long-term average.
- The storm situation for an extreme flood on Lake Ontario is markedly different than on Lake Erie, Lake Huron, Lake Michigan, Lake Superior.
- Coastal erosion on the Great Lakes exhibits extreme geographical and temporal variability during intervals of high mean lake level.

Quantitative analysis establishes that Great Lakes erosion cross sections expected during the 1-percent-annual-chance flood are 270 square feet on Lake Erie, Lake Huron, Lake Michigan, and Lake Superior and 190 square feet on Lake Ontario.

These amounts refer to the flood episode alone and lie entirely above the local 1-percent-annual-chance SWEL. The stated results derive from Great Lakes verification of an analysis similar to that which was performed for Atlantic Ocean and Gulf of Mexico regions for the 540-square-feet erosion cross section in seacoast 1-percent-annual-chance floods. Appropriate application of this erosion guidance can depend on basic type of shore morphology, as illustrated in Figures D-38 (bluff) and D-39 (sand dune).

The cases consider no shore features lakeward of the basic flood barrier, because any distinct topography presumably will be removed by storm erosion before the peak effects to be considered. For the bluff case in Figure D-38, erosion projection is based on a retreated profile parallel to the existing bluff, but with a potential adjustment to the eroded face governed by soil stability considerations for the site. For the dune case in Figure D-39, erosion projection makes use of an escarpment slope of 45°, corresponding to the usual duneface geometry for storm conditions. In each case, the barrier is presumed to be appreciably more sizable than the specified erosion cross section, even though that usually is more appropriate for bluff erosion where the barrier in effect is unlimited. Erosion analysis may be unnecessary for very large coastal dunes, extending 20 feet or more above the SWEL; such sand accumulations may be considered resistant to notable storm erosion and to wave overtopping on the Great Lakes.

These quite simplified depictions of eroded profile geometry for Great Lakes shores may require modification in accordance with site-specific factors, engineering judgment, or the more detailed erosion considerations usually appropriate on seacoasts (FEMA, 1995). Comparison of present assessment results to historical effects for notable local floods must recognize the extreme variability evident in Great Lakes shore erosion during a given storm. Documented large or small amounts of erosion during a notable historical storm or flood at a particular Great Lakes site do not imply that similar effects should be expected for the 1-percent-annual-chance

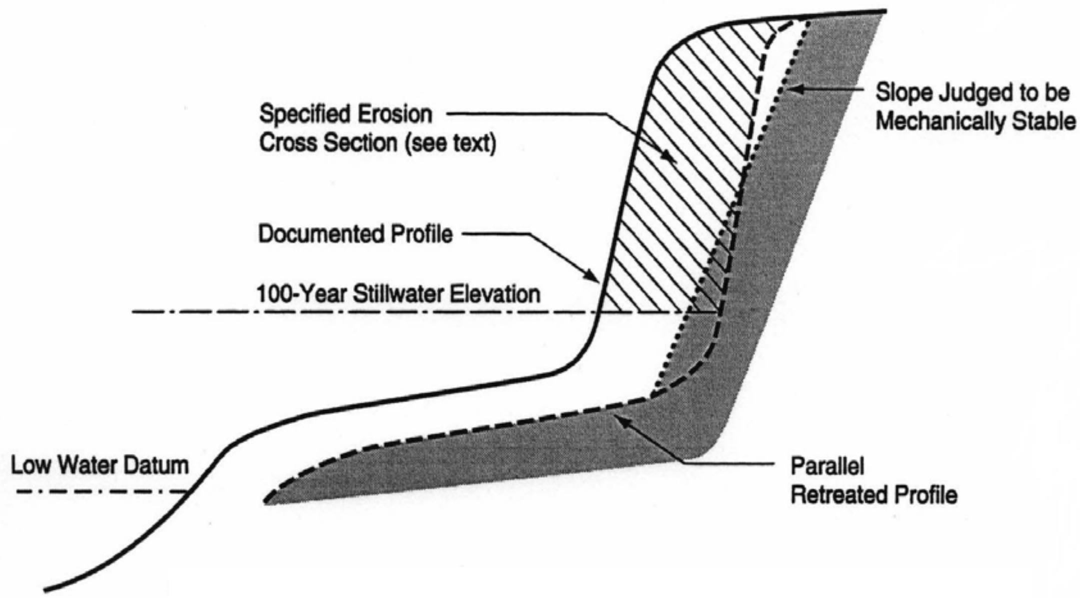

Figure D-38. Basic Erosion Considerations for Coastal Bluff Provides Shaded Shore Profile for Great Lakes Base Flood.

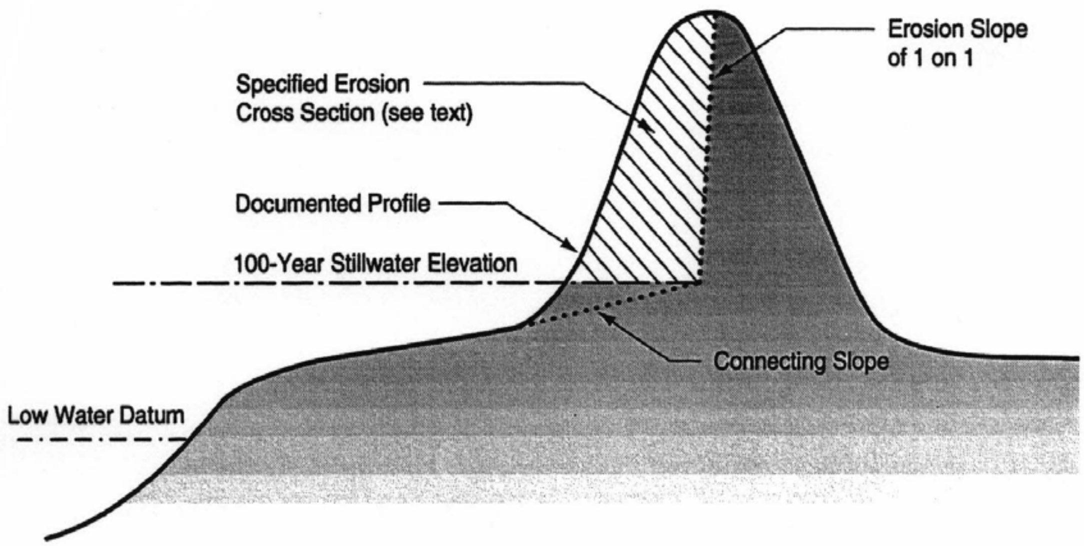

Figure D-39. Basic Erosion Considerations for Coastal Sand Dune Provides Shaded Shore Profile for Great Lakes Base Flood.

flood. The only appropriate conclusion to be based directly on historical effects is that if a Great Lakes site has experienced no erosion over the past ten years, one should not assume that erosion will accompany the 1-percent-annual-chance flood.

The present evaluation guidelines outlined in Figures D-38 and D-39 lead to appropriate flood hazard identification, given that sizable wave effects on Great Lakes shores seldom penetrate inland past an erodible flood barrier in accordance with the geometrical consideration outlined in Figure D-40. In a Great Lakes FIS, the major result of an erosion assessment is a barrier profile both convenient and appropriate for ensuing wave analyses.

[February 2002]

D.3.5 Wave Runup and Overtopping

Wave runup and overtopping constitute coastal hazards beyond those associated with stillwater coastal flooding and incident wave geometry. Wave runup is the uprush of water on a shore barrier intercepting the stillwater level. The water wedge both thins and slows during its excursion up the barrier, as residual momentum from wave motion near the shore is fully dissipated. The most significant characteristic of this process for present purposes is wave runup elevation: the vertical height above stillwater level ultimately attained by the extremity of uprushing water. Likely runup must be assessed for wave conditions expected to accompany the 1-percent-annual-chance flood. The extent of runup can vary greatly from wave to wave in storm conditions, so that a wide distribution of wave runup elevations provides the precise description of a specific situation. Wave overtopping occurs when an individual runup impulse surpasses the barrier crest and flood water penetrates inland of the shore barrier, perhaps with wave-like effects or with ponding of the flood waters behind the barrier.

Current NFIP policy is that the mean runup elevation (rather than some occasional extreme) for a situation is appropriate in mapping coastal hazards of the 1-percent-annual-chance flood. The FEMA Great Lakes Wave Runup Model (GLWRM), which is based on methodologies recommended by the USACE, Detroit District, can be used to compute the mean runup elevation, as discussed in Subsection D.3.5.1. Although the GLWRM provides an entirely suitable runup elevation, it can treat only the three types of shore situation judged to be most frequently encountered on the Great Lakes. Therefore, adjustment or modification to computed results may be needed in applications at some sites. Section D.3.5.2 introduces some methods for extending the applicability of the GLWRM and also discusses other considerations potentially important for a Great Lakes coastal flood hazard evaluation.

[February 2002]

D.3.5.1 Use of Great Lakes Wave Runup Model

The runup analysis begins with the determination of significant wave conditions near the shore. The site must be categorized as one of three shore types typical of the Great Lakes: smooth vertical wall, rip-rap revetment having a single face slope, or sloping sand beach. For a revetment or beach, the characteristic slope, considered the grade of the slope from the mean lake

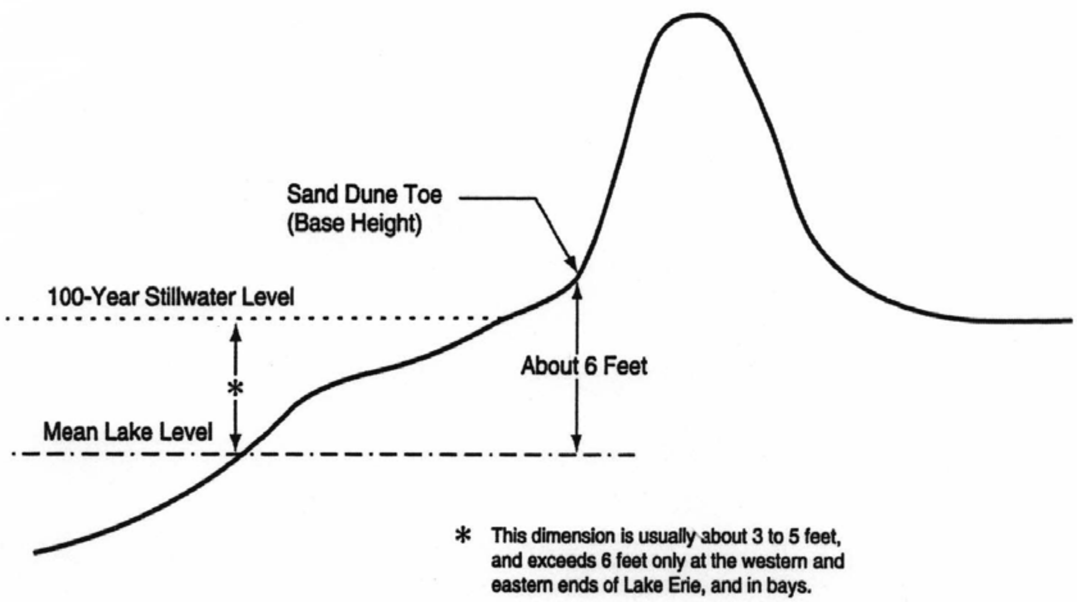

Figure D-40. Typical Great Lakes Coastal Geometry Prevents Wave Penetration Inland of Eroded Dune Site in Base Flood.

level up to the 1-percent-annual-chance SWEL, must be determined. For a vertical structure or a sloping revetment, the wave conditions must be determined at the specified water depth of the structure toe and at a water depth of 26 feet for a sand beach. The depths to be used in analyzing wave conditions should be the depths of water below the local 1-percent-annual-chance flood level.

The wave runup elevation for the shore barrier can be estimated using the GLWRM, which is available from FEMA in digital format. The program executes step-by-step procedures for runup computation at Great Lakes sites, following the recommendations from the *Great Lakes Wave Runup Methodology Study* (USACE, June 1989). The interactive format occasionally prompts the user for input or review of hydraulic and topographic descriptions of a site, including the shore barrier specification, the 1-percent-annual-chance SWEL (see Subsection D.3.2.1), and offshore storm-wave characteristics (see Subsection D.3.2.6).

Tables D-15, D16, and D-17 present examples of computation input and output for the three distinct situations, namely, a vertical structure, a sloping revetment, and a sand beach.

Table D-15. Final GLWRM Results for Wave Runup on Vertical Structure. Diamonds Added to Identify Lines with Site Specific Specifications Input or Confirmed in Response to Interactive Screen Prompts.

wave runup on◆	vertical wall
1% annual chance flood◆	582.6 feet
water depth at toe◆	5.5 feet
3-year wave period T◆	9.1
T':	2.6
L:	121.01
3-year deep water wave H◆	20.0 feet
K:	5.5
alpha:	0.0180
Hmo:	3.3
d bar:	0.0021
epsilon:	0.0068
Hs/Hmo◆	0.907
Hs at structure:	3.3
d/Lo:	0.0130
H/Ho'◆	1.3500
Ho':	2.4
Ho'/(gT**2):	0.00090
ds/Ho':	2.3
runup/Ho':	2.58
vertical wall runup:	6.2
runup elevation:	588.8 feet

Table D-16. Final GLWRM Results for Wave Runup on Sloping Revetment. Diamonds Added to Identify Lines with Site Specific Specifications Input or Confirmed in Response to Interactive Screen Prompts.

wave runup on◆	revetment
1% annual chance flood◆	581.6 feet
water depth at toe◆	4.5 fect
3-year wave period T◆	9.1
T′:	2.4
L:	109.45
3-year deep water wave H◆	20.0 feet
K:	6.1
alpha:	0.0189
Hmo:	2.7
d bar:	0.0017
epsilon:	0.0062
Hs/Hmo◆	0.920
H at structure:	2.7
tan(theta)◆	0.22500
revetment (Greek ltr) xi:	2.8
revetment runup:	3.4
runup elevation:	585.0 feet

Table D-17. Final GLWRM Results for Wave Runup onto Sand Beach. Diamonds Added to Identify Lines with Site Specific Specifications Input or Confirmed in Response to Interactive Screen Prompts

```
           wave runup on◆  beach
   1% annual chance flood◆ 582.6 feet
       water depth at toe:  26.0 feet
    3-year wave period  T◆   9.1
                       T':   5.7
                        L: 263.09
 3-year deep water wave  H◆  20.0 feet
                        K:   2.6
                    alpha:   0.0125
                      Hmo:   9.4
                    d bar:   0.0098
                  epsilon:   0.0089
                   Hs/Hmo◆   1.084
        Hs in deep water:  10.2
              beach slope◆   0.17300
    beach (Greek ltr) xi:   1.115
             beach runup:  11.0
        runup elevation: 593.6 feet
```

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D.3.5.2 Additional Considerations

As mentioned earlier in this Appendix, the GLWRM treats three shore configurations: smooth vertical wall, rip-rap revetment having a single face slope, or sloping sand beach. For some studies, the Mapping Partner may be required to evaluate other shore situations (e.g., grass or gravel shore slopes, mounds formed of other material or with a compound front slope). Although other methods and models for determining wave runup elevations could be used (see USACE, 1984 and 1992; Dewberry & Davis, 1991), the GLWRM runups can be adjusted to analyze these other shore situations. Using the GLWRM will provide consistency of results within a single study.

One parameter frequently used in NFIP coastal assessments is a roughness coefficient measuring barrier surface effects along the runup excursion (Dewberry & Davis, 1995; Stone & Webster, 1981). Table D-18 presents typical values of the roughness coefficient, usually designated as r, for common barrier materials. Wave runup elevation is assumed to vary directly with roughness coefficient, given no other difference in the geometrical configuration. Thus, GLWRM results for a sand beach (having a situation otherwise identical to that shown in Table D-13) may be multiplied by 0.90 to apply with grass, or by 0.70 to apply with gravel. For relatively steep slopes common to manmade shore structures, GLWRM results for a rip-rap revetment might be adjusted for application with other construction materials, using the appropriate ratio between roughness coefficients. Expressed formally, the runup on a rough surface is given as r times runup for a smooth surface, so that for rip-rap

$$R_1 = r_1 R \tag{1}$$

and for some other rough barrier material

$$R_o = r_o R = r_o R_1/r_1 \tag{2}$$

where the value R_1 is obtained directly from the GLWRM.

Another simplification long employed in NFIP coastal assessments is the composite-slope method (Saville, 1958), where a hypothetical uniform slope is taken to represent the segmented barrier profile (Figure D-41). That equivalent slope customarily extends from the water depth with initial wave breaking to the limit of wave runup, or from a water depth equal to incident wave height when waves do not break (at a very steep shore). For a man-made structure, the GLWRM assumes a clearly identifiable toe or seaward limit to the wave barrier, so it is appropriate to start the equivalent uniform slope at that point. Because the landward limit assumed for the uniform slope is at the runup limit, some manual computation may be needed in iterative adjustment of the input slope to attain suitable consistency with calculated runup elevation.

Table D-18. Appropriate Values for Roughness Coefficient in Wave Runup Calculations

ROUGHNESS COEFFICIENT	DESCRIPTION OF BARRIER SURFACE
1.00	Sand; smooth rock, concrete, asphalt, wood, fiberglass
0.95	Tightly set paving blocks with little relief
0.90	Turf, closely set stones, slabs, blocks
0.85	Paving blocks with sizable permeability or relief
0.80	Steps; one stone layer over impermeable base; stones set in cement
0.70	Coarse gravel; gabions filled with stone
0.65	Rounded stones, or stones over impermeable base
0.60	Randomly placed stones, two thick on permeable base
0.50	Cast-concrete armor units: cubes, dolos, quadripods, tetrapods, tribars, etc.

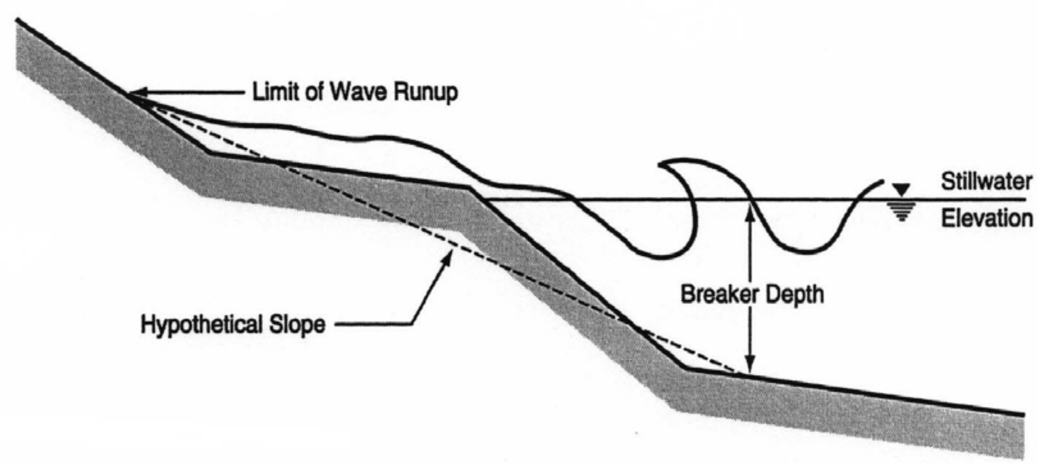

Figure D-41. Hypothetical Slope for Determining Wave Runup on Composite Profiles.

Once a definite runup elevation has been obtained for the shore situation, the Mapping Partner must compare it with barrier crest elevation to assess the possibility of wave overtopping. The examination takes into account that calculated runup elevation refers to common rather than extreme water excursions on the barrier, whereas all expected hazards of the 1-percent-annual-chance flood must be projected. If wave runup elevation reaches more than halfway from the stillwater level to the barrier crest, the Mapping Partner shall perform an overtopping assessment for flood hazards because likely wave runups occasionally will proceed over the shore barrier. Overtopping discharges in storm conditions may be estimated using empirical results in *Random Seas and Design of Maritime Structures* (Goda, 1985) for vertical walls, in "Design of Seawalls Allowing for Wave Overtopping" (Hydraulics Research Station, 1980) for sloping structures, and in "Wave Runup and Overtopping at Dunes during Extreme Storm Surge" (Delft Hydraulics Laboratory, 1983) for sand dunes with common erosion geometry. The Mapping Partner shall evaluate the effects of the discharge in terms of potential wave impacts, runoff depths, or ponding areas on ground landward of the shore barrier.

A distinct type of overflow situation can occur at low bluffs or banks backed by a nearly level plateau, where calculated wave runup may appreciably exceed the top elevation of the steep barrier. A memorandum entitled "Special Computation Procedure Developed for Wave Runup Analysis for Casco Bay, FIS - Maine, 9700-153" provides a simple procedure to determine realistic runup elevations for such situations, as illustrated in Figure D-42 (French, 1982). An extension to the bluff face slope permits computation of a hypothetical runup elevation for the barrier, with the imaginary portion given by the excess height $R' = (R\text{-}C)$ between calculated runup and the bluff crest. Using that height R' and the plateau slope m, Figure D-43 defines the inland limit to wave runup, X, corresponding to runup above the bluff crest of (mX) or an adjusted runup elevation of $R_a = (C + mX)$. This procedure is based on a Manning's "n" value of 0.04 with some simplifications in the energy grade line and is meant for application only with positive slopes landward of the bluff crest. A different treatment of wave overflow onto a level plateau, for possible FIS usage, is provided in "Overland Bore Propagation Due to an Overtopping Wave" (Cox & Machemehl, 1986).

A less common situation on the Great Lakes is that calculated wave runup exceeds a relatively high barrier crest backed by negative slopes. In such cases, a general rule limits the appropriate runup elevation to 3 feet above maximum ground elevation. Floodwaters overtopping the barrier percolate into the bed, or run along the back slope until encountering another flooding source or a ponding area. A runoff area is usually designated as Zone AO, with depth of flooding of 1, 2, or 3 feet; a ponding area may be designated as Zone AH, with a flood elevation. Standardized NFIP procedures have been developed for the treatment of sizable runoff and ponding, but are beyond the scope of this presentation; see *Guidelines and Specifications for Wave Elevation Determination and V Zone Mapping* (FEMA, 1995).

Aside from these considerations relating to the inland limit of flooding from wave runup and overtopping, the Mapping Partner must integrate the runup elevation at the shore barrier with calculated wave crest elevations near the shore.

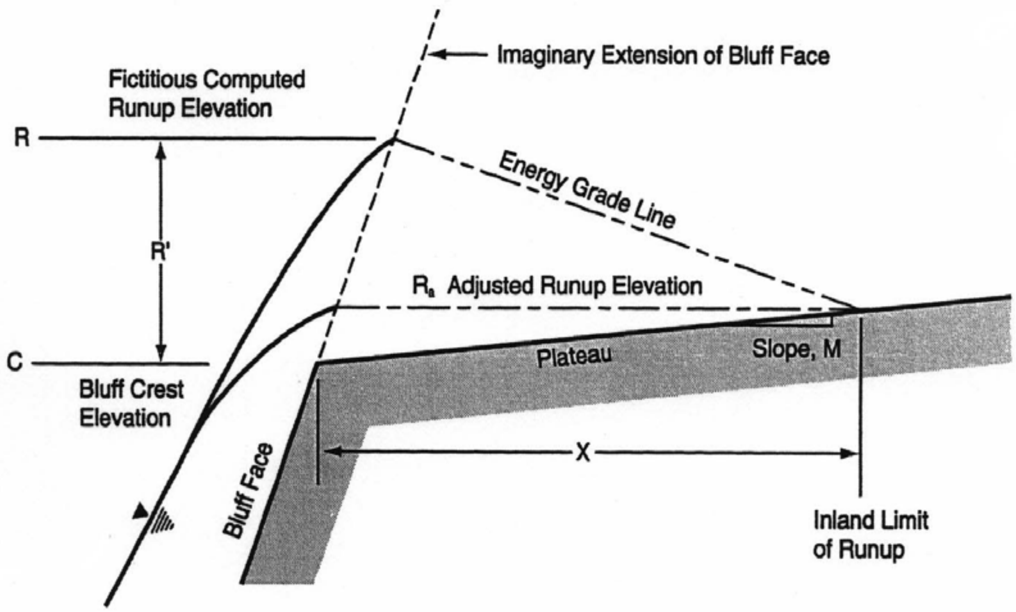

Figure D-42. Treatment of Wave Runup onto Plateau above Low Bluff.

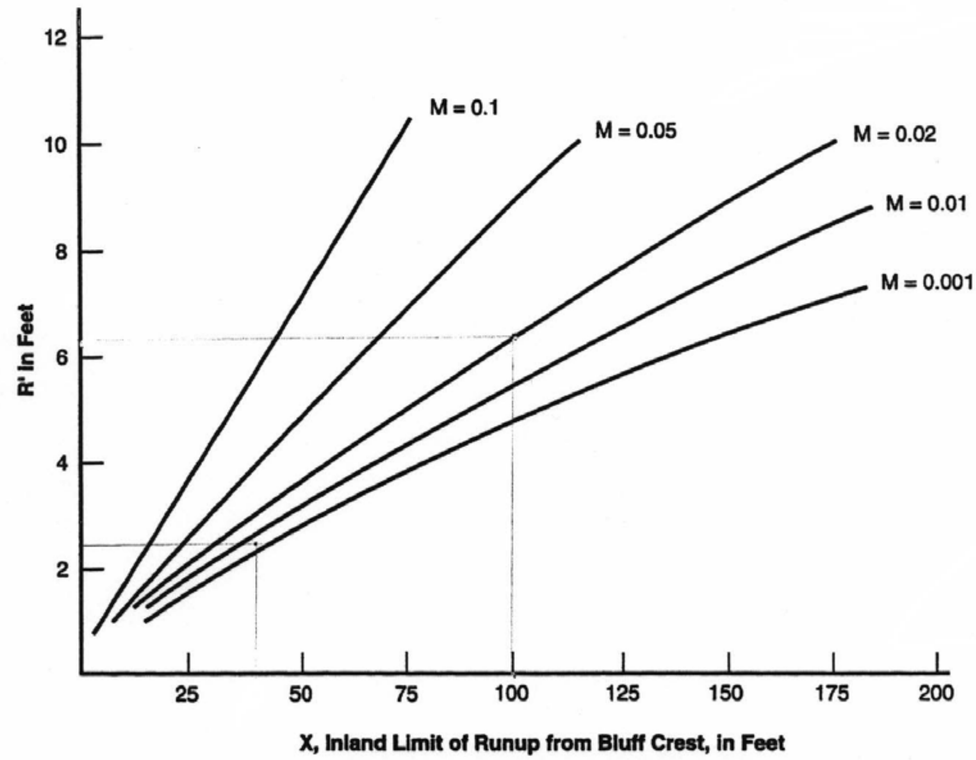

Figure D-43. Computation of Wave Runup for Low Bluffs.

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D.3.6 Nearshore Wave Dimensions

As waves propagate near the shore and over a flooded area, they undergo transformations caused by local winds, interaction with the bottom, and physical features such as buildings, trees, or marsh grass. Figure D-44 illustrates the effects at a transect of obstructions on the wave crest elevations and the flood zone. For Great Lakes coasts, the effects must be calculated objectively along each transect, from the Low Water Datum to the flooding limit. Fundamental analysis of wave effects for an FIS is provided by the FEMA computer program Wave Height Analysis for Flood Insurance Studies (WHAFIS). The program calculates wave heights, wave crest elevations, flood hazard zone designations, and the location of zone boundaries along a transect. The current program version for the Great Lakes region, WHAFIS 3.0 GL, incorporates windspeeds appropriate to Great Lakes events (40 mph over fully exposed waters and 30 mph for inland waters or marsh).

Wave description for an FIS addresses the controlling wave height, equal to 1.6 times the significant wave height common as a basic wave description, with the dominant (or spectral peak) wave period. Significant wave height is the average height of the highest one-third of waves, and controlling wave height is slightly less than average height of the highest one percent of waves in storm conditions. The wave condition of interest is that expected to accompany the 1-percent-annual-chance flood.

Within WHAFIS, a wave action conservation equation governs wave regeneration caused by wind and wave dissipation caused by marsh plants. This equation is supplemented by the conservation of waves equation, which expresses the spatial variation of the wave period at the peak of the wave spectrum. The wave energy (i.e., wave height) and wave period respond to changes in wind conditions, water depths, and obstructions as a wave propagates. These equations are solved as a function of distance along the transect. Technical details are fully documented in the WHAFIS program documentation (FEMA, September 1988).

The current NFIP treatment of wave dimensions has resulted from periodic upgrades of technical procedures, with the original basis being the NAS methodology documented in *Methodology for Calculating Wave Action Effects Associated with Storm Surges* (NAS, 1977). The NAS methodology, which was developed to be suitable for manual computations, accounts for varying fetch lengths, barriers to wave transmission, and the regeneration of waves over flooded land areas. Several aspects of usual Great Lakes situations suggest that simplified analysis, considering only water depth and thin vertical barriers, might give a useful outline of wave effects for some sites.

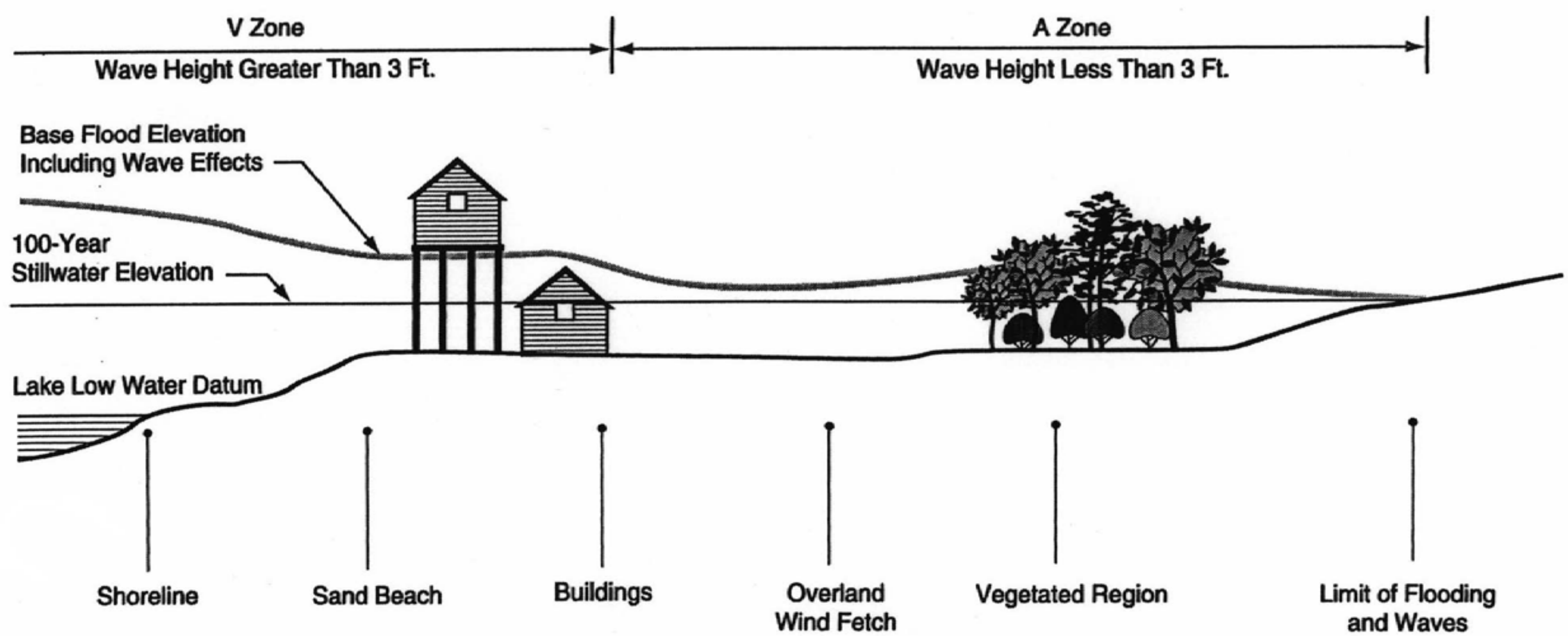

Figure D-44. Schematic Wave Effects along a Coastal Transect.

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D.3.6.1 Simplified Wave Height Analysis

The potential usefulness of the simplified wave analysis method for treating 1-percent-annual-chance flood waves is suggested by certain aspects of the Great Lakes situation: the relatively low windspeeds, reducing the intensity of wave regeneration; the relatively simple eroded geometries, which are generally featureless lakeward of the ultimate flood barrier; the absence of barrier islands and back bays so that another flood source or elevation is seldom encountered; and the typical narrowness of the Coastal High Hazard Area. This method would not be appropriate where the transect includes coastal wetlands, other land cover providing appreciable flow resistance, or an extensive lowland area liable to flooding. Before any wave analysis, there must be confirmation that sizable waves likely propagate towards shore during the local 1-percent-annual-chance flood.

All elements of this treatment are extracted from the basic NAS methodology (Dawdy & Maloney, 980; FEMA, February 1981; NAS, 1977), with wave heights entirely regulated by local water depth. The estimated flood elevation (Z) is defined by wave action accompanying the flood, with the majority of the waveform in the crest above the 1-percent-annual-chance SWEL (S):

$$Z = S + 0.7\ H \tag{3}$$

where H is the local controlling wave height. A bound to H is given by wave breaking in shallow water, with the upper limit

$$H_* = 0.78\ d \tag{4}$$

where local water depth (d) equals (S-G), G being ground elevation. Combining these relations, local ground elevation constrains the flood elevation to an upper limit of

$$Z_* = S + 0.55\ d \tag{5}$$

Equation (4) implies that a minimum water depth of 3.85 feet is required for the 3-foot wave height characterizing a V Zone.

An obstruction on the transect may conveniently be treated as a thin barrier if flooding occurs to the same S on each side. Wave transmission is assumed to occur only if the barrier top elevation (C) is below S plus one-half the incident wave height (H_i). Transmitted wave height is

$$H_t = 0.5\ H_i + B \tag{6}$$

where B = ½[0.78 (S-C)] if the barrier is submerged, but B=[(S-C)] otherwise; the upper limit of $H_t = H_i$ occurs when H_i is less than [0.78 (S-C)], requiring that H_i is not depth-limited. Transmitted wave height beyond the barrier remains limited by ground elevation on the landward side of the barrier (G_t), through Equation (2), just as incident wave height is limited by ground elevation on the lakeward side (G_i). With engineering judgment, wave obstructions other than walls might be represented by proper choices of G_i, C, and G_t in this procedure.

Figure D-45 presents an idealized numerical example demonstrating estimated wave heights, flood elevations, and flood zones. Note that varying elevations of depth-limited wave crests mirror the ground slopes.

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D.3.6.2 Use of WHAFIS 3.0 GL Model

Careful preparation and input of required site data are necessary in using WHAFIS. Like the other coastal treatments, the WHAFIS model considers the study area by representative transects. For WHAFIS, transects must be defined considering major topographic, vegetative, and cultural features. The transect, referenced to NGVD29, begins at the local elevation of Low Water Datum (Table D-13) and proceeds landward until either the ground elevation exceeds the SWEL or another flooding source is encountered.

Fundamental specifications for WHAFIS input include the 1-percent-annual-chance flood SWEL and a description of waves existing at the transect start. The wave description provides for an overwater fetch length, an initial significant wave height, or an initial period of dominant waves. In most Great Lakes applications, the wave period should be the input description, because that parameter is readily available from information about offshore waves (see Subsection D.3.2.6).

The Mapping Partner shall locate transects on the work maps and plot the transect ground profile from the topographic data, adjusted for erosion. The Mapping Partner shall ensure that each transect has all the input data identified on the profile plot for ease of input coding. The Mapping Partner also shall identify the location, height, and width of elongated manmade structures and show them as part of the ground profile, after confirming the structure's stability under forces of the 1-percent-annual-chance flood (see Subsection D.3.3).

Buildings are specified on the transect as rows perpendicular to the transect. Because buildings are not always situated in perfect rows, the Mapping Partner shall exercise judgment to determine which buildings can be represented by a single row. The required input value for each row of buildings is the ratio of open space to total space. This is simply the sum of distances between buildings in a row, divided by the total length of that row.

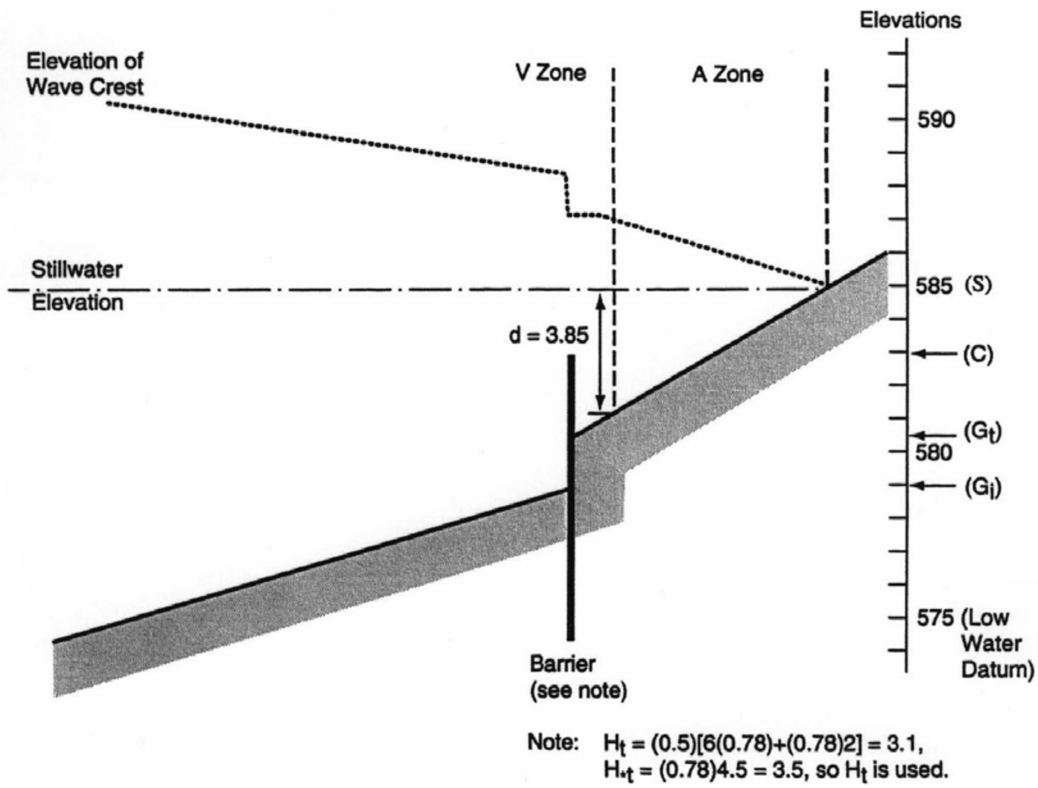

Figure D-45. Schematic Example of Simplified Wave Height Analysis Regulated by Local Water Depth, with All Indicated Quantities in Feet.

The first row or two of buildings along the shoreline is not always to be considered as obstructions. During a 1-percent-annual-chance flood, it is sometimes appropriate to assume that if they are not elevated on pilings, these buildings will be destroyed before the peak of the flood occurs. If they are elevated, the waves should propagate under the structures with minimal reduction in height. The Mapping Partner shall contact local officials to obtain typical construction methods and the lowest elevations of structure.

The WHAFIS program has two routines for vegetation: one for rigid vegetation that can be represented by an equivalent "stand" of equally spaced circular cylinders (NAS, 1977) and one for marsh vegetation that is flexible and oscillates with wave action (FEMA, 1984). For either type, considerable care is required in selecting representative parameters and in ruling out that the vegetation will be intentionally removed or that effects during a storm would be markedly reduced through erosion, uprooting, or breakage.

For the areas of rigid vegetation located on the transect, the required input values are the drag coefficient, CD; mean wetted height, h; mean effective diameter, D; and mean horizontal spacing, b. The value of CD should vary between 0.35 and 1.0, with 1.0 being used in most cases of wide vegetated areas. When the vegetation is in a single stand, a value of 0.35 should be used. Representative values for h, D, and b can be obtained from stereoscopic aerial photographs or by field surveys. Various guides for terrain analysis can provide procedures for estimating these values from aerial photographs. Table D-19 provide a useful procedure developed from Terrain Analysis Procedural Guide for Vegetation (Messmore, Vogel, & Pearson, 1979).

For marsh vegetation, a more complicated specification is required for completeness, and the eight parameters used to describe the attenuation properties of a specific vegetation type are explained in Table D-20.

WHAFIS includes considerable basic information on eight common types of seacoast marsh plants listed in Table D-21 (FEMA, 1984; FEMA, 1989), but among these, apparently only the *Juncus* species are likely to occur in the freshwater marshes on the Great Lakes. For vegetation not listed in Table D-21, the Mapping Partner shall input the geometrical parameters to WHAFIS.

At lakeshore elevations that are seldom flooded and thus are important for the 1-percent-annual-chance flood, a great diversity of wetland vegetation can occur along with upland vegetation species. Prevalent marsh plants at relatively high elevations (Levels Reference Study Board) may include combinations of grasses (*Phalaris arundinacea*, *Calamagrostis canadensis*), sedges (*Carex lacustris*, *C. rostrata*, *C. stricta*, *C. lasiocarpa*), rushes (*Juncus canadensis*, *J. effusus*), or cattails (*Typha* varieties). The Mapping Partner shall specify each existing type of vegetation s, along with its fractional coverage in any sizable patch; a patch of at least 10,000 square feet (0.09 hectare) can affect wave heights appreciably.

Table D-19. Procedure for Vegetation Analysis Using Stereoscopic Aerial Photographs.

1. Using the parallax bar or wedge, determine the height of three representative trees and compute the average height, h.

2. Locate three representative tree crowns, measure the diameters, and compute the average crown diameter, CD.

3. Determine the type of vegetation and calculate the stem diameter, D, using the following formulae:

Southern Pines	D (inches) = 5 + 0.5 CD (feet)
Eastern Hardwoods, Northern Pines and Others	D (inches) = 0.75 CD (feet)

4. Based on the scale of the aerial photographs, determine the diameter of a circle containing 0.08 hectares using Table 4. Place the circle on the photograph, over a representative area of trees, and count the number of trees, n, in the circle. A magnifier may be needed. More than one area can be counted and an average used for n. Calculate the number of trees per hectare, N, using the following formula:

$$N = \frac{n}{0.08}$$

5. Determine the horizontal spacing between trees using the following formula:

$$b \text{ (feet)} = 3.28 \left(\frac{12732}{N} \right) - \frac{D \text{ (inches)}}{12}$$

Table D-19. Procedure for Vegetation Analysis Using Stereoscopic Aerial Photographs (Cont.)

CIRCLE DIAMETERS
.08 HECTARE AREA, (1/5 ACRE)
(800 Square Meters, 8712 Square Feet)

PHOTO SCALE	.08 HECTARE CIRCLE	CIRCLE DIAMETER INCHES	CIRCLE DIAMETER MILLIMETERS
1:5,000		.253	6.38
1:6,000		.211	5.32
1:7,000		.1805	4.56
1:8,000		.158	3.99
1:9,000		.140	3.55
1:10,000		.126	3.192
1:11,000		.115	2.90
1:12,000		.105	2.66
1:13,000		.092	2.46
1:14,000		.090	2.28
1:15,000		.084	2.13
1:16,000		.079	1.99
1:17,000		.074	1.88
1:18,000		.070	1.77
1:19,000		.067	1.68
1:20,000		.063	1.60
1:21,000		.060	1.52
1:22,000		.057	1.45
1:23,000		.055	1.39
1:24,000		.053	1.33
1:25,000		.051	1.28

Table D-20. Marsh Plant Parameters

PARAMETER	EXPLANATION
C_D	Effective drag coefficient. Includes effects of plant flexure and modification of the flow velocity distribution. Default value is 0.1, usually appropriate for marsh plants without strong evidence to the contrary.
F_{cov}	Fraction of coverage. A default value is calculated by the program so that each plant type in the transect is represented equally, and the sum of the coverage for the plant types is equal to 1.0.
h	Unflexed stem height (feet). The stem height does not include the flowering head of the plant, the inflorescence.
N	Number density. Expressed as plants per square foot. The relationship to the average spacing between plants, b, can be expressed as $N = 1/b^2$.
D_1	Base stem diameter (inches). Default value may be determined from stem height and regression equations built into the program.
D_2	Mid stem diameter (inches). Default value may be determined from plant type and base stem diameter.
D_3	Top stem diameter (inches), at the base of the inflorescence. Default value may be determined from plant type and base stem diameter.
CA_b	Ratio of the total frontal area of the cylindrical portion of the leaves to the frontal area of the stem below the inflorescence. Default value may be determined from the plant type.

Table D-21. Abbreviations of Marsh Plant Types Used in WHAFIS

SPECIES OR SUBSPECIES	ABBREVIATION
Cladium jamaicense (saw grass)	CLAD
Distichlis spicata (salt grass)	DIST
Juncus gerardi (black grass)	JUNM
Juncus roemerianus (black needlerush)	JUNR
Spartina alterniflora (medium saltmeadow cordgrass)	SALM
Spartina alterniflora (tall saltmeadow cordgrass)	SALT
Spartina cynosuroides (big cordgrass)	SCYN
Spartina patens (saltmeadow grass)	SPAT

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D.3.6.3 Input Coding

After all the necessary input data have been identified on the transect, the Mapping Partner shall divide the transect into continuous segments, each representing a single open fetch or obstruction. Fetches are flooded areas with no obstructions, such as dunes, manmade barriers, buildings, and vegetation. The Mapping Partner shall subdivide fetches at points where the ground elevation abruptly changes and in the transition area of changing SWELs. The Mapping

Partner shall subdivide obstructions at the transect's seaward edge to more accurately model the wave dissipation. Rigid vegetation is to have two to three seaward segments extending 10 to 50 feet, and the first two or three rows of buildings are to have a segment for each row. Marsh vegetation will be subdivided by the WHAFIS model, and thus segmented input is not necessary.

The Mapping Partner shall enter the necessary data using 11 line types, including the Title line. The ten remaining lines each describe a certain type of fetch or obstruction, listed as follows:

- The IE (Initial Elevation) line describes the initial overwater fetch and the initial SWELs.
- The IF (Inland Fetch) and OF (Overwater Fetch) lines define the endpoint stationing and elevation of inland and overwater fetches, respectively.
- Obstructions are categorized either as buildings (BU line), rigid vegetation (VE line), marsh vegetation (VH and MG lines), dunes and other natural or manmade elongated barriers (DU line), or areas where the ground elevation is greater than the 1-percent-annual-chance SWEL (AS line).
- The ET (End of Transect) line enters no data but indicates the end of the input data.

Each line has an alphanumeric field describing the type of input for that line, followed by ten numeric fields describing the parameters.

To ensure proper modeling, the Mapping Partner shall enter all segments of each transect either as fetches or obstructions, with one input line required for each fetch or obstruction segment. The first two columns of each line identify the type of fetch or obstruction. The remaining 78 columns consist of one field of six columns followed by nine fields of eight columns. The Mapping Partner shall right-justify the numbers in any data field only if no decimal point is used. Decimal points are permitted but not required. The end point of one fetch or obstruction is the beginning of the next. The first two numeric fields of each line are used to read in the stationing (measured in feet from the beginning of transect) and elevation (in feet) of the end point. The last two fields used on each line are for entering new SWELs. An interpolation is performed within a transect segment starting at the closest station with an input SWEL. This interpolation uses the new SWEL input at the end point of the segment and the SWEL input at a previous segment. If these fields are blank or zero, the SWELs remain unchanged.

The input data requirements are summarized below for each line type. The Title line must be the first line, followed by the IE line, followed by any combination of the various fetch and obstruction lines. The ET line must be the last card entered for the transect. A blank line must follow to signify the end of the run. If multiple transects are being run, the Title line for the next transect will follow the blank line. All units are in feet unless otherwise specified.

TITLE Line (Title)

This line is required and must be the first input line.

DATA FIELD	COLUMNS	CONTENTS OF DATA FIELDS
0	1-2	Blank
1-10	3-80	Title information centered about column 40

<u>IE Line (Initial Elevations)</u>

This line is required and must be the second input line. This line is used to begin a transect at the shoreline and compute the wave height arising through the overwater fetch.

DATA FIELD	COLUMNS	CONTENTS OF DATA FIELDS
0	1-2	IE
1	3-8	Stationing of end point of initial overwater fetch in feet (zero at beginning of transect)
2	9-16	Ground elevation at end point in feet (usually Low Water Datum at beginning of transect)
3	17-24	Overwater fetch length (miles), if wave condition is to be calculated. Values of 24 miles or greater yield identical results.
4	25-32	10-percent-annual-chance SWEL in feet
5	33-40	1-percent-annual-chance SWEL in feet
6	41-48	Initial wave height; a blank or zero causes a default to a calculated wave height
7	49-56	Initial wave period (seconds); a blank or zero causes a default to a calculated wave period. The period is usually the most convenient wave specification for Great Lakes cases.
8-10	57-80	Not used

<u>AS Line (Above Surge)</u>

This line is used to identify the end point of an area with ground elevation greater than the 1-percent-annual-chance SWEL (such as a high dune or land mass). It is used when the ground surface temporarily rises above the 1-percent-annual-chance SWEL. The line immediately preceding the AS line must enter the stationing and elevation of the point at which the ground elevation first equals the 1-percent-annual-chance SWEL. The SWEL on the leeward side may be different from the SWEL on the windward side. The ground elevation entered on the AS line must equal the SWEL that applies to the leeward side of the land mass. The computer calculations will be terminated if a ground elevation greater than the 1-percent-annual-chance SWEL is encountered.