D.2.2 Study Methodology

This subsection provides guidance for selecting and combining specific technical methods and data into a study methodology. The selection of methods depends upon the coastal setting and the available data.

D.2.2.1 Overview

In this appendix, "methods" means the individual techniques used to make specific computations. "Study methodology" is the combination of appropriate methods and data necessary to develop flood insurance risk zones for depiction on a FIRM. A variety of technical methods are available for application in the unique settings of each coast, with those most appropriate for the Atlantic and Gulf coasts presented in Subsections D.2.3 through D.2.10 of this appendix. In most cases, several methods may apply to a specific coastal setting, and in some cases, methods used for the Atlantic coast will differ from those used for the Gulf Coast region. This would be expected for the coastal areas dominated by northeaster coastal flood events, as opposed to those influenced primarily by hurricanes. The objective of this subsection is to provide guidance for developing an appropriate methodology based on coastal settings and available data.

A significant portion of Appendix D is devoted to the presentation of technical methods that were established in previous guidance dating back to 1989. It is important to remember that the objective of this document is to provide updated guidance for developing flood insurance risk zones and maps. These updates are based on recent advancements in coastal engineering and recommendations from the technical panel of coastal experts convened to evaluate existing methodologies and new technical approaches for analyzing the Atlantic and Gulf coasts, previously presented in the 2003 version of Appendix D. The updates from the more developed of the coastal panel recommendations were presented in FEMA Procedure Memorandum No. 37 and serve as the primary basis for the updates in the subsections to follow. When considering the technical approach for a coastal setting, the Mapping Partner must keep in mind that the level of technical analysis should remain consistent with the objective of this document. It is only necessary to obtain the data and conduct the analyses that are required to accomplish this objective. Because there are often several methods available to conduct similar analyses, the Mapping Partner must choose methods that are technically consistent, are applicable for the study setting, use available data, and are appropriate for project resources.

The recommended generalized study methodology is summarized below. There are many well-established methods for Mapping Partners to follow in developing flood insurance risk zones and maps, and they provide the approach that best suits the objectives of this document. It is important, though, to consider all the coastal processes that occur during the base (1-percent-annual-chance) flood event, and to consider what data and technical methods are appropriate for application and update, and what existing data is still valid to use in the determination of flood insurance risk zones and BFEs. At the outset of the study process, the Mapping Partner should begin the onshore analysis by identifying the information that is required to develop the flood insurance risk zones and mapping. This involves identifying all of the physical coastal processes

that are likely to contribute to flood hazards in the study area, and their interaction with particular coastal settings in the onshore, nearshore, and offshore environments of the study area. In some cases, this initial review will not resolve all of the questions related to coastal processes and hazard zones. However, the review should identify the data requirements for one or more methods that can be applied to make these determinations.

New or additional data may be required to perform analyses with the updated methodologies presented in this volume. FEMA recently adopted changes to wave runup analyses that require Mapping Partners to analyze directly or convert from the mean to the 2-percent wave runup depth. The conversion of the 2-percent to mean wave runup approximately doubles the total runup depth for hazard zones and BFE determination. Shorelines where previous analyses using the mean wave runup method did not predict runup depths greater than the wave height effects may now warrant further consideration. Further discussion of the 2-percent wave runup analyses can be found in Subsection D.2.8.1 of these guidelines. When a coastal protection structure is present in a study site the Mapping Partner will need to identify the data and methods needed to determine whether the structure will withstand the forces associated with the base flood, or if it requires the application of newly adopted methods to predict failed structure conditions. These are just two examples of the types of changes in the study process that must now factor into the data requirements and technical approach of Mapping Partners, based on the update to Appendix D.

After a review of probable hazards at the shoreline, the Mapping Partner should proceed offshore, considering what data and analyses are required at each level and for each setting within the study area to accomplish the onshore analysis. This will establish the limit of the offshore data and computations necessary to conduct the analyses. In most cases, this limit will correspond to offshore conditions. Once the offshore data requirements for the study are established, the wave data and other information will be brought back onshore to determine the information needed to develop the hazard zones. In other words, the mapping needs are established by progressing from the hazard map to the offshore area, but the analysis proceeds in the direction of the physics — from offshore to onshore.

Different data requirements are associated with different analysis methods. For example, if methods are based on the deep water, unrefracted, significant wave height and peak wave period, it is not necessary to examine the details of the spectrum. If it is not necessary to transform the waves across the surf zone, the surf zone bathymetry is not required for this method. More advanced methods generally require additional data. New methods that have been developed for wave setup and evolving guidance on wave runup methods will require a higher level of data requirements, depending on their significance in the detailed coastal analyses.

It should be noted that the two initial and significant phases of a full coastal restudy to determine the SWELs, the hydrodynamic storm surge inundation modeling and statistical methods for flood frequency analysis, have changed with the evolving world of coastal science and engineering since the first guidance was presented in 1981 for the Tetra Tech surge model (TTSURGE) and the Joint Probability Method (JPM). This surge and statistical guidance was developed and maintained separately from the detailed coastal analyses of wave effects, erosion, and mapping criteria that were initially published in 1989. This update begins to merge the two by including a generalized discussion on data submission requirements of a storm-surge modeling effort

(Subsections D.2.1.2.6 and D.2.12.2) and flood frequency analysis methods and statistical theories (Subsection D.2.3). The results that the Mapping Partner obtains from new hydrodynamic and statistical methods will influence the study methodology for wave effects, erosion assessments, and final hazard zone mapping. Although well documented and applied along floodprone coastal regions, many of the surge modeling and statistical methods have not been fully resolved and documented as NFIP methodologies in a comprehensive set of guidelines. At this time, user guidance for a specific model or method setup and application to a FEMA Flood Map Project are not available in this guidance and will generally be documented and supported independently by the author and/or developer of the model or method.

In selecting analysis methods, logic must be applied to both the overall study (study methodology) and to the selection of methods for each major coastal process to be analyzed in developing flood insurance risk zones (Figure D.2.2-1). The basic logic begins with the definition of objectives, which should focus on the development of flood insurance risk zones at an appropriate resolution and level of accuracy, considering potential damages, the inherent uncertainty in the analyses, schedule, and budget. The geomorphic setting is a key factor in identifying the dominant physical processes that must be analyzed and the appropriate methods for analysis. The potential methods applicable to a given setting may have different data requirements, and the availability of data may influence the selection of methods. Once a methodology (combination of methods and data) has been defined, the Mapping Partner must confirm that the methodology satisfies the study objectives, including time and budget constraints.

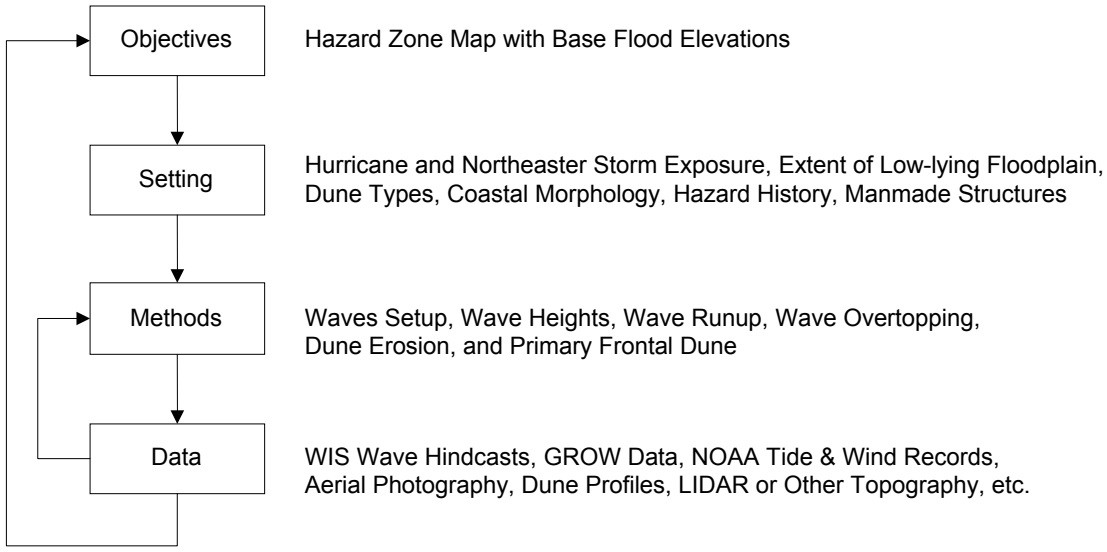

Figure D.2.2-1. Study Methodology Development Considerations

D.2.2.2 Setting

The study area setting and hazard history will determine which methods and data are necessary and/or appropriate. Important considerations include the coastal exposure to hurricanes and northeaster storm events (both on open ocean coasts and in inland bays or other sheltered

waters), the shoreline morphology (small or large dune fields, barrier islands, inlets and rivermouths, coastal bluffs or cliffs, etc.), and the shore conditions (topography, development, etc.). Consideration of each of these conditions frames the data requirements and the appropriate analysis methods.

D.2.2.2.1 Open Ocean Coasts, Inland Bays, and Sheltered Waters

A primary consideration is the exposure of the shoreline, which can be classified into three groups: open ocean coasts, inland bays, and other sheltered waters. Open ocean coasts are exposed to the full influence of the Atlantic Ocean or the Gulf of Mexico and include processes such as prolonged and substantial hurricane and northeaster storm surges, large fluctuations of astronomical tides, and large wave effects accompanying storm surges. For most inland bays, storm surge and wave effects result from an exposure to open ocean processes and weather conditions, combined with local processes and weather conditions. In more isolated portions of sheltered waters and inland bays, the waves and flood levels may be primarily caused by local weather and tide conditions and require special hazard analysis considerations, such as timing of peak surge levels with peak wind driven wave effects.

On the open ocean coast, the interrelationships between storm surge and wave processes, such as the influence wave setup exerts upon storm surge flood levels, may be quite complex. Depending upon the scope of the coastal restudy, the simultaneous assessment of wave setup processes is recommended during the hydrodynamic modeling of wind setup from hurricanes and northeasters, to avoid underestimating the contribution of wave setup processes to total stillwater flood levels. This is a key point for the Atlantic and Gulf coasts that can not be addressed properly in Appendix D. The methodologies presented here will be for independent assessments of each process, until the time when Appendix D can be cross-referenced to new guidance for the complex processes involved with hydrodynamic modeling and statistical analyses prior to the more simplified analyses for wave effects and erosion assessments.

In sheltered waters, the waves are typically generated by local weather, which simplifies the interrelationships. As a result, statistical or simulation techniques may be used to analyze these processes. However, tidal amplification, currents, and the effects of river inflows must be considered differently in sheltered waters than larger inland bays. While most methods for open ocean coasts and inland bays are also applicable for sheltered waters, a number of special considerations exist for sheltered waters which have been addressed in the Pacific Coast guidelines.

D.2.2.2.2 Shoreline Profile Settings

The shoreline morphology determines which analysis tools are appropriate for estimating shoreline responses. The general shoreline settings on the Atlantic and Gulf coasts include:

- Sandy beach backed by low or high sand barrier dune formations
- Sandy beach backed by coastal shore protection structures
- Cobble, gravel, shingle, or mixed-grain-size beach
- Erodible bluffs and plateau

- Nonerodible bluffs and cliffs
- Tidal marshes and wetlands.

Details of the specific methods for each setting are given in Subsection D.2.9. Other special considerations for the detailed analyses, due to unique coastal nearshore features, would include the presence of fringing submerged or exposed reefs and rock outcrops, breakwaters, and shore protection structures such as groins and jetties.

Figure D.2.2-2 summarizes key considerations for each of these six settings. In all settings, the existing shoreline conditions must be determined. These are required to determine the present location of the shoreline, the condition of structures, etc. For settings in which seasonal adjustments to beach profiles are needed, the initial profile from which storm-induced changes are calculated should be determined. Profile changes not completed using established erosion assessment methods (such as the 540-square-foot erosion criteria; see Subsection D.2.9) are estimated with appropriate methods or historical documentation to yield a feasible and technically justified eroded profile. If the eroded profile results in dune breaching, structure failure, or bluff recession, then an adjusted final profile must be determined. Wave setup, wave runup, wave overtopping, and wave height overland propagation are determined for the final profile. These results are then used for mapping the flooding hazards.

- For a sandy beach backed by a low sand berm or high sand dune, the 540 ft^2 methodology is appropriate. If the dune is overtopped or breached, then the profile may require additional adjustments to construct a final erosion-adjusted profile before continuing with the wave effect analyses.

- For a sandy beach backed by shore protection structures, the eroded profile is determined from data or other overtopping considerations rather than the 540 SF erosion methodology. The structure may cause local scour and the structure may fail. The final profile based on these processes is then examined for overtopping depths and possibly ponding. In overtopping cases with structures, profile adjustments should consider FEMA policy for stability of fill placed landward of a coastal structure. Fill placed landward of a coastal structure is considered to be stable only to the crest of the structure, and fill placed in excess (or above) the crest of the structure should be eroded and not included in the adjusted profile. This would hold true for the failed structure scenario as well. If the structure in its certified or failed condition has crest elevations at or below the seaward toe of a dune (located adjacent and landward of the structure) or 10-percent-annual-chance flood elevation, then the 540 SF methodology criteria should be considered in making final adjustments to the beach profile.

- For a cobble beach, little analytical guidance is available because many of the cobble beaches on the northeast-Atlantic coast are mixed grain sizes and are difficult to model, while there are no cobble beaches in the mid-Atlantic coast south and into the Gulf Coast region. As a result, observed profiles during large events are used as the basis for determining wave runup, wave overtopping, and possibly ponding.

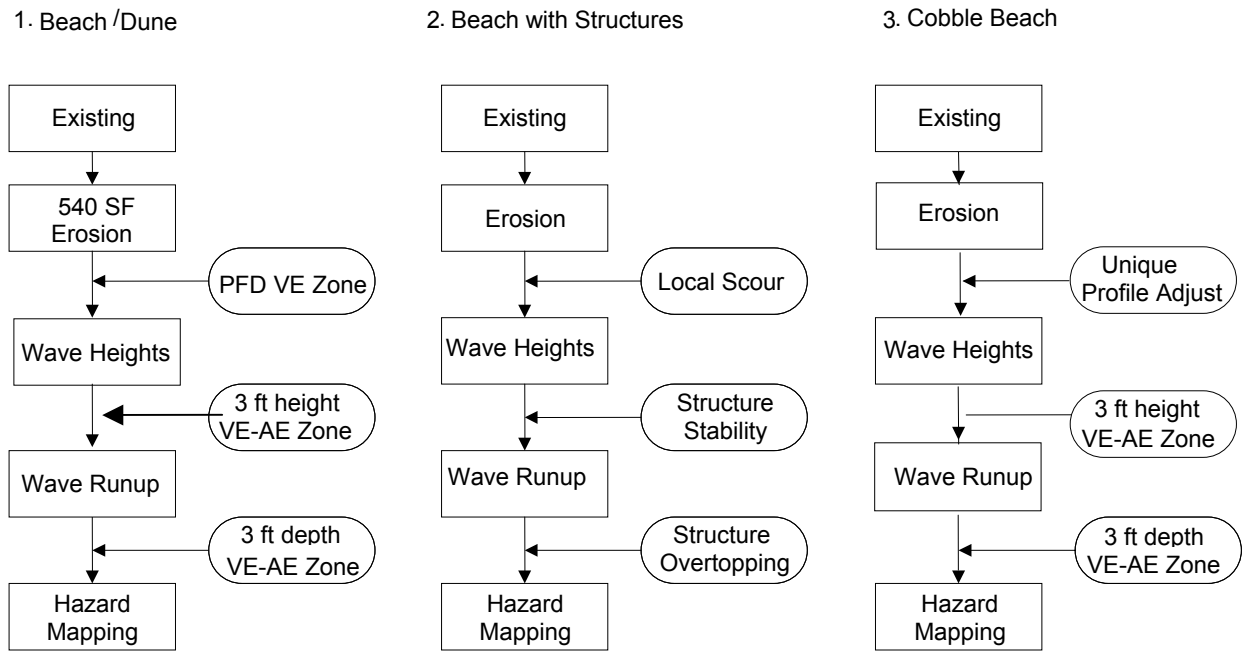

Figure D.2.2-2a. Shoreline Profile Setting Nos. 1 - 3

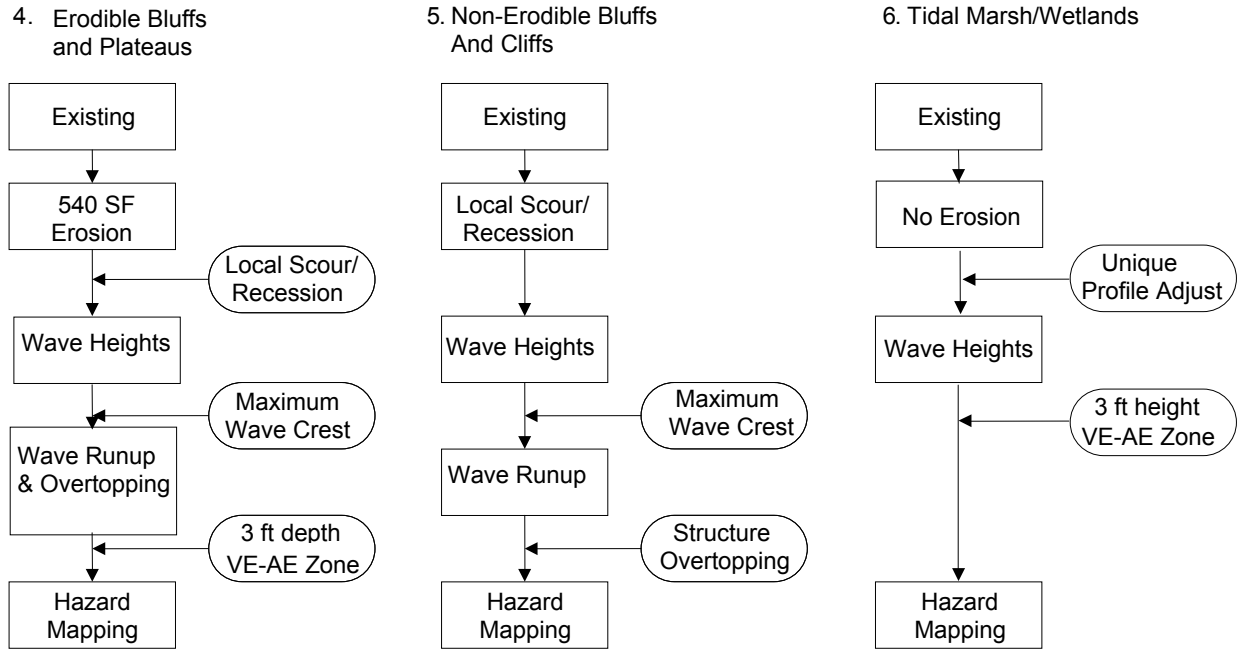

Figure D.2.2-2b. Shoreline Profile Setting Nos. 4 - 6

- For erodible bluffs, the eroded beach profile is determined from use of the 540 SF methodology, if applicable (see Subsection D.2.9), local bluff recession assessments, or historic measurements of storm-induced erosion. The bluff recession is estimated with a bluff erosion model, and bluff toe scour should be considered for possible collapse. The resulting profile is then used to determine the wave runup, wave overtopping, and possibly ponding.

- For non-erodible bluffs, the eroded beach profile is determined from historic measurements of storm-induced erosion or local bluff recession assessments if any are applicable to the bluff-type. This profile is then used to determine the wave runup, wave overtopping, and and possibly ponding.

- For tidal flats and wetlands, it is assumed that there is no erosion over the duration of the base flood event. If historic measurements or data indicate any type of unique profile adjustments (such as in coastal Louisiana marshes), then the profile adjustment should be applied before being used for overland wave propagation modeling of wave effects.

D.2.2.3 Coastal Zones

Figure D.2.2-3 shows the cross-shore divided into four zones. The offshore zone is the area influenced by waves and water levels that are not substantially influenced by bathymetry or topography. The dominant processes in this zone include swell, seas, astronomical tides, and storm surge. The shoaling zone is the area outside the surf zone, where offshore conditions are transformed by interaction with bathymetry or topography. This typically includes the refraction, diffraction, dissipation, and generation of waves, but along the Atlantic and Gulf coasts this area is characterized by fully developed sea conditions.

In these coastal regions, storm waves are local, caused by storms that pass close to or make landfall at the shore, resulting in predominantly shore-perpendicular wave propagation. The surf zone is where waves break as they interact with the bottom. The dominant processes include wave setup, runup, overtopping, erosion, and interaction with structures. The backshore zone is the area outside the normal surf zone (under normal weather conditions), which may be subject to inundation during coastal flooding events. This area has hazards characterized by wave effects such as wave runup, wave overtopping, and overland wave height propagation. The backshore zone is subject to development and is the critical area for determining flood hazards.

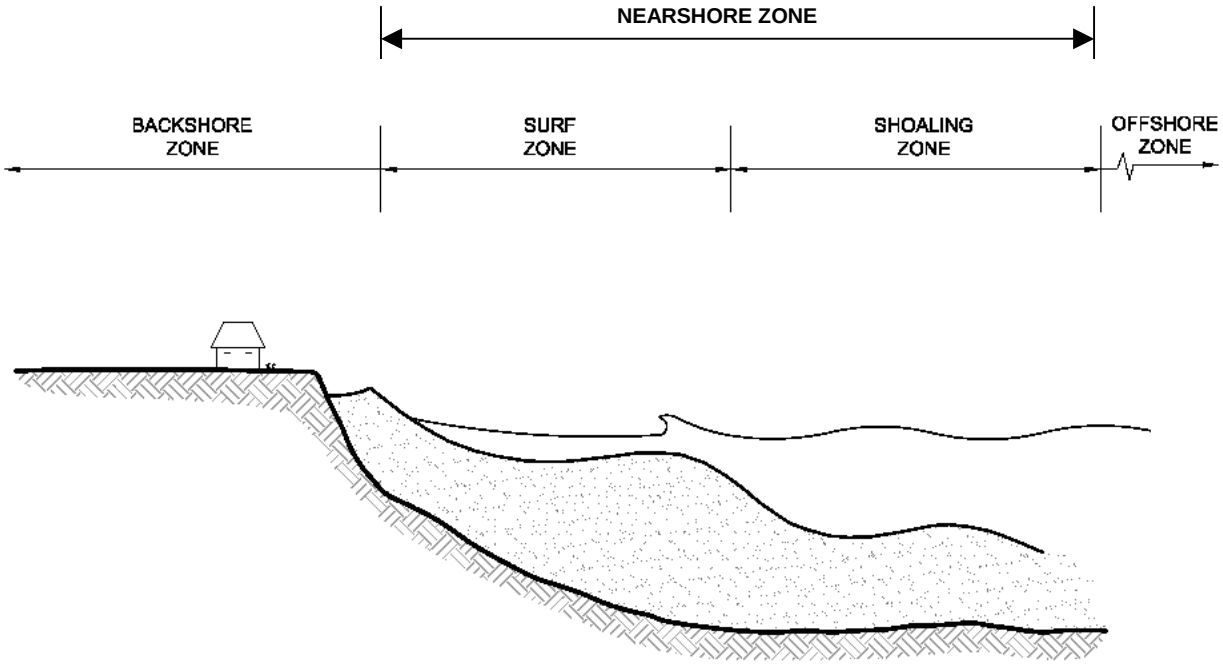

Figure D.2.2-3. Coastal Zones

Figure D.2.2-4 shows the coastal processes as they are referred to in the analysis methods given in Subsections D.2.3 through D.2.10. It should be noted that "offshore" does not necessarily imply deep water conditions, which are defined according to water depth and wave length. Although this deep water condition is typical, an "offshore" designation might only mean that the processes being considered are outside the surf zone. If the offshore zone is not in deep water, then the offshore and shoaling zones are combined.

Except for storm surge elevation determinations (statistical flood levels), the computations made in each zone use data from the preceding zone and pass the results to the next zone. Computations generally start in the offshore zone. Wave information is determined from measurements or hindcasts. Stillwater levels are determined from previously completed flood reports or storm-surge modeling, and are derived from methods described in other guidance materials. The resulting estimates for waves and stillwater levels are then passed to the shoaling zone. The definition of shoaling zone above indicates that this is a zone where bottom friction affects wave movement. Thus, waves will change from deep water to shallow water waves and wave height, length, and period should change.

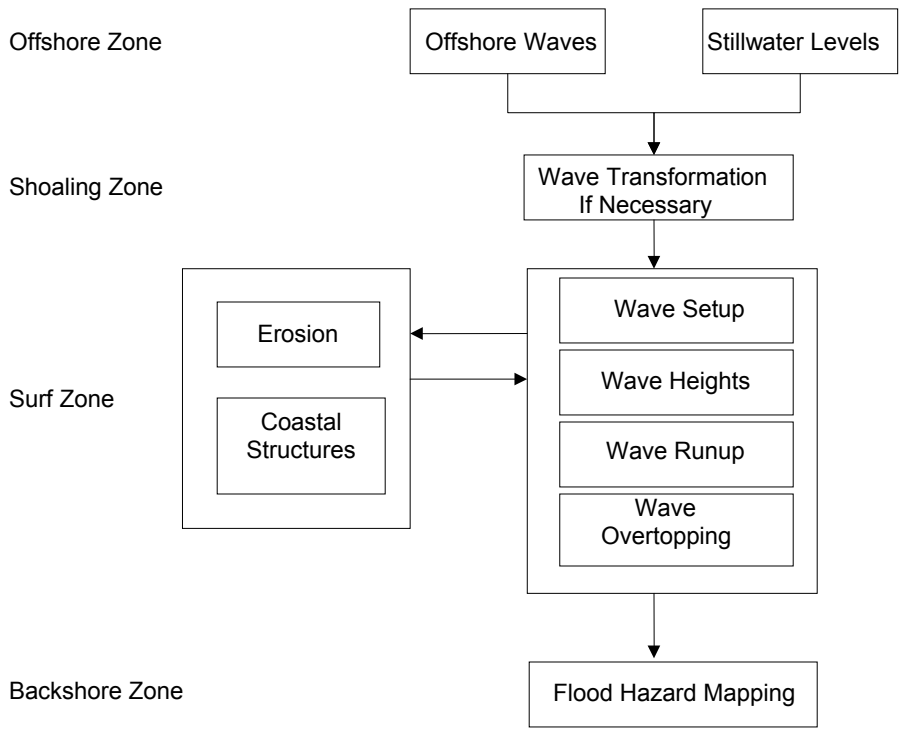

Figure D.2.2-4. Coastal Zones and Processes

In the shoaling zone, the offshore waves are transformed onshore to a water depth outside the breaker line. This requires information for the bathymetry and possibly other factors, such as dissipation over submerged reefs, rock outcrops or barrier islands, mud flats, or wetlands. Several of the surf zone analysis methods require unrefracted deep water wave conditions. After the waves have been transformed across the shoaling zone, the corresponding unrefracted deep water conditions may also be determined. These results are then passed on to the surf zone. Surf zone computations use nearshore bathymetry and either the wave conditions determined outside the breaker line or the unrefracted deep water conditions. Wave setup, wave runup, wave overtopping, wave heights, and erosion are estimated at the shoreline, based on the specific shoreline conditions. These results are then, as appropriate, passed to the backshore zone to determine flood hazards, mostly in the form of overland sheet flow and "splash zone" effects from wave runup, and overland wave height propagation through vegetation and buildings. In the backshore, information from the surf zone is combined with topography and land-use type to calculate the hazard zones and BFEs needed to develop a hazard map.

D.2.2.4 Event and Response Analysis Considerations

On the Atlantic and Gulf coasts, the 1-percent-annual-chance flood has typically been associated with a 1-percent storm event condition defined offshore and transformed to the surf zone. Because increased wave heights and water levels are both associated with the same forcing event, typically a hurricane, this association is reasonable. Statistical tools such as JPM, Monte Carlo, and empirical simulation methods are easily applied in these areas. In the coastal areas of the Northeastern United States, an alternative is to use the statistical relationships of measured

water-level conditions for a large coastal region (e.g., Long Island Sound to the U.S.-Canadian border).

An event corresponds to a set of time-dependent wave and water-level conditions taken as a paired data set with a specific duration. This type of analysis is not generally applicable in the Atlantic and Gulf coasts. However, the concept of using a set of conditions to define responses and performing statistical analysis on the responses may be applied in sheltered water. The 1-percent response may be determined at the boundary of any one of the zones shown in Figure D.2.2-3. For example, a 1-percent-annual-chance combination of waves and water levels might be statistically determined in the offshore zone by examining the joint occurrence of waves and water levels. This condition could be transformed onshore, the setup and runup estimated, and the flood insurance risk zone mapped. However, it is unlikely that this single combination of waves and water levels with a 1-percent-annual-chance storm event in the offshore zone corresponds to the 1-percent-annual-chance flood hazard in the backshore zone.

Other combinations of waves and water levels that have a lower probability of occurrence may result in higher levels of flood hazard because of differing responses in the form of runup, setup, erosion, or coastal structure interaction in the backshore zone. These responses are dependent on variables such as wave period and event duration in the sheltered water. The 1-percent-annual-chance flood is defined as the basis for hazard zone mapping by FEMA; thus, the response at the backshore is the condition of interest.

Although the response-based approach is reasonable theoretically, it may not be practical to include all coastal processes in the computations before statistical analysis in the backshore. However, the further the response-based approach can practically be carried onshore, the better the estimate of the 1-percent-annual-chance flood hazard in the backshore zone will be. As a standard methodology, it is recommended that the 1-percent-annual-chance determination be made on total SWELs (consideration of astronomical tide, wind setup for storm surge response, and wave setup). If overtopping occurs, then the determination of the overtopping rate and overtopping volume should be made using the 1-percent-annual-chance runup and the associated storm. These are the most significant hydrodynamic parameters influencing flood hazards. This standard methodology may require modification where processes in the backshore (ponding, riverine flows, etc.) influence the flood hazards (Subsection D.2.4.1.5.4 offers guidance on riverine flow considerations).

D.2.2.5 Selection of Events

Offshore wave conditions, as either measured data or hindcasts, are available for most of the open-coast shorelines of the Atlantic and Gulf coasts. The methods for selecting events are documented in Section D.4.2.5 of the Pacific Coast guidelines and should be consulted for use and application for open ocean coasts, inland bays, or sheltered water. The determination of the 1-percent-annual-chance flood hazards based on a 1-percent-annual-chance response at the shoreline (as opposed to estimating 1-percent-annual-chance storm conditions offshore) provides a more direct connection between the actual causal events and the flooding response and is presented in more detail in the above-referenced subsection.

The 0.2-percent-annual-chance conditions (500-year conditions) are used to map the X zones. The determination of the 0.2-percent conditions and the associated flood hazards is completely analogous to the methods used to determine the 1-percent conditions. These SWELs are generally computed in previously completed storm surge studies or modeling.

D.2.2.6 Summary of Methods

Table D.2.2-1 is a summary of methods presented in Section D.2. This table provides an overview of the available methods and a reference to the appropriate subsection of the document.

Table D.2.2-1. Summary of Methods Presented in Section D.2

Zone/Process	Method	Comments
All Zones	**Statistics (D.2.3)** 1-percent condition – Generalized Extreme Value (GEV) and maximum likelihood fit Peak over threshold with Pareto distribution	Annual maxima are used to determine the 1-percent condition.
	Joint Probability Methods (JPM), Monte Carlo, Empirical Simulation Technique (EST)	JPM, Monte Carlo, or EST are only used in hydrodynamic storm-surge modeling for flood frequencies
Offshore Zone	**Water Level (D.2.4)** Measured Stillwater Level NOAA or USACE tide gauging, storm-surge modeling	In most cases, the measured stillwater level does not include wave setup, represents regional conditions, and is used in all the analyses.
	Sheltered Waters Seiche, tidal amplification, rivers	A number of other factors can influence the water level in sheltered waters.

Table D.2.2-1. Summary of Methods Presented in Section D.2

Zone/Process	Method	Comments
Offshore Zone	**Waves (D.2.5)** Measured NDBC, CDIP Hindcast GROW, WIS, WAVEWATCH III	The use of significant wave conditions (height, period, direction, storm duration) or directional spectra depends upon the choice of the methods selected for determining setup, runup, and overtopping. The wave record must be long enough (30 years or longer) to reasonably estimate the 1-percent- annual-chance condition.
	Wave Generation 2-D models CEM parametric model	Wave generation methods are only applicable in combined surge modeling, sheltered water, or a regional-scale offshore model.
Shoaling Zone	**Wave Transformations (D.2.5)** Straight and parallel contours shoaling and Snell's Law Spectral methods transformation coefficients, CDIP Nearshore transformations 2-D spectral and time domain models Sheltered waters seiching, inlets	Numerical models are typically only required for complex bathymetry

Table D.2.2-1. Summary of Methods Presented in Section D.2

Zone/Process	Method	Comments
Surf Zone	**Wave Setup, Overland Wave Heights, and Wave Runup (D.2.6-D.2.8)** Beaches DIM parametric or numerical for wave setup Wave setup using advanced wave models - Boussinesq	DIM methods combine wave setup and runup. Parametric method only requires significant wave height. Advanced models are only necessary for complex conditions.
	Structures van der Meer, CEM Overland WHAFIS 3.0 Runup RUNUP 2.0 at 2-percent runup SPM for vertical structures/bluffs TAW for sloped structures	
Surf Zone and Backshore Zone	**Erosion (D.2.9)** Beaches Geometric Models – 540 SF method Shore Protection Structures CEM local scour equations Cobble Beaches Observed storm profiles Erodible Bluffs 540 SF method or bluff recession Non-Erodible Bluffs and Cliffs No erosion, local scour or bluff recession Tidal Flats and Wetlands No erosion – unique profile adjustments if known	Atlantic and Gulf Coast "540 Rule" is primary methodology recommended for the Atlantic and Gulf coasts.

Table D.2.2-1. Summary of Methods Presented in Section D.2

Zone/Process	Method	Comments
Backshore Zone	**Overtopping (D.2.8)** Beaches CEM Structures CEM, Besley	30 foot splash zone minimum requirement if no mean overtopping rates known 1.0 CFS mean overtopping rate needed for splash zone Wave runup overtopping limited to 3 foot above crest of dune ridge or structure regardless of runup elevation
Backshore Zone	**Overland Flow (D.2.5)** Cox and Machemehl, WHAFIS	New velocity hazard zone considered for sheet flow greater than 200 CFS
Backshore Zone	**Hazard Indicators (D.2.11)** 3-foot wave runup depth Overtopping splash distance 3-foot wave height Primary frontal dune landward heel/limit	