D.2.5 Wave Determination

This subsection provides guidance for estimating wave conditions, from the region where the waves are generated by wind blowing across the water surface to the shoreline. The generation, transformation, and attenuation of waves are addressed.

D.2.5.1 Overview

One of the ultimate objectives of flood hazard studies is to determine wave dimensions on land areas flooded during the base flood. These overland wave dimensions are used in conjunction with stillwater flood levels to determine BFEs and flood insurance risk zones.

Estimation of wave dimensions on land requires knowledge of incident wave conditions at the shoreline during the base flood, as well as upland topography, development, and frictional characteristics. Incident wave characteristics at the shoreline will depend upon the wave characteristics that result from wave generation in the offshore and/or nearshore regions, shoaling effects, and, in some cases, wave attenuation cause by nearshore bottom interactions (e.g., wave dissipation due to bottom friction, bottom percolation, and/or movement of a cohesive [muddy] bottom).

The general study process is summarized in Figures D.2.5-1, D.2.5-2, and D.2.5-3.

Open-coast shorelines without wave attenuation as a result of nearshore bottom effects will result in depth-limited waves at the shoreline during the base flood, and the study procedure will follow the path shown on Figure D.2.5-1.

Sheltered water shorelines[1] without wave attenuation as a result of nearshore bottom effects may or may not result in wave heights smaller than depth-limited heights. The Mapping Partner will have to make this determination based on wave generation and fetch conditions during the base flood[2]. In the case of depth-limited waves, the study process will follow the path shown on Figure D.2.5-1; in the case of wave heights smaller than depth-limited heights, the study procedure will follow the path shown on Figure D.2.5-2.

Shorelines subject to waves that are attenuated as a result of bottom effects will experience wave heights less than depth-limited heights, and the study procedure will follow the path shown on Figure D.2.5-3. Note that this scenario could be used in both open coast and sheltered water situations.

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[1] See Sections D.2.5.3 and D.4.2.2.1 for a discussion of sheltered waters.

[2] FEMA's model for overland wave propagation (WHAFIS) automatically assumes depth-limited waves if the fetch is 24 miles or greater.

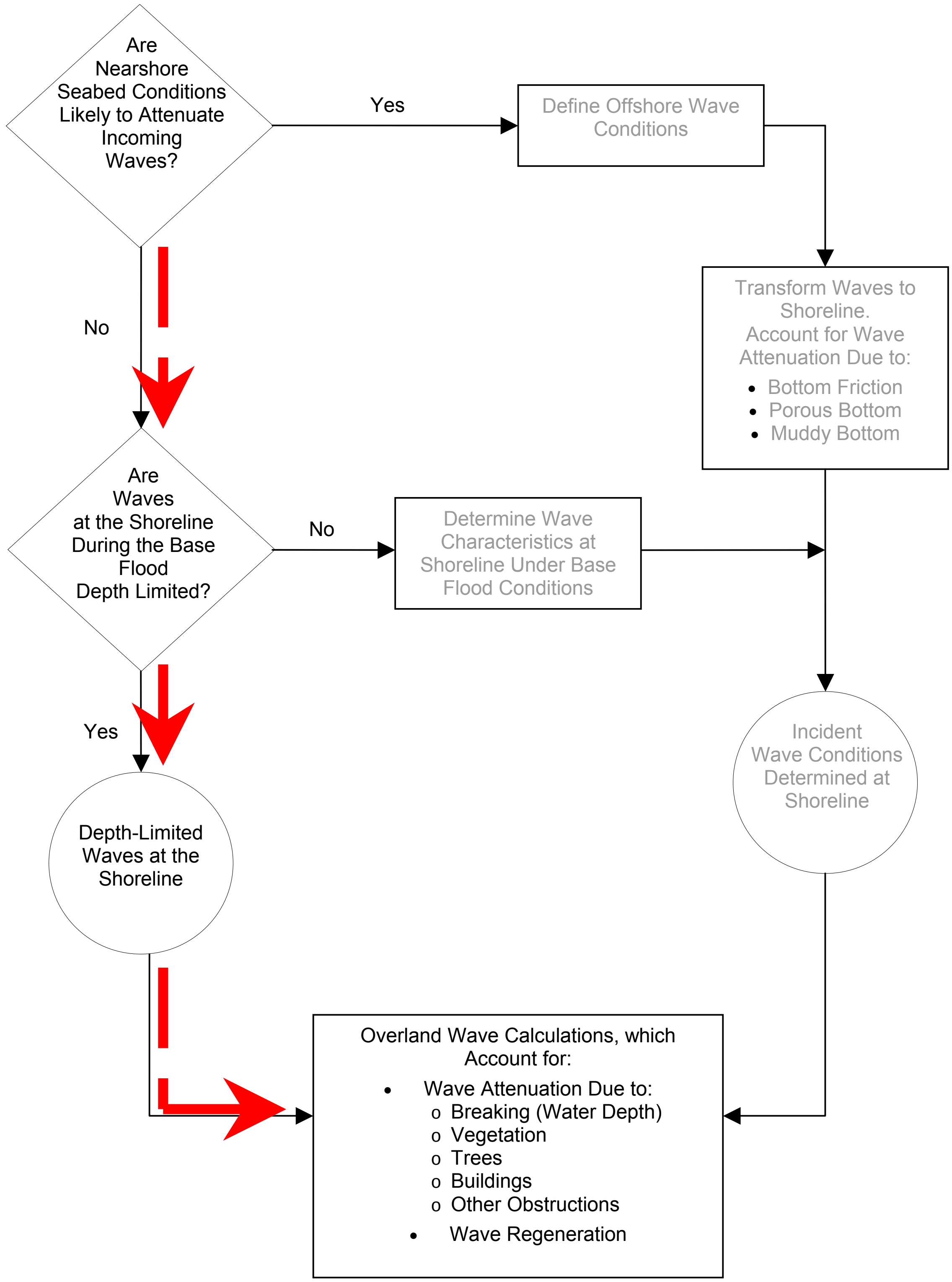

Figure D.2.5-1. Flow Chart for Determining Incident and Overland Wave Dimensions, Open Coast or Sheltered Water Shorelines without Wave Attenuation Due to Nearshore Bottom Effects; Depth-Limited Waves at Shoreline.

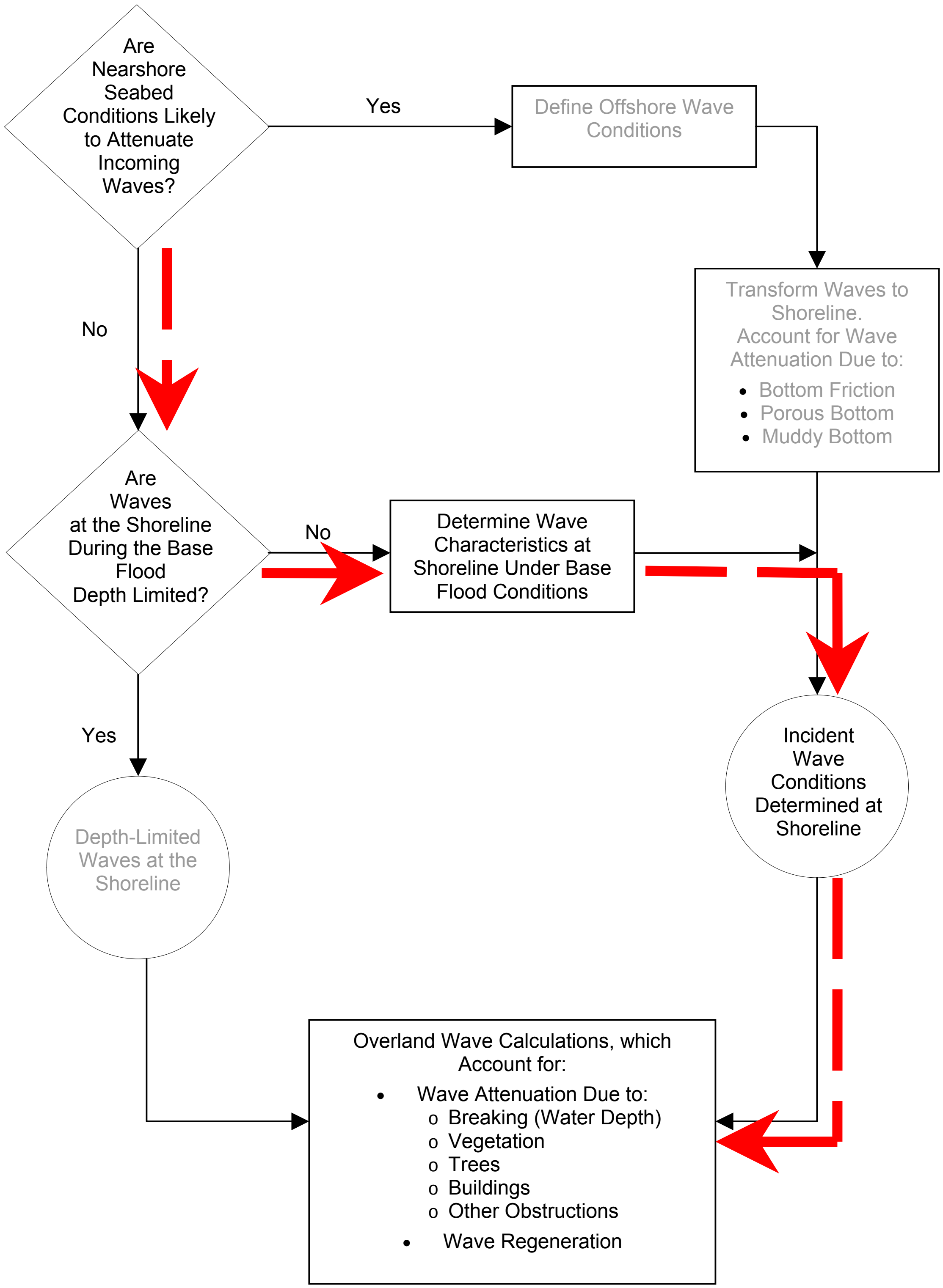

Figure D.2.5-2. Flow Chart for Determining Incident and Overland Wave Dimensions, Sheltered Water Shorelines <u>without Wave Attenuation</u> Due to Nearshore Bottom Effects; <u>Less than Depth-Limited Waves at Shoreline</u>.

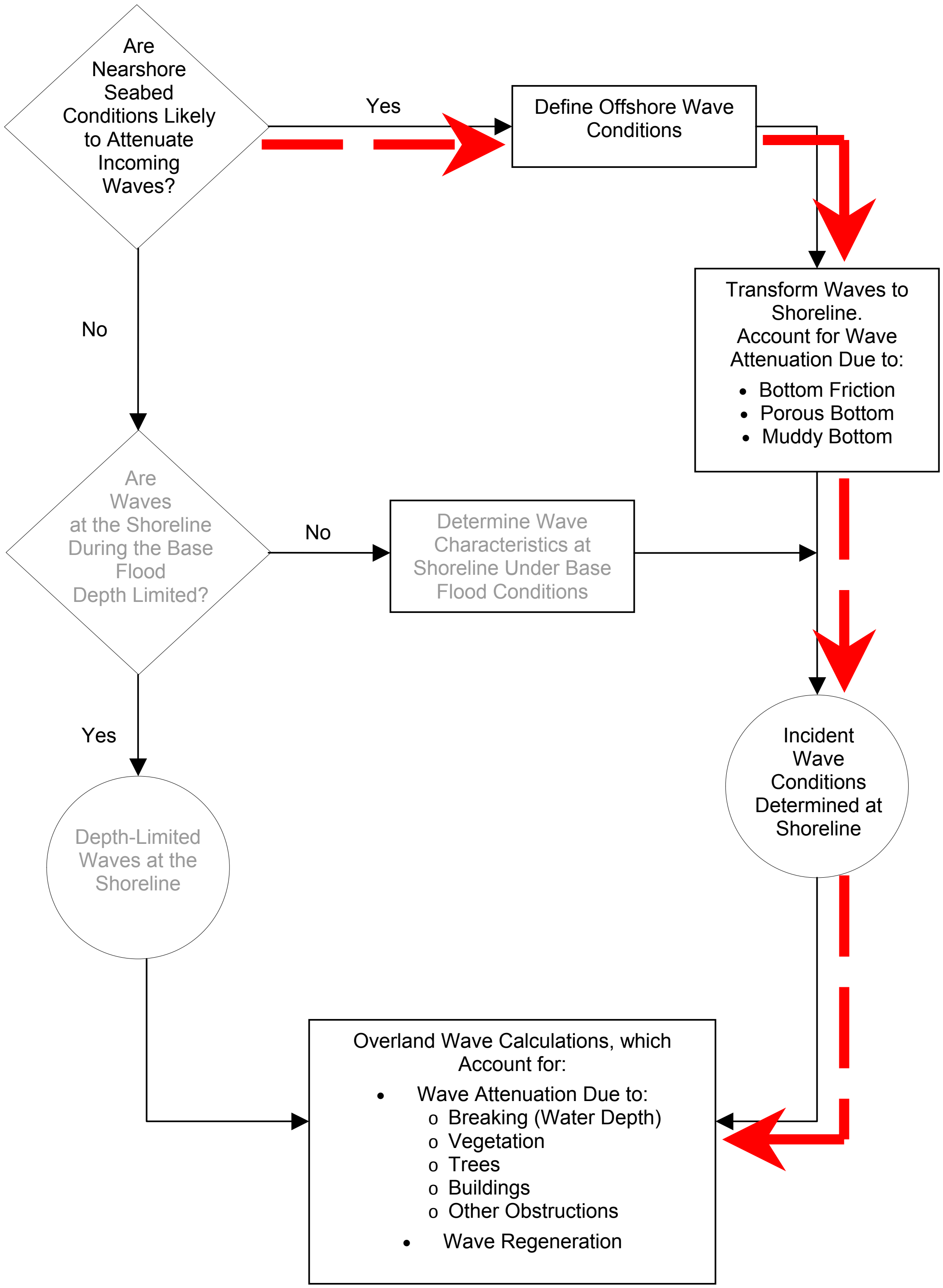

Figure D.2.5-3. Flow Chart for Determining Incident and Overland Wave Dimensions, Open Coast or Sheltered Water Shorelines with Wave Attenuation Due to Nearshore Bottom Effects.

Wave energy is dissipated when waves propagate over relatively broad, shallow areas. The dissipation can be caused by increased bottom friction, percolation in sandy seabeds, the movement of cohesive seabeds, and drag induced by vegetation (see Figure D.2.5-4 for a conceptual definition sketch). Dissipation mechanisms can result in smaller wave heights than predicted by typical shoaling and depth-induced breaking relationships. Available analysis methods rely on parameters that have a wide range of values and can be difficult to reliably quantify. The overall approach required to quantify dissipation may entail the use of empirical data, possibly collected by the Mapping Partner at the study site or available from a similar site. In most situations, the amount of dissipation will be small, and the effort required to analyze the dissipation processes can be great. In addition, the risk of overestimating wave dissipation with the available tools, resulting in an underestimation of flood risk, can be significant.

For the Atlantic and Gulf coasts, wave attenuation caused by bottom effects is likely to be a rare situation and will not be part of the typical flood study process. In instances where bottom effects are known to be a significant factor in the attenuation of waves (for example, portions coastal Louisiana with large expanses of muddy bottom in the nearshore), the Mapping Partner shall consult with the FEMA Study Representative prior to finalizing the study approach. If wave attenuation due to bottom interactions is to be included in the study, procedures outlined in Subsection D.4.5.3.2.1 should be used.

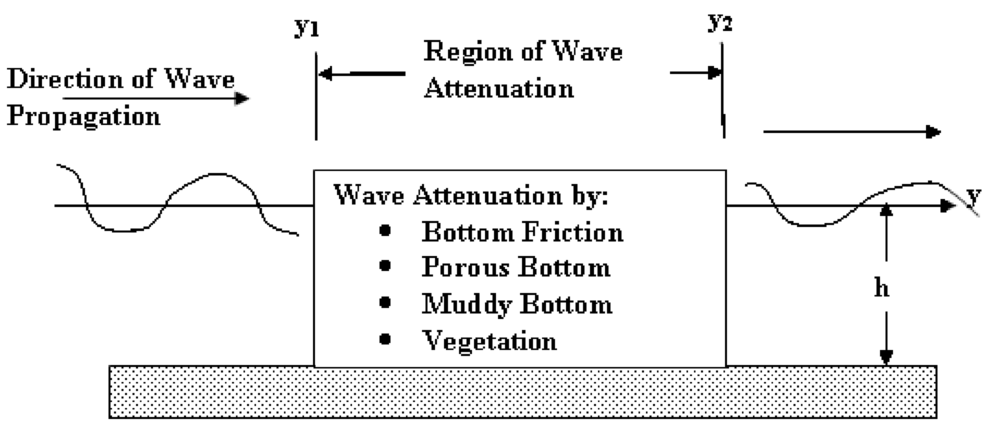

Figure D.2.5-4. Schematic of Wave Attenuation Processes Caused by Bottom Effects

D.2.5.2 Open Coasts

Many areas in which flood mapping is to be conducted are open coast settings. These open coasts may be characterized by a variety of morphologies ranging from a nearly straight coastline, as along many portions of the east coast of Florida, to convoluted coastlines, as near the entrances of large embayments such as the Chesapeake Bay. In order to carry out the wave setup and wave runup calculations required to conduct flood mapping, nearshore wave information must be developed. This requires first quantifying deepwater waves and then transforming these waves to the shoreline. Each of these steps is discussed below. A simplifying factor in the case of wave runup is that the nearshore wave height will usually be depth limited; thus, the determination of deepwater wave height will not be important to this determination. Wave setup depends more directly on the deepwater wave height; however, in areas where hurricanes govern, wave setup may account for only 20 to 25 percent of the total surge, thus perhaps relaxing the need for high accuracy in the determination of wave characteristics. In areas where extratropical storms are dominant in the determination of flood mapping, wave setup may represent a greater percentage of the total surge. The selection of a method for determining the deepwater wave height requires the Mapping Partner to evaluate the sensitivity of the total surge value of interest to the deepwater wave height and the capabilities of the various available methods to provide the requisite accuracy.

D.2.5.2.1 Wave Source

FEMA's mapping program is evolving towards the application of 2-D wave models, rather than the use of a single wave with defined characteristics. Additionally, FEMA appears to be moving toward the use of EST methodology rather than the traditional JPM in the mapping process. These approaches were discussed in detail in Subsection D.2.3. The most effective approach to determine nearshore wave conditions may depend on the type of methodology (EST or JPM) selected.

Three generic types of wave models are described below: (1) detailed 2-D models, (2) a simplified 2-D method that is a modification of a method originally developed by Bretschneider, and (3) a 1-D transect method. In addition, combinations of these methods may be possible. The model selected shall be discussed with and authorized by FEMA.

Additionally, hindcast wave data may already be available for a study area, and the Mapping Partner should investigate such data before undertaking detailed modeling for an FIS. One source of hindcast data is the USACE WIS project, described at http://frf.usace.army.mil/cgi-bin/wis/atl/atl_main.html.

D.2.5.2.1.1 Detailed Two-Dimensional Models

The 2-D wave models require a windfield and bathymetry/topography as input and have the advantage of determining wave conditions from deepwater to the breaking zone. Several models that are available for this purpose will be discussed later in this subsection. A disadvantage of 2-D models is that they add a considerable computational load to the overall process; however, computational power is increasing rapidly and several mapping efforts in which 2-D wave modeling is being applied are underway (as of July 2006). One question that the Mapping Partner must address in designing the computational process is the link between the storm-surge model and the wave model. One approach is to complete the storm-surge model run to determine the water elevations caused by wind and atmospheric pressure, and then run the wave model with these modified water levels. However, in shallow water and over land, the wave setup contributes to the water depth and thus affects the wind surge component. A second, more interactive and ambitious, approach is to run the surge model for a certain time, then run the wave model through wave setup, recompute the total water level, then continue with the wind surge model, and so forth.

Several publicly available wave models are available for 2-D modeling. These include WAM, SWAN (a shallow-water version of WAM), STWAVE, and REFDIF. In addition, commercial models are available, including the Danish Hydraulic Institute “Mike” series and Delft 3D. As noted, these models require the windfield and the bathymetry/topography to be input over the area of interest. Each of the available models has advantages and disadvantages. The Mapping Partner shall review the characteristics of the various available models and ensure that the selected model is appropriate for the particular conditions of the area to be mapped. In addition to reviewing the published characteristics of the models, the Mapping Partners should discuss their experiences with similar applications with other users. If the Mapping Partner has a successful experience with a particular model, this may help others select a model.

The use of a detailed 2-D wave model will usually require more than one grid system to be used, with the outer grid elements coarser than those of the grid system(s) closer to shore. These grid systems will usually, be “nested;” that is, the coarser grids will extend to shore, and their output will be used as input for the finer grids on their boundaries.

D.2.5.2.1.2 Simplified Two-Dimensional Models

In addition to detailed 2-D models, as described above, simplified 2-D parametric models are available for application. One such model, modified from a procedure presented in the Shore Protection Manual and based on the work of Bretschneider, is described in Subsection D.2.5.1 in the presentation of a procedure for calculating wave setup. This method is based on calculating the fields of deepwater wave height and period, using the hurricane parameters as input (central pressure deficit, radius to maximum winds, and forward translation speed). The modifications to the Bretschneider method, as presented in Subsection D.2.5.1, include recommendations for calculating the equivalent wave characteristics at shore with the hurricane at arbitrary distances from the shoreline.

If this method is of interest to the Mapping Partner, it should be verified, by one or more comparisons with 2-D models, that this simplified method provides sufficiently accurate results.

D.2.5.2.1.3 One-Dimensional Transect Method

The 1-D transect approach is the traditional FEMA methodology for shallow-water computations, but it may also be applied for deepwater conditions. The shallow-water applications consider a particular transect, and the waves and storm surge are determined along the transect for a specified windspeed field. One application of the transect method is to calculate waves to a nearshore location by a detailed 2-D model and then to apply the 1-D transect method for more landward locations. This method allows for ready application of detailed characteristics along the transect, such as bottom friction or vegetation characteristics. The transects are spaced commensurate with the longshore variability of the bathymetry/topography over which the waves are propagating. Following the transect calculations, the results may be interpolated in an alongshore direction to establish conditions between transects. The advantages of the transect method include the capability to calculate waves and wave setup in the same program. Thus, this involves a tradeoff between the detailed 2-D method, which requires iterations of the storm-surge modeling and the wave modeling, and the transect method, which conducts both wind surge and wave setup simultaneously. An additional advantage of the transect method is that the grid spacing along the transect can be sufficiently detailed to calculate wave setup, which may vary substantially over a fairly narrow cross-shore zone. Examples of this method and a further discussion will be presented in a later subsection.

D.2.5.2.2 Wave Transformation

Wave transformation describes the process by which waves are modified as they propagate from deepwater toward shore. Wave transformation processes include growth, refraction, diffraction, reflection, and dissipation. Of these processes, especially in natural areas, wave growth, refraction, and dissipation are generally of the greatest significance. Dissipation is generally of greatest significance in the shallower portions of the profile, although dissipation over long distances in deeper water may reduce the wave height considerably unless the wave system is in an active generation area.

For flooded areas, wave transformation includes the modifications to the waves as they propagate over dissipative bottoms and through vegetation and structures. Various approaches are available for calculating wave transformation. Some of these methods have been developed into computer programs, including FEMA's computer program WHAFIS, which is applied to a transect and will be discussed in greater detail in Subsection D.2.7.

An advantage of the 2-D models is that they account for several wave transformation processes. In particular, wave refraction is included in all of the models, and physics-based wave diffraction is included in some of the models. Publicly available 2-D models may include transformation processes with spatially variable bottom friction factors. The Mapping Partner shall review the characteristics of the various models and select a model that provides an appropriate "match" to the needs and resources of the particular mapping effort.

D.2.5.3 Sheltered Coast

Some features of the most appropriate methodology for sheltered coasts may be similar to those for open coasts. Again, windfields will be required and may be associated with tropical or extratropical storms. Portions of the Mississippi coastline, with barrier islands some 6 to 8 miles seaward of the mainland, represent a special case of a sheltered water body that is coupled with Gulf waters through inlets incised through the barrier islands. With high storm surges, as occurred in Hurricane Katrina, these barrier islands become inundated and the system is modified from a sheltered coast to an open-coast system. Lake Pontchartrain in Louisiana is a sheltered water body that is coupled to Lake Borgne through two passes.

As noted, the methods for determining wave heights for sheltered waters may be based on the same detailed models as those developed for open coasts, or on transect methods developed by FEMA, USACE, or others. The Mapping Partner shall investigate the range of possible models for their application to the particular geometry and determine the most appropriate method. As in the case of open coasts, if the determining storms are hurricanes, as they will be in the Gulf of Mexico and lower east coast, the windfield may be based on the parameters of each hurricane (JPM method), accounting for any wind reduction as the wind traverses over land before reaching the sheltered water, or directly for historical storms, if the EST method is applied. If the determining storms are extratropical, they are usually of larger scale than hurricanes, and the winds may be determined by examining the historical occurrences of storms and applying one of the previously discussed models that transforms winds to waves and storm surge. In some cases, tide gage data may be adequate to determine the surge levels of interest. However, depending on the water depth in which the tide gage is located, the wave setup included in the tide gage recordings may not be representative of wave setup at the shoreline.

D.2.5.4 Additional Considerations

D.2.5.4.1 Extratropical Storms

For some extratropical storms, such as those that dominate along the northeast coast, it may be appropriate to use a wave height with an established return period. The possible databases for this wave height include the WIS data developed by USACE or the Global Reanalysis of Ocean Weather (GROW) data that have been developed by Ocean Weather and are available commercially. The GROW data are based on the analysis of several decades of wind data and the more limited buoy data and can be extrapolated to the return period of interest. The Mapping Partner should compare results from these databases, and if they differ significantly, attempt to resolve the cause of the differences and select the most appropriate data source for further computations. In some areas, sufficient tide gage data may be able to serve as the basis for calculation of the BFE.

D.2.5.4.2 Wind Characteristics

Even in the case of windspeeds, which are constant when averaged over a long period, winds vary about the average. This raises the question of the appropriate windspeeds to use to calculate waves and storm surges. Windspeeds are usually reported as the maximum windspeed when averaged over a specific time interval. For example, the 1-minute windspeed would represent the fastest windspeed, averaged, in a 1-minute period. The 1-minute periods considered when determining the fastest 1-minute windspeed should be measured when the average windspeed is constant. Obviously, the speed representative of a particular windspeed decreases with the averaging interval. That is, the 1-minute windspeed will be greater than the 10-minute windspeed. For structural damage, it is usually the 3-second wind gust that is considered relevant. Statistically, this is on the order of 30 percent greater than the 1-minute windspeed. The appropriate windspeed for wind and storm surge computations is the 30-minute windspeed. Winds are present as a boundary layer over land and water, and the windspeed increases with elevation. The relevant height for calculating the windspeed for storm surge and waves is 33 feet (meteorologists use 10 meters, which is 32.8 feet). If the windspeed is available at an elevation, z, which differs from 33 feet, then the following relationship may be applied:

$$U(33) = U(z)\left(\frac{33}{z}\right)^{1/7} \tag{2.5-1}$$

in which U is the windspeed.

D.2.5.5 Documentation of Wave Attenuation

Areas where wave attenuation was examined and the results obtained shall be described. The characteristics of these areas that led to the consideration of wave attenuation and the values of the attenuation parameters used in the analysis shall be quantified. Results of interest include the potential effect of wave attenuation on the hazard zones and the decisions reached as to whether to further include wave attenuation in the analysis leading to hazard zone delineation. Any field measurements and/or observations shall be recorded, as well as documented or anecdotal information regarding previous overland damping during major storms, perhaps by runup events less than expected in the lee of attenuation features, as discussed in this subsubsection. Any notable difficulties encountered and the approaches to addressing them shall be clearly described.