2.1 GENERAL DESIGN CONSIDERATIONS

This chapter introduces the physical nature and mechanics of floods and explains how flood probabilities are determined and how flood hazard areas are identified. It describes the types of flood damage that can result when critical facilities are located in flood hazard areas or are affected by flooding. A series of requirements and best practices are introduced that facility owners, planners, and designers should consider for reducing the risks from flooding to new critical facilities and to existing facilities already located in areas prone to flooding.

This chapter demonstrates why avoidance of flood hazard areas is the most effective way to minimize the life-safety risk to the occupants and general public who rely on these facilities, as well as to minimize the potential for damage to buildings and other elements of critical facilities. When an existing facility is exposed to flooding, or if a new facility is proposed for a flood hazard area, steps need to be taken to minimize the risks. A well-planned, designed, constructed, and maintained critical facility should be able to withstand damage and remain functional after a flooding event, even one of low probability.

2.1.1 NATURE AND CHARACTERISTICS OF FLOODING

Flooding is the most common natural hazard in the United States, affecting more than 20,000 local jurisdictions and representing more than 70 percent of Presidential disaster declarations. Several evaluations have estimated that 7 to 10 percent of the Nation's land area is subject to flooding. Some communities have very little flood risk; others lie entirely within a floodplain.

Flooding is a natural process that may occur in a variety of forms: long-duration flooding along rivers that drain large watersheds; flash floods that send a devastating wall of water down a mountain canyon; and coastal flooding that accompanies high tides and onshore winds, hurricanes, and nor'easters. When the natural process does not affect human activity, flooding is not a problem. In fact, many species of plants and animals that live adjacent to bodies of water are adapted to a regimen of periodic flooding.

Flooding is only considered a problem when human development is located in flood-prone areas. Such development exposes people to potentially life threatening situations and makes property vulnerable to serious damage or destruction. It also can disrupt the natural surface flow, redirecting water onto lands not normally subject to flooding.

Flooding along waterways normally occurs as a result of excessive rainfall or snowmelt that creates water flows exceeding the capacity of channels. Flooding along shorelines is usually a result of coastal storms that generate storm surges or waves above normal tidal fluctuations. Factors that can affect the frequency and severity of flooding and the resulting damage include:

- Channel obstructions caused by fallen trees, accumulated debris, and ice jams
- Channel obstructions caused by road and rail crossings where the bridge or culvert openings are insufficient to convey floodwaters
- Erosion of shorelines and stream banks, often with episodic collapse of large areas of land
- Deposition of sediment that settles out of floodwaters or is carried inland by wave action
- Increased upland development of impervious surfaces and manmade drainage improvements that increase runoff volumes

- Land subsidence, which increases flood depths

- Failure of dams (resulting from seismic activity, lack of maintenance, flows that exceed the design, or destructive acts), which may suddenly and unexpectedly release large volumes of water

- Failure of levees (associated with flows that exceed the design, weakening by seismic activity, lack of maintenance, or destructive acts), which may result in sudden flooding of areas behind levees

Each type of flooding has characteristics that represent important aspects of the hazard. These characteristics should be considered in the selection of critical facility sites, the design of new facilities, and the expansion or rehabilitation of existing flood-prone facilities.

Riverine flooding results from the accumulation of runoff from rainfall or snowmelt, such that the volume of flow exceeds the capacity of waterway channels and spreads out over the adjacent land. Riverine flooding flows downstream under the force of gravity. Its depth, duration, and velocity are functions of many factors, including watershed size and slope, degree of upstream development, soil types and nature of vegetation, topography, and characteristics of storms (or depth of snowpack and rate of melting). Figure 2-1 illustrates a cross-section of the generic riverine floodplain.

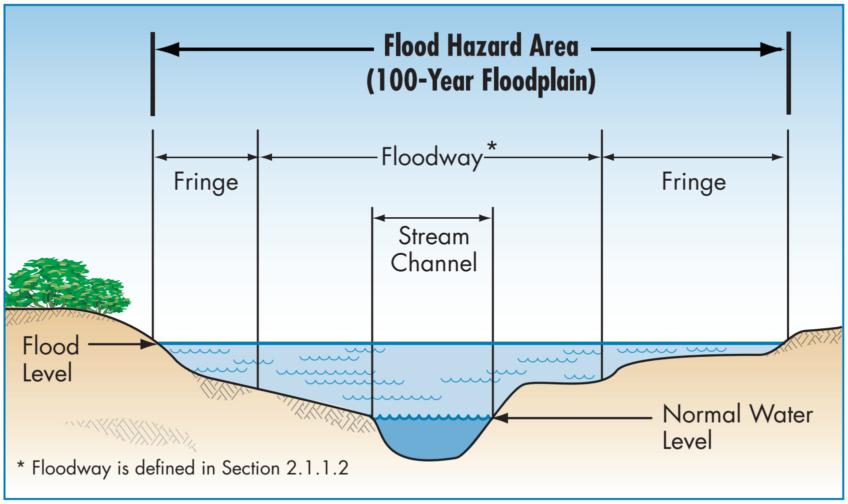

Figure 2-1:
The riverine floodplain

Coastal flooding is experienced along the Atlantic, Gulf, and Pacific coasts, and many larger lakes, including the Great Lakes. Coastal flooding is influenced by storm surges associated with tropical cyclonic weather systems (hurricanes, tropical storms, tropical depressions, typhoons), extratropical systems (nor'easters), and tsunamis (surge induced by seismic activity). Coastal flooding can also be characterized by wind-driven waves, which also affect reaches along the Great Lakes shorelines; winds blowing across the broad expanses of water generate waves that can rival those experienced along ocean shorelines. Some Great Lakes shorelines experience coastal erosion, in part because the erosion is associated with fluctuations in water levels. Figure 2-2 is a schematic of the generic coastal floodplain.

A number of factors associated with riverine and coastal flooding are important in the selection of sites for critical facilities, in site design, and in the architectural and engineering design of critical facilities.

Depth: The most obvious characteristic of any flood is the depth of the water. Depending on many factors, such as the shape of a river

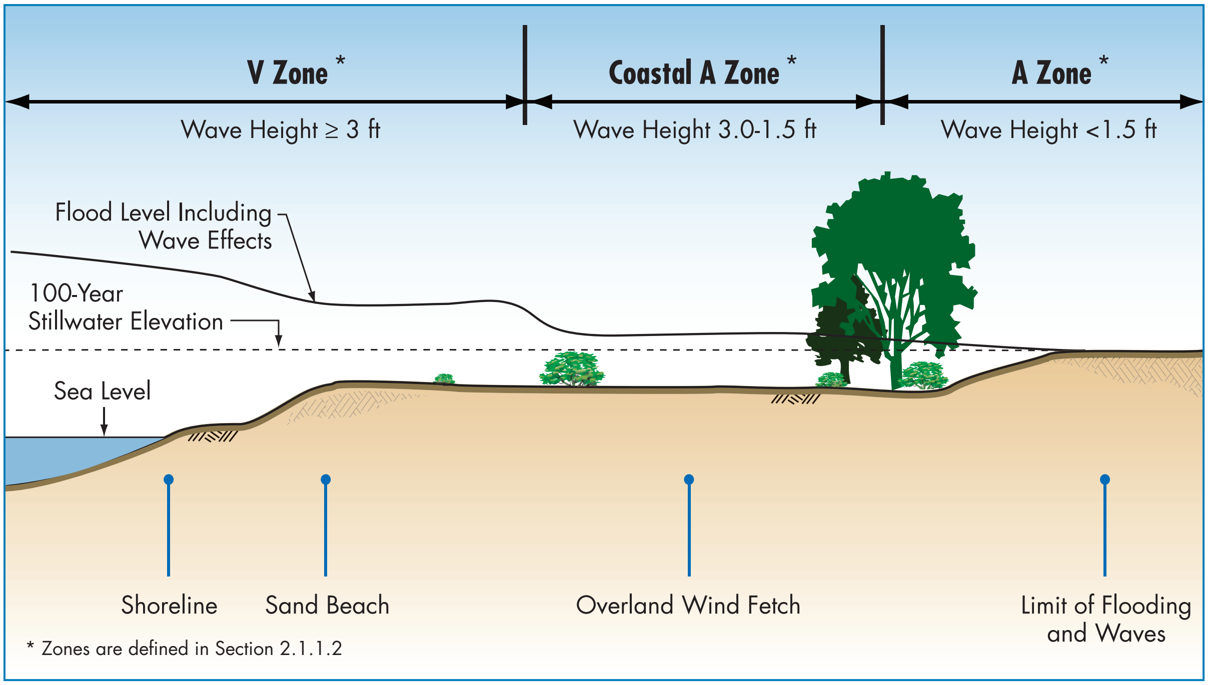

Figure 2-2: The floodplain along an open coast

valley or the presence of obstructing bridges, riverine flooding may rise just a few feet or tens of feet above normal levels. The depth of coastal flooding is influenced by such factors as the tidal cycle, the duration of the storm, the elevation of the land, and the presence of waves. Depth is a critical factor in building design, because the hydrostatic forces on a vertical surface (such as a foundation wall) are directly related to depth, and because costs associated with protecting buildings from flooding increase with depth. Under certain conditions, hurricanes can produce storm surge flooding that is 20 to 30 feet above mean sea level or, in extreme cases such as reported during Hurricane Katrina, as much as 35 feet above mean sea level.

Duration: Duration is the measure of how long the water remains above normal levels. The duration of riverine flooding is primarily a function of watershed size and the longitudinal slope of the valley (which influences how fast water drains away). Small watersheds are more likely to be “flashy,” which refers to the rapidity with which floodwaters rise and fall. Areas adjacent to large rivers may be flooded for weeks or months. Most coastal flooding is influenced by the normal tidal cycle, as well as how fast coastal storms move through the region. Areas subject to coastal flooding can experience long duration flooding where drainage is poor or slow as a result of topography or the presence of flood control structures. For example, there may be depressions in the land that would hold water, or water may be trapped behind a floodwall or levee with inadequate drainage. More commonly, coastal flooding is of shorter duration, on the order of 12 to 24 hours, especially if storms move rapidly. Flooding along large lakes, including those behind dams, can be of very long duration because the large volume of water takes longer to drain. For building design, duration is important because it affects access, building usability, and saturation and stability of soils and building materials. Information about flood duration is sometimes available as part of a flood study, or could be developed by a qualified engineer.

Local drainage problems create ponding and local flooding that often is not directly associated with a body of water such as a creek or river. Although such flooding is relatively shallow and not characterized by high velocity flows, considerable damage may result. Areas with poor drainage frequently experience repetitive damage. Some local drainage problems are exacerbated by old or undersized drainage system infrastructure. Flooding caused by drainage problems typically occurs as sheetflow or along waterways with small drainage areas. This type of flooding is often not mapped or regulated.

Velocity: The velocity of floodwaters ranges from extremely high (associated with flash floods or storm surge) to very low or nearly stagnant (in backwater areas and expansive floodplains). Velocity is important in site planning because of the potential for erosion. In structural design, velocity is a factor in determining the hydrodynamic loads and impact loads. Even shallow, high-velocity water can threaten the lives of pedestrians and motorists. Accurate estimates of velocities are difficult to make, although velocity information may be found in some floodplain studies.

Wave action: Waves contribute to erosion and scour (see Figure 2-2), and also contribute significantly to design loads on buildings. The magnitude of wave forces can be 10 to more than 100 times greater than wind and other design loads, and thus may control many design parameters. Waves must be accounted for in site planning along coastal shorelines, in flood hazard areas that are inland of open coasts, and other areas where waves occur, including areas with sufficient fetch that winds can generate waves (such as lakes and expansive riverine floodplains). Waves on top of storm surges may be as much as 50 percent higher than the depth of the surge.

Impacts from debris and ice: Floating debris and ice contribute to the loads that must be accounted for in structure design. The methods and models used to predict and delineate flood hazard areas do not specifically incorporate debris loads. Thus, there are few sources to determine the potential effects of debris impact, other than past observations and judgment.

Erosion and scour: Erosion is the lowering of the ground surface as a result of a flood event, or the gradual recession of a shoreline as a result of long-term coastal processes. Scour refers to a localized lowering of the ground surface due to the interaction of currents and/or waves with structural elements, such as pilings. Soil characteristics influence an area's susceptibility to scour. Erosion and scour may affect the stability of foundations and filled areas, and may cause extensive site damage.

2.1.1.1 Probability of Occurrence or Frequency

The probability of occurrence, or frequency, is a statement of the likelihood that an event of a certain magnitude will occur in a given period of time. For many decades, floodplain management has been based on the flood that has a 1 percent chance of occurring in any given year, commonly called the “100-year flood.” For certain critical actions and decisions, such as planning or constructing a critical facility, the basis of risk decisions should be the flood that has a 0.2 percent probability of occurring in any given year, commonly called the “500-year flood.”

The term “100-year flood” as an expression of probability or frequency is often misunderstood because it conveys the impression that a flood of that magnitude will occur only once every 100 years. Actually, the 1-percent-annual-chance flood has one chance in 100 of occurring in any given year. The fact that a 1-percent-annual-chance flood is experienced at a specific location does not alter the probability that a comparable flood could occur at the same location in the next year, or even multiple times in a single year. As the length of the period increases, so does the probability that a flood of a specific magnitude or greater will occur. For example, during a 30-year period (the usual lending period for a home mortgage), the probability that a 100-year flood will occur is 26 percent. And during a 70-year period (the potential useful life of many buildings), the probability increases to 50 percent. Similarly, the 500-year flood has a 0.2-percent probability of being equaled or exceeded in any given year, and during a 70-year period the probability of occurrence is 18 percent.

The assigned frequency of a flood (e.g., 100-year) is independent of the number of years between actual occurrences. Hurricane Camille hit the Mississippi coast in 1969 with storm surge flooding that far exceeded previous events, and Hurricane Katrina affected much the same area. Although just 36 years apart, both storms produced flood levels significantly higher than the 100-year flood.

Regardless of the flood selected for design purposes (the “design flood”), the designer must determine specific characteristics associated with that flood. Determining a flood with a specific probability of occurrence is done in a multi-step process that typically involves using computer models that are in the public domain. If a sufficiently long record of flood information exists, the design flood may be determined by applying statistical tools to the data. Alternatively, water resource engi-

Flood frequency analyses are performed using historical records, and the results are influenced by the length of the record. Such analyses do not account for recent changes to the land (upland development or subsidence) or future changes (additional development, greater subsidence, or climatic variations).

neers sometimes apply computer models to simulate different rainfall events over watersheds, to predict how much water will run off and accumulate in channels. Other computer models are used to characterize the flow of water down the watershed and predict how high the floodwaters will rise.

For coastal areas, both historical storms and simulated storm surge models can be used to predict the probability that floodwaters will rise to a certain level and be accompanied by waves of certain heights. Many coastal storms will produce storm surge flooding that, depending on local topography, may extend inland significantly farther than anticipated for the 1-percent-annual-chance flood. Statistically, such extreme storm surges occur less frequently than the 1-percent or 0.2-percent-annual-chance floods, but their consequences can be catastrophic.

Planners and designers should research the relationship between the flood levels for different frequency events and extreme events, especially in hurricane-prone communities. The difference in flood levels may be extreme in some situations, depending on local conditions and the source of flooding. In other areas the lower probability flood depths might not be much higher than the 1-percent-annual-chance flood.

The National Flood Insurance Program (NFIP) is a Federal program that encourages communities to regulate flood hazard areas and, in return, offers property owners insurance protection against losses from flooding (see Sections 2.1.3.1 and 2.1.3.2). The NFIP uses the 1-percent-annual-chance flood as the basis for flood hazard maps, for setting insurance rates, and for application of regulations in order to minimize future flood damage. The 1-percent-annual-chance flood is also used as the standard for examination of older buildings to determine the measures to apply in order to reduce future damage.

Satisfying the minimum requirements of the NFIP does not provide adequate protection for critical facilities that need to be functional even after low probability events. Nearly every year, a very low probability flood occurs somewhere in the United States, often with catastrophic consequences. Therefore, for planning and design of critical facilities, use of a lower probability flood (at least the 500-year) is strongly recommended. As noted in Section 2.1.3.3, the 500-year level of protection is required if Federal funds are involved in constructing facilities that are vital for emergency response and rapid recovery, including hospitals, EOCs, emergency shelters, and other buildings that support vital services. This reinforces the importance of protecting both the functionality and financial investment in a critical facility with stricter standards than those applied to other buildings.

The Saffir-Simpson Hurricane Scale categorizes hurricanes based on sustained wind speeds (see Section 3.1.1). Storm surge is not always correlated with the category because other factors influence surge elevations, notably forward speed of the storm, tide cycle, offshore bathymetry, and land topography.

2.1.1.2 Hazard Identification and Flood Data

Flood hazard maps identify areas of the landscape that are subject to flooding, usually flooding by the 1-percent-annual-chance flood. Maps prepared by the NFIP are the minimum basis of State and local floodplain regulatory programs. Some States and communities have prepared maps of a floodplain based on the assumption that the upper watershed area is fully developed according to existing zoning. Some communities base their regulations on a flood of record or a historically significant flood that exceeds the base flood shown on the NFIP maps.

The flood hazard maps used by the appropriate regulatory authority should be consulted during planning and site selection, site design, and architectural and engineering design (whether for the design of new buildings or rehabilitation of existing buildings). Regardless of the flood hazard data required for regulatory purposes, additional research should be conducted on past major floods and other factors that could lead to more severe flooding.

The NFIP produces Flood Insurance Rate Maps (FIRMs) for more than 20,000 communities nationwide. FIRMs are prepared for each local jurisdiction that has been determined to have some degree of flood risk. The current effective maps are typically available for

It is important to note that the number of revised and updated FIRMs is increasing rapidly. During the last few years FEMA, in partnership with many States and communities, has been implementing an initiative to modernize and update all maps that are determined to be out of date. The modernization process may involve an examination of flood experience in the period since the original flood studies were prepared, use of more detailed topography and base maps, re-computation of flood discharges and flood heights, and re-delineation of flood hazard area boundaries.

viewing in community planning or permit offices.[1] It is important to use the most recent flood hazard map when determining site-specific flood hazard characteristics. Although many FIRMs are more than 15 years old, often one or more panels or portions of a map panel have been revised and republished. Communities must adopt revised maps to continue participating in the NFIP.

Some FIRMs do not show the 0.2-percent-annual-chance flood hazard area (500-year floodplain), and many FIRMs do not provide detailed information about predicted flood elevations along every body of water, especially smaller streams and tributaries. Determining the 500-year flood is especially difficult when records of past flood events are limited. When existing data are insufficient, additional statistical methods and engineering analyses are necessary to determine the flood-prone areas and the appropriate characteristics of flooding required for site layout and building design.

If a proposed facility site or existing facility is affected by flooding, a site-specific topographic survey is critical to delineate the land that is below the flood elevation used for planning purposes. If detailed flood elevation information is not available, a floodplain study may be required to identify the important flood characteristics and data required for sound design. Having flood hazard areas delineated on a map conveys a degree of precision that may be misleading. Flood maps have a number of limitations that should be taken into consideration, especially during site selection and design of critical facilities. Some of the well-known limitations are:

- Flood hazard areas are approximations based on probabilities; the flood elevations shown and the areas delineated should not be taken as absolutes, in part because they are based on numerical approximations of the real world.

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[1] Flood maps may also be viewed at FEMA's Map Store at http://www.fema.gov. For a fee, copies may be ordered online or by calling (800) 358-9616. The Flood Insurance Study (FIS) and engineering analyses used to determine the flood hazard area may be ordered through the FEMA Web site.

- FIRMs and Flood Insurance Studies (FISs) are prepared to meet the requirements of the NFIP. For the most part, floodplains along smaller streams and drainage areas (less than 1 square mile) are not shown.
- Especially for older maps, the topography used to delineate the flood boundary may have had contour intervals of 5, 10, or even 20 feet, which significantly affects the precision with which the boundary is determined. The actual elevation of the ground relative to the flood elevation is critical, as opposed to whether an area is shown as being in or out of the mapped flood hazard area.

In communities along the Gulf and Atlantic coasts, facility owners, planners, and designers should check with emergency management offices for maps that estimate storm surge flooding from hurricanes. Local planning or engineering offices may have post-disaster advisory flood maps and documentation of past storm surge events. The FIRMs and regulatory design flood elevations (DFEs) do not reflect low probability/high magnitude flooding that may result from a hurricane making landfall at a specific location.

- Maps are based on the data available at the time they were prepared, and therefore do not account for subsequent upland development (new development that increases rainfall-runoff tends to increase flooding).
- The scale of the maps may impede precise determinations (many older maps are 1 inch = 2,000 feet).
- Flooding characteristics may have been altered by development, sometimes by upland development that has increased runoff, and other times by local modifications that have altered the shape of the land surface of the floodplain (such as fills or levees).
- Local conditions are not reflected, especially conditions that change regularly, such as stream bank erosion and shoreline erosion.
- Areas exposed to very low probability flooding are not shown, such as flooding

Designers and property owners in coastal regions should be aware that current FIRMs may not fully account for natural and manmade changes to beaches, wetlands, and other coastal environments (e.g., the erosion of protective dunes during the base flood). Since the original FIRMs were published in the early 1980s, FEMA has made significant improvements in the models and methods used to identify coastal flood hazards. Before any action is considered, the Flood Insurance Study report should be checked to verify that all pertinent hazards have been addressed. A coastal engineer or similar professional should be consulted if there are any questions concerning the coastal flood data.

from extreme hurricane storm surges, extreme riverine flooding, dam failures, or overtopping or failure of levees.

The flood hazard maps prepared by the NFIP show different flood zones to delineate different floodplain characteristics (see Figures 2-3 and 2-4). The flood zones shown on the NFIP maps, and some other designations, are as described below.

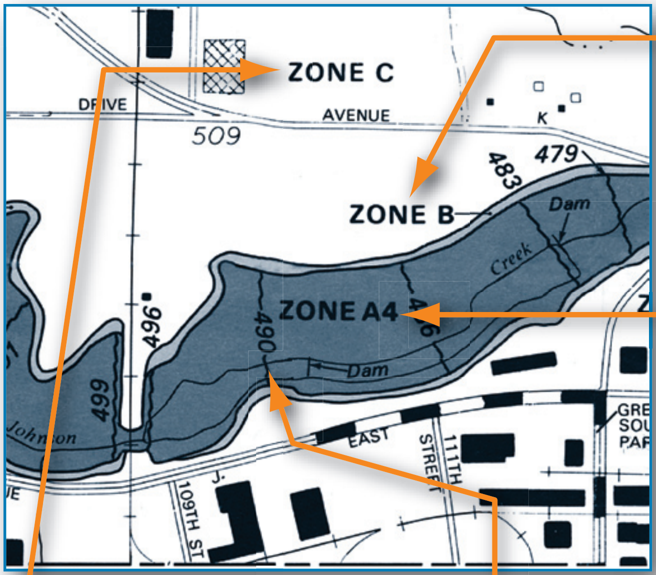
A Zones: (also called “unnumbered A Zones” or “approximate A Zones”). This designation is used for flood hazard areas where engineering analyses have not been performed to develop detailed flood elevations. Base flood elevations (BFEs) are not provided. Additional engineering analyses and site-specific assessments usually are required to determine the design flood elevation.

“Base flood elevation” is the elevation above a datum to which floodwaters are predicted to rise during the 1-percent-annual-chance flood (also called the “base flood” or the 100-year flood).

AE Zones or A1-A30 Zones: (also called “numbered A Zones”). These designations are used for flood hazard areas where engineering analyses have produced detailed flood elevations and boundaries for the base flood (1-percent-annual-chance flood). BFEs are provided. For riverine waterways with these zones, FISs include longitudinal profiles showing water surface elevations for different frequency flood events.

Floodways: The floodway includes the waterway channel and adjacent land areas that must be reserved in order to convey the discharge of the base flood without cumulatively increasing the water surface elevation above a designated height. Floodways are designated for most waterways that have AE Zones or numbered A Zones. FISs include data on floodway widths and mean floodway velocities.

AO and AH Zones: These zones include areas of shallow flooding and are generally shown where the flood depth averages from 1 to 3 feet, where a clearly defined channel does not exist, where the path of flooding is unpredictable, and where velocity flow may be evident. These zones are characterized by ponding or sheetflow. BFEs may be provided for AH Zones; flood depths may be specified in AO Zones.



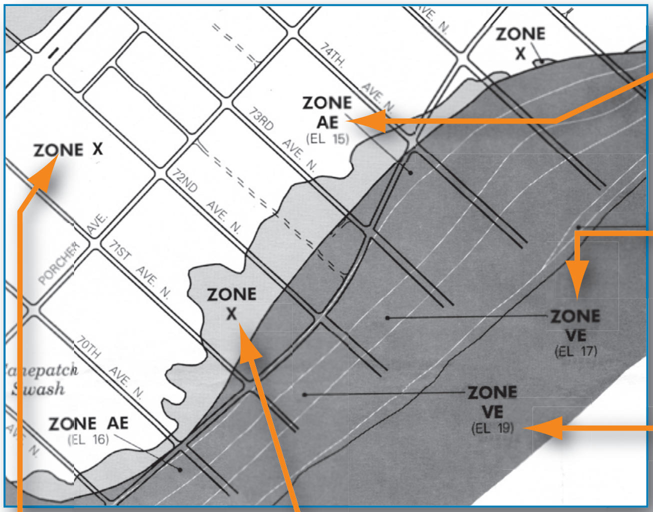
Zone B (or shaded Zone X) is subject to flooding by the 500-year flood (0.2 percent annual chance), and is a moderate risk area.

Zone A, A Zones A1-A30, and **Zone AE** are subject to flooding by the base of the 1percent annual chance (100-year) flood, and are considered high-risk areas.

Zone C (or Zone X) is all other areas, considered low-risk.

Base Flood Elevation (BFE), is the predicted water surface elevation of the base flood at specific locations (in feet above the datum).

Figure 2-3: Riverine flood hazard zones



Zone A, A Zones A1-A30, and **Zone AE** are subject to flooding by the base or 100-year flood (1percent annual chance), and waves less than 3 feet.

Zone V, V Zones V1-V30, and **Zone VE** are where waves are expected to be 3 feet or more.

Base Flood Elevation (BFE) is the predicted water surface elevation (in feet above datum).

Zone X
is all other areas.

Shaded Zone X
(or Zone B) is subject to flooding by the 500-year flood (0.2 percent annual chance).

Figure 2-4: Coastal flood hazard areas

Shaded X (or B) Zones: This zone shows areas of the 500-year flood (0.2-percent-annual-chance flood), or areas protected by flood control levees. This zone is not shown on many NFIP maps; its absence does not imply that flooding of this frequency will not occur.

Unshaded X (or C) Zones: These zones are all land areas not mapped as flood hazard areas that are outside of the floodplain and designated for the purposes of regulating development pursuant to the NFIP. These zones may still be subject to small stream flooding and flooding from local drainage problems.

V Zones (V, VE, and V1-V30): Also known as coastal high-hazard areas or special flood hazard areas subject to high-velocity wave action. V Zones are relatively narrow areas along open coastlines and some large lake shores that are subject to high-velocity wave action from storms or seismic sources. V Zones extend from offshore to the inland limit of a primary frontal dune, or to an inland limit where the height of breaking waves drops below 3 feet.

Coastal A Zone: This zone, which is not delineated on NFIP maps, is where the potential of breaking wave heights is between 1.5 feet and 3 feet during base flood conditions. Coastal A Zones are landward of the mapped V Zone, or landward of open coasts that do not have a V Zone because breaking waves are predicted to be less than 3 feet high. In these areas, the principal sources of flooding are tides, storm surges, seiches, or tsunamis, not riverine flooding.

Coastal A Zone: The current editions of the model building codes refer to ASCE 7 and ASCE 24, which are two design standards that include requirements for Coastal A Zones that account for the increased risk from the additional wave height (see Section 2.3.2).

Flood hazards and characteristics of flooding must be identified to evaluate appropriately the impact of site development, to calculate flood loads, to design floodproofing measures, and to identify and prioritize retrofit measures for existing critical facilities. Table 2-3 in Section 2.5 outlines a series of questions to facilitate this objective.

Many characteristics of flooding are not shown on the FIRMs but may be found in the FIS or the study or report prepared by the entity that produced the flood hazard map. Hurricane storm surge inundation maps based on the National Hurricane Center models have been prepared by the U.S. Army Corps of Engineers for most reaches of the Atlantic and Gulf coasts. The maps combine the results of many scenarios to show the maximum potential surge inundation associated with different categories of hurricanes. State and local emergency management offices use the maps for evacuation planning.

Hurricanes can produce storm surge flooding and waves that rise much higher than the BFE shown on the FIRMs.

2.1.1.3 Design Flood Elevation

The DFE establishes the minimum level of flood protection that must be provided. The DFE, as used in the model building codes, is defined as either the BFE determined by the NFIP and shown on FIRMs, or the elevation of a design flood designated by the community, whichever is higher. The DFE will always be at least as high as the BFE. Communities may use a design flood that is higher than the base flood for a number of reasons. For example, a design flood may be used to account for future upland development, to recognize a historic flood, or to incorporate a factor of safety, known as freeboard.

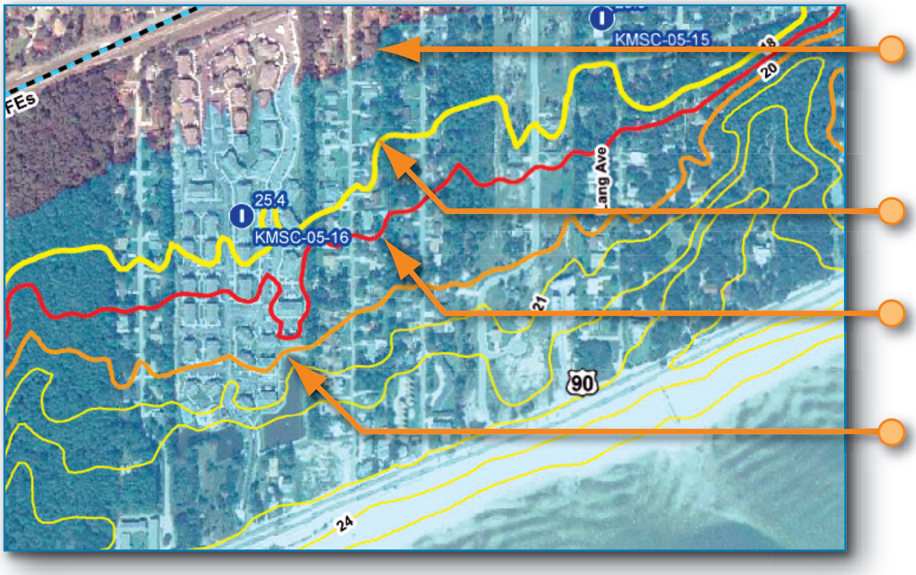
"Freeboard" is a factor of safety usually expressed in feet above a flood level. Freeboard compensates for the many unknown factors that could contribute to flood heights, such as wave action, constricting bridge openings, and the hydrological effect of urbanization of the watershed. A freeboard from 1 to 3 feet is often applied to critical facilities.

Facility owners, planners, and designers should check with the appropriate regulatory authority to determine the minimum flood elevation to be used in site planning and design. Although the NFIP minimum is the BFE, State or local regulations commonly cite the 0.2-percent-annual-chance flood (500-year flood) as the design requirement for critical facilities, or the regulations may call for added freeboard above the minimum flood elevation. Even if there is no specific requirement to use the 0.2-percent-annual-chance flood for siting and design purposes, it is strongly recommended that decisionmakers take into consideration the flood conditions associated with this lower probability event or from other floods of record.

2.1.1.4 Advisory Base Flood Elevation

The flood maps and flood hazard data described in Section 2.1.1.2 are the minimum information required to be used for regulatory purposes. The updating of FIRMs is a continuous process and it relies heavily on examination of storm event data and physical changes to the landscape. If significant flood events have occurred since the effective date of the FIRM, these events may change the statistical analyses, which would then prompt an update of the flood maps and produce revised elevations for the 1-percent-annual-chance flood. Critical facility owners, planners, and designers should contact community officials to determine whether there have been any significant flood events or other changes that may affect flood hazards since the effective date of the FIRM. The best available information should be used at all times.

FEMA works closely with communities to develop new flood hazard data or revise existing data during the standard flood study process. Updating flood hazard data includes the analysis of historical data. If a major flood event significantly alters the physical environment or if it is determined to be statistically significant, FEMA may decide to release Advisory BFEs (ABFEs) and Flood Recovery Maps (see Figure 2-5).



Limits of Katrina surge inundation

ABFE inland limit

Approximate limit of 1.5-foot wave zone

Approximate limit of 3-foot wave zone

Figure 2-5: Example of a flood recovery map showing ABFEs and other flood hazard information.

After Hurricane Katrina, FEMA expedited development of Flood Recovery Maps and ABFEs for the Mississippi coast—the new maps were delivered just 3 months after the storm.

ABFEs represent the best estimate of the expected 1-percent-annual-chance flood elevations. They are provided as interim flood hazard information until more detailed flood hazard data become available. Flood Recovery Maps depict the ABFEs, and in general, reflect additional information such as inundation limits and surveyed high water marks (but not the 500-year flood hazard area). For coastal areas, the Flood Recovery Maps may also show the inland debris line and the limit of the 1.5-foot wave (Coastal A Zone).

When ABFEs and Flood Recovery Maps are produced and released, FEMA strongly encourages States and communities, as well as private property owners and critical facility owners, to use the information to make decisions about reconstruction until more definitive data become available. FEMA issues guidance to help the users apply the updated flood elevation information at specific locations.

After Flood Recovery Maps are released, FEMA begins the formal process of updating the FIRMs. The community and property owners are notified through public notices and meetings when the preliminary revised maps are available and a formal comment period is opened. The final maps are prepared after consideration of comments. Communities are required to adopt and use the revised FIRMs in order to continue their participation in the NFIP.

2.1.2 FLOOD LOADS

Floodwaters can impose a variety of loads on buildings and building elements. This section provides a brief overview of flood loads and factors that are important for calculating flood loads, including:

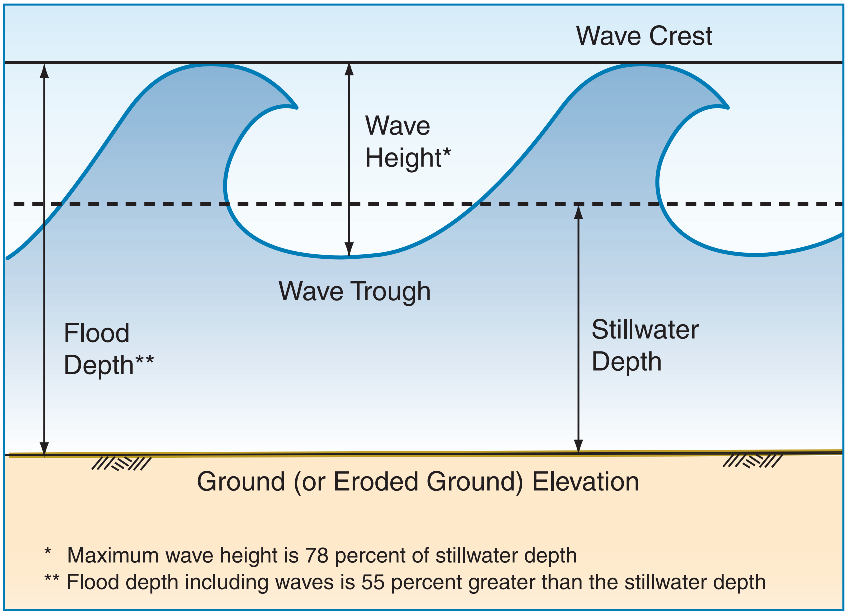
- ❍ Hydrostatic loads, including buoyancy, which increase as the depth of water increases
- ❍ Hydrodynamic loads, which result from moving water

- Breaking wave loads, which are most likely to occur in coastal areas
- Impact loads resulting from floating debris striking a building or building element
- Long-term erosion and localized scour, which can increase the effects and magnitudes of other loads

2.1.2.1 Design Flood Depth

Water depth associated with the design flood is computed by determining the DFE (see Section 2.1.1.3 or 2.1.1.4) and subtracting the elevation of the ground at the building site. Since these elevation data usually are obtained from different sources, it is important to determine whether they are based on the same datum. If not, standard corrections must be applied.

Flood depth is the most important factor required to compute flood loads, because almost every other flood load calculation depends directly or indirectly on this factor. In riverine areas, the flood depth rarely accounts for waves. In coastal areas, the total flood depth is composed of a "stillwater" depth, plus the expected height of waves (see Figure 2-6).



* Maximum wave height is 78 percent of stillwater depth
** Flood depth including waves is 55 percent greater than the stillwater depth

Figure 2-6:
Definition sketch—wave height and stillwater depth

The following characteristics that may add to the flood depth should be taken into consideration.

Small waves: In Coastal A Zones (see Section 2.3.2), the DFE shown on FEMA's maps does not include the wave height. Coastal A Zones are characterized by 1.5- to 3-foot high waves. The flood depth should be increased by 3 feet for sites close to the V Zone boundary or the shoreline. For sites farther inland, where the flood depth is at least 3 feet, it should be increased by 1.5 feet. Interpolation may be used to determine the amount that should be added to the flood depth to account for waves in the Coastal A Zone.

Waves and storm-induced erosion are most common in coastal areas. However, wide rivers and lakes may experience wind-driven waves and erodible soils are found throughout the United States. For more information about waves and erosion, refer to FEMA 55, *Coastal Construction Manual*.

Erosion and scour: Flood depths in areas with erodible soils should consider the effects of erosion where floodwaters lower the ground surface or cause local scour around foundation elements. In these areas, the flood depth determined using the design flood elevation should be increased to account for changes in conditions during a flood event. Not only does lowering the ground surface effectively result in deeper water against the foundation, it may also remove supporting soil from the foundation, which must be accounted for in the foundation design.

2.1.2.2 Design Flood Velocity—Riverine

There are few sources of information that are readily available for estimating design flood velocities at specific locations along riverine bodies of water. If a riverine source has been studied using detailed hydraulic methods, some information may be available in summary form in published studies. Studies prepared for the NFIP (see Section 2.1.1.2) contain tables of data for waterways for which floodways were delineated. For specified cross-sections along the waterway, the Floodway Data Table includes a mean velocity expressed in feet per second. This value is the average of all velocities across the floodway. Generally, velocities in the flood fringe (landward of the floodway) will be lower than in the floodway.

For waterways without detailed studies, methods that are commonly used in civil engineering for estimating open channel flow velocities can be applied.

2.1.2.3 Design Flood Velocity—Coastal

Estimating design flood velocities in coastal flood hazard areas is subject to considerable uncertainty, and there is little reliable historical information or measurements from actual coastal flood events. In this context, velocity does not refer to the motion associated with breaking waves, but the speed of the mass movement of floodwater over an area.

The direction and velocity of floodwaters can vary significantly throughout a coastal flood event. Floodwaters can approach a site from one direction as a storm approaches, then shift to another direction (or through several directions) as the storm moves through the area. Floodwaters can inundate some low-lying coastal sites from both the front (e.g., ocean) and the back (e.g., bay, sound, or river). In a similar manner, at any given site, flow velocities can vary from close to zero to very high. For these reasons, when determining flood loads for building design, velocities should be estimated conservatively and it should be assumed that floodwaters can approach from the most critical direction and that flow velocities can be high.

Despite the uncertainties, there are methods to approximate coastal flood velocities. One common method is based on the stillwater depth (flood depth without waves). Designers should consider the topography, the distance from the source of flooding, and the proximity to other buildings and obstructions before selecting the flood velocity for design. Those factors can direct and confine floodwaters, with a resulting acceleration of velocities. This increase in velocities is described as the “expected upper bound.” The “expected lower bound” velocities are experienced in areas where those factors are not expected to influence the direction and velocity of floodwaters.

Upper bound velocities caused by Hurricane Katrina along the Mississippi coast, where storm surge depths neared 35 feet deep, have been estimated at nearly 30 feet per second (20 miles per hour).

Figure 2-7 shows the general relationship between velocity and stillwater depth. For design purposes, actual flood velocities are assumed to lie between the upper and lower bounds. Conservative designs will take into account the upper bound velocities.

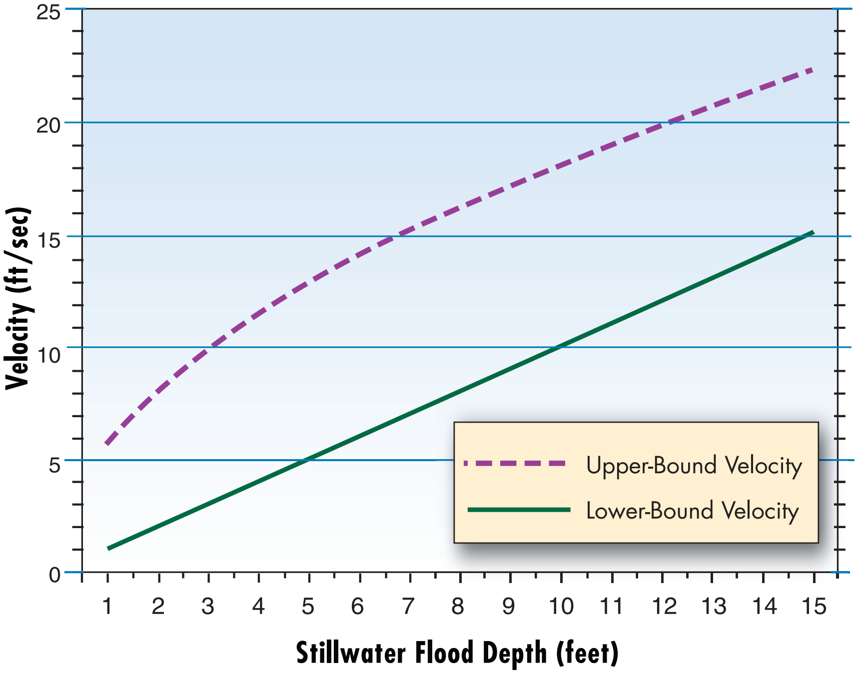


Figure 2-7:
Velocity as a function of stillwater flood depth

2.1.2.4 Hydrostatic Loads

Hydrostatic loads occur when water comes into contact with a building or building component, both above and below the ground level. They act as lateral pressure or vertical pressure (buoyancy). Hydrostatic loads on inclined or irregular surfaces may be resolved into lateral and vertical loads based on the surface geometry and the distribution of hydrostatic pressure.

Lateral hydrostatic loads are a direct function of water depth (see Figure 2-8). These loads can cause serious deflection or displacement of buildings or building components if there is a substantial difference in water levels on opposite sides of the component (or inside and outside of the building). Hydrostatic loads are balanced on foundation elements of elevated buildings, such as piers and columns, because the element is surrounded by water. If not oriented parallel to the flow of water, shearwalls may experience hydrostatic loads due to a difference of water depth on either side of the wall. To reduce excessive pressure from standing water, floodplain management requirements in A Zones call for openings in walls that enclose areas below the flood elevation (see description of continuous perimeter wall foundation in Section 2.3.1.2).

Buoyant forces resulting from the displacement of water are also of concern, especially for dry floodproofed buildings and aboveground and underground tanks. Buoyancy force is resisted by the dead load of the building or the weight of the tank. When determining buoyancy force, the weight of occupants or other live loads (such as the contents of a tank) should not be considered. If the building or tank does not weigh enough "empty," then additional stabilizing measures need to be taken to avoid flotation. This becomes a significant consideration for designs intended to dry floodproof a building. Buoyancy force is slightly larger in saltwater, because saltwater weighs slightly more than fresh water.

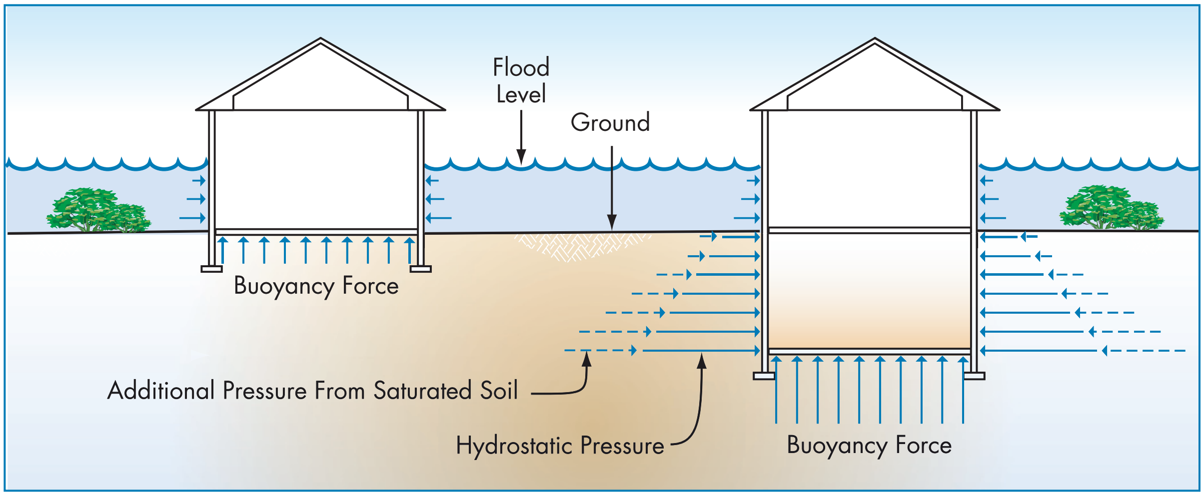


Figure 2-8: Hydrostatic loads on buildings

2.1.2.5 Hydrodynamic Loads

Water flowing around a building or a structural element that extends below the flood level imposes hydrodynamic loads. The loads, which are a function of flow velocity and structure geometry, include frontal impact on the upstream face, drag along the sides, and suction on the downstream side (see Figure 2-9). Ways to determine or estimate flood velocities are described in Section 2.1.2.2 and Section 2.1.2.3.

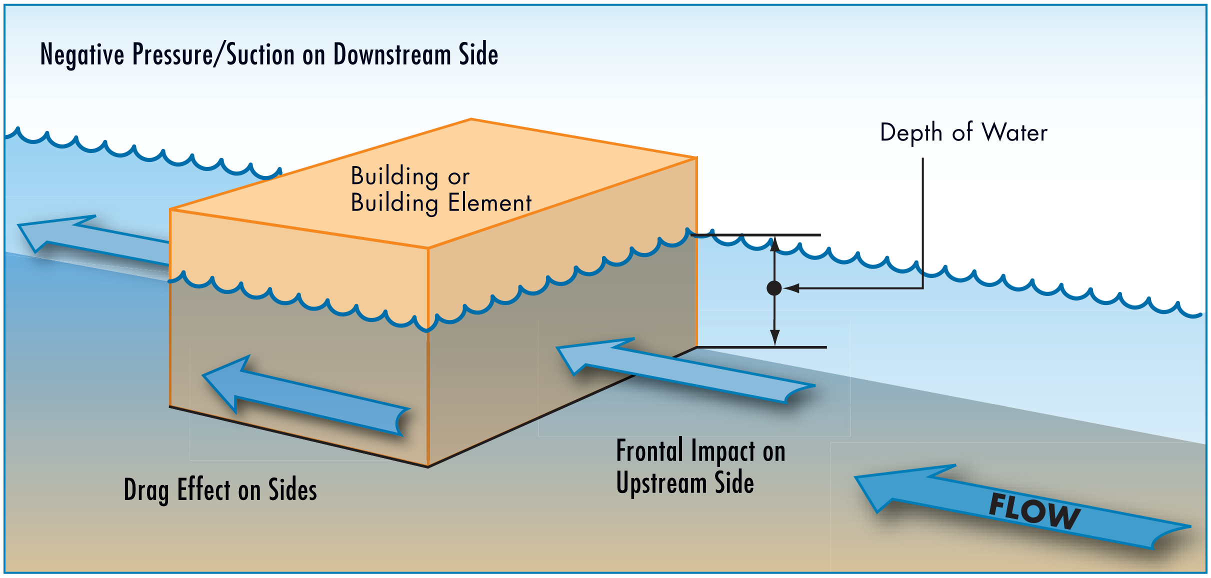


Figure 2-9: Hydrodynamic loads on a building or building element

The most common computation methods for hydrodynamic loads are outlined in the design standard *Minimum Design Loads for Buildings and Other Structures*, produced by the American Society of Civil Engineers' Structural Engineers Institute (ASCE/SEI, 2005). Those methods assume that the flood velocity is constant (i.e., steady state flow) and that the dynamic load imposed by floodwaters moving at less than 10 feet per second can be converted to an equivalent hydrostatic load. This conversion is accomplished by adding an equivalent surcharge depth to the depth of water on the upstream side. The equivalent surcharge depth is a function of the velocity. Loads imposed by floodwaters with velocities greater than 10 feet per second cannot be converted to equivalent hydrostatic loads. Instead, they must be determined according to the principles of fluid mechanics or hydraulic models.

Hydrodynamic loads become important when flow reaches moderate velocities of 5 feet per second. The components of hydrodynamic loads are laterally imposed, caused by the impact of the mass of water against the building, and drag forces along the wetted surfaces. Drag coefficients for common building elements, such as columns and piers, can be found in a number of sources. ASCE 7 recommends values for a variety of conditions.

Another component of hydrodynamic loads is wave loads. As described in ASCE 7, "design and construction of buildings and other structures subject to wave loads shall account for the following loads: waves breaking on any portion of the building or structure; uplift forces caused by shoaling waves beneath a building or structure, or portion thereof; wave runup striking any portion of the building or structure; wave-induced drag and inertia forces; and wave-induced scour at the base of a building or structure, or its foundation."

Wave forces striking buildings and building elements can be 10 to 100 or more times higher than wind forces and other forces. Forces of this magnitude can be substantial, even when acting over the relatively small surface area of the supporting structure of elevated buildings. Post-storm damage inspections show that breaking wave loads overwhelm virtually all wood-frame and unreinforced masonry walls below the wave crest elevation. Only engineered and massive structural elements are capable of withstanding breaking wave loads. The magnitude of wave forces is the rationale behind the floodplain management requirement for the bottom of the lowest horizontal structural member to be at or above the design flood elevation in environments where waves are predicted to be 3 feet or higher (V Zones). Because waves as low as 1.5 feet can impose considerable loads, there is a growing awareness of the value of accounting for waves in areas that are referred to as "Coastal A Zones."

Computation of wave loads depends on the determination of wave height. Equations for wave height are based on the assumption that waves are depth-limited (on the order of 75 to 80 percent of stillwater depth) and that waves propagating into shallow water break when the wave height reaches a certain proportion of the underlying stillwater depth. These assumptions are used by FEMA to determine coastal high hazard areas (V Zones) where breaking waves are predicted to be 3 feet or higher. At any given site, wave heights may be moderated by other factors. Designers should refer to ASCE 7 for detailed discussion and computation procedures.

Breaking wave loads on vertical walls or supporting structural members reach a maximum when the direction of wave approach is perpendicular to the wall. The duration of individual loads is brief, with peak pressures probably occurring within 0.1 to 0.3 seconds after the wave breaks. It is common to assume that the direction of approach will be perpendicular to the shoreline, in which case the orientation of the wall to the shoreline will influence the magnitude of the load placed on the wall. ASCE 7 provides a method for reducing breaking wave loads on vertical walls for waves that approach a building from a direction other than straight on. Structures should be designed for repetitive impact loads that occur during a storm. Some storms may last for just a few hours, as hurricanes move through the area, or for several days, as during some winter coastal storms (nor'easters) that affect the Mid-Atlantic and northeastern States.

2.1.2.6 Debris Impact Loads

Debris impact loads are imposed on a building or building elements by objects carried by moving water. Objects commonly carried by floodwaters include trees, dislodged tanks, and remnants of manmade structures such as docks and buildings (see Figure 2-10). Extreme impact loads result from less common sources, such as shipping containers, boats, and barges. The magnitude of these loads is very difficult to predict, yet some reasonable allowance should be made during the design process.

Impact loads are influenced by the location of the building in the potential debris stream. The potential for debris impacts is significant if a building is located immediately adjacent to, or downstream from, other buildings, among closely-spaced buildings, or downstream from large floatable objects. While these conditions may be observable in coastal areas, it is more difficult to estimate the potential for debris in riverine flood hazard areas. Any riverine waterway, whether a large river or smaller urban stream, can carry large quantities of debris, especially uprooted trees.

Figure 2-10:
The South Cameron Memorial Hospital, Cameron, LA, was damaged by debris carried by Hurricane Katrina's storm surge (2005).

SOURCE: LSU AGCENTER

The basic equation for estimating the magnitude of impact loads depends on several variables that must be selected by the designer. These variables include several coefficients, building or building element stiffness, debris weight, debris velocity, and duration of impact. The latter three variables, described in more detail in ASCE 7, are briefly described below.

Debris weight: Debris weight is one of the more difficult variables to estimate. Unless otherwise indicated by field conditions, ASCE 7 recommends using an average object weight of 1,000 pounds. This weight corresponds to a 30-foot long log only 1 foot in diameter, small in comparison to large trees that may be uprooted during a flood. In coastal areas, expected debris weights depend on the nature of the debris. In the Pacific Northwest, large trees and logs are common, with weights in excess of 4,000 pounds. In areas where piers and pilings are likely to become debris, 1,000 pounds is reasonable. In areas where most debris is likely to result from building damage (failed decks, steps, failed walls, propane tanks), the average debris weight may be less than 500 pounds.

Debris velocity: The velocity of the debris depends on the nature of the debris and the velocity of floodwaters. For the impact load computation, the velocity of the water-borne object is assumed to be the same as the flood velocity. Although this assumption is reasonable for smaller objects, it is conservative for large objects.

Debris impact duration: Duration of impact is the elapsed time during which the impact load acts on the building or building element. The duration of impact is influenced primarily by the natural frequency[2] of the building or element, which is a function of the building's stiffness. Stiffness is determined by the properties of the material, the number of supporting members (columns or piles), the height of the building above the ground, and the height at which the element is struck. Despite all the variables that may influence duration of impact, early assumptions suggested a 1-second duration. A review of results from several laboratory tests that measured impacts yielded much briefer periods, and ASCE 7 currently recommends a duration of 0.03 second.

2.1.2.7 Erosion and Localized Scour

Erosion generally refers to a lowering of the ground surface as a result of a flood event. Erosion may occur in riverine and coastal flood hazard areas. In coastal areas, erosion may affect the general ground surface and may cause a short-term or long-term recession of the shoreline. Erosion should be considered during load calculations, because it increases the local flood depth, which in turn influences load calculations. In areas subject to gradual erosion of the ground surface, additional foundation embedment depth can mitigate the effects. However, where waterways are prone to changing channels and where shoreline erosion is significant, engineered solutions are unlikely to be effective. Avoidance of sites in areas subject to active erosion is the safest and most cost-effective course of action.

Localized scour results from turbulence at the ground level around foundation elements. Scour occurs in both riverine and coastal flood hazard areas, especially in areas with erodible soils.

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[2] The frequency at which an object will vibrate freely when set in motion.

Determining potential scour is critical in the design of foundations to ensure that failure during and after flooding does not occur as a result of the loss in either bearing capacity or anchoring resistance around the posts, piles, piers, columns, footings, or walls (see Figure 2-11). Scour determinations require knowledge of the flood depth, flow conditions, soil characteristics, and foundation type.

At some locations, soil at or below the ground surface can be resistant to localized scour, and calculated scour depths based on unconsolidated surface soils below will be excessive. In instances where the designer believes the underlying soil at a site will be scour-resistant, the assistance of a geotechnical engineer or geologist should be sought.

Figure 2-11:
Local scour undermined this shallow foundation (also note that the building was not anchored to the foundation).

2.1.3 FLOODPLAIN MANAGEMENT REQUIREMENTS AND BUILDING CODES

The NFIP is the basis for the minimum requirements included in model building codes and standards for design and construction methods to resist flood damage. The original authorizing legislation for the NFIP is the National Flood Insurance Act of 1968 (42 U.S.C. 4001 et seq.). In that act, Congress expressly found that "a program of flood insurance can promote the public interest by encouraging sound land use by minimizing exposure of property to flood losses…"

The most convincing evidence of the effectiveness of the NFIP minimum requirements is found in flood insurance claim payment statistics. Buildings that pre-date the NFIP requirements are, by and large, not constructed to resist flood damage. Buildings that post-date the NFIP (i.e., those that were constructed after a community joined the program and began applying the minimum requirements) are designed to resist flood damage. The NFIP reports that aggregate loss data indicate that buildings that meet the minimum requirements experience 70 percent less damage than buildings that pre-date the NFIP. There is ample evidence that buildings designed to exceed the minimum requirements are even less likely to sustain damage.

2.1.3.1 Overview of the NFIP

The NFIP is based on the premise that the Federal government will make flood insurance available in communities that agree to recognize and incorporate flood hazards in land use and development decisions. In some States and communities this is achieved by guiding development to areas with a lower risk. When decisions result in development within flood hazard areas, application of the criteria set forth in Federal regulation 44 CFR §60.3 are intended to minimize exposure and flood-related damage. State and local governments are responsible for applying the provisions of the NFIP through the regulatory permitting processes. At the Federal level, the NFIP is managed by FEMA and has three main elements:

- Hazard identification and mapping, under which engineering studies are conducted and flood maps are prepared in partnership with States and communities. These maps delineate areas that are predicted to be subject to flooding under certain conditions.

- Floodplain management criteria for development, which establish the minimum requirements to be applied to development within mapped flood hazard areas. The intent is to recognize hazards in the entire land development process.

- Flood insurance, which provides some financial protection for property owners to cover flood-related damage to buildings and contents.

"Substantial damage" is damage of any origin sustained by a structure whereby the cost of restoring the structure to its condition before the damage would equal or exceed 50 percent of the market value of the structure before the damage occurred.

"Substantial improvement" is any repair, reconstruction, rehabilitation, addition, or improvement of a building, the cost of which exceeds 50 percent of the market value of the building before the improvement or repair is started (certain historic structures may be excluded).

Federal flood insurance is intended to shift some of the costs of flood disasters away from the taxpayer by providing property owners an alternative to disaster assistance and disaster loans. Disaster assistance provides limited funding for repair and cleanup, and is available only after the President signs a major disaster declaration for the area. NFIP flood insurance claims are paid any time damage from a qualifying flood event[3] occurs, regardless of whether a major disaster is declared. Community officials should be aware that public buildings may be subject to a mandated reduction in disaster assistance payments if the building is in a mapped flood hazard area and is not covered by flood insurance.

Another important objective of the NFIP is to break the cycle of flood damage. Many buildings have been flooded, repaired or rebuilt, and flooded again. Before the NFIP, in some parts of the country this cycle occurred every couple of years, with reconstruction taking place in the same flood-prone areas, using the same construction techniques that did not adequately resist flood damage. NFIP provisions guide development to lower risk areas by requiring compliance with performance measures to minimize exposure of new buildings and buildings that undergo major renovation or expansion (called "substantial improvement" or repair of "substantial damage"). This achieves the long-term objective of building disaster-resistant communities.

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3. For the purpose of adjusting claims for flood damage, the NFIP defines a flood as "a general and temporary condition of partial or complete inundation of two or more acres of normally dry land area or of two or more properties (at least one of which is the policyholder's property) from: overflow of inland or tidal waters; unusual and rapid accumulation or runoff of surface waters from any source; mudflow; or collapse or subsidence of land along the shore of a lake or similar body of water as a result of erosion or undermining caused by waves or currents of water exceeding anticipated cyclical levels that result in a flood as defined above."

2.1.3.2 Summary of the NFIP Minimum Requirements

The performance requirements of the NFIP are set forth in Federal regulation 44 CFR Part 60. The requirements apply to all development, which the NFIP broadly defines to include buildings and structures, site work, roads and bridges, and other activities. Buildings must be designed and constructed to resist flood damage, which is primarily achieved through elevation (or floodproofing). Additional specific requirements apply to existing development, especially existing buildings. Existing buildings that are proposed for substantial improvement, including restoration following substantial damage, are subject to the regulations.

Although the NFIP regulations primarily focus on how to build structures, one of the long-term objectives of the program is to guide development to less hazardous locations. Preparing flood hazard maps and making the information available to the public is fundamental in satisfying that objective. With that information, people can make informed decisions about where to build, how to use site design to minimize exposure to flooding, and how to design buildings that will resist flood damage.

The NFIP's broad performance requirements for site work in flood hazard areas are as follows:

- Building sites shall be reasonably safe from flooding.
- Adequate site drainage shall be provided to reduce exposure to flooding.
- New and replacement sanitary sewage systems shall be designed to minimize or eliminate infiltration of floodwaters into the systems and discharges from the systems into floodwaters.
- Development in floodways shall be prohibited, unless engineering analyses show that there will be no increases in flood levels.

The NFIP's broad performance requirements for new buildings proposed for flood hazard areas (and substantial improvement of existing flood-prone buildings) are as follows:

- Buildings shall be designed and adequately anchored to prevent flotation, collapse, or lateral movement resulting from hydrodynamic and hydrostatic loads, including the effects of buoyancy.
- Building materials used below the design flood elevation shall be resistant to flood damage.
- Buildings shall be constructed to minimize flood damage (primarily by elevating to or above the base flood level, or by specially designed and certified floodproofing measures).
- Buildings shall be constructed with electrical, heating, ventilation, plumbing, and air conditioning equipment and other service facilities designed to prevent water from entering or accumulating within the components.

Owners, planners and designers should determine if there are any applicable State-specific requirements for floodplain development. Some States require that local jurisdictions apply standards that exceed the minimum requirements of the NFIP. In particular, some States require that critical facilities be located outside of the floodplain (including the 500-year floodplain) or they are to be designed and constructed to resist conditions associated with the 500-year flood. Some States have regulations that impose other higher standards, while some States have direct permitting authority over certain types of construction or certain types of applicants.

States often use governors' executive orders to influence State-constructed and State-funded critical facilities, requiring location outside of the 500-year floodplain where feasible, or protection to the 500-year flood level if avoiding the floodplain is not practical. In 2004, a review of State and local floodplain management programs determined that Alabama, Illinois, Michigan, New York, North Carolina, Ohio, and Virginia have requirements for critical facilities (ASFPM, 2004).

As participants in the NFIP, States are required to ensure that development that is not subject to local regulations, such as State construction, satisfies the same performance requirements. If critical facilities are exempt from local permits, this may be accomplished through a State permit, a governor's executive order, or other mechanisms that apply to entities not subject to local authorities.

2.1.3.3 Executive Order 11988 and Critical Facilities

When Federal funding is provided for the planning, design, and construction of new critical facilities, or for the repair of existing critical facilities located within the 500-year floodplain, the funding agency is required to address additional considerations. Executive Order 11988, Floodplain Management, requires Federal agencies to apply a decisionmaking process to avoid, to the extent possible, the long- and short-term adverse impacts associated with the occupancy and modification of floodplains, and to avoid the direct or indirect support of floodplain development whenever there is a practicable alternative. If there is no practicable alternative, the Federal agency must minimize any adverse impacts to life, property, and the natural and beneficial functions of floodplains.

The executive order establishes the base flood elevation as the minimum standard for all Federal agencies. Implementation guidance specifically addresses "critical actions," which are described as those actions for which even a slight chance of flooding would be too great. The construction or repair of critical facilities, such as fire stations, hospitals and clinics, EOCs, the storage of hazardous wastes, and the storage of critical records, are examples of critical actions.

After determining that a site is in a mapped flood hazard area, and after giving public notice, the Federal funding agency is required to identify and evaluate practicable alternatives to locating a critical facility in a 500-year floodplain. If the Federal agency has determined that the only practicable alternative is to proceed, then the impacts of the proposed action must be identified. If the identified impacts are harmful to people, property, and the natural and beneficial functions of the floodplain, the Federal

FEMA's eight-step decisionmaking process for complying with Executive Order 11988 must be applied before Federal disaster assistance is used to repair, rehabilitate, or reconstruct damaged existing critical facilities in the 500-year floodplain.

agency is required to minimize the adverse effects on the floodplain and the funded activity.

Having identified the impacts of the proposed action and the methods to minimize these impacts, the Federal agency is required to re-evaluate the proposed action. The re-evaluation must consider whether the action is still feasible, whether the action can be modified to relocate the facility or eliminate or reduce identified impacts, or if a "no action" alternative should be chosen. If the finding results in a determination that there is no practicable alternative to locating a critical facility in the floodplain, or otherwise affecting the floodplain, then a statement of findings and a public explanation must be provided.

2.1.3.4 Scope of Model Building Codes and Standards

The *International Building Code* (IBC, 2003) and the *Building Construction and Safety Code*™ (NFPA 5000, 2003) were the first model codes to include comprehensive provisions that address flood hazards. Both codes are consistent with the minimum provisions of the NFIP that pertain to the design and construction of buildings. The NFIP requirements that pertain to site development, floodways, coastal setback lines, erosion-prone areas, and other environmental constraints are found in other local ordinances. The codes require designers to identify and design for anticipated environmental loads and load combinations, including wind, seismic, snow, and flood loads, as well as the soil conditions.

The IBC and NFPA 5000 incorporate by reference a number of standards that are developed through a rigorous consensus process. The best known is *Minimum Design Loads for Buildings and Other Structures* (ASCE 7-05). The model building codes require that applicable loads be accounted for in the design. The 1998 edition of ASCE 7 was the first version of the standard to include flood loads explicitly, including hydrostatic loads, hydrodynamic loads (velocity and waves), and debris impact loads.

The IBC and NFPA 5000 also incorporate by reference a standard that was first published by ASCE in 1998 and revised in 2005, *Flood Resistant Design and Construction* (ASCE/SEI 24-05).

Developed through a consensus process, ASCE 24 addresses specific topics pertinent to designing buildings in flood hazard areas, including floodways, coastal high hazard areas, and other high-risk flood hazard areas such as alluvial fans, flash flood areas, mudslide areas, erosion-prone areas, and high floodwater velocity areas.

Section 1.2 describes the four categories used by ASCE 7 to classify structures based on occupancy; different requirements apply based on a structure's category. The same categories are used in ASCE 24 and different flood-resistant requirements apply to the different categories. Table 2-1 summarizes the elevation requirements of ASCE 24 that exceed the NFIP minimum requirements for the critical facilities addressed by this manual (Category III or Category IV structures).

ASCE 7-05 outlines methods to determine design loads and load combinations in flood hazard areas, including hydrostatic loads, hydrodynamic loads, wave loads, and debris impact loads.

ASCE 24-05 addresses design requirements for structures in coastal high-hazard areas (V Zones).

Table 2-1: ASCE/SEI 24-05 provisions related to the elevation of critical facilities

		Category III	Category IV
Elevation of Lowest Floor or Bottom of Lowest Horizontal Structural	A Zone: elevation of lowest floor	BFE +1 ft or DFE, whichever is higher	BFE +2 ft or DFE, whichever is higher
	V Zone and Coastal A Zone: where the lowest horizontal structural member is parallel to direction of wave approach	BFE +1 ft or DFE, whichever is higher	BFE +1 ft or DFE, whichever is higher
	V Zone and Coastal A Zone: where the lowest horizontal structural member is perpendicular to direction of wave approach	BFE +2 ft or DFE, whichever is higher	BFE +2 ft or DFE, whichever is higher
Elevation Below which Flood-Damage-Resistant Materials Shall	A Zone	BFE +1 ft or DFE, whichever is higher	BFE +2 ft or DFE, whichever is higher
	V Zone and Coastal A Zone: where the lowest horizontal structural member is parallel to direction of wave approach	BFE +2 ft or DFE, whichever is higher	BFE +2 ft or DFE, whichever is higher
	V Zone and Coastal A Zone: where the lowest horizontal structural member is perpendicular to direction of wave approach	BFE +3 ft or DFE, whichever is higher	BFE +3 ft or DFE, whichever is higher
Minimum Elevation of Utilities and Equipment	A Zone	BFE +1 ft or DFE, whichever is higher	BFE +2 ft or DFE, whichever is higher
	V Zone and Coastal A Zone: where the lowest horizontal structural member is parallel to direction of wave approach	BFE +2 ft or DFE, whichever is higher	BFE +2 ft or DFE, whichever is higher
	V Zone and Coastal A Zone: where the lowest horizontal structural member is perpendicular to direction of wave approach	BFE +3 ft or DFE, whichever is higher	BFE +3 ft or DFE, whichever is higher
Dry Floodproofing	A Zone: elevation to which dry floodproofing extends	BFE +1 ft or DFE, whichever is higher	BFE +2 ft or DFE, whichever is higher
	V Zone and Coastal A Zone: dry floodproofing not allowed	Not applicable	Not applicable

2.2 CRITICAL FACILITIES EXPOSED TO FLOODING

2.2.1 EVALUATING RISK AND AVOIDING FLOOD HAZARDS

Even in communities with expansive floodplains, it should be possible to avoid locating new critical facilities in floodways and coastal areas subject to significant waves (V Zones).

Flood hazards are very site-specific. When a flood hazard map is prepared, lines drawn on the map appear to precisely define the hazard area. Land that is on one side of the line is "in" the mapped flood hazard area, while the other side of the line is "out." Although the delineation may be an approximation, having hazard areas shown on a map facilitates avoiding such areas to the maximum extent practical. Where it is unavoidable, facility owners should carefully evaluate all of the benefits and all of the costs in order to determine long-term acceptable risks, and to develop appropriate plans for design and construction of new facilities.

Section 2.2.2 describes the damage sustained by existing buildings exposed to flood hazards, including site damage, structural and nonstructural building damage, destruction or impairment of service equipment, and loss of contents. These types of damage, along with loss of function and community service, are avoided if critical facilities are located away from flood hazard areas. Damage is reduced when critical facilities that must be located in flood hazard areas are built to exceed the minimum requirements.

2.2.1.1 Benefits/Costs: Determining Acceptable Risk

Extreme hurricane storm surge flooding may be a very low-probability event, but the flood water depths and waves may be much more severe than the conditions of the base flood shown on the FIRMs. The potential impacts on a critical facility must be carefully considered in order to make an informed decision regarding acceptable risk and potential damage. If possible, it is always best to avoid locating critical facilities in areas subject to extreme storm surge flooding.

Many decisions that are made with respect to critical facilities are, in part, based on a determination of acceptable risk. Risk includes the potential losses associated with a hazard. Ideally, risk is defined in terms of expected probability and frequency of the hazard occurring, the people and property exposed, and the potential consequences. Choosing a site that is affected by flooding is a decision to accept some degree of risk. Although the flood-prone land may have a lower initial cost, the incremental costs of construction, plus the likely increased costs of maintenance, repair, and replacement, may be significant. Another cost of locating a critical facility in a flood-prone area is related to access problems if roads and driveways are impassable. Although the building may be elevated and protected, if access is restricted periodically, then the use of the facility is affected.

The building owner and the design team can influence the degree of risk (e.g., the frequency with which flooding may affect the site). They control it through the selection of the site design and the building design measures. Fundamentally, this process is a balancing of the benefits of an acceptable level of disaster resistance with the costs of achieving that degree of protection. With respect to mitigation of future hazard events:

- Benefits are characterized and measured as future damages avoided if the mitigation measures (including avoiding flood hazard areas) are implemented.

- Costs are the costs associated with implementing measures to eliminate or reduce exposure to hazards.

Section 2.2.2 describes damage and losses that are incurred by buildings exposed to flooding. Direct damage includes damage to physical property, including the site, the building, building materials, utilities, and building contents. Indirect damage that is not listed includes health hazards, loss of functionality, emergency response, evacuation, and expenses associated with occupying another building during repairs.

Sometimes developers are required to set aside land to meet adequate facilities requirements, or land may be donated to support community or non-profit facilities, such as fire stations. If the donated land is affected by flood hazards, it may be difficult to avoid floodplain impacts entirely. Careful consideration should be made whether the benefits of accepting the land outweigh the costs and risks associated with mitigating the flood risk.

Benefits other than avoided physical damage are difficult to measure. They are associated with future damage that does not occur because of the mitigation activity, cleanup that is not required because of the mitigation activity, and service that is not interrupted because flooding does not affect normal operation of the facility. In addition, benefits accrue over long periods of time, thus making it more difficult to make a direct comparison of the benefits with the up-front costs of mitigation. Mitigation costs can be more readily expressed in terms of the higher costs of a flood-free site, or the initial capital costs of work designed to resist flood damage. Thus, without a full accounting of both benefits and costs, decisionmakers may not be able to make fully informed decisions. Some questions that should be answered include:

- If the site is flood-prone and the building is out of the flood hazard area or is elevated on fill, what are the average annual cleanup costs associated with removal of sand, mud, and debris deposited by floods of varying frequencies?

- If the facility building is elevated by means other than fill, will periodic inundation of the exposed foundation elements cause higher average annual maintenance costs?

- If the facility is protected with floodproofing measures, what are the costs of annual inspections, periodic maintenance and replacement of materials, and staff training and periodic drills?

- If the critical facility meets only the minimum elevation requirements, what are the average annual damage and cleanup costs over the anticipated useful life of the building, including the occurrence of floods that exceed the design flood elevation?

❍ How do long-term costs associated with periodic inundation compare to up-front costs of selecting a different site or building to a higher level of protection?

❍ If the facility is located in a hurricane-prone community, how should the facility design account for low probability, but high impact, storm surge flooding?

❍ If access to the facility is periodically restricted due to flooding, especially long-duration flooding, what are the cost effects? How often should an alternate location be provided to continue normal operations?

2.2.1.2 Identifying Flood Hazards at Critical Facilities Sites

As part of site selection and to guide locating a new critical facility and other improvements on a site, facility owners, planners, and designers should investigate site-specific flood hazard characteristics. Similarly, when examining existing critical facilities and when planning improvements or rehabilitation work, an important step is to determine the site characteristics and flood hazards. The best available information should be examined, including flood hazard maps, records of historical flooding, storm surge maps, and advice from local experts and others who can evaluate flood risks. Table 2-3 in Section 2.5 outlines questions that should be answered prior to initiating site layout and design work.

2.2.1.3 Critical Facilities as Emergency Shelters

Emergency managers regularly identify facilities (especially schools) to serve as short-term and long-term shelters. Schools are attractive sites for shelters because they have kitchen facilities designed to serve many people, restroom facilities likely to be adequate for many people, and plenty of space for cots in gymnasiums, cafeterias, and wide corridors.

New schools that will function as emergency shelters warrant a higher degree of protection than other schools and should be appropriately designed as critical facilities (see Section 1.3 for an overview on performance-based design). If located in, or adjacent to, flood hazard areas, it is appropriate to provide protection for the building and utility systems to at least the 0.2-percent-annual-chance (500-year) flood level or, at a minimum, 2 to 3 feet above the DFE. Additional guidance on hazard-resistant shelters is found in FEMA 361, *Design and Construction Guidance for Community Shelters*.

Additional measures that may be appropriate for consideration when flood-prone critical facilities are used as shelters include the following:

- Wastewater service must be functional during conditions of the flooding.
- Emergency power service must be provided.
- Dry ground access is important, in the event flooding exceeds design levels.

2.2.2 VULNERABILITY: WHAT FLOODING CAN DO TO EXISTING CRITICAL FACILITIES

Existing flood-prone facilities are susceptible to damage, the nature and severity of which is a function of site-specific flood characteristics. As described below, damage may include: site damage, structural and nonstructural building damage, destruction or impairment of utility service equipment and loss of contents.

Regardless of the nature and severity of damage, flooded facilities typically are not functional while cleanup and repairs are undertaken. The length of closure, and thus the impact on the ability of the facility to become operational, depends on the severity of the damage and lingering health hazards. Sometimes repairs are put on hold pending a decision on whether a facility should be rebuilt at the flood-prone site. When damage is substantial, rehabilitation or reconstruction is allowed only if compliance with flood-resistant design requirements is achieved (see Section 2.1.3.2).

2.2.2.1 Site Damage

The degree of site damage associated with flooding is a function of several variables related to the characteristics of the flood, as well as the site itself.

Erosion and scour: All parts of a site subject to flooding by fast moving water could experience erosion, and local scour could occur around any permanent obstructions to flow. Graded areas, filled areas, and cut or fill slopes are especially susceptible. Stream and channel bank erosion, and erosion of coastal shorelines, are natural phenomena that may, over time, threaten site improvements and buildings.

Debris and sediment removal: Even when buildings are not subject to water damage, floods can produce large quantities of debris and sediment that can damage a site and be expensive to remove.

Landscaping: Grass, trees, and plants suffer after floods, especially long-duration flooding that prevents oxygen uptake, and coastal flooding that stresses plants that are not salt-tolerant. Fast-moving floodwaters and waves also can uproot plants and trees.

Fences: Some types of fences that are relatively solid can significantly restrict the free flow of floodwaters and trap floating debris. Fences can be damaged by flowing water, and can be knocked down under pressure of flowing water or if the buildup of debris results in significant loads (see Figure 2-12).

Accessory structures: Accessory structures can sustain both structural and nonstructural damage. In some locations, such structures can be designed and built using techniques that minimize damage potential, without requiring elevation above the DFE.

Access roads: Access roads that extend across flood-prone areas may be damaged by erosion, washout of drainage culverts, failure of fill and bedding materials, and loss of surface (see Figure 2-13). Road damage could prevent uninterrupted access to a facility and thus impair its functionality.

Figure 2-12:
Katrina's storm surge flooding knocked down this fence adjacent to a fire station (2005).

Figure 2-13:
Flooding caused the failure of this road bed.
SOURCE: U.S. ARMY CORPS OF ENGINEERS

Parking lots and parking garages: Paved parking lots may be damaged by failure of bedding materials and loss of driving surface. Vehicles left in parking lots and parking garages could also be damaged. Most large parking garages are engineered structures that can be designed to allow for the flow of water.

Stormwater management facilities and site drainage: Site improvements such as swales and stormwater basins may be eroded, filled with sediments, or clogged by debris.

2.2.2.2 Structural Damage

Structural damage includes all damage to the load-bearing portions of a building. Structural damage can be caused by each of the characteristics of flooding described in Section 2.1.1.

Damage to other components of buildings is described below, including saturation of materials (Section 2.2.2.3), utility service equipment (Section 2.2.2.4), and contents (Section 2.2.2.5).

Depth: The hydrostatic load or pressure against a wall or foundation is directly related to the depth of water (refer to Figure 2-9). Standard stud and siding, or unreinforced brick veneer walls, may collapse under hydrostatic loads associated with relatively shallow water. Reinforced masonry walls perform better than unreinforced masonry walls (see Figure 2-14), although an engineering analysis is required to determine performance. Walls and floors of below-grade areas (basements) are particularly susceptible to damage by hydrostatic pressure. When soils are saturated, pressures against below-grade walls are a function of the total depth of water, including the depth below-grade and the weight of the saturated soils.

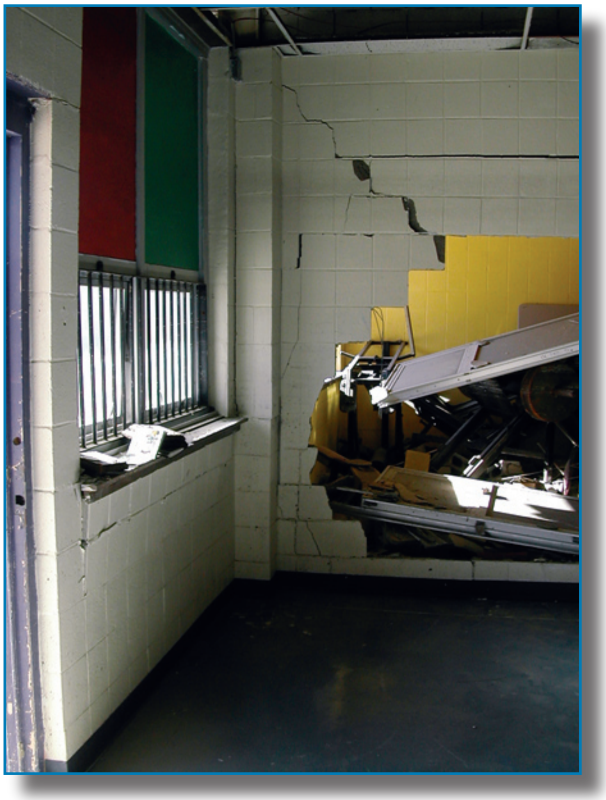


Figure 2-14:
Interior unreinforced masonry walls of the Port Sulphur High School in Louisiana were damaged by hydrostatic loads associated with Hurricane Katrina's storm surge (2005).

Buoyancy and uplift: If below-grade areas are essentially watertight, buoyancy or uplift forces can float a building out of the ground or rupture concrete floors (see Figure 2-15). Buildings that are not adequately anchored can be floated or pushed off foundations. Although rare for large and heavy critical facility buildings, this is a concern for outbuildings and portable (temporary) units.

Figure 2-15:
Concrete floor ruptured by hydrostatic pressure (buoyancy). Hurricane Katrina (2005)

Duration: Long duration saturation can cause dimensional changes and contribute to deterioration of wood members. By itself, saturation is unlikely to result in significant structural damage to masonry construction. Saturation of soils, a consequence of long duration flooding, increases pressure on below-grade foundation walls.

Velocity, wave action, and debris impacts: Each of these components of dynamic loads can result in structural damage if buildings are not designed to resist overturning, repetitive pounding by waves, or short-duration impact loads generated by floating debris.

Erosion and scour: Structural damage is associated with foundation failure when erosion or scour results in partial or complete removal of supporting soil (see Figure 2-16). Erosion of slopes, especially unprotected slopes, can lead to slope failures and loss of foundation supporting soil.

Figure 2-16:
Scour around the foundation of this building contributed to significant damage.

2.2.2.3 Nonstructural Damage

Many flood-prone buildings are exposed to floodwaters that are not fast moving, or that may be relatively shallow and not result in structural damage. Simple inundation and saturation of the building and finish materials can result in significant and costly nonstructural damage, including long-term health complications associated with mold. Floodwaters often are contaminated with chemicals, petroleum products, or sewage. Under such circumstances, recovery generally involves removal of nonstructural materials and finishes because cleanup and decontamination is expensive and time-consuming. Damage to contents is discussed in Section 2.2.2.5.

Nonstructural damage can vary as a function of the duration of water exposure. Some materials are not recoverable even after very brief inundation, while others remain serviceable if in contact with water for only a few hours. Use of water-resistant materials will help to minimize nonstructural damage caused by saturation and reduce the costs of cleanup and restoration to service (see *Flood-Resistant Materials Requirements*, FIA-TB-2).

Wall finishes: Painted concrete and concrete masonry walls usually resist water damage, provided the type of paint can be readily cleaned, such as high strength epoxy paints. Tiled walls may be acceptable, depending on the type of adhesive and foundation (gypsum board substrate and wood-framed walls with tile typically do not remain stable).

Flooring: Many critical facilities have durable floors that resist water damage. Ground floors often are slab-on-grade and finished with tile or sheet goods. Flooring adhesives in use since the early 1990s likely are latex-based and tend to break down when saturated. Most carpeting, even the indoor-outdoor kind, is difficult to clean. Wood floors are particularly susceptible to saturation damage, although short duration inundation may not cause permanent de-formation of some wood floors. However, because of low tolerance for surface variations, gymnasium floors in schools are particu-larly sensitive and tend to warp after flooding of any duration (see Figure 2-17).

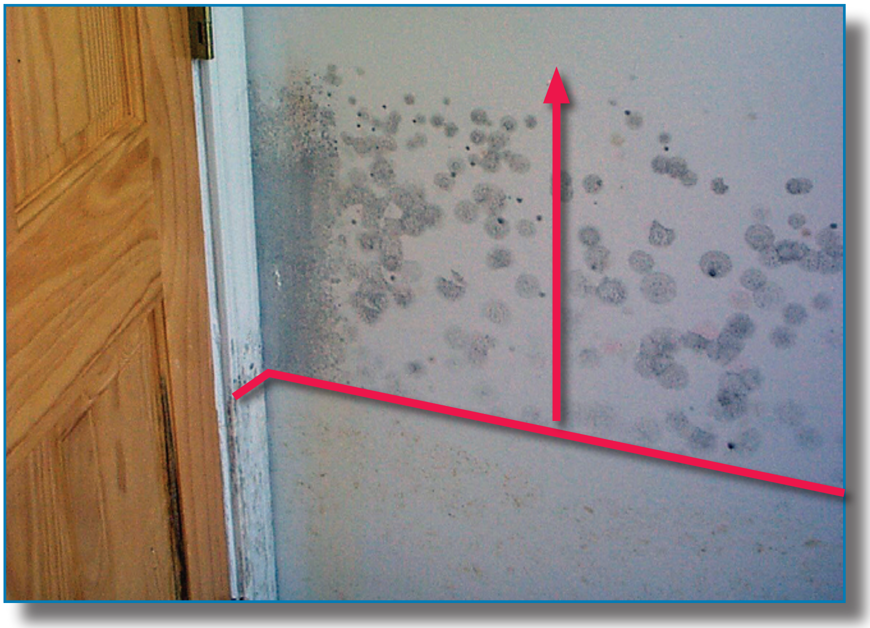
Figure 2-17:
This parquet wood gymnasium floor was damaged by dimensional changes due to saturation. Hurricane Katrina (2005)

Wall and wood components: When soaked for long periods of time, some building components change composition or shape. Most types of wood will swell when wetted and, if dried too quickly, will crack, split or warp. Plywood can delaminate and wood door and window frames may swell and become unstable. Gypsum wallboard, wood composition panels, other wall materials, and wood cabinetry not intended for wet locations can fall apart (see Figure 2-18). The longer these materials are wet, the more moisture, sediment, and pollutants they absorb. Some wall materials, such as the paper facing on gypsum wallboard, "wick" standing water, resulting in damage above the actual high-water line (see Figure 2-19).

Figure 2-18:
Damaged walls and cabinets

Figure 2-19:
Water damage and mold growth extend above the water line

SOURCE: OAK RIDGE NATIONAL LABORATORY



Metal components: Metal structural components are unlikely to be permanently damaged by short-term inundation. However, hollow metal partitions are particularly susceptible when they come into contact with water because they cannot be thoroughly dried and cleaned. Depending on the degree of corrosion protection on the metal, repetitive flooding by saline coastal waters may contribute to long-term corrosion.

Metal connectors and fasteners: Depending on the composition of the metal, repetitive flooding, especially by saline coastal waters, may contribute to long-term corrosion. Connectors and fasteners are integral to the structural stability of buildings; therefore, failure caused by accelerated corrosion would jeopardize the building.

2.2.2.4 Utility System Damage

Utility system service equipment that is exposed to flooding is vulnerable to damage. Damage may result in a total loss, or may require substantial cleaning and restoration efforts. The degree of damage varies somewhat as a function of the characteristics of flooding. Certain types of equipment and installation measures will help minimize damage and reduce the costs of cleanup and restoration to service.

Displacement of equipment and appliances: Installation below the flood level exposes equipment and appliances to various flood forces, including drag resulting from flowing water and buoyancy. Gas-fired appliances are particularly dangerous: flotation can separate appliances from gas sources, resulting in fires and explosive situations. Displaced equipment may dislodge lines from fuel oil tanks, contributing to the threat of fires and causing water pollution and environmental damage.

Elevators: If located in areas subject to flooding, elevator component equipment and controls will be damaged, and communication between floors will be impaired.

Corrosion: Corrosion related to inundation of equipment and appliances may not be apparent immediately, but can increase maintenance demand and shorten the useful life of some equipment and appliances.

Electrical systems and components: Electrical systems and components, and electrical controls of heating, ventilation, and air conditioning systems, are subject to damage simply by getting wet, even for short durations. Unless specifically designed for wet locations, switches and other electrical components can short out due to deposits of sediment, or otherwise not function even when allowed to dry before operation. Wiring and components that have been submerged may be functional, although generally it is more cost-effective to discard flooded outlets, switches, and other less expensive components than to attempt thorough cleaning.

Communications infrastructure: Critical communications infrastructure, such as control panels and wiring for warning systems, 911 systems, and regular telephone and wireless networks, are most susceptible to failure during emergencies if located in below-grade basements.

Specialized piping: Unprotected piping for medical gas supply systems may be damaged and threaten care that depends on uninterrupted supply of oxygen and other gasses for the treatment of patients.

Ductwork damage: Ductwork is subject to two flood-related problems. Flood forces can displace ductwork, and saturated insulation can overload support straps, causing failure.

Mold and dust: Furnaces, air handlers, and ductwork that have been submerged must be thoroughly cleaned and sanitized. Otherwise, damp conditions contribute to the growth of mold and accumulated sediment can be circulated throughout the critical facility, causing respiratory problems. Fiberglass batt or cellulose insulation that has been submerged cannot be sanitized and must be replaced. In sensitive environments, ductwork should be replaced rather than cleaned.

Gas-fired systems: Water-borne sediment can impair safe functioning of jets and controls in gas-fired furnaces and water heaters, necessitating professional cleaning and inspection prior to restoration of service. Control equipment (valves, electrical switches, relays, temperature sensors, circuit breakers, and fuses) that have been submerged may pose an explosion and fire hazard and should be replaced.

Emergency power generators: Generators that are installed at-grade are susceptible to inundation and will be out of service after a flood (see Figure 2-20).

Tanks (underground): Underground storage tanks are subjected to significant buoyant forces and can be displaced, especially when long-duration flooding occurs. Computations of stability should be based on the assumption that the tank is empty in order to maximize safety. Tank inlets, fill openings, and vents should be above the DFE, or designed to prevent the inflow of floodwaters or outflow of tank contents during flood conditions.

Tanks (aboveground): Aboveground storage tanks are subject to buoyant forces and displacement caused by moving water. Standard strapping of propane tanks may be inadequate for the anticipated loads. Tank inlets, fill openings, and vents should be above the DFE, or designed to prevent the inflow of floodwaters or outflow of tank contents during flood conditions.

Public Utility Service: Damage to public utility service (potable water supply and wastewater collection) can affect operations and may cause damage to critical facilities:

Figure 2-20:
Although it was anchored and not displaced by floodwaters, this generator was out of service after being submerged.

- Potable water supply systems may become contaminated if public water distribution lines or treatment facilities are damaged, or if wellheads are submerged.

- During heavy rains, sewers back up from infiltration and inflow of stormwater into the sewer lines and manholes, cross connections between storm and sanitary sewers, and flooded wastewater treatment plants. Sewer backup into a critical facility poses a major health hazard. Even when the water has receded, exposed building components, finish materials, and contents are contaminated, and usually must be removed because adequate cleaning is difficult, if not impossible.

2.2.2.5 Contents Damage

Critical facilities may contain high-value contents that can be damaged and become unrecoverable when subjected to flooding. For the purpose of this discussion, the term "contents" includes items such as furniture, appliances, computers, laboratory equipment and materials, records, and specialized machinery. The following types of contents are often considered a total loss.

Furniture: In long-duration flooding, porous woods become saturated and swollen, and joints may separate. Furniture with coverings or pads generally cannot be restored. Metal furniture is difficult to thoroughly dry and clean, is subject to corrosion, and typically is discarded. Some wood furniture may be recoverable after brief inundation.

Computers: Flood-damaged computers and peripheral equipment cannot be restored after inundation, although special recovery procedures may be able to recover information on hard drives.

Communications equipment: Even though some communications equipment may be able to be restored with appropriate cleaning, the loss of functionality would seriously impair the ability of the facility to provide critical services immediately after a flood. Equipment with printed circuit boards generally cannot be restored.

Office records and police files: When facilities are located in flood-prone space, valuable records may be lost. Although expensive, some recovery of computerized and paper records may be possible with special procedures (see Figure 2-21).

Health care equipment and laboratory materials: Most medical and health care equipment cannot be cleaned and restored to safe functioning, and would need to be replaced. Depending on the nature of laboratory materials and chemicals, complete disposal or special cleanup procedures may be required.

Kitchen goods and equipment: Floodwaters can dislodge appliances that can float and damage other equipment (see Figure 2-22). Stainless steel equipment generally has cleanable surfaces that can be disinfected and restored to service. Because of contamination, all food stuffs must be discarded.

Vehicles associated with critical facilities: If left in flood-prone areas, fire engines, police cars, ambulances, and other vehicles require replacement or cleaning to be serviceable and may not be functional and available for service immediately after a flood.

Figure 2-21:
Medical records saturated by floodwaters

SOURCE: HANCOCK MEDICAL CENTER

Figure 2-22:
Kitchen appliances and equipment from Port Sulphur High School were displaced and damaged by Hurricane Katrina floodwaters (2005).

2.3 REQUIREMENTS AND BEST PRACTICES IN SPECIAL HAZARD AREAS

2.3.1 RISK REDUCTION IN "A ZONES"

Flood hazard areas designated as A Zones on FIRMs are areas where significant wave action is not expected (see Section 2.1.1.2). A Zones are found along riverine bodies of water (rivers, streams, creeks, etc.), landward of V Zones, and on some open coastlines that do not have mapped V Zones. When constructing a critical facility on a site affected by an A Zone flood hazard, site design is influenced by several constraints, such as the presence of flood hazard areas, wetlands, poor soils, steep slopes, sensitive habitats, mature tree stands, and the environmental requirements set by the various regulatory authorities and the agency that approves development plans.

Four aspects of the design of flood-resistant buildings and sites are described in this section: site modifications, elevation considerations, flood-resistant materials, and floodproofing considerations. Section 2.3.5 addresses related facilities, including access roads, utility installations, water and wastewater systems, storage tanks, and accessory structures.

2.3.1.1 Site Modifications

When sites being considered for critical facilities are affected by flood hazards, planners and designers may want to evaluate the feasibility of certain site modifications in order to provide an in-

Site modifications are not appropriate in floodways along riverine waterways, where obstructions to flows can increase flood elevations. Engineering analyses are required to determine the impact of such modifications.

creased level of protection to buildings. The evaluations involve engineering analyses to determine whether the desired level of protection is cost-effective, and whether the proposed site modifications alter the floodplain in ways that could increase flooding. The effectiveness of typical site modifications and their ramifications must be examined for each specific site.

Earthen fill: Fill can be placed in the flood hazard area for the purpose of elevating a site above the design flood elevation. If the fill is placed and compacted so as to be stable during the rise and fall of floodwaters, and if the fill is protected from erosion, then modifying a site with fill to elevate a facility is preferred over other methods of elevation. Not only will buildings be less exposed to flood forces, but, under some circumstances (such as long duration floods), critical facilities may be able to continue to function. Whether nonstructural fill is placed solely to modify the site, or structural fill is placed for the purpose of elevating buildings, placement of fill can change flooding characteristics, including increased flooding on other properties. Engineering analyses can be conducted to determine whether eliminating floodplain storage by filling will change the direction of the flow of water, create higher flow velocities, or increase the water surface elevation in other parts of the floodplain. Fill is a less effective elevation method in flood hazard areas exposed to wave action, such as the banks of wide rivers, back bays, or Coastal A Zones, because wave action may erode the fill and adequate armoring or other protection methods can be expensive.

Excavation: Excavation alone rarely results in significantly altering the floodplain on a given parcel of land. Excavation that modifies a site is more commonly used in conjunction with fill in order to offset or compensate for the adverse impacts of fill.

Earthen levee: A levee is a specially designed barrier that modifies the floodplain by keeping the water away from certain areas (see Figure 2-23). Levees are significant structures that require detailed, site-specific geotechnical investigations; engineering analyses to identify whether flooding will be made worse on other properties; structural and site design to suit existing constraints; design of interior drainage (on the land side); and long-term commitment for maintenance, inspection, and repairs. It is important to remember that areas behind levees are protected only up to a certain design flood level—once overtopped or breeched, most levees fail and catastrophic flooding results. Levees that protect critical facilities usually are designed for at least the 0.2-percent-annual-chance flood (500-year) and have freeboard to increase the factor of safety.

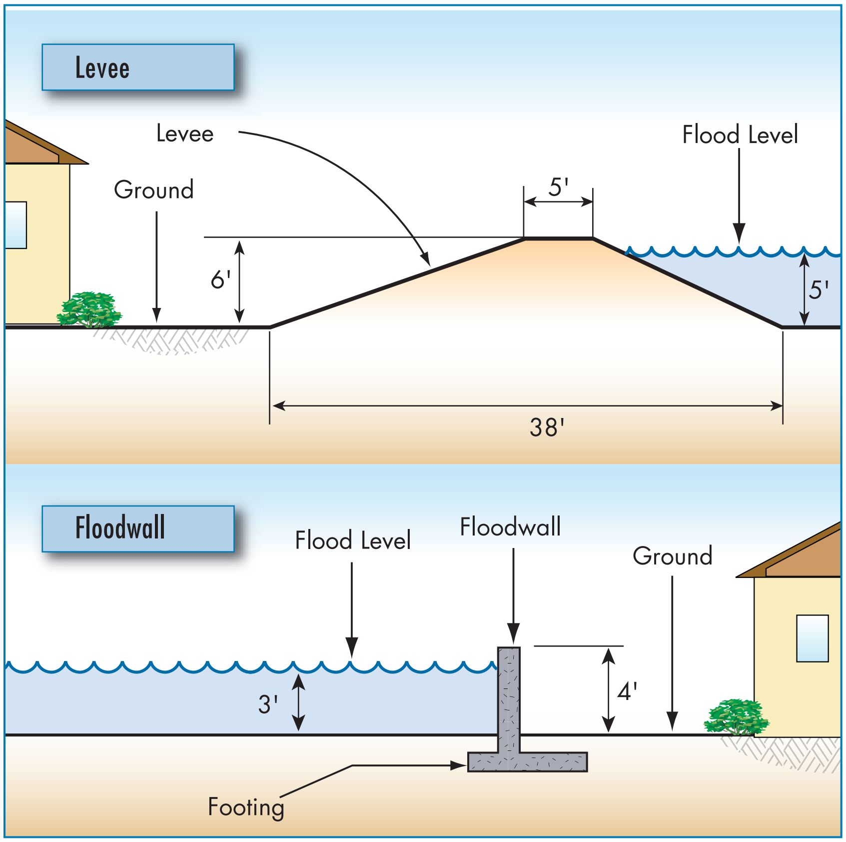


Figure 2-23: Schematic of typical earthen levee and permanent floodwall

Floodwall: Floodwalls are similar to levees in that they provide protection to certain areas (see Figure 2-23). Failure or overtopping of a floodwall can result in catastrophic flooding. A floodwall is a significant structure that is designed to hold back water of a certain depth based on the design flood for the site. Generally, due to design factors, floodwalls are most effective in areas with relatively shallow flooding and minimal wave action. As with levees, designs must accommodate interior drainage on the land side, and maintenance and operations are critical for adequate performance.

Floodwalls that protect essential and critical facilities usually are designed for the 0.2-percent-annual-chance flood (500-year) and have freeboard to increase the factor of safety.

2.3.1.2 Elevation Considerations

"Lowest floor" is the floor of the lowest enclosed area (including the basement). An unfinished or flood-resistant enclosure, usable solely for parking of vehicles, building access, or storage in an area other than a basement, is not the lowest floor, provided the enclosure is built in compliance with applicable requirements.

The selection of the appropriate method of elevating a critical facility in an A Zone flood hazard area depends on many factors, including cost, level of safety and property protection determined as acceptable risk, nature of the flood hazard area, and others. Methods of elevation are described below. The minimum elevation requirement is that the lowest floor (including the basement) must be at or above the DFE (plus freeboard, if desired or required). Table 2-1 in Section 2.1.3.4 summarizes the elevation requirements in ASCE 24. Given the importance of critical facilities, elevation of the lowest floor to or above the 0.2 percent-annual-chance flood (500-year) elevation is crucial.

ASCE 7 outlines methods to determine design loads and load combinations in flood hazard areas, including hydrostatic loads, hydrodynamic loads, wave loads, and debris impact loads. ASCE 24 addresses design requirements for structures in flood hazard areas.

For elevation methods other than fill, the area under elevated buildings in A Zones may be used only for limited purposes: parking, building access, and limited storage (crawlspaces are treated as enclosures, see below). Owners and designers are cautioned that enclosures below the design flood elevation are exposed to flooding and the contents will be damaged or destroyed by floodwaters. The walls surrounding an enclosure must have flood openings that are intended to equalize interior and exterior water levels during rising and falling flood conditions, to prevent differential hydrostatic pressures that could lead to structural damage. The enclosed area must not contain utilities and equipment (including ductwork) below the required elevation.

Communities may require a registered design professional to certify that buildings elevated on fill are reasonably safe from flooding. FEMA NFIP Technical Bulletin 10 (2001) discusses criteria for this certification.

Slab-on-grade foundation on structural fill: This is considered to be the safest method to elevate a building in many flood hazard areas, except those where waves and high velocity flows may cause erosion. Structural fill can be placed so that, when water rises up to the DFE, it will not touch the building (see Figure 2-24) and building access is maintained. The fill must be designed to minimize adverse impacts, such as increasing flood elevations on adjacent properties, increasing erosive velocities, and causing local drainage problems. To ensure stability, especially as floodwaters recede and the soils drain, fill must be designed for the anticipated water depths and duration. A geotechnical engineer or soil scientist may need to examine underlying soils to determine if the bearing capacity is sufficient to carry the added weight of fill, or if consolidation over time may occur. In addition, the effects of long-term compaction of the fill should be considered, and may prompt additional elevation as a factor of safety. The horizontal extent of fill from the foundation should be designed to facilitate access by emergency and fire vehicles, with a minimum 25-foot width recommended. Designers are cautioned to avoid excavating a basement into fill without added structural protection (and certification that the design meets requirements for dry floodproofing), due to the potential for significant hydrostatic loads and uplift on basement floors.

Figure 2-24: Municipal building elevated on fill

Stem wall foundations: Stem wall foundations have a continuous perimeter grade beam, or perimeter foundation wall, that is backfilled with compacted earth to the underside of the concrete floor slab (see Figure 2-25). Because this foundation type is backfilled and has no crawlspace, hydrostatic pressures are minimized. Stem wall foundations are designed to come in contact with floodwaters on the exterior. They are more stable than perimeter wall foundations with crawlspaces, but could experience structural damage if undermined by local scour and erosion. Designs must account for anticipated debris and ice impacts, and incorporate methods and materials to minimize impact damage.

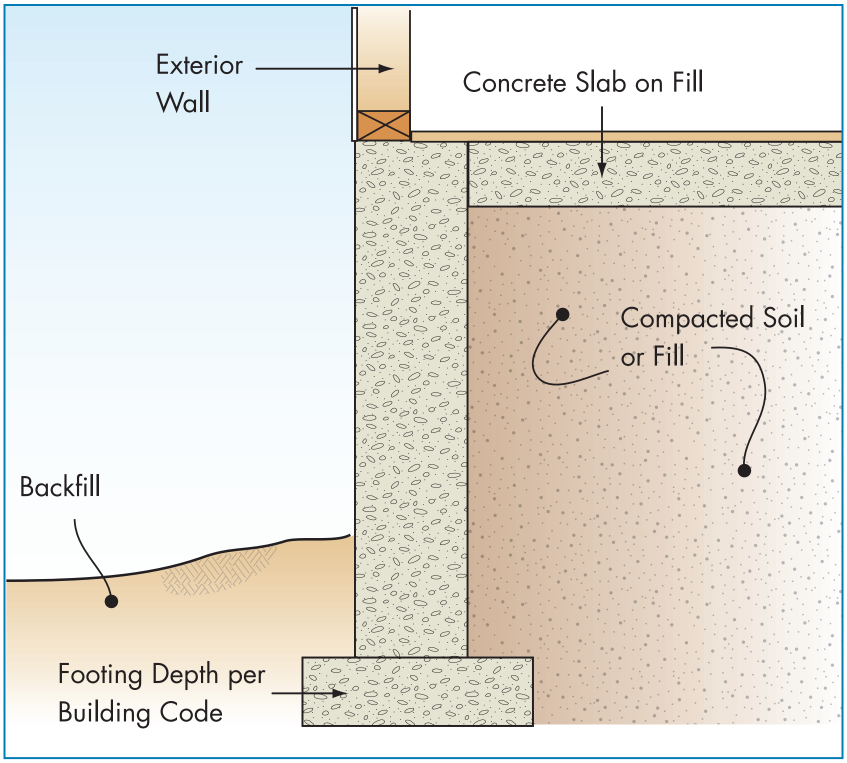


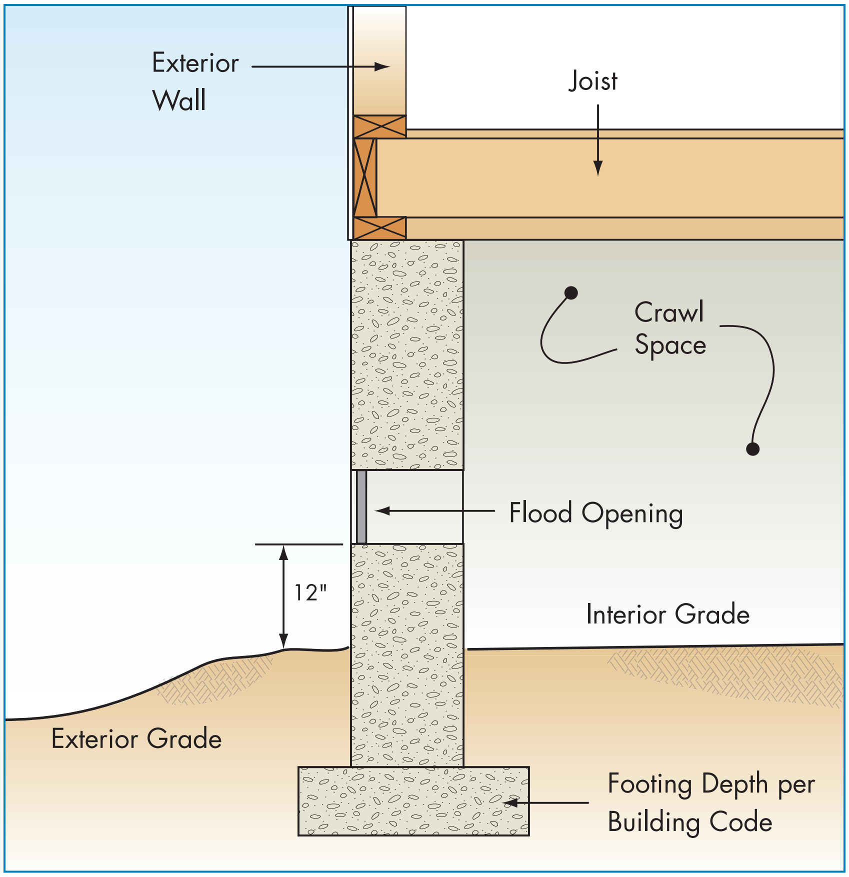
Figure 2-25: Typical stem wall foundation

Columns or shear wall foundations (open foundations): Open foundations consist of vertical load bearing members (columns, piers, pilings, and shear walls) without solid walls connecting the vertical members. Open foundations minimize changes to the floodplain and local drainage patterns, and the area under the building can be used for parking or other uses (see Figure 2-26). The design of the vertical members must also account for hydrodynamic loads and debris and ice impact loads. Flood loads on shear walls are reduced if they are oriented parallel to the anticipated direction of flow. Erodible soils may be present and local scour may occur; both must be accounted for in designs by extending the load-bearing members and foundation elements well below the expected scour depth. Depending on the total height of the elevated facility, the design may need to take into consideration the increased exposure to wind and uplift, particularly where breaking waves are expected.

Figure 2-26: School elevated on columns

Continuous perimeter walls (enclosed foundations with crawlspace): Unlike stem wall foundations, continuous perimeter walls enclose an open area or crawlspace (see Figure 2-27). The perimeter walls must have flood openings that are intended to equalize interior and exterior water levels automatically during changing flood conditions to prevent differential hydrostatic pressures that could lead to structural damage. Flood openings may be engineered and certified for the required performance level, or must meet prescriptive requirements (notably, the opening must provide at least 1 square inch of net open area for each square foot of area enclosed). Perimeter wall design must also account for hydrodynamic loads, and debris and ice impact loads. Enclosed crawlspaces must not contain utilities or equipment (including ductwork) below the required elevation. Designers must provide adequate underfloor ventilation and subsurface drainage to minimize moisture problems after flooding.

Figure 2-27: Typical crawlspace with flood openings



Pier supports for manufactured and portable units: Manufactured buildings and portable units must be elevated above the DFE (plus freeboard, if required). Pier supports must account for hydrodynamic loads and debris and ice impact loads and units must be anchored to resist wind loads. Although written specifically for manufactured housing units, FEMA 85, *Manufactured Home Installation in Flood Hazard Areas*, has useful information that is applicable to portable units.

2.3.1.3 Flood-Resistant Materials

All structural materials, nonstructural (finish) materials, and connectors that are used below certain elevations (see Table 2-2) should be flood-resistant. Flood-resistant materials have sufficient strength, rigidity, and durability to adequately resist flood loads and damage due to saturation. They are building materials that are capable of withstanding direct and prolonged contact with floodwaters without sustaining any damage that requires more than cosmetic repair. As defined in ASCE 24, the term "prolonged contact" means partial or total inundation by floodwaters for 72 hours for non-coastal areas (fresh water) or 12 hours for coastal areas.

FEMA NFIP Technical Bulletin FIA-TB-2, *Flood-Resistant Materials Requirements,* provides some additional information. Many types of materials and application products are classified by degrees of resistance to flood damage.

In general, materials that are exposed to floodwaters are to be capable of resisting damage, deterioration, corrosion, or decay. Typical construction materials range from highly resistant to not at all resistant to water damage. FEMA NFIP Technical Bulletin FIA-TB-2 contains tables with building materials, classified based on flood resistance (Table 2-2).

In areas away from the coast, exposed structural steel should be primed, coated, plated, or otherwise protected against corrosion. Secondary components such as angles, bars, straps, and anchoring devices, as well as other metal components (plates, connectors, screws, bolts, nails angles, bars, straps, and the like) should be stainless steel or hot-dipped galvanized after fabrication.

Table 2-2: Classes of Flood-Resistant Materials

NFIP	Class	Class Description
Acceptable	5	Highly resistant to floodwater damage. Materials in this class are permitted for partially enclosed or outside uses with essentially unmitigated flood exposure.
	4	Resistant to floodwater damage. Materials in this class may be exposed to and/or submerged in floodwaters in interior spaces and do not require special waterproofing protection.
Unacceptable	3	Resistant to clean water damage. Materials in this class may be submerged in clean water during periods of intentional flooding.
	2	Not resistant to water damage. Materials in this class require essentially dry spaces that may be subject to water vapor and slight seepage.
	1	Not resistant to water damage. Materials in this class require dry conditions.

SOURCE: FROM U.S. ARMY CORPS OF ENGINEERS, *FLOODPROOFING REGULATIONS* (1995).

Concrete and masonry that are designed and constructed in compliance with applicable standards are generally considered to be flood-resistant. However, masonry facings are undesirable finishes unless extra anchoring is added to prevent separation (see Figure 2-28). Wood and timber members exposed to flood waters should be naturally decay resistant species or pressure treated with appropriate preservatives.

Structural steel and other metal components exposed to corrosion should be stainless steel or hot-dipped galvanized after fabrication.

Figure 2-28:
Brick facing separated from the masonry wall at Port Sulpher High School, LA.

2.3.1.4 Dry Floodproofing Considerations

Dry floodproofing involves a combination of design and special features that are intended to prevent the entry of water into a building and its utilities while also resisting flood forces. It involves structural reinforcement so that exterior walls are sufficiently robust to withstand the loads described in Section 2.1.2 (hydrostatic pressure, hydrodynamic loads, wave loads, and debris impact loads). Exterior walls must also be designed to prevent infiltration and seepage of water, whether through the wall itself or through any openings, including where utility lines penetrate the envelope. Floodproofed buildings constructed on permeable soils require additional design attention, because they are susceptible to hydrostatic pressure from below.

Communities that participate in the NFIP will require that a registered professional engineer or architect develop or review the structural design, specifications, and plans, and certify that the dry floodproofing design and methods of construction to be used are in accordance with accepted standards of practice. The standards of practice require that the building, together with attendant utility and sanitary facilities, be designed so that it is watertight, with walls substantially impermeable to the passage of water and with structural components having the capability of resisting hydrostatic and hydrodynamic loads and effects of buoyancy associated with the design flood event.

According to the NFIP regulations, nonresidential buildings and nonresidential portions of mixed-use buildings may be dry floodproofed. Areas used for living and sleeping purposes in health care facilities and dormitory rooms at fire stations may not be dry floodproofed. Although floodproofing of the nonresidential spaces is allowed, careful consideration must be given to the possible risk to occupants and additional physical damage.

All flood protection measures are designed for certain flood conditions. Therefore, there is some probability that the design will be exceeded (i.e., water will rise higher than accounted for in the design). When this happens to a dry floodproofed building, the consequences can be catastrophic. As a general rule, dry floodproofing is a poor choice for new critical facilities when avoidance of the floodplain or elevation methods to raise the building above the flood level can be applied. Floodproofing may be acceptable for retrofitting existing buildings under certain circumstances (see Section 2.4.4).

A number of dry floodproofing limitations and requirements are specified in ASCE 24:

- Dry floodproofing is limited to areas where flood velocities at the site are less than or equal to 5 feet per second.

- If human intervention is proposed, such as measures to protect doors and windows, the flood warning time shall be a minimum of 12 hours unless the community operates a flood warning system and implements a notification procedure that provides sufficient time to undertake the measures requiring intervention.

- At least one door satisfying building code requirements for an exit door or primary means of escape must be provided above the level of protection.
- An emergency plan, approved by the community and posted in at least two conspicuous locations, is required in floodproofed buildings; the plan is to specify the location of panels and hardware, methods of installation, conditions that activate deployment, a schedule for routine maintenance of any aspect that may deteriorate over time, and periodic practices and drills.

Windows and doors that are below the flood level used for dry floodproofing design present significant potential failure points. They must be specially designed units (see Figure 2-29) or be fitted with gasketed, mountable panels that are designed for the anticipated flood conditions and loads. Generally speaking, it is difficult to protect window and door openings from water more than a few feet deep. The framing and connections must be specifically designed for these protective measures, or water pressure may cause window and door frames to separate from the building.

The documents *Flood Resistant Design and Construction* (ASCE 24-05), *Flood Proofing: How to Evaluate Your Options* (USACE, 1993), *Flood Proofing Regulations* (USACE, 1995), *Floodproofing Non-Residential Structures* (FEMA 102, 1986), *Non-Residential Floodproofing – Requirements and Certification* (FIA-TB-3 [FEMA NFIP, 1993]), *Flood Proofing Systems & Techniques* (USACE, 1984) provide additional information about floodproofing.

Dry floodproofing is required to extend to 1 or 2 feet above the BFE (see Table 2-1). For the purpose of obtaining NFIP flood insurance, the floodproofing must extend at least 1 foot above the BFE, or the premiums will be very high. Therefore, a higher level of protection is recommended.

Floodproofing techniques are considered to be permanent measures if they are always in place and do not require any specific human intervening action to be effective. Use of contingent floodproofing measures that require installation or activation, such as window shields or inflatable barriers, Dry floodproofed critical facilities must never be considered safe for occupancy during periods of high water; floodproofing measures are intended only to reduce physical damage.

may significantly reduce the certainty that floodproofing will be effective. Rigorous adherence to a periodic maintenance plan is critical to ensure proper functioning. The facility must have a formal, written plan, and people responsible for implementing the measures must be informed and trained. These measures also depend on the timeliness and credibility of the warning. In addition, floodproofing devices often rely on flexible seals that require periodic maintenance and that, over time, may deteriorate and become ineffective. Therefore, a maintenance plan must be developed and a rigorous annual inspection and training must be conducted.

Figure 2-29: Permanent watertight doors for deep water

SOURCE: PRESRAY CORPORATION

Safety of occupants is a significant concern with dry floodproofed buildings. Regardless of the degree of protection provided, dry floodproofed buildings should not be occupied during flood events, because failure or overtopping of the floodproofing measures is likely to cause catastrophic structural damage. When human intervention is required, the people responsible for implementing those measures remain at risk while at the building, even if a credible warning system is in place, because of the many uncertainties associated with predicting the onset of flood conditions.

2.3.2 RISK REDUCTION IN "V ZONES"

Flood hazard areas designated as "V Zones" on FIRMs are relatively narrow areas along open coasts and lake shores where the base flood conditions are expected to produce 3-foot or higher waves. V Zones, sometimes called coastal high hazard areas or special flood hazard areas subject to high-velocity wave action, are found on the Pacific, Gulf, and Atlantic coasts, and around the Great Lakes.

Every effort should be made to locate critical facilities outside of V Zones, because the destructive nature of waves makes it difficult to design a building to be fully functional during and after a flood event. This is particularly true in coastal areas subject to hurricane surge flooding (see Section 2.3.4). However, when a decision is made to build a critical facility in a V Zone or Coastal A Zone, the characteristics of the site and the nature of the flood hazards must be examined prior to making important design decisions.

Beach front areas with sand dunes pose special problems. Manmade alterations of sand dunes are not allowed unless analyses indicate that such modifications will not increase potential flood damage. The site modifications described in Section 2.3.1.1 that may be used in some A Zones to reduce flood hazards generally are not feasible in V Zones because of wave forces and potential erosion and scour. In particular, structural fill is not allowed as a means to raise a building site above the flood level.

The NFIP and ASCE 24 do not allow use of dry floodproofing measures to protect nonresidential structures in V Zones.

2.3.2.1 Elevation Considerations

The selection of the appropriate method of elevating a critical facility in a V Zone flood hazard area depends on many factors, including cost, desired level of safety and property protection, and the nature of the flood hazard area. The NFIP regulations and the building codes require the elevation of the bottom of the lowest horizontal structural member of the lowest floor (including basement) to be at or above the DFE (plus freeboard, where required). Given the importance of critical facilities, elevation to or above the 0.2-percent-annual-chance flood (500-year) elevation is appropriate and strongly recommended.

Communities that participate in the NFIP will require that a registered professional engineer or architect develop or review the structural design, specifications, and plans, and certify that the design and methods of construction to be used are in accordance with accepted standards of practice. The standards of practice require that the foundation and structure attached thereto is anchored to resist flotation, collapse, and lateral movement due to the effects of wind and water loads acting simultaneously on all building components. Water loading values shall be those associated with the base flood conditions, and wind loading values shall be those required by applicable State or local building codes and standards.

Buildings in V Zones must be elevated using open foundations, which consist of vertical load bearing members (columns, piers, pilings, and shear walls) without solid walls connecting the vertical members. The design of the vertical members must also account for hydrodynamic loads and debris impact loads. Flood loads on shear walls are reduced if the walls are oriented parallel to the anticipated direction of flow. Since erodible soils may be present and local scour may occur, both conditions must be accounted for in designs of load-bearing members and foundations.

The area under elevated buildings in V Zones may be used only for limited purposes: parking, building access, and limited storage. Owners and designers are cautioned that enclosures below the DFE are exposed to flooding. Areas under elevated buildings may be open or enclosed by lattice walls or screening. However, if areas are enclosed by solid walls, the walls must be specifically designed to break away under certain flood loads to allow the free passage of floodwaters under the building. Breakaway walls are non-load bearing walls, i.e., they do not provide structural support for the building. They must be designed and constructed to collapse under the impact of floodwaters in such a way that the supporting foundation system and the structure are not affected.

2.3.2.2 Flood-Resistant Materials

Section 2.3.1.3 addresses the general requirement that all structural materials, nonstructural (finish) materials, and connectors that are used below certain elevations are to be flood-resistant materials. In coastal areas, airborne salt aerosols and inundation with saline water increase the potential for corrosion of some metals. Structural steel and other metal components that are exposed to corrosive environments should be stainless steel or hot-dipped galvanized after fabrication.

2.3.3 RISK REDUCTION IN "COASTAL A ZONES"

Coastal A Zones are areas of the mapped floodplain where breaking waves that are between 1.5 to 3 feet high are expected under base flood conditions. Coastal A Zones are part of the area shown as the A Zone on a FIRM, landward of the mapped V Zone or landward of open coasts that do not have a V Zone. FIRMs do not distinguish between Coastal A Zones and A Zones. Designers should determine whether Coastal A Zone conditions are likely to occur at a critical facility site because of the anticipated wave action and loads. This determination is based on an examination of the site and its surroundings, the actual surveyed ground elevations, and the predicted stillwater elevations found in the Flood Insurance Study.

Coastal A Zones are present where two conditions exist: where the expected floodwater depth is sufficient to support waves 1.5 to 3 feet high, and where such waves can actually occur (see Figure 2-30). The first condition occurs where stillwater depths (vertical distance between the stillwater elevation and the ground) are more than 2 feet deep. The second condition occurs where there are few obstructions between the shoreline and the site. The stillwater depth requirement is necessary, but is not sufficient by itself to warrant designation as a Coastal A Zone, because obstructions in the area may block wind and dampen waves. Obstructions that may dampen waves include buildings, locally high ground, and dense tree stands.

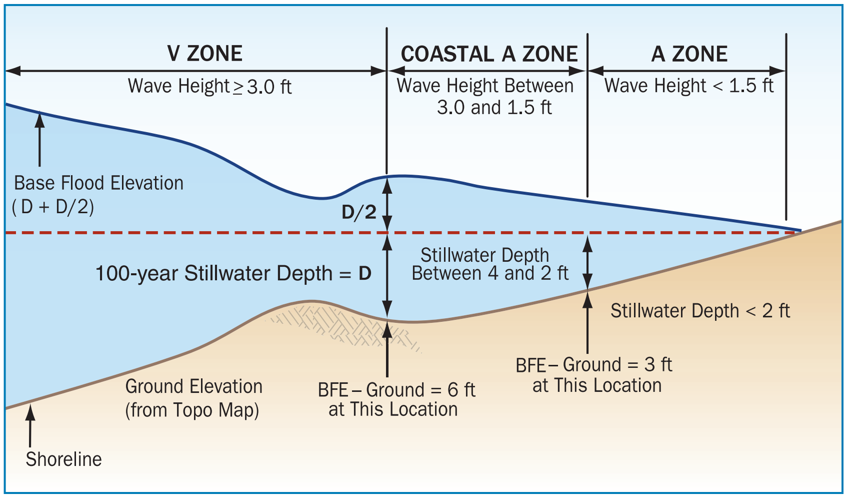


Figure 2-30: Flood hazard zones in coastal areas

Although the NFIP regulations and the model building codes allow dry floodproofing of nonresidential buildings in flood hazard areas where waves are predicted to be between 1.5 and 3 feet during the base flood (called Coastal A Zones), designers are cautioned to fully consider the additional forces associated with wave impacts, which may make dry floodproofing a less feasible alternative.

Field observations and laboratory research have determined that flooding with breaking waves between 1.5 and 3 feet high produces more damage than flooding of similar depths without waves. Therefore, ASCE 24 specifically requires application of the NFIP's V Zone design requirements in Coastal A Zones. Section 2.3.2.1 addresses elevation requirements and foundation types, and Section 2.3.2.2 addresses flood-resistant materials, used in V Zones and Coastal A Zones. The designers are advised to pay special attention to two additional considerations:

- Debris loads may be significant in Coastal A Zones landward of V Zones where damaged buildings, piers, and boardwalks can produce battering debris. Foundations designed to account for debris loads will minimize damage.

- Especially in high wind regions, designers must pay special attention to the entire roof-to-foundation load path when designing and specifying connections. If designed to meet V Zone requirements, designs for buildings in Coastal A Zones will account for simultaneous wind and flood forces. Corrosion-resistant connections are especially important for the long-term integrity of the structure.

2.3.4 RISK REDUCTION IN HURRICANE STORM SURGE AREAS

Coastal communities along the Atlantic and Gulf coasts are subject to storm surge flooding generated by hurricanes and tropical storms. Depending on a number of variables, storm surge flood depths may significantly exceed the BFE. In addition, waves are likely to be larger than predicted for the base flood, and will occur in areas where significant wave action during the base flood is not expected. Application of the minimum requirements related to elevation of the lowest floor and foundation design does not result in flood resistance for such extreme conditions. The following special considerations will provide a greater degree of protection for critical facilities located in areas subject to storm surges.

Higher foundations: Foundations should be designed to elevate the building so that the lowest horizontal structural members are higher than the minimum required elevation. Additional elevation not only reduces damage that results from lower probability events, but the cost of Federal flood insurance is usually lower. However, accessibility may be affected and there will be some additional construction costs that must be balanced against avoided future damage and a higher likelihood that a facility can be more rapidly restored to full function.

Scour and erosion: Storm surge flooding and waves can cause scour and erosion, even at locations that are some distance from the shoreline. Foundation designs for critical facilities in coastal communities should account for some erosion and local scour of supporting soil during low probability surge events.

Water-borne debris: Storm surge flooding can produce large quantities of floating debris, even at locations that are some distance from the shoreline. Debris damages nonstructural building components and, in some cases, prolonged battering can lead to structural failure. Foundation designs for critical facilities in coastal communities should account for debris loads. This is especially important where damage to other buildings in the area may generate additional debris, thereby increasing the loads.

Continuous load path: Especially in high wind regions, designers should pay special attention to the entire roof-to-foundation load path when designing and specifying connections. Connections must be capable of withstanding simultaneous wind and flood forces. Poorly connected buildings may fail or float off of foundations when floodwaters and waves are higher than the design flood elevation. Corrosion-resistant connections are critical for the long-term integrity of the structure, and should be inspected and maintained periodically.

Emergency equipment: Equipment that is required for emergency functioning during or immediately after a storm surge event, such as emergency generators and fuel tanks, is best installed well above the design flood elevation.

Occupancy of surge-prone areas: Designers and owners should plan to use the lowest elevated floor for non-critical uses that, even if exposed to flooding more severe than the design flood, will not impair critical functioning during post-flood recovery.

2.3.5 RISK REDUCTION FOR RELATED FACILITIES

Critical facilities do not exist as purely independent buildings. They usually are accompanied by a variety of related facilities, such as utility installations both inside and outside of buildings, gas and electric services, water and wastewater services, above-ground or underground storage tanks, accessory structures and outbuildings, and access roads and parking lots.

2.3.5.1 Access Roads

Access roads to critical facilities should be designed to provide safe access at all times, to minimize impacts on flood hazard areas, to minimize damage to the road itself, and to minimize exposing vehicles to dangerous situations. Depending on the site and specific flood characteristics, balancing those elements can be difficult. Designers should take the following into consideration.

Safety factors: Although a critical facility's access road may not be required to carry regular traffic like other surface streets, a flood-prone road always presents a degree of risk to public safety. To minimize those risks, some State or local regulatory authorities require that access roads be designed so that the driving surface is no more than 1 to 2 feet below the DFE. To maximize evacuation safety, two separate accesses to different feeder roads are recommended. In some circumstances, especially long-duration flooding where a critical facility is built on fill, dry access may allow continued operations.

Floodplain impacts: Engineering analyses may be required to document the effects on flood elevations and flow patterns if large volumes of fill are required to elevate a road to minimize or eliminate flooding above the driving surface.

Drainage structure and road surface design: The placement of multiple drainage culverts, even if not needed for local drainage, can facilitate the passage of floodwaters and minimize the potential for a road embankment to act as a dam. Alternatively, an access road can be designed with a low section over which high water can flow without causing damage. Embankments should be designed to remain stable during high water and as waters recede. They should be sloped and protected to resist erosion and scour. Similarly, the surface and shoulders of roads that are intended to flood should be designed to resist erosion. The increased resistance to erosion may be accomplished by increasing the thickness of the road base.

2.3.5.2 Utility Installations

Utilities associated with new critical facilities in flood hazard areas must be protected either by elevation or special design and installation measures. Utilities subject to this provision include all systems, equipment, and fixtures, including mechanical, electrical, plumbing, heating, ventilating, and air conditioning. Potable water systems (wellheads and distribution lines) and wastewater collection lines are addressed in Section 2.3.5.3.

Utility systems and equipment are best protected when elevated above the DFE (plus freeboard, if required). In some cases, equipment can be located inside protective floodproofed enclosures, although it must be recognized that flooding that exceeds the design level of such an enclosure will adversely affect the equipment (see Figure 2-31). Designers should pay particular attention to underfloor utilities and ductwork to ensure that they are properly elevated. Plumbing conduits, water supply lines, gas lines and electric cables that must extend below the DFE should be located, anchored, and protected to resist the effects of flooding. Equipment that is outside of elevated building also must be elevated:

For more information on utility installations, see *Protecting Building Utilities from Flood Damage: Principles and Practices for the Design and Construction of Resistant Building Utility Systems* (FEMA 348, 1999).

- In A Zones, equipment may be affixed to raised support structures or mounted on platforms that are attached to or cantilevered from the primary structure.

- In V Zones and Coastal A Zones, equipment may be affixed to raised support structures designed for the flood conditions (waves, debris impact, erosion, and scour) or mounted on platforms that are attached to or cantilevered from the primary structure. If an enclosure is constructed under the elevated building, the designer must take care that utilities and attendant equipment are not mounted on or pass through walls that are intended to break away.

Figure 2-31:
Equipment room with watertight door

SOURCE: PRESRAY CORPORATION

Although it is difficult to achieve, the model building codes and NFIP regulations provide an alternative that allows utility systems and equipment to be located below the DFE. This alternative requires that such systems and equipment be designed, constructed, and installed to prevent floodwaters from entering or accumulating within the components during flood events.

2.3.5.3 Potable Water and Wastewater Systems

New installations of potable water systems and wastewater collection systems are required to resist flood damage, including damage associated with infiltration of floodwaters and discharge of effluent. Health concerns arise when water supply systems are exposed to floodwaters. Contamination from flooded sewage systems poses additional health and environmental risks. Onsite water supply wellheads should be located on land elevated from the surrounding landscape to allow contaminated surface water and runoff to drain away. Well casings should extend above the design flood elevation, and casings should be sealed with a tight-fitting, floodproof, and vermin-proof well cap. The space between the well casing and the side of the well must be sealed to minimize infiltration and contamination by surface waters.

Sewer collection lines should be located and designed to avoid infiltration and backup due to rising floodwaters. Devices designed to prevent backup are available and are recommended to provide an added measure of protection.

Onsite sewage systems usually are not used as the primary sewage disposal system for new critical facilities. However, it would be prudent for owners, planners, and designers to consider a backup onsite sewage system if a facility's functionality will be impaired if the public system is affected by flooding. Designers are advised that local or State health departments may impose constraints that limit or prevent locating septic fields in floodplain soils or within a mapped flood hazard area. If allowed, septic fields should be located on the highest available ground to minimize inundation and impairment by floodwaters. An alternative to a septic field is installation of a holding tank that is sized to contain wastewater for a period of time, perhaps a few days if the municipal system is expected to be out of service.

2.3.5.4 Storage Tank Installations

Aboveground and underground storage tanks located in flood hazard areas must be designed to resist flotation, collapse, and lateral movement. ASCE 24 specifies that aboveground tanks are to be elevated or constructed, installed and anchored to resist at least 1.5 times the potential buoyant and other flood forces under design flood conditions, assuming the tanks are empty. Similarly, underground tanks are to be anchored to resist at least 1.5 times the potential buoyant forces under design flood conditions, assuming the tanks are empty. In all cases, designers are cautioned to address hydrodynamic loads and debris impact loads that may affect tanks that are exposed to floodwaters. Vents and fill openings or cleanouts should be elevated above the DFE or designed to prevent the inflow of floodwaters or outflow of the contents of tanks.

2.3.5.5 Accessory Structures

Depending on the type of accessory structures, full compliance with floodplain management regulations is appropriate and may be required. For example, buildings or portable classrooms that serve educational purposes (e.g., offices, classrooms), even if detached from the primary school building, are not considered to be accessory in nature and must be elevated and protected to the same standards as other buildings.

Some minor accessory structures need not fully comply, but may be “wet floodproofed” using techniques that allow them to flood while minimizing damage. Examples include small storage sheds, garages, and restrooms. Accessory structures must be anchored to resist flotation, collapse, and lateral movement. Flood-resistant materials must be used and utilities must be elevated above the DFE (plus freeboard, if required). Openings in walls must be provided to allow the free inflow and outflow of floodwaters to minimize the hydrostatic loads that can cause structural damage. Because wet floodproofed accessory buildings are designed to flood, critical facility staff must be aware that contents will be damaged.

2.4 RISK REDUCTION FOR EXISTING CRITICAL FACILITIES

2.4.1 INTRODUCTION

Section 2.2.2 describes the type of damage that can be sustained by critical facilities that already are located in flood hazard areas. The vulnerability of these facilities can be reduced if they can be made more resistant to flood damage. Decisionmakers may take such action when flood hazards are identified and there is a desire to undertake risk reduction measures proactively. Interest may be prompted by a flood or by the requirement to address flood resistance as part of proposed substantial improvement or an addition. Some questions and guidance intended to help identify building characteristics of importance when considering risk reduction measures for existing facilities are included in the checklist in Section 2.5.

Work on existing buildings and sites is subject to codes and regulations, and the appropriate regulatory authority with jurisdiction should be consulted. With respect to reducing flood risks, work generally falls into the categories described in the following subsections.

Owners and operators of public and not-for-profit critical facilities should be aware of the importance of flood insurance coverage for facilities that are located in the flood hazard areas shown on NFIP maps. If not insured for flood peril, the amount of flood insurance that should have been in place will be deducted from any Federal disaster assistance payment that would otherwise have been made available. A particular facility may have to absorb up to $1 million in unreimbursed flood damage per building, because the NFIP offers $500,000 in building coverage and $500,000 in contents coverage for nonresidential buildings (coverage limits as of early 2006).

2.4.2 SITE MODIFICATIONS

A plan to modify the site of an existing facility that is subject to flooding requires careful examination by an experienced professional engineer. Determining the suitability of a specific measure requires a complex evaluation of many factors, including the nature of flooding and the nature of the site. The first part of Table 2-3 in Section 2.5 identifies elements that influence the choice of mitigation measures applicable to existing sites. Some flood characteristics may make it infeasible to apply site modification measures to existing facilities (e.g., depths greater than 3 to 4 feet, very high velocities, insufficient warning because of flash flooding or rapid rate of rise, and very long duration).

A common problem with all site modifications is the matter of site access. Depending on the topography of the site, construction of barriers to floodwaters may require special access points. Access points may be protected with manually installed stop-logs or designed gates that drop in, slide, or float into place. Whether activated by automatic systems or manually operated, access protection requires sufficient warning time.

Other significant constraining factors include poor soils and insufficient land area which can make site modifications either infeasible or very costly. A critical facility may be among several buildings and properties that can be protected, increasing the benefits. For any type of barrier, rainfall that collects on the land side must be accounted for in the design, whether through adequately sized stormwater storage basins constructed on land set aside for this purpose, or by providing large-capacity pumps to move collected water to the water side of the barrier.

Each of these site modification measures described below has limitations, including the fact that floods larger than the design flood will exceed the level of protection.

Regrading the site (berm): Where a facility is exposed to relatively shallow flooding and sufficient land area is available, regrading the site or constructing an earthen berm may provide adequate protection.

Earthen levee: Earthen levees are engineered structures that are designed to keep water away from land area and buildings. Hydraulic analyses and geotechnical investigations are required to determine their feasibility and effectiveness. For existing sites, constraints include the availability of land (levees have a large "footprint" and require large land areas), cost (including availability of suitable fill material and long-term maintenance), and difficulties with site access. Levees are rarely used to protect a single site, although they may offer a reasonable solution for a group of buildings. Locating levees and floodwalls within a designated floodway is generally not allowed. Rapid onset flooding makes it impractical to design a flood levee with access points that require installation of a closure system. Earthen levees may also be subject to high velocity flows that cause erosion and affect their stability.

Permanent floodwall: Floodwalls are freestanding, permanent engineered structures that are designed to prevent encroachment of floodwaters. Typically, a floodwall is located some distance from a building, so that structural modification of the existing building is not required. Floodwalls may protect only the low side of a site (in which case they must "tie" into high ground) or completely surround a site (which may affect access because special closure structures are required and must be installed before the onset of flooding, see Figure 2-32).

Figure 2-32:
A masonry floodwall with multiple engineered openings protected the Oak Grove Lutheran School in Fargo, ND from flooding in 2001.

SOURCE: FLOOD CENTRAL AMERICA, LLC

Mobilized floodwall: This category of flood protection measures includes fully engineered flood protection structures that have permanent features (foundation and vertical supports) and features that require human intervention when a flood is predicted (horizontal components called planks or stop-logs). Mobilized floodwalls have been used to protect entire sites, or to tie into permanent floodwalls or high ground. Because of the manpower and time required for proper placement, these measures are better suited to conditions that allow long warning times.

2.4.3 ADDITIONS

All model building codes generally treat additions as new construction and require additions to critical facilities in flood hazard areas to be elevated or dry floodproofed to minimize exposure to flooding. However, full compliance with the code and NFIP requirements is only required if an addition is a substantial improvement (i.e., the cost of the addition plus all other work equals or exceeds 50 percent of the market value of the building). Designers are cautioned that existing buildings as well may be required to be brought into compliance with the flood-resistant provisions of the code or local ordinances if the addition is structurally connected to the existing building.

For more information on additions and substantial improvements, see *Answers to Questions About Substantially Damaged Buildings* (FEMA 213, 1991).

Section 2.3.1.2 outlines elevation options that are applicable to additions in A Zones (see Section 2.3.2.1 for elevation considerations applicable to additions in V Zones). Elevation of an addition on fill may not be feasible unless structural fill can be placed adjacent to the existing building. Utility service equipment for additions must meet the requirements for new installations (see Section 2.3.5.2).

With respect to code compliance and designing additions to resist flood damage, one of the more significant issues that may come up is ease of access. If the lowest floor of the existing facility is below the DFE, steps, ramps, or elevators will be required for the transition to the new addition. Some jurisdictions may wish to allow variances to the requirement for elevation, because alternative means of access are available, such as ramps and elevators.

Under the regulations of the NFIP and FEMA guidance, it is not considered appropriate to grant such a variance.

2.4.4 REPAIRS, RENOVATIONS, AND UPGRADES

Every critical facility that is considered for upgrades and renovations, or that is being repaired after substantial damage from any cause, must be examined for structural integrity and stability to determine compatibility with structural modifications that may be required to achieve acceptable performance. When an existing facility is located in a flood hazard area, that examination should include consideration of measures to resist flood damage and reduce risks.

The model building codes and the regulations of the NFIP require that work constituting "substantial improvement" of an existing building be in compliance with the flood-resistant provisions of the code. Non-substantial improvements should take into account measures to reduce future flood damage, such as those described in Section 2.4.8, and wet floodproofing measures that allow water to enter the building to avoid structural damage, as well as emergency measures (see Section 2.4.9).

Additional information on rehabilitation of existing buildings is provided in *Flood Proofing: How to Evaluate Your Options* (USACE, 1993), *Floodproofing Non-Residential Structures* (FEMA 102), *Floodproofing—Requirements and Certification* (FIA-TB-3), and *Engineering Principles and Practices for Retrofitting Flood-prone Buildings* (FEMA 259, 1995). Although written primarily for homes, this last reference contains very detailed checklists and worksheets that can be modified. They also provide some guidance for evaluating the costs and benefits of various measures.

Compliance with flood-resistant provisions means the existing building must be elevated or dry floodproofed. Both options can be difficult for existing critical facilities, given the typical use, size, and complexity of some of these buildings. Retrofit dry floodproofing (described in Section 2.4.5) is generally limited to water depths of 3 feet or less, unless the structural capacity of the buildings have been assessed by a qualified design professional and found to be capable of resisting the anticipated loads.

Elevating an existing building presents an entirely different set of challenges and also requires detailed structural engineering analyses. It involves the same equipment and methods used to move other types of buildings; expert building movers have successfully moved large, heavy, and complex buildings, sometimes by segmenting them. A critical facility that is elevated in-place must meet the same performance standards set for new construction.

2.4.5 RETROFIT DRY FLOODPROOFING

"Dry floodproofing" refers to measures and methods to render a building envelope substantially impermeable to floodwater.

Modification of an existing building may be required or desired in order to address exposure to design flood conditions. Modifications that may be considered include construction of a reinforced supplementary wall, measures to counter buoyancy (especially if there is below-grade space), installation of special watertight door and window barriers (see Figure 2-33), and providing watertight seals around the points of entry of utility lines. The details of structural investigations and structural design of such protection measures are beyond the scope of this manual.

Figure 2-33: Boulder Community Hospital, Boulder, CO installed this permanently mounted floodgate in a low floodwall; the floodgate swings to the left to close off the door that leads to the mechanical equipment room.

Because of the tremendous flood loads that may be exerted on a building not originally designed for such conditions, detailed structural engineering evaluations are required to determine whether an existing building can be dry floodproofed. The following elements must be examined:

- The strength of the structural system
- Whether non-load bearing walls can resist anticipated loads; secondary walls can be constructed immediately adjacent to existing walls, with a waterproof membrane, to provide adequate strength
- The effects of buoyancy on the walls and floors of below-grade areas
- Effective means to install watertight doors and windows, or mountable panels
- Protection where utilities enter the building
- Methods to address seepage, especially where long-duration flooding is anticipated
- Whether there is sufficient time for human intervention measures, given the availability of official warnings of predicted flood conditions

Application of waterproofing products or membranes directly to exterior walls may minimize infiltration of water, although there are concerns with durability and limitations on use (this measure is most effective for shallow, short-duration flooding). Retrofit measures that require human intervention are considered emergency measures and are discussed in Section 2.4.9.

2.4.6 UTILITY INSTALLATIONS

Some aspects of an existing flood-prone critical facility's utility systems may be modified to reduce damage. The effectiveness of such measures depends not only on the nature of the flooding, but the type of utility and the degree of exposure. Table 2-3 in Section 2.5 lists some questions that will help facility planners and designers to examine risk reduction measures.

Even if a facility is unlikely to sustain extensive structural damage from flooding, high costs and delayed reoccupancy may result from flood-damaged utility systems. The risk reduction design measures described below can be applied, whether undertaken as part of large-scale retrofits of existing buildings, or as separate projects.

Additional guidance on improving the flood resistance of utility installations in existing buildings is found in FEMA 348, *Protecting Building Utilities From Flood Damage: Principles and Practices for the Design and Construction of Flood Resistant Building Utility Systems.*

Relocate from below-grade areas: The most vulnerable utility installations are those located below grade, and the most effective protection measure is to relocate them to properly elevated floors or platforms that are at least 2 feet above the DFE. The complexity of rerouting pipes, conduits, ductwork, electrical service, lines, and connections will depend on site-specific factors.

Elevate components: Whether located inside or outside of the building, some components of utility systems can be elevated-in-place on platforms, including electric transformers, communications switch boxes, water heaters, air conditioning compressors, furnaces, boilers, and heat pumps (see Figure 2-34).

Figure 2-34:
Elevated utility box

Anchor tanks and raise openings: Existing tanks can be elevated or anchored, as described in Section 2.3.5.4. If anchored below the DFE, tank inlets, vents, fill pipes, and openings should be elevated above the DFE, or fitted with covers designed to prevent the inflow of floodwaters or outflow of the contents of the tanks.

Protect components: If utility components cannot be elevated, it may be feasible to construct watertight enclosures, or enclosures with watertight seals that require human intervention to install when flooding is predicted.

Elevate control equipment: Control panels, gas meters, and electrical panels can be elevated, even if the equipment they service cannot be protected.

Separate electrical controls: Where areas within an existing facility are flood-prone, separation of control panels and electrical feeders will facilitate shutdown before floodwaters arrive, and help protect workers during cleanup.

Protect against electrical surges: Current fluctuations and service interruptions are common in areas affected by flooding. Equipment and sensitive electrical components can be protected by installing surge protection and uninterruptible power supplies.

Connections for portable generators: Pre-wired portable generator connections allow for quick, failure-free connection and disconnection of the generators when needed for continued functionality.

2.4.7 POTABLE WATER AND WASTEWATER SYSTEMS

All plumbing fixtures that are connected to the potable water system may become weak points in the system if they allow floodwaters to contaminate the system. Relocating the uses that require plumbing to elevated floors and removing the fixtures that are below the DFE provides protection. Wellheads can be sealed with watertight casings or protected within sealed enclosures.

Wastewater system components become sources of contamination during floods. Rising floodwaters may force untreated sewage to backup through toilets. Specially designed back-flow devices can be installed, or restrooms below the DFE can be provided with overhead piping that may require specially designed pumps to operate properly. Septic tanks can be sealed and anchored.

2.4.8 OTHER DAMAGE REDUCTION MEASURES

A number of steps can be taken to make existing facilities in flood hazard areas more resistant to flood damage, which also facilitates rapid recovery, cleanup, and reoccupancy. Whether these measures are applicable to a specific facility depends, in part, on the characteristics of the flood hazard and the characteristics of the building itself. Facility planners and designers should consider the following:

- ❍ Rehabilitate and retrofit the building envelope with openings specifically designed to allow floodwaters to flow in and out to minimize hydrostatic pressure on walls (called wet floodproofing, see Figure 2-35). Although it allows water to enter the building, this measure minimizes the likelihood of major structural damage. Walls that enclose interior spaces would also be retrofitted with openings.

Figure 2-35:
The enclosed entry and storage area to the right of the fire truck bays were retrofitted with flood openings.

SOURCE: SMART VENT, LLC

- Replace interior walls that have cavities with flood-resistant construction or removable panels to facilitate cleanup and drying.
- Abandon the use of below-grade areas (basements) by filling them in to prevent structural damage.
- Permanently relocate high-value or sensitive functions that are often found on the ground floor of critical facilities (e.g., offices, records, libraries, and computer laboratories) to higher floors or elevated additions.
- Install backflow devices in sewer lines.
- Pre-plan actions to move high-value contents from the lower floors to higher floors when a flood warning is issued.
- Replace wall, flooring, and finish materials with flood-resistant materials.
- Use epoxy or other impervious paints on concrete and other permeable surfaces to minimize contamination.
- Install separate electric circuits and ground fault interrupter circuit breakers in areas that will flood. Emergency measures should be provided so that electrical service can be shut down to avoid electrocution hazards.
- Relocate chemicals to storage areas not subject to flooding.

2.4.9 EMERGENCY MEASURES

Emergency response to flooding is outside the scope of this manual. However, it is appropriate to examine feasible emergency measures that may provide some protection. The following discussion pertains only to emergency measures that have been used to reduce flood damage to older buildings that are already located in flood hazard areas. These measures do not achieve compliance with building and life safety codes, they may not provide protection to occupants, and they can experience a high frequency of failure depending on human factors related to deployment.

Emergency barriers are measures of "last resort," and should be used only when a credible flood warning with adequate lead-time is available and dependable. These measures have varying degrees of success, depending on the available manpower, skill required, long-term maintenance of materials and equipment, suitability for site-specific flood conditions, and having enough advanced warning. Complete evacuation of protected buildings is required, as these measures should not be considered adequate protection for occupants. Furthermore, emergency barriers are not acceptable in lieu of designed flood resistant protection for new buildings.

Sandbag walls: Unless emergency placement is planned well in advance or under the direction of trained personnel, most sandbag barriers are not constructed in accordance with proper practices, leading to leakage and failures. Because of the intensive work effort and length of time required for protection from even relatively shallow water, sandbag walls are not a reliable protection measure. To be effective, sandbags and sand should be stockpiled and checked regularly to ensure that sandbags have not deteriorated. Sandbags have some other drawbacks, including high disposal costs and their tendency to absorb pollutants from contaminated floodwaters, which necessitates disposal as hazardous waste.

Water-filled barriers: A number of vendors make water-filled barriers that can be assembled with relative ease, depending on the source of water for filling. The barriers must be specifically sized for the site. Training and annual drills are important so that personnel know how to place and deploy the barriers. Proper storage, including cleaning after deployment, is necessary to protect the materials over long periods of time.

Panels for doors: For shallow and short-duration flooding, panels of sturdy material can be made to fit doorways to minimize the entry of floodwaters. Effectiveness is increased significantly if a flexible gasket or sealant is provided, and the mounting hardware is designed to apply even pressure. Personnel must know where the materials are stored and be trained in their deployment. A number of vendors make special doors for permanent installation and drop-in panels or barriers that are designed to be watertight (see Figure 2-36).

Figure 2-36:
Example of an aluminum flood barrier used for flooding less than 3 feet deep.

SOURCE: SAVANNAH TRIMS

2.5 CHECKLIST FOR BUILDING VULNERABILITY OF FLOOD-PRONE CRITICAL FACILITIES

The Checklist for Building Vulnerability of Flood-Prone Critical Facilities (Table 2-3) is a tool that can be used to help assess site-specific flood hazards and building vulnerability. The checklist is useful during site selection, preliminary design of a new building, or when considering rehabilitation of an existing facility. In addition to examining building design issues that affect vulnerability, the checklist also helps users to examine the functionality of the critical and emergency systems upon which most critical facilities depend. The checklist is organized into separate sections, so that each section can be assigned to a subject expert for greater accuracy of the examination. The results should be integrated into a master vulnerability assessment to guide the design process and the choice of appropriate mitigation measures.

Table 2-3: Checklist for Building Vulnerability of Flood-Prone Critical Facilities

Vulnerability Sections	Guidance	Observations
Site Conditions		
Is the site located near a body of water (with or without a mapped flood hazard area)? Is the site in a flood hazard area shown on the community's map (FIRM or other adopted map)? If so, what is the flood zone?	All bodies of water are subject to flooding, but not all have been designated as a floodplain on FIRMs. Flood hazard maps usually are available for review in local planning and permit offices. Electronic versions of the FIRMs may be available online at www.fema.gov. Paper maps may be ordered by calling (800) 358-9616.	

Table 2-3: Checklist for Building Vulnerability of Flood-Prone Critical Facilities (continued)

Vulnerability Sections	Guidance	Observations
Site Conditions (continued)		
(continued) Is the site affected by a regulatory floodway ? Is the site located in a storm surge inundation zone (or tsunami inundation area)?	(continued) Development in floodways, where floodwaters typically are fast and deep, must be supported by engineering analyses. In coastal communities, even sites at some distance inland from the shoreline may be exposed to extreme storm surge flooding. Storm surge maps may be available at State or local emergency management offices.	
What is the DFE (or does an analysis have to be done to determine the DFE)? What is the minimum protection level required by regulatory authorities? Does the FIS or other study have information about the 500-year flood hazard area? Has FEMA issued post-disaster advisory flood elevations and maps? What are the expected depths of flooding at the site (determined using flood elevations and ground elevations)?	Reference the FIS for flood profiles and data tables. Site-specific analyses should be performed by qualified engineers. Check with regulatory authorities to determine the required level of protection. If a major flood event has affected the community, FEMA may have issued new flood hazard information, especially if areas not shown on the FIRMs have been affected. Sometimes these maps are adopted and replace the FIRMs; sometimes the new data are advisory only.	
Has the site been affected by past flood events? What is the flood of record?	Records of actual flooding augment studies that predict flooding, especially if historic events resulted in deeper or more widespread flooding. Information may be available from local planning, emergency management, and public works agencies, or State agencies, the U.S. Army Corps of Engineers, or the Natural Resources Conservation Service. The flood of record is often a lower probability event (with higher flood elevations) than the 100-year flood.	

Table 2-3: Checklist for Building Vulnerability of Flood-Prone Critical Facilities (continued)

Vulnerability Sections	Guidance	Observations
Site Conditions (continued)		
What is the expected velocity of floodwaters on the site? Are waves expected to affect the site?	Velocity is a factor in computing loads associated with hydrodynamic forces, including drag on building surfaces. Approximations of velocity may be interpolated from data in the FIS Floodway Data Table if the waterway was studied using detailed methods, application of approximation methods based on continuity, local observations and sources, or site-specific studies. Waves can exert considerable dynamic forces on buildings and contribute to erosion and scour. Wind-driven waves occur in areas subject to coastal flooding and where unobstructed winds affect wide floodplains (large lakes and major rivers). Standing waves may occur in riverine floodplains where high velocities are present.	
Is there information on how quickly floodwaters may affect the site? What is the expected duration of flooding?	Warning time is a key factor in the safe and orderly evacuation of critical facilities. Certain protective measures may require adequate warning so that actions can be taken by skilled personnel. Duration has bearing on the stability of earthen fills, access to a site and emergency response, and durability of materials that come into contact with water. Records of actual flooding are the best indicator of duration as most floodplain analyses do not examine duration.	
Is there a history of flood-related debris problems or erosion on the site?	Site design should account for deposition of debris and sediment, as well as the potential for erosion-related movement of the shoreline or waterway. Buildings exposed to debris impact or undermining by scour and erosion should be designed to account for these conditions.	
Is the site within an area predicted to flood if a levee or floodwall fails or is overtopped? Is the site in an area predicted to be inundated if an upstream dam were to fail?	Flood protection works may be distant from sites and not readily observable. Although a low probability event, failure or overtopping can cause unexpected and catastrophic damage because the protected lands are not regulated as flood hazard areas.	

Table 2-3: Checklist for Building Vulnerability of Flood-Prone Critical Facilities (continued)

Vulnerability Sections	Guidance	Observations
Site Conditions (continued)		
	(continued) The effects of an upstream dam failure are not shown on the FIRMs or most flood hazard maps prepared locally. Although dam failure generally is considered an unlikely event, the potential threat should be evaluated due to the catastrophic consequences. (Note: owners of certain dams should have emergency action plans geared toward notification and evacuation of vulnerable populations and critical facilities.)	
Does the surrounding topography contribute to the flooding at the site? Is there a history of local surface drainage problems due to inadequate site drainage?	If areas with poor local drainage and frequent flooding cannot be avoided, filling, regrading, and installation of storm drainage facilities may be required.	
Given the nature of anticipated flooding and soils, is scour around and under the foundation likely?	Scour-prone sites should be avoided, in part due to likely long-term maintenance requirements. Flooding that is high velocity or accompanied by waves is more likely to cause scour, especially on fills, or where local soils are unconsolidated and subject to erosion.	
Has water from other sources entered the building (i.e., high groundwater, water main breaks, sewer backup, etc.)? Is there a history of water intrusion through floor slabs or well-floor connections? Are there underground utility systems or areaways that can contribute to basement flooding? Are there stormwater sewer manholes upslope of window areas or openings that allow local drainage to enter the basement/lower floor areas?	These questions pertain to existing facilities that may be impaired by water from sources other than the primary source of flooding. The entire building envelope, including below-grade areas, should be examined to identify potential water damage.	

Table 2-3: Checklist for Building Vulnerability of Flood-Prone Critical Facilities (continued)

Vulnerability Sections	Guidance	Observations
Site Conditions (continued)		
Is at least one access road to the site/building passable during flood events? Are at-grade parking lots located in flood-prone areas? Are below-grade parking areas susceptible to flooding?	Access is increasingly important as the duration of flooding increases. For the safety of occupants, most critical facilities should not be occupied during flood events. Areas where vehicles could be affected should have signage to warn users of the risk. Emergency response plans should include notification of car owners.	
Are any portions of the building below the Design Flood Elevation? Has the building been damaged in previous floods?	For existing buildings, it is important to determine which portions are vulnerable in order to evaluate floodproofing options. If flood depths are expected to exceed 2 or 3 feet, dry floodproofing may not be feasible. Alternatives include modifying the use of flood-prone areas.	
Are any building spaces below-grade (basements)?	Below-grade spaces and their contents are most vulnerable to flooding and local drainage problems. Rapid pump out of below-grade spaces can unbalance forces if the surrounding soil is saturated, leading to structural failure. If below-grade spaces are intended to be dry floodproofed, the design must account for buoyant forces.	
Are any critical building functions occupying space that is below the elevation of the 500-year flood or the Design Flood Elevation? Can critical functions be relocated to upper levels that are above predicted flood elevations? If critical functions cannot be relocated, is floodproofing feasible? If critical functions must continue during a flood event, have power, supplies, and access issues been addressed?	New critical facilities built in flood hazard areas should not have any functions occupying flood-prone spaces (other than parking, building access and limited storage). Existing facilities in floodplains should be examined carefully to identify the best options for protecting functionality and the structure itself.	

Table 2-3: Checklist for Building Vulnerability of Flood-Prone Critical Facilities (continued)

Vulnerability Sections	Guidance	Observations
Site Conditions (continued)		
Have critical contents (files, computers, servers, equipment, research, and data) been located on levels of the facility above the flood elevations? Are critical records maintained off-site?	For existing facilities that are already located in flood hazard areas, the nature of the facility may require continued use of flood-prone space. However, the potential for flooding should be recognized and steps taken to minimize loss of expensive equipment and irreplaceable data. If critical contents cannot be permanently located on higher floors, a flood response plan should take into account the time and attention needed to move such contents safely.	
Building Envelope		
Are there existing floodproofing measures in place below the expected flood elevation? What is the nature of these measures and what condition are they in? Is there an annual inspection and maintenance plan? Is there an "action plan" to implement floodproofing measures when flooding is predicted? Do the building operators/occupants know what to do when a flood warning is issued?	Floodproofing measures are only as good as the design and their condition, especially if many years have passed since initial installation. Floodproofing measures that require human intervention are entirely dependent on the adequacy of advance warning, and the availability and ability of personnel to properly install the measures.	
For existing buildings, what types of openings penetrate the building envelope below the 500-year flood elevation or the DFE (doors, windows, cracks, vent openings, plumbing fixtures, floor drains, etc.)?	For dry floodproofing to be effective, every opening must be identified and measures taken to permanently seal or to prepare special barriers to resist infiltration. Sewage backflow can enter through unprotected plumbing fixtures.	
Are flood-resistant materials used for structural and nonstructural components and finishes below the 500-year elevation or the DFE?	Flood-resistant materials are capable of withstanding direct and prolonged contact with floodwaters without sustaining damage that requires more than cosmetic repair. Contact is considered to be prolonged if it is 72 hours or longer in freshwater flooding areas, or 12 hours or longer in areas subject to coastal flooding.	

Table 2-3: Checklist for Building Vulnerability of Flood-Prone Critical Facilities (continued)

Vulnerability Sections	Guidance	Observations
Utility Systems		
Is the potable water supply for the facility protected from flooding? If served by a well, is the wellhead protected?	Operators of critical facilities that depend on fresh water for continued functionality should learn about the vulnerability of the local water supply system and the system's plans for recovery of service in the event of a flood.	
Is the wastewater service for the building protected from flooding? Are any manholes below the DFE? Is infiltration of floodwaters into sewer lines a problem? If the site is served by an onsite system that is located in a flood-prone area, have backflow valves been installed?	Most waste lines exit buildings at the lowest elevation. Even buildings that are outside of the floodplain can be affected by sewage backups during floods.	
Are there any aboveground or underground tanks on the site in flood hazard areas? Are they installed and anchored to resist flotation during the design flood? Are tank openings and vents elevated above the 500-year elevation or the DFE, or otherwise protected to prevent entry of floodwater or exit of product during a flood event?	Dislodged tanks become floating debris that pose special hazards during recovery. Lost product causes environmental damage. Functionality may be impaired if tanks for heating fuel, propane, or fuel for emergency generators are lost or damaged.	
Mechanical Systems		
Are air handlers, HVAC systems, ductwork, and other mechanical equipment and systems located above the 500-year elevation or the DFE? Are the vents and inlets located above flood level, or sealed to prevent entry of floodwater?	In existing buildings, utility equipment that is critical for functionality should be relocated to higher floors or into elevated additions.	

Table 2-3: Checklist for Building Vulnerability of Flood-Prone Critical Facilities (continued)

Vulnerability Sections	Guidance	Observations
Plumbing and Gas Systems		
Are plumbing fixtures and gas-fired equipment (meters, pilot light devices/burners, etc.) located above the 500-year elevation or the DFE?	In existing buildings, utility equipment that is critical for functionality should be relocated to higher floors or into elevated additions.	
Is plumbing and gas piping that extends below flood levels installed to minimize damage?	Piping that is exposed could be impacted by debris.	
Electrical Systems		
Are electrical systems, including backup power generators, panels, and primary service equipment, located above the 500-year elevation or the DFE? Are pieces of electrical stand-by equipment and generators equipped with circuits to turn off power? Are the switches and wiring required for safety (minimal lighting, door openers) located below the flood level designed for use in damp locations?	In existing buildings, utility equipment that is critical for functionality should be relocated to higher floors or into elevated additions.	
Fire Alarm Systems		
Is the fire alarm system located above the 500-year elevation or the DFE?	In existing buildings, utility equipment that is critical for functionality should be relocated to higher floors or into elevated additions.	
Communications and IT Systems		
Are the communication/IT systems located above the 500-year elevation or the DFE?		

Table 2-3: Checklist for Building Vulnerability of Flood-Prone Critical Facilities (continued)

Vulnerability Sections	Guidance	Observations
Structural		
What is the construction type and the foundation type and what is the load bearing capacity? Has the foundation been designed to resist hydrostatic and hydrodynamic flood loads? If the building has below-grade areas, are the lower floor slabs subject to cracking and uplift?	If siting in a floodplain is unavoidable, new facilities are to be designed to account for all loads and load combinations, including flood loads. Building spaces below the design flood level can be dry floodproofed, although it must be recognized that higher flood levels will overtop the protection measures and may result in severe damage. Dry floodproofing creates large unbalanced forces that can jeopardize walls and foundations that are not designed to resist the hydrostatic and hydrodynamic loads.	
If the building is elevated on a crawlspace an open foundation, are there any enclosed areas?	New buildings may have enclosures below the flood elevation provided the use of the enclosures is limited (crawlspace, parking, building access, limited storage). In addition, the enclosures must have flood openings to automatically allow for inflow and outflow of floodwaters to minimize differential hydrostatic pressure. Existing buildings that are elevated and have enclosures below the flood elevation can be retrofit with flood openings.	
For an existing building with high value uses below the flood elevation, is the building suitable for elevation-in-place or can it be relocated to higher ground?	Elevating a building provides better protection than dry floodproofing. Depending on the type and soundness of the foundation, even large buildings can be elevated on a new foundation or moved to a site outside of the floodplain.	

2.6 REFERENCES AND SOURCES OF ADDITIONAL INFORMATION

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Organizations and Agencies:

FEMA: FEMA's regional offices (www.fema.gov) can be contacted for advice and guidance on NFIP mapping and regulations.

NFIP State Coordinating offices help local governments to meet their floodplain management obligations, and may provide technical advice to others; the offices are listed by the Association of State Floodplain Managers, Inc. (www.floods.org/stcoor.htm).

State departments of education or agencies that coordinate State funding and guidelines for critical facilities may have State-specific requirements.

U.S. Army Corps of Engineers: District offices offer Flood Plain Management Services (www.usace.army.mil/inet/functions/cw/).

FEMA publications may be obtained at no cost by calling (800) 480-2520, faxing a request to (301) 497-6378, or downloaded from the library/publications section online at http://www.fema.gov.