



# 2

## Design Considerations in Floodproofing

The most effective flood mitigation methods are relocation and elevation, but when these methods are not feasible or cost-effective, floodproofing may be an appropriate alternative. Some emergency measures can be accomplished without expert construction assistance, and many can be used for low-level or nuisance flooding while significantly reducing losses from these types of events.

The development of a floodproofing strategy should include considerations of a number of factors that will influence the design of the floodproofing measure or measures. This chapter contains a discussion of these factors, which are:

- **Design requirements.** Regulatory requirements, building codes, design standards, and other guidance documents (Section 2.1)
- **Design loads and site characteristics.** Hydrostatic loads, hydrodynamic loads, wave loads, impact loads from flood-borne debris, internal drainage, and site drainage (Section 2.2)
- **Flood characteristics.** Flood elevations, duration of flooding, rate of floodwater rise and fall, flood frequency (Section 2.3)
- **Site factors.** Flood hazard boundaries, erosion and scour, and geotechnical considerations (Section 2.4)
- **Functional, operational, and economic factors.** Functional use requirements of the building, occupant safety, flood warning time, flood emergency operations plans, inspection and maintenance plans, and BCAs (Section 2.5)
- **Vulnerability assessments.** All-hazards vulnerability assessments, structural condition assessments of the building, and utility assessments (Section 2.6)



### Cross Reference

Have questions about the NFIP?

See FEMA F-084, *Answers to Questions about the NFIP (FEMA 2011b)* at: <http://www.fema.gov/media-library/assets/documents/272>. This document is intended to acquaint the public with the NFIP. It is designed for readers who do not need a detailed history or technical or legal explanations but who do need a basic understanding of the program and the answers to some frequently asked questions. For legal definitions, see the *NFIP Flood Insurance Manual (FEMA 2013)*, and *National Flood Insurance Program Regulations (FEMA 2009a)*.

## 2.1 Regulatory Requirements, Building Codes, Design Standards, and Guidance Documents

Floodproofing may be proposed voluntarily by building owners or may be necessary to meet floodplain management regulations or building codes. This section contains a discussion of the floodplain management regulations and building codes that can affect the type and design of floodproofing measures.

### 2.1.1 National Flood Insurance Program

Communities that participate in the NFIP are required to adopt and enforce local regulations for development in mapped Special Flood Hazard Areas (SFHAs) to reduce the risk of flooding (see 44 CFR Parts 59 and 60). However, communities are encouraged to adopt requirements that exceed Federal regulations. Homeowners, renters, and business owners, as well as communities that own buildings in participating communities are eligible for NFIP flood insurance coverage.

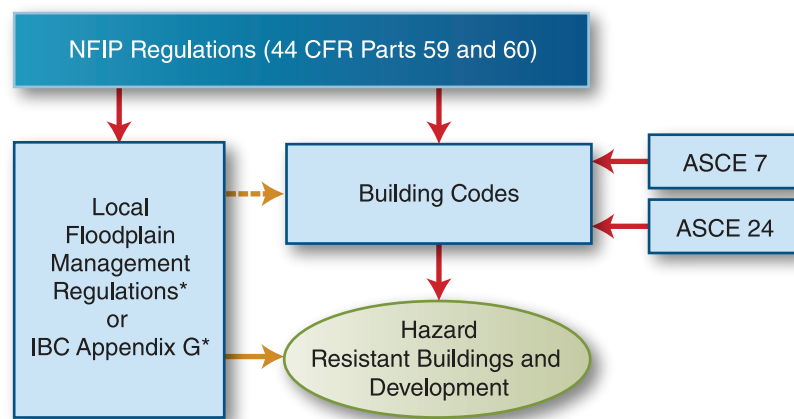
With the inclusion of NFIP-consistent provisions in the *International Code Series* (I-Codes), communities that have adopted the I-Codes have two ways of enforcing NFIP flood-resistant design and construction requirements for buildings and structures:

- Using the I-Codes with NFIP-consistent provisions intact and IBC Appendix G; or
- Using the I-Codes with NFIP-consistent provisions intact and local floodplain management regulations that include requirements comparable to those in Appendix G.

These tools are designed to work together to result in buildings and structures, and all other development, that are resistant to flood loads and flood damage.

If a participating community has not adopted the I-Codes or if the NFIP-consistent provisions of the codes are not intact, the community must adopt local floodplain management regulations that include detailed and specific requirements for buildings and structures.

Consensus standards are incorporated into building codes by reference; ASCE 7, *Minimum Design Loads for Buildings and Other Structures* (2010), and ASCE 24 are two consensus standards that are consistent with NFIP regulations. See Section 2.1.7 for more information on consensus standards. Figure 2-1 shows how building design is regulated by the NFIP regulations and building codes.



\*NFIP-consistent administrative provisions, community-specific adoption of Flood Insurance Studies and maps, and technical requirements for development outside the scope of the building code (and higher standards, in some communities)

Figure 2-1. Satisfying NFIP requirements through building codes

The requirements in 44 CFR Part 60 apply to all development, which the NFIP broadly defines to include buildings and structures, site work, roads and bridges, and other activities. The regulations require buildings to be designed and constructed to resist flood damage, which is achieved primarily through elevation. Dry floodproofing can be used to fulfill the requirements for non-residential buildings in SFHAs that are not subject to high velocity wave action. Some requirements apply to existing buildings when the cost of repairing or improving a building in an SFHA equals or exceeds 50 percent of the building's market value. The NFIP requires that new and Substantially Improved buildings be constructed in ways that minimize or prevent flood damage. As with new non-residential buildings, existing non-residential buildings may be brought into compliance by elevating them on compliant foundations or, if determined to be feasible, by implementing dry floodproofing measures.

The NFIP's performance requirements are identical for new construction and for Substantial Improvement or repair of Substantial Damage of existing buildings. Some of the key requirements are:

- 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 (44 CFR §60.3(a)(3)(i)).
- Building materials used below the BFE shall be resistant to flood damage (44 CFR §60.3(a)(3)(ii)).
- Buildings shall be constructed by methods and practices that minimize flood damage (44 CFR §60.3(a)(3)(iii)).
- Buildings shall be constructed with electrical, heating, ventilation, plumbing, and air-conditioning equipment and other service facilities that are designed and/or located so as to prevent water from entering or accumulating within the components (44 CFR §60.3(a)(3)(iv)).



### Special Note

The NFIP establishes minimum criteria and design performance requirements that communities participating in the NFIP must enforce for structures in SFHAs. The criteria specify how a structure should be constructed in order to minimize or reduce the potential for flood damage. A primary requirement is that buildings shall be elevated to or above the BFE. Depending on flood zone, non-residential buildings may be protected with specifically designed and certified dry floodproofing measures that are watertight below and protect to the BFE. See Section 2.1.2 for information on the Floodproofing Certificate.



### Terminology

**“Substantial Damage”** is damage of any origin sustained by a structure whereby the cost of restoring the structure to its before-damage condition would equal or exceed 50 percent of the market value of the structure before the damage occurred (FEMA 2010c).

**“Substantial Improvement”** is any repair, reconstruction, rehabilitation, addition, or improvement of a building, the cost of which equals or exceeds 50 percent of the market value of the building before the improvement or repair is started (certain historic structures may be excluded) (FEMA 2010c).

**Substantially Impermeable:** FEMA uses USACE's definition of substantially impermeable from *Flood Proofing Regulations* (USACE 1995). This document states that a substantially impermeable wall “shall not permit the accumulation of more than 4 inches of water depth during a 24-hour period and, sump pumps shall be required to control this seepage.”

- New and replacement water supply systems shall be designed to minimize or eliminate infiltration of flood waters into the systems (44 CFR §60.3(a)(5)).
- New and replacement sanitary sewage systems shall be designed to minimize or eliminate the infiltration of discharges from the systems into floodwaters (44 CFR §60.3(a)(6)(i)).
- All new construction and Substantial Improvement of non-residential structures within Zones A1–30, AE, and AH on the community’s Flood Insurance Rate Map (FIRM) must (i) have the lowest floor (including basement) elevated to or above the base flood level or, (ii) together with attendant utility and sanitary facilities, be designed so that below the base flood level the structure 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 (44 CFR §60.3(c)(3)).
- Within any Zone AO on the community’s FIRM, all new construction and Substantial Improvement of nonresidential structures must (i) have the lowest floor (including basement) elevated above the highest adjacent grade at least as high as the depth number specified in feet on the community’s FIRM (at least 2 feet if no depth number is specified), or (ii) together with attendant utility and sanitary facilities be completely floodproofed to that level to meet the floodproofing standards specified in 44 §60.3(c)(3)(ii) and 60.3(c)(8).



### Special Note

This publication specifies that in order for dry floodproofing to achieve a favorable NFIP insurance rating, it must extend to the BFE + 1 foot of freeboard. For new construction or Substantial Improvement/Damage, it must extend to the BFE. However, the owner may choose to protect an existing building from lesser events of shallower, more frequent flooding using dry floodproofing measures provided Substantial Improvement/Damage is not triggered.

When dry floodproofing measures are proposed for non-residential buildings, communities that participate in the NFIP require applicants to provide certification that registered professional engineers or architects have developed or reviewed the structural design, specifications, and plans for proposed dry floodproofing measures. In addition, the dry floodproofing design and proposed methods of construction are to be certified as being in accordance with accepted standards of practice (see Section 2.1.2). The standards of practice require that the building, together with attendant utility and sanitary facilities, be designed so that it is watertight below the BFE, with walls substantially impermeable to the passage of water and with structural components



### Special Note

The NFIP does not strictly prohibit hazardous materials from areas subject to flooding, but requiring such materials to be protected from floodwaters, is an effective way to reduce or eliminate the chance of damage associated with the release of harmful materials. FEMA 480, *Floodplain Management Requirements, A Study Guide and Desk Reference for Local Officials*, provides a list of potential contaminants that may be of concern (FEMA 2005).



that are capable of resisting hydrostatic and hydrodynamic loads and effects of buoyancy associated with the design flood event.

Although NFIP regulations require non-residential buildings to be watertight and protected only to the BFE for floodplain management purposes (to meet NFIP regulations), protection to a higher level is necessary for dry floodproofing measures to be considered for NFIP flood insurance rating purposes. Because of the additional risk associated with dry floodproofed buildings, to receive an insurance rating based on 1-percent-annual-chance (100-year) flood protection, a building must be dry floodproofed to an elevation at least 1 foot above the BFE. Insurance premiums will be lower if dry floodproofing extends higher than the BFE + 1 foot. Dry floodproofed buildings with active floodproofing measures and requiring human intervention are subject to higher insurance premiums than dry floodproofed buildings with completely passive floodproofing measures that do not require human intervention.



**Special Note**

A building that is valued at \$150,000 and located in a zone A can have differing insurance premiums based on the level of floodproofing. If the building is floodproofed to 1 foot above the BFE, the annual premium would be approximately \$1380. If the same building is floodproofed to 2 feet above the BFE, the annual premium would be approximately \$540. The increase in floodproofing design level would result in a **61 percent** savings in annual insurance premiums that would be passed onto the building owner.

Wet floodproofing also has implications for NFIP flood insurance rating purposes. NFIP floodplain management regulations restrict the use of space below the BFE to parking of vehicles, building access, and storage.

Although floodwalls or levees can be used to keep floodwaters away from buildings, implementing these measures will not affect a building’s flood insurance rating unless the flood control structure is accredited in accordance NFIP requirements (44 CFR §65.10) and provides protection from at least the 1-percent-annual-chance (100-year) flood. In addition, floodwalls or levees as a retrofit measure will not bring the building into compliance with NFIP requirements for Substantial Improvement/Damage.

Tables 2-1 and 2-2 provide other requirements for dry and wet floodproofing based on the NFIP.

**Table 2-1. NFIP General Requirements for Dry Floodproofing**

NFIP General Requirements for Dry Floodproofing	References
For new construction and Substantial Improvement/Damage, permitted only in non-residential buildings in special flood hazard areas not subject to high velocity wave action (i.e., permitted in Zone A).	44 CFR §60.3(c)(3) 44 CFR §60.3(c)(8)
Must be designed so the structure is watertight below the BFE with walls substantially impermeable to the passage of floodwater. <sup>(a)</sup>	44 CFR §60.3(c)(4)
Attendant utility and sanitary facilities must be completely floodproofed to below the BFE. <sup>(a)</sup>	Technical Bulletin 3 (FEMA 1993a)
A registered design professional must develop and/or review structural designs, specifications, and plans and certify that the design and methods of construction are in accordance with accepted standards of practice.	
Not permitted in Coastal High Hazard Areas (Zone V).	

<sup>(a)</sup> Dry floodproofed properties are eligible for insurance only if floodproofing extends to 1 foot above the BFE; 44 CFR §60.3(c)(3) requires floodproofing to the BFE.

**Table 2-2. NFIP General Requirements for Wet Floodproofing**

NFIP General Wet Floodproofing Requirements	References
Permitted only for attached garages or parking, access, and storage areas below the BFE	44 CFR §60.3(a)(3)
Some historic structures, accessory structures, structures functionally dependent on proximity to water, and agricultural buildings may be wet floodproofed	44 CFR §60.3(c)(5)
Portions of the structure below the BFE must be constructed of flood-resistant materials	44 CFR §60.6(a)
Must be designed to allow for automatic entry and exit of floodwaters	44 CFR §60.6(a)(7) Technical Bulletin 7 (FEMA 1993b)

### 2.1.2 Floodproofing Certificate for Non-Residential Buildings in Zone A



#### Special Note

When dry floodproofing is used to comply with local regulations or building code requirements, the NFIP and model building codes require the submission of a certificate stating that the design satisfies all applicable requirements. Strictly speaking, certification is not required for retrofit measures that are not required to meet the minimum requirements; however, FEMA recommends that communities require it for all retrofit dry floodproofing projects. The recommended form to use for this purpose is the FEMA Floodproofing Certificate for Non-Residential Structures (FEMA Form 086-0-34) (FEMA 2012b). This form is required for the floodproofing measures to be recognized for NFIP flood insurance purposes. It is important to note that this certificate is not an “as-built” certification; it is used by the designer only to certify the design. Certification of design is not required for wet floodproofing. For floodwalls and levees, a certificate is required only if the mitigation results in a change to the FIRM.

The design certification is required for the following types of buildings in Zone A:

- Dry floodproofed non-residential structures (no residential uses)
- Dry floodproofed portions of mixed-use buildings that have all residential uses located above the floodproofing design elevation

The certificate is submitted as part of the permit application and has the following three sections:

Design professionals need to be aware of several requirements not explicitly noted on current floodproofing certificates, specifically, they must:

- Provide interior drainage (pumps) to control seepage into building
- Provide a continuous source of electricity to operate any necessary floodproofing components
- Use flood-resistant materials in areas where seepage is expected to occur
- Conduct planning, including developing a flood emergency operations plan and an inspection and maintenance plan

To ensure better documentation and to demonstrate the importance of implementing active measures, FEMA suggests that local officials require a photograph of the building to be submitted with the certificate. If there are openings on the floodproofed portion of the building, the photograph should be taken with opening protection fully installed/in place.

Further, the designer should sign off on the floodproofing certificate stating that he or she has reviewed the emergency operations plan AND inspection and maintenance plan and that they are adequate.

Finally, additional technical documentation, such as design drawings and material specifications, may be required for insurance purposes.

- **Section I.** FIRM information, including community number, map panel number, date of the FIRM index, flood zone, and BFE.
- **Section II.** Floodproofing information. The designer is required to identify the floodproofing design elevation and the height of the floodproofing measures above the lowest adjacent grade.
- **Section III.** Certification by the design professional licensed in the State where the project is located. The designer signs to certify that the dry floodproofed area of the building, together with attendant utilities and sanitary facilities, will be watertight to the floodproofed design elevation indicated, with walls that are substantially impermeable to the passage of water. The designer is also required to certify that all structural components are capable of resisting hydrostatic and hydrodynamic flood forces, including the effects of buoyancy, and anticipated debris impact forces.

The designer provides copies of the completed certificate to the building owner who submits it with the permit application to his/her insurance agent/company and the community official. Communities are required to maintain copies of design certifications as part of their commitment to the NFIP.

### 2.1.3 Floodproofing Historic Buildings

The NFIP gives special consideration to the unique value of designated historic buildings and structures. Provided such structures retain their designations, communities do not have to require them to be brought into compliance if the structures will be Substantially Improved or have been Substantially Damaged. The NFIP definition of “historic structures” includes structures that are (1) listed or preliminarily determined to be eligible for listing in the National Register of Historic Places, (2) certified or preliminarily determined by the Secretary of the Department of Interior as contributing to the historical significance of a registered historic district or a district preliminarily determined to qualify as a registered historic district, or (3) designated as a historic site under a State or local historic preservation program that is approved by the Secretary of the Department of Interior. The definition does not include structures that are merely old, those that residents refer to as historic, or those that happen to be located in historic districts. Section 4.5.3 includes a case study involving the application of floodproofing to historic buildings.

When voluntary retrofit floodproofing measures are applied to historic buildings, the measures should be designed to mitigate or reduce the flood risk while preserving the building’s historic integrity. Consultation with the State Historic Preservation Officer and a design professional (engineer or architect), preferably one experienced in rehabilitating historic structures, is necessary. Ideally, any retrofit floodproofing measure applied to a historic building and/or its site will not affect the property’s designation. If a structure does not retain its historic designation, it is subject to the basic NFIP requirements for Substantial Improvement/Damage.

Retrofit floodproofing measures for historic buildings need not be comprehensive to provide at least some degree of protection. The techniques listed below may have minimal impact on the historically significant features of the structure (FEMA 2008b):

- Elevating electrical and mechanical systems and utilities
- Relocating contents
- Creating positive drainage, where the grade allows water to drain away from the building
- Using flood damage-resistant materials

- Filling in basements or wet floodproofing basements
- Installing small floodwalls to protect openings such as window wells

### 2.1.4 National Policies for Federal Actions in Floodplains

When Federal assistance is provided for the planning, design, and construction of buildings or for the repair of existing buildings located in SFHAs (and within the 0.2-percent-annual-chance [500-year] floodplain if the activity funded is a “critical action” or critical facility), the funding agency is required to address additional considerations.

Executive Order (EO) 11988, Floodplain Management, requires Federal agencies to follow a decision-making process to avoid, to the extent possible, the short- and long-term adverse impacts associated with the occupancy and modification of floodplains and to avoid supporting floodplain development directly or indirectly whenever there is a practicable alternative. If there is no practicable alternative, the Federal agency must take steps to minimize any adverse impacts on people’s lives, property, and the floodplain’s natural and beneficial functions. EO 11988 applies directly to Federal agencies and indirectly to tribes, States, and local governments through Federal actions and requirements.

FEMA’s regulations in 44 CFR Part 9 set forth the agency’s policy, procedure, and responsibilities for implementation and enforcement of EO 11988 and also EO 11990, Protection of Wetlands. Other Federal agencies have similar regulations or policies that satisfy the requirements of the order.

As defined in 44 CFR §9.4, a critical action is an action for which even a slight chance of flooding is too great. The minimum floodplain of concern for critical actions is the 0.2-percent-annual-chance (500-year) floodplain. Critical actions include actions that create or extend the useful life of structures or facilities such as those that produce, use, or store highly volatile, flammable, explosive, toxic or water reactive materials; hospitals, nursing homes, and housing for the elderly; emergency operation centers, data storage centers; utility systems and power generating plants.



#### Warning

Although 44 CFR Part 9 implementation rules addresses “critical actions” in SFHAs (actions for which even a slight chance of flooding is too great), sometimes relocating a critical action (building) is a better option than elevating or floodproofing



#### Special Note

44 CFR §9.11(d)(1) states that FEMA, as part of its implementation of the Disaster Relief Act of 1974, shall apply certain minimization provisions. Specifically, FEMA funding shall not be used to support new construction or Substantial Improvement in a floodway, and no new construction in a coastal high hazard area, except for (i) a functionally dependent use or (ii) a structure or facility which facilitates an open space use.

44 CFR §59.1 defines the regulatory floodway as the channel of a river or other watercourse and the adjacent land areas that must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than a designated height.

44 CFR §59.1 defines the coastal high hazard area as an area of special flood hazard extending from offshore to the inland limit of a primary frontal dune along an open coast and any other area subject to high velocity wave action from storms or seismic sources.



Critical actions should be given special consideration when developing regulatory alternatives and floodplain management plans. Under EO 11988 and 44 CFR Part 9, critical actions are required to avoid the 0.2 percent-annual-chance (500-year) floodplain or to elevate or protect structures and essential components to the 0.2-percent-annual-chance (500-year) flood level. Critical actions should not occur in a floodplain, if possible.

The 8-step decision-making process called for in EO 11988 is further developed and clarified in 44 CFR §9.6(b). FEMA uses the decision-making process illustrated in Figure 2-2 to satisfy the requirements.

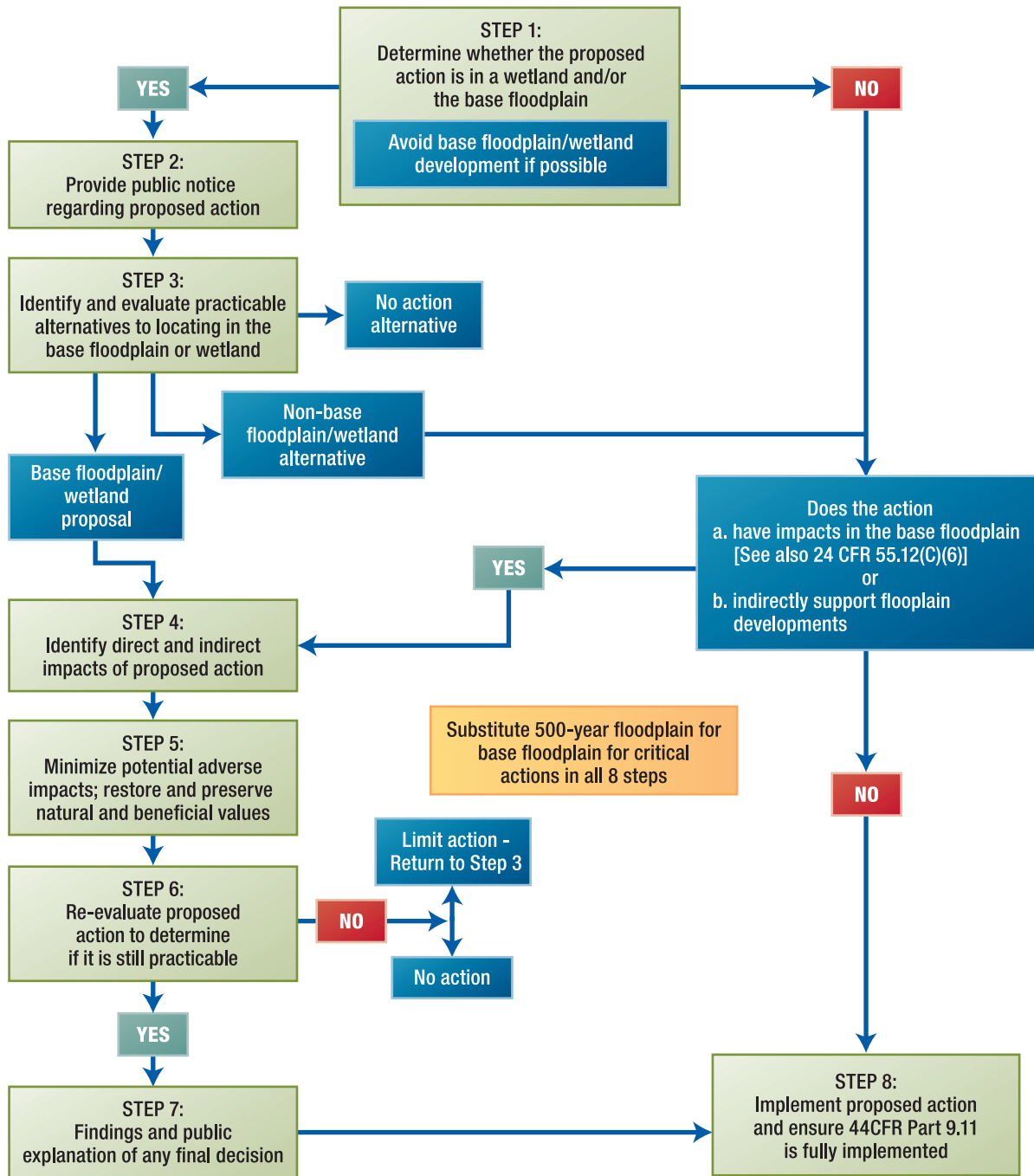


Figure 2-2. FEMA's 8-step decision-making process for compliance with Executive Order (EO) 11998 and 44 CFR Part 9

### 2.1.5 Local Floodplain Management Regulations

To participate in the NFIP, communities are required to adopt and enforce local floodplain management regulations that meet or exceed the minimum requirements established in 44 CFR Parts 59 and 60. Until the advent of model building codes that included flood provisions deemed consistent with NFIP requirements for buildings (see Section 2.1.1), communities adopted stand-alone floodplain management regulations or ordinances that included administrative, land use, and building requirements.

Some States have requirements that exceed the minimum NFIP requirements, and many communities adopt higher standards to achieve a greater level of protection and public safety. The most common higher standards are:

- Requirement to protect to a higher elevation than the minimum requirement (freeboard)
- A cumulative Substantial Improvement in which the improvements and repairs are tallied over a certain period of time (e.g., 5 or 10 years). The effect of a cumulative improvement provision is that more existing buildings are required to be brought into compliance with the requirements for new construction
- Prohibition of new construction in the floodway, SFHA, or conservation zones
- Prohibition of the use of building materials and practices that have proven to be ineffective in flooding
- Restrictions on the use and type of construction fill material



#### Warning

For any building that is proposed for dry floodproofing, always determine whether the community where the building is located has adopted higher standards.

### 2.1.6 Model Building Codes

Many States and communities regulate the construction of buildings by adopting and enforcing building codes based on model building codes. Building codes have minimum requirements on issues such as structural design, materials, fire safety, number and location of exits, natural hazard mitigation, sanitary facilities, light and ventilation, environmental control, fire protection, and energy conservation. Building codes apply to the construction of new buildings and structures and to existing buildings and structures, including alteration, relocation, enlargement, replacement, repair, and change of occupancy.

The I-Codes and the National Fire Protection Association (NFPA) *Building Construction and Safety Code* (NFPA 5000 [2012]) were the first model codes to include comprehensive provisions for flood hazards. The flood provisions were incorporated into building codes in the early 2000s. Both codes are consistent with the minimum provisions of the NFIP that pertain to the design and construction of buildings and other structures.

The IBC and *International Existing Building Code* (IEBC [2012]) are pertinent to this manual because they address the primary requirements for design and construction of non-residential buildings and because of their widespread use in the United States. The IBC contains flood provisions, and the IEBC references the flood provisions of the IBC for all repairs, additions, and alterations to existing buildings in flood hazard areas that are proposed to be Substantially Improved or that have sustained Substantial Damage.

The IBC incorporates by reference a number of standards developed through a formal or accredited consensus process. The standards that are related to flood-resistant design are ASCE 7, *Minimum Design Loads for Buildings and Other Structures*, and ASCE 24, *Flood Resistant Design and Construction*. The IBC addresses flood loads and flood-resistant construction primarily in Section 1612. FEMA has determined that the flood provisions of the I-Codes are consistent with NFIP requirements for buildings and structures. The family of I-Codes addresses all of the key building requirements of the NFIP. Communities that enforce building codes based on the I-Codes should coordinate their floodplain management ordinances with the codes to minimize duplication and conflicts and to ensure that all requirements are addressed, including requirements for development other than buildings and structures.



### Cross Reference

The International Code Council's family of building codes can be purchased at <http://www.iccsafe.org/>. The I-Codes are NOT available for free (although some States have made them available through separate copyright agreements). Excerpts of the flood provisions of the I-Codes are posted on the FEMA Building Science Web site: <http://www.fema.gov/building-science>.

Some key code requirements from the 2012 IBC are described in Table 2-3 (previous editions of the IBC have the same or similar requirements).

A dry floodproofing retrofit project may trigger several sections of a community's building code that must be considered during the design. The designer or engineer should be cognizant of codes that may be triggered when considering flood mitigation projects (see code trigger example on page 2-13).

Table 2-3. Key Code Requirements for Flood-Resistant Design from IBC 2012

IBC 2012 Section <sup>(a)</sup>	Requirement	Comments
110.3.3 [Required Inspections] Lowest Floor Elevation	In flood hazard areas, upon placement of the lowest floor, including the basement, and prior to further vertical construction, the elevation certificate required in Section 1612.5 shall be submitted to the building official.	Requires submission of elevation certificate once lowest floor has been constructed, before further vertical construction.
1403.6 [Exterior Walls] Flood Resistance	For buildings in flood hazard areas as established in Section 1612.3, exterior walls extending below the elevation required by Section 1612 shall be constructed with flood-damage-resistant materials. Wood shall be pressure-preservative treated in accordance with AWPA-U1-12, <i>Use Category System: User Specification for Treated Wood</i> (AWPA 2012) for the species, product, and end use using a preservative listed in Section 4 of AWPA U1 or decay-resistant heartwood of redwood, black locust, or cedar.	Requires buildings in flood hazard areas to use flood-damage-resistant materials on exterior walls below the required elevation.
1605.2.1 [Structural Design] Load Combinations (using strength design or load and resistance factor design) and Other Loads.	Where flood loads, $F_a$ , are to be considered in the design, the load combinations of Section 2.3.3 of ASCE 7 shall be used. Where self-straining loads, $T$ , are considered in design, their structural effects in combination with other loads shall be determined in accordance with Section 2.4.4 of ASCE 7. Where an ice-sensitive structure is subjected to loads due to atmospheric icing, the load combinations of Section 2.3.4 of ASCE 7 shall be considered.	Requires buildings designed for flood hazard areas to be designed to resist flood loads, along with other loads.
1605.3.1.2 [Structural Design] Load Combinations (using allowable stress design) and Other Loads.	Where flood loads, $F_a$ , are to be considered in design, the load combinations of Section 2.4.2 of ASCE 7 shall be used. Where self-straining loads, $T$ , are considered in design, their structural effects in combination with other loads shall be determined in accordance with Section 2.4.4 of ASCE 7. Where an ice-sensitive structure is subjected to loads due to atmospheric icing, the load combinations of Section 2.3.4 of ASCE 7 shall be considered.	Requires buildings designed for flood hazard areas to be designed to resist flood loads, along with other loads.
1612.1 [Structural Design] Flood Loads	Within flood hazard areas as established in Section 1612.3, all new construction of buildings, structures and portions of buildings and structures, including Substantial Improvement and restoration of Substantial Damage to buildings and structures, shall be designed and constructed to resist the effects of flood hazards and flood loads. For buildings that are located in more than one flood hazard area, the provisions associated with the most restrictive flood hazard area shall apply.	Requires all new buildings, Substantial Improvement, and repair of Substantial Damage to be designed to resist the most restrictive flood hazard applicable to the location.
1612.4 [Structural Design] Flood Loads	The design and construction of buildings and structures located in flood hazard areas, including flood hazard areas subject to high-velocity wave action, shall be in accordance with Chapter 5 of ASCE 7 and with ASCE 24.	References ASCE 7 and ASCE 24 for the specific requirements for the design and construction of buildings in flood hazard areas.

International Building Code (IBC), American Society of Civil Engineers (ASCE), American Wood Protection Association (AWPA)

<sup>(a)</sup> Flood-resistant provisions of the I-Codes can be found at <http://www.fema.gov/building-science/building-code-resources>.



### Code Trigger Example

An example of a requirement that could be triggered by a floodproofing retrofit project is means of egress. The IEBC has criteria on means of egress that may be relevant depending on the level of alteration. Level 2 alterations “include the reconfiguration of space, the addition or elimination of any door or window, the reconfiguration or extension of any system, or the installation of any additional equipment.” Under the IEBC, in a Level 2 alteration, the requirements for both Level 1 and Level 2 alterations need to be followed. The requirements may involve finish, structural, accessibility/egress, fire-resistance, and other requirements. For example, a Level 2 alteration may trigger means of egress requirements that include:

- Minimum number of exits in the work area, as required by the IBC (some buildings are required to have only one exit if certain criteria are met)
- Fire escapes requirements such as unobstructed access
- New fire escape requirements
- Mezzanine egress requirements
- Requirements for openings in corridor walls
- Means of egress lighting, exit signs, handrails, and guard

## 2.1.7 Consensus Standards

The consensus standards relevant to flood-resistant design are ASCE 7 and ASCE 24. The requirements in these standards are consistent with the minimum NFIP requirements.

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. To compute the loads and load combinations, the designer must identify site-specific characteristics, including flood depths, velocities, waves, and the likelihood that debris impacts need to be considered.

ASCE 24 addresses design and construction requirements for 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-velocity areas. ASCE 24 sets forth requirements for elevation, foundation designs, enclosures below elevated buildings, materials, dry and wet floodproofing, utility



### Warning

ASCE 24 addresses design and construction requirements for buildings in coastal high-hazard areas (Zone V), Coastal A Zones, and high-flood-velocity areas but limits the applications of dry floodproofing in these areas because of increased hydrodynamic and wave loads.



### Cross Reference

ASCE standards are available for purchase at: <http://www.asce.org/codes-standards/>. Highlights of ASCE 24 are posted on the FEMA Building Science Web page: <http://www.fema.gov/building-science>.

installations, building access, and miscellaneous structures (e.g., decks, porches, patios, garages, chimneys and fireplaces, pools, above- and below-ground storage tanks).

ASCE 24, Section 6.2 and Commentary 6.2, Dry Floodproofing, specify design and construction requirements for dry floodproofing when used for the construction of new buildings or when existing buildings are proposed to be Substantially Improved (including repair of Substantial Damage). Table 2-4 provides a list of general requirements and limitations for dry floodproofing. ASCE 24 promulgates the standards of practice and should be used for floodproofing retrofits, even if the work does not constitute a Substantial Improvement.

**Table 2-4. ASCE 24 Requirements and Limitations for Dry Floodproofing**

ASCE 24 Section	Dry Floodproofing Requirements and Limitations
Minimum Elevation of Floodproofing (Table 6-1)	Specifies the minimum elevation of dry floodproofing relative to the base flood elevation (BFE) or design flood elevation (DFE) as a function of structure/risk category and limits use of dry floodproofing to flood hazard areas outside of high risk flood hazard areas.
Limitations (Section 6.2.1)	Dry floodproofing of buildings is not permitted in: <ul style="list-style-type: none"> <li>• Coastal High Hazard Areas (Zone V)</li> <li>• Coastal A Zones</li> <li>• Other High Risk Flood Areas where the following are known to occur: alluvial fan flooding, flash floods, mudslides, ice jams, high velocity flows, or erosion</li> <li>• Areas where flood velocities adjacent to buildings is greater than 5 feet per second during the design flood</li> </ul>
Requirements (Section 6.2.2)	Buildings shall be designed and constructed: <ul style="list-style-type: none"> <li>• So that any area below the applicable elevation specified in Table 6-1 is flood resistant with walls that are substantially impermeable to the passage of water</li> <li>• To resist all flood related loads resulting from flooding to the elevation listed in Table 6-1, including hydrostatic, hydrodynamic, and other flood related loads, including the effects of buoyancy</li> <li>• To have soil or fill adjacent to the structure compacted and protected against erosion and scour in accordance with ASCE 24, Section 2.4</li> <li>• To have at least one door satisfying building code requirements as an exit door or primary means of escape above the applicable elevation specified in Table 6-1</li> </ul>
Human Intervention (Section 6.2.3)	Buildings proposed to be dry floodproofed that require human intervention to activate or implement measures prior to flooding shall be permitted only if all of the following conditions are satisfied: <ul style="list-style-type: none"> <li>• Minimum of 12-hour warning time, unless community operates a flood warning system and implements an emergency plan to ensure safe evacuation and the community can provide a minimum warning time to allow the implementation of measures requiring human implementation</li> <li>• Removable shields or covers for openings must be designed to resist flood loads specified in Section 1.6</li> <li>• Flood emergency plan must be approved by the authority having jurisdiction, shall specify certain information critical to implementation, and shall be posted in at least two locations within structure</li> </ul>

Section 6.3 and Commentary 6.3, Wet Floodproofing, in ASCE 24 specify design and construction requirements for wet floodproofing measures. Table 2-5 provides a list of general requirements for wet floodproofing. ASCE 24 Section 6.3 and Commentary 6.3 should be reviewed for more information on these requirements.

**Table 2-5. ASCE 24 Requirements and Limitations for Wet Floodproofing**

ASCE 24 Section	Wet Floodproofing Requirements and Limitations
Limitations on use (Section 6.3.1)	<ul style="list-style-type: none"> <li>Wet floodproofing of enclosed areas below elevations listed in Table 6-1 shall be limited to: Category I structures (from Table 1-1, includes certain agricultural structures, certain temporary facilities, and minor storage facilities)</li> <li>Enclosures used solely for parking, building access or storage</li> <li>Structures that are functionally dependent on close proximity to water</li> <li>Agricultural structures not included in Category I structures that cannot be located elsewhere and that are used solely for agricultural purposes</li> </ul>
Requirements (Section 6.3.2)	<p>Wet floodproofing shall be accomplished by:</p> <ul style="list-style-type: none"> <li>Use of techniques that minimize damage to the structure associated with flood loads</li> <li>Meeting the requirements for enclosures (Section 2.6 or Section 4.6) depending on the flood hazard area</li> <li>Installation of utilities, including plumbing fixtures, in conformance with the requirements of Section 7 (Utilities)</li> </ul>

### 2.1.8 Additional Federal Guidance Documents

Two important Federal guidance documents on floodproofing are:

- NFIP Technical Bulletin 3-93, *Non-Residential Floodproofing: Requirements and Certification for Buildings Located in Special Flood Hazard Areas in Accordance with the National Flood Insurance Program* (FEMA 1993a)
- USACE’s *Flood Proofing Regulations* (EP 1165-2-314), a technical model for floodproofing-related regulations but not a regulation (USACE 1995)

FEMA’s Technical Bulletins provide guidance on complying with the minimum requirements of existing NFIP regulations on limited topics including non-residential floodproofing, wet floodproofing, flood damage-resistant materials, and elevators. The NFIP Technical Bulletin 3-93 provides step-by-step guidance on:



#### Terminology

Regulations and building codes establish the requirements that must be met. Guidance is additional information that may be useful to code officials and others who are responsible for interpreting, enforcing, and complying with regulations and codes. Guidance can also provide recommendations that are beyond the minimum requirements of building codes, standards or regulations.



#### Cross Reference

FEMA’s Technical Bulletins are available at: <http://www.fema.gov/national-flood-insurance-program-2/nfip-technical-bulletins>.

USACE’s Flood Proofing Regulations is available at: [http://publications.usace.army.mil/publications/eng-pamphlets/EP\\_1165-2-314/toc.htm](http://publications.usace.army.mil/publications/eng-pamphlets/EP_1165-2-314/toc.htm).

- NFIP regulations that apply to the design of floodproofing for non-residential buildings
- Planning considerations (e.g., warning time, flood characteristics)
- Minimum engineering considerations and equations for calculating flood forces
- Preparing the Floodproofing Certificate for Non-Residential Structures (see Section 2.1.2)

USACE's *Flood Proofing Regulations* was among the earliest documents to provide an administrative and technical model for code design and enforcement and to present detailed information on implementing floodproofing techniques. It has served as the framework for the preparation of numerous other floodproofing publications. *Flood Proofing Regulations* pertains to riverine flooding and does not address wave action, corrosion, or erosion associated with coastal flooding, debris impact, mudslides, or high-density fluid problems.

## 2.2 Design Loads and Site Characteristics

Floodproofing measures must ensure that buildings will be designed and constructed to resist flotation, collapse, and lateral movement associated with flooding. The loads and conditions discussed in this section include but are not limited to:

- Flood-related hazards such as hydrostatic and hydrodynamic loads, flood-borne debris impact loads, and internal and site drainage considerations
- Site-specific soil and geotechnical considerations such as soil pressure, bearing capacity, land subsidence, erosion, scour, and shrink-swell potential

This section provides an overview of how these forces can act on a building. See FEMA P-259, *Engineering Principles and Practices for Retrofitting Flood-Prone Residential Structures* (FEMA 2012a) for more information on flood-related loads and conditions.



### Cross Reference

For areas in which BFEs have not been established, designers can refer to FEMA 265 *Zone A Manual: Managing Floodplain Development in Approximate Zone A Areas* (FEMA 1995) (<http://www.fema.gov/media-library/assets/documents/7273>). This guide provides information on obtaining and developing BFEs.

### 2.2.1 Identifying the Base Flood Elevation

Determining the expected BFE is critical to understanding the site-specific flood risk. The flood zone and estimated BFE of a project area are identified using a FIRM panel. Flood hazard area boundaries on many FIRMs are delineated for the 1- and 0.2-percent-annual-chance (100-year and 500-year) flood.

Figure 2-3 shows the location of a subject building on a FIRM. The area with blue dots is the 1-percent-annual-chance (100-year) flood hazard area. The area with black dots is the 0.2-percent-annual-chance (500-year) flood hazard area. After the building is located on the FIRM, the flood profiles in the relevant Flood Insurance Study (FIS) should be used to verify the BFE and to determine the flood elevations for other modeled flood recurrence intervals.





Figure 2-3. Building and stream location on a FIRM

Some FIRMs do not show the 0.2-percent-annual-chance (500-year) flood hazard area, and many FIRMs do not provide detailed information about predicted flood elevations along every body of water, especially smaller streams and tributaries. 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. If a proposed or existing site has been affected or has the potential to be affected by flooding, a site-specific topographic survey is critical to delineate the land below the flood elevation. 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.

## 2.2.2 Design Flood Elevation

The I-Codes, ASCE 7, and ASCE 24 define the design flood elevation (DFE) as “elevation of the design flood, including wave height, relative to the datum specified on the community’s flood hazard map.” The design flood is the “greater of the following two flood events: (1) the base flood, affecting those areas identified as SFHAs on the community’s FIRM or (2) the flood corresponding to the area designated as a flood hazard area on a

community’s flood hazard map or otherwise legally designated.” Some communities use the DFE to refer to the BFE plus locally required additional height (usually referred to as “freeboard”).

The I-Codes and ASCE 24 specify the elevation of buildings or the elevation of floodproofing measures based on the Occupancy/Risk Category of the building. All buildings are required to be assigned a category, which is then used in ASCE 24 to determine the level of protection. The more important the building, as indicated by the assigned category, the higher the level of protection.



### Terminology

**Base flood elevation (BFE)** – The elevation of the base flood relative to the datum specified on a community’s FIRM. The base flood has a 1-percent chance of being equaled or exceeded in any given year (commonly called the 100-year flood). BFEs are shown on FIRMs for many SFHAs. The BFE is the NFIP’s minimum elevation to which the lowest floor of a building must be elevated or floodproofed (Zone A). In Zone V, the bottom of the lowest horizontal structural member must be elevated to or above the BFE; floodproofing is not permitted in Zone V. Many SFHAs are shown on FIRMs without BFEs; in these areas, community officials and permit applicants are required to obtain and use information from other sources, or must estimate or develop BFEs at specific locations.

**Freeboard** – An added margin of safety, expressed in feet above a specific flood elevation, usually the BFE. In States and communities that require freeboard, buildings are required to be elevated or floodproofed to the higher elevation. For example, if a community adopts a 2-foot freeboard, non-residential buildings are required to be elevated or floodproofed to 2 feet above the BFE.

**Design flood elevation (DFE)** – The elevation of the design flood relative to the datum specified on the community’s FIRM. The design flood is associated with the greater of the area subject to the base flood or the area designated as a flood hazard area on a community flood map or otherwise designated. The I-Codes, ASCE 7, and ASCE 24 use the term DFE. In most communities, the DFE is identical to the BFE. Communities may designate a design flood (or DFE) in order to regulate based on a flood of record, to account for future increases in flood levels based on upland development, or to incorporate freeboard.

## 2.2.3 Determining the Flood Depth

The first step in determining the flood depth for a site is to identify the DFE that is specified by the building code or the floodplain management regulations that are enforced by the governing authority. The most common flood elevation used for design is the BFE. ASCE 24 requires some height of freeboard above the BFE, the amount of which is determined by the building occupancy. Local regulations and requirements should be compared to ASCE 24, and the most restrictive condition should be followed.



### Cross Reference

The FEMA publication, *Managing Floodplain Development through the NFIP*, IS-9 (FEMA 2007a), provides guidance on determining flood elevations through flood profiles in the FIS. The document can be downloaded here: <http://www.fema.gov/media-library/assets/documents/6029>.

If NFIP compliance is not required (the building does not have to meet the requirements of Substantial Improvement/Damage), then the flood depth is based on the flood protection level selected by the owner or designer. On the other hand, if the building must be brought into compliance with the requirements of NFIP, the flood depth is equal to the BFE/DFE.

The second step is to determine the expected elevation of the ground at the site. The expected ground elevation must account for any erosion, scour, subsidence, or other ground-eroding conditions that occur over time. Erosion is possible even in low-velocity flooding areas and can increase future flood hazards by lowering ground levels. Land subsidence is the lowering of the ground as a result of water, oil, gas extraction, soil consolidation, decomposition of organic material, and tectonic movement. The lowest expected ground elevation is determined by considering subsidence and erosion during flood conditions.



### Special Note

Subsidence effects can be estimated by lowering all existing ground elevations at the site by the product of the subsidence rate times the building lifetime. For example, if subsidence occurs at a rate of 0.05 foot/year and the building lifetime is 50 years, the profile should be lowered 2.5 feet.

In this publication, the flood depth ( $H$ ) is defined as the difference between the flood protection level and the lowest eroded ground surface elevation ( $GS$ ) adjacent to the building (see Equation 2-1). Because these data are usually obtained from different sources, determining whether they are based on the same datum is important. If not, standard datum corrections must be applied.



$$H = DFE - GS$$

where:

$H$  = flood depth (ft)

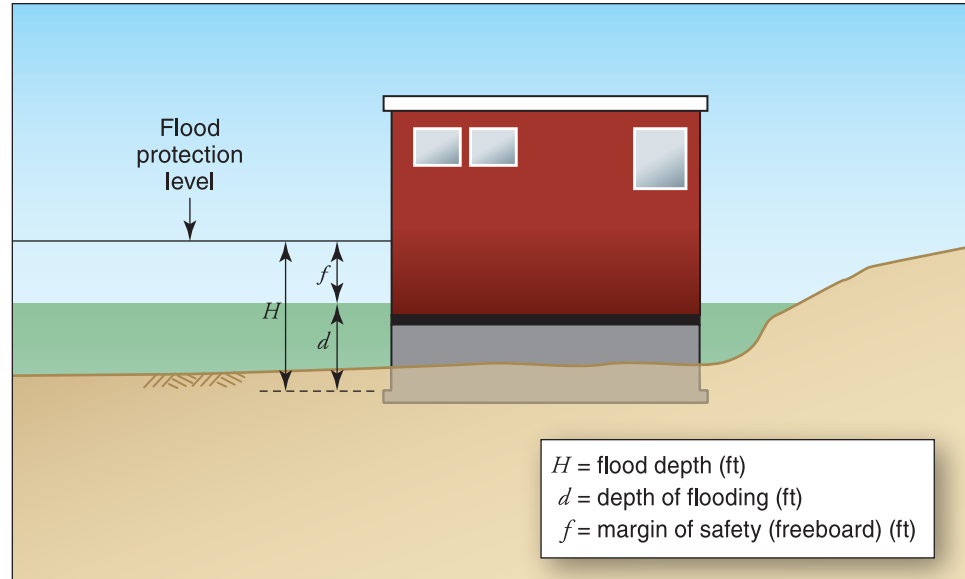
$DFE$  = flood protection level or design flood elevation (ft)

$GS$  = lowest eroded ground surface elevation adjacent to the building (ft)

### Equation 2-1. Flood depth

Determining the flood depth associated with the flood protection level is most important for load calculations. Nearly every other flood load parameter or calculation (e.g., hydrostatic load, hydrodynamic load, debris impact load, local scour depth) depends directly or indirectly on the flood depth. The flood depth is shown in Figure 2-4. For new construction or Substantial Improvement, if NFIP compliance is required, the flood protection level should be equal to the BFE/DFE.

Figure 2-4. Flood depth



### 2.2.4 Determining Hydrostatic Loads

Hydrostatic pressures occur when floodwaters come into contact with a foundation, building, or building element. These pressures are always perpendicular to the building surface and increase linearly with depth or “head” of water below the surface of the water. Hydrostatic pressures can cause severe deflection or displacement of buildings or building components if water levels on opposite sides of the component (or inside and outside the building) are substantially different. Figure 2-5 shows equal and unequal hydrostatic pressures applied to the exterior of a building. Dry floodproofing results in unequal hydrostatic forces that must be accounted for in the floodproofing design.



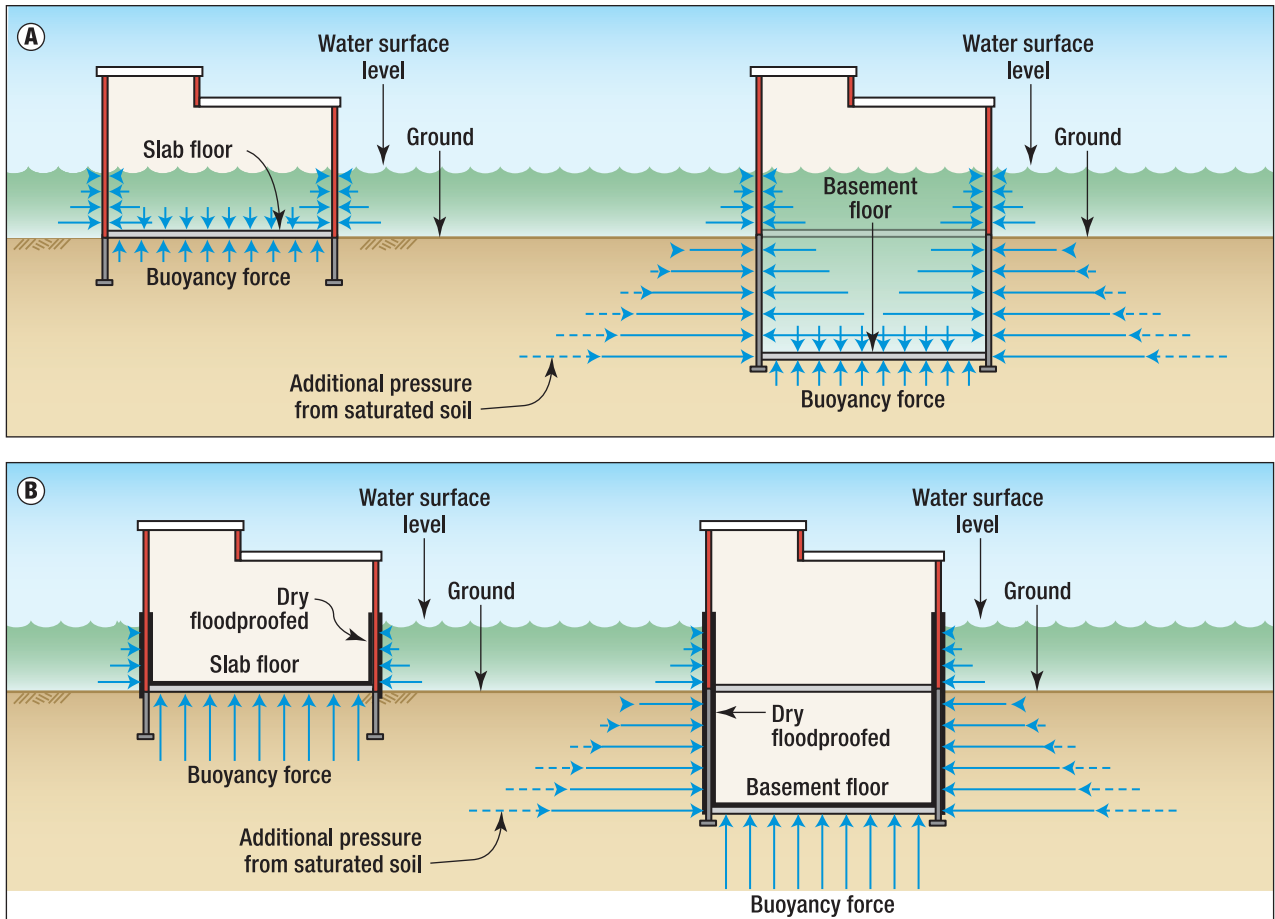


Figure 2-5. Equal (A) and unequal (B) hydrostatic pressures applied to the exterior elements of a building; (B) shows the building protected by dry floodproofing methods applied

The sum of the pressures over the surface under consideration represents the load acting on that surface. For structural analysis, hydrostatic forces are defined to act:

- Vertically upward on the underside of any submerged members such as floor slabs, walls, and footings
- Laterally on perimeter walls, piers, and similar vertical surfaces

The basic equation for analyzing the lateral force from hydrostatic pressures from the flood depth to the lowest eroded ground surface elevation adjacent to the building is illustrated in Equation 2-2.



$$f_{sta} = \frac{1}{2} P_b H = \frac{1}{2} \gamma_w H^2$$

where:

$f_{sta}$  = hydrostatic force from flood depth (lb/lf) acting at a distance  $H/3$  above ground

$P_b$  = hydrostatic pressure due to standing water at a depth of  $H$  (lb/ft<sup>2</sup>), ( $P_b = \gamma_w H$ )

$\gamma_w$  = specific weight of water (62.4 lb/ft<sup>3</sup> for fresh water and 64.0 lb/ft<sup>3</sup> for saltwater)

$H$  = flood depth (ft)

### Equation 2-2. Lateral hydrostatic forces

The resultant hydrostatic force  $f_{sta}$  acts at a point two-thirds of the distance down from the water surface or one-third the distance up from the bottom of the flooded or submerged surface.

If any portion of the building is below grade, saturated soil pressures must be included in the design load calculations. Saturated soil pressures include pressure from both the soil and water acting on the structure's wall and are applied from the lowest adjacent grade of the building to the bottom of the flooded or submerged surface. Since the lateral hydrostatic force equation already calculates standing water pressures from the bottom of the flooded or submerged surface a differential soil force equation must be used so that hydrostatic pressures are not accounted for twice in the load calculations.

The differential soil forces ( $f_{dif}$ ) equation is calculated by subtracting the unit weight of water from the equivalent fluid weight of the saturated soil (a combination of the unit weight of water and the effective saturated weight of soil based on a conversion from lateral earth pressure derived from shear strength properties). The equivalent fluid weights of the submerged soil and water can be found in various design manuals, including Table 4-3 in FEMA P-259 (FEMA 2012a).

When a structure is subject to hydrostatic forces from both saturated soil and standing water, the resultant cumulative lateral force is the sum of the lateral water hydrostatic force and the differential soil force. The basic equation for computing  $f_{dif}$  is illustrated in Equation 2-3. Although the differential soil force equation is not specifically site dependent, the equation is considered a more conservative approach for floodproofing design. Expansive or swelling soils may significantly increase lateral earth pressures and foundation heave pressures, and need to be evaluated separately and added to these cumulative forces. See Section 2.4.3 for discussion of procedures to evaluate these geotechnical behaviors.



$$f_{dif} = \frac{1}{2} (S - \gamma_w) D^2$$

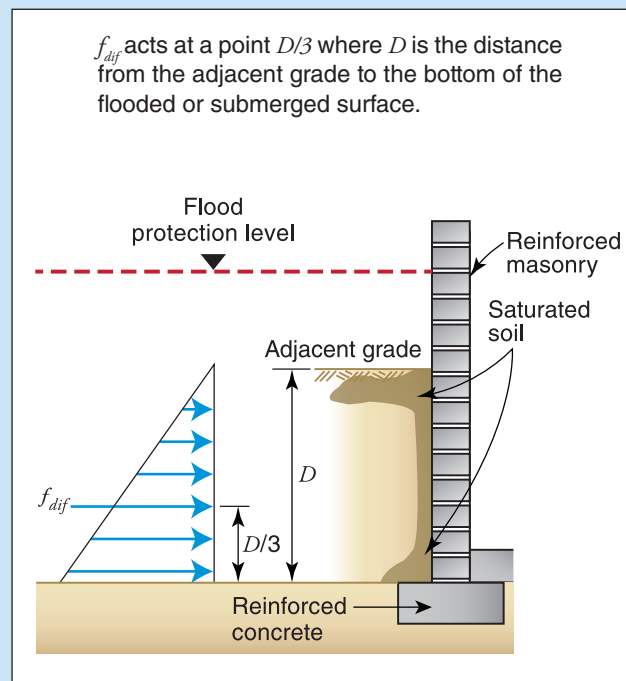
where:

$f_{dif}$  = differential soil/water force acting at a distance  $D/3$  from the point under consideration (lb/lf)

$S$  = equivalent fluid weight of submerged soil and water (lb/ft<sup>3</sup>) (shown in Table 4-3 of FEMA 259)

$D$  = depth of saturated soil from adjacent grade to the (bottom of the flooded or submerged surface ft)

$\gamma_w$  = specific weight of water (62.4 lb/ft<sup>3</sup> for fresh water and 64.0 lb/ft<sup>3</sup> for saltwater)



Equation 2-3. Submerged soil and water forces

Figure 2-6 shows a building subject to hydrostatic forces from saturated soil and water.

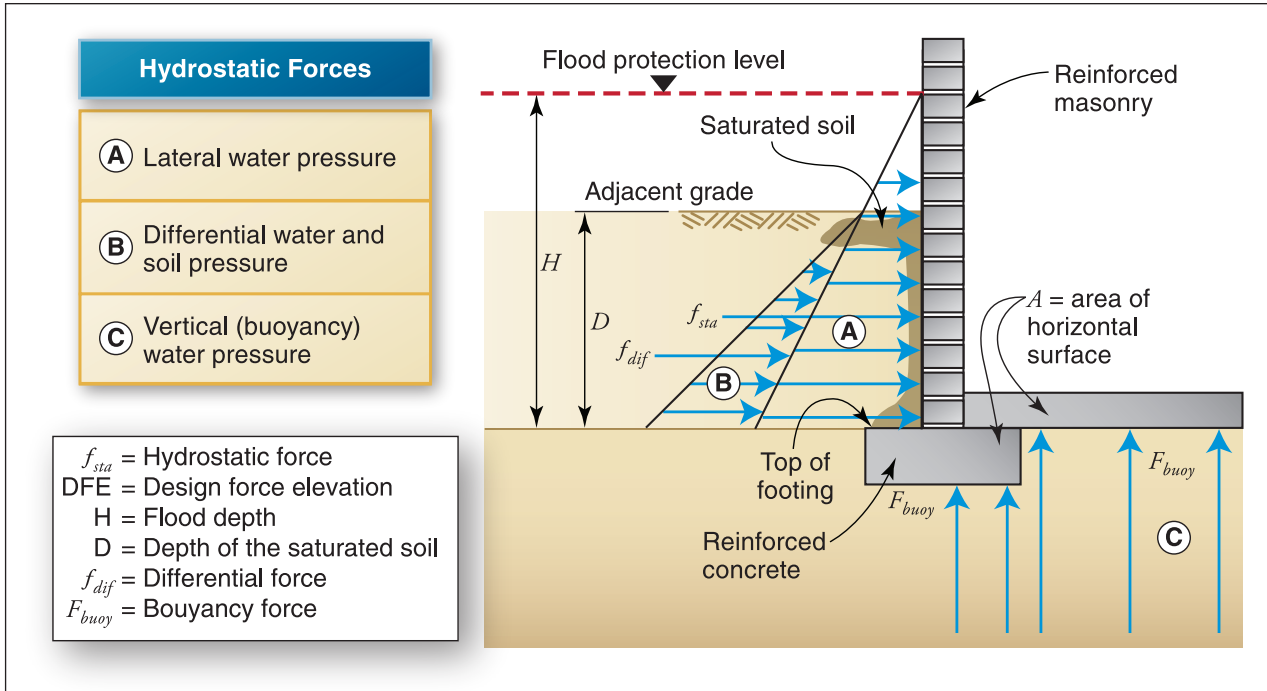


Figure 2-6. Hydrostatic forces acting on a foundation wall

In a basement, vertical hydrostatic pressure acts on the bases of the foundation walls and on the concrete floor slab. The total vertical hydrostatic force that acts on the structure is the volume of floodwater displaced by the submerged structure multiplied by the specific weight of water.

Vertical hydrostatic forces on a structure, also known as buoyant forces, must be resisted by the weight of the building itself. When a building is too light to resist buoyancy, other opposing forces, such as those from ground or soil anchors, must be added. Buoyant or flotation forces on a building can be of great concern when the elevation of floodwaters on the exterior of a building exceeds the elevation of floodwaters inside the building.

When a below-grade foundation or crawl space is backfilled with compacted structural fill that supports the floor slab, unbalanced lateral and vertical loads against the walls and foundation slab will be reduced. This is one way to help counteract the buoyancy forces during flooding.

The basic equation for analyzing buoyancy forces is shown in Equation 2-4.



$$F_{buoy} = \gamma_w (Vol)$$

where:

$F_{buoy}$  = vertical hydrostatic force resulting from the displacement of a given volume of floodwater (lb)

$\gamma_w$  = specific weight of water (62.4 lb/ft<sup>3</sup> for fresh water and 64.0 lb/ft<sup>3</sup> for saltwater)

$Vol$  = volume of floodwater displaced by a submerged object (ft<sup>3</sup>)

#### Equation 2-4. Buoyancy forces

As noted in Equation 2-4, the specific weight of freshwater is 62.4 pounds per cubic foot (lb/ft<sup>3</sup>), while the specific weight of saltwater is slightly higher at 64 lb/ft<sup>3</sup>. Both fresh and saltwater are relatively dense, so buoyant forces can be extreme. For example, the buoyant forces on a 24-by-36-foot foundation with 4 feet of freshwater flooding can be as high as 214,272 pounds (24 ft x 36 ft x 4 ft x 62 lb/ft<sup>3</sup>). Approximately 250,000 pounds of buoyant force will exceed the weight of all but the heaviest structures. It is assumed that the foundation walls and slab are substantially impermeable to the passage of water. Buildings with substantially impermeable basement walls and floor that have sump pumps to remove water that enters the basement can experience increased buoyant forces. When substantially impermeable buildings with below-grade areas are exposed to flooding, they can actually float on the floodwaters they displace.

The computation of hydrostatic forces is vital to the successful design of floodwalls, sealants, closures, shields, foundation walls, slabs, and a variety of other dry floodproofing measures. Computation of these forces is illustrated in Sections 4.1.2.2 through 4.1.2.6 of FEMA P-259.

### 2.2.5 Determining Hydrodynamic Forces

Water flowing around a building, structural elements, and other submerged objects imposes loads on submerged building elements. These loads are known as hydrodynamic loads (see Figure 2-7). Hydrodynamic loads are a function of flow velocity and structural geometry and include frontal impact on the upstream face, drag along the sides, and suction on the downstream side. One of the most difficult steps in quantifying loads imposed by moving water is determining the expected floodwater velocity.



#### Special Note

Sources of data for determining expected flood velocity include hydraulic calculations, historical measurements, Risk Mapping, Assessment, and Planning (Risk MAP) velocity data grids, and rules of thumb. If no data exist for flood flow velocity for a site, contact an experienced hydrologist or hydraulic engineer for estimates.



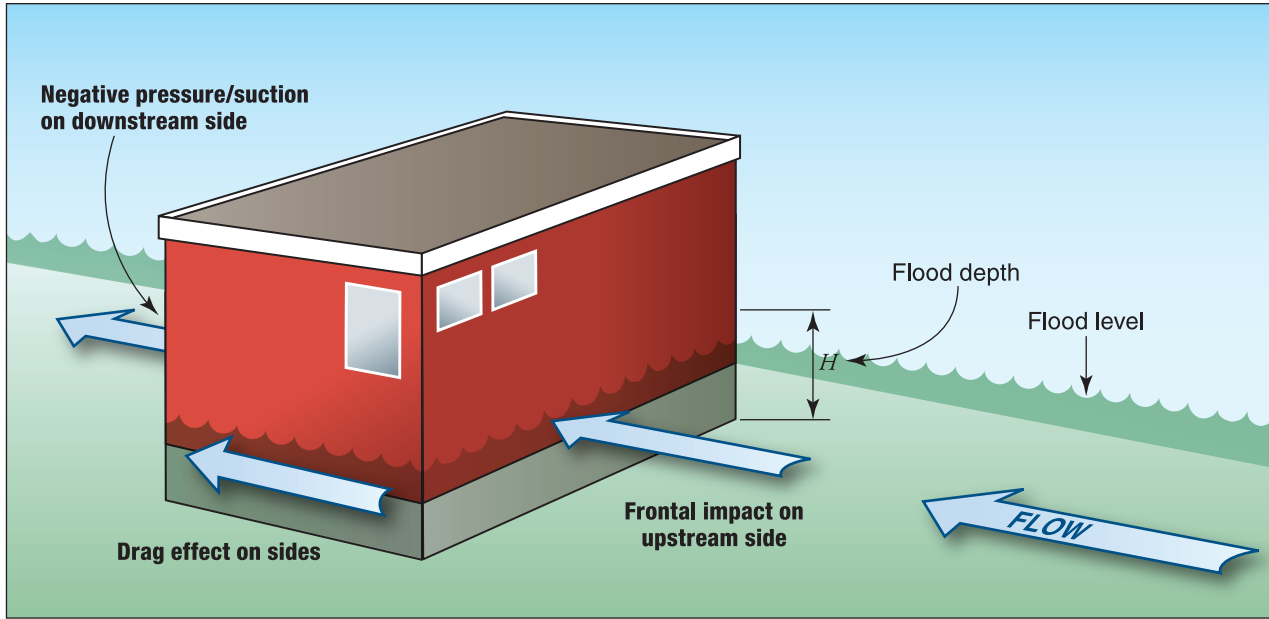


Figure 2-7. Hydrodynamic and impact loads

For the purpose of this publication, floodwater velocity is assumed to be 5 feet per second (ft/sec) or less. ASCE 24, which is incorporated by reference in the IBC, states that dry floodproofing should be limited to areas where flood velocities are less than or equal to 5 ft/sec during the design flood. The velocity of floodwater is also assumed to be constant (i.e., steady-state flow). Hydrodynamic loads can be calculated using Equation 25.

Equation 2-5 provides the total hydrodynamic force against a building of a given surface area,  $A$ . Dividing the total force by either length or width yields a force per linear unit; dividing by surface area,  $A$ , yields a force per unit area.



### Special Note

The 5 ft/sec velocity restriction for floodproofing is not a requirement of the NFIP but is used in USACE's *Flood Proofing Regulations* (1995) in the design of structures exposed to water loads from stagnant or flowing waters. Although effective dry floodproofing can be designed for higher velocities, this is a reasonable existing limit that addresses safety of dry floodproofed structures during a flood.



$$F_{dyn} = C_d \rho \frac{V^2}{2} A$$

where:

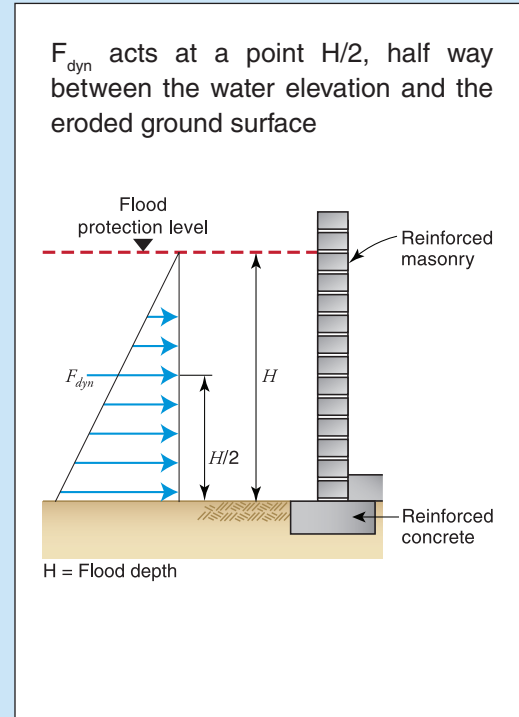
$F_{dyn}$  = horizontal drag force (lb)

$C_d$  = drag coefficient (taken from Table 2-6)

$\rho$  = mass density of fluid (1.94 slugs/ft<sup>3</sup> for fresh water and 1.99 slugs/ft<sup>3</sup> for saltwater)

$V$  = velocity of floodwater (ft/sec)

$A$  = surface area of obstruction normal to flow (ft<sup>2</sup>) =  $(w)(H)$  if the object is completely immersed



### Equation 2-5. Hydrodynamic load

The drag coefficient used in Equation 2-5 can be found in the *Shore Protection Manual, Volume 2* (USACE 1984). Additional guidance is provided in Section 5.4.3 of ASCE 7. The drag coefficient is a function of the shape of the object around which flow is directed. When an object is something other than a round, square, or rectangular pile, the coefficient is determined by one of the following ratios (see Table 2-6):

1. The ratio of the width of the object ( $w$ ) to the height of the object ( $b$ ) if the object is completely immersed in water, or
2. The ratio of the width of the object ( $w$ ) to the flood depth of the water ( $H$ ) if the object is not fully immersed

Table 2-6. Drag Coefficients for Ratios of Width to Depth (w/H) and Width to Height (w/h)

Width to Height Ratio (w/H or w/h)	Drag Coefficient ( $C_d$ )
1–12	1.25
13–20	1.3
21–32	1.4
33–40	1.5
41–80	1.75
81–120	1.8
>120	2.0

Source: *Shore Protection Manual, Volume 2* (USACE 1984)

Flow around a building or building element also creates flow-perpendicular forces (lift forces). When a building element is rigid, lift forces can be assumed to be small. When the element is not rigid, lift forces can be greater than drag forces. The equation for lift force is the same as that for hydrodynamic force except that the drag coefficient ( $C_d$ ) is replaced with the lift coefficient ( $C_l$ ). In this publication, the foundations of buildings in low-velocity riverine areas are considered rigid, and since hydrodynamic lift forces for rigid foundations are assumed to be small, they can be ignored.

### 2.2.6 Determining Impact Loads

Debris impact loads are imposed on a building by objects carried by moving water. The magnitude of these loads is difficult to predict, but a reasonable allowance must be made for them in the design of floodproofing measures. Factors that affect debris impact load include size, shape, and weight of the waterborne object; flood velocity; velocity of the waterborne object compared to the flood velocity; duration of the impact; portion of the building to be struck; depth of flooding; and blockage upstream of structure. Detailed guidance, including an equation for calculating debris loads, first appeared in ASCE 7 Commentary; guidance can also be found in Section 4.1.2.9 in FEMA P-259 (FEMA 2012a) and Section 8.5.10 of FEMA P-55 (FEMA 2011c). Figure 2-8 depicts normal impact loads for a structure.

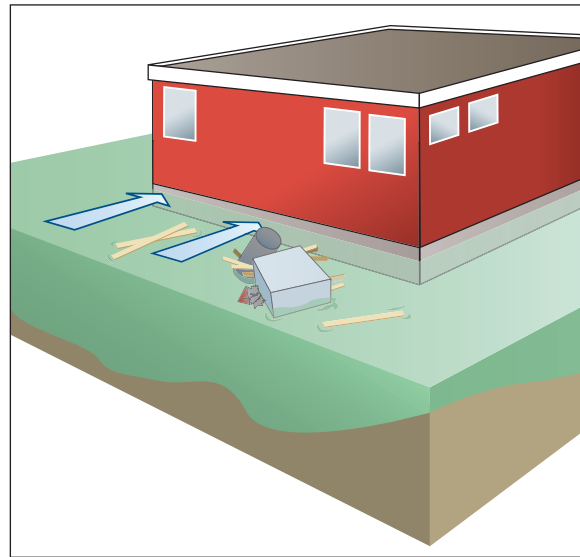


Figure 2-8. Frontal impact from debris

### 2.2.7 Interior Drain Systems

When floodwater surrounds a building or saturates surrounding soils, it has a high probability of seeping into the building through the exterior walls, foundations, and slabs. Interior drain systems for buildings are designed to keep water from accumulating in those interior below-grade areas. These systems do not require the soil to be excavated from around the exterior below-grade walls to install underdrains.

Sump pumps are perhaps the most familiar method of dewatering below-grade areas. The sump is generally constructed so that its bottom is well below the base of the floor slab. Water in the areas adjacent to below-grade walls and floor migrate along the lines of least resistance, which should be toward and into the sump.

It may be necessary to provide a more readily accessible path of least resistance for water that has collected in the fill material and around the structure to follow. To achieve this, pipe segments are inserted and sometimes drilled through the below-grade wall and into the fill behind, purposefully allowing the interior to flood. Gravel is placed around the pipe segments on the exterior of the foundation wall to filter the surrounding soil, not allowing it to enter the interior of the building. The pipe segments are then connected to larger diameter pipes running along a gravel-filled trench or cove area into the floor slab and into one or more sumps (see Figure 2-9).

Interior drain systems can be overwhelmed by a quickly rising water table and are subject to potential power outages.

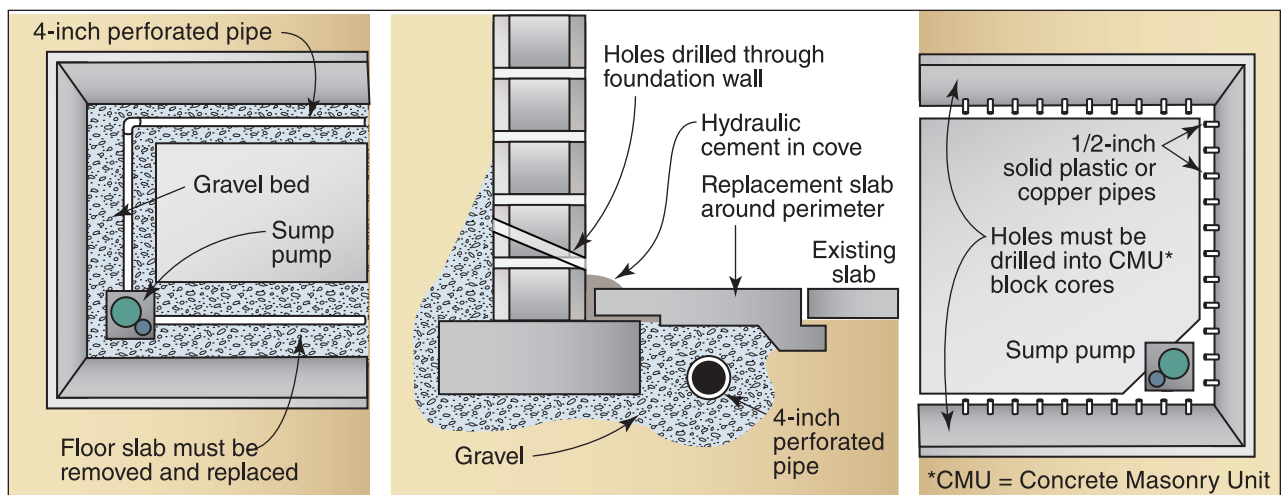


Figure 2-9. Typical interior drain systems

In selecting a sump pump for use in floodproofing, the designer should consider the advantages of each pump type and make a selection based on requirements determined from the investigation of the building. Considerations include pump capacity (gpm [gallons per minute]), pump head (vertical height that the water is lifted), and electrical power required to operate the pump. Section 3.7 provides more detail on internal drainage systems design.



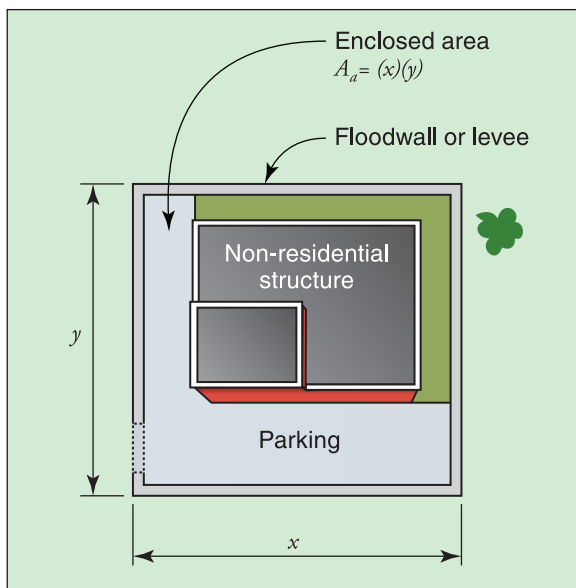
### Warning

Drilling holes around the interior floor slab and installing interior drains under the floor slab should be done in small segments. Cutting and replacing the perimeter of the interior floor slab in sections will prevent the foundation wall from rotating inward toward the interior of the building.

### 2.2.8 Determining Site Drainage for Floodwalls and Levees

A floodwall is a freestanding, permanent, engineered structure designed to prevent encroachment of floodwaters. Levees are constructed with compacted soil. Levees are more common than floodwalls as flood protection for a single building or a limited number of buildings, but given the cost of levees compared to other flood mitigation measures and the amount of land they require, they are less common for a single building than many of the other floodproofing measures discussed in this publication. Nevertheless, a properly designed and constructed floodwall or levee can be effective as a barrier to inundation.

The drainage system for the area enclosed by a floodwall or levee must accommodate the precipitation runoff from the interior area (and any contributing areas such as roofs and higher ground parcels) and the anticipated seepage through or under the floodwall or levee during flooding conditions (see Figure 2-10). Drainage systems may include pumps and holding ponds depending on the topography and layout of the site.



**Figure 2-10. Rectangular area enclosed by a floodwall or levee**

To determine the amount of precipitation that can collect in the contained area, the rainfall intensity, in inches per hour, must be determined for a particular location. This value is multiplied by the enclosed area,  $A_a$  (in square feet), a terrain runoff coefficient ( $c$ ), and a conversion factor of 0.01. The answer is given in gpm. See Equation 2-6.

When determining rainfall intensity, it is recommended to consult with water resource specialists and hydrologists. Overdesigning site drainage is a relatively easy way to provide added protection, however an under-designed system will cause increased damage to a particular site.



#### Special Note

The terrain runoff coefficient,  $c$ , is used to model the runoff characteristics of different land uses. Use the value for the predominant land use in the subject area or develop a weighted average for areas with multiple land uses. The most common coefficients are 0.70 for residential areas, 0.90 for commercial areas, and 0.40 for undeveloped land.



#### Warning

The rational equation is used to compute the amount of precipitation runoff from a given area. It has limited applicability and should only be used for areas that are 200 acres or less. Some other constraints include:

- The method should only be used for areas where rainfall is distributed uniformly.
- The method does not account for storage in the drainage area.
- Rainfall intensity is assumed to be uniform throughout the duration of the storm.





$$Q_a = 0.01ci_rA_a$$

where:

$Q_a$  = runoff from the enclosed area (gpm)

0.01 = factor converting the answer to gpm

$c$  = most suitable terrain runoff coefficient

$i_r$  = intensity of rainfall (in./hr)

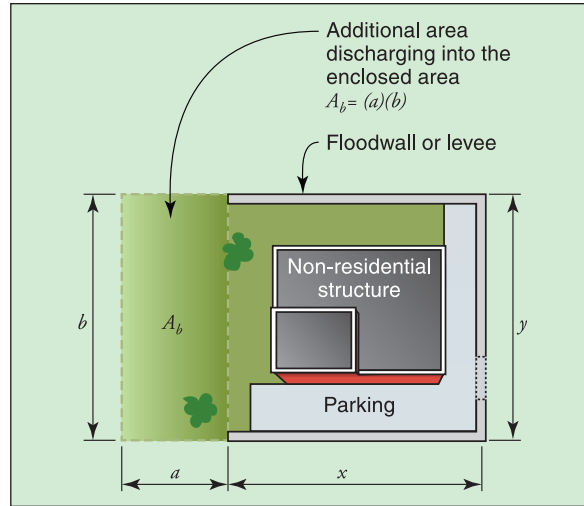
$A_a$  = area enclosed by the floodwall or levee (ft<sup>2</sup>)

When determining the minimum discharge size for pumps in enclosed areas, the designer should consider the impacts of the lag time between when the peak discharge is experienced in the enclosed area and the outfall to which it drains (i.e., inside and outside the enclosed area) and the storage capacity in the enclosed area after the gravity discharge system closes. If the designer is not familiar with storm lag time and the computation of storage in an enclosed area, the designer should consult an experienced hydrologist or hydraulic engineer.

Equation 2-6. Runoff quantity in an enclosed area

Some levees and floodwalls extend only partially around a property and tie into higher ground (see Figure 2-11). In such cases, the amount of precipitation that can flow downhill as runoff into the protected area,  $A_a$ , must be included. To calculate this value, the area discharging to the area partially enclosed by the floodwall or levee,  $A_b$ , should be estimated. This value is then multiplied by the previously determined rainfall intensity,  $i_r$ , by the most suitable terrain runoff coefficient, and by 0.01. See Equation 2-7.

Figure 2-11. Rectangular area partially enclosed by a floodwall or levee



$$Q_b = 0.01ci_r A_b$$

where:

$Q_b$  = runoff from additional contributing area (gpm)

0.01 = factor converting the answer to gpm

$c$  = most suitable terrain runoff coefficient

$i_r$  = intensity of rainfall (in./hr)

$A_b$  = area discharging to the area partially enclosed by the floodwall or levee (ft<sup>2</sup>)

### Equation 2-7. Runoff quantity from higher ground into a partially enclosed area

Seepage under or through the floodwall and levee along with the natural capillarity of the soil layer contribute to water inside the protected area. The water level inside the floodwall or levee increases as the depth of flooding outside the floodproofing structure increases and may compromise the effectiveness of the floodwall or levee for long-duration events if not addressed. The estimated seepage flow rates from the floodwall or levee vary depending on the site conditions and should be calculated by a geotechnical engineer or designer. Seepage rates may vary greatly with factors such as the depth of retained water and soil type.

The values for inflow in the enclosed area, runoff from uphill areas draining into the enclosure, and seepage through or under the floodwall/levee should be summed to estimate the minimum discharge size,  $Q_{sp}$ , in gpm. See Equation 2-8.



$$Q_{sp} = Q_a + Q_b + Q_c$$

where:

$Q_{sp}$  = minimum discharge for pump installation (gpm)

$Q_a$  = discharge from an enclosed area (from Equation 2-6) (gpm)

$Q_b$  = discharge from higher ground to partially enclosed area (from Equation 2-7) (gpm)

$Q_c$  = discharge from seepage through a floodwall or levee (gpm)

### Equation 2-8. Minimum discharge for pump installation

Important considerations in determining the minimum discharge size of a pump are the storage available in the enclosed area and the lag time between when the peak discharge is experienced in the enclosed area and the outfall to which it drains. Pumps continue to operate during flooding events (assuming power is constant or backup power is available), but gravity drains close when the floodwater elevation outside the enclosed area exceeds the elevation of the drain pipe/flap gate.

## 2.2.9 Understanding the All-Hazards Approach

In addition to flooding, a building might be subject to other hazards such as earthquakes, high winds, or tornadoes. The registered design professional should incorporate an all-hazards approach when selecting and designing floodproofing measures to avoid increasing the vulnerability of the structure, envelope, and systems to damage from other hazards. A mitigation measure that is appropriate for flooding, such as elevating a heavy chiller unit, may subject the building to greater seismic forces during earthquakes and increase vulnerability to damage unless the seismic hazard is accurately accounted for in the design.

Table 2-7 lists some FEMA resources with design guidance on mitigating damage to new and existing non-residential construction for multiple hazards.

Table 2-7. FEMA Resources on Design Guidance

Hazard	Resource
Seismic	<ul style="list-style-type: none"> <li>FEMA 232, <i>Homebuilders' Guide to Earthquake Resistant Design and Construction</i> (2006)</li> <li>FEMA P-420, <i>Engineering Guideline for Incremental Seismic Rehabilitation</i> (2009)</li> <li>FEMA 454, <i>Designing for Earthquakes: A Manual for Architects</i> (2006)</li> <li>FEMA 547, <i>Techniques for the Seismic Rehabilitation of Existing Buildings</i> (2007)</li> <li>FEMA P-749, <i>Earthquake-Resistant Design Concepts</i> (2010)</li> <li>FEMA P-750, <i>NEHRP Recommended Seismic Provisions for New Buildings</i> (2009)</li> </ul>
Tornadoes	<ul style="list-style-type: none"> <li>FEMA P-320, <i>Taking Shelter from the Storm: Building a Safe Room for Your Home or Small Business, Third Edition</i> (2008)</li> <li>FEMA P-361, <i>Design and Construction Guidance for Community Safe Rooms</i> (2008)</li> </ul>
High Winds	<ul style="list-style-type: none"> <li>FEMA P-55, <i>Coastal Construction Manual</i> (2011)</li> <li><i>Protect Your Property from High Winds</i> (2011); eight flyers</li> </ul>
Multi-Hazard	<ul style="list-style-type: none"> <li>FEMA P-424, <i>Design Guide for School Safety in Earthquakes, Floods, and High Winds</i> (2010)</li> <li>FEMA 543, <i>Design Guide for Improving Critical Facility Safety from Flooding and High Winds</i> (2007)</li> <li>FEMA 577, <i>Design Guide for Improving Hospital Safety in Earthquakes, Floods and High Winds</i> (2007)</li> </ul>

## 2.3 Other Flood Characteristics

Other flood characteristics of a site must be considered when determining whether dry floodproofing measures are best suited for a site. Flood characteristics that must also be considered include the duration of flooding, rate of floodwater rise and fall, and flood frequency.

These flood characteristics not only indicate the expected nature of flooding in a given area, they can also be used to anticipate the performance of dry floodproofing measures based on the potential hazards associated with each flood characteristic.

### 2.3.1 Duration of Flooding

Duration is the measure of how long water remains above normal levels. The duration of riverine flooding is primarily a function of watershed size and the longitudinal slope of the valley (slope influences how fast water drains). Small watersheds are more likely to experience a rapid rise and fall of floodwaters. Larger, shallow, basin-like watersheds adjacent to large rivers may be flooded for weeks or months.



#### Special Note

NFIP Technical Bulletin 2, *Flood Damage-Resistant Materials Requirements* (FEMA 2008a), defines a “flood [damage]-resistant material” as “any building product [material, component or system] capable of withstanding direct and prolonged contact with floodwaters without sustaining significant damage.” “Prolonged contact” means at least 72 hours, and “significant damage” means any damage requiring more than cosmetic repair.

An NFIP requirement is “building materials used below the BFE shall be resistant to flood damage (44 CFR §60.3(a)(3)(ii)).”

Prolonged contact with floodwaters may make some mitigation measures, including dry floodproofing, inappropriate because of the increased chance of seepage and potential structural failure. Long periods of inundation are more likely to cause greater damage to structural members and finishes than short periods of flooding. Increased durations also result in a higher probability of floodwater accumulation and ultimately affects pump design for interior drainage. Designers should consider the duration of flooding when determining the applicability of selected building materials, pump design, and flood mitigation measures.

### 2.3.2 Rate of Floodwater Rise and Fall

Steep topography and locations with small drainage areas may experience flash flooding, an event in which floodwater can rise very quickly with little or no warning. High-velocity water flows usually accompany flash floods and preclude certain types of flood mitigation measures, especially those requiring human intervention.

If a building is susceptible to flash floods, insufficient warning time may make the timely installation of shields on windows, doors, and floodwalls and the activation of pump systems and backup energy sources impossible. Temporarily relocating movable contents to a higher level may also be impractical. Floodproofing is not appropriate for sites in flash flood areas because of the potentially short warning time. Active floodproofing measures (those requiring human intervention) may be effective if a building is not subject to flash flooding and the area has adequate flood warning systems.

Rapid rates of the rise and fall of floodwater can also lead to unequal hydrostatic pressures on a building. The probability of unequal hydrostatic pressures increases when building exteriors are designed to be watertight.

### 2.3.3 Flood Frequency

Flood frequency analyses define the probability that a flood of a specific size will be equaled or exceeded in any given year. A flood elevation with a 1-percent-annual-chance flood of being equaled or exceeded in a given year is referred to as the “base flood,” commonly called the 100-year flood. Figure 2-12 illustrates the relationship between flood recurrence intervals and the probability of the event occurring within a given period. The probability that a base flood will be equaled or exceeded is 26 percent during a 30-year period. During a 70-year period (the potential useful life of many buildings), the probability increases to 50 percent. Although the base flood serves as the basis for NFIP insurance rates and regulatory floodplain management requirements, the relative frequency of any



#### Warning

ASCE 24 does not permit the use of dry floodproofing for buildings in high-risk flood hazard areas. These include alluvial fan, flash flood, mudslide, erosion-prone, high-velocity, wave action, and ice jam and debris-prone areas.



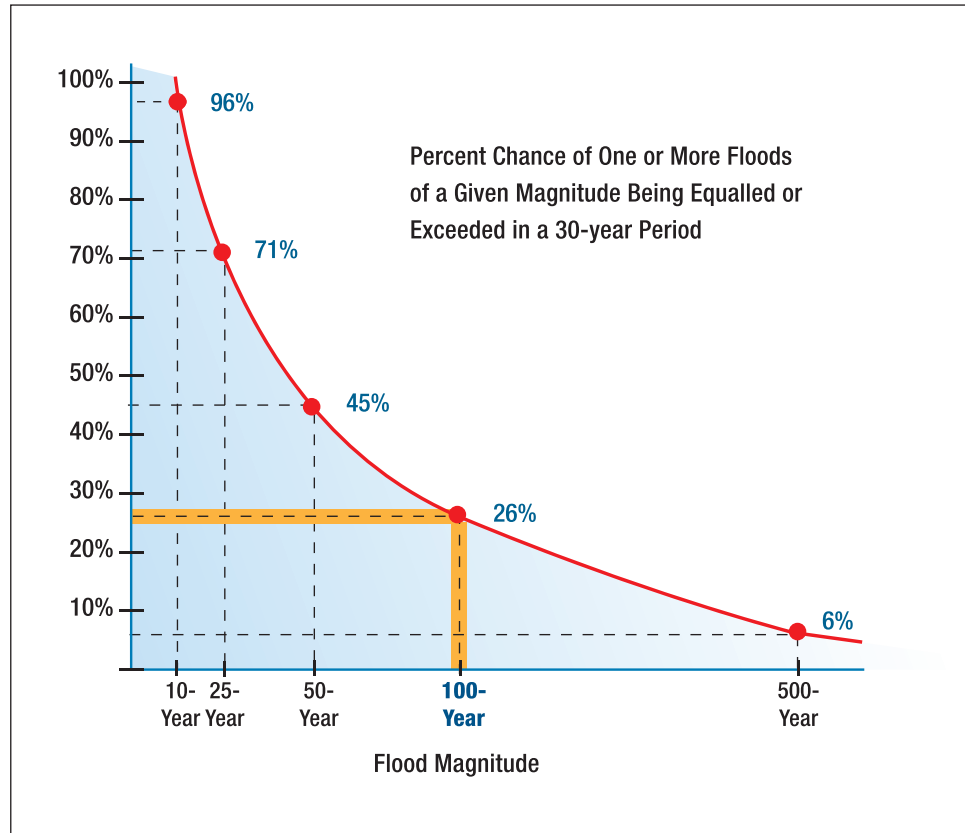
#### Special Note

Although buildings are required to be protected only to the BFE for floodplain management purposes (to meet the NFIP regulations), protection to a higher level is necessary for the floodproofing measures to be considered for flood insurance rating purposes. It is possible to protect buildings from lesser flood events using dry floodproofing measures, but doing so will not bring buildings into compliance with the NFIP.



given flood (e.g., 2-year or 10-year) serves as a useful reference point when selecting a retrofitting option and evaluating cost effectiveness.

**Figure 2-12.**  
Relationship between flood recurrence intervals and the probability of an event occurring within a given period



### 2.3.4 Future Conditions

Designers should use past events and trends as an indication of the nature and severity of effects likely to occur during those forecast events. Information about past events at the site of interest and at similar sites should be considered. This historical information should be combined with knowledge about the site and local conditions to estimate future hazard effects on the site.

## 2.4 Site Factors

Site characteristics such as flood hazard boundaries, vulnerability to erosion or local scour, and geotechnical considerations play a critical role in determining applicable floodproofing measures.

### 2.4.1 Flood Hazard Boundaries

As discussed in Section 2.2.1, the boundaries of flood hazard areas are delineated on FIRMs, which are developed based on data described in FISs. Designers may use data from FIRMs and FISs to determine the boundaries of the various flood hazard areas, flood depth, flood elevation, and flood frequency for a given site.

In addition to the aforementioned flood characteristics that can affect buildings, site location in relation to the floodplain is also an important factor when considering dry floodproofing. Designers should note whether buildings are in or near the floodway, on the floodway fringe, near road crossings or other obstructions because these may divert floodwaters toward the site.

## 2.4.2 Erosion

Erosion refers to the wearing or washing away of land and can occur in riverine as well as in coastal environments. Erosion is difficult to predict and is capable of threatening existing structures by lowering ground elevations, causing instability and failure in embankments, and transporting sediments landward or downstream. Erosion may also increase flood forces by increasing water depths. Erosion may be caused by natural actions such as flood-inducing storms and may be exacerbated by human actions such as constructing flood diversion or flood protection structures, dredging channels, damming rivers, and altering surface vegetation.

Riverine erosion affects the stability of stream banks and adjacent structures through the interaction of multiple geophysical and geotechnical factors. Variables that affect the stability (or erodibility) of stream banks include:

- Slope
  - Critical height
  - Inclination
  - Cohesive strength of the soil in the slope
  - Level and variation of groundwater in the slope
  - Degree of stabilization of the surface of the slope
  - Level and variation in level of water on the toe of the slope
- Distance of the structure in question from the shoulder of the stream bank
- Shear strength of the soil
- Frequency of rise and fall of the surface of the stream

Consideration of siting and the erodibility of land is critical when planning floodproofing projects because moving floodwater can undermine foundations and cause building, floodwall, and levee failure. Shallow foundation systems generally do not provide sufficient protection against soil erosion without some type of additional protection or armoring measure of below-grade elements. The local office of the Natural Resources Conservation Service has information concerning the erodibility of the soils native to a specific site, and community officials may have knowledge of local soil types and know whether erosion has occurred during past floods.

The analysis of erosion impacts to stream banks and nearby structures is a detailed effort that is usually accompanied by detailed geotechnical investigations.

### 2.4.3 Geotechnical Considerations

Site-specific soil properties are important factors in the design of any surface intended to resist flood loads. The properties include:

- Saturated soil forces
- Allowable bearing capacity
- Potential for scour
- Land subsidence
- Frost zone location
- Permeability
- Shrink-swell potential

The computation of lateral soil forces and determination of soil-bearing capacity are critical in the design of dry floodproofed foundations and walls. These forces and related geotechnical behaviors include a consideration of the frost depth, potential expansive or collapsible soils, or potential scour and erosion, and play an important role in selecting an acceptable foundation. Likewise, the permeability and compaction behavior of soils are key factors in selecting borrow materials for backfill, levee, or floodwall construction. For more information on these geotechnical issues, see Chapter 4 of FEMA P259 (2012a).

Site investigations for soils include surface and subsurface investigations. Surface investigations can identify the potential for landslides and evidence of areas affected by erosion or scour, determine accessibility for equipment needed for subsurface testing and construction, and help identify the suitability of a particular foundation type based on the performance of existing structures. Subsurface exploration provides invaluable data on soils below grade. The data are both qualitative (e.g., soil classification) and quantitative (e.g., bearing capacity). Subsurface exploration is complex and site-dependent. For example, testing for expansive soil requires assessing samples at various depths for plasticity, expansion index, and swell pressure to determine resulting swell forces under saturation conditions. Consultation with a geotechnical engineer familiar with the site is strongly recommended.

## 2.5 Functional, Operational, and Economic Factors

The functional, operational, and economic factors that should be considered when determining the appropriate floodproofing method for a building are:

- Functional use requirements of the building (how the flood-prone portions of the building are used)
- Occupant safety
- Flood warning time
- Flood emergency operations plan
- Inspection and maintenance plan
- Economic factors

### 2.5.1 Functional Use Requirements of the Building

The functions of non-residential buildings and whether active floodproofing measures (those requiring human intervention) can be used affect the types of floodproofing measures that are appropriate. For example, if a doorway that may be vulnerable to flooding is used by personnel and for freight delivery, permanently filling in the doorway is not feasible. Likewise, if extended interruption of function would be detrimental, floodproofing is not feasible because personnel should not occupy a building that is affected by floodwaters. Relocation may be a better option in this situation.

The current and future use of buildings must be evaluated carefully when deciding to what degree access can be limited, determining how long the facilities can be closed during floods, and assessing whether the effects of events exceeding the design flood can be tolerated.

Use requirements that should be considered when deciding whether floodproofing is a good option for non-residential buildings include but are not limited to:

- Access requirements
- Level and duration of business interruption that can be tolerated
- Ability to accommodate flood damage repair
- Ability to maintain dry floodproofing measures once implemented

Critical and essential facilities such as emergency operation centers, hospitals, and nursing homes may be floodproofed even if they are unoccupied during a flood event. Communities have an interest in protecting the contents of these facilities to minimize the downtime of such buildings and to ensure post-flood functionality. The protection and usage of critical and essential facilities may be vital to ensure an immediate response to the flood event and a rapid recovery.

### 2.5.2 Occupant Safety

The relationship of floodproofing options to occupant safety must be evaluated in the pre-design phase. Safe access to and egress from floodproofed buildings is a critical factor in the determination of whether floodproofing measures that depend on human intervention are appropriate.

If a floodproofed building is likely to be completely surrounded by floodwaters, provisions must be made for the evacuation of all occupants before the building is isolated. Evacuation is essential because it is possible that floods may exceed the design capacity of the floodproofing measures, which could result in extreme danger to any occupants who remain at the site. For events larger than the design event, specific additional emergency procedures should be developed.



#### Special Note

NWS river forecast centers can be accessed here: <http://water.weather.gov/ahps/rfc/rfc.php>.

The Advanced Hydrology Prediction Service (AHPS) offers data such as:

- Flood forecast levels
- Probabilities of a river exceeding minor, moderate, or major flooding
- Chances of a river exceeding a certain level, volume, and flow of water
- Maps of areas surrounding the forecast point likely to be flooded

If the proposed floodproofing measure is active (requires human intervention), all roads that provide access to the building should remain passable long enough for the floodproofing measures to be installed and for all personnel to safely evacuate the site.

### 2.5.3 Flood Warning Time

Some floodproofing methods require adequate warning to be successful. The length of warning time required varies from a few hours to several days depending on the complexity of the floodproofing method. For flood warnings to be effective, they must be issued promptly, and the forecasts that inform the flood warnings must be accurate.

A flood forecasting system should be able to determine when a flood is imminent and predict when specific areas will be flooded. Determining when and at what elevation the flood will crest may also be necessary. States and communities may have flood warning systems in place. Building owners should contact their local emergency management agency to determine any active flood warning systems in place.

River-flood forecasts are also prepared by National Weather Service (NWS) river-forecast centers and disseminated to the public by NWS offices. However, many non-residential buildings are located on smaller streams that are not included in a major forecasting network. In these areas, interested property owners can work with appropriate local and State agencies to develop an adequate flood forecasting system.

During periods of flooding, the NWS river-forecast centers issue forecasts of the height of the flood crest, the date and time when the river is expected to overflow its banks, and the date and time the flow in the river is expected to recede to within its banks. The U.S. Geological Survey and the NWS work together during a flood to collect and use the most up-to-date data and to update forecasts as new information is acquired. The NWS is also responsible for issuing flood and flash flood watches and warnings. The NWS conveys the data to other Federal agencies and to State and local agencies for use in flood management and disaster mitigation.

State and local emergency management officials use the flood data to make informed decisions on how and when to evacuate their communities. Building owners and operators should follow the guidance of State



#### Terminology

A **flood watch** indicates potential for flooding.

A **flood warning** means that flooding is imminent.



#### Special Note

When removable shields are to be used, flood emergency plans must include:

- Storage location for the shields
- Method of installation
- Conditions that activate installation
- Maintenance of shields and attachment devices
- Periodic practice of installing shields
- Testing sump pumps and other drainage measures
- Inspecting necessary material and equipment to activate floodproofing

Source: ASCE 24-05, Section 6.2.3



and local emergency management agencies, local weather reports, the NWS, or a local flood warning system regarding when to evacuate. The typical flood warning time should be considered when selecting a floodproofing measure.

#### 2.5.4 Flood Emergency Operations Plan

Flood emergency operations plans are highly recommended for floodproofing methods.

Plans should contain information on how floodproofing measures will work during and after the flooding event. For example, equipment such as sump pumps that require electricity will need to maintain power throughout the duration of the flood event. Maintaining power may require installing a generator and developing an operations plan for the generator to function during and after the flood event until power is restored. Maintaining power can be complicated by the fact that dry floodproofed areas should not be occupied during the flood event. Fueling and generator maintenance may require the generator to be located in an area above the desired level of flood protection.

Preparation of plans is the responsibility of the building owner or operator. The design professional certifying the floodproofing project is solely responsible for how the measures resist flood loads and make the building watertight but should be consulted on the maintenance, testing, and inspection schedule of the project.

A flood emergency operations plan should do the following:

- Establish a chain of command and assign responsibilities to each person involved in the installation and maintenance of the floodproofing measures. This will range from the authority to activate personnel through the duration of the event and restoration of the building to normal operations. The assigned personnel should not be assigned additional overlapping emergency duties to make sure that the floodproofing measures are installed in a timely manner and maintained. The chain of command should also take into account where assigned personnel live and their ability to access the site in an emergency. If key personnel are not available, a plan for succession of command and/or delegation of authority should also be covered.
- Delineate notification procedures for all personnel involved in the floodproofing operation. This includes details on making sure personnel can get to the building and enter areas of the building necessary to install the floodproofing measures. These areas include the floodproofed portion of the building and any storage facilities that house the flood shields and pumps.
- Assign personnel duties and include a description of the locations of floodproofing measures, installation procedures, and repair procedures. Instructions for each location should be posted close to the location.
- Include evacuation instructions for all personnel who normally occupy the building, and for the personnel who have installed the measures, what to do after the floodproofing measures are accomplished. Evacuation routes should be posted in the floodproofed areas. Any doors necessary to exit the floodproofed area should be marked and should not be possible to lock in a manner that prevents egress from the floodproofed area.

- Include a periodic drill and training program to make sure personnel clearly understand the procedures and timeliness by which they need to accomplish floodproofing measures and complete evacuation. Drills should be conducted at least once a year and coordinated with community officials.
- Include a schedule for regular evaluation and update of the flood emergency operations plan to reflect changes in personnel and procedures.

At a minimum, the plan should be posted in two clearly marked locations, but it is recommended that either the entire plan or relevant sections be posted close to every location where flood shields are to be installed. Requirements for the flood emergency operations plan are in FEMA's NFIP Technical Bulletin 3-93 (FEMA 1993a).

Although flood emergency operations plans are not required for wet floodproofing and floodwalls/levee mitigation measures, plans should be considered a best practice to ensure the effectiveness of all flood mitigation measures.

### 2.5.5 Inspection and Maintenance Plan

An inspection and maintenance plan should cover both the maintenance of the floodproofing measures and periodic inspections of the components. Inspections should cover the entire floodproofing system, including the walls, floor slab, openings, flood shields, valves, drainage system, and any pump system. A list of repairs should be developed after each inspection and implemented as required. Maintenance procedures should not rely on the annual inspection for identification but should be part of routine operations of the building's facility maintenance staff. Inspection and maintenance items include but are not limited to:



#### Special Note

Some communities require annual inspections of dry floodproofed buildings, especially if human intervention is required. Annual inspections lead to an increased awareness and effectiveness of floodproofing systems and also reduce concerns about liability.

- Wall systems, for cracks in the structural system or waterproofing coatings. Repair of cracks should be addressed immediately because ignoring them could result in significant structural damage to the building during a flood event.
- Entire floor slab, to make sure settlement or other cracks have not appeared. Additionally, it is important to make sure the floor slab is able to provide drainage for any water that may leak into the building.
- Openings, to clear debris trapped in the supports for flood shields, damage to permanently mounted hardware or gaskets, which would prevent proper operation of a flood shield.
- Flood shields, for damage to attached gaskets, proper labels identifying the proper location, and damage to the actual shield, which might prevent it from performing properly. The inspection should include an inventory of shields and all the hardware required to properly install them.
- Backflow valves or shutoff valves, to make sure they can properly operate and are clear of debris.
- Drainage system and pump systems, to make sure there is no damage to piping or debris that would prevent the pipes from draining properly. Sump pits should be inspected and cleared of any sediment

that may have built up. Switches and sump pumps should be inspected and tested to make sure they will run properly. If a generator is necessary for operation of the sump pump, it should be tested periodically to verify it will start and run during a flood event.

- An inventory of flood emergency equipment, supplies, and required tools to ensure that all required items are available in the event of a flood. The inventory should include a listing of the tools and where they are stored.

### 2.5.6 Economic Factors

When floodproofing has been determined to be feasible considering regulatory requirements and the physical characteristics of the site and building, the most cost-effective floodproofing option can be identified. A BCA can be used to validate cost-effectiveness. BCA is a way to estimate the future benefits of a mitigation project and compare the benefits to the cost. The result of the analysis is a benefit-cost ratio (BCR), which is derived by dividing the project's net benefits by the project cost.

In a cost-effective project, the total cost of floodproofing (installation, operation, and maintenance) is less than the value of physical flood damage, lost earnings, and other economic impacts that are likely to occur if the structure is not floodproofed. The BCR is a numerical expression of the cost-effectiveness of a project. A project is considered cost-effective when the BCR is 1.0 or greater, indicating the benefits of a prospective hazard mitigation project are sufficient to justify the costs.

Benefits are defined as avoided damage, and a BCA estimate may not account for all of the potential benefits. Therefore, a BCR of less than 1.0 should not automatically remove dry floodproofing from consideration.

The BCA described in Appendix B is used by FEMA to evaluate cost-effectiveness of projects under mitigation grant programs.

## 2.6 Building Vulnerability Assessments

For a building to remain functional during and following a natural hazard event, it must be undamaged, have sustained limited damage that does not prevent the building from functioning, or have sustained damage that can be readily repaired. Determining how well a building can withstand a natural hazard requires a building vulnerability assessment.

A vulnerability assessment can identify weaknesses in a building's structure, envelope, and electrical and mechanical systems. The assessment can determine which natural hazards the building can withstand *as is* and which mitigation opportunities are *available* to make the building more hazard resistant.



### Cross Reference

FEMA P-424, *Design Guide for Improving School Safety in Earthquakes, Flood and High Winds* (FEMA 2010a), contains checklists that can be used to assess a building's vulnerability to these natural hazards. The manual is geared to schools, but the guidance is also appropriate for other facilities. The flood checklist in FEMA P-424 is provided in Appendix C.

### 2.6.1 All-Hazards Vulnerability Assessment

The overall success of a building can only be achieved by identifying and managing natural hazard vulnerabilities. When mitigation measures for a flooding hazard are considered, an understanding of the other hazards, including frequency of occurrence of those other hazards, is important if the building is expected to perform as required by the owner. If other hazards are present that are likely to cause significant damage to the building and flooding is a relatively minor hazard, floodproofing alone may not be the best option.

The following should be completed and the results considered before the decision about floodproofing or other types of mitigation is made:

- Obtain the most up-to-date published hazard data to assess the vulnerability of the subject site
- Conduct or update a detailed risk assessment if there is reason to believe the physical site conditions have changed significantly since the hazard data were published or the published hazard data are not representative of the subject site
- Review or revise an existing risk assessment if there is reason to believe the physical site conditions will change significantly over the expected life of the building
- Ask the designer to review options that will mitigate the effects of any identified hazards in addition to the flooding risk after a risk assessment has been completed



#### Special Note

In structural engineering, there are two approaches in design and analyses: ASD (Allowable Stress Design) and LRFD (Load Resistance Factor Design). ASD is the older approach but is still widely used in wood, steel, and masonry design. LRFD is the newer approach. It is used almost exclusively in concrete design and frequently in steel design. Provisions for LRFD have been recently added to codes and standards governing wood and masonry design.

In ASD, service loads are applied to a structure, and the resulting stresses that the service loads create are calculated. The calculated stresses are compared with the maximum allowable stress for each component in the structure. Allowable stresses are determined by applying factors of safety to ultimate stress (typically stress at failure). If the calculated stresses from service loads are less than the allowable stresses, the design is acceptable.

In LRFD, the service loads are increased by load factors, and the ultimate strength of a structure is reduced by resistance factors. If the factored loads are less than the factored strengths, the design is acceptable.

### 2.6.2 Structural Condition Assessment

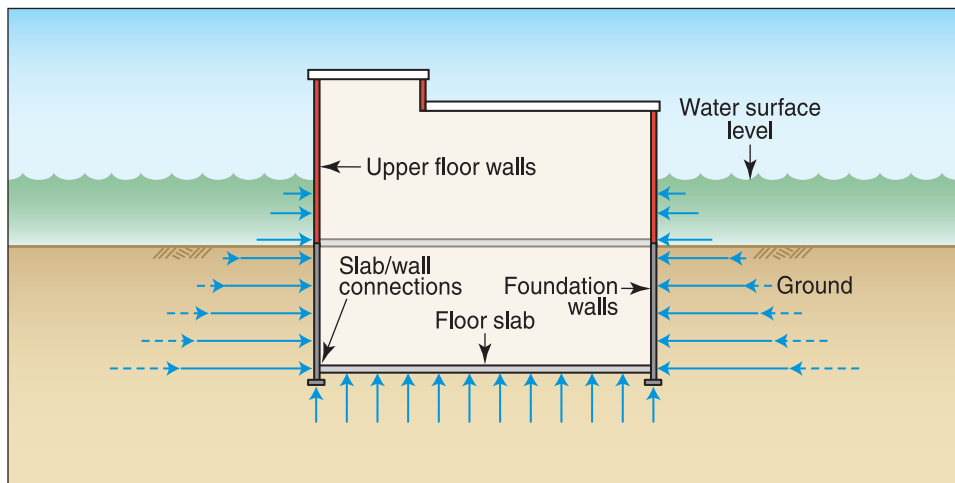
Assessing a building's vulnerability to flood involves identifying structural components that could fail when exposed to flood forces and structural components that could degrade or deteriorate when inundated with floodwaters. Structural degradation is much more of a problem in residential construction where wood framing is more prevalent than in non-residential construction. Structural degradation in commercial or industrial facilities is typically much less of a concern because the structures are usually built with steel, masonry, concrete, or other materials that offer inherent resistance to damage from floodwater inundation. Interior and exterior finishes in commercial and industrial buildings, however, may be vulnerable to

degradation from floodwater inundation because they are not often constructed with flood damage-resistant materials.

Assessing a building in two stages is recommended. First, a preliminary assessment is completed to help determine the overall feasibility of flood mitigation. The preliminary assessment is often based only on a visual examination of the building and, when available, a review of construction drawings. The depth of floodproofing desired can also be determined in the preliminary assessment.

If the preliminary assessment suggests that flood mitigation is possible, the next stage is to perform additional site and drawing reviews and conduct testing and analyses to confirm that flood mitigation is feasible. A detailed assessment requires accurate drawings of the building or, if drawings are not available, invasive testing to determine the structural aspects and condition of the building. Soil tests to determine the type and permeability of soils onsite may also be needed.

The loads for the proposed dry floodproofed area must then be determined. Load determination is discussed in Sections 2.2.4 through 2.2.6. When the loads are determined, the next step is to evaluate all portions of the building to assess its ability to withstand flood loads created by dry floodproofing without floatation, collapse, or lateral movement. All building components below the flood level may be exposed to flood loads, and portions of the building above the flood level can be exposed to flood loads (particularly buoyant forces) that translate through the building's structure. At a minimum, foundation walls, the connections between the foundation walls, and the floor slab below and structure above, and the floor slabs themselves should be evaluated. Figure 2-13 shows the major building components that are often exposed to flood loads.



**Figure 2-13. Basic building components exposed to flood loads**

Identifying structural vulnerabilities to floods involves quantifying the loads a flood will apply to a structure and the resistance the structure has to resist the loads. For a building's structure to withstand a flood, its structural components must be adequate to resist the applied flood loads without being overstressed (Allowable Stress Design [ASD]) or without the ultimate strength of the structural components being exceeded when exposed to factored flood loads in Load Resistance Factored Design (LRFD).

The walls should be inspected to verify that they are vertically plumb and that no bowing exists. An out-of-plumb wall can result from excessive pressure at the top or bottom of the wall. A bowed wall can result from excessive bending in the wall.

Concrete and masonry walls should also be checked for staining, which can result from corrosion in the reinforcing steel. If steel has extensive corrosion, its tensile strength or the strength of the bond from the steel to the concrete or masonry can be reduced, and the strength of the wall can be compromised. Staining can also result from water being in frequent contact with the walls, which may suggest that the soils are permeable enough to allow even short-duration floodwaters to expose the walls to hydrostatic loads.

Bowing, lateral movement, corrosion, staining, and evidence of frequent water entry all may indicate that the building is not an ideal candidate for dry floodproofing.

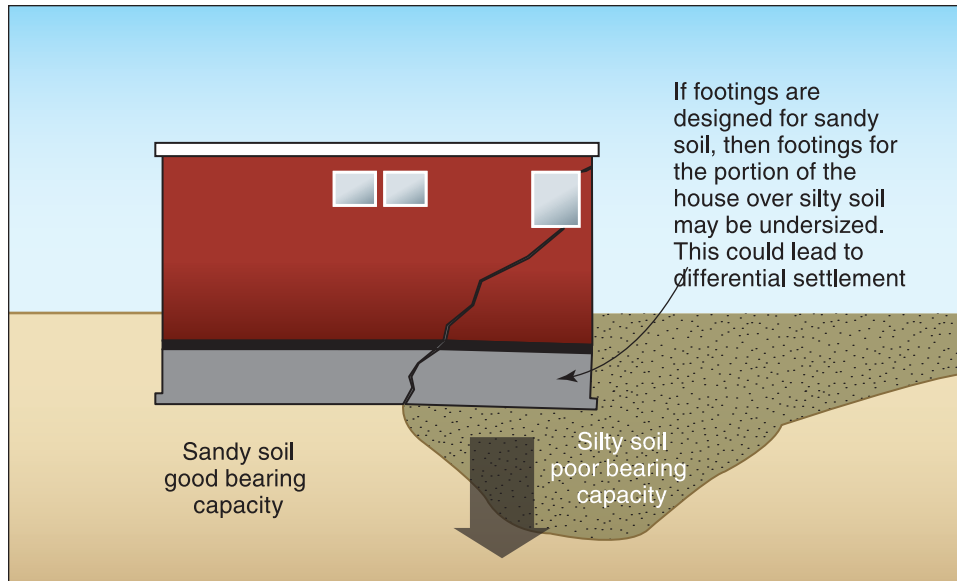
Once the preliminary assessment confirms that the foundation walls are free of evidence of existing structural problems, a determination must be made regarding the feasibility of strengthening them to resist flood loads from a design event. Except when a design flood will produce only a low level of flooding (about 2 feet), some wall strengthening will likely be required. The feasibility of ensuring the walls can be made to resist flood loads is typically done during subsequent evaluations when the details of the wall construction (thickness, height, reinforcement, and connection details) are known.

Walls can be strengthened with steel beams or grouting (concrete masonry unit [CMU] walls) or by overlaying fiber-reinforced polymers or carbon fiber strapping systems composed of sheets or strips that form a grid across the wall. How the wall system will be floodproofed is important to consider before selecting a system to improve the wall strength. If the waterproofing or sealant is to be applied on the same wall face as the wall-strengthening retrofit, the two measures need to be compatible.

Floor slabs should be evaluated in a manner similar to the wall system. As-built drawings are a good place to begin evaluating the slab, but it is likely that some field investigations will need to be done in order to ascertain the true properties of the slab. The initial evaluation should include any deficiencies in the floor slab that need to be addressed before correcting the floor slab to resist buoyancy forces. Issues such as settlement in the concrete slab may present retrofitting challenges if not properly corrected (see Figure 2-14). The reason for cracking in the slab is important to identify. Cracks may occur from soil expansion, soil contraction, or washing out of soils. Soils can wash out if underdrain lines were not properly installed when the building was constructed. On large commercial slabs where equipment such as forklifts are used, joints in the concrete slab should be checked to ensure that the slab has not rocked and created a void below the joints.

When the floor slab has been evaluated, the soil under the slab should be assessed to determine whether it may present problems under flood conditions. Some soils have low permeability and are slow to become saturated by floodwaters while highly permeable soils may become saturated quickly and need to be drained. Highly permeable soils may require installing underdrain lines, which should be sized for flood conditions.





**Figure 2-14. Significant differential settlement in the foundation causing slab failure**

Per NFIP requirements, dry floodproofing measures must be designed to meet the minimum requirements of being substantially impermeable, and these requirements assume there is no sump pump. For additional protection, the NFIP requires the installation of a sump pump when dry floodproofing is used as a retrofit technique, despite substantially impermeable requirements. See Section 3.7 for information on internal drainage systems. Whether or not underdrain lines are installed, the slab should be examined to determine the thickness and size and location of the slab reinforcing steel. This examination may require some destructive testing because slab reinforcing steel is usually small diameter wire mesh, which is difficult to detect.



### Special Note

Even in buildings that are designed to be substantially impermeable, sump pumps are required to control seepage, and flood damage-resistant materials, which are described in FEMA Technical Bulletin 2, Flood Damage-Resistant Materials Requirements (FEMA 2008a), must be used in all areas where seepage is likely to occur.

Unless designed to support heavy equipment, slabs generally cannot resist hydrostatic forces if water is allowed to accumulate beneath them because floor slabs are typically designed to resist dead loads applied from above when they are continuously supported by soils below. Most soil supported slabs, if reinforced, have reinforcement designed primarily for controlling thermal and shrinkage cracks. Reinforcement for controlling shrinkage and thermal effects alone is inadequate to enable the slabs to function as beams exposed to negative (upward) bending from buoyancy. If the reinforcing steel is too low to provide uplift resistance in the slab section, the slab will need to be retrofitted. If the slab is imagined as a beam, the reinforcing steel should be placed on the opposite side of the beam from the applied load or in the side of the slab in tension. Slabs supported by soils also lack positive connections that prevent the slabs from being lifted because they rely only on their self-weight to avoid being displaced vertically.

Although concrete can be added to thicken slabs (and increase their resistance to uplift strictly by increasing their weight), it is typically impractical to mitigate slabs to resist buoyant forces. If water can accumulate under a floor slab and installing underfloor drains cannot alleviate hydrostatic pressures acting to lift the slab, the building may not be a candidate for dry floodproofing. The only other mitigation technique that could be used to resist buoyancy on a concrete slab is to install soil anchors through the slab into the soil beneath the slab to provide upward resistance.

In addition, buoyant forces acting on submerged materials reduce their effective dead load and ability to resist uplift and overturning moments. Therefore, before dry floodproofing projects are undertaken, the overall stability of a building needs to be checked to ensure that buoyant forces will not make the building unstable. The load combinations contained in Chapter 2 of ASCE 7 should be used to evaluate the stability of the dry floodproofed building.

The deficiencies in the slab and the normal use of the floodproofed area are important considerations in selecting a retrofitting measure. If the area requires equipment to drive across the slab or maintenance crews to work in the area, maintaining a flat, unobstructed slab may be important. Similarly, maintaining the existing ceiling height may justify other retrofitting considerations.

The condition assessment should not only determine the ability of structural components to withstand flood loads, but also their impermeability. For example, basement walls between adjacent buildings should be evaluated for flood load resistance and impermeability. This is especially important in an urban environment or in buildings constructed in phases; otherwise, the source of flooding may become the adjacent building. Structural components, window wells, ventilation openings, and utilities (discussed in the subsequent section) can each be floodwater points of entry if not properly assessed and mitigated.

### 2.6.3 Vulnerability Assessments for Electrical and Mechanical Utilities and Systems

Utility and system assessments can determine how well the utilities that serve a facility and the major mechanical, electrical, and plumbing (MEP) systems in a facility can resist natural hazards. Although utilities and MEP systems can be damaged by high winds, seismic events, and winter storms, this discussion is focused on their vulnerability to flooding. In a discussion of system vulnerabilities, it is beneficial to distinguish utilities from systems components. Utilities are generally external to the building, while most mechanical and electrical systems are internal. Although utilities themselves can be vulnerable to flooding, this document focuses primarily on the vulnerability of buildings associated with utilities when they act as conduits and allow floodwaters to enter a building.

Utilities can be electrical or mechanical. Electrical utilities typically include power, communication (both copper-based and fiber-optic), and occasionally hard-wired annunciation systems such as fire alarm loops. This document focuses on electrical power utilities. Mechanical utilities include domestic water service, water service for fire suppression, steam service, and utilities to collect and dispose of sanitary sewer and storm sewer. In many municipalities, fossil fuels, namely natural gas, are also brought to buildings. Utilities can be private or municipal and can be part of a campus, which is the case when a group of buildings are supplied by a central plant.

Electrical utilities are often described as “dry utilities,” and mechanical utilities are often described as “wet utilities.”

Electrical systems include power distribution, controls, lighting, fire alarm, telephone, and IT (information technology). Mechanical systems include heating, ventilation, and air conditioning (HVAC); domestic water systems; drain, waste, and vent systems; smoke control systems; fuel storage and distribution systems; and fire suppression systems. Figure 2-15 shows common locations of these systems in buildings.

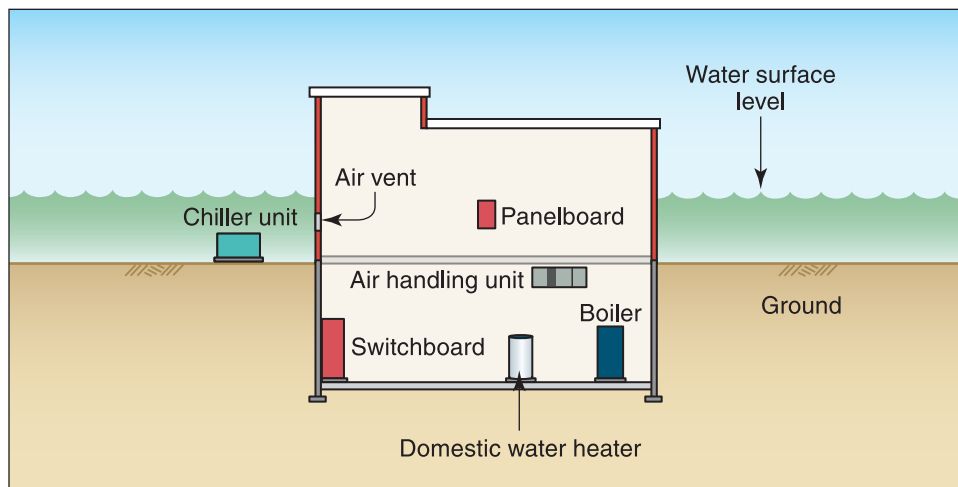


Figure 2-15. Typical systems in buildings

### 2.6.3.1 Utilities General

Utilities often enter a building below grade. In areas where groundwater levels are high and in areas vulnerable to flooding, all utility penetrations are potential sources of water entry.

In assessing the vulnerability of water entry through utilities, consider the following questions:

- The sealing of penetrations: When utilities enter the building, are the spaces around the conduits and pipes properly sealed to prevent water entry?
- The sealing of conduits: When conduits enter a building, are the spaces between cables within the conduits sealed to prevent water entry?
- Backflow prevention: For wet utilities, are measures in place to prevent floodwaters from entering the building through piping systems?
- Utility trenches: Are utility trenches provided with submarine doors or other methods that will prevent floodwaters from migrating between buildings?

### 2.6.3.2 Electrical Utilities

Electrical utilities may be overhead or underground. Overhead utilities are inherently resistant to damage from a design flood unless they are located below the DFE. When designed for submerged installations, the buried portions of underground electrical utilities are also generally resistant to flood damage, but above-ground components of underground electrical utilities such as below-grade electrical vaults, pad-mounted transformers, pad-mounted switchgear, and electrical substations can be damaged by floods when located below the DFE.

The following list summarizes the components of electrical utilities that may be damaged by flood inundation when located below the DFE. These components should be considered when assessing flood vulnerabilities associated with electric utilities.

- Electrical substations
- Pad-mounted transformers and other pad-mounted equipment (switchgear)
- Live-front electrical equipment (i.e., equipment with exposed energized terminations) in underground manholes
- Cable terminations and splices not designed for submerged conditions
- Underground transformer vaults
- Meter centers
- Electrical service equipment (switchboards in larger facilities, service panels in smaller facilities)
- Network interface devices for communication utilities
- Fire alarm master boxes below the DFE

### 2.6.3.3 Mechanical Utilities

Pressurized mechanical utilities such as domestic water services, fire suppression service, and fossil fuel services are generally resistant to flooding. Some vulnerability to floodwater inundation may exist in above-ground equipment such as pressure regulators and utility meters for natural gas lines. Occasionally pressurized systems rely on electrically driven pumps to maintain system pressure. These systems can become vulnerable to floodwater contamination if power is lost to electrically driven pumps. When system pressure is lost, pressurized systems are often assumed to be contaminated, and “boil water before use” orders are given until the system pressures can be restored and the systems can be decontaminated or disinfected.

Non-pressurized mechanical utilities such as gravity-draining sanitary sewers and gravity-draining storm sewers generally are not damaged by slow-moving or riverine flooding. However, they can become conduits that allow floodwaters to flow into a facility. Backflow prevention devices can reduce the potential for floodwaters entering facilities through non-pressurized utilities. These devices, which are essentially check valves that allow flows only in one direction, require periodic maintenance and testing to ensure they are functional and will not obstruct normal flows.

### 2.6.3.4 Electrical Systems

Nearly all electrical systems in a facility below the DFE are vulnerable to flooding. Electrical wiring, communication equipment, fire alarm and security systems, and other electrical equipment are inherently vulnerable to inundation unless specifically designed for submerged applications, and few electrical devices used in buildings are designed to be submerged. Conduit systems should not be considered watertight, and although the exterior sheaths of some electrical cables can resist water infiltration, they should not be considered 100 percent effective unless designed and installed for submerged applications. Sump pumps, underwater lighting fixtures, and some sensing devices or transducers are possible exceptions, but these devices account for only a small percentage of the electrical equipment in a typical facility.

### 2.6.3.5 Mechanical Systems

The vulnerability of mechanical systems to damage from flooding varies greatly. Pressurized piping such as domestic water systems, chilled water piping systems, and hot water piping systems can generally be exposed to flood inundation without significant damage. When flooding is saltwater flooding or when floodwaters are corrosive, piping systems may need to be cleaned to prevent degradation. In pressurized systems, pumps and controls can be damaged from floodwaters unless designed for submerged use.

Pipe insulation, particularly insulation that is not closed-cell foam, typically needs to be replaced after inundation. Any pipe insulation below the DFE should be considered vulnerable to flooding unless it is closed-cell foam.

Forced-air distribution systems are particularly vulnerable to flood damage. The ducts are designed for air pressures that are typically measured in inches or fractions of inches of water column and cannot resist hydrostatic pressures from even small depths of floodwaters. Also, duct systems are rarely watertight, and floodwaters can enter ducts, saturate internal insulation, contaminate duct systems, and lead to the formation of molds and mildews that can significantly affect air quality. When contaminated, it is often more practical to remove and replace submerged ducts system than to try to clean them particularly with insulated duct systems. Any ducts below the DFE should be considered vulnerable to flooding.

Floodwaters may also enter exhaust vents that remove stale air from a building's interior and intake vents that provide fresh make-up air. Water can flow into clothes dryer vents and bathroom or kitchen exhaust vents if the floodwater is higher than the exit locations on the building.

Boilers, chillers, domestic water heater, booster pumps, and HVAC controls are rarely designed for submerged installation and will be damaged by floodwater inundation.

Fuel distribution and storage systems can be vulnerable to flooding. Although fuel distribution piping is a closed pressurized system that is able to resist relatively high external and internal pressures, fuel tanks are much less so and can be damaged by floodwaters. Fuel tanks are typically designed to resist only internal pressures that result from the weight of the fuel stored within them and from filling operations. Tanks, unless specifically designed for submerged conditions, can fail when exposed to the external pressures that result from floodwater inundation. Tank failures can result from crushing pressures, which increase with the depth of inundation, and from anchorage failures, which increase with the amount of floodwater displaced by the tank. During Hurricane Sandy, many tanks located below grade were damaged when floodwaters filled basements. All tanks below the DFE should be considered vulnerable unless they are designed to resist crushing pressures and anchored to resist buoyancy.

In addition, fuel tanks are often located on the lowest floor of a building and pumps are installed to pump fuel to equipment, such as emergency generators, located on upper floors. When pumps are located below the DFE, they can be vulnerable to flooding. During vulnerability assessments, fuel pumps located below the DFE along with their power and control wiring should be considered vulnerable unless designed for submerged use.

